THE METALLURGICAL DEVELOPMENT OF THE ROMAN IMPERIAL COINAGE DURING THE FIRST FIVE CENTURIES A.D.

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Ph.D. Thesis

1974

Research Degree Thesis For the Degree of Doctor of Philosophy
of the Council for National Academic Awards

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Summary

The coinage of the Roman Imperial era (27 BC to AD 476) was found to present a complex and somewhat uncertain metallurgical picture of chronological change in its alloys in consequence of known or suspected variations in minting policies and practice, and in the availabilities of raw materials.

The accumulated coin assays and analyses - slender in number and of widely variable merit - which have been published sporadically since the dawn of modern analytical chemistry, have been critically reviewed to reveal the uncertainties, and the lacunae, as a basis for a more complete and accurate investigation than has ever been attempted before, whereby the trends of metallurgical development and the procession of a range of numismatic problems directly related to the material of the coinage might be deeply investigated.

In so far as possible only disposable but clearly identifiable coins have been obtained, pertaining to the full chronological sequence but concentrated where necessary at specific periods of known or discovered change. These have been analysed by the best classical techniques of metallurgical analysis supplemented by modern physical methods (such as neutron-activation, and mass-spectrometry) and metallography, where these were appropriate - the emphasis being always upon obtaining the highest possible accuracy compatible with useful metallurgical interpretation. To this end full advantage was taken of statistical theory and developed sampling practice for the acquisition of assay samples properly representative of the original coinage alloys unaffected by subsequent superficial enrichments or penetrating corrosion.

In consequence of the combined accuracies of sampling and analysis a hitherto unobtained degree of precision has been possible for the separation of different issues made with small sequential changes in fineness values and for the interpretation of their official alloy standards in terms of the Roman system of weights - despite evident small variations in the actual mass of the libra in Roman times.

The chronological trends in the developments and degradations of the Imperial silver, copper, brass, bronze, argentiferous bronze, and leaded bronze coinages are now revealed in toto, and with greater certainty than has previously obtained; and metallurgical explanations are offered for those features which were dependent upon mineral resources and processing rather than upon Imperial edict. The results are also correlated with extant records of Roman history and monetary legislation, and convincing new quantitative criteria are established for the resolution of a number of numismatic problems - some of which have hitherto defied explanation. Previous unknown metallurgical features of several coinage issues have also been revealed and confirmed, and fresh vistas have been opened for future numismatic research.

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Thesis submitted March 1974.
Examination, 2 May 1974.

THE METALLURGICAL DEVELOPMENT OF THE ROMAN IMPERIAL COINAGE DURING THE FIRST FIVE CENTURIES A.D.

A thesis submitted
By
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in partial fulfilment of the requirements for the degree of
Doctor of Philosophy
of the
Council for National Academic Awards

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March 1974

> "Nature has bestowed upon us an inquisitive disposition. Our vision opens up a path for ... investigation, and lays the foundation of truth so that our researches may pass from revealed to hidden things."
>
> Seneca (3 BC-AD 65)

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INTRODUCTION

Numismatic research on ancient coinages has long been the province of classical scholars, historians and - more recently - archaeologists. But scholars are now approaching the point of the near-exhaustion of the potentially available and relevant literary and inscriptional sources upon which their researches might advance, and so it is recognised that new criteria are necessary for deeper and more detailed studies to be made.

With modern advances in the physical sciences it is now the opportunity of the scientist, and the technologist - and in particular the metallurgist - to investigate properly the materials of the coins themselves, using sophisticated techniques of analysis and metallography in conjunction with the now well-developed techniques of classical chemical assay which have been devised and proved during this present century.

It is unfortunate that some of the earliest works on ancient coin analysis were necessarily dependent upon laboratory methods which can now be judged to be crude by present standards; for the latest techniques of metallurgical analysis are based on much more recent advances in physical chemistry, sampling techniques, and developments in scientific instruments which were not available to the pioneers. Some of their most painstaking work, therefore, through no fault of their own, was based on unspecific and inaccurate chemical separations - and hence some of the results are far from reliable. New investigations, especially those of the highest technical quality, can throw new light upon the technologies of the ancient moneyers, revealing both their achievements and their intentions, and thus providing the desirable new criteria whereby numismatists can determine relevant coinage policies and practice in particular historical circumstances. Such studies are especially profitable in the case of the Roman Imperial coinage, around which there is already a considerable volume of recorded history and legislation as well as a great number of surviving pieces of palpably different dimensions and metallurgical characteristics.

Until the advent of this present work, however, there was no substantially comprehensive and authoritative survey of the chronological variations in the compositions of the different metals and alloys of the Roman Imperial coinage - to show how they were developed metallurgically under the influences of changing economic conditions and availabilities of mineral and bullion resources.

With the notable exception of Professor Caley's fairly recent study of the composition of the Roman orichalcum coinage(1) the last and only attempt at anything resembling a true chronological survey of the then accumulated chemical analyses of Roman coins was made by J Hammer(2) in 1908; but this pioneer collation of the sporadic coin analyses of earlier investigators is - by its very nature - a rather uneven, unsystematic, and incomplete work. Hammer was not careful to avoid the unnecessary duplication of some identical results which had already been quoted in different works. He made no real scientific contribution himself, nor did he offer any critical appraisal of the individual merits of the published results of variable quality which he culled from widely different sources. In consequence there is still a tendency for the results he compiled to be treated as of equal scientific merit despite the reality that numbers of the nineteenth century analyses are of doubtful scientific quality and positively misleading for numismatic purposes. Sadly – but with less excuse - the same can be said of some much more recent results(3) which possess a deceptive superficial appearance of quality.

Hammer's work is also lacking in the numismatic precision with which the analysed Roman coins cited could - even then - be described, identified and dated; and so they fall far short of the precision which is now possible with the use of the most up-to-date works of reference. This matter is of particular importance for those periods of rapid change where a precise chronology is necessary for the proper understanding of a sequence of metallurgical change; and there are, in fact, very few of those earlier Roman coin analyses which lend themselves to sufficiently close dating to be of much numismatic value today.

Nevertheless, in the absence of anything better, Hammer's survey is still used by scholars seeking to quantify coinage fineness values (and other compositional variations) in conjunction with deduced weight standards, for advances to be made with the solution of some otherwise elusive Roman historical and economic problems involving the interrelationships of coinage denominations and the substance of coinage reforms.

Quite recently leading numismatists reached general agreement that further progress in their researches was being halted by ignorance of the true metallic composition of the coinage(4) - a view which the late

S Bolin(5), and Professor P M Bruun(6) and Dr C H V Sutherland(7) have expressed pointedly in each of their major works on the Roman Imperial coinage, published within the last few years. Indeed, it is now becoming necessary to know with some accuracy not only the intended chemical composition of the coinage but also its intended metrology. These data together will allow a much deeper and more certain penetration into the meanings of extant papyri and Codes of Laws, for the reconstruction of lost coinage legislation so that the official coinage policies at critical but somewhat hazy periods in Roman history can be more clearly revealed and understood.

Fortuitously, the Roman Imperial coinage was minted in such vast quantities, throughout the first five centuries of the Christian era, that many pieces remain to this day to bear mute testimony to the sequence of policies which governed their fabrication and to the state of metallurgical knowledge which existed when they were minted. This present work demonstrates the extent to which these can now be revealed by systematic scientific investigations which combine the techniques of chemical analysis, mensuration, and metallographic examination, for the thorough examination of coinages typical of each different phase of monetary policy.

Within the scope of a new general chronological survey of the coinage metals and alloys, both old and new numismatic problems have been investigated and studied in detail as far as the available material has allowed, and in most cases it has been possible either to suggest seemingly satisfactory numismatic solutions or to orientate the work towards their final resolution. Thus, valuable new criteria for studying the coinage have been explored and established, and fresh vistas of numismatic research have been revealed for future exploration in greater depth when suitable coins become available.

During the course of this work the author received an invitation from the Royal Numismatic Society to present a paper at the April meeting in 1970(8) and, a few months later, to make several contributions at the Society's International Symposium on Ancient Coin Analysis, which was held in London in the following December. In consequence four papers were completed for the volume of the resultant RNS Special Publication No 8(9,10,11,12).

Other works on specific topics arising out of the present study have also been solicited by those awaiting the results; and some of these have been printed in various numismatic and archaeological publications during the last five years(13,14,15,16,17). Two works have been included as scientific contributions in papers published by other authors(18,19), and one which was read at a Symposium at Oxford in 1972 is about to be published(20).

The Common Law of England - an accumulation of 'case-law' comprising an accepted code established by decisions made in the Courts since the thirteenth century - has also been moulded during the course of this present work. Until mid-1972 only those finds of coins which were obviously silver or gold in appearance have been declared to be Treasure Trove; in consequence numerous hoards of bronze-looking (but really much-debased) silver antoniniani and folles of the late third and early fourth centuries AD have escaped recognition and hence protection for the expert examination which they have deserved.

In 1968 the author published incontrovertible evidence(21) that these coinages contain small but definite controlled proportions of silver, and that in their day they were true silver denominations despite their severe debasement. At the Hemel Hempstead Coroner's Court, however, on 6 July 1972, expert numismatic evidence was accepted that the Scatterdells Wood hoard of nineteen large folles comprised silver coins - thus setting the legal precedent whereby every future British find of similar coins can be declared a Treasure Trove, 'seized for the Queen', and thus protected from distribution before proper examination, recording, and the selection of any desirable pieces for the national collection housed in The British Museum.

The beginnings of coinage and the Roman heritage

Writing in the middle of the fifth century BC the Greek historian Herodotus(22) credited the invention of coinage to the Lydians of Asia Minor who stamped bean-shaped pieces of their naturally-occurring gold-silver alloy, electrum, of definite weight and intrinsic value, with officially authorised devices guaranteeing their authenticity, nominal worth, and general exchangeability. Despite some ancient doubts, modern numismatic scholarship endorses Herodotus and ascribes the issue of the first electrum coinage proper to the Lydian King Ardys (652-625 BC)(23). This event, of great importance to the civilised world, gave practical realisation to the concept of coinage as a convenient repository of value, and as a portable and widely acceptable medium of exchange for goods and services between individuals or communities faced with the everyday problems of satisfying needs or desires differing from those available within their own immediate resources.

The first electrum coinage, however, soon became discredited; this was because of the wide range of gold and silver proportions which occur in the natural alloy, and the opportunities therefore offered - and, indeed, taken - for synthesising it, or for diluting it with more silver than could be properly justified by the token values of the coined pieces in comparison with their intrinsic worths as unminted metal. But Croesus (560-546 BC) - the Lydian King of legendary riches - renewed public confidence in coinage by introducing separate gold and silver coinages, minted in refined metals whose high purities were immediately apparent to the eye and could be proved by assay. This became the first system of bi-metal currency.

Once the plentifully-minted silver coins became more widely available (for commoner transactions needing much smaller denominational pieces than those of gold) the idea of coinage, properly maintained with official integrity, spread both eastwards and westwards, by virtue of Greek maritime and imperial influences, to the extremities of the known World. It was then but a small step to the development of tri-metallic coinage systems (incorporating gold, silver, and bronze denominations) and these eventually gained universal application as Rome grew, absorbing the remnants of Greece and gradually enforced its command over all the lands bordering the Mediterranean Sea.

There is, in consequence, a continuous history of some 2600 years of coinage to the present day; and this has involved the minting of an enormous variety of ancient, mediaeval, and modern coin types - of numerous shapes, dimensions, and weights - in a variety of metals and alloys. Being almost indestructible, the ancient coinages in gold, silver, bronze, brass, and copper, have ensured, in their surviving pieces, an historical record of the political events and economic circumstances of the civilisations which produced them. Their visual messages are often laconic in the extreme; but they cannot avoid bearing mute metallurgical testimony to the intentions and achievements of the men who made them, and these can be discovered by careful and systematic chemical analyses and metallographic examination.

The zenith of aesthetic achievement in the fine art of coining seems to have been reached by the Greeks in the fourth century before the birth of Christ; and their craftsmanship may never be surpassed for sheer excellence in using the artistic potentialities of the metallic coinage media to their limits in fabrication - and yet in perfect harmony with a common fitness for purpose. Indeed, the artistic quality of the best Greek coins was much admired by the first Roman Emperor Augustus - who is reputed to have collected them himself, and to have presented choice specimens to his friends.

The Emperor Nero was even more attracted to Greek art in all its manifestations; and the influence of Greek numismatic art on the design and execution of the Roman Imperial coinage of Nero's reign is clearly evident. But it is to Rome, rather than to Greece, that we turn to admire technical rather than artistic excellences in the metallurgical development and minting of coinages on a vast scale in new and previously untried metals and alloys, and for the exhibition of political skills in the fullest exploitation of coinage as a major military and economic tool for informing, directing, and controlling an Empire. Our own heritage of the Roman Imperial coinage which remains to this day provides an almost continuous documentary record, in a tangible form, as the basic material for a deeper understanding of the monetary laws which governed its fabrication and issue, and of the economic conditions in the empire of its day.

Of all the world's coinages, that of the Roman Empire has long been recognised as being of greater historical value than any other. This can be shown to be true, not only for the direct historical messages which the coinage pieces convey, but for the cryptic metallurgical information which can be extracted from the coinage materials themselves for the reconstruction of the circumstances in which they happened to be minted, and of the patterns of official thinking which governed their fabrication.

THE ROMAN EMPIRE

Origin and destiny

The year 753 BC is the traditional date assigned to the founding of the city of Rome; and this is attested by a few rare dated coins of the imperial era, and by recorded anniversaries. In due course a precise natalis urbis came to be defined, for the purpose of official celebration as the 21 April in each year. This is the date which should, perhaps, be considered as the precise one relevant to the institution of some of the later mint-recorded celebrations, such as: (i) the issue of a medallion for the 900th anniversary in AD 148; (ii) special coins for the millenary of Rome in AD 248; and (iii) the inauguration of a completely new argentiferous bronze coinage in three denominations for the major monetary reform which appears to have coincided with the 1100th anniversary in AD 348(24).

The city of Rome commenced with the founding, by the Latins of central Italy, of a small town on the left bank of the river Tiber, above the Ostian marshes and some 24 kilometres inland from the sea. This small Roman community then amalgamated with the Sabine and Etruscan peoples and grew, its government developing as an elected monarchy. Tradition has it that Romulus became the first king, and that he was succeeded by six others before 509 BC - when the ancient Roman monarchy was terminated for ever.

The last three of the seven kings of Rome were, in fact, not Romans, but of Etruscan origin. Gradually they alienated themselves from the mixed peoples of Rome and sowed the seeds of discontent which led to the formation of a Republican government. It was during the reign of the first of those three kings - while the Romans themselves were concerned with little more than domestic politics in a small part of Italy - that there emerged, in Babylon, the first of the four great world-empires centred in the regions of the Mediterranean. Unwittingly, Rome and Babylon, then on their separate courses, were destined to converge into the greatest and most dominant power in world history.

In the sixth century BC, and just a hundred years after the invention of coinage, a captive Jewish prophet, Daniel, revealed to King Nebuchadnezzar of Babylon that there was both glory and divine purpose in his Kingdom(25). To his son, Belshazzar, he later prophesied the actual eve of sudden destruction, and a destiny to be succeeded by a second (though inferior) Kingdom - that of Media-Persia(26) - which, in its turn was to be replaced by a third world empire - that of Greece - under 'the rough goat'(27) Alexander. Finally, after the division of the Greek empire into four parts (but not under its founder) there was to arise a fourth world empire - later to be identified as that of Rome - which would be "strong as iron" and exceeding its predecessors in both power and splendour. But this procession of empires (illustrated in Figure 1 to

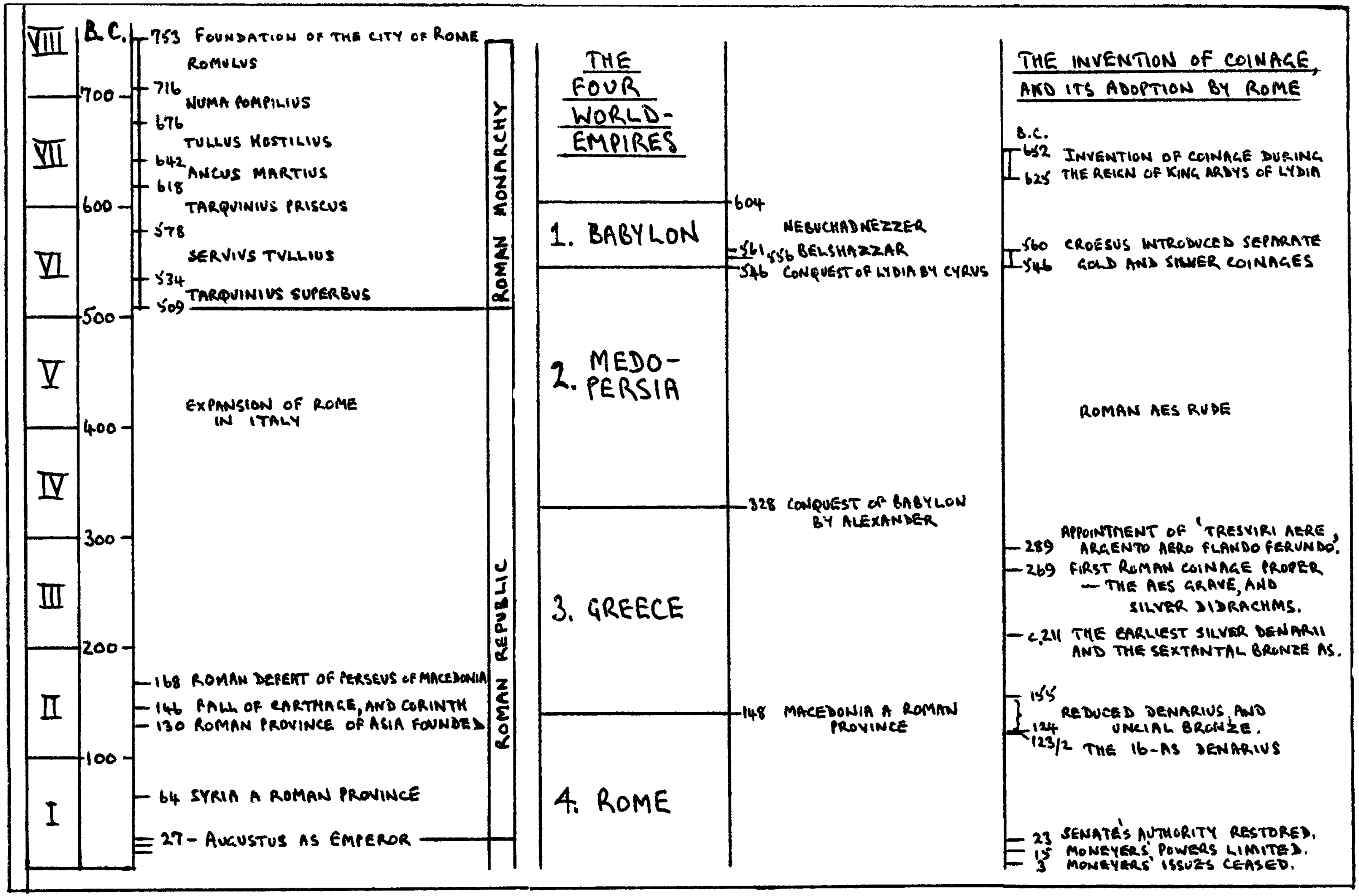


FIGURE 1. The procession of world empires, and Rome's adoption of coinage.

show the parallel development and adoption of coinage) was to involve a deterioration in fineness and quality with its very increase in strength(28) Thus, even half a millenium before its reality, the fourth world empire was both prophetically foreseen and predestined to disintegrate eventually through those weaknesses which would arise from and attend its own peculiar quality of strength. This was to be evident first by a two-fold division (now recognised as the separation into eastern and western sections of the empire) and ultimately, through further sub-division, but essentially by a progressive deterioration in unity which would arise from the original admixture of unequal and incompatible nationalistic factions (likened to iron mixed with clay) which would weaken from within the basic integrity and security of the whole.

Of this fourth world empire - then so far in the future, and hardly conceivable in the wildest imagination of the then-reigning penultimate king of Rome - Daniel further predicted (with both remarkable foresight and detailed accuracy concerning the Roman Empire which we can now survey with hindsight) that in its diversity from all other Kingdoms it would be: "dreadful and terrible, and strong exceedingly"; "devouring and breaking in pieces .... and crushing the residue"(29). It was to differ also from the two intermediate world-empires (of Media-Persia and Greece) in that its characteristics would persist - like those of Babylon – in the essential nature and fabric of all subsequent world power, until the final consummation of the human race.

Seemingly unaware of her great and terrible destiny Rome slowly grew in power and wealth, still apparently remote from middle-eastern power-politics and very much concerned with her own domestic problems. For the hatred engendered by the tyranny of the last of her kings, followed by an act of violence perpetrated by his son, sparked a rebellion which, in 509 BC, caused the ancient Roman monarchy to be abolished for ever.

In the ensuing bitter class struggles for supremacy and representation a form of Republican government evolved. Tacitus mentions the various experiments at the highest levels in pre-imperial government: there were elected consuls; dictatorships were assumed in emergencies; there was a brief Council of Ten, autocracies, and a Triumvirate. In the course of four and a half centuries these produced a complex system of Republican law and tradition - in practice subject to many abuses - which nourished a continued growth in national strength and resources and an enforced efficiency and sense of discipline.

Despite internal conflicts from the very beginning, the infant Roman Republic succeeded in defending herself against aggressive neighbours; then, towards the end of the 5th century BC she began to extend her territories in both the south and north of Italy. Subsequently the 4th and 3rd centuries BC saw Rome engaged in numerous other wars which led to her eventual mastery of all Italy south of the Rubicon and the Macra. Sicily then succumbed to Roman maritime exploits. Later the powerful Carthaginian empire fell and, in consequence, northern Italy, Cisalpine Gaul, and the north-western coastline of North Africa all became Roman territory; and the way into Spain lay open.

A critical political decision by the rulers of Rome was made in 146 BC - when they became mindful to punish the Greeks for the support which they had given to Carthage. And then Rome turned, inevitably, eastwards, acquiring by rapid conquest and annexation all the riches and remnants of the earlier middle-eastern civilisations - and finally the empire which Greece itself had conquered.

The Romans had managed to gain a foothold in Syria as early as 190 BC; but eastern possessions did not become substantially open until the same year as the fall of Carthage, when Corinth was sacked and Greek resistance was overcome. Thus Roman rule over both land and sea became firmly established in the eastern Mediterranean and the fourth world power commenced its destined rise from the remnants of Imperial Greece. When the Roman Province of Asia was founded in 130 BC, and Syria in 64 BC, much of Daniel's prophecy had become fact.

In the century before Christ, however, despite her wealth and overseas conquests, a languishing Roman Republic could not thrive. Weakened and shaken at home by intrigue and civil wars - arising initially from the new class divisions of extremely rich and poor, and later from the personal ambitions and rivalries of her rulers and successful generals – the Republic moved inexorably to an end.

Amazingly, the external expansion continued. Syria; then Judea, Gaul, and Egypt, - all fell under Roman domination in times of deep internal strife. Then, in the ultimate struggle for supreme power Gaius Julius Caesar Octavianus - already a military Imperator, and the great-nephew and posthumously adopted son of the State-deified Julius Caesar – avenged his great-uncle's death, eliminated his own rivals, and emerged triumphant as the founder of the Roman Empire, just one generation before the dawn of the Christian era.

Thereupon dawned a new and golden age of apparent world peace and universal prosperity. Augustus - as he became known - established a personal regime such as had never been known before, and the worldly and almost world-wide rule of Imperial Rome began. Its pervading influences - not least in our present laws and in the very fabric of our coinage - are with us still.

Humanly speaking, the Roman Empire was built on the most uncertain foundations. It could be argued that it would never have survived unless it had, indeed, a divine destiny to fulfil, for Daniel speaks of its founder being "... mighty, but not of his own power"; one whose policies would "... cause craft to prosper in his hand ... and by peace he shall destroy many"(30). This concept of destructive peace is difficult and seemingly paradoxical; but such, in reality, was the enforced peace of the Empire. With similar perception a British Chieftain is reported to have remarked that the destructive Romans "... create a desert and call it peace". There was a semblance of peace under Augustus - and he was much praised for it, as were many of his successors on their coinages. But the Roman peace lacked the characteristics of real peace, either in the hearts of those whose spirits had been forcibly subdued or throughout the Empire as a whole. The PAX ROMANA was a hollow thing.

Karl Pink has remarked that the Roman Empire was founded on a fiction "... the fiction that the Republic was still in existence"(31), for by his "craft" Augustus was careful to give the impression that the hallowed Republican constitution continued, while carefully concealing his increasing autocracy under the cloak of the State's principal benefactor. But he failed to establish any constitutional limitations upon the powers which were gathered into the hands of one man and he formulated no clear concept for the Imperial succession. This doomed the Empire, from its very beginning, to the emergence of some of the basest forms of human leadership, and to struggles for power which were to flare up all too frequently, to absorb and destroy much of the Empire's wealth faster than it could be created.

The temporal power of Rome - and its major weakness - lay in the strength of its army and in the enforced control and direction of the wills of its subjected peoples, to whom, St Augustine tells us, "The Romans gave their laws and coinage"(32). Indeed Augustus used the medium of his coinage for control of the Army and the people. Thinking themselves free, they became the more enslaved. Tacitus,(33) constantly stressing the evils of rule by one man, informs us that "Augustus seduced the army with bonuses" (thereby setting an imperial precedent which was to bring financial problems to generations of subsequent emperors) and that his cheap food policy (made possible by his personal acquisition of the entire granary of Egypt) "was successful bait for the Roman civilians. Having attracted everybody's good-will by the enjoyable gift of peace he subtly absorbed the functions of the Senate, the officials, and even the law".

It is plainly apparent that, on the human level, the Roman Empire had no lasting quality. Gibbon - in his philosophy of Roman history(34) - observed that "... the decline of Rome was the natural and inevitable effect of immoderate greatness". "Its ruin is simple and obvious, and instead of enquiring why the Roman Empire was destroyed we should rather be surprised that it had subsisted so long"; for in all the world's history no human institution has ever flourished quite like the Roman Empire, nor equalled it in its strength and power to dominate. Smaller and, perhaps, better quality empires preceded it and were consumed; others have followed in its wake and attempted to mould themselves in like manner, but, on its better features; none however, has grown so great nor persisted so long in essential transmitted character or ultimate influence, nor has any ever been so publicly conscious of its eternal destiny throughout – even though distorted. It would seem that there was something quite special about it - and for this we seem to be compelled to look beyond the human level, to the spiritual, and into divine purpose.

The Jewish historian Josephus(35) - an opportunist, a traitor to his country, and not himself a man much influenced by religious belief – adds his testimony to the supernatural power of Rome. Writing shortly before the empire had attained its greatest glory he explains the mystery of powerful and refractory nations (in particular the Gauls) being "... over-awed by the might of Rome, and still more by her destiny - which wins her more victories than do her arms". And ever since philosophers and historians have mused upon whether Roma Aeterna grew and persisted by a series of phenomenal accidents or according to some predestined design.

The earliest contemporary exposition of Rome's destiny is that of the Apostle Paul, who explained to the first-century Christians resident in Rome itself(36) that there were great truths concerning the organised world in which Rome gloried which could be discerned by the spiritually perceptive as fundamental to the apparently obvious circumstances of Nero's empire. By analogy with God's dealings with Pharaoh - in the far distant days of Egypt's own particular power and greatness - Paul showed an underlying identical and continuing divine principle ultimately governing the affairs of Rome, namely, "... for this cause have I raised you up, for to show in you my power; and that my name may be declared throughout all the earth"(37).

Thus Paul spans the intermediate point in world history, between the days of ancient Egypt and those of first-century Rome, when Daniel revealed the same divine purpose in his remarkable accounts of the coming rise and fall of the world-empires of Babylon, Media-Persia, and Greece. In Paul's view that purpose began to unfold in the reign of Caesar Augustus himself, when the "last days" were accomplished for God's revelation of Himself "by his Son"(38) - in somewhat stark contrast to the numismatically advertised claims to deity, sonship, and high priesthood made by Tiberius at the same time on his celebrated "tribute penny"(39) denarius bearing the image and superscriptions TI(berius) CAESAR DIVI AVG F(ilius) AVGVSTVS, and PONTIF(ex) MAXIM(us).

That God's purposes for Rome were achieved, and that they have since been progressing towards their final fulfilment has occupied the minds and hearts of the saints of all later generations. St Augustine - an eye-witness of the beginnings of Rome's final decline and the brink of fall – remarked that Divine Providence alone explains the establishment of kingdoms among men(40), and expressed his own conviction that God had willed that the Roman Empire should have spread so widely and endured so long.

Augustine considered that by his own lifetime God's purposes for Rome were almost complete; but with characteristic gentleness he acknowledged that whatever good had been achieved by Rome had been accomplished under that same Providence, and that the Romans had received their reward, in the eyes of the world, in the fame and glory which they had both sought and won(41). The better Romans had indeed set an example for all time in their inculcated national spirit of obedience and devoted service and endurance in the most extenuating of circumstances.

In the decline of the empire St Augustine saw a merciful and patient admonition of the frailty of human institutions rather than a Divine punishment, in order that the experiences of Rome might become known and profitable to all future generations. "For here we have no continuing city" - in the sense of ROMA AETERNA - "but we seek one that is to come"(42), "which has (lasting) foundations, whose builder and maker is God"(43).

There is no small element of faith - rather than scientific reasoning - in views of Rome's divine purpose and sovereignty; but experimentally they are in absolute accord with the historical records, some numismatic evidence, and subsequent reviews of events, which all show the prophesied purposes to have been accomplished consistent with every detail of the revealed plan. For those having eyes to see, the power of God to order the course of world history has always been manifest; and the paucity and impermanence of mere human achievements and institutions are seen in vivid contrast - especially when they deliberately deny that essential principle. The name of the one true God – and of his purposes for all mankind - although known in the cradle of civilisation, did not come to be declared throughout all the earth until the advent of the spreading and communicative Roman Empire. Although officially opposed to the "dangerous cult" of Christianity for three centuries - as a force opposing the system of the Roman gods and subverting the supposed unifying force of Emperor-worship - the Roman Empire provided the very best media whereby Christianity could thrive and spread in spite of the persecution. Within a few years of the birth of the Church there were even Christians in Caesar's household sending greetings via Paul to Phillipi(44); and eventually Christianity became the official religion of the State(45) - a vexed question which has led to arguments amongst Christians ever since!

Against this background the Roman imperial coinage is a convenient guide to the prevalent and formal religious thoughts of its day. For propaganda purposes its illustrated types and legends sufficed to convey those selected thoughts which the emperors wished to impress upon the populace; and long before the days of printing the minted words reached every home in the empire with messages extolling the virtues of the emperor and his achievements, his dependence upon the favour of the Roman gods, their constant companionship and protection, and the benefits to be derived from his paternal care for his subjects. Professor Grant has remarked that the coinage inscriptions record not only events but programmes(46) "They provide pious hopes, wishful thinking, and downright lies ...". They tended to be aspiratory rather than realistic - of which Otho's declaration of 'Peace throughout the world', during a reign remarkable for its unpeaceful brevity, is typical.

One wonders to what extent the peoples of the Empire were really deceived by the messages of the diminishing and debased coins, as they coped with the increasing complexities of life and suffered the hardships of the escalating inflation which began even before the empire had reached its zenith. For the common people the Roman laws were basically just, but in practice justice rarely prevailed over political ambition or state expediency. There must have been a growing dissatisfaction with the conditions and morality of the State, and the impotence of the Roman gods, which encouraged the spread of Christianity despite frequent and vicious persecutions over at least three centuries.

The eventual demise of the Roman Empire in the West spelled, moreover, the beginning, rather than the ending, of Christian influence in Europe: for it was the Eastern portion of the empire - now based on a capital at Constantinople rather than Rome - which succeeded in both resisting the barbarian inroads from Central Europe and avoiding the economic collapse of the Western empire. It lived on for another thousand years; and in doing so it effectively preserved much that was good in Roman life and culture. Furthermore, those who see the continuing hand of Divine Providence directing world history, see, in the longer preservation of the Eastern empire, the custodianship of Christian civilisation (until a straightened Western Europe was ready to recover it), and also a formidable bulwark to a vulnerable Europe, protecting it from incursions from the East under the growing military might of Islam.

In AD 1453 the Ottoman Turks captured Constantinople and put a complete end to the Eastern Roman Empire. By then, however, European civilisation had entered a new and distinctive phase of recovery, characterised not only by the rapid spread of Christianity throughout Europe but to well beyond the territorial limits of the old Empire, into the New World, and eventually to all regions of the earth.

Almost unwittingly the old Roman Empire had been the vital link in this continuous chain; but its coinage - issued mostly by men oblivious of their true destiny - tells us virtually nothing about it. It is interesting that some Christian symbols can be found in minor locations on the coinage of Constantine, but it is not certain that they had any important significance to the message conveyed by the legends and imagery. The Imperial author of the Edict of Milan - first Christian emperor, and convenor of the Church Council of Nicea - seems to have carefully avoided direct mention of either matter on his coinage, which shows no departure from traditional forms of iconography at any period in his reign. After his death even a 'Divus' coinage was issued in keeping with Roman tradition.

It is remarkable that the first bold appearance of a Christian symbol on the Roman coinage - a Greek Chi-Rho monogram flanked by the letters alpha and omega - is to be found on the coinage of a usurper, Magnentius(47). This was an issue which can now be shown to be of little intrinsic worth despite its impressive appearance. Its minting is an interesting insight into one of the distorted views of Christian ethics which became manifest in those early days. Perhaps Magnentius hoped to enlist the Christians to a cause designed to further his own ambition. We cannot tell: we do know that it failed.

Our awareness of the purposes and destiny of Rome does help with our study of the coinage; for we might perhaps expect to find metallurgical parallels matching the spiritual state of the nation. Indeed the vain pomp and glory is evident in the magnificence and technical excellence and quality of the early imperial issues in gold, silver, brass, and copper. The insidious decline of the Empire is to be seen in the protracted debasement of the silver coinage. Human struggles towards temporary recovery and restoration are to be seen in reforms which briefly engendered new hopes with coinages of improved quality. And the eventual fall is manifest not only by the low metallurgical quality of the common coinage but by its pathetically small dimensions.

The influence of the Roman Army

It is hardly possible to consider any aspect of the Roman Imperial coinage without some attention to the influence of the Roman Army, with its voracious appetite for hard cash; for the coinage of the empire was used primarily as a military tool, rather than a commercial aid, throughout the imperial period. In this respect it differed significantly from modern coinages and, as might be expected, its images and themes were substantially military in character.

On the physical level the empire was utterly dependent upon the Roman Army for its regular protection and preservation, apart from any attempted extension of its territories by imperial aggression. The army was at once the source of both the major strength and weakness of the Roman state. To reduce the chances of rebellion the troops had to be paid promptly, and in cash; and so, dating from Republican days, one of the main perquisites of a military Imperator was the right to mint coinage to pay the legions and acquire their arms and provisions. The coinage seems to have filtered thence into normal commercial use through the liberal spending of the soldiers on necessities or enjoyments. The precious metal coinages were then recovered by taxations and fines. The military function of the coinage seems to have predominated throughout the entire Roman era; and any concept of purely civilian or commercial utilisation seems to have been always subservient to military needs.

There was a sense in which almost everyone in the Roman Empire served the Army - of which the emperor was the commander-in-chief. His position was one which would today most closely resemble that of a military dictator who was in a position to make full use of the coinage as a powerful tool of office. Eventually, however, the support of the army and the huge accumulated bureaucracy of imperialism caused the economic ruin of the Empire.

Augustus, with the concept of himself as the single political Imperator - ruling abroad by virtue of his imperium and at home by means of his tribunicial powers - managed to acquire the exclusive right of coining in the precious metals and then abrogated the Senate's rights to mint the base-metal pieces while still retaining their nominal subservient supervision. His successors preserved these exclusive rights to issue the imperial coinages in all denominations, and hence maintained complete monetary control of both the army and the State in-so-far as they submitted to neither caprice nor compelling pressures to overspend.

In a study of the history of Rome one is inevitably forced to weigh the military achievements against the cost of imperial survival. The maintenance of the standing Roman Army, plus additional support for its frequent defensive or aggressive campaigns, was a costly affair and it became increasingly so. The cost of the army seems to have been a principal factor in the slowly escalating decline which culminated in the eventual fall of the empire; for successive emperors were either ignorant of, or indifferent to, the inflationary consequences of issuing a continual supply of lower and lower grade coinages without balancing their nominal worth against real increases in prosperity or devising suitable means for its recovery to the treasury before new issues were released.

Elaborate procedures were developed for the recovery and recirculation of gold as coin or equivalent bullion(48), but the silver - and in particular the much-debased silver coinage issues of the late third and early fourth centuries - seems to have been issued voluminously with almost gay abandon. So far as the true <u>aes</u> coinage is concerned there is no record of there ever having been any system for recovering any of it in fines or taxation before AD 414 - when some taxes could be paid in bronze(49). The supporting metallurgical evidence points to regular new supplies being minted and issued with little or no attempt at any official recycling during most of the imperial period.

Continued inflation hit hardest at the last recipients in the trading cycle - usually the civilian producers of essential goods, and in particular the farmers. But, inevitably, the soldiers themselves found that their pay acquired less and less as the inflationary effects permeated society. Consequently they demanded increases, and were given larger and more frequent donatives, and the destructive inflationary circle continued - stimulated mostly by military greed.

A Roman legionary officer or man was in a socially privileged and financially rewarding position, and he enjoyed considerable status compared with most other occupations. That their status was deeply felt was demonstrated when, on one occasion, Julius Caesar accused some of them of behaving like civilians. To be likened to 'Cives' was a sufficient reminder of their real dignity to stem their mutiny.

Although Roman soldiers were subject to extremely strict codes of military discipline it seems that they were allowed much unquestioned authority in dealing with civilians - especially those who lacked the legal protections of full citizenship. Roman soldiers also had a long record of being discontented, unfair, and avaricious. These known characteristics are revealed in some of the hardest but most necessary advice ever recorded as being given to Roman soldiers by a man who had no objective other than their individual betterment. When a group of them, touched in their consciences, asked John the Baptist how they should live - in expectation of a coming divine judgement - they were told "... to do violence to no man, neither accuse any falsely; and be content with your wages."(50) In those few words John located the principal faults of the Roman army of his and other days. Two centuries later Dio Cassius(51) observed the last of these three faults to be still prevalent as a fundamental Army weakness - making it necessary for a weak emperor to buy (rather than to inspire) the loyalty of his troops, and to keep them sweet by regular donatives and the provision of frequent opportunities for the acquisition of booty. It is a sad reflection on members of such a fine corps, otherwise so renowned for the finest qualities of human endurance, discipline, and obedience. But the baser attitudes constituted a leaven which permeated the whole during the course of the imperial era. The source of imperial weakness was manifest, in fact, at its point of greatest strength.

A Roman legion at full strength comprised some 5000 foot soldiers and 120 horsemen, all of whom were full Roman citizens engaged for up to 25 years service from the age of 18. Each legion was supported by an Auxilia, comprising non-citizen provincials in infantry or cavalry units some 500 to 1000 men strong - the total of the Auxilia being roughly the same as legionaries. In addition the emperor had a personal bodyguard – the Praetorian Guard - made up of some 5000 picked citizen troops.

Augustus, perhaps with greater wisdom than a number of his later successors, attempted to stabilise the army strength at 28 legions. Professor M Grant(52) has estimated that this represented a probable army strength of some 260,000 men. But before the end of his reign Augustus suffered the disastrous loss of 3 legions, under Varus in Germany in AD 9. This diminished the number to 25 and caused him great distress in his later years. Thereafter, for a century and a half, the number of legions fluctuated slightly but they were not increased substantially until Marcus Aurelius created two new ones in AD 165 to reinforce the upper Danube frontier. A generation later Septimius Severus added three more - thus bringing the total to a new high level of 33, and creating an army strength of between 300,000 and 400,000 men. He also raised the status of the officers, and their pay to fifty times that of a legionary. It is significant for our theme that this step, and the cost of the increased military activity towards the end of the second century AD, led to the most severe debasement of the Roman silver coinage to that date; for in the second year of his reign Septimius Severus dropped the nominal fineness standard of the denarius from 70.6% to 44.4% in one dramatic step(53), although its weight was maintained(54).

Suetonius(55) tells us that Augustus doubled the daily pay of the legionaries, to an annual income of 225 denarii. Therefore, if we assume a similar rate of pay for the Auxilia but make no allowance for the higher rates of pay of the centurions and officers the daily requirement for the army pay in the last few years before the birth of Christ would have been 154,000 denarii in silver or in silver and gold-multiple pieces. Since the denarii of Augustus were minted at 84 to the libra, in silver of high fineness(56), the actual daily minting requirement (if entirely silver) would have been 1,835 libra. In modern terms this was almost 600 Kg per day, or 218 tonnes per annum. Small wonder that "in those days", c. 6 BC(57), "there went out a decree from Caesar Augustus that all the world should be taxed"(58). This was essential in order to meet the enormous growing expenditure on the army and other affairs of state; and henceforth taxation had to be put on a regular and universal basis.

Dr G Webster(59) tells us that any investigations into army pay are complicated by the lack of knowledge of what the men received in kind, as equipment and rations, and precisely how much was deducted for various purposes. The conditions changed from time to time and the basic facts about pay are few and far between, although it is certain that pay was increased with the progressive inflation as we shall explain.

A much more insidious drain upon the imperial resources, however, was the matter of donatives. In his Will Augustus left 300 sestertii (equivalent to 75 denarii, or exactly a third of a year's pay) to all his legionaries. Tacitus(60) tells us that Tiberius doubled this amount – but only after the Pannonia Revolt about the army pay being a paltry 10 asses a day. Suetonius(61) tells us that Tiberius also rewarded the troops in Syria for their refusal to allow the statues of Sejanus to be placed with their standards; and that after the abortive invasion of Britain Caligula gave all the legionaries 4 gold pieces (100 denarii).

Claudius began another unfortunate precedent by making a donative to the praetorians upon his accession: The incredible sum of 150 gold pieces (3,750 denarii), was equivalent to about 17 years ordinary legionary pay for each guardsman! Later emperors felt obliged to follow this example in order to secure the loyalty of the troops. Tacitus(62) remarks that Nero made a donative on his assumption of the toga virilis – at his coming of age, a year ahead of that of normal citizens.

Vespasian managed to avoid his payment and survived - but only because he was able to satisfy the army's greed with ample booty. The donative was then not revived until the reign of Marcus Aurelius.

Another type of inflationary donative is to be found associated with imperial celebrations of vota, and other regnal anniversaries. Under the Empire the practice grew of the State making prayers (vota publica) for an emperor's health and safety or lengthy rule. Dr H Mattingly(63) has shown that at first these were expressed in ten-year periods (vota decennalia); but in the second century the five-year stage (vota quinquennalia) began to be emphasised, and this was openly expressed in the third century. Vota were generally undertaken (suscepta) on an emperor's accession day, and redeemed (soluta) on the appropriate subsequent anniversary. The Empire as a whole bore the full cost of these celebrations, when the imperial largesse was distributed as gold coins or medallions to the more eminent soldiers and civil servants, and as debased silver or bronze to lesser folk. The abundance of imperial celebrations in the fourth century made increasingly heavy demands on the State. D R Walker(64) has noted that it is "perhaps not by chance that the reductions in the weight of the follis coinage in 330 and 335 correspond to Constantine's 25th and 30th years respectively". This present work also demonstrates that economies in the proportions of silver in the coinage alloys were effected on the first occasion, and after the second, because, no doubt, of the shortage of bullion which resulted from the voluminous issues of the vota coinages. For the vicennalia in 326 the emperor had already been obliged to pay a donative of 5 gold solidi (to be repeated at every 5th anniversary) to an army of about 500,000 men. The coins weighed 1/72 libra; so the 2½ million to be minted for each occasion represented a gold bullion requirement of no less than 11.3 metric tonnes - to be found mainly by taxation, fines, confiscations, and purchases on the open market.

Discharge grants were also paid to pensioned legionaries. Dio Cassius(65) records that a figure of 3000 denarii (in AD 5) had reached 5000 denarii by the reign of Caracalla. An Edict of Constantine(66) (dated to either 13 Oct 320 or 326) stated that each veteran, on settlement, "shall receive 25,000 folles in cash, a yoke of oxen and 100 measures of assorted grains". Again, the impoverished State had to find the resources.

It was the expressed will of Augustus that the boundaries of the Empire should not be extended beyond the bounds that they had reached with his own conquests; so, in near conformity with this set policy, the number of legions fluctuated very little until an increase began in the middle of the second century. Domitian increased the legions to 30 in AD 83 and raised the legionary's pay to the equivalent of 300 denarii per annum(67); but this could now be payed in the smaller and somewhat debased Neronian standard denarii of 1/96 libra, so that, in intrinsic worth, there was no real increase. The rise in pay was no more than a nominal 'cost of living' adjustment if we assume that Domitian's denarii were about 86% fine; and, indeed, an assay of one of his coins published by the author(68), shows 85.40% silver.

The next phase began with the creation of the two new Italian legions (to replace two missing ones) by Marcus Aurelius in AD 165, and then the extension of the army to 33 legions by Septimius Severus who also increased the pay of a legionary to 500 denarii per annum and that of members of his Praetorian Guard from 1250 to 1700 denarii per annum. His post-AD 193 debased silver coinage, of only 44.4% fine, was probably necessitated by the limitations of the available silver; but his drastic inflationary manoeuvre was a portent of even worse things to come. With his army strength at around 300,000 men, Septimius Severus would have stood in need of at least 150 million denarii per annum. At the new low level of debasement which he had introduced his annual requirement of silver bullion would have been in the region of 217 tonnes. This is a fascinating figure, for it is almost identical with the requirements of Augustus two centuries earlier; and this calculated weight could indicate a fairly constant level of silver metal being kept as money in circulation throughout the empire. New mintings might have just balanced the actual silver recovered to the treasury in fines and taxes, with negligible overall increase to the treasury from any new sources of mined or captured silver. The nominal value of the silver money in circulation as army pay would, however, have more than doubled by the end of the second century.

Hence the coin assays provide us with a new appreciation of the degree of inflation which occurred in the first two centuries of imperial rule, and a glimpse of the fundamental reasons behind the actual degree of debasement chosen by Septimius Severus. His moneyers may have had to make these same calculations of the fineness to be adopted, so as to spread the available silver over the number of pieces of nominal value required in a manner which would have left the uninitiated unaware of anything serious having happened to coins which were virtually the same size and weight as hitherto. In terms of purchasing power, however, we can see that the same amount of silver (as actual bullion) was now being paid to 300,000 men instead of 250,000. Despite their apparent rise in their pay the army of post-AD 193 had suffered a loss in its intrinsic worth by 20%, compared with the troops of Augustus. It was not a good prospect for the beginning of the third century AD.

Inevitably, a rise in pay would have soon been sought again; and it is recorded that in AD 214 Caracalla gave the troops a 50% rise. Professor Grant(69) calculates that the army pay then amounted to an annual charge on the exchequer of about 70 million denarii, which was five times that for the Augustan era. In terms of denarius coins Grant's observation is factual, but because of the various reductions in both the weights and finenesses of this principal denomination Caracalla's total bullion requirement to meet his expenditure could not have been more than half as much again as that of Augustus.

If Caracalla's pay rise and the introduction of his new antoninianus piece actually coincided - so that these might be regarded as merely two aspects of a single financial measure; and we accept that the antoninianus was treated at its inception as a 2-denarius piece (yet with a fixed weight of only 1½ denarii) then Caracalla could, in fact, have effected the large nominal increase in military pay with exactly the same amount of silver metal in circulation as his illustrious predecessor, and without having to effect any further debasement. The author's coin analyses(70) do demonstrate that Caracalla did, indeed, continue to use the same fineness standard as Septimius Severus, and also that the same alloy was used for both the denarii and the antoniniani. It was, perhaps, in anticipation of the financial difficulties which lay ahead, that Caracalla then extended Roman citizenship to all within the empire - not really as an act of benevolence, but in order to enlarge the taxable population and, hopefully, to increase the silver resources of the treasury by directing into it more of the coins or treasures then in private hands.

The next highly expensive phase of army development came in the middle of the third century when Gallienus created a field arm of cavalry, based on Milan, and issued a special coinage to celebrate the importance of that event. But the feed for a horse cost as much as a man's rations;(71) and so increases in cavalry strength began to add considerably to the expense of equipping and maintaining the already large army.

By the end of the third century AD Diocletian recognised the impossibility of one man governing an empire extending from northern Britain to the borders of Arabia, when communications could be no faster than the fleetest rider on horse. His formation of a tetrarchic system of government, however, worsened the inflationary situation, for it necessitated the distribution of armed forces (together with local facilities for minting their pay) amongst the four Imperial colleagues located at strategic points within the expanse of the empire. The direct result was the raising of the number of armed men to over half a million. Annual conscription had to be introduced to maintain the strength of the forces; an increasing burden of taxation fell upon the populace; and there was a necessary proliferation of mint cities to meet the immediate needs of hard cash close to hand in each of the rulers' territories.

The gold coinage issued during all these tribulations had, to some extent, helped to stabilise the currency against complete collapse; but a serious blow was delivered in the latter half of the second century when Aurelian lost the Dacian gold mines and, despite his valiant attempt at the restoration of both the Empire and its traditional coinage in AD 274, he was unable to revive a fine silver coinage or to make substantial issues of gold. A generation later Diocletian managed to do both; but he and his successors failed to maintain the supply, and his new silver coinage disappeared within 15 years of its inception.

When Constantine began his rise to power there were great hopes of a full recovery of empire. The unifying movement owed a little, perhaps, to both Christian inspiration and aspirations; but on the human level it was inevitably upon the basis of a more powerful land fighting force than hitherto, supplemented by a navy. Constantine recognised that his forces had to be paid, and without delay. Professor P M Bruun(72) remarks that "Constantine's pathway to supremacy in the whole Roman Empire left a glittering trail of gold". During his reign, however, he had to tax heavily in order to remain solvent. To do this, in addition to conventional taxes, he increased the essential bullion supply by five principal means:

(i) by large acquisitions of coin and bullion as the spoils of war in his campaigns against his rival Licinius;
(ii) by confiscations (towards the end of his reign) of pagan temple treasures;
(iii) by gold rents from the Imperial estates;
(iv) by two new taxes – a 'collatio lustralis' levied on traders;
and (v) by the 'gleba senatoria' tax levied on senators.

These methods did not increase the production of bullion from the mines nor did they improve the real wealth of the Empire whose resources had been heavily drained by internal conflict; but they did enable Constantine to issue a new fine silver coinage - the siliqua - even a year before his ultimate conquest of the Empire. The more common argentiferous bronze coinage, however, suffered further diminution and debasement before Constantine's death in AD 337 - no doubt the result of the enormous military donatives which were required for at least three Imperial celebrations, with which the coinage types and fineness changes are now clearly identified in this work.

Following Constantine's death a pathetically small leaded-bronze coinage came into use in parallel with the slightly increased number of silver siliquae, and a further reform became a necessity just over a decade later. For all his greatness in the affairs of state and in personal achievement Constantine proved to be incapable of stemming the mounting tide of early fourth century inflation: indeed he contributed to it in no small measure.

In the second half of the fourth century AD the Roman Army was further enlarged to meet the needs of a divided empire, despite the raising, in AD 367, of the minimum height for acceptance (by nearly 6 inches) to 5 feet 5 inches. Theodosius even mobilised 40,000 barbarian confederates to serve as Roman cavalry.

By the end of the fourth century the army had reached a numerical strength nearly twice that of the Imperial army of two centuries earlier, but it was much more expensive to maintain because of the much higher proportion of cavalry needed to match the developments which had taken place in fighting techniques. Despite its size and seemingly greater flexibility of manoeuvre, however, it was incapable of keeping pace with the barbarian attacks mounting along the line of northern defences extending from the Asian minor to the North Sea.

In the fifth century the incessant barbarian invasions, and trouble and despair within, spelled the final death of the Western Empire. In AD 406 the usurper, Constantine III, stripped Britain of troops for his conquest of Gaul and Spain. Four years later, with barbarians at the gates of Rome, the despairing Emperor Honorius withdrew the legions from Britain to protect the core of the Empire. But by the middle years of the fifth century the provincial forces which had not been lost in battle were gradually disbanded; and by the end of the century the Roman Army in the West had altogether ceased to exist.

Imperial exhaustion

Although the Roman Army was largely responsible for a continual heavy drain upon the Empire's resources it was not the only cause of the constant and worsening economic problems. The Army system was symptomatic of the entire complex imperial regime, which seems to have fostered a Roman predilection for a continued enlargement of the bureaucracy of government, so that the Roman Empire became slowly enmeshed in its own intricate web of expensive controls.

Sir Kenneth Clark(73) observes that even those civilisations which seem to be complex and solid are actually quite fragile. They can be destroyed by fears that lead to ennui and a total loss of confidence; and by that feeling of hopeless exhaustion which can overtake people with even a high degree of material prosperity. The Roman Empire collapsed, he says, from sheer exhaustion: the exhaustion of almost every kind of resource it had ever possessed.

In his substantial treatise on the decline and fall of the Roman Empire - which occupied his attention for more than 17 years before the publication of the last three of its four volumes in 1788 - Edward Gibbon(75) shows philosophical insight into the cumulative variety of human attributes and failings whereby the fate of the Empire was eventually sealed. Gibbon dated the obvious beginnings of decline to the reign of Commodus (AD 180-192), although in reality the seeds of destruction had existed before the dawn of Empire.

The Roman Empire was far too dependent on the inconsistent and unreliable factors of human strength and discipline alone, and on the over-organised enterprise of the State. Such vital spiritual factors as did exist were unfortunately distorted and debased by the inculcation of not only the divine authority but the official divinity of emperors for whom the people could hold but little mortal or moral respect. These emperors enforced - rather than engendered - the spiritual aspirations of the people, using themselves as the personal focal point of loyalty. This Emperor-worship existed in forms which are difficult to comprehend today. Its reality and practical application are known. In the Courts, for example, a refusal to worship the image of the emperor provided a quick and simple sorting-test for identifying Christians - as the extant communications with the Emperor Trajan testify(76).

In the terms of Daniel's prophetic phraseology we observe that such attempts at an enforced unification of the admired incompatible elements of race and creed in a Roman mould could only preserve the individual factional weaknesses while failing, other than superficially, to combine their strengths. In reality the empire was rotting from within long before it had to face any serious damage or destruction from without.

At the height of the Empire's glory Tacitus(77) - while perhaps justly, as well as tactfully, uncritical of the contemporary and enlightened Emperor Trajan - wrote in studied condemnation of the evils and unreliability of earlier imperial rule. Tacitus actually traced the decline of the Empire from its very founder - whose vices he observed to have been perpetrated in every succeeding reign - and he was duly pessimistic about the future.

Despite, however, the emergence of a few really competent emperors during the succeeding centuries - who momentarily stemmed the decline or engendered fresh hopes of recovery - the downward path continued. The end of the second century AD is, as Gibbon observed, the most obvious point of declination. Dio Cassius of Nicaea(78) was an eye-witness of the events which took place from shortly after AD 180; and in his monumental eighty-book history of Rome - from its beginnings, to AD 229 – he picks out one fundamental element of imperial moral and economic disaster, that "... after a man had been declared emperor ... he had to reward his supporters by an immediate issue of money" - for no real loyalty can be thus acquired or retained. And, when he came to the events which followed the reign of Marcus Aurelius (AD 180) Dio Cassius observed that the history "... now descends from a Kingdom of gold to one of iron and rust, as affairs did for the Romans of that day". These words echo across the centuries almost the same phrases uttered by Daniel some eight centuries earlier.

The continual struggles over the imperial succession then continued to make a major contribution to the exhaustion of both the human and material resources of the empire during the third and fourth centuries; and for this reason the coinage of successive emperors is found to be most varied in its form and in its metallurgical composition. It is here that an intensive study is particularly well repaid.

In the course of nearly 500 years the Roman Empire was ruled by over a hundred legitimate emperors in addition to numbers of successful and unsuccessful usurpers. More than a third of these reigned in the turbulent third century alone.

During these third and fourth centuries the cumulative inflationary decay progressed inexorably. The State became one gigantic and complex bureaucracy whose management grew quite beyond the human controlling capacity of any one autocrat - no matter how personally efficient a politician, soldier, and administrator, he might be. The consequence was the drain and exhaustion of the Empire's natural resources – particularly of the forests and agricultural lands and food supplies. Then came the ultimate exhaustion of man-power in an inflexible, hierarchical and costly system in which everyone was classified and compelled into some extensive form of public service. The State became all consuming and barely productive.

Eventually no-one was really free to act or to change his rôle in Roman society without official permission from a higher authority. This led to rampant corruption amongst a regimented population caught in their hopeless and miserable plight. In this system no-one could assuredly make any sort of provision for the future; so frustration and inertia replaced enterprise as coinage as a repository of value became less and less reliable. To be delivered from such an enervating complexity of life by invading barbarians of crude simplicity was, even to the people of the privileged and parasitic City of Rome, a not unwelcome relief when it came in AD 410.

As the coinage shows, the costly imperial peace, then, the military anarchy of the years AD 192-284, followed by the increasing imperial bureaucracy which intensified from AD 284 onwards, led to both individual and national ruin in a series of economic crises which happened with increasing frequency as the Empire neared its end. Then, with its ebbing strength firmly bound in a stagnant and indifferent society of its own creation, the Roman Empire and its Army lacked the flexibility, the will, and the ability to survive in a changing world not appreciative of even the traces of the finer virtues which lingered.

After the disastrous battle of Hadrianople in AD 378 an over-organised, corrupt (and now divided) empire began to face the last eighty dismal years of economic ruin within and struggles against barbarian inroads from without. In late AD 394 Theodosius managed to reunite and re-organise momentarily the tottering Eastern and Western portions of the Empire - just a few weeks before his death; but, as the Empire re-divided, the western provinces bore the brunt of external attack, while both East and West suffered the worsening economic conditions.

In AD 410 the City of Rome was captured by Alaric, King of the Visigoths. The Roman Empire reeled but did not collapse. In desperation Honorius concentrated his military strength for the defence of the heart of the empire - rather than its fringes. Ready to blame anyone or anything rather than themselves for their plight, the orthodox Romans attributed Rome's troubles to the revenge of the pagan gods of Rome in whom faith had largely been lost and whose cults had been largely suppressed in favour of Christianity by the joint Emperors Gratian and Theodosius. It was in formal reply to this accusation that Saint Augustine of Hippo wrote his greatest work 'De Civitate Dei', between the years AD 413 and 426, in erudite proof of the impotence of the so-called gods of Rome to help her. In vindication of Christianity he contrasted the real and eternal City of God amongst men in every conceivable manner with the City of Rome and all that it represented of transient worldly pride and wisdom. To him the end was inevitable, and explicable. Contrary to the opinions of the influential leaders of Rome Augustine exposed the truth that the ordinary people had completely lost faith in their State and its system. Some preceding fourth century Emperors – with the notable exception of Julian the Apostate - and later ones too, would seem to have a measure of agreement with him, for the extant Edicts of all the emperors from Constantine to Theodosius II (promulgated in the Codex Theodosianus on 25 December AD 438) show that they regarded the Christian Church as a bulwark against disruption rather than as a disrupting force itself(79). Sadly, however, these chastened and enlightened emperors inherited a complex and corrupt state system which could not then be revived either by entreaty or by further legal enforcements.

A few years later the real beginning of the visible end came when Atilla and his Huns commenced their mass invasion of northern Italy in AD 452. Shortly afterwards the Vandalic invasion of Rome, in AD 455, gave the word 'vandalism' that place in our language which expresses that sheer wanton destruction which evades any other description. But it was not until Odacer's formal deposition of the ironically-named Romulus Augustulus, in AD 476, that the system of unified rule of the Roman Empire in the western territories bordering the Atlantic and the Mediterranean officially collapsed.

The chronological limits of the Imperial coinage

Although the Roman Empire in the western world lasted for almost five centuries, its exact beginning and ending are difficult to locate precisely for either historical or numismatic purposes. The old Republic merged into the Empire in both custom and coinage; and for a while the Empire continued many of the hallowed Republican traditions - including the arrangements for minting its coinage - in only slightly modified forms. In similar fashion the exhausted Empire expired in a series of death pangs rather than by such a cataclysmic event as destroyed Babylon, literally overnight.

The beginning of the Imperial coinage era is marked by those issues which bear the name of Augustus or other marks of his extended personal imperium. It is difficult, without chemical analysis, to detect any significant changes in the silver and copper-rich coinage alloys used at the beginning of this period, for it was some years before the major Augustan coinage reform inaugurated a truly Imperial coinage embodying those innovations which gave distinctive metallurgical features to a coinage system which was to endure in its essential form for nearly half of the subsequent Imperial era.

Imperial Roman coinage emerged, therefore, amongst the series of military and political events whereby Gaius Julius Caesar Octavianus acquired supreme power and became Augustus - the first Emperor:

i) In 43 BC Octavianus was acclaimed a Republican Imperator – which at that time was purely a military distinction without the political significance which became attached to the term later.

ii) Between 43 and 36 BC the rule of the Triumvirate came to an end; and the coins minted in this period were entirely Republican in character.

iii) Between 36 and 29 BC Octavian's image appeared on the coinage issues - now as the acknowledged head of the State (and 'son' of the 'deified' Julius Caesar) but without any attribution to him of Imperial titles.

iv) After Octavian's success, against Mark Antony, in the battle of Actium, in 31 BC; followed by the annexation of Egypt in 30 BC, and the triple Triumph celebrated on his return to Rome in 29 BC, the Imperial characteristics of the Roman coinage – including the inscription IMP CAESAR-began to emerge. At this time Octavian dropped his former personal praenomen of Gaius and assumed the name 'Imperator' in its stead(80) – thus altering the concept from its simple military meaning to a personal political one.

v) Octavian then effected a drastic purge and reform of the Roman Senate which, in 28 BC awarded him the title of 'Princeps Senatus'. Tacitus(81) remarks that thence he "... subjected the world to Empire under the title of Prince".

vi) On 16 January 27 BC the titular cognomen of Augustus was formally conferred upon Octavian, by decree of the subservient Senate, and the coinage issues of 26 BC bore this new Imperial name.

vii) Between the years 27 and 24 BC Augustus spent his time in Spain - commencing a series of conquests which were not eventually completed until 19 BC. In 24 BC he returned to Rome, received the tribunician powers for the first time, and the coins bearing tribunician awards can be dated from this period.

viii) Then, in 23 BC, the minting of the aes (copper-based) coinage was restored to the nominal control of the Senate, and by 20 BC appointed moneyers became responsible for the subsequent issues of gold, silver and aes coinages until 15 BC. Their names are recorded on the coin reverses.

ix) By a further monetary reform of Augustus in 15 BC the moneyers privilege of issuing gold and silver was withdrawn and they became restricted to the issue of only the base-metal denominations - until 3 BC. This reform brought an important distinction between the Imperial (precious metal) and the Senatorial (base-metal) coinages although, in fact, the issues of both coinages were nevertheless under the control of the emperor himself. Augustus thus exercised, reserved, and began to establish, the exclusive right of an emperor to control all coinage issues.

x) In 3 BC the moneyers privilege and responsibility for striking the empire's brass and copper coinage was finally withdrawn and granted, nominally, to the Senate. The current denominations were not altered: it was the control of issue which passed more firmly into the Emperor's hands. The coinage in all denominations then became fully imperial in style and character - although nominal recognition of the Senate's eclipsed authority was continued with the appearance of large S C (senatus consulto) inscriptions on the reverses of the *aes* pieces. This practice was continued for the next two and a half centuries, although the diminution of the lettering with the passage of time might be taken as visible evidence of the negligible part which the Senate played in its issue!

xi) On 5 February 2 BC Augustus received the title of 'Pater Patriae', and he publicly adopted his two grandsons, Gaius and Lucius, as his intended successors. The full Imperial concept - political, dynastic, and numismatic - was then almost complete.

xii) In AD 5, following the premature deaths of both Gaius and Lucius, Tiberius (the stepson of Augustus) was nominated as the Imperial successor and a partner in the Imperial powers.

xiii) The death of Augustus, in AD 14, marked the legal termination of the Roman Republic, and the establishment of Imperial rule.

It can be seen that the years 29 to 27 BC mark the major political transition from Roman Republic to Empire. The Imperial coinage can thus be taken as commencing in 29 BC (with the IMP CAESAR issues) or when Octavian became Augustus on 16 January 27 BC; and in theory a study could well commence with those issues of 27 BC which bear both the image and imperial superscription of Augustus, but a metallurgically distinctive

Imperial coinage cannot be shown to appear until about the time of the reform of 23 BC. Some authorities have placed this event - the introduction of a gold, silver, brass and copper coinage system in place of one of gold, silver, and bronze - as coincident with the second monetary reform of 15 BC; but the metallurgical evidence of this work supports Mattingly's(82) earlier date of 23 BC for the reform which brought the technical innovations of orichalcum (brass) for sestertii and dupondii, and plain copper for the common As in place of the traditional leaded bronze of the Republican era.

The earliest Imperial coin which could be obtained for destructive analysis was a copper As (Code No MAZ.2, RIC237) minted at Emerita, Spain, at some date between 24 and 23 BC, after the bestowal of tribunician powers. (Emerita Augusta became Roman colony in 25 BC). A slightly earlier As, AVGVSTVS DIVI F. (Code No MAZ.1, Cohen 706) minted in Ercavica, Spain, between 27 and 24 BC is in a typical Republican leaded medium-tin bronze alloy. Was it the wealth of copper to be found in Spain, and perhaps a general shortage of tin for alloying, that led Augustus to contemplate and institute the copper coinage during his Spanish campaigns? In any event, the practice was quickly adopted at Rome for an early moneyers As of c. 23 BC (Code No S.L.51; RIC.74 note).

The end of the Roman Empire in the West was much more protracted than its birth; so it is even more difficult to fix a precise date for the termination of its coinage and to make a beginning for the coinage of the Byzantine Empire and of the independent European states which emerged; and metallurgically there is also no sharp transition to be found.

The principal work of reference on the late Roman bronze coinage(83) selects the terminal date as the reform of the Eastern bronze coinage, by Anastasius, in AD 498. But in the West the mint cities which fell into the hands of the barbarian invaders ceased their operations very much earlier in the fifth century. Indeed, shortly after AD 400 Rome remained the only important mint for the coinage of bronze in the Western Empire. In Gaul Lugdunum closed c.423; Arelate c.425; Treveri c.430: thereafter there was very little western coinage in comparison with the copious issues from the many western mints which had flourished during most of the fourth century.

In April AD 395 the demonetisation of the bronze Maior pecunia(84) left only two small pieces of almost intrinsically worthless leaded-bronze in circulation for common use: after AD 423 only the smaller of these pieces (weighing barely one gram) remained. The period of interesting metallurgical variety in the Imperial coinage can, however, be considered to end even before the beginning of the fifth century AD. Then in the sixth century the Byzantine lower denomination coinage seems to have reverted to the plain copper of early Imperial days - but lacking the purity and quality of the copper coinages of the earliest emperors, and exhibiting little apparent metallurgical variation for several succeeding centuries.

The latest disposable Roman Imperial coin which could be obtained for chemical analysis was one of the minute ones minted for Honorius, in the period AD 410 and 423. Between the chronological extremities of the four and a half centuries delineated by the minting of the Augustan As and this piece the numerous metallurgical changes in the Roman Imperial coinage materials - according to necessity, caprice, economic wisdom, or technical innovation - have been examined. The chemical compositions of coins from issues which have never been analysed before are also recorded for the first time. Furthermore, the high degree of analytical accuracy maintained throughout the investigation has allowed a firm re-appraisal of many results obtained by earlier workers and has shown that the majority of the Imperial coinage was minted to high technical standards for weight and metallic composition, apparently with deliberate intent and for specific purposes which can now be more closely discerned.

The Dating of the Coinage

With but few notable exceptions, which hark back to the founding of the City, the Roman coinage does not bear dates in the manner of most modern coinages. Nevertheless the majority of issues can be dated with a remarkable degree of precision because of the Roman propensity for the systematic recording of important events on the coinage as well as on monuments and other official records.

There are few coins which do not bear, together with the imperial image, some superscription which allows an issue to be placed in each reign in its position in a reliable sequence in which the names and titles tended to assume shorter forms as the reign lengthened and the ruler’s titles became better known.

Within each reign the known historical and military events which are recorded on the coins also provide confirmation of the place in the sequence or provide their own positive chronological location. Imperial achievements and acclamations, mint-marks, and in particular the consular appointments and regular bestowals of registered tribunician powers, in accordance with traditional Roman formulae, on special calendar days, give combinations of records which enable some coins to be dated much more precisely than modern coins - even to within a few days in their year of issue.

The standard works of reference which have been used for this work take all these factors into consideration in allocating sequences and probable dates of issue; but some assessments of these are too hopeful – especially for coins minted in periods for which the regnal chronologies are themselves confused by a lack of extant records, by irresolvable differences between them, or by conflicts between coin markings and other documentary evidence. The coin analyses, and the fineness variations in particular, now provide new criteria for determining the sequential chronologies of some hitherto doubtfully dated pieces. In some cases, however, (and the sole reign of Gallienus provides the most striking example) a new sequence has had to be devised because the previously accepted one fails to match the obvious sequence of metallurgical trends which embrace the more positively located issues of the series.

Only the most laconic coins of the longer reigns - such as those minted by Hadrian with the simplest inscriptions and legends - are difficult to date to within a few years. Here again the metallurgical trends help to suggest or confirm the sequence; but until chemical analyses become available on a much more statistical basis for use in conjunction with other dating criteria (such as weight and module) these and similar coins are plotted on the graphs as points within lines which extend across the assured broad chronological limits between which they were minted.

The Roman weights system

It is generally supposed that the balance originated in predynastic Egypt but it could have had an even earlier origin in that cradle of civilisation - Babylonia. The earliest Biblical reference to a weighing (of silver), presupposing a balance being available, occurs c. 1860 BC(85); and this record also mentions the shekel as the weight unit, the word being derived from the Hebrew, shaqal, 'to weigh'. The shekel was almost certainly the earliest unit of weight and it continued to be mentioned (even to the exclusion of the mina) in all early Hebrew literature and in the scriptures from 1860 BC to at least as late as 445 BC(86). It became the basis of all later ancient weight systems, including the Roman.

The earliest balances were of the cord-supported type, the beam being suspended at its centre by a cord attached to a fixed support (or held in the hand) with the scale pans similarly suspended from the ends of the beam. By 1500 BC refinements had been made, to reduce pivot friction, to indicate the point of balance, and to ensure constant equality of arm length during weighing; but it was not until the start of the Roman Imperial era that a pin fulcrum began to be placed at the beam centre and slightly beneath the level of the end pivots - thus greatly improving balance sensitivity and the precision of weighing. No other significant development took place until modern chemical balances began to be designed in the 18th century AD.

Roman balances were, therefore, extremely advanced for their day: a moneyer's balance of c. AD 350 (now in the Petrie collection) has a sensitivity of 0.03 gram., making it responsive to a mass of less than a single wheat grain of about 0.045g.

Most metrologists are now agreed that the source of all ancient weights and measuring systems is the Babylonian, which was constructed with rigid precision upon the basis of a unit of length astronomically ascertained long before 3000 BC. A cubic vessel, based on a fraction of this unit, furnished the unit of volume; and the weight of water contained in this volume became the unit of weight.

Professor W Ridgeway(87), however, suggests that in all probability man "made his earliest essays in weighing by means of the seeds of plants, which nature had placed ready to his hand as counters and weights", and even close to our own time barley grains have furnished the apothecary and the goldsmith with their smallest weight unit - the Troy grain, of 0.0648 gram. Significantly, early temple accounts, dating from 2000 BC, recovered from Telloh in Southern Babylonia, reveal the sub-division of the shekel into 180 shé (or grains of wheat) in the Babylonian sexagesimal weights system in which 60 shekels made a mina and 60 minas made one talent. If the weight of a wheat-grain is taken at its usual estimate of 0.70-0.72 of a Troy grain (which was originally a barley grain) the ancient Babylonian shekel of 180 wheat grains comes to 126-130 Troy grains, or 8.17-8.40g - which closely matches the weight of the shekel revealed by actual stone weights discovered by Dr C F Lehmann and published in 1893(88).

The equality of the Hebrew and the Babylonian talent in 701 BC is attested by the independent but identical amounts of Hezekiah's indemnity to Sennacherib as recorded in the Biblical account(89) and on the Assyrian inscribed hexagonal prism(90) made in 686 BC and now in the British Museum. That the Roman libra itself was derived from the Babylonian system and very closely related to it is attested by a weight marked PONDO CXXV TALENTVM SICLORVM III (M), which equates 125 Roman librae with 3000 heavy shekels or tetradrachms.

It follows that although we have no direct evidence for the incorporation or use of a wheat-grain unit in the Roman weights system it is historically and metrologically entwined in it; and the author is of the opinion that it was, indeed, regularly used for small dealings in gold and silver and for monetary purposes. Roman balances were capable of dealing with such units, with precision, and numerous Roman gold and silver coin weight standards in both the Republican and Imperial eras are translatable into simple multiples of wheat-grains if one postulates a system of 7200 wheat-grains per libra superimposed on the conventional system of:

1 unit = 1 libra = 12 unciae (c. 325 g.)
1/12 " = 1 uncia = 24 scrupula (c. 27.1 g.)
1/288 " = 1 scrupulum = 2 obols (c. 1.13 g.)
1/576 " = 1 obol (c. 0.565g.)

(On this basis the scrupulum would have equalled 25 wheat-grains.).

If we make comparisons between the known ancient systems we find simple multiples all translatable into shekels, and therefore into wheat-grains. For modern convenience we will consider their metric equivalents and abandon the old comparisons made in Troy grains which are unnecessarily deceptive.

We discover that the light mina of c. 491.2 g. - which became the standard weight unit of Egypt - was one and a half times the weight of the Roman libra (c. 327 g.) which was itself one-third of the corresponding heavy mina of c. 982 g. On this basis the 125 libra weight mentioned above equated with 3000 tetradrachms of c. 13.6 g; didrachms of c. 6.8 g; and obols of c. 0.57g. It also becomes apparent that the Roman libra exactly equated with forty ancient Babylonian shekels of

c. 8.3 g - and this relationship can be shown to have persisted in the average weight of the much debased Roman tetradrachms of Alexandria issued as late as the final series in Diocletian's reign. The 6-obol denarius-drachm, weighing exactly 3 Roman scrupula (one Egyptian zuz) c. 3.4 g, also provides a direct link between the Egyptian, Greek and Roman coinage and weight systems.

Our problem, because of a natural variability in the weights of both the ancient and present-day wheat-grains, is to decide the nominal weight of the Roman libra, and then to determine what the libra standard was (in modern terms) if such a thing did in fact ever exist as a single official standard at all times and in all parts of the Roman Empire. Consideration of the fundamental and derived units; the wheat-grain; the 180-grain Babylonian shekel; the 40-shekel Roman libra; yields a possible range of 326.6 to 335.9 metric grams for the libra, which spans from 0.26% below to 2.84% above the oft-quoted and over-precise value of 327.45 g calculated from groups of coins by A Böckh in 1838, adopted by T Mommsen in 1865 and endorsed by P Hultsch in 1882.

Roman weight-standards were always closely associated with the coinage. Indeed it is the extant mint-fresh gold coinages, made to known libra fractions, which provide the best means of establishing the probable weight of the libra, because other known weights of base metal or stone are now generally corroded or worn and thus tantalisingly removed by an indeterminate amount from the standards which they were originally intended to represent. It is important to review the values attributed to the weight of the Roman libra in view of the wide differences between quoted figures which, like chemical analyses, can possess different degrees of reliability. Professor P Grierson(91) has rightly remarked that the value of 327.45 g for the libra is "... only the result of calculations of disputed validity based mainly on the observed weights of .... Roman coins", and suggests that a value of 325 grams is, perhaps, to be preferred. We need the most reliable figure for dealing with the debased silver and bronze coinages so that the degree of metallurgical control exercised in alloying and in the prevention of melting losses can be determined, so that an intended norm can be compared with an actual one achieved, and that the concentration of the non-oxidisable silver in a base argentiferous coinage can be determined and the true fineness standard ascertained.

In considering Roman metrology and metallurgical practice it is necessary to remember that the decimal fractions with which we are now so familiar arise from mathematical concepts and developments of the sixteenth century associated with the use of Arabic numerals. We have to recognise this as an artificially imposed barrier to an understanding of Roman metrology and then reorientate our thinking to that which would have pertained to Roman times. The Romans would have made their coinage alloys on the basis of simple proportions of materials weighed according to their own duodecimal weights system. There is no evidence that they ever used decimal fractions (as distinct from multiples) for their metallurgical calculations which would have been, in any case, complicated by their numerical notation.

Statistically significant analyses of good accuracy have revealed that expressions in percentage compositions have obscured some of the simple metallurgical relationships which were used. A bronze analysis of 8.33% tin can be more clearly understood as a Roman alloy made with 1 uncia of tin per libra; and a much-debased coinage with a norm of about 1.39% silver as an issue minted to an intended fineness standard of 4 scrupula per libra. The author's appreciation and application of this principle has, indeed, led to the identification of a whole range of Roman coinage alloy standards which had been hitherto concealed.(92,93)

The various attempts to define a single metric equivalent of the Roman libra are detailed in Table I and illustrated in Figure 2. A glance suffices to reveal the wide range of estimates to be much greater than either the precision of weighing or reproduction of standards possible in Roman times. We ought, really, to disregard the indirect evidence from coins and weights made outside the Imperial era; and even within it we should concede a drift and variation of standards over the five centuries and between the empire's geographical extremities. Thirion's(94) recent deductions, for example, point rather to a slightly heavier 1st century libra than to the improbable 1/44th libra fraction which he proposes as the acceptable standard for the minting of Neronian gold.

TABLE 1

THE ROMAN LIBRA

The Various Metric Equivalents Proposed, Arranged in Ascending Weight Order

Item	Value (grammes)	Fundamental basis of the estimate	Authority
1	318.90	The (18th century) Constantinople pound; 6004 Paris grains.	P Guilhermoz (1906)
2	322.56	The four-scrupula Constantinian solidus of 4.48g (av) x 72.	L Naville (RSN 1920-22)
3	"	Confirmation by 350 mint-fresh solidi of AD 467-72, of which the heaviest was 4.515 g. (No allowance for wear.)	P Grierson (NC 1964) quoting G Boni (1899)
4	323.136	Thirion's basic estimate; derived from new data for weights of aurei minted between AD 64 and 180, and adjusted to harmonise the differences between the Imperial and Republican coins.	M Thirion (1972)
5	323.26	A series of basalt weights ex Palestinia.	M Lazzarini (1908)
6	323.47	" " " " " (Modification, after later study).	" (1948)
7	325.	A new view; 'but insufficient grounds for making such a change'. (It corresponds with a 4.51 g solidus standard.)	P Grierson (NC 1964)
8 9	325.06 325.4	)Implied by two serpentine weights from near)Cuenca, Spain.	E Hübner (1861)
10	325.440	An estimate which attempts to harmonise apparent differences between figures derived from Republican and Constantinian gold coins.	R Sydenham (1952)
11	325.80	Arbitrary (but not unreasonable) 1% + correction to Naville's value (2. above) for wear. (Theoretical solidus then 4.525 g.)	P Grierson (NC 1964)
12	325.8	Derived from a 1st century 10-libra serpentine weight, ex Pompeii or Herculaneum, now in the Naples museum (3258 g).	L Caguazzi (1825)
13	326.337,231	Deduced from Charlemagne's 15 ounce pound of AD 794 - weighing 407.921,529 g. (Merovingian and Carolingian coins, + 1%, are said to correspond.)	M Thirion (1972) after J Lafaurie (1970)
14	326.367,360	Thirion's 1% + adjustment to 4. above; following the suggestion of G F Hill regarding allowances for wear, NC 1924.	M Thirion (1972)
15	327.18	'Coin groups'	J A Letronne (1817)
16	327.45 " "	Coin groups (calculations in terms of Paris grains). Adopted. Endorsed; and now widely quoted and accepted despite its less reliable foundations than some other values.	A Böckh (1838) T Mommsen (1865) F Hultsch (1882)

THE ROMAN LIBRA

PROPOSED METRIC EQUIVALENTS

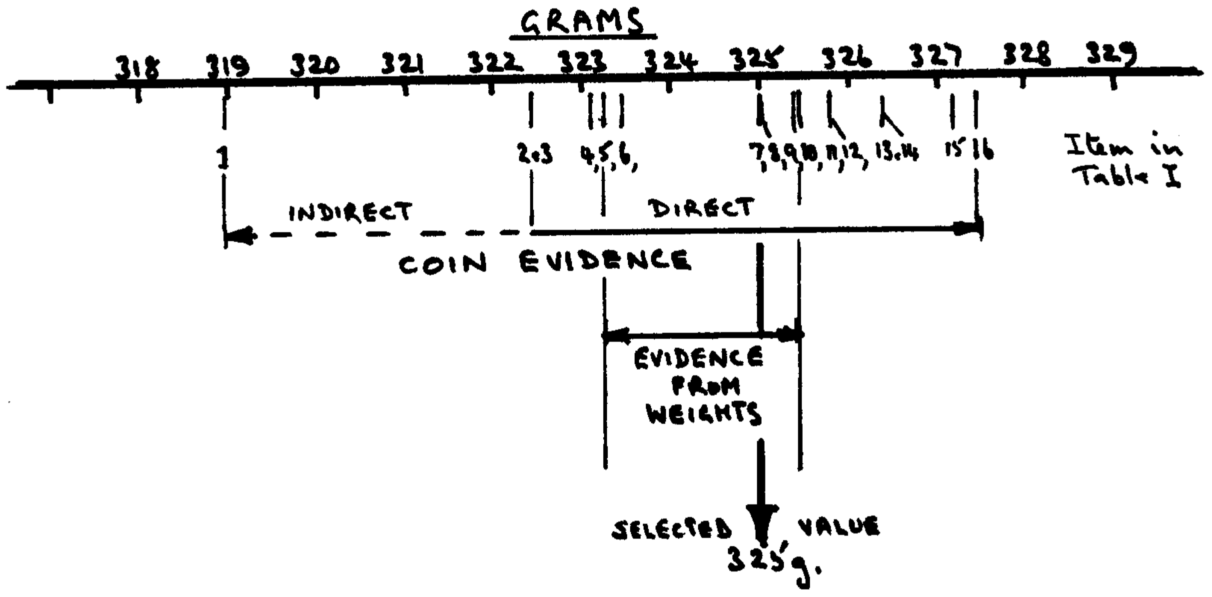


FIGURE 2

Attempts to arrive at an agreed consistent value for the Roman libra are all based on the unjustified assumption that a fixed constant weight standard persisted throughout the long Imperial era and in all Provinces. There is no evidence, however, that an official standard ever existed in any form similar to that of the standard metric kilogramme, which is defined, copied, and regularly compared for international metrological purposes. The imperial coinage weights seem to indicate that the Roman libra could have been somewhat imprecise and variable; and so all attempts to define it exactly in modern metric terms are fraught with fundamental difficulty. We have to contend with real differences in basic data which must lead to different estimates, ranging over several grams, for a tantalising theoretical norm of uncertain reality.

The sixteen proposed values in Table I extend from 318.90 to 327.45g. If we discount the lowest value, as being based on far too modern a copy of an Imperial standard, the range of not unreasonable alternative values is substantially reduced from 322.56 to 327.45g, which is still a span of 4.89g. So it is not possible to be certain of a 'standard' Roman libra to less than 1.37%, at present, and this makes nonsense of those attempts to define the libra, with great exactitude, to six (or even nine) significant figures. It seems that we must accept that slightly variable libra standards were used at different periods and in different places in the Empire, but that the variations were of little practical consequence either at the time or for the purpose of this study. A new approach should be the statistical determination of the metric equivalents of the librae pertaining to different dates and places based on mint-fresh pieces of the gold coinage. But already it is apparent that the Republican libra was probably heavier than the early Imperial one; then this, in turn, seems to have been heavier than the ones pertaining to either the Constantinian or Byzantine periods. For the time being it is considered to be quite reasonable to endorse Grierson's suggested value of 325g for the average Roman Imperial libra, and this is the unified figure adopted for all the calculations of coin weights and alloy compositions for this work.

COIN ANALYSIS

Objectives and fundamental principles

There are three main reasons why numismatists may need to know the chemical composition and metallurgical structure of a coin:

(i) because a detailed knowledge of the metal or alloy used should reveal something of the intentions of the issuing authority - and of how closely the moneyers were able to carry out those intentions;

(ii) for the purpose of studying the provenance of the coin itself or the possible sources from which the principal alloying elements might have been derived - by characterising the patterns of impurities or trace elements present and by determining any significant main alloy proportions;

(iii) to permit the authentication of an issue by showing its composition and structure to be typical of its period or provenance; or, conversely, to substantiate that a dubious coin is either an ancient or modern forgery, as shown by its composition characterisation and its mechanical and thermal history as revealed by metallography.

In particular the finenesses and associated weights of a series of coins in gold or silver alloys should indicate the monetary policies governing their issue. An understanding of a policy can be gained if there is no extant documentary evidence to throw light upon it, the degree of practical achievement can be shown if the policy is recorded, or the understanding may be extended in the case of incomplete records which are difficult to interpret.

The metallurgist is also interested in the techniques of metal extraction, refining, and coin fabrication used in ancient times, and in the levels of achievement when metallurgy was much more of an art than a science or technology. Nevertheless, he has not to lose sight of the ultimate numismatic and historical objectives to which his researches can be directed. It is paramount that mere scientific curiosity and trials of new analytical techniques are kept subservient and relevant to the solution of numismatic problems, and this is particularly important when the total or partial destruction of an ancient coin is involved.

Such a philosophy has not always prevailed, as even some recent analyses reveal. One can only regret the irreparable loss of those ancient coins which have been the subject of tinkering in the name of science when better use could have been made of them.

In the author's opinion it is the bounden duty of every analyst of ancient coins to perform the fullest reasonable and practical analysis on all but the most common pieces, always leaving, if at all possible, some unaffected portion for posterity to check or examine further. One can rarely justify the consumption of a complete coin for the wasteful determination of only one element, as has been all too common in the past. On the other hand it is not often necessary to determine every element which can possibly be present in the most minute proportions. One can never expect to find - let alone determine - all 92 of the known natural elements, nor even the 75 metallic elements.

In a recent study(95) of over 100 specimens of Irish copper ores the Royal Anthropological Institute decided upon 20 possibly significant elements for determination; and a Stuttgart team, doing similar work, determined 11 elements, of which only five were considered to be significant. For their study of British copper ores H H Coghlan and R F Tylecote(96) sought 46 elements but found only 23 present above the limits of detection.

The present author did, on one occasion, obtain an almost complete mass-spectrometric analysis of a Roman gold coin(97) - for every element above mass 7, except indium and tantalum which the technique rendered indeterminate - but found that only 36 elements other than gold could be detected at levels above 0.05 parts per million for any monoisotopic element; and of these only 3 (plus gold) were present in proportions (above 100 ppm) which would have enabled them to be determined by a conventional wet chemical analysis of a sample of about 1 gram. This ancient gold happened to be of excellent purity, but in similar mass-spectrographic analyses of Roman copper coins it was unusual to encounter more than 30 elements just detectable and, of these, less than 12 were found in excess of 100 ppm; the most common impurities were Fe, Ag, Ni, Pb, Sb, As, Sn, S, Bi, Co, Se and In - roughly in that order, and sometimes small proportions of Zn and Si may also be found.

It will be noticed that only those base elements are present which have thermodynamic properties allowing their oxides to be carbothermically reduced at temperatures below about 1600°C - perhaps the hottest and most active reducing condition possible in an ancient forced-draught charcoal-fired smelting furnace. Prior to the mass-spectrometric study mentioned above, no more than 20 elements had, in fact, been positively detected in ancient coinages. Even some elements which could have been reduced (such as Hg, Cd and Cr) have not yet been reported; but it is understandable that the first two of these could readily escape by distillation, even if originally present in a furnace charge.

It is most unlikely, therefore, that those reported traces of calcium, titanium and aluminium(98) could really have been present in any ancient coinage alloys. On theoretical thermodynamic grounds this possibility must be discounted and the presence of any calcium or aluminium attributed to extraneous material entrapped within or adherent to the coin - such as slag, or clay-earth residues which were not completely removed from the surface before analysis.

Certain non-metallic impurities, particularly sulphides, can be deemed to have been carried over from the ore as solubles in the metal; or, as in the common case of oxygen in copper - carried over from a refining furnace atmosphere.

In an earlier work(99) the author has listed three main categories of elements to be found in the Roman silver and aes coinages:

(i) five which are present as major constituents - Ag, Cu, Pb, Zn, Sn;

(ii) eleven which are often present as minor alloys or as impurities in excess of 0.1% - Fe, Au, Ni, Co, Sb, As, S, O_2, Si, P, Bi;

(iii) minor impurities, generally of little significance, which are rarely sought but have been encountered in proportions of a few tens to hundreds of parts per million; Mn, Se, Cl, Ge.

(Although chlorine is included in this last category it is most likely to be found as a surface or penetrating corrosion contaminant rather than as a real constituent of a coin alloy).

Only 15 of these elements are commonly found in influential proportions in Roman silver and aes coinages; and from these just 9 essential elements can be selected as a basis for a scheduled systematic routine analysis. Six of these (Ag, Cu, Pb, Sn, Zn and Au) are important, and the failure of many analysts to determine or report the presence of each of these in most coin analyses has led to some sincere but erroneous metallurgical deductions being made by numismatists or historians in otherwise excellent and authoritative works. Professor A H M Jones(100), for example, describes the much-debased silver coinage of Gallienus as being "vilely minted" ... and, "virtually copper". With the first observation we can readily agree, but a literal following of the latter interpretation has precluded - even in quite recent analytical work on the same coinage(101) - the observation of a series of alloy developments (binary Cu-Ag alloys, argentiferous tin-bronzes, and argentiferous leaded tin-bronzes) which can now be shown to be directly relevant to the real sequence and chronology of a most complicated and little-understood series of issues differing substantially from the contemporaneous simpler copper-silver coinage alloys of the contemporaneous Gallic Emperor Postumus in both fineness and metallurgical quality.

For this present work eight or nine elements have been generally determined in every routine coin analysis. Where the need has arisen, however, for a statistical approach to silver fineness determinations, for the much-debased coin alloys of the third and fourth centuries, in the limited time available, single determinations of silver have been made - but on no more than one half of the coin sample. From the sample solution the tin, gold, antimony and arsenic extracts have also been removed and stored for subsequent determination. These and the remaining coin portion or prepared sample have then been set aside for an eventual full analysis and the ultimate publication of the complete results.

The selection of methods of chemical analysis

Having considered what elements can be expected in Roman coins, and in what rough proportions, it is possible to consider the available methods for chemical analysis. We will assume for the moment that we are in possession of a truly representative and homogenous metal sample; and will consider the many problems of obtaining such a sample later.

Ideally one would wish to use a completely non-destructive method of chemical analysis - so that every ancient coin analysed might be preserved entire and then returned to its Cabinet. This is, however, but a fond hope. There are numerous metallurgical limitations, set by each individual coin, which militate against it ever becoming a reality.

The nearest approach to a completely non-destructive analysis is probably that obtained indirectly by a density determination, which may be possible with rare uncorroded gold or silver coins. But Professor Caley(102) has proved how inaccurate this method can be even in the case of known pure binary alloys of gold and silver, if only because of the limited number of determinable specific gravity increments which lie between the extremes of possible composition. More recently, by using a dense stable organic immersion fluid (perfluoro-l-methyl decalin), almost twice as dense as water, W A Oddy and M J Hughes(103) claimed an improved accuracy for gold-silver alloys, and a technique suitable for the analysis of gold-silver-copper alloys. Later, however, they admitted that the influence of 5% of copper had much more effect on the calculated gold content than they had at first believed - lowering it by 3½% and not by the 2% originally claimed(104). Even when copper is absent the estimate of the gold content can be as much as 3% in error, and after having obtained a figure there always remains the uncertainty of how much the density has been influenced by the presence of unknown proportions of silver, copper and lead - all of which could be present.

The density method is really suitable only for indicating a gold of high purity, since all the possible impurities always lower the density. With silver it could indicate high purity; but lead is often present and would have the effect of raising the density of an otherwise debased alloy to make it seem purer. So far as brass and bronze coins are concerned the density of even a corrosion-free coin is of even less value, for both zinc and tin as alloys lower the density of copper, and lead will increase it - and all can be present in substantial proportions. Similarly, silver coins will be affected not only by the presence of base metals, but by surface enriched or porous layers of uncertain thickness.

Neutron activation analysis provides what seems to be a completely non-destructive method of chemical analysis, which has been used with moderate success for both gold, silver and argentiferous bronze coins; but it can be widely inaccurate if lead is present or if there is a substantial depth of corrosion or enrichment with the noble metals. A disadvantage is that the coin is always left in a radioactive condition -

although a sufficiently light initial irradiation can often be arranged such that the residual activity remains below the internationally agreed legal limit for the definition of 'radio-active', ie below 2 micro-curies per gramme. This can, however, preclude a later conventional analysis by which the most active constituents are concentrated.

A fast neutron flux is to be preferred in that it more evenly penetrates and activates the elements in a coin throughout its variable thickness than does a thermal or epithermal neutron flux which is more readily attenuated. But in either case the physical measurements of the resultant gamma emissions at selected energy levels are handicapped by the widely different gamma attenuations provided by the matrix and the individual alloying elements disposed in different thicknesses and often in segregated zones. Thus geometrical and flux-attenuation factors and self-shielding effects - which are most significant, unfortunately, in the cases of the gold and silver-rich coins which one is most anxious to preserve by the use of this method - all militate against analytical accuracy. The ubiquitous element lead is a nuisance in the self-shielding and it cannot be determined by the method. Dr Coleman(105) deliberately ignored the possible presence of lead or iron in Merovingian gold coins, assumed that the gold, silver and copper represented the entire alloy, compared his results with those obtained by the specific gravity method, and pronounced that the neutron activation analysis confirmed its reliability and gave a precision which was "satisfactory for most numismatic purposes".

The neutron-activation method can be used, however, with much greater accuracy, for the determination of silver in copper-based coins for which the matrix neutron-attenuation is of a much lower magnitude than in either gold or silver-rich alloys. The author and Dr Gilmore(106) have been successful in locating a rare antoninianus in its appropriate fineness category in a series of reformed issues by the neutron activation assay of its silver and gold contents; but care had to be taken to do the analysis alongside three closely-dated expendable contemporaneous coins of expected similar alloy composition, weight, and geometry, which were then destructively assayed by a classical technique for calibration purposes. Even with such elaborate precautions a neutron activation assay can only enable the total amount of silver to be determined; it tells nothing of any variations in distribution between the surface and the inner regions, and the result is therefore generally in error by an uncertain amount so far as the alloy is concerned.

Two techniques which are almost non-destructive are spark-source optical spectrometry and X-ray fluorescence analysis, since they may leave only the slightest visible superficial mark on a coin. Their main limitation, however, is this very superficial nature of their penetration. Neither technique allows a proper entry to the core of the alloy: only the surface layers are activated to a depth which may not exceed 200 microns, and with most of the radiation emission from the upper 60 microns. Thus one obtains the proportions of elements present only in the surface-enriched or depleted layers which all types of coin alloys can manifest - whether they are palpably corroded or not. A further disadvantage in the case of optical spectrometry is that it is quite unsuitable for determining the proportions of the principal elements with any accuracy, although it is good for identifying all the elements which are actually present. The X-ray fluorescence technique does not suffer this limitation and so it has been preferred by numerous workers in this field in recent years. It does require, however, the preparation of a small optical flat on a surface or at the coin edge; the analysis is limited to this zone and to 200 microns depth, and the accuracy which can be expected varies between 2% and 20% for the common elements at their usual concentrations(107). Dr J A Charles(108) has shown that even after the attempted chemical removal of superficial corrosion products from debased silver coins the X-ray fluorescence determination of silver can lie anywhere between 46 and 88% of its true chemical assay, due to the preferential leaching of the less noble constituents from the core alloy immediately beneath the corroded layers.

X-ray fluorescence analysis and electron-probe micro-analysis are useful techniques when suitable sections can be taken to expose unaffected coin interiors; but one is then involved at least in a partly destructive analysis, and there remains the problem of obtaining a general alloy composition for common multi-phase alloy structures which are chemically heterogenous in all three dimensions yet are 'seen' by the electron beam only to a shallow depth beneath the two-dimensional prepared plane(109).

In a recent publication(110) the author has reported the full analysis and metallographic structure of a debased silver coin, belonging to a numismatically important but fairly rare issue, for which none of the non-destructive or partially-destructive techniques of modern analysis would have been suitable. All would have led to erroneous and numismatically deceptive determinations, due to: surface enrichment in silver from the coin fabrication processes; superficial and penetrating selective corrosion in archaeological time; heterogeneities of internal microstructure. The features are typical of many Roman coins; but a complete metallurgical examination, followed by a planned destructive chemical analysis performed with thoroughly reliable and highly accurate classical techniques, resulted in the sure determination of the composition of the original alloy and of the otherwise inaccessible fabrication and corrosion history of the coin.

Although desirable, all non-destructive methods of analysis lack what might be termed 'a third dimension'; so that, apart from any limited potential accuracy, they always contain intangible elements of uncertainty which severely restrict their application to numismatic problems. On the other hand, in those cases where it can be permitted, the proper analysis of a carefully prepared sample by established wet-chemical or dry-assay techniques provides the best results.

Chemical analysis by gravimetric methods will always provide the ultimate basis for determining the exact composition of a metal or alloy so, fundamentally, the classical techniques ought to be used whenever possible in the interests of both certainty and accuracy. During the present century wet-chemical methods for quantitative metallurgical analysis have been developed to a state of near-perfection, because the fundamental principles of physical chemistry upon which they are based, and the technology upon which their accuracy depends, are now firmly established and developed for nearly all the known elements. There is also a wealth of experience in their practical application to different types of alloys in which some elements often interfere with the determination of others. In general the potential accuracy is now limited only by the amount of sample available and the ultimate accuracy of the analytical balances.

Half to one-gramme samples suffice for the quite routine determination of every element to be found in ancient coins where the proportions are in excess of about 0.01% - below which an element is usually only of interest if characterisation is required for provenance purposes. The analysis procedures vary slightly in experimental detail, but their principles are now internationally adopted and incorporated in accepted analytical standards which have been thoroughly calibrated and tested for specific metals and alloy combinations.

In addition, there are supplementary physical methods of chemical analysis which have been substantially developed in recent decades. With proper calibration against proven standards these can be used with greater economy in time, particularly for more routine purposes, and sometimes with less demand upon laboriously acquired analytical skills. Correctly applied, they can also be used to determine specific elements for which they are most suited and to determine some trace elements when present down to even fractional parts per million, and below which they lose all but academic significance even as characterising elements. Examples of suitable methods used in this work are the neutron-activation analysis of chemically extracted residues for gold, antimony and arsenic, and the instrumental analysis of sulphur.

It is unfortunate that the wide ranges of alloy and impurity combinations found in ancient coinages militate against the adoption of standard physical methods of chemical analysis because of the wide variations in possible matrix effects which interfere either with the accuracy of determination or the clear resolution of specific elements. The physico-chemical methods of analysis do, however, provide some of the most sensitive means of detecting or determining some elements which are present in minute but significant proportions (eg gold in much debased silvers), and hence they provide a most useful extension to the bulk analysis, for such elements.

By combining the proven analytical procedures on fractions of the prepared bulk coin sample the main constituents and impurities of coin alloys can now be determined to degrees of accuracy much greater than the degree of control which could possibly have been exercised in their manufacture. One can thus eliminate most of the old uncertainties attending the interpretation of the meanings of coin analyses. The only present limitation is the analyst's time, and hence the cost. Professor Caley, with expert assistance, took 25 years to accumulate the 25 full duplicate analyses of Roman orichalcum coins upon which his special publication on the subject(111) was based. The British Ceramic Association, presenting recent evidence for the adoption of some physical and instrumental analysis methods in place of the older classical wet-chemical techniques for the routine analysis of clays and refractories, remark that in these days the latter, though ideal, are "a luxury that the industry can ill afford"(112). In his scientific summary of the proceedings of the Royal Numismatic Society's Symposium on coin analysis Dr E T Hall admitted that '... there is no doubt that analysis of the complete coin (rather he should have said 'a prepared sample from it') by acid dissolution is the most accurate technique available'(113) – and that it also permits the metallographic study of the fabrication technique en route - but he added that "there cannot be many .... who are willing to take the immense time and trouble .... even if the material is available from the numismatic point of view".

Nevertheless the level of certainty which pertains to wet-chemical techniques for the bulk alloy analysis of the original material of a coin convinced the author - who was trained in such methods - that the tedium and expenditure of effort would be well worth while for the reliable and authoritative information which can then be offered to the numismatist for interpretation. Less accurate data have to be applied with much more reserve and uncertainty and rarely help the numismatist. This does not mean that there is no place at all for speedier or cheaper methods of lesser accuracy; Professor Caley has already observed that a wide spread of rough trial analyses (if there is ample material available) can help us to select effectively our detailed rigorous analyses of key coins(114). And Dr M A Zammitt(115) has indeed used modern rapid EDTA methods for such exploratory studies - which led to the discovery (and later more accurate analysis) of a brass dupondius of Vespasian containing an exceptionally high proportion of zinc, in a period for which it had been erroneously suspected (on the basis of a few known analyses) that the manufacture of the orichalcum had declined.

Professor E R Caley's recommended wet-chemical methods for ancient coin analysis(116) have been adopted for all the main coin analyses performed for this work. They are based on the standard and internationally approved analytical procedures adopted for the various elements in the metals and alloys now produced in the world's metallurgical industries; but they have been carefully combined and optimised for use with the ancient alloys which often contain different combinations and proportions of elements from the modern alloys for which the basic methods have already been exhaustively proved.

In the region of one gramme of the selected and prepared solid coin sample, whether it be a gold, silver or copper alloy, is first treated with a measured amount of strong nitric acid (of specific gravity 1.2). It is essential that this is a chloride-free analytical reagent - otherwise it will affect even the minute gold and silver determinations - and the author always tests a sample from each new stock (with silver nitrate solution), because accidental contamination with chloride is a not uncommon happening in a laboratory which has to be shared with others. Similarly, fresh analytical reagents and their filtered solutions are used in every phase of the work.

Where iron has to be deliberately introduced (for the alkaline co-precipitation of arsenic and antimony) the precaution is taken of preparing a nitrate solution from spectrographically-pure iron. This may seem to be an unnecessarily expensive procedure, but it does ensure that arsenic, and the many other metallic and non-metallic impurities present in even the highest quality commercial irons, do not cause complications. This assurance is well worth having when analysing unfamiliar alloys; and a few grams suffice for many determinations of arsenic and antimony by the neutron activation method which is used to supplement the chemical techniques used for the other elements. Hardened 'ashless' filter papers and pulp are also used throughout the analysis procedure except where Gooch crucibles are feasible.

The insolubles resulting from the nitric acid dissolution of the bulk of the coin sample, after dilution and gentle boiling, contain the gold, the tin as beta-metastannic acid (of the colour of the 'purple of Cassius' if tin is present together with small proportions of gold), and some of the arsenic and antimony as partly-soluble acidic compounds.

Gold is determined directly, or by separation by solution in aqua regia if contaminated. Alternatively, or by way of confirmation, it is determined by the neutron-activation of the filtered and dried precipitate.

Generally the tin is determined as the oxide which results from the ignition of the filtered and washed insolubles from which the gold has been separated. It can be determined more accurately by finding the volatilisation loss which occurs after heating at 475°C with sufficient ammonium iodide to ensure a complete reaction; but antimony, which is often present, will interfere. Professor Caley admits that the tin determination is the most uncertain part of the entire analysis routine because of the possible interfering impurities present in widely different proportions in ancient coins. These contaminate the metastannic acid, because it readily absorbs iron and copper which cannot be completely removed by repeated washing with either nitric acid or distilled water. The recommended iodide volatilisation separation leads to an improved estimate for tin, but this includes most of the unknown portion of the antimony present - whose iodide is also volatile. For most numismatic purposes the effects of these impurities on the simple determination of the generally much larger tin content is of no consequence. It is only in the context of analytical perfection, or where the real tin content is extremely low, that careful separation is necessary. Otherwise the tin determination by plain ignition can be expected to be well within 10% of the proportion really present. We would agree with Caley that even that extremity of error would be neither metallurgically nor numismatically significant.

Many Roman _aes_ and debased silvers are found to contain all the tin-contaminating elements in significant proportions. The most highly accurate analyses necessitate a separate (second sample) determination of tin by a more selective method of separation (as used by commercial assayers). But this involves the additional complication of segregation causing compositional variation between adjacent samples which can even exceed the 10% error which one is seeking to refine. The author's solution to this problem (when the proportions of arsenic and antimony are substantial) is to determine the approximate tin content of the bulk sample by Caley's method - separating the gold and volatilising the tin and antimony - then to determine the proportions of gold, antimony and arsenic (and sometimes the tin also) by neutron activation of the filtered and dried but unfired insolubles taken from another portion of the prepared sample. Segregation effects can be minimised by chopping and mixing the pieces used for the two parallel analyses. Any ignition losses of arsenic or antimony are avoided in the second sample by the air-drying of the precipitate on its filter paper - which suffices for a neutron activation analysis. Since one cannot guarantee that all the arsenic and antimony are precipitated at the first stage the author removes the silver from the filtrate (thereby conveniently obtaining a duplicate analysis for this most important element), adds prepared ferric nitrate solution to provide about ten times the amount of iron as there is arsenic and antimony present, and co-precipitates with enough excess aqueous ammonia to complex all the copper to the soluble form. The filtered and washed co-precipitate is then combined and dried with the initial insolubles for the neutron activation analysis of the entire proportions of Au, Sn, As and Sb present in the alloy. Corrections can then be made to the results for the original 'ignited' tin determination, or all the results can be tabled and reported and the selected most probable values indicated for a final acceptable analysis of the bulk composition.

In those cases in this work where only the silver proportion in a coin is reported it is to be understood that not only has a similar portion of the sample been reserved for eventual complete analysis but the first insolubles together with a later iron co-precipitate from the silver determination sample have been set aside for neutron activation (or any other type of analysis) of the gold, tin, antimony and arsenic.

Silver is determined as the almost insoluble chloride precipitated from the first filtrate after sample dissolution. The method is both highly accurate and sensitive. Indeed the test for silver by chloride precipitation is so sensitive that it is always possible - by the observation of some slight turbidity in the dilute reacted solutions - to detect the presence of silver at levels well below those at which the fine precipitate can be weighed on even an assay balance, for 1 part of AgCl will produce appreciable turbidity in between 3 and 5 million parts of solution. In such cases (usually well below 0.01%) when the silver is detectable but hardly measurable the proportion is reported as 'trace'. With the very low proportions of silver sometimes encountered in Roman coppers and bronzes it is usually desirable to allow the solution to stand for a day or so for the precipitate to coagulate and settle, otherwise it may pass through the pores of even the finest Gooch crucible available and become indeterminable. Professor Caley does not discuss this time factor in the detailed presentation of the method but the author has found solution-standing to be important in this case and in the case of the nickel and zinc determinations which follow.

In that they are absolute methods of analysis whereby the accuracy of other methods of analysis can be judged there was really no point in standardising the wet-chemical methods used - even if an acceptable standard Roman coin alloy could be found; but in view of persistent claims by fire-assayers that their cupellation technique was the most accurate available for silver and gold, and because of the importance of the silver determination in the evaluation of the Roman moneyer's intentions, the author undertook some comparative assays using both Roman coins and high purity silver as standards. Caley's method was found to be both precise and highly accurate with respect to the pure silver standards, but differences were observed, particularly with the results on the base silver coins which are of much numismatic consequence, between the wet-chemical and cupellation techniques. This led to the eventual admission, by the assayers involved, that arbitrary corrections have always to be made with cupellations to allow for the volatilisation of a proportion of the silver determined, and that the oxidation-removal of copper in quantity presents problems which force the fire-assayer to separate the copper first by a wet-chemical technique in any case if he is to obtain reproducible results! The final comment of the experienced commercial assayer involved in this joint exercise was that Caley's method, as used by the author, ".... is certainly neater than our traditional methods, ..."(117).

Lead is mostly removed from the filtered de-silvered solution, and estimated as the sulphate. But since lead sulphate has a finite and temperature-variable solubility in the remaining solution and in the washings it is not all removed at this stage. To the determined main fraction has always to be added the small proportion which is fortuitously deposited as an oxide at the anode during the subsequent electrolytic determination of copper - provided adequate oxidising conditions are provided by adjustment of the mixed acidity of the solution in the manner recommended by Caley.

Copper, determined electrolytically, is an absolute assay. All other methods give either incomplete or inaccurate results. The cathode deposit should be bright salmon-pink and non-porous. If chocolate brown, or spongy, these are signs that there is contamination - usually by arsenic or antimony which has persisted in solution to this stage - and a re-solution and re-electrolysis after co-precipitation with added iron is required for accurate determination. This possibility is not mentioned by Caley; but the author finds it to be important when analysing the highly-leaded (and generally more arsenical) copper coinage alloys of the later empire which Caley did not study.

From the copper-free solution iron is readily precipitated as the ferric hydroxide and ignited to its oxide for determination. It presents no problems, and the addition of ethanol to facilitate filtration is unnecessary. In brasses a little zinc might have a tendency to co-precipitate, but this can be easily obviated by the addition of an excess of ammonia which is easily removed later by boiling the filtered solution.

After careful neutralisation and pH adjustment the nickel is then precipitated as the dimethylglyoximate. It can be filtered and weighed in this form or ignited to its oxide. M. Duval(118) has recently demonstrated that earlier fears of loss by volatilisation on ignition are completely unfounded.

Cobalt is precipitated as the alpha-nitroso beta napthol compound which is ignited to the oxide Co_3O_4. Zinc is finally determined as the pyrophosphate. In the case of high-zinc almost cobalt-free brasses it is found that these determinations can be reversed in order.

This effectively completes the bulk analysis. The author has now gained considerable experience with the application of Caley's routine method to a much wider range of Roman coinage alloys than Caley originally explored; but apart from the minor details mentioned he finds no fault in them. This is hardly surprising for they are based on sound fundamental chemical principles which require only the establishment of optimum conditions of temperature and solution and reagent concentrations, together with scrupulous care and cleanliness in working, for the practical achievement of high accuracy.

The analysis totals themselves provide both a satisfactory confirmation of analytical accuracy and completeness. A recovery of 99.8 to 99.95% is generally sought. This is, of course, dependent on having determined all the elements of any consequence in the standard routine; for a lower total might indicate, for example, the presence of some other element such as sulphur in substantial proportion (since this element has now been found as a mixed metallic sulphide even in excess of 0.5% in second century copper coins in which it was never suspected, as will be seen below). If there have been no other indications, then a low analysis total could point to the presence of proportions of metal oxides in the alloy. In any event a low analysis total should encourage the analyst both to check his original results; first, for clerical or arithmetic error; secondly, for any possible occasion of solution spitting or spillage; thirdly, for the presence of some non-routine elements (eg O_2, S, Bi, P or Si) which need separate determination.

Weighing facilities are often taken for granted in modern laboratories but care is necessary to check the calibration of the balance against standard weights, and to check the level and zero the instrument at the commencement of each work period. This is found to be most important in a shared laboratory. Another precaution is to use one balance exclusively for any given assay - from the weighing of the sample to the weighing of all the extracted precipitates. Standard analytical balances were used for the assays, allowing absolute readings to a tenth of a milligram (10^{-4}g) and normal determinations on 1-gram samples to within 0.01%, or even less when the factor for conversion is low because a much heavier molecule contains the element being isolated as a precipitate. An example of this is in the gravimetric determination of sulphur, in which the sulphur comprises only 13.74% of the barium sulphate compound whereby it is isolated and determined. In this case a sulphur determination to ± 0.002%, on a 1 gramme sample, is feasible.

Ultra-microbalances are now more readily available with a capacity of 2½ g and a sensitivity of 0.1 microgram - allowing absolute weighings to 10^{-7} g with a reproducibility of ± 2 microgram on full load. Commercial assayers of gold and silver use these, but they are not normal equipment in even advanced analytical laboratories. Apart from determining gold:silver ratios with the utmost accuracy there is really no need for such instruments in general coin analysis. A special assay balance has not been used for the author's analyses in this present work, although commercial assayers have used one to obtain results for Roman silver coin assays which the author has previously published. Hence the reporting there of the more precise figures for gold and silver which the assayers claimed to have achieved(119).

Special techniques of analysis

Caley's recommended method for determining arsenic and antimony involves a complicated distillation procedure using the co-precipitated hydroxide extracted from the nitrate solution of the coin after excess iron has been added. The co-precipitation process enables the quantitative isolation of both the arsenic and antimony, which are then separated by fractional chloride distillations for individual determination. This is the classical method which can be used for a wide range of industrial materials.

The specific activities, however, of the neutron-irradiated gamma isotopes of arsenic and antimony do allow a highly accurate analysis of these elements concurrent with gold, and indium, and tin if required. The local availability of a suitable reactor, with full neutron activation and analysis services, enabled the application of this alternative procedure for base-metal coin analysis, and so it was used on a regular basis. Some of the major limitations of the neutron-activation analysis of whole coins do not apply to the analysis of chemical extracts – particularly the matrix attenuation and geometrical factors which are, respectively, reduced and standardised when dealing with concentrates separated from the coins.

For the neutron-activation part of each analysis a new standard routine has been devised. A second selected coin sample - preferably adjacent to the first one used for the gravimetric analysis - is dissolved in strong nitric acid and the solution is boiled, reduced in volume, and diluted and digested in the same manner. The insolubles, containing the gold, tin and some of the arsenic and antimony are then filtered and washed on a small pulp pad of 'ashless' filter paper and set aside for later addition to the arsenic-plus-antimony co-precipitate. Silver is precipitated in the filtrate by the now conventional addition of just a little more than the quantitative requirement of hydrochloric acid solution, then filtered and dried to provide a second and confirmatory determination of this most important element. Sufficient high-purity ferric nitrate (approx 1 ml of a 20% solution) is added to the filtrate to provide an excess of at least ten times the amount of the expected quantity of arsenic and antimony present; the liquid is then thoroughly stirred and excess strong ammonia solution is added to dissolve all the copper as a complex. After filtration, and washing with dilute ammonia to remove as much of the copper as possible, the original insolubles are added to the co-precipitate, dried, and packed into the bottom few millimetres of a standard 16 mm diameter by 30 mm tall polythene irradiation assay container. By this means the gold, tin, arsenic, antimony, and indium of the original coin sample are conveniently concentrated and located with the minimum of inert material in a standard form for irradiation and analysis. Traces of copper persist, but these and the added iron have characteristic gamma rays which are removed from the gamma-ray spectral ranges used for the determination of the required elements, and so they do not interfere. Highly leaded coins provide some lead hydroxide contamination, but the proportion of lead present is fairly harmless; its slight neutron attenuation and its gamma attenuation effects can be compensated by the incorporation of similar amounts of lead in the separate co-precipitated standards for each element which are always irradiated with the samples of identical geometry in the same magazine.

The Universities Research Reactor at Risley was used for all these irradiations. It provides a neutron flux of mixed spectrum with a thermal component of 10^{12}n/cm^2/sec in the central vertical facilities used for neutron activation analysis. A suitable irradiation time is generally less than 20 minutes, after which each capsule is positively located at about 10 cm from a Ge(Li) detector connected to a multichannel analyser, having 4000 spectrum channels, each of approximately 0.5 KeV resolution. An automatic print-out of the Covell area beneath each gamma emission peak is made, and corrections are applied for the 'clock-time' of the counting operation; the decay during counting; and for the decay time which elapses between assaying standards and individual samples.

The selected active isotopes which are monitored for the analysis are as follows:

^{76}As	26.4h	½-life, main gamma-ray	559.2	KeV
^{122}Sb	2.68d	" " " "	564.0	"
^{124}Sb	60.3d	" " " "	602.6	"
^{198}Au	2.68d	" " " "	411.8	"
^{116m}In	54 mins	" " " "	417.0	"
^{123}Sn	39.4 "	" " " "	160.2	"

With the detector having a resolution of 4.5 KeV full width half maximum it will be appreciated that when arsenic and antimony are both present their gamma emission distributions will overlap beneath their particular peaks. Separation is effected therefore by using the substantial difference which exists between their characteristic half-lives. The total 'Bactrian camel' distribution is first measured, then (about ten days later) the residual antimony peak is measured alone.

Corrections are made for the antimony decay between the counts, and subtraction provides a real value for the original arsenic component.

For those few cases where this method of analysis has been used for whole coins which could not be released for destructive assay use was made of the short-lived isotopes ^{108}Ag and ^{110}Ag produced by neutron irradiation. These have half-lives of 2.4 m and 24 secs, respectively, and main gamma emissions of 632.9 KeV and 657.8 KeV. A sodium iodide detector was used in this case, and the possible interference of arsenic was eliminated by using a discriminating procedure involving a very short initial irradiation of less than one minute. Consumable standards of near-contemporary coins were also included in the batch as realistic standards possessing similar geometries and attenuation characteristics.

Gold in the coin insolubles can be determined even down to fractional parts per million by the neutron-irradiation technique, and with great accuracy at trace levels too low to measure by the conventional gravimetric assay methods. This is especially useful for effective comparisons to be made between the silver:gold ratios of the silver-rich coinage and the much-debased issues, to indicate whether the gold derives from the silver or the copper or both. Roman coppers themselves have been shown to contain extremely small proportions of gold. It would seem that the gold is generally derived from the alloyed silver.

During the determination of the lowest gold levels it was observed that some slight interference occurred when measurements were made after very short decay periods in the region of 10 minutes. This was identified by Dr G R Gilmore(120) as being due to the ^{116m}In isotope, and was confirmed by mass-spectrometry. Further investigations were planned in an attempt to identify the source of the indium and to ascertain its value as a characterising element. Early orichalcum was first studied in the expectation that the indium might have originated in some of the zinc ores used for its manufacture during the first century AD. No direct correlation was found with zinc or with any orichalcum alloy series, but it is now evident that indium is quite regularly associated with the lead present in the coin alloys of widely different periods - as is arsenic. Indeed the arsenic:indium ratios can be shown to be fairly constant in value. The absence of indium, however, in silver cupelled from lead is attributed to its removal by the drastic oxidising conditions of the refining process.

Electron-probe micro-analyses have been used as a metallographic adjunct for determining the detailed compositions of distinct structural phases present in coinage alloy sections(121). This has led to the positive identification and quantitative analysis of non-metallic inclusions and metal separations of both simple and complex types, and therefore to the location and preferred distribution of elements which are smeared into averages for the alloy by the normal routine chemical analysis.

Attempts to determine the average composition of multiphase alloys by this technique have been shown to be moderately successful if skilfully used, but they provide no real substitute for classical wet-chemical analysis. The main problem is the necessity for determining the volume fractions of the separately analysed phases from two-dimensional sections of materials which really exist in three dimensions in segregatable forms. A statistical approach to this problem, with automatic point-counting in sections taken in different planes, provides the only practical solution. For single-phase coinage alloys, however, the method has the advantage of being useful and only semi-destructive; but no extensive use has been made of the technique because the microstructural features which have been studied already are typical of those which are commonly encountered in studies of Roman coin metallography.

Following the work of Dr R H Brill and his colleagues(122) on the use of lead isotope abundance ratio measurements for indicating the probable geographical sources of ancient leads from the determination of their geological types, some samples were submitted to him for help with an investigation into the origin of the lead in the various unmarked folles of the early fourth century. Other samples - including duplicates for comparison with the available international standards - were also submitted (via the Liverpool Polytechnic) to the Aldermaston Physico-Chemical Measurements Unit. In each case lead sulphate extracts from the gravimetric determinations were used, and these were converted to the peroxide for consistent behaviour in the course of mass spectrometry. The study has not been extended, however beyond that already reported in the numismatic literature(123,124). One difficulty has been the exceedingly high cost of the determinations made on highly developed equipment which has to be operated by specialists who have developed the appropriate analytical skills necessary for obtaining closely reproducible results.

A few trace element analyses by optical spectrometry have been made available to the author by R Morley(125). In general these supplement the gravimetric analyses and provide information on a few elements (eg bismuth) not included in the normal analysis schedule.

Spark-source mass spectrometry has been developed since the mid-1950s and has displaced optical spectrometry for a number of purposes. The outstanding characteristic of mass spectrometry is its high sensitivity, enabling the determination of elements present in excess of 0.05 parts per million atomic with respect to any monoisotopic element and the detection of some if present even as low as one part per billion. There are several other features in which it is superior to optical spectrometry. The mass spectrometer provides a comprehensive element coverage, ranging from lithium (at mass 7) to uranium (of mass 238), with a remarkably simple spectrum compared with the spectral complexity which attends optical spectrometry. There is also a linearity of response, over a compositional range of as much as 100,000 to 1 - since the ion intensity of a particular element is always directly proportional to its concentration. This means that a high-level standard for an element can be used for equally accurate calibration and subsequent determinations at a whole variety of concentrations - such as is common in ancient coinage alloys. Other valuable features are the high precision and the near-equality of the relative sensitivities of the various elements which, as a rule do not differ by more than a factor of three from unity. This makes possible a quite acceptable semi-quantitative analysis for many elements, ever without elaborately prepared standards.

The MS7 mass spectrograph at British Nuclear Fuels Ltd, Capenhurst was made available for a few analyses of Roman gold coins and copper Asses through the generosity of the Chief Technical Manager, Mr G R H Geoghegan. The instrument is delicate to operate and is found to behave most reliably if it is kept in regular use by the introduction of some work-load in addition to standards at slack periods in industrial demand. By this means the most complete analysis ever performed on a Roman gold coin was made for comparison with those results which were possible with the few elements present in proportions determinable by wet assay. Several copper coins have also been thoroughly explored for possible characterising elements.

Phosphorus is occasionally encountered in ancient coppers and persists in bronzes made from them. Where it has been thought necessary to make a determination the conventional gravimetric method for brasses and bronzes - in which the phosphorus is isolated and weighed as an insoluble ammonium phospho-molybdate - has been used.

Sulphur is quite frequently encountered in the Roman aes coinage. Apart from oxygen it is the most common non-metallic impurity - usually found in the form of simple or complex metallic sulphides distributed fairly uniformly throughout the microstructure, and even small proportions are readily detected by optical microscopy because of the insoluble nature of sulphides in metals in the solid state. Professor E R Caley(126) made a special study of sulphur in early Roman brass; and for this he devised a modified analytical procedure - based on the classical gravimetric barium sulphate method - especially for those ancient coinage alloys which presented complications due to the presence of tin, silver, lead, and iron as common alloys or impurities. The author has adopted this method as a basic chemical standard, but has also obtained analyses of sulphur in Roman brass, copper and bronze coinages by the combustion method generally used in the steel industry(127). A one-gram sample of the alloy is heated rapidly to 1250°C in a porcelain boat and fully oxidised by a swift (1 litre per minute) flow of oxygen. The gases are passed through a dry filter plug to remove any oxide smoke and into an absorption vessel solution. This is acidified with hydrochloric acid and titrated with potassium iodate and potassium iodide solution. Sulphur can be rapidly determined thereby to ± 0.002%. Duplicate samples have generally been used and these confirm the reproducibility of the method together with an accuracy similar to that of the classical method. Some difficulty was expected with zinc oxide fume in the case of orichalcum coins; but in practice there is no significant difference found between the oxidation behaviour of the brasses and bronzes. It could be that the oxidising reaction is so rapid that complete fusion and slagging suppresses the formation and escape of fume.

A similar but even more accurate instrumental method of sulphur analysis is provided by the LECO CS-44 combustion apparatus with direct reading from an electronic digital display of the measure of sulphur dioxide which enters a Luft-type non-dispersive infra-red detector. The calibration is made with standards of known sulphur content; then an analysis can be completed automatically every 45 seconds to a potential accuracy of ± 0.001% or ± 3% of the sulphur present - whichever is the greater. Some twenty orichalcum and copper analyses, in duplicate, have been obtained by this method alone in a series of studies which have more than quadrupled the known reliable analyses for sulphur in pieces of the Roman Imperial coinage.

Oxygen is to be found, even in the solid uncorroded metals of coin interiors, if suitable deoxidising alloying elements or more readily oxidisable residual impurities are not present. A special exploratory study has been made of the fairly pure coppers used for the early imperial Asses, and this has already been reported(128). Thermodynamic considerations reveal that heating in a flow of dry hydrogen at any temperature above a dull red heat suffices for the effective reduction of copper oxides, but that much higher temperatures are needed to ensure the reduction of any tin oxide to the metallic state. The BNFMRA adopt a standard temperature for hydrogen reduction of 850°C but there is just the possibility that there might be some unaccountable loss from the volatilisation of arsenic (and perhaps some lead) at this temperature. Therefore 600°C was adopted as the reduction temperature for coin oxygen analyses, (10°C below the BP of arsenic) and this gave satisfactory results. The arsenic-free coins which were subject to a second higher-temperature reduction showed no signs of further weight lose. A substantially arsenical copper is awaited to test if the 650°C limit presently set is really necessary. The problem of blistering, whereby hydrogen diffuses into the copper, and reduces internal oxides, but the resultant steam molecules are too large to escape via the same route - was encountered in some cases. The application of a vacuum at some high-temperature stage in the hydrogen reduction cycle was found useful as a means of rupturing any blisters which would have otherwise engendered a low result for the overall oxygen determination.

Sample preparation

It is axiomatic that the very best analyst can only determine what the submitted sample contains, and even then he is limited to the ultimate achievable accuracy of each element determined. He is completely powerless to make proper corrections for any inadequacies in sampling procedure of which he is unaware; so it is fundamental to any coin analysis that as truly representative a metal sample as possible is first prepared - based on sound metallurgical and statistical principles - before any attempt at a final analysis.

It is, of course, necessary for a policy decision to be made on what one is really attempting to represent, because a deliberate study of, say, the surface and sub-cutaneous layers of a coin would require quite a different sampling approach from one involving the study of the original metal of the coin - and, indeed, both requirements might have to be satisfied with the limited material available from quite a small coin. In general, it will be the composition of the original material of a coin which will be required in the first instance, as it was, unaffected by either the fabrication stages in minting or subsequent corrosive influences. Such an analysis can provide the nearest possible indication of the original metallurgical intentions, and hence the monetary policy governing the issue. Most of the analyses produced by the author have this as their major purpose, or as the foundation for more extensive studies.

The basic metallurgical problem of sampling lies in the fact that even virgin and uncorroded metallurgical materials are rarely found in a fully homogeneous condition, and ancient coins are likely to be even more variable than modern coinage alloys in this respect. When sampling ancient coins, therefore, one has always to contend with metallic and non-metallic segregations, exudations, and various internal heterogeneities of structure and composition, as well as general or selective surface corrosion and any of its penetrating effects into the body of the coin. Failure to attend to any or all of these features in the preparation of the analysis samples has been the all too frequent weakness of many of the coin analyses already reported in the literature. Consequently many published analyses are unreliable, and some are positively misleading with respect to the original or intended metallic composition.

There is no absolute solution to the problems of sampling, but at least they have to be fully recognised and intelligently considered and carefully compensated in the preparation of all coin analysis samples. One tantalising and almost insoluble problem is that of segregation in the melting pot, because the finished coins made from a single melt can vary substantially in composition due to this phenomenon despite the blending of an intended standard melt in the crucible. Silver-copper alloys, argentiferous bronzes, and in particular the leaded versions of any of the usual coinage alloys are all liable to such variations in composition, fundamentally associated with density differences in liquid metals. The practical remedy at the mint is to give the melt a vigorous stir, and then to cast the contents of the crucible rapidly; but we have no idea how well this operation may have been done in the case of each batch of ancient coins.

Even during pouring gravitational segregation can continue, and some measure of the possible effect has been obtained by C T Peters(129) in a fabrication study of a typical highly-leaded argentiferous bronze coinage alloy issued by Constantine from the mints of Ostia and Arelate in early AD 313. Peters found that a libra melt of such a bronze, containing 1.39% silver and 12.5% lead, gave solid metal varying in silver content from 1.15 to 1.57%, and in lead from 10.35 to 14.62%, from the start to the finish of a single pour into a strip for later sub-division and minting experiments. These results can be attributed partly to gravitational segregation of the lead in the melting pot, and partly to the mutual affinity of lead and silver in a bronze containing them both.

Similar segregation effects - due to solidification phenomena involving the separation of solid phases which are not mutually soluble – at all temperatures - also occur in the coins themselves as a result of casting and remelting and re-solidification stages when segments of the cast strip are used for button and flan preparation before final striking; and these can cause even wider departures from the standard composition of an original melt. The author and H N Billingham(130) assayed the separate prepared halves of a leaded follis of the mint of Rome and determined 1.08 and 1.42% silver, respectively, by an identical method of assay. Though each determination was accurate to the second decimal place the interpretation of these results (to obtain the intended alloy fineness) was complicated, for, tantalisingly the percentages correspond almost exactly with nominal finenesses of 3 and 4 scrupula per libra. One analysis of a single segregateable coin alloy - or even duplicate analyses - cannot, therefore, reveal with certainty the intended fineness.

The only answer to such a problem is to perform statistically significant analyses of large samples taken from closely dated coins – preferably from the same mint. It was partly for this reason that so intensive an examination was made of sixty-five weight-reduced Constantinian folles of AD 310 to 328. The forty-three analysed pieces minted between AD 310 and 318 divide into two simple categories which each give two unmistakeable frequency distributions(131), each matching as well-controlled a 4-scrupula per libra fineness standard as was no doubt possible with the bronze coinage alloys from the different western mints of the Roman Empire which ranged in their lead proportions from 2.02% to 13.34%. Statistically significant analyses provide, therefore, much greater confidence in the interpretation of intended alloying practices, and in estimating their degree of achievement, than any isolated result - even though the latter may be quite an accurate analysis in itself.

The segregations which occur in metals are due to differences in their solubilities in their liquid and solid states at various temperatures. Lead is a nuisance in that it forms immiscible liquids with copper over a wide range of temperatures and compositions which were not unusual in ancient bronze melting and casting practice. The extent of the 'immiscibility loop' is somewhat modified by the presence of tin and silver(132), and these are observed to have a refining and homogeneising effect on the microstructures of the more complex solidified alloys, compared with plain copper-lead alloys; but the general effect of lead is always to cause variable composition throughout the body of the coin.

Due to the different affinities of metals for each other in a more complex alloy mixture it is not unusual to find that the segregation effects of one element influence another. The known affinity of lead for silver is visibly manifest by particles of a bright silvery phase which is preferentially associated with the lead-phase in the microstructures of argentiferous bronze coins. Copper, similarly, has a greater affinity for tin; so that electron-probe micro-analyses generally show the lead-phase to be virtually tin-free. Only when large proportions of lead are present does any tin partition into the lead-phase - and then in only small proportions(133). These micro-segregation effects can often manifest themselves in macro-segregations which, being of unknown dimensions, militate against the use of micro-analysis techniques on small samples for reliable results, and encourage the acquisition of a substantial (one-gram) sample to provide the opportunity for a statistical incorporation of micro-segregations in the volume of metal selected for analysis.

The degrees of segregation possible with different metals and their non-metallic inclusions are related to their solid solubilities compared with their much greater, or even complete, solubility in the original melt. The classic works of Hansen(134) and Elliott(135) on the constitution of binary alloys provide data whereby the solubilities of the common impurities present in the Roman copper and silver coinages can be compared to indicate their segregation potentials(136). At the levels normally encountered it is the elements which are virtually insoluble in the solid state which cause the major segregations influencing distribution within a coin and complicating its sampling. These are, unfortunately, the common impurities: lead, iron, cobalt, sulphur and oxygen - the last two being usually present as compounds with those elements in the alloy with which they possess the greatest chemical affinity. But in fine gold or silver they can occasionally be present as entrapped gases.

Those elements which have slight solid solubilities also cause micro- and macro-segregation, and in the worst cases (eg antimony, arsenic and lead together) they can lead to the formation of liquid phases of such low melting point that they are literally expelled as excrescences or exudations at the surface - as was the case with a second century sestertius(137). It is important not to remove such features before the overall coin alloy analysis, because they once really belonged to the genuine original alloy which is now internally depleted of the separated constituents. They do warrant localised (EPMA or neutron activation) analysis, however, for identification.

The elements with partial solid solubilities do not cause serious sampling problems provided an adequate sample size is taken so as to include all their random microstructural effects. In this category fall zinc, tin, and silver, in copper alloys - in that order of diminishing solid solubility and increasing complication of sampling. Similarly, in silver-rich alloys, copper has so limited a partial solubility at ambient temperatures that the separation of the silver-rich and copper-rich microstructural phases is clearly manifest in fractures and metallographic sections, thus allowing the sampler to take suitable action to locate and select a structure typical of the original material. If this is not possible it is usually better to abandon altogether the analysis itself, so as to avoid presenting a doubtful result in the literature.

It is found that a fractured surface and a metallographic study of a coin section provide some of the most valuable pre-sampling information possible concerning not only the internal structure but also of the superficial effects which are to be either included or avoided. The door of opportunity to these studies is wide open when a coin is made available for total destruction for the purpose of analysis, and it should not be missed. The texture and colour of a fracture can even be a guide to composition. It is clearly possible to discern medium and highly leaded alloys thereby.

Since a fractured section also provides one of the most useful means of detecting the depths of effects produced by external corrosive environments the author now considers an initial fracture of the coin to be a routine part of every metallurgical investigation. Some of the tougher orichalcum and copper coins require a saw-cut nick to act as a stress-raiser, and they might then require several reverse bends with vice and pliers before they fracture; the middle empire zinc- and leaded-bronzes and many antoniniani and folles fracture readily upon impact; some of the poorer quality highly-leaded bronzes of the late empire can even be broken in the fingers; but every fracture is a guide to the subsequent stages of sampling, and the confidence with which a reliable analysis sample can be obtained.

External corrosion manifests itself either as a purely superficial effect with little or no penetration (as is evident with many of the early copper Asses, some of the later first-century orichalcum, and some Gallic antoniniani); or by deeper and more subtle effects involving interstitial corrosion penetration; and denudations by selective corrosion attack and a consequent surface and sub-surface enrichment in the nobler metals; and re-depositions such as that of copper during the dezincification of orichalcum in an almost stagnant aqueous environment. The extreme depths of these effects commonly go further than a fracture usually reveals, and sometimes right through the body of a coin itself. The author has seen an apparent copper As, with the radiate head of a dupondius, which was originally a real orichalcum dupondius dezincified to such an extent that only a minute core of the original alloy remained. It was deceptive that even a deep-filed edge abrasion pointed to the coin being solid copper throughout; but its diametral fracture and a metallographic study showed structural differences revealing the full extent of dezincification and associated copper re-deposition. This explained the apparent radiate-crown anomaly - for the coin was, indeed, originally an orichalcum dupondius.

Numismatists have been rather slow to discover the profound effects which corroded and other surface material included in the sample can have on the results of coin analyses, since it is only within the last decade and a half that their attention appears to have been drawn specifically to much earlier and quite well-established general metallurgical knowledge on the subject. Dr E T Hall's pioneer paper on the surface-enrichment of buried metals did not appear until 1961(138); but it was quickly recognised and followed in rapid succession by the works of E R Caley(139) (on general coin sampling and analysis); G F Carter(140) (on the preparation of ancient coins for accurate X-ray fluorescence analysis); and J Condamin and M Picon(141) (on the analytical problems pertaining to the silver-copper alloy coinages). In consequence J Guey(142) was prompted, in 1965, to question the validity of all existing analyses of debased ancient silver coins, and to attempt corrections to 23 of the 90 assays of Roman silver issues of AD 177-211 which he had already published(143) before appreciating how much they might be in error. Guey made reductions of as much as 11.6% in the rectified results for silver contents; but these are still open to doubt because the compensation should have been related to individual coin microstructures, and it does not seem to have been done on this basis but in a more general fashion.

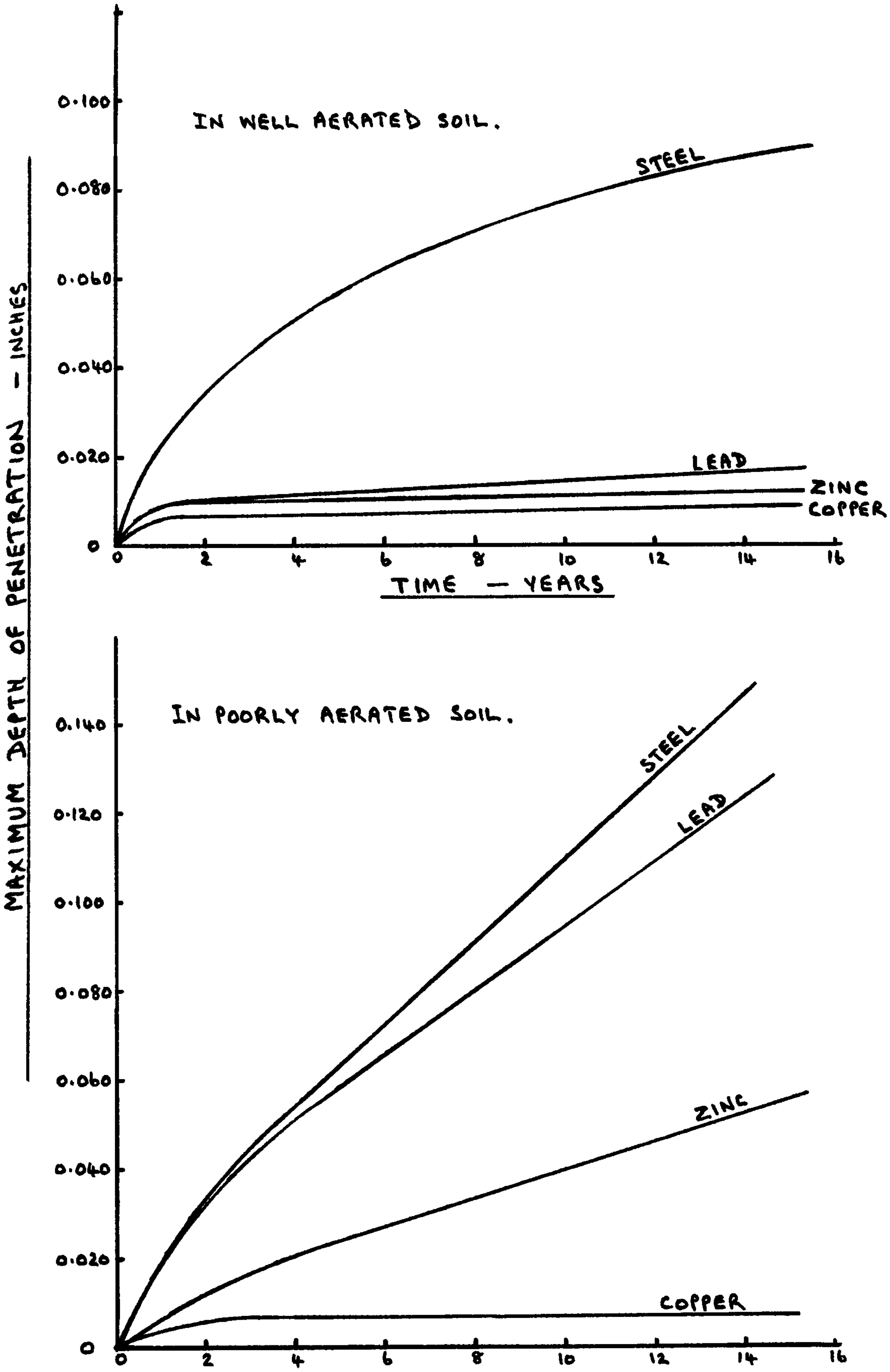
A first approximation to the problem of the corrosion of Roman coins in aqueous media - and indeed for elevated temperature oxidation and chloridisation too - is provided by the standard electrode potentials of the pure metals upon which the alloys are based. In descending order of nobility these are:-

Element	Standard electrode potential, Volts	Ion	
Gold	+ 1.42	Au+++	(1.7V for Au+)
Silver	+ 0.80	Ag+	
Copper	+ 0.34	Cu++	(0.52V for Cu+)
Tin	- 0.14	Sn++	
Lead	- 0.126	Pb++	
Zinc	- 0.763	Zn++	

In alloys which contain these metals as separate phases exposed at the surface it is the lowest one which is sacrificially depleted by corrosion. Solid solutions introduce complications; but essentially the order remains, for the higher zinc alpha-brasses can be dezincified, high-tin bronzes can be destannified, and the copper-rich phase of a silver-copper alloy is certainly anodic to the silver-rich phase and corrodes away much more readily. Lead - which is almost completely insoluble in most coinage alloys in the solid state - is particularly prone to preferential dissolution, or conversion, in situ, to lead salts. If the proportion of lead is low enough for the lead-phase to be present as discrete microstructural particles, it is only those exposed at the surface which become corroded. But the highly leaded alloys, which were commonly used for coinages minted from the middle of the second century onwards, often contain lead as an interconnected microstructural phase; and this provides an easy path for corrosion penetration deep into a coin interior. In the worst cases there is complete localised perforation, or the coin readily disintegrates if cleaned in acid. Such coins are generally unsuitable for analysis, unless nothing better can be obtained, in which case a complete reduction of the mechanically cleaned coin back to the metallic state is desirable. Caley's methods of analysis do cater for corroded samples, in extremis; but the extra separations involved, and the complications and uncertainties introduced by the unknown extents of any chloride or sulphate corrosion products present are a deterrent.

It does not follow that all highly leaded coin alloys are to be found deeply corroded. Much depends on the particular environment in which they have spent their archaeological time and, if that has been moist and corrosive, the degree of aeration. Figure 3 shows the profound effect which anaerobic conditions can have on the corrosion rate of lead compared with a similar but atmospheric environment. Coins which have remained on or near to the surface of the soil will, in consequence, be in a much better state of preservation than those which have been buried deeper.

Experience teaches that fractography and metallography provide the best guidance to the amount of external material to be removed to expose sound metal for sampling, after which one has the choice of chemical or mechanical methods of removal. Chemical cleaning is best avoided



CORROSION BEHAVIOUR IN DIFFERENT SOILS.

FIGURE 3.

altogether - except for the mild dissolution of the more obvious corrosion products which prevent a coin from being properly read and identified – because it will rarely remove the more noble surface enriched layers and will generally worsen the depth of existing corrosion. Mechanical removal by filing and abrasion is always to be preferred as the preparatory step.

On the not unreasonable assumption that the segregation in Roman coins are generally to be found disposed radially, Caley recommends taking pie-shaped sectors, or half or whole coins - depending on the size of the coin and the sample weight required to provide an analysis of a desired degree of accuracy - and this has been adopted as routine practice. But it is now known (from the Author's X-ray studies of the larger second and third century AD aes coins) that their blanks were cast vertically, on edge, with a consequent non-radial distribution of structure. The remedy, for an overall analysis, is to section such coins on the vertical axis which divides the lead segregation and the pouring gate, and to make use of a half coin - despite its excess weight. Once an aqueous solution is obtained, however, one can proceed with a small aliquot for the metal determinations which follow those for gold, tin and silver in the normal sequence. It is possible that only the lead is severely segregated in such coins. A recent study of the variations in sulphur content in a highly leaded sestertius, from top to bottom, revealed that the metallic sulphides were very uniformly distributed throughout the matrix, and the obvious lead segregation had had negligible influence upon their distribution.

For those coins which can be expected to contain internal oxides which pertain to their original melts rather than to any subsequent corrosion (eg the copper Asses of the early Empire and the much debased copper-silver alloys of the Gallic antoniniani) it is sometimes convenient to determine the oxygen content, by the hydrogen-reduction of the coin in the solid state, before using the deoxidised coin for the bulk analysis. Thereby one obtains a value for the oxygen content of the refined metal and the opportunity of a more complete metallic analysis total. Some slight desulphurisation can also take place, and this is usually evidenced by traces of a bronze stain, downstream, on the supporting refractory. In such cases sulphur must be separately determined on an unreduced coin sample and corrections applied to both the 'oxygen' result and to the bulk analysis of the deoxidised and desulphurised sample.

Coins that are deeply oxidised or corroded are best recovered by a special sampling technique involving complete fusion-reduction as an extension to the normal technique for oxygen determination. There are some Roman coins which are obtainable in hardly any other form because of their corrosion susceptibility. Examples are the later antoniniani of the sole reign of Gallienus and almost all of the late fourth-century small leaded-bronzes, in which there is often only a little unaffected metal in the central core region. Even if this could be separated it would be generally inadequate in quantity and perhaps also unrepresentative of the original severely segregated whole-coin alloy.

For fusion-reduction the coin is first cleaned of all its more obvious corrosion encrustations (which might introduce, say, iron contamination), and any silvered layers, and fractured as a guide to its condition and approximate composition. It is then rapidly fused in a graphite or alumina capsule, in a hydrogen atmosphere, at about 1150°C. The metal is thereby freed from its entrapped corrosion products - some of which are properly reduced to their original metallic state - and a bright clean button is produced which can be used as it is or flattened and divided into two halves for separate solution for bulk analysis and the neutron activation analysis of the extracts. This method has had to be adopted as the general sampling procedure for nearly all the Gallienic and Claudian antoniniani, the later Alexandrian tetradrachms, and for the majority of the argentiferous and plain leaded-bronzes of AD 330 onwards. The major advantage is the recovery of the majority of the metallic constituents of the original coin in their correct proportions, leading to a simpler analysis routine and a more complete and sure total.

In the presence of both carbon and hydrogen, at 1150°C, all those oxidised metals which were originally carbothermically reducible by the smelting operations (see Figure 4) are recovered and re-alloyed, whereas any more recent silicious or aluminous earthy matter which might have penetrated into the coin is brought to the surface of the metal as an insoluble powdery deposit which is easily removed by wiping with a tissue to expose a bright solid sessile drop for analysis. The flowing hydrogen effectively reduces the exposed oxides of copper, lead, nickel, cobalt, tin, and iron, as the temperature rises to about 680°C; thereafter the carbon effectively reduces any residual soluble oxides as the metal becomes completely molten. The continued hydrogen flow assists in

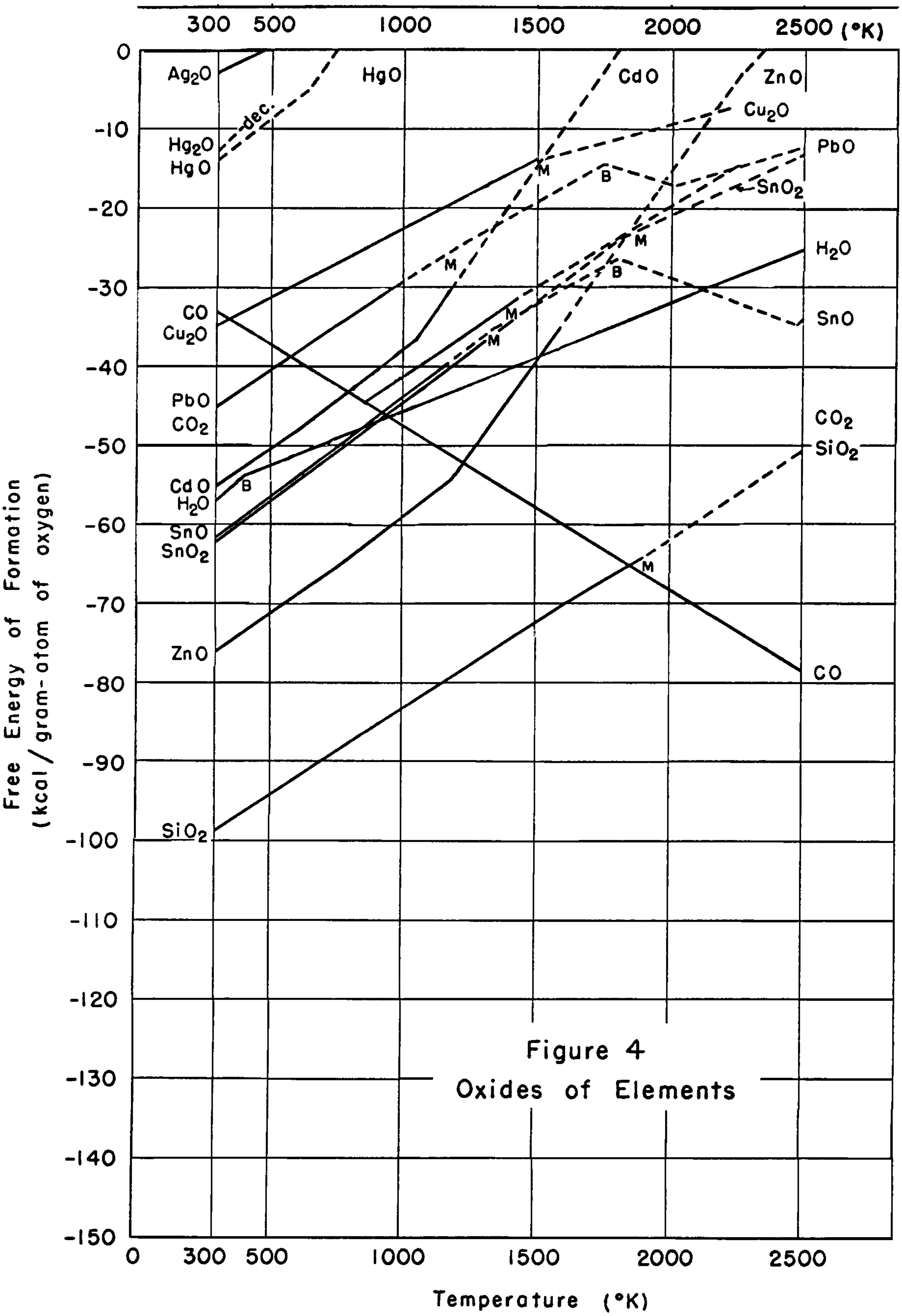


Figure 4
Oxides of Elements

cooling, and then provides a positive protective atmosphere right down to room temperature and the withdrawal of the analysis sample. Any previously segregated impurities are likely to be re-distributed in radial form, so the sessile drop can be flattened and halved for analysis samples which are likely to be better homogeneised than the coin from which they came.

Insidious chloride corrosion - which may have converted some of the alloyed silver to a highly insoluble form - is also effectively removed by the fusion-reduction process (see Figure 5) for, although hydrogen and carbon are not directly involved in these reactions, some of the reduced lead (which seems always to be abundant in the much-debased Roman coinages) will perform the same powerful reducing and 'collecting' function as it does in the scorification stage of a conventional fire assay of precious metals. One can be certain, therefore, of obtaining all the alloyed silver in its metallic form in the sample, for a simple subsequent wet-chemical assay.

Fusion-reduction is not really suitable for orichalcum or the zinc-bronzes, on account of the high volatility of zinc (which boils at 906°C) and the impossibility of reducing it to metal except in the gaseous phase; but it has not yet been found necessary to apply it to these coinages. The process is really most suited to the recovery of the debased silver coinages of AD 64 to 363 which are, fortuitously, almost always zinc-free.

The vapour pressure data illustrated in Figure 6 indicate that although most of the metals present in Roman coinages have low vapour pressures at 1150°C there is the likelihood of some lead being evaporated. This is, indeed, manifest by a film of lead condensate which forms occasionally at the cool end of the refractory reduction-tube. For very exact analyses this distilled lead can be carefully dissolved in nitric acid, added to the bulk, and determined; but if the heating to fusion and subsequent cooling are both rapid, and holding-time after fusion is short, there is found to be little lead loss of practical significance - and possibly no more than could have occurred in any case during a re-melting or scrap-recovery operation at the mint. Since it is the low silver content of the baser alloys which is of the greatest numismatic consequence it will be appreciated that even the loss of a fair proportion of lead from an alloy can make but little difference to a silver content which is always related to a much larger proportion of copper. In practice there

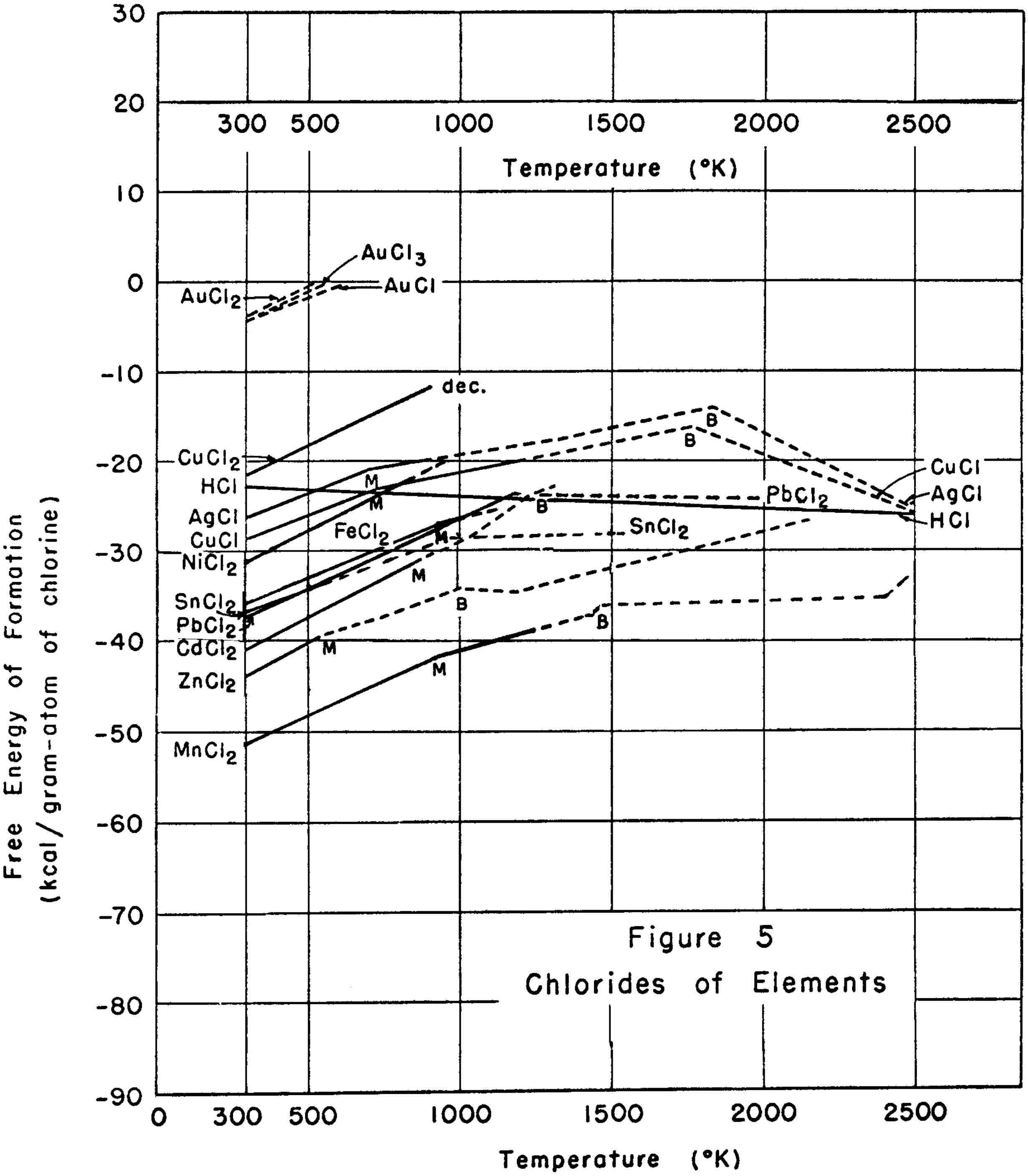


Figure 5
Chlorides of Elements

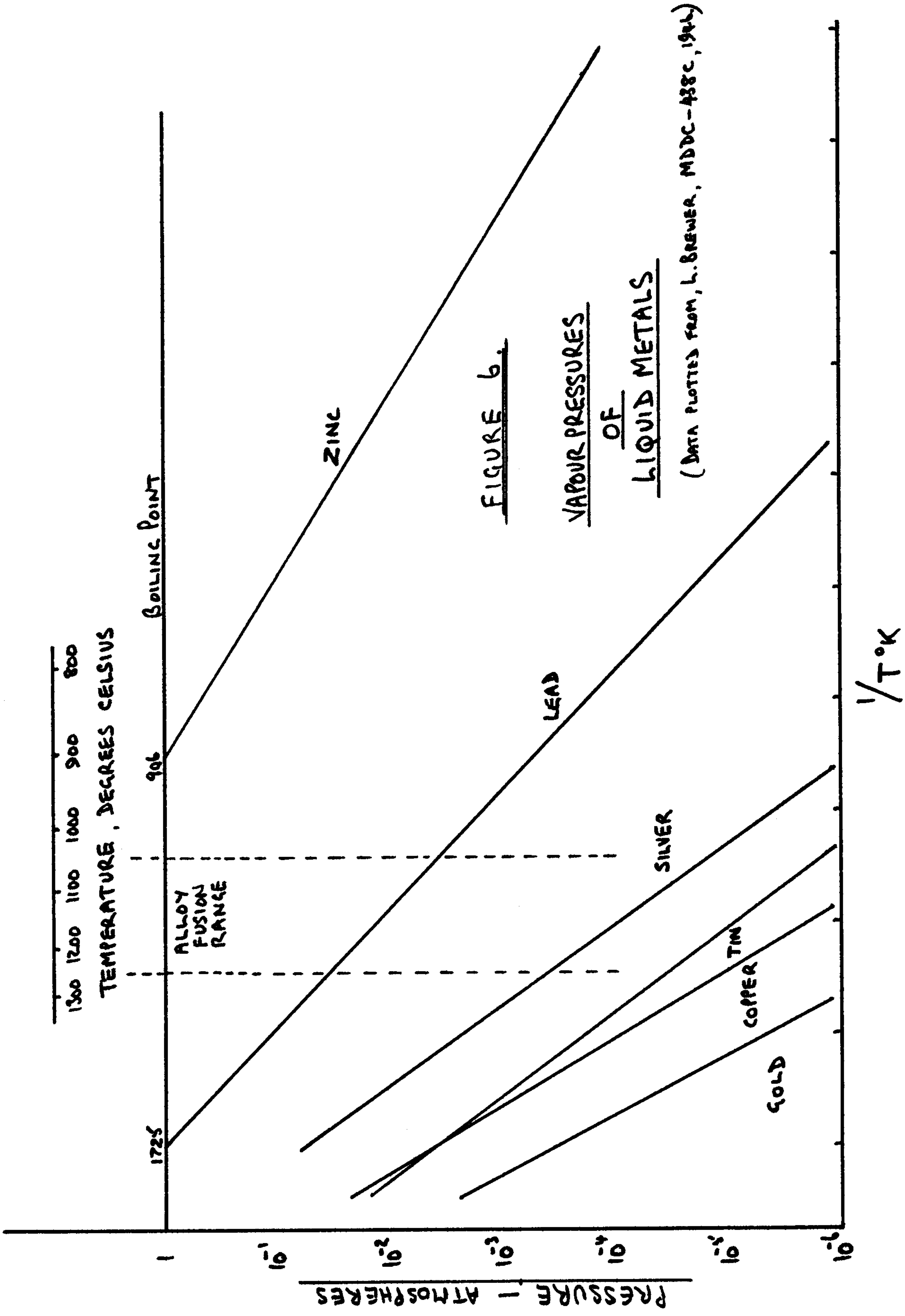


FIGURE 6.

VAPOUR PRESSURES OF LIQUID METALS

(DATA PLOTTED FROM, L. BREWER, MDDC-438C, 1946) is no real complication in the interpretation of the fineness standards; and if the coin materials and separated solids are both weighed after the reduction, a correction factor (involving the unknown fractions of mainly carbonate, oxide, and volatilisation losses) can be obtained for a close estimate of the maximum possible silver enrichment.

The common metallic sulphides are not reducible by carbon because of the relative instability of CS_2 (see Figure 7); so the metal sulphide content remains virtually as it was unless sulphate corrosion leads to an increase in sulphides reduced from any sulphates present. The hydrogen atmosphere, however, is capable of reducing bismuth and antimony sulphide and perhaps a small proportion of copper sulphide. Because of the possible complications a sulphur determination is never performed on a fusion-reduction prepared sample, and all traces of suspected external sulphate corrosion are always removed mechanically before processing. This is particularly important in the case of the very highly leaded alloys on which insoluble sulphate encrustations are often found.

Metallography

The uses of the metallurgical microscope in numismatic studies were thoroughly reviewed by Professor F C Thompson in 1956(144). Since then a few more sophisticated techniques - such as electron-probe and scanning microscopy and quantimetric measurements - have been added to the simpler ones, but the essential principles of exploration and the possible conclusions concerning coin fabrication are virtually the same. A destructive analysis provides, ipso facto, an almost unrestricted opportunity for a metallographic examination, and the opportunity is not to be missed for a study whereby the mechanical and thermal history of a coin can be traced and its individual microstructure related to the analysis for the fullest appreciation of its metallurgical meaning.

Analyses reveal that many Roman bronze coins contain an appreciable proportion of tin - rather more than we might now regard as an optimised amount for good minting properties. The highest figures recorded for tin could lead one to imagine that some proportion of the brittle delta-phase must inevitably be present; but every coin that the author has examined shows this not to be the case, for all the Roman Imperial coins - in every metal - show unmistakeable signs of having been hot-struck from well-homogeneised coin alloy blanks. In the case of the higher-tin bronzes this reveals they must have been always given a prolonged

JOURNAL OF THE IRON AND STEEL INSTITUTE

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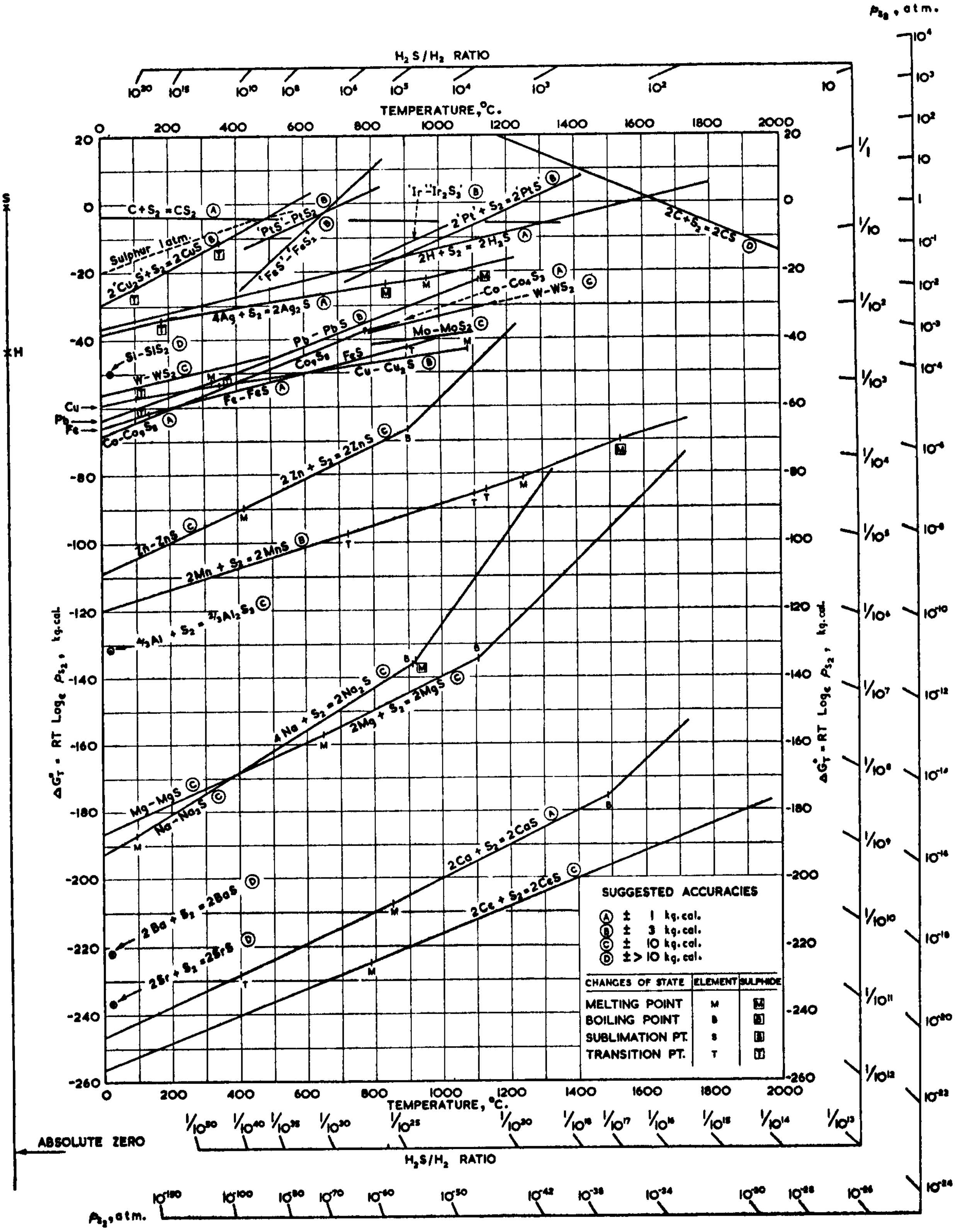


Free-energy diagram for sulphides of metals

FIGURE 7.

anneal - perhaps at a dull red heat for several hours - to effect the observed degree of uniformity of structure. Yet their grain size is also exceedingly fine - indicating that the coin blanks themselves were substantially worked and annealed to flan dimensions near to those of the finished coins before being given their final hot-striking.

Hardness determinations support this general thesis of hot-working and hot-striking, which is quite different from modern minting by cold-striking annealed blanks which have been punched from cold-rolled strip. Sometimes traces of cold work are visible in Roman coins as strain lines; but these are generally found to be concentrated near to the coin surface, where the chilling effect of the dies is manifest following insufficient residual heat being present in the body of the coin to effect re-crystallisation before the whole piece cooled to ambient temperature.

In contrast the debased silver-copper coinage of the second and third centuries AD is found to be much harder, in general, than can be attributed to any cold work - of which there is usually no sign(145). The reason for the hardening is that a subtle sub-microscopic change takes place in the coin structure, in archaeological time - a phenomenon which Professor F C Thompson has also observed(146). If silver-copper alloys are rapidly quenched from a bright red-heat, they are obtained in their softest 'solution-treated' condition. Reheating to 250°C induces maximum age-hardening in about an hour; but it is only recently that it has been appreciated that at ambient temperatures the diffusion process kinetics are such that full ageing can be accomplished at ambient temperatures in archaeological times.

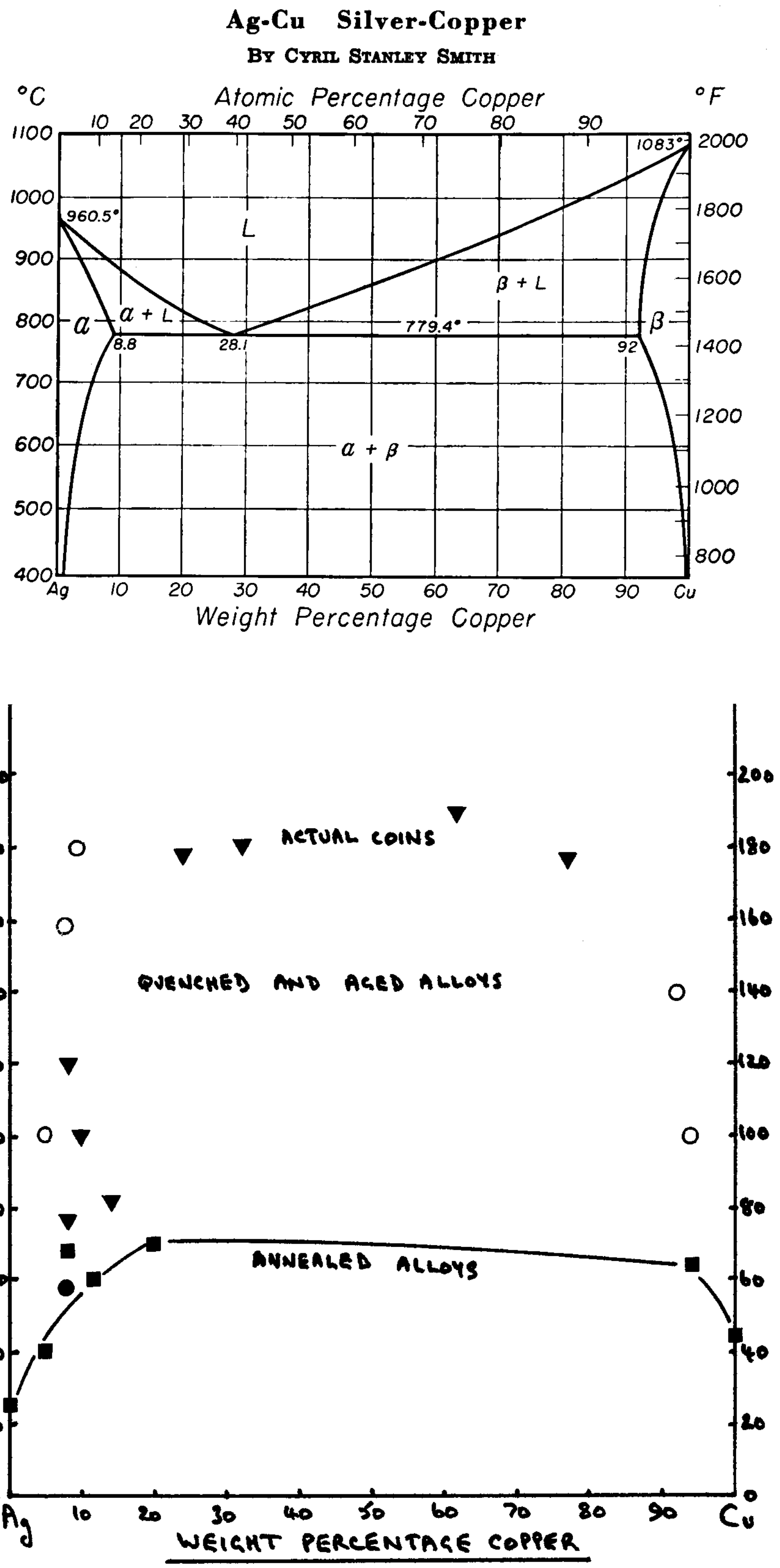
It is now clear that the Roman silver coinage must have been generally quenched (perhaps into a citric or acetic acid blanching bath) directly after striking. It might have even been reheated for this process, which was more likely aimed at producing a clean and aesthetically attractive silvery surface than at any then unknown metallurgical strengthening. Reheating the coins to their annealing temperature can be shown to restore the lower hardness values which should pertain to their different compositions (Figure 8).

It would appear that 1½ thousand years at ambient temperatures can suffice to produce the same increase in hardness as is possible by ageing for about an hour at 250°C; but whether the maximum hardness was reached long ago, or just recently, is of metallurgical interest. It is surprising

FIGURE 8.

THE HARDNESS OF SILVER-COPPER ALLOYS

(DATA FROM VARIOUS SOURCES, RELATED TO THE BINARY Ag-Cu ALLOY SYSTEM AND COIN HARDNESSES)



that despite the long history of silver smithing, and considerable industrial interest in sterling silver in modern times, and early appreciations of its age-hardening mechanisms(147), the kinetics of the process are still little understood(148). Accordingly, some solution-treated sterling silver specimens were prepared: after 40,000 hours at room temperature (c. 18°C), in a centrally-heated study, they had hardened to around 70 VPN, which is to about 20% of the possible maximum increase. It is feasible that a few hundred years - rather than thousands - may have sufficed for the hardness levels of the coins to have reached their maxima.

It was mainly by metallographic study that the author was able to classify the various and previously confused ancient silver 'plated' and 'washed' coinages into their distinctive metallurgical categories(149). This facilitated their classification and identification and allowed really practical explanations to be given for the different surface-silvering processes, to replace some of the untenable hypotheses which the numismatic literature on this topic contains. Generally speaking all the debased Roman silver coin issues of AD 64 to a little later than 260 were fortuitously surface-silvered with enriched layers as a consequence of their normal process of minting by hot-striking and blanching coins made from similarly-prepared flans.

When debasement reached a level (perhaps 8% silver) below which the silver-rich microstructural phase ceased to be continuous, an overall white-metal appearance could not be produced by conventional minting, and so a technique for providing an applied coating by a pyrometallurgical process before final striking had to be devised. It is possible that the thin silver coatings were then produced by immersion in molten silver chloride at just about a dull red heat. The thermodynamic feasibility of the reduction of silver chloride, in situ, by the copper, tin, and lead constituents exposed at the surface of a bronze coin flan was apparent from Figure 5: its practicability was demonstrated by experiments in which the author has produced thin silver 'washes', on worn bronze-looking coins of the period, which bear close metallurgical resemblance to those found on a proportion of the same Roman coinage which has not been subject to substantial wear or corrosion. The chemical stabilities of the chlorides are such that tin and lead, in that order, are more effective than copper alone in replacing the silver. Furthermore, the mixed chlorides present in a worked 'bath' in which bronzes have been treated form eutectics which actually facilitate the process of silvering and the draining away of excess chlorides - making it quite a practical and speedy production process. If coin blanks are quenched from the mixed chloride pot the excess salts shatter and fall away to expose the bright silvering. Since the silver chloride fraction is virtually insoluble, whereas the other chlorides present have some solubility, it can be recovered as a purified sludge, dried, and recycled with negligible waste. Without metallographic examination of the different types of silver-surfaced coinages - in addition to their chemical analysis - it would not have been possible to distinguish them clearly or to postulate and test realistic techniques which might have been used for their manufacture.

Metallographic sections are often mounted in thermo-setting plastics before polishing for examination; but it has not always been appreciated that the usual temperatures for their polymerisation can seriously affect the structures of the coin materials. Gold readily recrystallises; silver, copper and some brasses might be stress-relieved or even fully recrystallised by the temperatures and times sustained in the mounting press, or by some so-called 'cold-setting' media; and silver-copper alloys might be either aged or overaged during setting. There are, however, epoxy-resin mounting media which can polymerise slowly at room-temperature over a period of a day or so; and it is one of these (Araldite X83/307) which has been selected for mounting all Roman coinage specimens to preserve their 'as-received' condition for the micro-examination and hardness testing.

Earlier analyses of the Roman coinage

The earliest recorded studies of the metallic composition of any pieces of the Roman coinage - indeed, the first quantitative analyses of brass objects of any kind - were announced by Martin Heinrich Klaproth in Berlin in July 1795 and published three years later(150). Klaproth analysed six first-century orichalcum coins minted between the reigns of Caligula and Trajan; and he expressed the results in weight proportions of the Apothecaries scale, which are strange and almost incomprehensible to modern analysts accustomed to thinking in terms of percentages for major constituents and in parts per million for the minor elements. Nevertheless, this event marked the very dawn of modern analytical chemistry, and perhaps the beginnings, too, of modern metallurgical analysis and process control - for brass was then still being produced by the old Roman cementation process, and the analysis results for the Roman brass coins suggested that chronological differences existed due to changes in orichalcum manufacture.

In its infancy analytical chemistry advanced, perhaps, with more enthusiasm than accuracy in the quest to extend the scientific knowledge of a wide variety of ancient materials and objects, and to satisfy the curiosity of a growing industrial society - then beginning to exploit metallurgical materials on a hitherto unprecedented scale - in unraveling the metallurgical mysteries of earlier civilisations. But the parallel advance of chemistry brought improvements in analytical technique and in the development of the principles of physical chemistry upon which specific separations could be improved. The older results must, therefore, be viewed with some caution, especially where the analytical methods are not described.

In 1834 J Y Akerman(151) published fifteen assays of early Roman Imperial denarii minted between the reigns of Augustus and Septimius Severus. During the next few years a steady stream of further exploratory analyses appeared of Roman coinages minted in silver, and also in copper-based alloys. In 1842 F Göbel(152) reported the first analyses of some Roman Republican aes; in 1843 Höpfer(153) provided assays of Imperial denarii and antoniniani; and in 1850 J and L Sabatier(154) extended these results with further Roman silver and bronze analyses. In England J A Phillips(155) produced, in 1852, his "chemical examination of the metals and alloys known to the ancients", including studies of both Roman silver and bronze coins; while on the continent A von Rauch(156,157) provided analyses of Roman tetradrachms (in 1857 and 1874), and E von Bibra(158,159) explored the compositions of various denarii and antoniniani (reported in 1869 and 1873). Of these, von Rauch's later work was the most voluminous to date - containing the analyses of over 170 early denarii and antoniniani, down to Diocletian's reform of AD 294, and Roman aes minted from the earliest times. E von Bibra's works extended, in particular, the knowledge of the Roman bronze coinage alloy compositions, into the Byzantine era and as far as the 12th century AD.

The early years of the 20th century saw the publication of further similar works: in 1901 A Markl(160) reported the compositions of four antoniniani of Quintillus, and tetradrachms of Claudius II; G Dattari(161) (in 1903) reported some analyses of Alexandria tetradrachms; and H A Grueber(162) (1904) published studies of early Republican and Imperial aes of the period 45 to 3 BC. In 1905 other results derived from A Blanchet(163), and M Bahrfeldt(164); and it was the latter who provided the only known analysis of an early orichalcum coin minted for Julius Caesar.

These were the principal sources of sporadic investigation upon which, in 1908, J Hammer(165) based his collation of the known analyses of Roman Republican and Imperial coins. He assembled about two hundred Roman aes coin analyses, and nearly two hundred and forty assays of both fine and debased silver denominations in a sort of chronological order in which he listed the issues according to known or assumed denomination or weight. It is not possible to be precise about totals because although some analyses are obviously repeated in different lists there is some attendant uncertainty.

Despite its various shortcomings, however, Hammer's survey became the most complete review of all existing knowledge on the composition of the Roman coinage alloys. It might have been expected to stimulate immediate interest in further investigation - aimed at confirming the main features and filling the more obvious lacunae - but, strangely, the flow of new results diminished just when industrial needs and developments in analytical chemistry led to more reliable techniques for metallurgical analysis.

We may note that to this point (1908) only the broad alloy compositions of the coinage had been studied, and little attention had been paid to trace element analysis. Furthermore, despite developments in optical microscopy there were no reported studies of the internal structures of coins. In 1908-12 J Maurice(166) provided a few Constantinian coin analyses in his work on that coinage; but it was not until 1912 that T K Rose(167) provided the first indications of Roman minting methods, as discerned by micro-structural examinations. Later mentions of coin metallography were infrequent, and not extensive: the works of H Garland(168), in 1913; W Gowland(169), in 1920; G F Hill(170), in 1922; C F Elam(171), in 1931; W Campbell(172), in 1933; and A E Smith(173) in 1939 are faint gleams in metallurgical darkness. Dr Elam's work, however, although pertaining only to Greek silver coins, set new scientific standards for micro-structural studies combined with accurate analyses. These led to the discernment of the methods of manufacture; to a quantitative appreciation of the skill of the Laurion metallurgists, (of times before Alexander the Great) in refining coin silver to standards superior to 98.2%; and to the detection of lead, gold and traces of iron as common residual impurities. Unfortunately the work was spoiled in publication by the illustrations not matching the coins described - so that one has to be skilled in metallography to sort them out.

In the years between the two World Wars there was little further progress with analyses in any branch of numismatics. The year 1924 saw the publication, by W Brambach(174) of one of the best examples of 'bucket chemistry' that it is possible to find. Brambach took a batch of 216 coins from a Constantinian hoard of 1,017 coins of the period AD 320-330 and melted them down to provide one huge sample (of c. 675g) reported to contain 1.98% silver. As recently as 1966 Professor P M Bruun, in his standard work of reference on the Roman Imperial coinage of AD 313-337, regarded this result as "... the most reliable examination of the silver content of Constantinian folles ......"(175). We shall show below that a number of different finenesses pertained to the folles of the decade in question, and that Brambach's result is a misleading average figure which obscures the realities of the individual coin finenesses which went to make up the synthesised sample batch of various unrecorded pieces.

Bruun was, however, necessarily limited in his judgement to the number of coin assays (three) available for comparison; so it is unfortunate that their close resemblances masked the real differences which can now be shown, and which provide evidence for hitherto unsuspected coinage reforms and differences in minting practice in the east and the west. In a more recent review(176) of the work of P Bastien and H Huvelin(177), however, Professor Bruun remarks that the work of the present author now "... assists in dispelling the mist still lingering over many of Constantine's coining activities".

The inter-War years saw also the publication, by H Mattingly(178), between 1923 and 1940, of four volumes describing the coins of the Roman Empire in the British Museum. These included a few coin analyses executed in the British Museum laboratory or at the Royal Mint. With reference to the results for the orichalcum pieces, Caley(179) remarks that although the number of analyses exceeds those published by any one writer up to 1964 only one coin seems to have been satisfactorily analysed. The present author is aware that the remains of at least some of the coins still occupy their positions in trays in the British Museum, and so there will be opportunity for check analyses to be made at some future date to determine to what extent Caley's criticism is really justified.

In 1941 L C West(180) published a review of the gold and silver coin weight and fineness standards in the Roman Empire, based entirely on earlier published results. For the finenesses of the Imperial silver coinage West endeavoured to provide averages for the silver content of the coinage of each reign, or 'points (modes) of concentration'. These have the great disadvantage that undetermined fineness reforms within reigns are masked, and a false idea is given of a single yet non-existent standard where two or more standards really pertained. The American works of this era are particularly lacking in scientific quality. The nine new follis coin analyses provided by the Lewis brothers(181) in 1937 were apparently used to bolster the idea that the large tetrarchic folles were minted in silver-free alloys and that their lustres were not due to silver coatings. Both these concepts have been demonstrated to be false. The present author has accumulated over fifty assays to prove this point – including check analyses on the remains of Lewis's samples acquired from the Strasbourg city museum. In 1954 H L Adelson(182) tabulated all the known fourth-century 'bronze' coin analyses without attempting a chronological classification. Quite uncritically he paid particular attention to Lewis's conclusions, interpreted Roman coinage law out of context, and lent his own support to the numismatically erroneous conclusions. In marked contrast Professor Caley published, in the following year, a work on the chemical composition of Parthian coins(183) and another on the chronological variations in the composition of Roman brass(184) which marked the dawn of a new era of quality and accuracy in chemical analyses. This was soon followed in 1956, by studies of the chemical composition of some mid third century antoniniani by Caley and McBride(185), using the same methods which were fully published by Caley(186) in 1964. Before the close of the 1950's Caley(187) published similar high quality results for fourteen selected Alexandrian tetradrachms.

The decade commencing with 1960 witnessed the most intensive and varied analytical activities known. There were advances and retrogressions. Sampling techniques still lagged behind the standards of analytical achievement so that even those who put the latter into operation still produced highly questionable results. Some workers (eg R C Reece(188,189,190,191) even went back to old school text-book methods and used schoolboy assayers to produce results of doubtful validity and chemical interpretation on silver coin samples which were given no sample preparation other than quartering. Others (eg J Guey(192)) were apparently at first unaware of the errors of even their good assays commissioned on unprepared samples. To Guey's credit, he did attempt, immediately, to correct the results for posterity(193) in consequence of the illuminating metallographic work of Condamin and Picon(194). But the 1960s are to be recognised for the many attempts to apply newly developed techniques of physical analysis to coins on as non-destructive a basis as possible. In 1960 H C Chitwood and Q Quick(195) drew attention to X-ray fluorescence as a new method of coin analysis - soon to be explored by Hall(196) and then by G F Carter(197,198). In that same year (1960) M Aitken, V Emeleus and E T Hall(199) advocated the use of neutron activation analysis for ancient silver coins, and this was followed by the results of V Emeleus and C M Kraay(200) based on the even earlier (1958) studies of Emeleus(201).

Further work at Oxford led to the acquisition, by M R Harold and C H V Sutherland(202) of assays of early large Diocletianic folles which, even though possibly inaccurate by a few per cent of the fineness values quoted, at least provided the first reliable evidence for refuting the views of N and D Lewis(203) which had stood for nearly a generation. In 1963 A Ravetz(204) made similar studies of the later diminished and generally more debased folles of the early to late fourth century - whose inexplicable fineness fluctuations provided the original stimulus to this present work.

Again in the early 1960s, A Bandaret and P Bastien(205) used electron probe micro analysis (EPMA) to study the thin white metal 'washes' found on some Roman bronzes; and by 1963 E S Hedges and D A Robins(206), using X-ray fluorescence techniques to examine the 'washes' on late antoniniani and the subsequent issues of folles, demonstrated conclusively that the white metal coatings were mainly silver, and not tin - as had sometimes been supposed.

In the early 1960s there also appeared the publication of 720 conventional assays of a sequence of antoniniani, minted between AD 215 and 274, which had been provided for P Le Gentilhomme(207), towards the end of the war years, by the Société des Cendres; a valuable work by E R Caley(208) on sulphur in Roman brass; and Caley's special study(209) of the compositions of Roman orichalcum. By the middle years of the same decade P Bastien - concentrating on Gallic issues - had provided ten original analyses of the coinage of Magnentius(210), and two for Postumus(211); P M Bruun(212) had added a few analyses of coins of the Constantinian era; and D McDowall(213) had obtained new analyses in support of his studies of Nero's orichalcum coinage.

In 1970 J Lallemand and M Thirion(214) published sixty analyses of the common coinage of the last Gallic emperors; and in the December of that year, the Royal Numismatic Society, having recognised the impact of the natural sciences on archaeology and the developing interest among numismatists, convened an international Symposium to discuss the various methods of analysing coins and interpreting the results. The resultant publication(215) gave an outlet for many new analyses of Roman coins, and matters pertaining to them, in addition to numerous advances in other fields of study.

The lacunae

Because of the immense variety of Roman coinage issues most analysts in the past have restricted themselves to studying just small sections of the coinage pertaining to fairly narrow historical periods. The accumulated results can hardly be expected, therefore, to provide either a systematic survey or an even representation - and they do not. The lacunae in the existing analyses are not immediately apparent, yet they had to be exposed so that material could be sought in order to fill them.

The list of early imperial copper, orichalcum and bronze coinage analyses collated by Hammer, and supplemented by more recent results prior to 1969, is shown in Table II. Those reigns for which there were no analyses is immediately apparent. But, deceptively, the Table gives the visual impression that some of the more important reigns are fairly well represented by results. This illusion is revealed by the presentation of the same data in Figure 9, in which the number of coin analyses for each reign is depicted against the regnal period. For only a few of the shorter reigns does the representation reach an average level of one coin for each year - which is a remarkably small proportion of those which must have been actually issued. A surprising feature is that the longest reigns are seen to be least well represented on a proportionate

TABLE II

Emperor	Length of reign	AES ANALYSES			
		Brass and Bronze		Copper	
		Hammer	Caley et al	Hammer	Carter et al
Augustus	41y	SSSSSDDD	SD	AA?AAQ	A
Tiberius	23y	?	D	Se Se	
Caligula	4y	?	SSSD	AA?	Q
Claudius	13y	D?S???	SD	AQA	
Nero	14y	?SSS	DDD	A?	
Galba	<1y				
Otho	4 months				
Vitellius	1y				
Vespasian	10y	?S?		AA?	A
Titus	2y	DD		?	
Domitian	15y	?D		AAAA	A
Nerva	2y		DD	A	
Trajan	19y	DS????	SDDD	A???	
Hadrian	21y	SDDSSSSS	D	A????	D
Antoninus Pius	23y	SSSSSDD?	SDDD	AASe	
M Aurelius	19y	SSS	SSSDD	AAA?ASe	AA
Lucius Verus	8y	SD			
Commodus	12y	SSDSS	SD		A
Pertinax	3 months				
Didius Julianus	4 months				
Pescinnius Niger	1+y				
Clodius Albinus	4y				
Septimius Severus	18y			A?	
Caracalla	6y	D			
Macrinus	1y				
Elagabalus	4y	?		A	
Severus Alexander	13y	SSDSDSS		?	
Maximinus I	3y				
Gordian I & II	1 month				
Balbinus & Pupiennus	3 months				
Gordian III	6y	SDSSSS			
Philip I & II	5y	SSDD		?A	
Trajan Decius	2y				
Trebonianus Gallus	2y				
Aemilian	1y				
Valerian & G	6y				
Gallienus	9y				

Key: S = Sestertius Se = Semis
D = Dupondius Q = Quadrans
A = As ? = Uncertain denomination

basis, and some (for example the numismatically eventful 18-year reign of Septimius Severus) were not represented by even a single aes coin analysis.

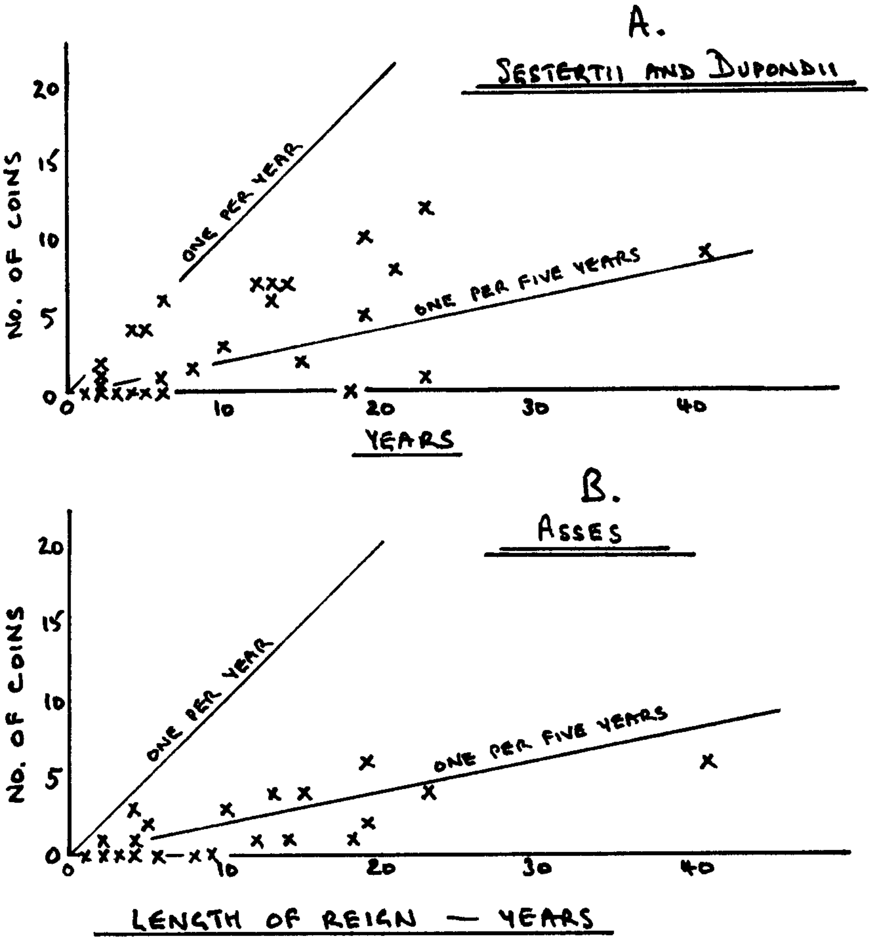


Figure 9. The numbers of aes coin analyses available, before 1969, for reigns of different length.

If we consider the copper Asses alone (Table II and Figure 9B) the representation was even poorer. It was, therefore, upon the bases of these assessments of what had been done that the list of desiderata for a more thorough study was compiled. The objective has been to fill the lacunae with analyses of closely dated pieces so as to achieve a more uniform chronological representation, while increasing the representation within periods of known metallurgical change. This ideal has not been fully realised due to the limited material available - apart from the limitations of time for analysing every desirable piece - but it has been applied in principle to both the aes and silver coinages for which a similar situation obtained.

The known coin analyses for the debased silver and bronzes of the late third to early fifth centuries were remarkably few; and so it has been for this later imperial period of quite intensive monetary activity and change that the exposure of the lacunae and the completion of new analyses has been most rewarding. Previously nothing was known of the metallurgical substance of the Gallienic coinage and the subsequent Aurelianic and Diocletianic reforms; the metallic characteristics of the independent British Imperial coinage; the final decline of the tetradrachm; the fineness vicissitudes of the reduced Constantinian folles; the nature of the FEL. TEMP. REPARATIO reform, and its subsequent decline; and of the coinage alloys used in the twilight of empire. There are still many lacunae to fill; but it is now possible to pin-point the numismatically significant ones with much greater certainty than hitherto.

THE METALLURGICAL DEVELOPMENT OF THE ROMAN IMPERIAL COINAGE

A conspectus

The Emperor Augustus replaced the trimetallic Roman Republican coinage of gold, silver, and leaded-bronze pieces with an Imperial quadrimetallic system comprising issues in gold, silver, brass (orichalcum) and copper.

Throughout the Imperial era it is believed that the gold coinage, despite numerous changes in its weight and denomination, was maintained at a high degree of purity. The main evidence for this lies in its consistent colour and high density - rather than in actual chemical analyses - and in the strict application of known laws(216) concerning the recovery of gold coins for tax payments and their regular refining before re-minting. The author's publication of the most complete analysis yet made, of a Neronian aureus(217), substantiates the high degree of fineness (99.55%) which was possible in the days of the early empire; and at the other extremity a Byzantine tremissis of Justinian I(218) was found to be not much inferior – at 97.57% fine. Apart from aesthetic attractions the main numismatic interest in the Roman gold coinage lies in its metrology in relation to the contemporaneous issues of other denominations, and its present rarity precludes the destructive analysis of any but the most damaged specimens. The principal numismatic and metallurgical interest is to be found in the silver and the aes which were the more common coinages for daily transactions.

The first Imperial silver coinage was of similar fineness to the best issues of Republican silver; but its deliberate debasement - at first with copper, and later with copper, tin, and lead - began in AD64 and proceeded, stepwise(219), to a nadir(220) c. AD270. The metallurgical transition was from cupellation-refined silver to silver-copper alloys of increasing debasement, and thence to argentiferous bronzes with and without alloyed lead. The argentiferous bronzes served for more than a century for the principal coinage of the closing decades of the third century and for the common coinage which followed Diocletian's short-lived re-introduction of a high quality silver piece in AD294. A fairly fine silver coinage appeared again in AD323, in conjunction with one in argentiferous bronze, and became more plentiful (though slightly debased) as the fourth century progressed. By AD363 the distinctive yet variable argentiferous bronze coinage alloys were replaced by cheaper more highly leaded bronze alloys which were later degraded to impure leaded coppers.

The early Imperial aes coinage originally comprised simple brass and refined copper pieces for the different low denominations. The generic term aes was (and still is) used to describe any copper-base Roman coinage, but it lacks metallurgical precision. In some late fourth century Roman laws(221) it is used also to describe what must be argentiferous bronzes and leaded coppers.

Before the end of the first century tin was added in small proportions to the plain alpha-brass coinage of the type minted by the earlier emperors. The proportions of zinc were then diminished, and those of tin and lead were increased until, by the end of the second century AD the brass denominations – having passed through a zinc-bronze alloy transition - terminated as zinc-free highly leaded tin bronzes. In the mid third century this coinage fell into disuse because it ceased to be economically viable in association with the much debased silver issues which were the consequence of persistent inflations of the currency.

The copper denominations suffered a similar economic fate. Although minted in virtually pure copper for most of the first century AD, the necessity to exploit sulphide ores after the exhaustion of most of the known oxidised deposits (during Trajan's reign), led to the acceptance of impure coppers to which lead began to be added. Eventually these were replaced by leaded tin-bronzes. In the final phase before their demise all the early aes denominations were struck in the same type of highly leaded tin bronze - as was the ultimate restored aes coinage of Aurelian - and all semblance of the original visual distinction between the yellow and red metal denominations disappeared.

A true aes coinage - one containing no deliberately added silver - fell almost completely out of use between c. AD 268 and 294. A leaded bronze was, however, re-introduced for Diocletian's smallest radiate and laureate denominations and re-appeared sporadically in Constantinian times. Metallurgically these later aes bear compositional similarities to their contemporaneous argentiferous bronzes, but without the silver. Ultimately the cheapest highly leaded bronzes replaced those of the previously more carefully optimised metallurgical composition and the eventual aes coinage of the Empire descended to an impure leaded copper except that, towards the end, a small proportion of tin began again to be added to what had then become a pathetically tiny everyday coinage of almost negligible intrinsic worth.

We shall now follow the detailed chronological changes which the analyses reveal for each type and phase of the Roman Imperial coinage – studying the numismatic implications and interpretations en route. Different periods, however, call for the examination of their coinage alloys on different scales; and so for the purpose of this work the Roman Imperial coinage is divided into five broad categories - influenced by major coinage reforms - across which metallurgical continuities, unifying the whole, will be observed. These are:

I The early Imperial coinage of 27 BC to AD 274.

II The restored Imperial coinage of AD 274 to 294; including the coinages of the independent Gallic and British Empires.

III The reformed coinage of Diocletian, and of the subsequent Licinian and Constantinian eras.

IV The FEL. TEMP. REPARATIO reformed coinage issues of AD 348 to 357, including the independent issues of Magnentius and Decentius.

V The later Imperial coinage of AD 357 to 476.

The early Imperial silver coinage

a) From Augustus to the joint reign of Valerian and Gallienus, 27 BC to AD 260

The progressive yet protracted debasement of the early Imperial silver coinage, from the reign of Nero onwards, has attracted much attention from numismatists hopeful of combining the figures for coin fineness and weight for calculating their intrinsic worths and comparative denominational relationships with the gold coinage. But most attempts have been frustrated, for only in the last decade have reliable assays become available because of earlier ignorance of the metallurgical problems of coin sampling. In general, therefore, the majority of the earlier results are somewhat silver-rich with respect to the fineness standards to which the debased coins were originally minted, but to indeterminable greater or lesser degrees. Consequently we can well expect to find the wide scatter in the assay results which is clearly evident from a graphical representation, on a regnal basis, (Figure 10) of Hammer's accumulation of well over two hundred assays of denarii and antoniniani minted during the first three centuries of the Christian era. The immediate impression is one of much more haphazard changes in fineness than should have really occurred, or much poorer metallurgical control than could have been tolerated by the imperial authority. This blurred appearance has led some (eg Reece (222))to take an alternative extreme view that the

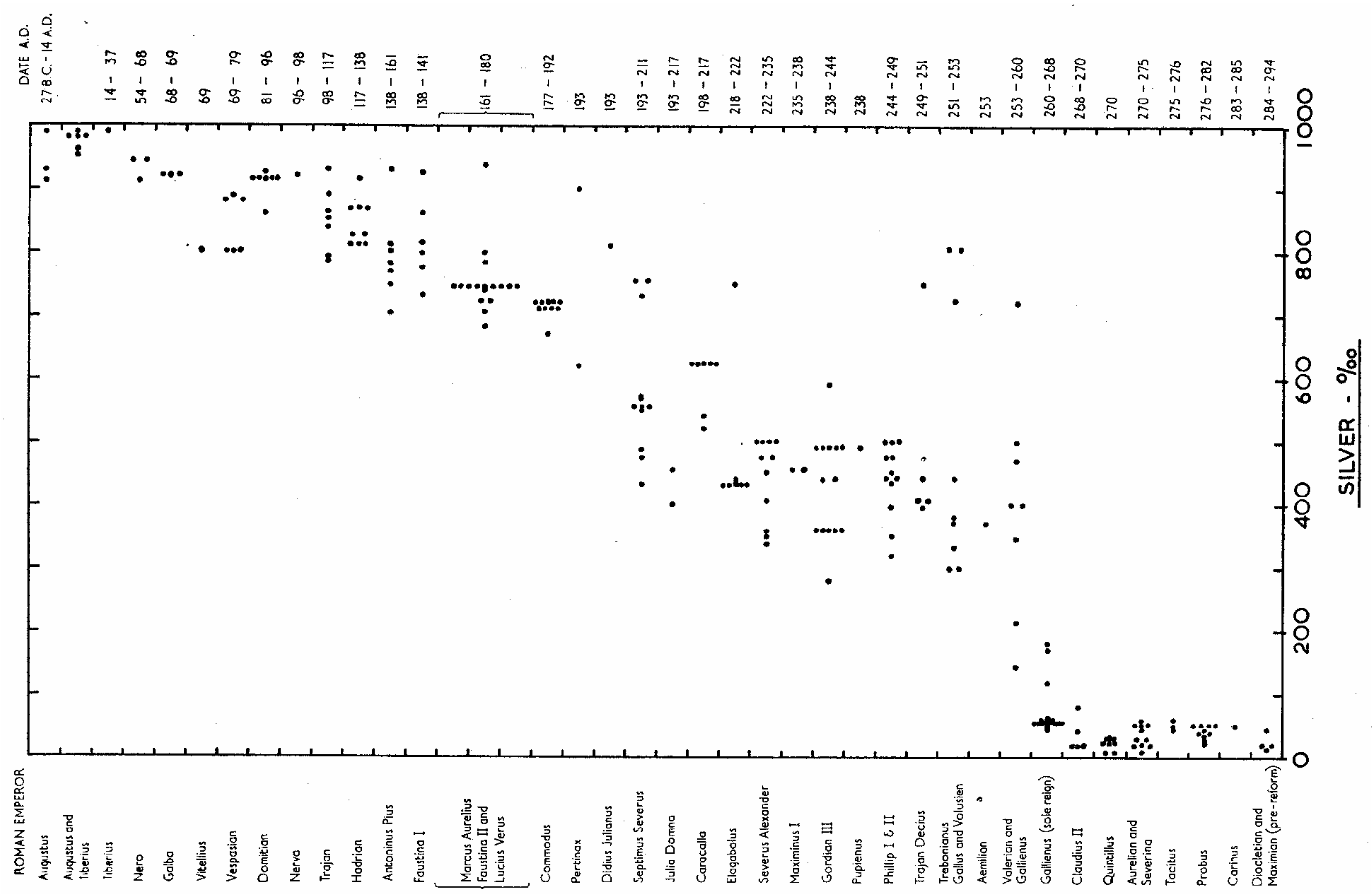


Figure 10. The chronological trends of debasement suggested by the assay results compiled by Hammer in 1908.

actual chronological decline in fineness should be smooth and gradual; but there is no evidence at all to support this.

However, a consideration of the common necessity for governments to conserve and control their limited allocations of precious metals for coining, and for their officials to be held accountable for receipts of bullion against coin output, leads to the inevitable conclusion that the Roman moneyers would have been given no more metallurgical freedom in the preparation of silver alloys for minting than were enforced by the limitations of the best-known melting practices in vogue - except, perhaps, in the blending of the different base metal components which facilitated or cheapened fabrication when silver alloys of the lower finenesses were decreed. The author advanced this concept in 1967(223) and has since tested its validity for a wide variety of Roman argentiferous coinage issues, ranging from nearly fine alloys to those containing as little as 1 scrupula of silver per libra (0.35%). There is convincing statistical evidence for some of the fineness standards employed; and any elements of chance are diminished by the observation of step-changes in fineness at times of known coinage reforms, and by the obvious operation of different controlled fineness standards for contemporaneous silver denominations. Such evidences confirm deliberate transitions and the selection and operation of coinage alloy standards, and point to the real existence of chronological step-changes in fineness. For the early Imperial issues of 27 BC to AD 260 these range from the high purity of the Augustan silver issues down to a 2 unciae per libra standard for the last issues of the joint reign of Valerian and Gallienus. At certain points in the chronology the standards can now be firmly established; and a revised chronological variation is depicted in Figure 11, based on reliable new assays published by the author in 1972(224) and in this work. For the purpose of delineating trends which have yet to be firmly established some selected assays which await confirmation are also included.

In 1958 S Bolin(225) selected what, in his opinion, were the 112 most trustworthy existing Roman coin assays; but from these we have to eliminate at least 21 which were assay estimates based on density measurements which were admitted to be up to 5% in error even allowing the now doubtful assumption that their structures were completely homogeneous. Earlier, L C West(226) had selected 133 assays for his calculations of the decline in the intrinsic worths of the Roman silver coinage; but in attempting to provide both average compositions and weight standards for each reign he unwittingly complicated and masked the vital evidence for definite alloy standards by indicating artificial and non-existent averages for reigns where two or more widely different fineness standards can now be shown to exist.

For calculations of intrinsic worths it is necessary to establish the weight standards as well as those for fineness. The chronological variations in the average weights recorded by West, together with new data for the Imperial denarii and antoniniani, have been converted to metric units for a comparative graphical display (Figures 12A and 12B) against calculated fractional standards of the Roman libra to which some - and perhaps all - are known to have been minted.

An Augustan standard of 1/84 libra is generally accepted. That the average weight is close to the theoretical one is easy to understand metallurgically because the fine silver in which Augustus' denarii were minted would have given little or no oxidation or volatility losses, so that weight control would have depended only on the careful weighing of the coin blanks,

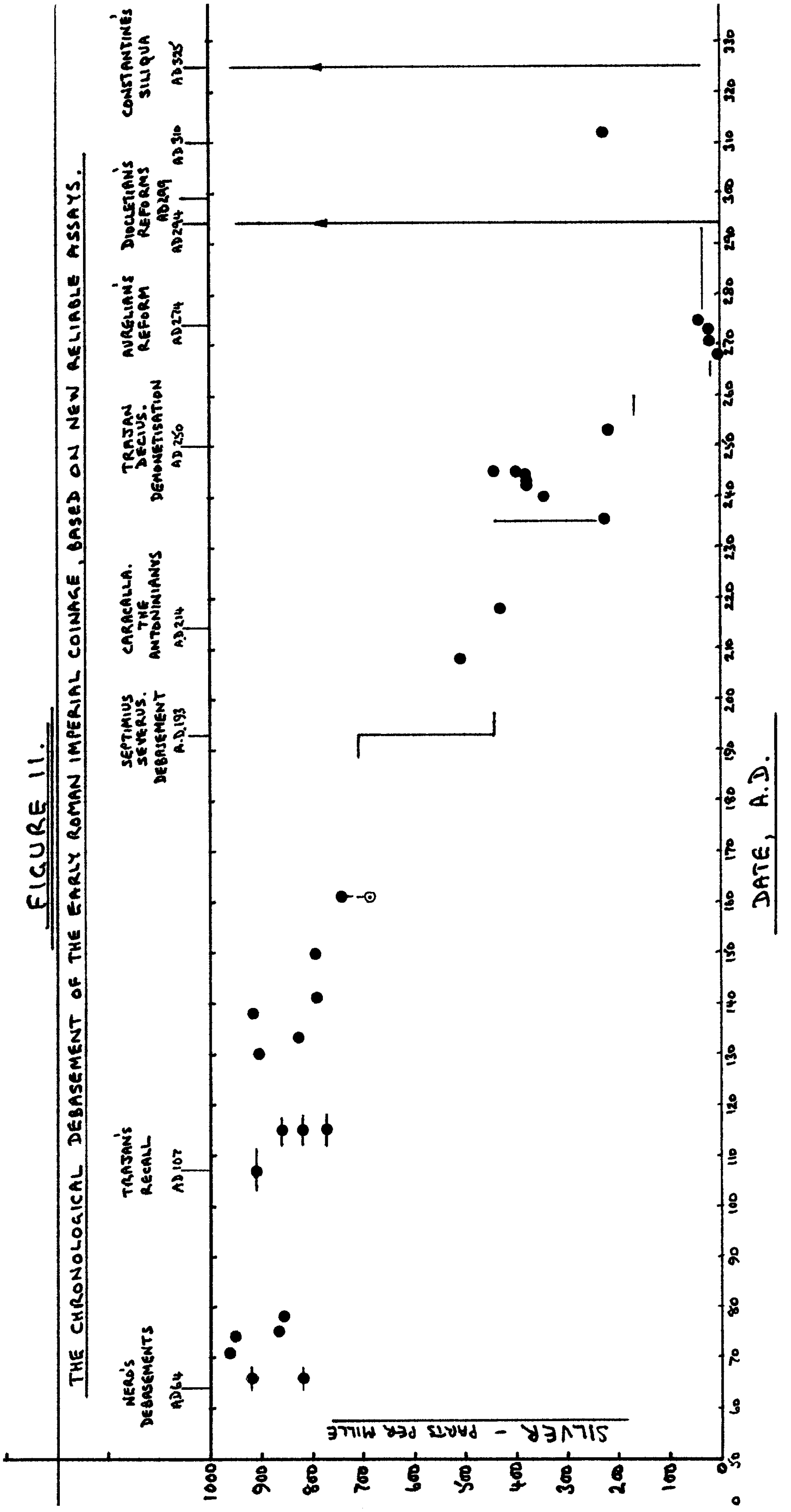


FIGURE 11.

THE CHRONOLOGICAL DEBASEMENT OF THE EARLY ROMAN IMPERIAL COINAGE, BASED ON NEW RELIABLE ASSAYS.

FIGURE 12A. ROMAN IMPERIAL SILVER COIN WEIGHTS

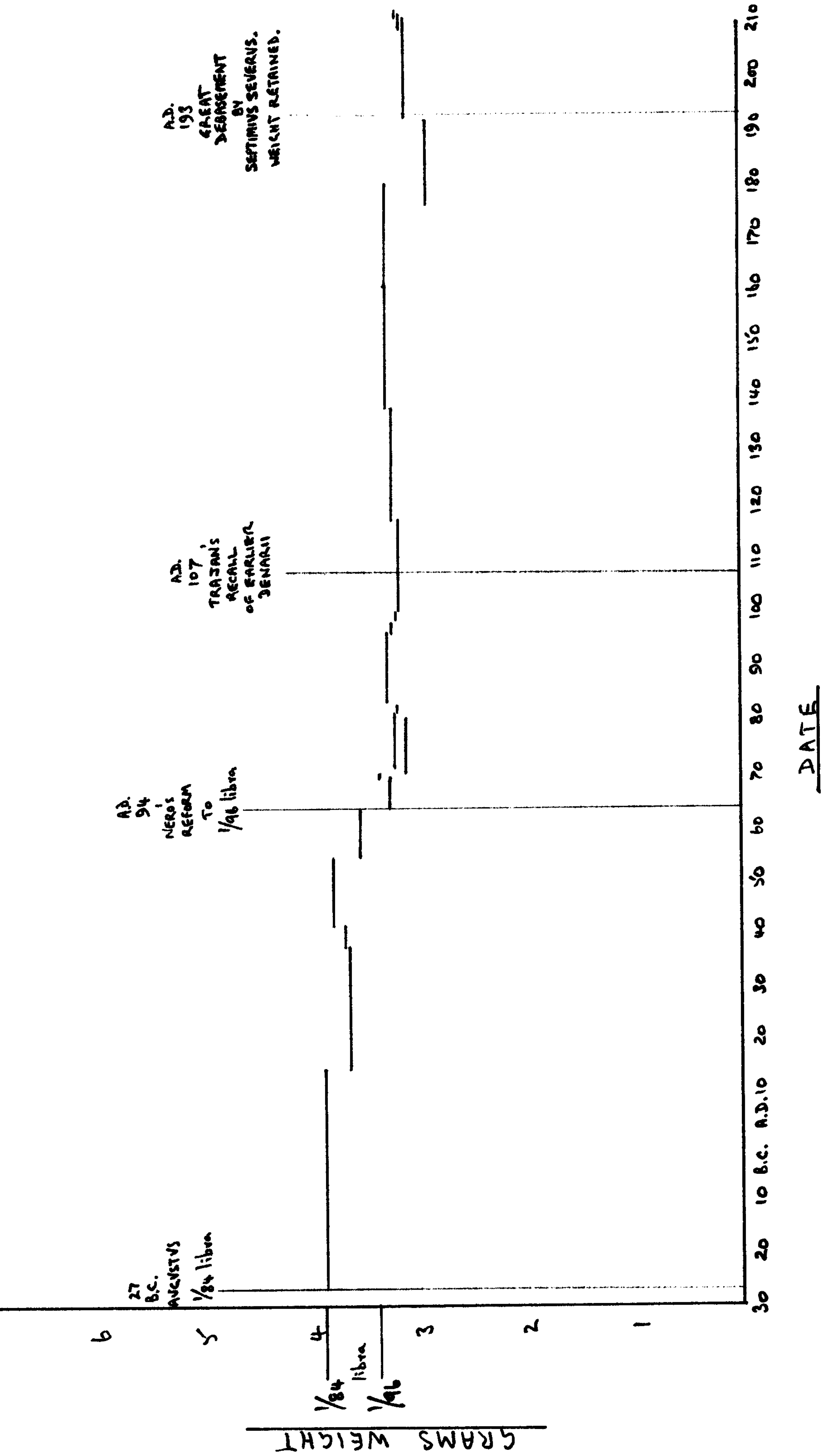
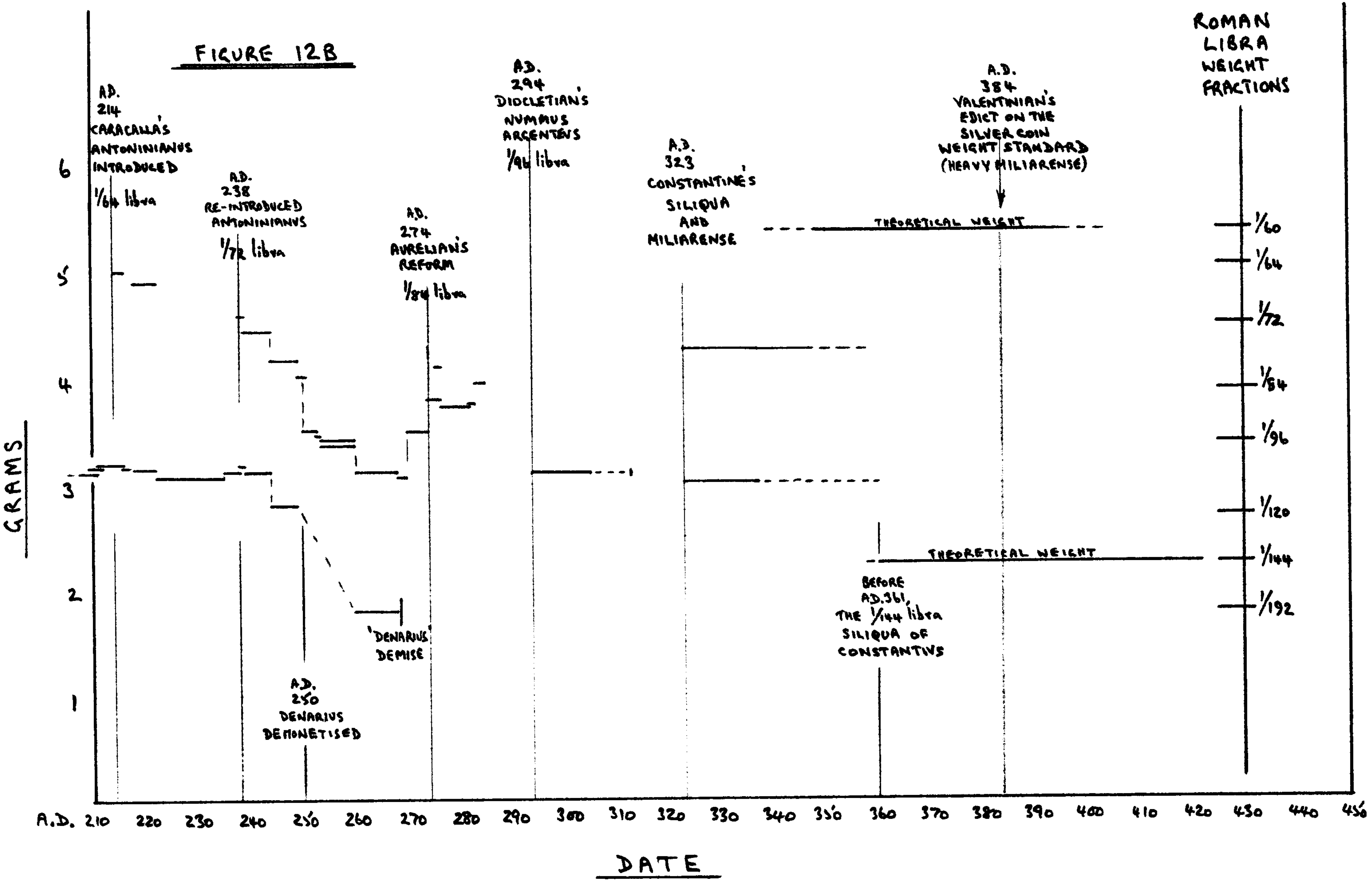


FIGURE 12B


A.D. 214 CARACALLA'S ANTONINIANUS INTRODUCED 1/64 libra
A.D. 238 RE-INTRODUCED ANTONINIANUS 1/72 libra
A.D. 274 AURELIAN'S REFORM 1/84 libra
A.D. 294 DIOCLETIAN'S NUMMUS ARGENTEUS 1/96 libra
A.D. 323 CONSTANTINE'S SILIQUA AND MILIARENSE
A.D. 384 VALENTINIAN'S EDICT ON THE SILVER COIN WEIGHT STANDARD (HEAVY MILIARENSE)
ROMAN LIBRA WEIGHT FRACTIONS
THEORETICAL WEIGHT
THEORETICAL WEIGHT
1/60
1/64
1/72
1/84
1/96
1/120
1/144
1/192
'DENARIUS' DEMISE
A.D. 250 DENARIUS DEMONETISED
BEFORE A.D.361, THE 1/144 libra SILIQUA OF CONSTANTIUS
GRAMS
6
5
4
3
2
1
A.D. 210
220
230
240
250
260
270
280
290
300
310
320
330
340
350
360
370
380
390
400
410
420
430
440
450
DATE

individually or in small batches. This control appears to have varied in subsequent reigns, but not so much as to indicate any positive change in weight standard before AD 63.

Nero's introduction of a debased silver, however, would have complicated weight control by virtue of small oxidation losses of copper in the melting, hot coining, and (now necessary) blanching operations. Nevertheless, Nero and his immediate successors appear to have kept to a fairly consistent 1/96 libra denarius weight standard. The average weight, however, never exceeds the theoretical one - which points to little or no compensation being made for alloying losses. In any case these might have become unnecessary as experience in the melting and minting practices with debased alloys improved, for slightly better weights are recorded for the mid second-century denarii despite further small debasements with alloy before AD 180.

With the great debasement by Septimius Severus, in AD 193, however, the coinage alloy came very close to the Ag-Cu eutectic composition(227). Although easier to cast, this alloy would have been much more prone to oxidation than the earlier materials by virtue of its much higher proportion of copper. The average coin weights reflect this, for the still extant 1/96 libra nominal standard was not so nearly achieved between AD 193 and 244 as it was between AD 64 and 180, and these two families of denarii can be distinguished in Figures 12A and 12B. Since the same alloy fineness was used for both the contemporaneous denarii and antoniniani(228) after AD 214, however, the more substantial weight differences of 1⅓ to 1 between the initial antoniniani (of 1/64 libra) and the ones re-introduced in AD 238 (at 1/72 libra) can be accepted as due to deliberate policy - as can the reduction of the antoninianus to the standard weight of the earliest 1/96 denarii immediately after the demonetisation of the true denarius in AD 250. Those 'denarii' which were minted rarely between AD 250 and 294 might, perhaps, be better regarded as half-antoniniani - corresponding to whatever denominational value the antoninianus held at the time. The intrinsic worths would have permitted the antoniniani to have been issued at l½d. - but no less - in AD 214, and at l½d. with a good margin of state profit (nearly 11%) in AD 238. If issued as 2d. pieces on either or both occasions the gains to the imperial treasury would have been considerable, and there would have been a powerful incentive for denarii to disappear into hoards from AD 238 onwards, while the authorities would have made every endeavour to recover them. It is surprising that it then took 12 years for the demonetisation of the denarius; but this could be explained by the desire of the emperors to recover in taxes as many as possible, at their nominal value, before the completion of a transition to an antoninianus coinage.

All the post-Neronian reformed silver coins contain copper - apparently added in its refined form - as the principal base-metal alloy, in proportions of between 3.81% and 76.96%, according to their date of issue, down to AD 260. No earlier issues have been acquired to check the possibility that experiments with a slightly debased coinage were made earlier in the first century AD, so this remains to be investigated.

Tin is not to be found in other than traces in the silver coinage of this era, which points clearly to the fact that earlier recovered bronze coins were never used for alloying. Iron, though ubiquitous, occurs as a marginal impurity at levels between 0.005% and 0.054%; and cobalt varies from nil to 0.014%. The presence of nickel can be attributed to that of copper, for it varies from 0.002% in the least debased alloys to 0.06% in those in which copper is most abundant. Surprisingly, zinc ranged from nil to 1.65% in the coins of this series. Since zinc is readily volatilised and oxidised during cupellation it is likely that it entered the coinage alloys in association with the less pure coppers which were produced in the third century and were used for alloying with refined silvers which contained such small proportions of lead that a lead-zinc association can be discounted.

An interesting technical feature of the early Imperial silver coinage is the degree of refinement which is indicated by the residual lead proportions. Some of this could, of course, have been re-introduced by way of impurity in the alloying copper, but this would have been unlikely much before the end of the first century AD when the purer oxide ores of copper were being exploited almost exclusively and the proportions of copper in the silver alloys were small. The distribution of the residual lead contents in the 23 early Imperial coinage analyses reported by the author in 1972(229) are shown in Figure 13, which depicts the practical level of Roman silver refinement by cupellation. The best quality is slightly less than that which Dr Elam(230) discerned for the Greek silver coinage of 500-300 BC, and certainly below that which the Romans themselves could have attained. But here we see the degree of their normal achievements in silver refining. In two exceptional cases the refinement was poor; and in one of these the silver with 6.08% residual lead had been treated as fully

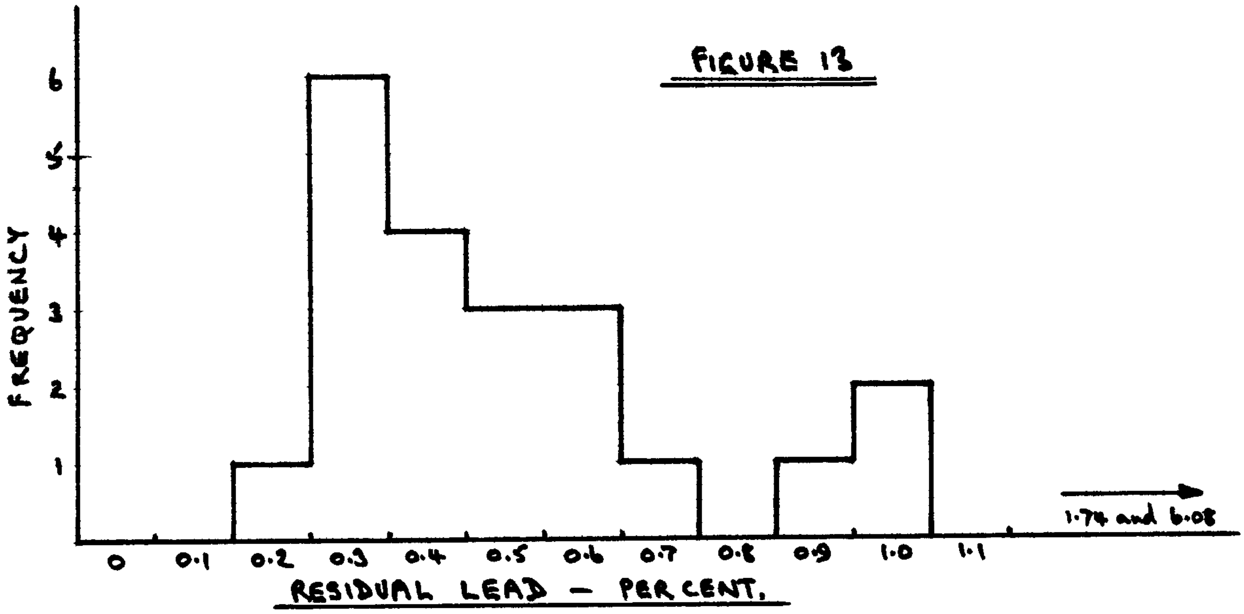


FIGURE 13

refined bullion for the purpose of blending the 5 unciae per libra standard alloy fineness(231) then in vogue. These findings would seem to contradict O Davies'(232) remark, based on W Gowland's(233) data, that the Greeks cupelled less perfectly than the Romans; but Davies was really commenting on the efficiency with which the Romans could extract silver from lead (down to less than 0.01%) and not about their ability to refine the extracted silver.

Ancient silvers are always found to contain small yet variable proportions of gold, and the Roman silver coinage is no exception. In the processes of coinage recovery, refining, and re-minting the gold:silver ratios would have tended to increase very slightly due to the greater volatility of molten silver, which is shown in Figure 6; and to have a trend towards a common value, due to casual blending. The later appearances of small gold:silver ratios, after a period of stability at a relatively high level, and also wide variations within short periods of time, are indicative of new sources of silver being introduced into the bullion pool for minting, because the other alloys added were generally gold-free, or nearly so. For this era the author has determined gold ratios of between 0.24 and 7.33 parts per thousand parts of silver. Trajan's Dacian conquests apparently brought the introduction of new sources of less auriferous silver than currently circulated in the earlier Empire; and even lower auriferous silvers – perhaps virgin materials from new sources - appeared particularly in the reigns of Hadrian and Antoninus Pius. The sporadic nature of these incidences of both high and low Au/Ag ratios reflects the considerable movement of silver of different origins about the Empire in the forms of both bullion and coin, and is indicative of a constant search for new silver mineral resources in addition to the more obvious acquisitions of silver as booty during military campaigns.

Attempts have been made to investigate more fully the substance of the Neronian reform of AD 64, which was fundamental to the pattern of debasements which occurred over the next two centuries. The accurate analyses of two seemingly identical denarii, however, reveal not only an initial and identifiable debased standard close to that suggested by the earliest published assays, but a previously unknown greater debasement of 3 unciae of alloy to the libra of silver for presumably later issues of the same VESTA (hexa-style temple) type of denarius, RIC 58, minted between AD 64 and 68, as follows:

	Silver	Gold	Copper	Lead	Iron	Nickel	Au/1000 Ag ratio
Ca.37	91.21%	0.59%	7.17%	0.98%	0.05%	0.01%	6.5
A.9	81.78%	0.28%	16.59%	0.78%	0.04%	n.d.	3.4

Nero's successors seem to have raised their fineness standards above Nero's, because two of Vespasian's coins have assayed 95.20 and 94.50% silver and four others minted before AD 117, and three issued before AD 138, are superior to the lower Neronian alloy standard(234). A repeated pattern (visible in Figure 11) is one in which each succeeding Emperor apparently commenced his reign with the highest of the debased fineness standards which he could afford - and significantly equivalent to Nero's first debasement – until economic necessity prevented him from maintaining it. All of the downward steps appear then to have been consistent with additional units of 1 uncia of alloy to each libra of silver, until a 5 unciae copper addition was the lowest one reached before the great debasement of Septimius Severus, in AD 193, brought the standard down to 15 unciae of alloy to the silver libra and created a new series of Imperial 'silver' coinage alloys which, from that date until c. AD 294, were predominately base metal.

The policy changes which are now apparent from the metallic contents of the coinage of this era are summarised in Table III.

b) The silver coinage of the sole reign of Gallienus, AD 260-268

When L C West(235) summarised the finenesses of the Roman Imperial

TABLE III

The Early Roman Imperial Silver Coinage 27 BC to AD 260

Principal silver coinage policy changes for which the metallic contents provide evidence

Event	Date BC or AD	Authority	Remarks
1. Augustus issued Imperial denarii in silver of above 990 parts per mille fine.	27 BC	J Hammer's survey of assays (Ref 2)	Superior, in fineness, to the average Republican denarii, and much superior to the 'legionary' issues of Mark Antony.
2a. Denarii reduced in weight by Nero, to 1/96th libra, and their fineness to ~ 940 parts per mille by the deliberate addition of alloy.	64	“	Evidence for fineness limited to three assays only; these were performed in the early 19th century, and are a somewhat doubtful accuracy.
b. Nero's first debased silver alloy standard identified as having 1 uncia of copper per libra of silver.	64	The author: this work	Denarius, VESTA, RIC 58; Code No Ca.37.
c. The discovery of the lowest known Neronian silver standard, equivalent to 2 unciae of alloy per libra of silver.	64-68	The author: this work	Denarius, VESTA, RIC 58; Code No A.9
3. The quality of the denarii fell, under Vespasian, to as low as 800 parts per mille.	69/79	J Hammer (Ref 2)	Similar evidence to Item 2 above.
4. Vespasian revealed to have first issued denarii of higher quality than Nero's reduced standard, and to have adopted two lower alloy standards later in his reign.	69/79	The author (Ref 53)	The present work establishes the existence of previously unknown finer pieces, and one other (lower) standard which matches some of the assays listed by Hammer.
5. Domitian said to have improved the standards used in his reign, following a steady decline since Nero.	81/91	Various; but all based on Hammer's survey.	Deductions previously based on slender evidence, and without any reliable assays of the coinage issues of Nero-Domitian
6. Trajan now known to have issued higher quality denarii at the beginning of his reign	c. 98	The author (Ref 53)	Earlier assays vaguely indicated this, but there are uncertainties concerning the dates of the particular issues and the types involved.
7a. Trajan called in the intrinsically superior (heavier and finer) Republican denarii.	c. 107	Various	The advantage to the Roman Treasury now calculable - in the light of 7b below.

/Contd

7b. Trajan issued baser denarii of lower weight.	107-117	Various	The author (in Ref 53) shows the different alloys to have contained 2,3 and 4 unciae of alloy to each libra of silver.
8a. Hadrian issued some early denarii matching the fineness of Trajan's best.	c.117	This work.	The standard was not inferior to Nero's first debased alloy, (one uncia per libra). Early issues for Sabina are confirmed.
8b. Hadrian adopted a lower standard later in his reign.	c.132	This work.	Standard identified as 3 unciae of alloy per libra of silver.
9. Drastic debasement of the denarius alloy by Septimius Severus. A suspected reform for which there is no remaining literary evidence.	193/4	J Guey reported statistically significant corrected assays. In this work they are interpreted in practical metallurgical terms.	Denarius alloy reduced from a norm of 706‰ fine, to 444‰ fine. Debasement represents a change from 5 to 15 unciae of alloy per libra bar of silver.
10a. Caracalla introduced the antoninianus, at 1½ times the weight of the denarius. (Possibly a 1½d piece at this time).	214	Various; and weights of the coinage pieces themselves.	Previous work by the author (Ref 53) shows Caracalla's antoniniani (and those of his successor, Elagabalus) to have been made in the same 444‰ fine silver as the contemporaneous denarii.
10b. Silver-copper coinage alloys of the antoniniani and the denarii were of similar high purity.	214 to post-238	The author (Ref 53).	Identical binary silver-copper alloys used for both denominations.
11. The demonetisation of the denarius; followed by its demise c.268.	c.250	Various.	Intrinsic worths of the debased and weight-reduced antoniniani now much inferior to those of earlier denarii.
12. Small proportions of tin (up to 2.74%) added to the debased silver alloys issued by: Trajan Decius; Trebonianus Gallus; and Valerian.	 249-251 251-254 254-260.	E R Caley and H D McBride (Ref 185); and the author (Ref 53).	Possibly the beginnings of the argentiferous bronze coinage alloys.

silver coinage, in 1941, he divided the eighteen known assays of the antoniniani of Gallienus into four which averaged 50.9% silver and fourteen which he described as "poor" - with an average of 6.4% silver. Not until the appearance of P Le Gentilhomme's(236) simple assays in 1962, however, did the exceeding complexity and metallurgical fascination of the elaborate series of issues of the sole reign of Gallienus become apparent. The low quality and poor execution of many of the pieces has, indeed, hitherto detracted both scientists and numismatists from their more detailed study; and the tendency then to seek only the silver content has, until now, prevented the discovery of an unprecedented pattern of silver alloy developments, an important mid-reign coinage reform, and a revised sequence for the issues from the mint of Rome.

The problem with the Gallienic issues of the sole reign has been mainly that of determining the numerous fineness standards used during a series of precipitate changes with small coins, many of which were poorly fabricated in the first place and have since suffered from deep corrosion effects. The interpretation of the results has then been complicated by the previously inexplicable feature (revealed by the graphical display of P Le Gentilhomme's results which the author(237) made in 1967) of seemingly parallel issues, from all the mints, with upper and lower silver standards. In other words, there are coins which bear the same classification number in the numismatic works of reference which have quite different finenesses. Superficially this gives the impression of different contemporaneous standards being operated, and P Tyler(238) has recently stretched this evidence to suggest that different contemporaneous standards were in operation for coins intended for use in different parts of the Empire. Apart from the economic inviability of such a scheme at that time the metallurgical evidence for chronological transitions in alloy types now endorses the author's previous view(239) that some of the seemingly identical issues might be repeat issues of later date and lower fineness bearing titulatures and mint markings which once belonged to earlier issues of higher-fineness standards. On this basis the Riby hoard(240) can be judged to consist of coins mainly minted at Rome some short time later than the majority of those found in the Gibraltar Hoard(241); and it then becomes quite unnecessary to use the specious argument that they were intended for use in different postulated economic zones of the same Empire.

Otto Voetter's(242) classification of the antoniniani of Gallienus has remained virtually unchallenged since 1900. In the 1950's R Göbl(243) proposed some elaborations; but the essential simplicity of the division of the issues of the principal mint of Rome into seven successive substantive issues, in accordance with the coin arrangements of both Voetter and Göbl, was not generally appreciated until summarised by R A G Carson(244) in 1961.

There is still no doubt that the initial issues of the sole reign were from the six Latin-numbered officinae which had commenced operation in the joint reign of Valerian and Gallienus, or that the later issues were minted by the Greek-numbered officinae of increased number and expanded output; but there has been some recent uneasiness about the issue sequences within these groups following detailed studies of two major hoards. R H M Dolley and Miss M A O'Donovan(245), and H D Gallwey(246), found it difficult to reconcile the statistical distributions of the different coin types in the Beachy Head and Gibraltar hoards, respectively, with the expected mode of operation of the officinae and their apparent outputs. In consequence Dolley and O'Donovan have suggested that Voetter's "fifth" and "sixth" issues should really be combined into a "quinisext" group to match the most probable course of minting - and in so doing they have sown the seeds of at least one revision which can now be shown to be necessary on the basis of metallurgical evidence.

No certain reason for the change from Latin to Greek numbering in the middle of the sole reign of Gallienus has ever been proposed; but it can now be shown to coincide with a previously unknown coinage reform which Gallienus apparently sought to make obvious, first with issues of new (and more hopeful) reverse types without mint-mark, and then by the re-numbering of the officinae which produced them.

In a recent review of the use of analyses of mid-third-century Roman antoniniani as historical evidence, P Tyler(247) remarked that "any consistent variation in the alloy standards employed .... is historically significant even to within a limit of 1 per cent by weight or less so far as the silver is concerned"; but, while admitting the likelihood of the Roman moneyers being able to control their alloy standards to this level (approximately equivalent to 3 scrupula of silver per libra of alloy), he is altogether too pessimistic about the possibilities of determining such differences because of the present poor condition and complicated metallurgical structures of most of the available coins. Nevertheless, his own published assays do indicate the feasibility, and show that his opinion "that the extent of overlap in the silver content amongst each group tabulated .... and between each group represented, is greater than the combined effects of differential leaching and experimental error would lead us to expect" is far from justified except perhaps in extreme cases of the most unsuitable analytical samples poorly assayed.

If we assume that Gallienus instructed his moneyers to work to fineness standards stepped as little as 3 scrupula per libra apart - and this was almost certainly the case towards the close of the reign - it would have been most unlikely that their inaccuracies in weighing the bullion for such dilute alloys would have amounted to as much as plus or minus one scrupulum. Even if they had been this lax, then two adjacent standards of 3 and 6 scrupula per libra would have been made up in the ranges of 2-4 and 5-7 scrupula per libra; this would still have left a 1 scrupulum gap (equivalent to a silver difference of 0.35%) between the two alloy populations - allowing quite easy separation by modern methods of assay. The actual fineness ranges employed can, indeed, be judged from the substantial number of published and new assays spread over the range of coinage issues; and they become apparent when their cumulative frequency is plotted in order of determined fineness - as does the spacing between them.

In Figure 14 the finenesses of the Gallienic antoniniani of the sole reign (according to Le Gentilhomme) are arranged in descending order, separately for the coins from the Latin- and Greek-numbered officinae. Allowing for the probable enrichment of some of Le Gentilhomme's samples in silver by the corrosion losses of base metal and the effects of any unremoved surface silvering, it is visibly evident that the fineness standards descended in 6 scrupula intervals from a 2 unciae (48 scrupula) standard right down to 6 scrupula per libra before the cessation of the minting of the Latin-officinae types. Then a mid-reign reform - involving the issue of unmarked Greek-officinae types which were later numbered - restored a 30 scrupula per libra alloy standard which descended again, step-wise, to a final 6 scrupula standard. The same trends are revealed, with somewhat sharper precision, by the author's new assays of carefully prepared samples plotted in the same manner in Figure 15. In consequence embryonic new sequences for the issues in both series can be constructed to replace those due to Voetter and Göbl, and this is detailed - in so far as it is possible with the limited number of available coin assays, separately, in Tables IV and V, for the Latin-numbered and Greek-numbered series, respectively. The detailed coin analyses are

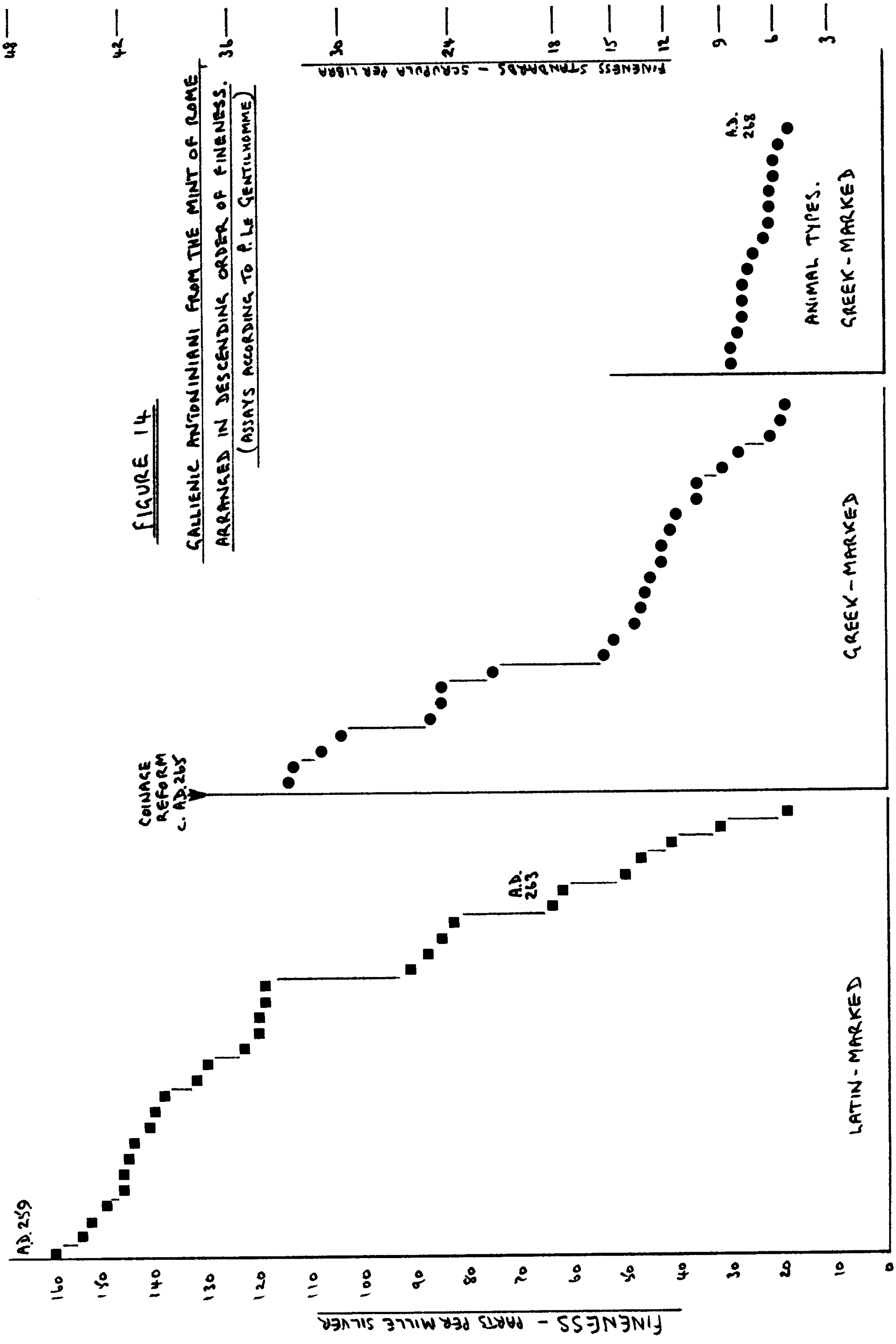


FIGURE 14

GALLIENIC ANTONINIANI FROM THE MINT OF ROME ARRANGED IN DESCENDING ORDER OF FINENESS. (ASSAYS ACCORDING TO P. LE GENTILHOMME)

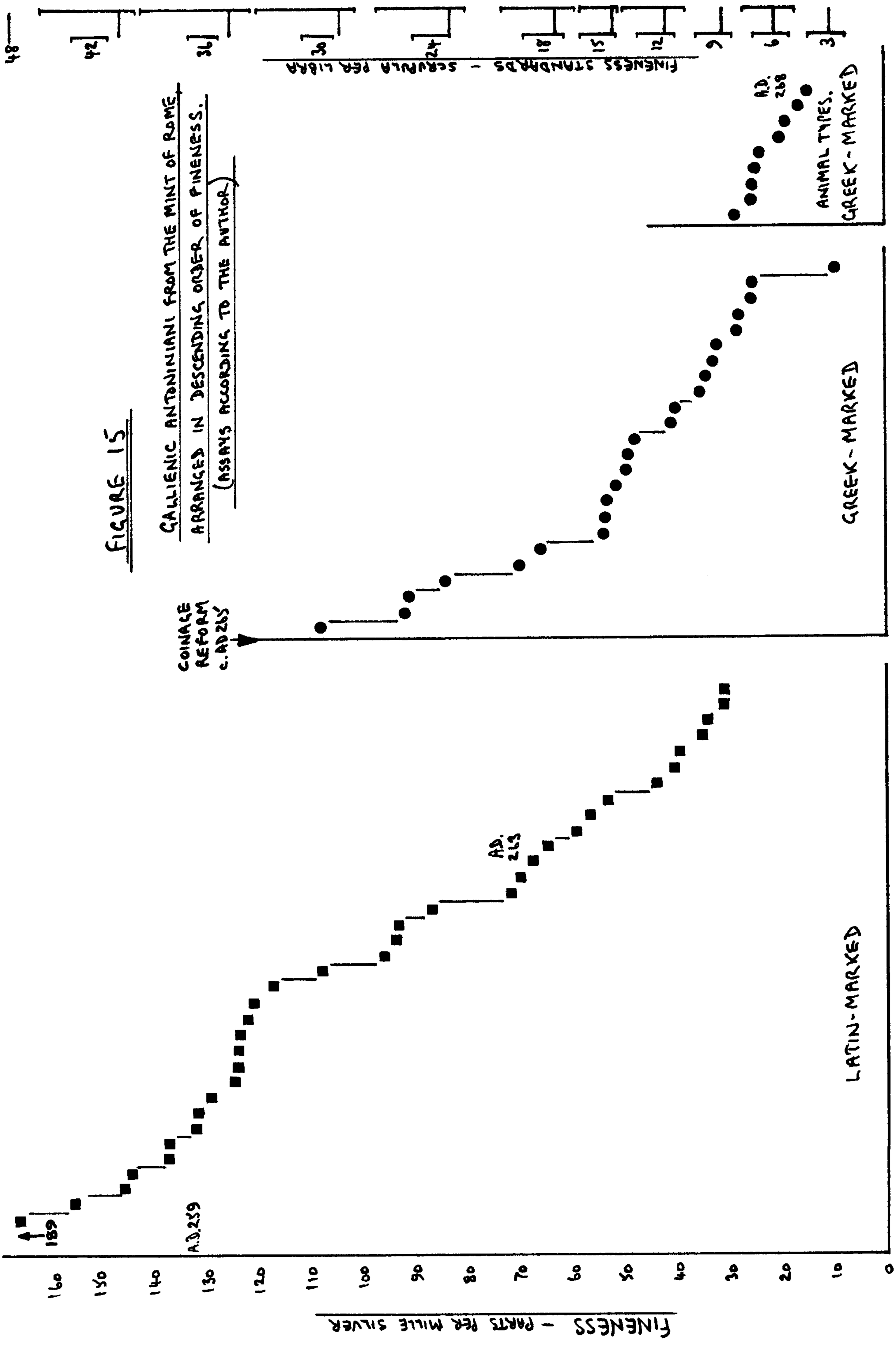


FIGURE 15

GALLIENIC ANTONINIANI FROM THE MINT OF ROME ARRANGED IN DESCENDING ORDER OF FINENESS.
(ASSAYS ACCORDING TO THE AUTHOR)

TABLE IV

GALLIENUS - SOLE-REIGN

Apparent sequence of issues of antoniniani from the Latin-numbered officinae

Officina	FINENESS STANDARD - SCRUPULA OF SILVER PER LIBRA										
	48	42	36	30	24	18	15	12	9	6	3 ?
	163-187 ppm	142-164 ppm	In Operation Dec 261 122-141 ppm	101-119 ppm	80-96 ppm	In Operation by Autumn 263 59-73 ppm	50-61 ppm	38-50 ppm	28-38 ppm	17-26 ppm	7-15 ppm
P		VIRTVS AVG (153) CONCORD AET (145)	VIRTVS AVG 124 INDVLGENT AVG (130)	VIRTVS AVG (120)	PIETAS AVG (83)					PROVID AVG (25)	
S		IOVI VLTORI (153,165) LIBERAL AVG (148,151, 148)	IOVI VLTORI 137 (141) LIBERAL AVG (120,123,127 128,140) LIBERT AVG 122 FORTVNA REDVX 121,132	IOVI VLTORI (101,112, 119) LIBERAL AVG (111) FORTVNA REDVX (120)	IOVI VLTORI 96,93 (80) FORTVNA REDVX (91)	IOVI VLTORI 65,72 (60, 64,70)	IOVI VLTORI (57) AEQVIT AVG (57)	IOVI VLTORI LIBERAL AVG 40,44 (40, 43,48)	PIETAS AVG 31		
T	PAX AVG (168)	PAX AVG 165,144 (143,155) VICTORIA AVG III (143,144, 149)	PAX AVG 124 FELICIT PVBL (132) VICTORIA AVG III (127,135)	VICTORIA AVG III (120)	VICTORIA AVG III (86)	PAX AVG (60,65,68) VICTORIA AVG III (76) SALVS AVG (64)	PAX AVG (52) VICTORIA AVG III (56)	PAX AVG 40 (42,47,50)	PAX AVG 29,31 (36) FELICIT PVBL(32)		PAX AVG (13)

Assay figures in parentheses are those obtained by P Le Gentilhomme; the plain figures are the author's assays.

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Q	VESTA 189 PVDICITIA (195)	VESTA (144) PVDICITIA (149)	VESTA 137	PVDICITIA 117				ANNONA AVG (50)	ANNONA AVG (34)	PVDICITIA (19)	
V	PAX AVG (199,159)	PAX AVG (152) LAETITIA AVG (144,144, 148,157, 163,163)	PAX AVG (137,139,140) ANNONA AVG 124	PAX AVG (111,120) PAX PVBLICA (119)	PAX AVG 87,94 (82,87,97) GENIVS AVG 94 (88) LAETITIA AVG (90)	PAX AVG 59,68,70 LAETITIA AVG (67,76)	LAETITIA AVG 53	LAETITIA AVG (39,41,46)	PAX PVBLICA 35 LAETITIA AVG 34 (35)	PAX AVG (19)	
VI		AEQVITAS AVG 145 (142,144, 148,150) PVDICITIA 155 VIRTVS AVG (142,147, 150)	PVDICITIA 125 (123) VIRTVS AVG (120,122)	VENUS GENETRIX 108 SECVRIT ORBIS (119)	AEQVITAS AVG (90) VENUS GENETRIX (85)	VIRTVS AVG (62,64,65, 77)	AEQVITAS AVG (55) VIRTVS AVG (52,53)	VIRTVS AVG (44,45) SECVRIT AVG (39)	AEQVITAS AVG (33,36)		
Unmarked		LIBERAL AVG (150) PAX AVG (146)	ANNONA AVG 129 (141) FELICIT PVBL (130) PM TRP X COS IIII PP (128)	PAX PVBLICA (102)		IOVI VLTORI (69) VENVS GENETRIX (69) AEQVITAS AVG (64) VOTIS DECENNALIB (61)	ANNONA AVG (57)		LIBERT AVG (35)		

Assay figures in parentheses are those obtained by P Le Gentilhomme; the plain figures are the author's assays.

TABLE V

Apparent Sequence of Issues of Antoniniani From the Greek-Numbered Officinae

FINENESS STANDARD - SCRUPULA OF SILVER PER LIBRA

Officina	30 101-119 ppm	24 80-96 ppm	18 59-73 ppm	12 38-50 ppm	9 28-38 ppm	6 17-26 ppm	3 7-15 ppm	6 Animal Types	3?
								17-26 ppm	7-15 ppm
A	Marti Pacifero (113) unmarked		Marti Pacifero 54			Marti Pacifero (19)		Soli Cons Aug 18 (22)	
B	Abundantia Aug (114) unmarked		Abundantia Aug 70		Abundantia Aug (36)		Abundantia Aug (10)	Libero P Cons Aug (29)	Libero Cons Aug 15
Γ	Aeternitas Aug (108) unmarked		Aeternitas Aug 54 (54)					Dianae Cons Aug 19,26 (21)	
Δ			Fecunditas Aug 54 (53)	Pax Aug (45) Fecunditas Aug (40,43,45) Pax Aetern (43,43)	Pax Aeterna 31 (34,36,36) (36,29,31,32) (32)	Pax Aeterna (26)		Apollini Cons Aug (28)	
ε			Uberitas Aug (54,55,59,59, 59,61,65)	Uberitas Aug (43,48,50)	Uberitas Aug 32 (31)	Uberitas Aug (22,25)	Uberitas Aug (13,16)	Herculi Cons Aug 25 (21) Dianae Cons Aug (25)	
ζ	Iovis Stator 108 (104) unmarked	Iovis Stator 92 Fortuna Redux 84	Fortuna Redux (75)	Fortuna Redux 49 (40 42,45, 46)	Fortuna Redux 28,33 (37)			Neptuno Cons Aug (29) Iovi Cons Aug (22,25,25)	

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Z		Oriens Aug (85,87)		Oriens Aug (52,54,55,56) Victoria Aet 48	Oriens Aug (37,38) Victoria Aet 34	Oriens Aug (22,23,27,27)	Oriens Aug (10)	Apollini Cons Aug 20,24 (23)	
H	Securit Perpet (112) unmarked	Securit Perpet (87)		Securit Perpet 51				Apollini Cons Aug (18)	
N		Fides Militum (85) Iuno Conservat (89)	Fides Militum (53,54)	Fides Militum 41 (42,46,47, 47,48,49,49, 50,52,53) Iovi Conservat (40,44,45)		Iovi Conservat (25,31,32) Iuno Conservat 26		Neptuno Cons Aug 25 (20,22)	Neptuno Cons Aug 13
X				Provident Aug (46) Provid Aug 41 (42,46)		Virtus Augusti (20)	Virtus Augusti (15)	Dianae Cons Aug 29 (20,22)	
XI			Indulgentia Aug 66	Indulgentia Aug 49,50 (47) Iovi Propugnat (38,39,39,39, 42,46,47)	Libertas Aug (28)	Libertas Aug (22) Iovi Propugnat (20,22)		Dianae Cons Aug 29 (27) Soli Cons Aug (27)	
XII								Dianae Cons Aug 17,28 (25,27)	
Unmarked	see above	Iovis Stator 91 Uberitas Aug (91) Fides Militum (89)				Iovi Propugnat 26			

Assay figures in parentheses are those obtained by P Le Gentilhomme and P Tyler; the plain figures are the author's assays.

TABLE VI

Chemical analyses of antoniniani minted at Rome in the Latin-numbered officinae during the sole reign of Gallienus, Autumn AD 259 to early 265

Code No	Reverse type	RIC No	Alloy Composition - Weight Per Cent					
			Copper	Silver	Tin	Lead	Iron	Nickel
Officina P								
HDG1	Virtus Aug	317	-	12.40	2.92	0.74	0.05	0.03
Officina S								
HDG4	Iovi Ultori	221K	81.83	13.72	0.38	0.88	0.10	0.10
HDG18	Fortuna Redux (seated)	194a	-	13.21	4.35	2.05	0.05	0.03
BM160	Iovi Ultori	221	83.70	13.15	2.30	0.62	0.06	0.03
BM161	Libert Aug	232	83.74	12.20	2.52	1.59	0.04	0.05
HDG19	Fortuna Redux (seated)	194a	85.99	12.12	1.93	1.95	0.30	0.24
BM156	Iovi Ultori	220	86.85	9.58	2.50	0.84	0.02	0.03
HDG2	Iovi Ultori	221	80.61	9.31	3.78	1.19	0.06	0.04
BM159	Iovi Ultori	221	86.95	7.21	4.70	0.85	0.02	0.03
HDG3	Iovi Ultori	221	85.59	6.45	3.38	1.35	0.10	0.04
Ca75	Aequit Aug	159	92.37	5.76	0.26	2.53	0.13	0.05
MAZ32	Liberal Aug	227	89.93	4.40	2.92	0.49	0.06	0.06
B155	Liberal Aug	227	88.22	4.04	6.50	0.80	0.12	-
Ca76	Pietas Aug	507	88.56	3.10	0.31	2.88	0.16	0.05
Officina T								
MAZ33	Pax Aug	256	74.68	16.53	4.36	2.36	0.08	0.08
LS4	Pax Aug	256	-	14.40	3.44	1.21	0.08	-
HDG6	Pax Aug	256F	80.69	12.37	2.44	1.86	0.10	0.04
BM166	Pax Aug	256	-	3.96	5.50	0.33	0.04	0.05
HDG5	Pax Aug	256	-	3.11	2.75	0.39	0.03	0.03
Officina Q								
HDG20	Vesta (seated)	32	79.90	18.91	1.07	1.26	0.28	0.09
HDG21	Vesta (seated)	32	-	13.74	2.50	0.80	0.08	0.05
HDG22	Pudicitia (seated)	25	84.85	11.68	2.05	1.35	0.06	0.05
Officina V								
BM163	Annona Aug	161	82.50	12.37	2.29	2.73	0.03	0.04
HDG8	Pax Aug	256K	85.61	9.39	1.50	1.06	0.10	0.08
HDG9	Pax Aug	256F	-	8.71	1.89	2.38	0.04	0.04
BM162	Pax Aug	256	90.05	6.98	2.19	0.56	0.04	0.05
HDG7	Pax Aug	256K	-	6.75	3.44	0.46	0.07	0.04
BM157	Pax Aug	255	90.47	5.90	2.46	0.85	0.07	0.06
BM165	Laetitia Aug	226	92.40	5.35	1.68	0.50	0.05	0.06
HDG23	Pax Publica (seated)	260	89.10	3.56	4.24	3.30	0.01	0.03
BM164	Laetitia Aug	226	90.70	3.41	5.45	0.28	0.03	0.02
Officina VI								
HDG24	Pudicitia (seated)	25	-	15.49	1.72	0.73	0.04	0.06
HDG15	Aequitas Aug	159	81.15	14.52	1.86	2.16	0.23	0.06
HDG25	Pudicitia (seated)	25	84.40	12.49	2.29	0.60	0.08	0.04
BM158	Venus Genetrix	30	87.60	10.79	0.86	0.42	0.06	0.06
Unmarked issues								
HDG16	Annona Aug	161	-	12.88	3.26	2.39	0.03	0.02

TABLE VII

Chemical analyses of antoniniani minted at Rome in the Greek-numbered officinae during the sole reign of Gallienus, early 265 to c. Sept 268

Code No	Reverse type	RIC No	Alloy Composition - Weight Per Cent					
			Copper	Silver	Tin	Lead	Iron	Nickel
Officina A								
Ca47	Marti Pacifero	236	-	5.41	4.64	0.33	0.03	0.04
A16	Soli Cons Aug (Pegasus)	283	88.52	1.75	6.53	3.01	0.13	0.06
Officina B								
HDG26	Abundantia Aug	157	87.60	7.02	3.81	1.63	0.01	0.02
MAZ34	Abundantia Aug	157	89.34	0.96	8.55	1.71	0.12	0.07
BM403	Libero P Cons Aug	250	87.94	1.48	4.78	2.81	0.08	0.06
Officina Γ								
Ca48	Aeternitas Aug	160	-	5.35	4.81	2.06	0.03	0.04
A17	Dianae Cons Aug	180K	86.75	2.64	8.07	3.10	0.15	0.06
W12	Dianae Cons Aug	178K	-	1.93	8.00	6.51	-	-
Officina Δ								
W8	Fecunditas Aug	5	84.42	7.92	5.39	2.37	0.01	0.03
BM404	Pax Aeterna	253	88.74	3.10	5.76	2.46	0.33	0.05
Officina ε								
BM406	Uberitas Aug	cf 287	88.82	3.23	6.98	2.49	0.30	0.05
BM407	Herculi Cons Aug	202	85.96	2.48	6.96	2.29	0.13	0.06
Officina ζ								
HDG32	Iovis Stator	216K	87.71	9.18	4.72	1.76	0.25	0.07
HDG28	Fortuna Redux	193K	88.39	8.40	4.62	1.40	0.16	0.06
HDG29	Fortuna Redux	193K	87.12	4.92	4.00	1.76	0.08	0.02
Ca21	Fortuna Redux	193	-	3.30	6.18	4.34	0.03	0.04
W7	Fortuna Redux	194a	87.17	2.80	6.73	1.67	0.01	0.04
Officina Z								
BM411	Victoria Aet	297	88.15	4.80	4.42	2.08	0.16	0.05
CJ01	Victoria Aet	297	-	3.43	6.70	1.90	0.03	0.05
B106	Apollini Cons Aug	163	87.74	2.39	7.20	2.23	0.03	0.02
LHC27	Apollini Cons Aug	163	-	2.01	7.04	4.96	0.04	0.04
Officina H								
BM412	Securit Perpet	280	87.48	5.11	5.86	2.78	0.16	0.06
Officina N								
HDG31	Fides Militum	192a	92.02	4.06	2.50	0.40	0.01	0.04
HDG35	Iuno Conservat	11	92.31	2.56	4.73	1.15	0.11	0.12
Ca20	Neptuno Cons Aug	245	-	2.53	7.22	2.54	0.04	0.04
Officina X								
HDG36	Provid Aug	287K	-	4.12	6.53	2.78	0.06	0.05
A19	Dianae Cons Aug	179	90.02	2.87	5.73	2.76	0.16	0.06
Officina XI								
HDG37	Indulgentia Aug	206K	82.42	6.63	5.66	1.52	0.06	0.04
HDG38	Indulgentia Aug	206K	-	4.96	7.56	0.58	0.06	0.06
A15	Indulgentia Aug	206	89.12	4.88	4.12	3.15	0.28	0.06
LHC26	Dianae Cons Aug	181	-	2.87	7.04	3.28	0.02	0.04

/Contd

Officina XII								
Ca80	Dianae Cons Aug	179	87.83	2.83	5.90	3.12	0.15	0.04
Ch8	Dianae Cons Aug	181	-	1.67	6.55	3.84	-	-
Unmarked issues								
HDG33	Iovis Stator	216K	-	10.78	2.75	0.32	0.06	0.06
HDG34	Iovis Stator	216K	85.04	9.12	2.38	1.54	0.04	0.02
B107	Iovi Propugnat	213	85.20	2.55	7.60	4.50	0.01	0.02
Ca78	Soli Cons Aug (Pegasus)	283	92.47	0.25	2.60	2.62	0.08	0.04

listed, similarly, in Tables VI and VII, according to individual officinae of origin, and for each officina they are placed in descending order of fineness so as to facilitate observations of their chronological changes in alloy composition. A few analyses of coins minted at Milan and Siscia during the sole reign are listed in Table VIII to show the different types of alloys in vogue throughout the empire during this period.

TABLE VIII

Chemical analyses of antoniniani minted at Milan and Siscia during the sole reign of Gallienus

Code No	Reverse type	RIC No	Alloy Composition - Weight Per Cent					
			Copper	Silver	Tin	Lead	Iron	Nickel
Mint of Milan								
U of S 7	Marti Pacifer	492	83.37	14.38	0.31	0.87	0.10	0.04
HDG17	Aequitas Aug	464	85.50	13.50	nd	0.52	0.02	0.04
H2	PM TRP VII COS	455	-	8.72	0.10	0.49	-	-
B156	Aetern Aug	465a	90.80	5.93	1.82	1.12	0.04	0.04
Ca77	Secur Tempo	513	81.10	5.73	1.84	1.84	0.14	0.04
Mint of Siscia								
HDG14	Pax Aug	575	87.25	8.69	3.00	0.90	0.01	0.02
Ca19	Salus Aug	581		0.25	9.28	1.92	0.15	0.04

The joint reign of Valerian and Gallienus had ended with the capture of Valerian, by the Persian, Shaphur, at Edessa, most probably in the autumn of AD 259. The last issues bearing the name of Valerian, from the mints of Rome, Milan, Samosate, and Antioch, all possess finenesses which can be identified as matching a contemporaneous standard of 2 unciae of silver per libra. This is shown by P Le Gentilhomme's(248) assays: the small proportions of other base alloying elements associated with copper at this time are revealed by the following analyses of coins of the joint reign:

TABLE IX

Chemical analyses of antoniniani of the joint reign of Valerian and Gallienus, AD 253-259

Code No	RIC No	Date AD	Mint	Composition - Weight Per Cent					
				Silver	Copper	Tin	Lead	Iron	Nickel
M1	87	c.253	Rome	17.60	78.46	3.14	0.89	0.05	0.05
Ls.2	112	254/5	Rome	16.25	80.79	2.52	0.70	0.03	0.03
Ca.45	124	254/9	Rome	15.96	79.02	1.46	0.39	0.06	0.06
Ca.46	cf 24	253/9	Cologne	13.59	-	present	-	-	-
M2	45	257/8	Cologne	18.38	79.11	0.83	1.14	0.09	0.02

The manner in which the coinage alloys were developed at the mint of Rome during the sole reign of Gallienus is illustrated in Figures 16 and 17, which depict the combined lead and tin variations, and then each of these in association with the fineness reductions for both the Latin and Greek series of issues. There are significant differences between the two series, yet a period of transition or back-stepping in preferred alloy compositions can also be identified.

Figure 16 reveals that the alloys fall into three main categories of argentiferous bronze - which might now be helpful in identifying the series to which any badly worn or unmarked coins may belong. The coins fall into the following metallurgical groups:

(i) alloys with up to 2½% tin and up to 3½% lead - issued almost entirely by the Latin officinae

(ii) alloys with 4½% to 8% tin and more than 1% lead - characteristic of those minted later by the Greek officinae

(iii) alloys with, in the middle phase of the reign, 2½ to 6½% tin and less than 2½% lead - which can be attributed to either series.

The main lines of demarcation enclosing the two main compositional zones which overlap are shown in Figure 16. The reason for the intermediate stage of overlapping in alloy compositions is more apparent from Figure 17 where lead and tin proportions are separately plotted against the decreasing proportions of silver. Coins alloys of the joint reign, and those minted by the Latin officinae during the early part of the sole reign are similar in their broad compositions; but with the progression of subsequent debasements, the tin content, although much scattered in selected level, is found to be generally increased, while the lead present shows a tendency to fall before it rises again for the most debased alloys. These trends provide the evidence for Roman minting experiments having been designed to explore the substitution of tin for some of the silver, perhaps with the object of whitening the much-debased alloys in compensation for the yellowing effects of simply reducing the proportions of silver.

We know now, in consequence of the work of E Gebhardt and G Petzow(249) on the phase equilibria of the silver-copper-tin alloy system, that such experiments would have been limited by the difficulties of working copper-silver-tin alloys containing greater proportions of tin, due to tin decreasing both the alpha and beta solid solution ranges and causing general hardening and stiffening of these structures against plastic deformation,

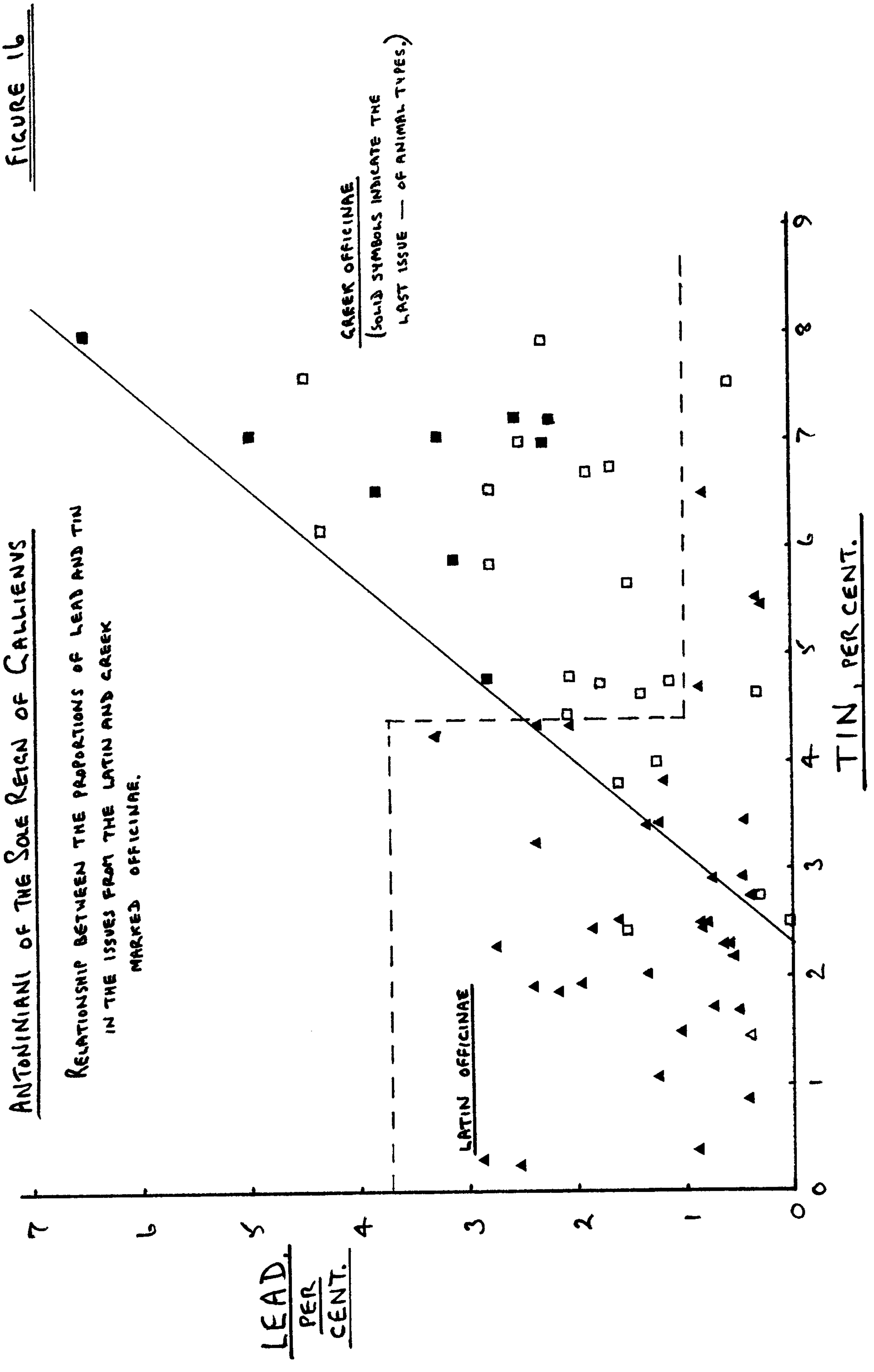


FIGURE 16

ANTONINIANI OF THE SOLE REIGN OF GALLIENUS

RELATIONSHIP BETWEEN THE PROPORTIONS OF LEAD AND TIN IN THE ISSUES FROM THE LATIN AND GREEK MARKED OFFICINAE.

FIGURE 17

ANTONINIANI OF THE SOLE REIGN OF GALLIENVS

KEY

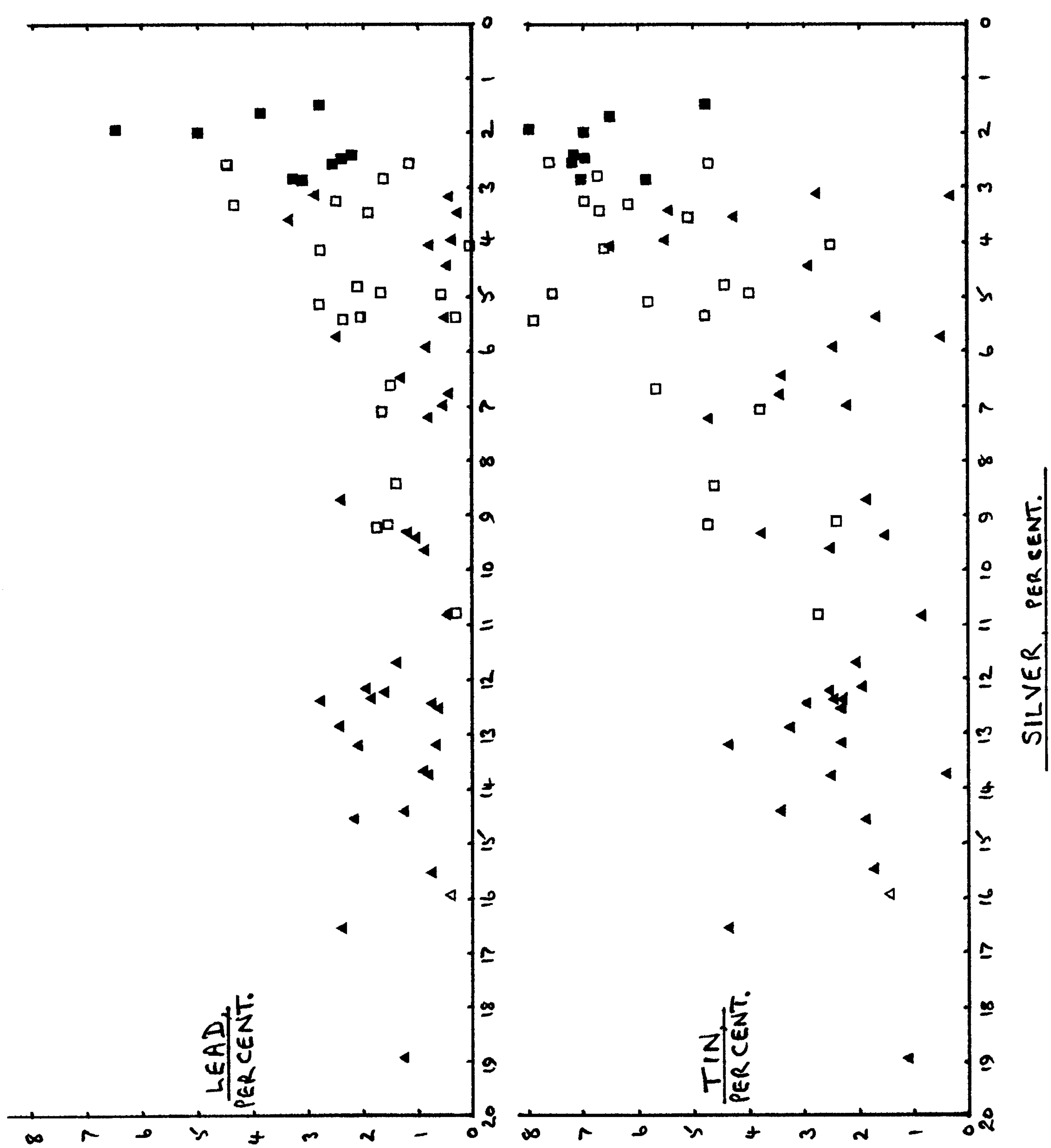
△ JOINT REIGN

▲ LATIN OFFICINAE

□ GREEK OFFICINAE

■ DITTO: ANIMAL TYPES

ALLOY PROPORTIONS OF LEAD AND TIN, RELATED TO COINAGE FINENESS.



and to the appearance of more complex phases when tin is present at levels between 5 and 10 weight per cent. The coins themselves reveal a decline in workability, for even the comparatively lead-free alloys of this period show a marked susceptibility to edge-cracking. No doubt the moneyers found an empirical solution to their fabrication problems by placing an upper limit of ½ uncia per libra (4.3%) on the tin content of the Latin series of coinage alloys; but the wide range of tin proportions found in the most debased issues in the Latin-numbered series indicates that there was not complete metallurgical agreement on this matter either within or between the various officinae. Low lead proportions would have helped in the fabrication of the tin-treated baser alloys; and it is significant that when lead is present in the later coins in this series it is often found at levels (below 1%) which can be attributed to general impurity rather than to deliberate addition.

When the Gallienic fineness reform led to the re-numbering of the officinae in Greek it is interesting to note that there was an immediate return to the lower tin alloying practices which had pertained to coins of the same fineness previously issued by the Latin officinae. This reveals a dissatisfaction with the partly developed metallurgical materials and the achievement of an instinctive desire to return to familiar blends of alloys of known coining characteristics. We find, in consequence, that the early Greek-numbered coins are rather better executed pieces than either the late Latin issues or the subsequent Greek ones, and that they do not contain much more than 2½% of tin.

When the finenesses of the Greek series of coins began to be decreased, however, the tin content of the coin alloys was again increased. So, in Figures 16 and 17 we find an overlap in the base alloy compositions of the Latin and Greek issues which possess similar intermediate fineness standards, revealed by an intermingling of their plotted points. But when further substantial debasement was decreed the incentive to enter upon a second phase of tin substitution returned; and just before the final 'animal' coin types emerged a family of higher tin coinage alloys had become standard. These contain between 7 and 8% of tin, which could be the consequence of an optimised addition of 1 uncia of tin per libra - subject to normal melting losses. Possibly the use of greater tin additions was explored; but successful coining at this stage would have been found difficult due to both coin cracking and heavy die wear.

The lead alloy content was also increased at the later stages of development - perhaps as a convenient diluent of the tin to facilitate alloying it with the molten copper, or to aid the founding of the coin blanks at the sessile drop stage.

In summary, the metallurgical development of the Gallienic antoniniani of the sole reign proceeded from plain copper-silver and copper-silver-tin and copper-silver-tin-lead alloys in which the base metals other than copper were in minor proportions, through a phase of exploration of increased tin proportions and reduced lead, and into a phase of higher tin proportions and lead alloy additions - as the fineness standards were reduced. Their microstructures always show a high degree of alpha-phase homogenisation, no matter how high the tin content, showing that the coin blanks were given careful and prolonged annealing to minimise their otherwise inherent propensity for cracking when struck.

There are, as yet, insufficient coin analyses available to discern any parallel metallurgical developments at the other Gallienic mints. The analyses given in Tables VIII and IX indicate that the mint of Milan continued to coin in the familiar plain copper-silver alloys used during the joint reign, eventually allowing the addition of only small proportions (less than 2%) of tin and lead for argentiferous bronze issues of the lowest fineness made there. If the highly debased Siscian piece (Ca. 19) is as genuine as it appeared to the experts, it has the highest recorded tin content (9.28%) for the era. Superficially this might indicate that Sicia adopted Roman mint practices; but it is likely that the coin is a good near-contemporaneous forgery, for it closely matches the compositions of known forgeries of coins which were attributed to Claudius II, circa AD 270.

The poor quality of so many of the coins of the reign of Gallienus must have tempted the counterfeiters of his day and made less than normal demands on their skills. It is hardly surprising, therefore, that the more barbarous pieces; those more difficult to attribute; and even some seemingly official pieces; show an unconventional metallurgical pattern when compared with the bulk of the coins analysed. Generally the silver content is found to be negligible; and either the lead or tin, or both, are found at much higher levels than would appear to be normal. Some examples of suspected forgeries of this period have the following compositions:

Code No	Type	Apparent RIC No	Silver %	Tin %	Lead %
W.11	Fortuna Redux	193	0.56	6.59	11.43
Ca.19	Salus Aug	581 (Siscia)	0.25	9.28	1.92
Br.7	Laetitia Aug	226	nil	11.00	1.17
Ca.79	Iovi Cons Aug	207	0.18	8.46	3.29

The substantial accumulation of new analyses listed in Tables VI to IX sheds considerable light on the sequence of the coinage issues of the sole reign. Colonel H D Gallwey(250) has already expressed the view that the PAX AVG type from the Latin officinae T and V (or unmarked) was probably the first - since it continued directly from the joint reign for which it bore the plural PAX AVGG inscription in conjunction with the same mint marks. Similarly he believes that IOVI VLTORI was the earliest sole-reign type issued from officina S - since there are more imperial busts than heads and the obverse IMP title is frequent. Both the finenesses and the base alloy proportions of the PAX AVG coins endorse Gallwey's deductions with positive metallurgical evidence, for the earliest pieces have identical alloy characteristics with the typical coinage of the end of the joint reign with Valerian. Similarly, two of the six analysed IOVI VLTORI pieces - although not found at the highest sole-reign fineness standard - are also identifiable with early issues in the Latin series corresponding with the first reduced silver standard.

PAX AVG was abundant in the Gibraltar hoard, where it accounted for 351 mint-marked pieces out of the 2,642 Latin issues of all types. Five pieces from that hoard (together with three from other sources) have been analysed; and the much more important metallurgical evidence which has emerged with respect to issue sequence is that neither the PAX AVG nor IOVI VLTORI types can be confined to any particular issue series on the Voetter pattern. They are to be found in each identifiable fineness and alloy group over the entire Latin series. Reference to Table IV shows the high degree of probability that the same is true of the VIRTVS AVG, LAETITIA AVG, and FORTVNA types. If so, this spells an end to Voetter's concept of a series of four chronological issues - which is disturbed in any case by the discovery that specimens of his so-called 'fourth' issue, of seated figures, are to be found with silver, tin, and lead proportions compatible with their proper location amongst the earliest issues of the sole reign. So far only one seated type (PAX PVBLICA; Code no HDG23) has been found at a low fineness level (12 scrupula per libra) - which places them amongst the later Latin issues, but not at the end as their designation 'fourth' would imply.

A much more extensive metallurgical survey of the coinage will be necessary to determine the fineness standards at which new and subsidiary reverse types were introduced, and to discover at what levels some of the early types might have declined in mint production or been abandoned; but it is now plain that Voetter's detailed system needs drastic revision to match both the metallurgical evidence of the coins and their observed statistical distributions in recent large hoards. What is true of the Latin series can be shown to apply also to the Greek ones.

Both P Le Gentilhomme's assays and those of the author point to a descent to a standard as low as 3 scrupula of silver per libra before the end of the Latin issue series. P Le Gentilhomme's assays, substantiated by two pieces encountered by the author, show that subsequently the highest reformed fineness standard was 30 scrupula per libra, and that this was used for an issue of new types - at first without mint mark - which were later identified with different Greek-numbered officinae. The introduction of Greek markings seems to have coincided with the operation of a reduced (24 scrupulae) fineness standard which had already been put into use for the unmarked IOVIS STATOR type, at least. (HDG33 and HDG34.)

It is interesting that an unmarked SECVRIT PERPET issue, later attributed to officina H, is to be found at the 30 scrupula standard in P Le Gentilhomme's assays, for this points to the expansion from six to nine officinae having been effected before they began to use their Greek numbers on the coins. Table V reveals that the additional officinae X, XI and XII did not commence operations before the next downward step in fineness standard to 18 scrupulae per libra. In future assays one might encounter coins of higher fineness pertaining to these three officinae; but finding them will be largely a matter of chance.

Voetter's identification of the animal types (his 'seventh' issue) as the final issue of the sole reign is not in question; indeed the analyses show a distinctive alloy development which was taken to its extreme limits in the later reign of Claudius II. The author has previously identified the fineness and metallurgical nadir of the antoninianus in the reign of Claudius II Gothicus; but there is now slender (though seemingly positive) evidence that the Greek-numbered types under Gallienus dipped to the low fineness level of 3 scrupula per libra both before the striking of the animal types and with their last issues. If so, then the introduction of the animal types would represent a minor reform in the silver standard - which was then established at a well maintained 6 scrupula per libra, as revealed by a substantial number of assays made by both P Le Gentilhomme and the author.

The question of determining into which silver standard category a coin belongs is based fundamentally on the statistical distribution of the assays around points of fineness concentration. Some of the distributions are broad and asymmetric, due to the base-metal oxidation losses of melting concentrating the silver in different proportions above the already variable upper and lower limits of weighing used at the time of alloy blending. But several peaks emerge, at or near to what would have been convenient Roman weight proportions for metallurgical control and bullion and coin accounting. The most probable theoretical fineness standards used are listed in Table X together with their practical ranges of achievement on the assumption that the bullion weighing was done to the nearest scrupulum; that good melting practice gave a 4% concentration due to base metal loss; and that poorer practice might have resulted in anything up to 10% enrichment. These standards and their ranges are marked

TABLE X

Theoretical Roman Fineness Standards for Debased Coinage Alloys. and their Practical Ranges of Achievement

Theoretical Standard (Scrupula of silver per libra of alloy)	Theoretical Standard, Expressed as Parts per Mille in the Alloy	Practical Fineness Ranges for Weighing Limitations of Plus and Minus One Scrupulum of the Theoretical Standard		
		Without any Melting Loss	With a Consistent 4% Loss of Base-Metal in Melting	With Between Zero and 10% Loss of Base-Metal in Melting
48 (2 unciae)	167	163-170	170-177	163-187
42	146	142-149	148-155	142-164
36	125	122-128	127-133	122-141
30	104	101-108	105-112	101-119
24 (1 uncia)	83	80-87	83-90	80-96
18	63	59-66	61-69	59-73
15	52	49-56	51-58	49-61
12	42	38-45	40-47	38-50
9	31	28-35	29-36	28-38
6	21	17-24	18-25	17-27
3	10	7-14	7-14	7-15

on the right-hand ordinates of Figures 14 and 15, and the widest range is presently used for classifying the coin issues whose assays are displayed in Tables IV and V. It will be observed that at the five lowest standards listed this creates apparently negligible gaps between the standards we are seeking to separate; but, in practice, it is found that there is a concentration of assays in each of these ranges close to the postulated theoretical norm. The use of the widest range does show how poor was some of the metallurgical practice at Rome in this era, but it does enable a few assays to be placed in their most reasonable compartments. The general principle of separation in this manner is justified by the fact that very few assays attributable to the six highest fineness standards fall in any of the gaps between the calculated fineness extremes, or even close to those limits. It provides, therefore, a sound basis for the statistical treatment of future coinage assays on theoretically sound and practical metallurgical principles.

Having established a method for arranging the sequence of coin assays it is now possible to determine a better chronology for the issues, which do not lend themselves to any classification according to criteria of coin module or weight. Recent combined papyrological and numismatic research by Dr M J Price(251) has provided more precise limits for the commencement of the joint reign of Valerian and Gallienus (c. September 253), and a later terminal date (September or October 268) for the sole reign of Gallienus. Between these limits there are uncertainties in existing records, and very few fixed points of reference, complicated by some lack of agreement on the correlation of the tribunician and consular datings which appear on some of the coins.

If Dr Price's almost irrefutable evidence is accepted for the commencement of the joint reign in the early autumn of 253, and we assume that the emperors took their tribunician powers immediately, and renewed them on 10 December in the same year, it is possible to accommodate properly the sixteen known bestowals so that the sixteenth extends into the final part year of the reign of Gallienus, and to match these with the accepted dates for the consular appointments. Coins bearing both citations can then be dated precisely and their assays used to follow the progress of the determined debasements and to bracket the issues lying between them. Some of these coins have been assayed for P Le Gentilhomme, although the author has not been able to obtain any.

A key date, and fineness, is provided by the VOTIS DECENNALIB issue (RIC 334) which must have been in circulation in the autumn of AD 263, or perhaps from the autumn of 262 if it was minted from the beginning of the tenth regnal year. The assay, 63‰ silver, neatly matches the 18 scrupula per libra standard. We can deduce, therefore, that the six higher fineness standards were in use over the previous four years 259-263, and into this period it is possible to locate the 128‰ assay for the PM TRP X COS IIII PP issue (RIC 154) at late December AD 261 - corresponding to an extant standard of 36 scrupula per libra. These deductions would be consistent with revisions of the coinage fineness standard at approximately eight-month intervals in the first part of the sole reign.

According to R A G Carson(252) the war with Postumus began most probably in the late summer of AD 264 and was concluded before the end of the year. The financial burden of this encounter, together with the cost of dealing with continued unrest throughout the empire at this time, must have involved Gallienus in the further rapid coinage debasements which are represented by the most debased coins of the Latin series. But an assay of an Antiochene coin (RIC602) PM TRP XIII C VI PP, with 137‰ silver, reveals that a standard equivalent to the reformed standard at Rome was operating at Antioch between December 264 and December 265. Seemingly the standard is one of 36 scrupula, but the average for the 'branch' mint-mark series to which this issue belongs is 122‰ - and therefore identical with the new Roman 30 scrupula standard. Le Gentilhomme's one assay might have become enriched by coin corrosion or inadequate sample preparation, but not enough to mislead us in the discovery that the coinage reform which heralded the Greek issues at the mint of Rome was equivalent to that operating at Antioch during AD 265.

There are other assays of dateable coins of subsequent years which show the progress of debasement at the mints other than Rome:-

TABLE XI

Assays of dateable coins for the later years of the sole reign of Gallienus

Reverse Type	Coin Ref. in RIC	Mint	Date	Fineness, ‰
PM TRP VII COS	460	Milan	AD 266	91 and 80
" " " "	455	"	"	87.2*
Four various VIIC coins		Antioch	AD 266	99,99,99 and 110
PM TRP XV PP (VIIC)	603	"	Dec.266-Dec.267	102
Seven various PXV coins		"	Dec.266-Dec.267	81-119
PM TRP XVI COS VII	550	Siscia	Dec.267-Sept 268**	44

*The author's assay of coin H.2. **Revised terminal date (after Dr M J Price).

These lead to the conclusion that a general 24 scrupula fineness operated throughout most of AD 266, and part way into 267; but there is just the possibility that the standard was dropped to this from the 30 scrupula level very early in 266. Thereafter the descents were rapid, because the assays reveal a 12 scrupula standard to have been in operation when the mint of Milan changed hands in mid 267; and the last item in Table XI shows that this was also the Siscian mint standard at the end of 267 or early in 268.

This 'other mint' evidence is in harmony with the proposed date and level of the AD 265 reformed standard at Rome, and with the precipitate fineness descents observed everywhere in the last year or so of the reign. At Rome the 30 scrupula standard seems to have lasted for most of the year AD 265. The only apparent problem is the crowding of the last (Voetter's 'sixth') 6-scrupula Greek-marked issues and the subsequent and final issue of animal types into the first 3 months of 268, instead of into the more conventionally accepted period 266-268. If the once postulated date of 22 March 268 for the death of Gallienus were still valid this might pose real difficulty in view of the intensive coining activity which would have had to be accommodated in only a few months; but Dr Price's revision of the date for the death of Gallienus to post-29 August 268 makes the dating of the animal issues to AD 268 much more credible. Another pointer to their later dating is provided by the assays of the coinage of Milan - which abruptly ceased operating for Gallienus, then struck for Postumus, following the revolt of Aureolus in the summer of 267. The lowest finenesses recorded for the Milanese issues, by both P Le Gentilhomme and the author, are 37, 51, and 57.3‰, respectively, corresponding to fineness standards of 12 or 15 scrupula per libra. These match the now emergent pattern for the chronology of the parallel issues at Rome, from which we can infer that the officinae X to XII were probably created early in 267 to assist in producing the apparent flood of later base issues from all twelve officinae.

It is significant that the Gibraltar hoard, previously judged to have been concealed no later than early 267, contains only a sprinkling of animal types and very few pieces indeed from the officinae X to XII, and consists for the most part of much finer pieces which the hoarder hoped to keep for better days, in view of their substantially higher intrinsic worths than the issues current at the date of concealment. If we redate the Gibraltar hoard by a few months to late 267, or even to very early in 268, there is no conflict with its internal evidence of dateable coins, and we can see good reasons for the deposition of the hoard at that time.

Although the eastern mints are generally considered to have operated right to the end of the reign, it now seems likely that first Antioch, then Siscia, were ordered to cease minting in 267 when the Roman officinae had been finally expanded to twelve - just before the unexpected loss of Milan. Certainly we find no assay evidence for an overlap of Rome's later mintings with those of Antioch, nor any Antiochene issues positively dateable much beyond those of the fifteenth tribunate towards the end of 266; but Siscia does overlap with Rome to as far as the 12 scrupula fineness standard of the TRP XVI (RIC 550) issue which commenced in Dec. 267. The mint of Sirmium – if Alföldi's identification is correct - struck earlier for a short period which R A G Carson(253) suggests as being AD 265-6. The silver standard, at 122‰, matches exactly what is to be expected at this time according to the chronology derived above for the first of the reformed Greek-numbered issues from the mint of Rome.

Colonel H D Gallwey(254) has remarked that R Göbl's attempts at precise dating are not well supported by the evidence of the Gibraltar hoard, for Göbl gave the huge Greek officinae issues a total duration of six months against 2½ years or more for the preceding Latin series, and 1½ years for the less common types of his sixteenth issue which followed. So Gallwey proposes what he considered to be a more reasonable supposition - that the Greek-numbered issues lasted much longer than the Latin-numbered ones because the hoard contained approximately 14,000 of the former and only 3,000 of the latter. Even allowing for the greater number of Greek officinae the output per officina was evidently still more than twice as great. In this argument Gallwey is, of course, assuming the hoard to be proportionately representative of original officinae outputs, and he makes no allowance for the reduced availability of earlier types (due to official recovery and the activities of other hoarders having a comparable knowledge of their better intrinsic worths) at the time of deposition. Indeed, Gallwey observes the Latin-marked coins of the hoard to be "of better quality than what was to follow - in higher relief and with a much better silver wash"; and this is endorsed by the analyses of their alloys. What R A G Carson, in his report on the Hollingbourn hoard, calls "a difference in status of the earlier and later issues" is now clearly manifest.

The chronology proposed in this work allows just over 5 years for the Latin series, and nearly 4 years for the Greek varieties. The assays linked to the chronology also confirm the later start observed by Gallwey for the last three Greek officinae, and the apparent contemporaneous and balanced operation of the first nine Greek officinae as revealed by their Gibraltar hoard statistics. While agreeing with Gallwey's basic criticism of Göbl's chronology, therefore, it is not necessary to accept the extent of his view in the other direction - otherwise we would have to distort, on the basis of a debatable assumption, the more logical arrangement which links determined coin finenesses with known historical circumstances affecting all the mints.

Colonel Gallwey rightly challenges the RIC dating of AD 259 for the PM TRP VII COS issue of Milan. On numismatic grounds he regards VII as describing the 'COS' and not the 'TRP', and therefore dates the issue to AD 266. The two assays listed above now confirm his revised dating, for the finenesses - which are distinctly below the silver standard which operated in 259 - then match those in operation at the other imperial mints in 266.

It is now possible to gain an understanding of the wide variation in the weights and types of the gold issues of the sole reign, which would have had to bear some reasonable relationship to the much varied silver issues. Dr J P C Kent(255) has shown that the Gallienic gold issues of widely differing weights cannot be classed under one category, but comprise four types belonging to different periods. His view that the early laureates and radiates continued from the joint reign until AD 261, followed by reduced-weight radiates for 261-2, and then much smaller laureates for 263-266, would closely harmonise with the observed fineness decline of the Latin-numbered antoniniani. Furthermore, the larger of the later laureates - for their weight range of 2½-8 grams is exceptionally wide - could match the raised standard of the AD 265 silver reform and the subsequent reductions; and the Schufkranz (reed-crowned) gold pieces which Dr Kent dates from 266 onwards would now seem to have been issued in association with the later Greek-numbered antoniniani. Indeed Dr Kent really suspected the Gallienic coinage reform which is now identified, because he points out that the hoard analysis shows a major break in the gold series about AD 266, and suggests that the Schufkranz aurei for Gallienus and Claudius were part of a new monetary system. This view can now be endorsed, and quantified to some extent.

c) The coinage of the independent Gallic Empire

The Rev E A Sydenham(256) remarked that the most important event during the reign of Gallienus was the founding of an imperium in imperio known as the Empire of the Gauls. We will find that it had a metallurgically distinctive coinage, linked, at its inception, to that of the Roman Empire, but remaining, thereafter, almost unaffected by the alloy developments of the mint of Rome. Postumus, governor of one of the Germanies, was the architect of the coup - aimed at self-government in Gaul rather than a bid for the Empire itself - and he managed to defy Gallienus and reign for just over ten years. Gallienus and Postumus were both killed within a matter of weeks of each other, and were both followed by fairly short-lived successors before Gaul was eventually recovered for the Empire by Aurelian in the spring of AD 274.

One fundamental problem is the exact dating of the Gallic coinage – without which a proper comparison of the parallel coinage policies of the two emperors cannot be made. Dr H Mattingly(257) remarked that the political history of the Gallic Empire seldom emerges even into a half light; but he did suggest an outline of regnal dates which would "seem to work out best" in the light of the coinage and the known history - both of which are difficult to interpret:-

Postumus - early in 259 to mid 268.
Laelianus - a short time before the death of Postumus in 268.
Marius - a few weeks or months after the death of Postumus.
Victorinus - mid 268 to late 270 (perhaps a rival to Marius, but who outlived Claudius and Quintillus).
Tetricus I & II - late 270 to their abdication in 274.

More recently Professor J Lafaurie(258), basing his dates on ones proposed or deduced from the studies of Professor J Schwartz(259), has tabulated his view of the parallel chronologies of the Roman emperors and the Gallic usurpers Apart from corrections now necessary for the Roman reigns, on the evidence of Dr M J Price's studies, it is difficult to accept Lafaurie's dates proposed for the Gallic emperors because of lack of historical correlation for the dates for the Tetrici and Aurelian at the end, and the difficulty of placing the regular TRP(I) COS II coinage for Postumus at the beginning.

The greatest problems for a metallurgical comparison of the two coinages lie within the region of Postumus; but at least we have his acquisition of the mint of Milan from Gallienus in the summer of AD 267 as a fixed point of reference for the fineness standard used by both emperors at that late date in their independent reigns. R A G Carson(260) has reviewed the range of dates previously suggested for the capture of Valerian at Edessa, and their influence on the date for the commencement of the reign of Postumus in Gaul, and has derived the most probable date for the latter as the summer or autumn of 259. Postumus was already a consul: if we assume that he took his first tribunate on 10 Dec. 259, and his second consulate at the beginning of 260, then the common PM TRP COS II PP coinage could be satisfactorily located in 260. But it is then impossible to accommodate his ten annual tribunates between the dates now acceptable for his revolt and his death. It seems most likely that he assumed the tribunicial powers on usurping, and TRP II on 10 Dec. 259. We are then faced with the problem which Lafaurie also failed to resolve. It could be that Postumus broke the normal rules and allowed himself a second consulship before the end of 259. Alternatively, the unspecified 'TRP' on the coinage might not really imply 'I', but 'II' in this case.

Balancing the evidence educed by Mattingly, Lafaurie, Carson and Price with the marked coinages, and placing the death of Postumus shortly after Gallienus, in late 268, a suggested parallel chronology for the Gallic and Roman emperors - against which we can proceed to compare the two coinages – is given in Figure 18.

P Le Gentilhomme obtained a number of assays for the antoniniani of the Gallic emperors; but the first analyses for any of their alloys were those performed for this work and are listed in Table XII for Postumus.

A second problem with the antoniniani of Postumus is whether they were the products of one mint, or two. In RIC V P H Webb(261) splits the issues between two mints of origin (the earlier being postulated in southern Gaul), because the coinage "shows two distinct and successive styles from 259 to 264 and from 265 to 268, with an intermediate bridging style in 264".(262) R A G Carson comments that these "two distinct styles do not, of necessity, postulate two separate mints, but at the same time they do not rule out this possibility". Consideration of the alloy compositions could assist in the solution of this problem because alloying techniques did differ at the Imperial mints at this time, apart from the possibility that they drew upon different metal supplies having characteristic impurities.

During World War II G Elmer(263) advanced an alternative view that the whole of the coinage for Postumus was issued from a single mint, which he identified as Cologne - whose obvious mint signature (CCAA or Col. Cl Agrip) is found on some of the later issues. In 1953 R A G Carson(264) added a further refinement with the suggestion that the initial Gallic coinage - in the few months before Postumus captured the mint-city of Cologne - could have been struck at his camp, which may then have been the nearby legionary base at Bonn.

The coin analyses listed in Table XII and their minor elements which are

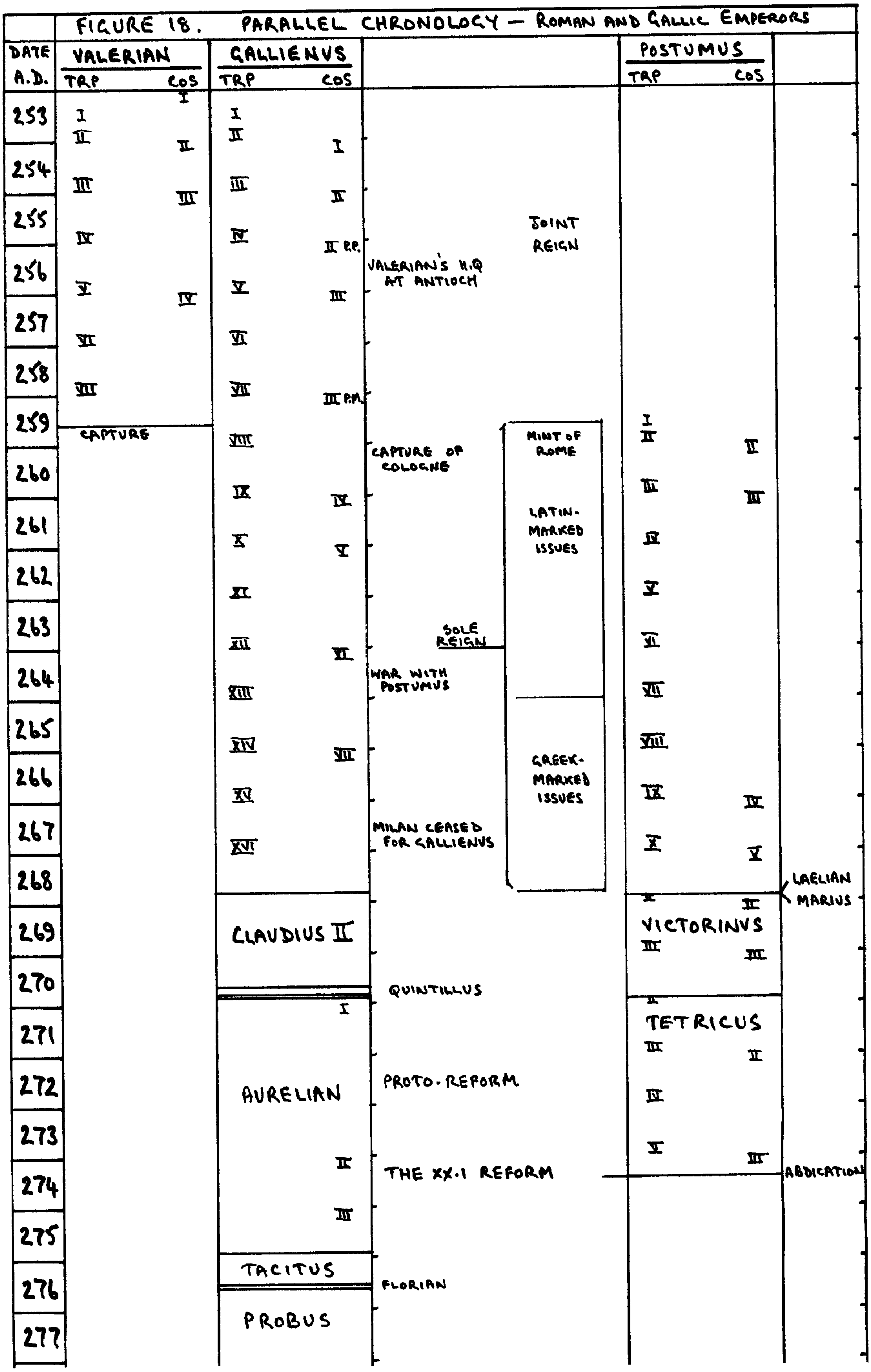


FIGURE 18. PARALLEL CHRONOLOGY — ROMAN AND GALLIC EMPERORS

TABLE XII

Analyses of Antoniniani of the Gallic Emperor Postumus, Minted at Cologne, AD 259-269; Arranged in Order of Diminishing Module

Code No	Reverse Type	RIC No.	Elmer No.	Die Module (mm)	Composition, weight per cent			
					Silver	Copper	Tin	Lead
Valerian II (for comparison)								
Ls 3	Consacratio (eagle)	9	-	21	20.97	76.52	0.19	0.34
Postumus								
BM 169	Victoria Aug	89	125	21.5	16.44	-	0.05	0.99
Ca 18	PM TRP Cos II PP	54	129	22(est)	15.11	82.92	-	1.22
BM 167	“ “ “ “	54	129	21	14.78	83.70	trace	1.14
Ca 51	“ “ “ “	54	129	21	9.85	-	0.19	-
BM 174	Herc Pacifero	67	299	21	16.87	81.50	trace	1.10
BM 176	Herc Deusoniensi	66	316	21;20.5	16.68	81.90	0.23	0.80
Ca 53	Laetitia Aug (galley)	73	130	21	15.25	83.12	0.29	1.13
BM 170	“ “ “	73	130	21;20.5	16.31	82.60	trace	0.87
BM 173	Iovi Propugnat	70	290	20.5	16.60	82.10	trace	1.00
NMW 54	“ “	70	290	21;20.5	16.13	-	0.06	-
Ls 5	Moneta Aug	315	336	21	18.51	79.22	0.44	0.99
M 7	“ “	75	336	21;20.5	16.17	79.93	trace	1.11
NMW 53	“ “	75	336	20.5;20	19.53	78.48	0.30	1.14
NMW 56	Pax Aug	78	333	20.5	16.86	-	0.02	-
BM 187	Felicitas Aug	58	335	20.5	85.88	13.44	0.16	0.35
BM 188	Providentia Aug	80	337	20.5	20.71	78.60	nil	0.52
EHR 2	“ “	80	337	20.5	17.45	-	nil	0.43
BM 194	Serapi Comiti Aug	329	383	20;19.5	17.66	81.55	nil	0.65
BM 195	Dianae Luciferae	299	396	20;19.5	18.18	81.05	nil	0.69
BM 193	Saeculi Felicitas	325	593	20.5	17.65	81.70	nil	0.51
BM 196	Salus Postumi Aug	328	414	20;19.5	17.46	81.75	nil	0.69
EHR 1	Iovi Statori	309	563	20;19.5	14.54	-	nil	0.42
BM 190	Oriens Aug, P|_	316	568	20;19	7.79	89.89	0.09	1.43
NMW 57	“ “ “	316	568	20	7.47	90.59	0.09	0.11
BM 189	Iovi Victori	311	571	19.5(est)	6.95	92.40	nil	0.61
BM 192	COS IIII	287	586	19(est)	5.91	93.80	nil	0.19
Ca 52	Pax Aug, P|_	318	566	20(est)	5.46	93.36	0.13	0.97
BM 191	“ “ “	318	566	20	5.14	94.60	nil	0.16
Ca 50	Imp X COS V	288	597	20	5.41	93.70	0.10	0.76
NMW 58	COS .V.	288	591	19.5;19	4.20	-	0.06	-
NMW 59	Pax Aug, P|_	316	568	not measurable	1.05	96.89	0.03	1.84
Mint of Milan								
NMW 55	Concord Equit	372	610	21(est)	5.33	89.86	2.89	0.74

not listed, do not, however, enable us to make any metallurgical distinctions for the early period. Yet there are considerable differences between the main issues and the Milanese coin listed last. This has a definite tin alloy content - comparable with the near-contemporaneous Milanese coinage for Gallienus; and the antimony and arsenic contents of the Milanese coin for Postumus (0.079% and 0.046%, respectively) are significantly greater than the few parts per million found in the bulk of the coinage which appears to have been made from materials from metallurgically similar sources different from those available at Milan. On this basis the double-mint theory might be rejected, the differences in style being attributed to chronological change, involving changing mint personnel at a single mint, coupled with weight, module and fineness adjustments, dictated by a worsening economic situation in the main Empire from which Postumus was only able to insulate himself partly. So far it is not possible to identify any alloy differences which would distinguish a pre-Cologne mint for Postumus. Further analyses may allow this; but if Postumus and Saloninus acquired essentially identical Gallic supplies of bullion and copper in AD 259 it may never be possible on metallurgical criteria.

The alloys of the Postumus antoniniani minted at Cologne are metallurgically very distinctive from those of the mint of Rome - except perhaps in the earliest days, c. AD 259, when Rome, Milan, and Cologne, were all minting comparatively pure copper-silver alloys at the same Imperial fineness standard of 2 unciae per libra. But, whereas Rome embarked on a series of alloy developments under Gallienus, the mint of Cologne - founded as it was from Milan – continued with the simpler alloy tradition; and the Gallic coinage alloys, even when more debased towards the end of the reign, retain their comparatively high degree of purity. Tin is often undetectable and, with one exception, it does not exceed 0.3% in any of the 32 analyses listed. Lead is a little more variable - but still as an impurity, ranging from 0.11 to 1.84%, with an average of 0.79%. Nickel is generally less than 0.03%, and with one exception (the early coin of Valerian II) the cobalt and zinc contents are almost negligible. Furthermore the antimony and arsenic proportions are generally found in the few parts per million range, while the gold:silver ratios are quite conventional at between 3 and 9 parts per thousand of the silver present.

The observed changes in style match approximately the Latin- and Greek-marked issue periods at Rome, but this correlation may be nothing more than coincidental because there are no apparent contemporaneous changes in Postumus' fineness standards except for the most unusual analysis encountered with coin BM187. This FELICITAS AVG issue is usually regarded as of the mid-reign, c. AD 263. A typical specimen in the British Museum collection has a density of 9.22g/cm²(265), which matches an expected 2 unciae silver standard; but this coin assayed 85.88% silver. It is as if the alloy were made accidentally to a 2-unciae per libra copper standard instead. Otherwise, its exceedingly high fineness is inexplicable: the only precedent is one of P Le Gentilhomme's assays for a coin minted for Gallienus in the same era.

In 1967 Marcel Thirion(266) observed that the greater part of Postumus' hoards contain only his coins - the explanation being the wide discrepancy in fineness between his coins and those of Gallienus; and Thirion went on to cite some of P Le Gentilhomme's assays in support of a view that Postumus maintained his high-fineness standard until AD 268. In a review of Thirion's publication, however, R A G Carson(267) rightly criticises Thirion's avoidance of Le Gentilhomme's(268) own observation that the fineness of the antoniniani of Postumus fell sharply to 50 parts per mille in 266, adding that visual inspection alone supports a marked falling off in fineness well before 268, and that the evidence of British hoards is that coins of Gallienus and Postumus were collected together - suggesting no great disparity in fineness. For the resolution of this question Carson points to the double necessity of obtaining a greater body of fineness figures and a more secure chronological framework of issues than is provided by Elmer's system. In this work the author has attempted to devise a chronology which, though needing further refinement, cannot be far from reality, and a substantial number of new analyses to go with it.

The histograms for P Le Gentilhomme's assays and the author's (ex Table XII) are compared in Figure 19. These reveal an unmistakeable 2-unciae fineness standard, and the degree of its achievement, for the majority of the issues. The mode is rather more accurately located by the author's assays, for which, although the span is identical, the histogram is steeper, less skewed, and not so far displaced above the norm. This is most probably due to the very careful preparation given to all the author's samples to ensure the removal of surface enrichments in silver arising from fabrication or later corrosion.

We might, therefore, question the existence of an apparent middle group of fineness standards which a few of Le Gentilhomme's assays suggest. In

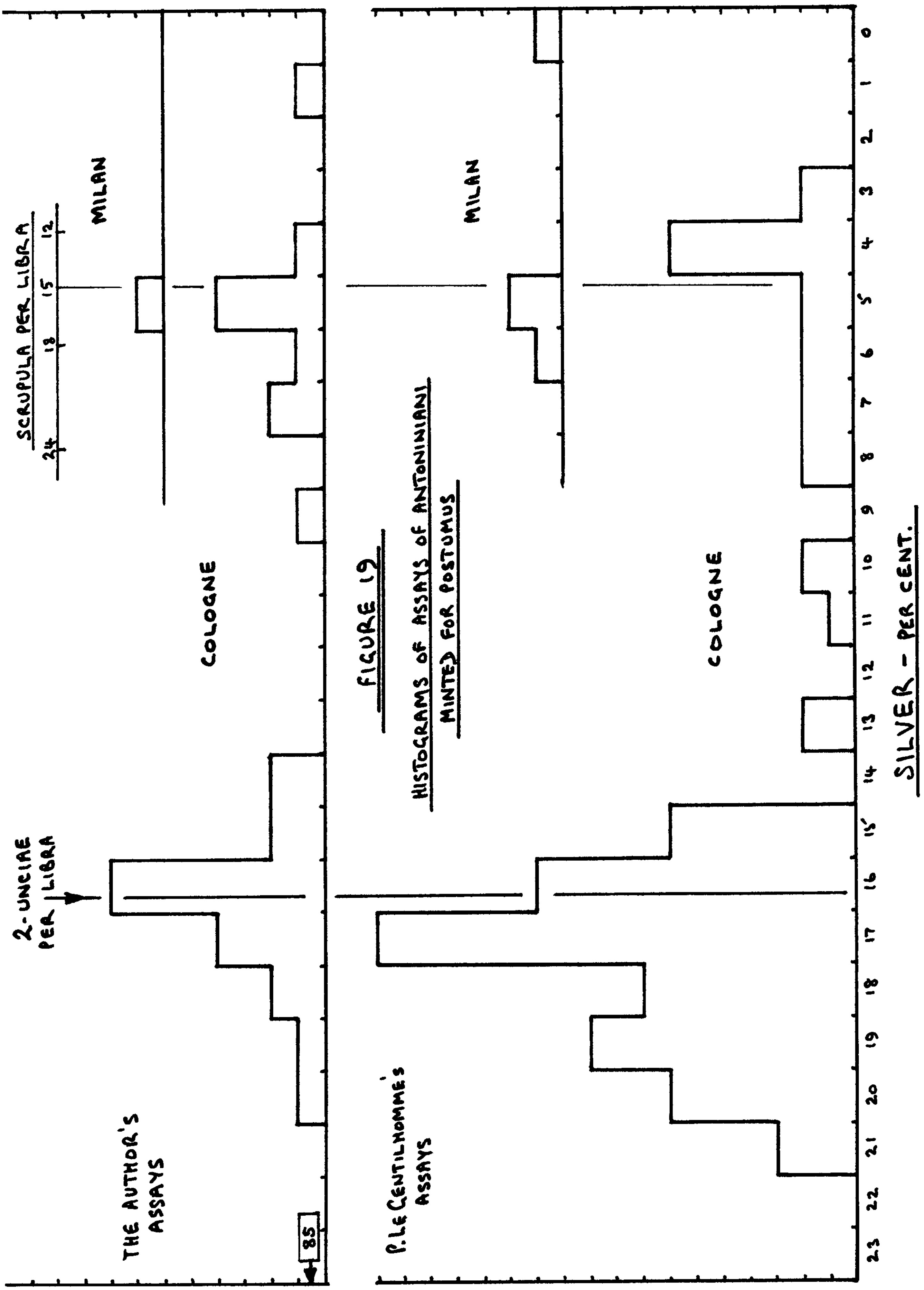


FIGURE 19

HISTOGRAMS OF ASSAYS OF ANTONINIANI MINTED FOR POSTUMUS reality there seems to be a precipitate drop to a series of, perhaps, 30, 24, 18, 15, and 12 scrupula per libra standards, of which we can only clearly identify a 15 scrupula standard pertaining to the issues of both Cologne and Milan in AD 267. These certainly support Carson contra Thirion on this point, whereas Thirion is correct in noting a protracted maintenance of standard before a rapid descent.

So far as the sequence of issues is concerned there are a few dateable types represented:

Postumus coins, first series:	Fineness (parts per mille)	
PM TRP COS II PP	171.5	
" " " " "	154-158	
" " " " "	151.1	(Ca.18)
" " " " "	147.8	(BM.167)
" " " " "	98.5	(Ca.51)
PM TRP IIII COS III PP	219	
" " VIIII " IIII "	173	
" " " " " "	167	

Second series:		
CCAA COS IIII	83	
COS IIII	27/70	
COS IIII	59.1	(BM.192)
COS V	55	
TRP X COS V PP	59	
IMP X COS V	43	
" " " "	54.1	(Ca.50)
COS.V.	42.0	(NMW58)

Although they skip a critical five-year gap between the fourth and ninth tribunates - during which Gallienus (at Rome) debased drastically, then reformed his coinage - the assays of the coins of Postumus indicate the maintenance of the original silver standard perhaps just into AD 267. The rapid drop and further descents happen during the fourth and fifth consulates. Postumus minted no equivalent coinage to that of the more debased Latin-numbered issues of Gallienus, and he has no parallel with either the Gallienic reform or its subsequent steps downwards in fineness. It could be that his independent preservation of the 2 unciae silver standard forced upon Gallienus a necessity to restore confidence - at least amongst the border peoples who interchanged their coinages - by making a coinage reform which he could not afford to maintain; and eventually Postumus found that the drain on his own bullion resources - due perhaps to a Gallic preference for his pieces, which Thirion finds manifest in the hoards - had to be stemmed by following suit, right down to the level currently in use for the much more debased Roman and Milanese issues. A reappraisal of the contents of British hoards will be required in the light of the determined finenesses of the different coins, to discover whether the Britons were casual in accepting both coinages as of equal value over the entire double-reign period of Postumus and Gallienus, or just at the extremities of both reigns when most of the coins were comparable in intrinsic worth.

So far as the general sequence of issues is concerned the analyses in Table XII contain some numismatic surprises. Most of the main types which R A G Carson(269) divided into apparent early, middle, and late issues, in 1961, are represented. But the criteria of both die-module and fineness compel the grouping of the so-called 'middle' issues of MONETA AVG and PROVIDENTIA AVG with the 'early' types. A bridging issue is difficult to find by either criterion. The 'late' issues, however, are substantiated by style, module, and fineness.

After Postumus the coinages of Marius, Victorinus, and the Tetrici, are comparatively lacking in metallurgical interest. The following analyses, of coins attributable to Victorinus, from Cologne (which became a two-officinae mint to cope with an increased output of the much debased coinage), show that alloys typical of those minted by Postumus continued to be used - except that the fineness descended to new depths.

TABLE XIII

Chemical analyses of antoniniani of Victorinus, AD 268-270

Code No	CJO.2	B.157
Reference	RIC.117	RIC.108
Type	PAX AVG, V/*	FIDES MILITVM
Dies	19 mm	20 mm
Composition, wt.%		
Copper	95.74	96.12
Tin	0.38	0.43
Silver	3.23	1.48
Lead	0.29	1.65
Iron	0.17	0.11
Nickel	0.05	0.08
Cobalt	0.03	0.02
Zinc	0.02	0.02
Total	99.91	99.91

The fineness of CJO.2 equates with the standard revealed by P Le Gentilhomme's two assays of the same 'V'-marked type (3.0 and 2.7% silver) and might indicate an attempt by Victorinus to fix a silver standard at 8 scrupula per libra for a 5-denarii radiate 'antoninianus'. This is conjectural, but it will be seen that the standard is possibly equivalent to one used for some of the better pieces then being minted by the Roman Emperor Claudius II, and to the proto-reform standard(270) reached at Aurelian's first attempt at Imperial coinage reform in AD 272(271).

Under the Tetrici the fineness of the Gallic antoninianus reached its nadir, with 0.3% silver. This was probably a minimum token standard of 1 scrupulum per libra - which we meet again almost a century later - but it paid respect to the prevalent Roman idea of a silver denomination having at least a finite proportion of silver in it. For assays of barbarous, or even good, local copies of these antoniniani usually reveal no trace of silver.

J L Allemand and M Thirion(272) have reported no less than sixty analyses of coins of the Tetrici for copper, tin, lead, and silver. Most of these contain in the region of 0.3% tin, 2% lead, and 1% silver; but some of the coins contain as little as 0.3% silver - as P Le Gentilhomme discovered, and the author has since confirmed. It is a striking demonstration of the Gallic Empire's independence that the small proportions of lead and tin in the coinage alloys continued, uninfluenced by the radical metallurgical developments of highly leaded tin bronzes at the Imperial mints at this time. A close examination of the numerous analyses provided by Allemand and Thirion does not allow any metallurgical distinctions to be made between the products of the two Gallic mints which are supposed to have been in operation between AD 268 and 274. This could indicate, however, the centralisation of bullion and copper supplies by the Gallic emperors.

d) The antoniniani of Claudius II Gothicus and Quintillus, and those of pre-reform Aurelian, AD 268-272

The author(273) has already traced the absolute nadir of the Imperial antoninianus to the reign of Claudius II Gothicus - who inherited all the economic problems created by Gallienus. But he did take the coinage alloys to a metallurgical nadir too with respect to alloy composition. There is little to add to what has already been published on this topic, except to state that some partial analyses of types not represented in the published work confirm the discovery of the most highly leaded and tin-alloyed argentiferous tin bronzes ever used for the Roman Imperial coinage as being typical of this reign. The lead and tin proportions exceed those used for the 'animal' issues of Gallienus, and represent the last stage in the development of debased silver coins.

Modern metallurgists might wonder how the Claudian antoniniani - with as much as 8½% tin and up to 10% lead - could have been struck without serious edge-splitting (which is less prevalent than in the Gallienic antoniniani containing lower proportions of alloy). The answer lies in the observation that even the highest tin alloys are free from the brittle delta-bronze constituent and have negligible traces of coreing in their microstructures. The coin blanks must have been given prolonged annealing, and some intermediate working, before final striking.

In the course of preparing coins as reduction-fused buttons for analysis, it has been found that after slow cooling over several hours the resultant sessile drops can be reduced and spread smoothly by hammering - even when cold to coin flan dimensions. The particular microscopic distribution of the globular lead-phase in the button would appear to have less influence on the coining properties than the proportion of lead present might suggest.

Three new assays of Claudian antoniniani, minted at Rome but without officina mark, are:-

(i)	SL19,	RIC 52	IOVI STATORI	2.69% silver
(ii)	Ca.57	" 98	SALVS AVG	2.28% "
(iii)	Ca.22	" 109	VIRTVS AVG	2.79% "

Each would match a 6 scrupula fineness standard; so the dating of the first two types to early in the reign, as R A G Carson suggests(274), but upon which the author(275) cast doubts because of the discovery of some with low-fineness, is not now so firmly questioned.

No further coins of Quintillus or early Aurelian have been obtained for analysis; but the appearance of the coins in collections, and the analyses already published by the author(276) reveal that from towards the end of the reign of Claudius II, when the 6-scrupula fineness was restored, the quality of the coinage fabric improved due to better optimisation of the lead and tin proportions than had been achieved for several years.

The Aurelianic era opened, therefore, with a metallurgical preparedness for further refinements in the quality and fabric of an established argentiferous bronze alloy for the basic silver denomination of the future Empire. At this landmark we halt and return to the beginning of the Imperial era to see how the base-metal coinage denominations fared between 27 BC and AD 274 in sympathy with the vicissitudes of the silver.

The early Imperial aes coinage

a) The copper As

The earliest known Roman coinage denomination was the heavy As, made in cast leaded bronze. It became reduced in size during the Roman Republican era and was eventually struck - rather than cast - in a wide variety of bronze alloys. J Hammer(277) records nineteen analyses for the pre-imperial coins; but in an attempt to arrive at an average composition for coins which contained between 3.9 and 12.96% tin and zero to 29.32% lead he failed to observe how meaningless such an average composition could be for coins spanning two centuries, or that their compositional extremes represented bronzes of wide metallurgical variation in structure - some suitable for both casting and striking, others for casting only.

The As and its subdivisions provided the coin media for the majority of daily transactions, even when the silver denarius - literally a 10-As piece – came into being; so the As remained a fundamental part of the Republican coinage and survived well into the third century of the Imperial era as a copper denomination which was finally altered back to a leaded bronze.

There are no full analyses available for the early asses, but there is no reason to suppose that the metals of which they were made were well refined. An analysis of a Republican triens, struck in 211 BC, shows the type of alloy then being used for small struck pieces. It is probably the most impure Roman coinage bronze yet reported, for there are nearly 2% tramp elements - some of which are at higher levels than have been encountered with any of the later Imperial coins in which they are found as impurities:-

Code No B.102

Roman Republican triens, (Sydenham 157b), 7.33g, 22mm die, 211 BC

Composition, wt %

Copper	91.97
Tin	3.68
Silver	0.14
Lead	2.40
Iron	0.26
Nickel	0.18
Cobalt	0.29
Zinc	0.04
Antimony	0.42
Arsenic	0.40
Bismuth	0.17
Gold	17 ppm
Total	99.95%

When Octavian came to power he did not at first depart from the traditional bronze alloys for his initial issues of asses. An As from Ercavica (Spain) in the early part of his reign (27-26 BC), bearing his AVGVSTVS DIVI F inscription (Code no MAZ.1; Cohen 706) but minted prior to the monetary reform of 23 BC, is a heavily leaded 5.38% tin bronze containing a small amount of silver (0.12%) and 0.031% sulphur. A slightly later Spanish As, minted for Augustus by the legate P Carisius, at Emerita, in 23 BC, (Code no MAZ.2; RIC 237) has a different composition but is still basically a leaded bronze:- Copper, 88.99%; Tin, 1.63%; Silver, 0.42%; Lead, 7·55%; Nickel, 0.58%; Zinc, trace; Total, 99.17%. Its microstructure revealed a leaded alpha-bronze, of extremely fine grain size, with slight coreing. Some sulphide inclusions were also observed - so this element now remains to be determined.

In 23 BC, however, a dramatic change was effected, for Augustus introduced a refined copper coinage for the As and its diminutives, in place of the traditional bronze. The red-metal colour of new and regularly circulating pieces would have provided a simple visual means of distinguishing them from the yellow brass coins of higher denomination - and particularly from the dupondius of closely similar dimensions. A moneyer's copper As dateable to 23 BC and struck for Augustus by L SURDINVS (SL.51; RIC 74 note) is found to have a zero tin content and 0.25% silver as its principal impurity; and subsequent issues for Augustus and his immediate successors follow a similar non-alloyed pattern (Table XIV).

The low intrinsic value of the imperial asses, their comparative abundance, and their superficial look of purity, have militated in the past against any penetrating investigation into their real metallurgical characteristics. J Hammer lists only 30 partial analyses for coins which were issued in enormous numbers over at least the first two centuries of Imperial rule, including three which Bibra reports as being exactly 100% copper – and which are obviously questionable. Even the last sixty years has seen little advance in our knowledge of this coinage: Caley(278) has published one; Carter(279), twelve partial analyses; G C Boon(280), one; and the author(281) and R Warren have reported a metallurgical study and analysis of one other.

In a summary of the known analyses of Imperial asses minted between AD 14 and 249 E R Caley(282) lists one of his own analyses with nine others taken from Hammer's survey, and concludes that "a fairly regular composition" - of about 98.14 to 99.65% copper - was maintained; and G F Carter's subsequent work reveals a similar degree of purity (98.00-99.96% copper) for a dozen

TABLE XIV

Analyses of Imperial Cooper and Copper-Alloy Asses

Code No	Emperor	Coin Reference	Composition- wt.%								Date of Issue	Remarks
			Copper	Tin	Silver	Lead	Iron	Nickel	Cobalt	Zinc		
MAZ.1	Augustus	C. 706	-	5.38	0.12	-	-	-	-	-	27-26 BC	Ercavica, Spain.
MAZ.2	“	RIC.237	88.99	1.63	0.42	7.55	nil	0.58	nil	trace	25-23 BC	P Carisius, Emerita.
SL.51	“	RIC.74 note	-	nil	0.25	-	-	-	-	-	23 BC	L Surdinus.
B.2	“	R1C.81	96.86	0.06	0.55	1.35	0.12	0.39	0.06	0.01	22 BC	C Cassius Celer.
W.9	“	Uncertain	97.01	0.05	0.61	0.03	0.16	0.62	0.11	0.02	22 BC	C Gallius Lupercus.
B.4	“	RIC.192	99.67	0.01	0.08	nil	0.20	-	-	-	12 BC	M Maecilius Tullus.
LHC.34	“	RIC.360	99.85	0.06	0.11	0.01	0.03	0.02	nil	nil	10-4 BC	ROM ET AVG, Altar,Lyons.
MAZ.3	Tiberius	C.p.216;2	99.63	nil	tr	tr	0.30	tr	nil	nil	AD 14-21	Romula, Spain.
SL.37	Caligula	Uncertain	-	nil	nil	-	-	-	-	-		TCA countermark.
B.151	Vespasian	RIC.497	98.00	0.06	0.07	1.67	0.02	tr	-	0.01	AD 71	
U of S.3	Domitian	RIC.395	99.22	0.26	0.12	nil	0.19	0.002	0.01	0.02	AD 90-91	Complete Analysis published in Ref. 10.
B.17	Hadrian	RIC.546a	94.08	2.80	0.11	2.10	0.15	0.03	-	-	AD 118	A leaded bronze alloy.
B.66	M Aurelius	RIC.AP.1238	99.17	0.03	0.01	0.12	0.06	0.04	0.08	0.04	AD 140-4	)
B.38	Lucilla	RIC.MA.1741	90.88	3.01	0.02	4.41	0.15	0.10	-	-	AD 161-180	)
B.47	Sept. Severus	RIC.706	-	moderate	0.03	present	-	-	-	-	AD 193-211	)
MAZ.26	Iul. Mamaea	RIC.674	90.48	3.04	0.14	5.93	0.03	0.02	tr	0.03	AD c. 220	) The era of leaded
B.173	Gordian III	RIC.306b	-	moderate	traces	-	-	-	-	-	AD 242	) bronze asses.
MAZ.25	H Etruscilla	RIC.134b	89.43	4.29	0.11	5.59	0.05	0.02	0.04	0.03	AD 249-51	)
AJHG4	Aurelian	RIC.80	-	6.98	nil	abundant	-	-	-	-	AD 270-4	)

Note: Antimony and arsenic, and traces of gold are usually present. U of S.3 is exceptional - with 0.10% Sb and 0.039% As.

fairly early asses minted between c. 10 BC and AD 54. Caley's comparison is, however, based on only ten selected results spanning nearly the full range of issues, and it is over-simplified to the point of considerable error in its broad conclusion. Closer examination of the same literary sources, particularly for analyses of coins minted in the later part of the period reviewed by Caley, reveals several copper-alloy asses which Caley omitted for no specified reason. One result (J Hammer, p.136, ex Bibra p.60, No 25) even belongs to the same reign as the final item listed in Caley's comparative Table 45, and shows a definite bronze alloy As of Philip I (AD 244-249) containing 7.62% tin and 3.32% lead.

A systematic investigation of the compositions of asses minted between 27 BC and AD 274 (Table XIV) now establishes that the plain copper asses introduced in 23 BC were, in fact, eventually replaced by leaded tin-bronzes, and that the transition actually commenced more than fifty years before Philip became emperor. It is evident, furthermore, that the very first Imperial asses were minted in leaded bronze, and that small alloying proportions of tin and lead also occur in some asses minted near to the beginning of the second century AD; the really pure coppers belong to the period between. A fuller study of the second century issues will be profitable, but the overall chronological variations partly observed by the earliest workers are now confirmed and extended by the new analyses listed in Table XIV.

A parallel comparison with the first Imperial brass denominations reveals a period, starting just before the beginning of the third century AD, when the distinctive alloys of the two base-metal Roman coin series merge into a common composition. This happened when the more severe silver coinage debasements, and the associated great inflation - commencing with Septimius Severus - diminished the usefulness of the minor denominations and made their minting in both pure metal and special brass an increasingly uneconomic proposition. Then they began to be made in a cheaper material which continued until they were eventually displaced completely by the smaller argentiferous antoniniani of higher nominal value but lower intrinsic worth. We will note that for the quarter to half-century over which a common leaded bronze alloy was adopted for both asses and dupondii the original copper-red and yellow-brass colour distinction between these aes denominations of similar dimensions finally disappeared. Long before this, however, the As and the dupondius had been given laureate and radiate heads, respectively, to distinguish them in a manner which neither tarnish nor corrosion could easily mask.

The purer copper asses are difficult to prepare for analysis: they clog the teeth of files and saws, and require many bends to effect a silky fracture, even after slitting, Such properties are characteristic of good fire-refined tough-pitch coppers; so an investigation was made of the degree of deoxidation achieved by the Roman refiners. Thirteen copper asses minted between 15 BC and AD 144 were found to contain less than 0.06% oxygen - the average being 0.04%(283). These compare with the best grade of modern tough-pitch copper, for which 0.04-0.08% residual oxygen is normally specified, and only two coins were found with higher proportions of oxygen (0.10% and 0.15%). The early Roman Imperial copper coins could be made, therefore, in refined and extremely well-deoxidised metal - representing no mean metallurgical achievement for those days.

Some of the analyses listed in Table XIV are incomplete, since replicate analyses for some elements are required in view of their minute proportions, and because of the degree of possible segregation which can be influenced by the presence of non-metallic oxide and sulphide inclusions. Other analyses are at an exploratory stage pending full analysis; but the available results enable certain firm metallurgical and numismatic conclusions to be drawn. The first is that there is no evidence of any blending of materials between the different denominations.

The almost total absence of zinc, even in the later leaded-bronze era, shows that the orichalcum (brass) coinage - even if it was ever recycled – was kept completely separate from the metal for the asses. And perhaps because of this strict mint practice the potential for deoxidising refined copper with a small amount of orichalcum seems not to have been discovered.

An indication that there was also no recycling of older base-metal coinages is given by the negligible tin contents of the early copper asses compared with the previous Republican bronze asses. The addition of even a single Republican coin to a libra melt of plain copper would have raised the tin content to nearly 0.3%; but not until Domitian (AD 90/91) do we find any coin analysis (U of S.3) which would allow such an explanation. In the earlier period it would appear that virgin coppers from many sources were minted at Rome and Lugdunum. The analyses lend support, therefore, to a view that there was no formal mechanism for recovery either of the base-metal denominations to the Treasury (all taxes and fines being payable in silver or gold even when those accounts were nominally kept in sestertii) so that the continuous coin production made a substantial contribution to an Imperial inflation which grew insidiously throughout even the first century of Empire.

Apart from the sporadic occurrence of lead in the early asses the most abundant impurity is found to be silver. Its presence in each of the initial moneyer's asses, at levels slightly above those usual for more ancient coppers and bronzes, raises the question whether Augustus deliberately planned that the reformed As should bear some intrinsic worth of silver to relate it to the denarius, or whether some new source of argentiferous copper was used for minting asses before its silver content was appreciated. Further analyses of these ancient asses are undoubtedly required, but it is noteworthy that by 12 BC some silver-free coppers were being minted - and this was certainly the subsequent official policy. The question of whether the countermarked (and thus revalued or revalidated) asses of the Claudian era were selected from known argentiferous coppers in circulation is solved by the assay of the TCA-marked piece of Caligula (SL.37) which contains no silver.

The first century Imperial copper asses were virtually sulphur-free; and in general they contain much lower proportions of antimony and arsenic and other impurities than the Republican bronze issues, so their high purity makes mass-spectrometric analysis a useful route for characterising them by trace element patterns. In Table XV the fullest possible analyses of seven copper asses minted between 12 BC and AD 78 show that although 35 elements can be detected in each of the coppers few are present at levels determinable by the conventional methods of wet-chemical analysis. They are, however, the ones which can be determined chemically unless they happen to be in exceptionally low proportion - iron, silver, lead, antimony and arsenic. A comparison between the mass-spectrometric and chemical analyses is made between two coins listed in both Table XIV and XV, which represent the two highest purity coppers encountered. The slight differences in composition can be explained by the segregation of certain minor constituents and by traces of non-metallics dispersed in the metal, while the differences between the mass-spectrographic analyses themselves undoubtedly reveal the wide variety of sources of raw copper used. Particularly notable in this context are the variations in the solid-soluble elements, such as; silver, nickel, antimony, arsenic, zinc and gold, at levels which cross the brink of normal determination by chemical - rather than physico-chemical - means. It is interesting that Carter sought bismuth and arsenic by X-ray fluorescence analysis and

TABLE XV

Mass-Spectrographic Analyses of Early Imperial Copper Asses

Code No	B3	LHC34	LHC73	MAZ3	MAZ6	B5	B10
Emperor	Augustus	Augustus	Divus Augustus	Tiberius	Tiberius	Tiberius	Vespasian
Date of Issue	12 BC	c. 10-4 BC	c. AD 14/15	AD 14-21	AD 14-37	c. AD 22	AD 77/8
Coin Reference	RIC 189		RIC 1	C.p.216; 2	C. 140	RIC 16	RIC 764(b)
Mint	Rome, or Lugdunum	Lugdunum	Perhaps Lugdunum	Romula (Spain)	Ilici (Spain)	Rome	Lugdunum
Aluminium	2	0.8	0.8	3	0.2	0.6	0.1
Antimony	300	75	800	115	400	60	600
Arsenic	150	3	100	35	100	1.5	200
Bismuth	7	0.4	23	1	7	4.5	40
Bromine	0.3	3	1	0.08	0.5		0.1
Calcium	≤ 1	4	2	0.7	≤ 6	≤ 0.6	0.09
Chlorine	10	2	125	≤ 0.7	150	0.7	< 0.7
Chromium	≤ 0.01	≤ 0.3	0.7	0.2	0.8		0.2
Carbon	≤ 4		≤ 4		≤ 2	≤ 1	
Cobalt	35	≤ 1	2	7	3.5	2	7
Fluorine	2		1.5		0.8	2	
Gallium		0.8					
Germanium			0.2				
Gold		15		2			10
Indium	18	0.5	4	8	7.5	1	1
Iron	1000	15	3000	3000	60	550	200
Lead	300	1	700	30	125	8	250
Magnesium	0.3	≤ 1		< 0.5	1		≤ 0.6
Manganese		≤ 1	1.5	≤ 0.07	0.35	0.08	2
Molybdenum	0.8						
Nickel	800	200	65	50	115	30	100
Phosphorus	≤ 0.1	0.2	1	< 0.07	0.65	0.1	1
Potassium	1.5	0.7	1.2	0.1	0.7	≤ 0.06	0.2
Scandium	≤ 0.07	≤ 0.2	≤ 0.07	≤ 0.04	≤ 0.07	≤ 0.07	≤ 0.05
Selenium	12	10	60	6	15	3	30
Silicon	8	5	4	3	4	4	5
Silver	800	100	400	50	325	200	800
Sodium	0.4	0.2	0.2	< 0.05	1.2	0.04	≤ 0.1
Strontium					1.4		
Sulphur	0.2	2	25	2	17.5	17.5	10
Tin	100		75	60	100	2	100
Titanium		1.5		0.5			0.5
Tungsten				1			< 0.3
Vanadium		≤ 0.5	≤ 0.08	≤ 0.06		≤ 0.04	≤ 0.04
Zinc	1.2	10	1.5	4	3	0.8	20

Note: The proportion of each element is expressed in parts per million with respect to the copper matrix.

reported them as undetected. Whether the coppers he examined were really free from these elements, or were beneath the levels of detection by his method, is not certain; but the high sensitivity of mass-spectrography ensures the detection of any mono-isotopic element down to a limit as low as 0.03 ppm. The results given in Table XV are each the averages of two separate determinations made by tracking the excitation spark over radial cross-sections of interior coin metal, and are all reliable within less than a factor of three of the values recorded. They open up an entirely new field of numismatic investigation.

In the second century AD there is a short period of overlap between the copper and the leaded bronze asses which has yet to be defined more clearly; but the true copper asses do not appear to have been minted beyond the reign of Marcus Aurelius (AD 180). It is interesting that when Aurelian restored the As as a denomination, c. AD 274, he did not go so far as to mint it in the copper of Augustan days, but in the leaded bronze developed by his more recent predecessors between AD 190 and 250.

b) The Orichalcum coinage alloys and their development

A major metallurgical innovation at the coinage reform in 23 BC was the choice of orichalcum - a golden-yellow alpha-brass - for the sestertius and dupondius denominations. By this Augustus exploited, on a grand scale, the Roman invention of brass, whereby Julius Caesar had earlier enriched himself and had even issued experimental coins.

It was a sound practical and psychological choice for token coins of noble proportions; for the metallurgical concept of the day was that the treatment of copper with the 'drug' cadmea had a purifying effect because it turned the red metal into something closely resembling gold - hence Pliny's term(284) 'auri-chalcum' (golden copper) for what is now more usually described as "orichalcum". Furthermore, the State had the metallurgical monopoly, and perhaps the closely guarded secret, of its manufacture, and the inner knowledge that the 'purifying' yielded up to 40% more metal than the original copper invested in the process - although it would have been valued much more highly by virtue of its esteemed 'excellence' compared with copper.

The Roman coinage orichalcum, in its simple and later more varied compositional forms, was minted for well over two centuries, during which time there were significant metallurgical changes which are discussed in E R Caley's(285) comprehensive review on orichalcum and its related ancient alloys. Professor Caley saw the need, nevertheless, "to fill various gaps in our information about Roman coinage brass"(286) and encouraged the author to extend the work with that objective. Caley's own major work, published in 1964, is noteworthy for the high quality of its 25 new complete analyses of Roman orichalcum (which took the same number of years to acquire as duplicate results) and for his critical appraisal of the earlier published results – many of which were either incomplete or lacking in sufficient quality for firm conclusions to be based upon them. His own analyses have a few inevitable gaps in their chronological continuity but lack nothing more than statistical strength - which is probably the unavoidable consequence of the time and effort which has to be devoted to analytical work of such high quality - and they are limited to issues of the mint of Rome.

In 1965 G F Carter(287) reported an X-ray fluorescence analysis of a dupondius of Hadrian, and in the following year(288) he summarised his observations on the compositions of Roman copper coins, and two of orichalcum - one of which was an Augustan piece minted at Lugdunum. The importance of this work was that it revealed significant differences between Lugdenese and Roman copper and brass compositions. In particular the Augustan coin contained much less zinc (18.1%) than had been previously recorded for his reign; but it is confirmed by an even lower result reported here (SL35) which is relevant to the tricky matter of Roman orichalcum manufacture by a small batch process.

By 1970 the author had acquired sufficient material to fill a substantial number of the more obvious lacunae in Caley's survey. Eighteen orichalcum coin samples were first prepared for an analytical programme undertaken by R Morley(289), which included a study of more rapid techniques of analysis for comparison with the established chemical methods. The dates of the selected issues (AD 68-195) were planned to cover much more completely the critical middle and later periods of issue investigated by Caley - during which a transition from brass - to zinc-bronze - to leaded tin-bronze occurred. The results were then supplemented by others completed by the author and H N Billingham, listed in Table XVI below, which, together with the results of Caley, Carter, and Morley, are combined in Figures 20 and 21 to show the important chronological variations of zinc and tin in the coinage alloys.

In his assessment of the orichalcum coinage compositions, reign by reign, for the two and three-quarter centuries from Augustus to Philip, Caley considered that the initial plain orichalcum divided into two main groups. The first he identified with the period from Augustus to Claudius – for which Augustus set a compositional standard (for zinc) which remained

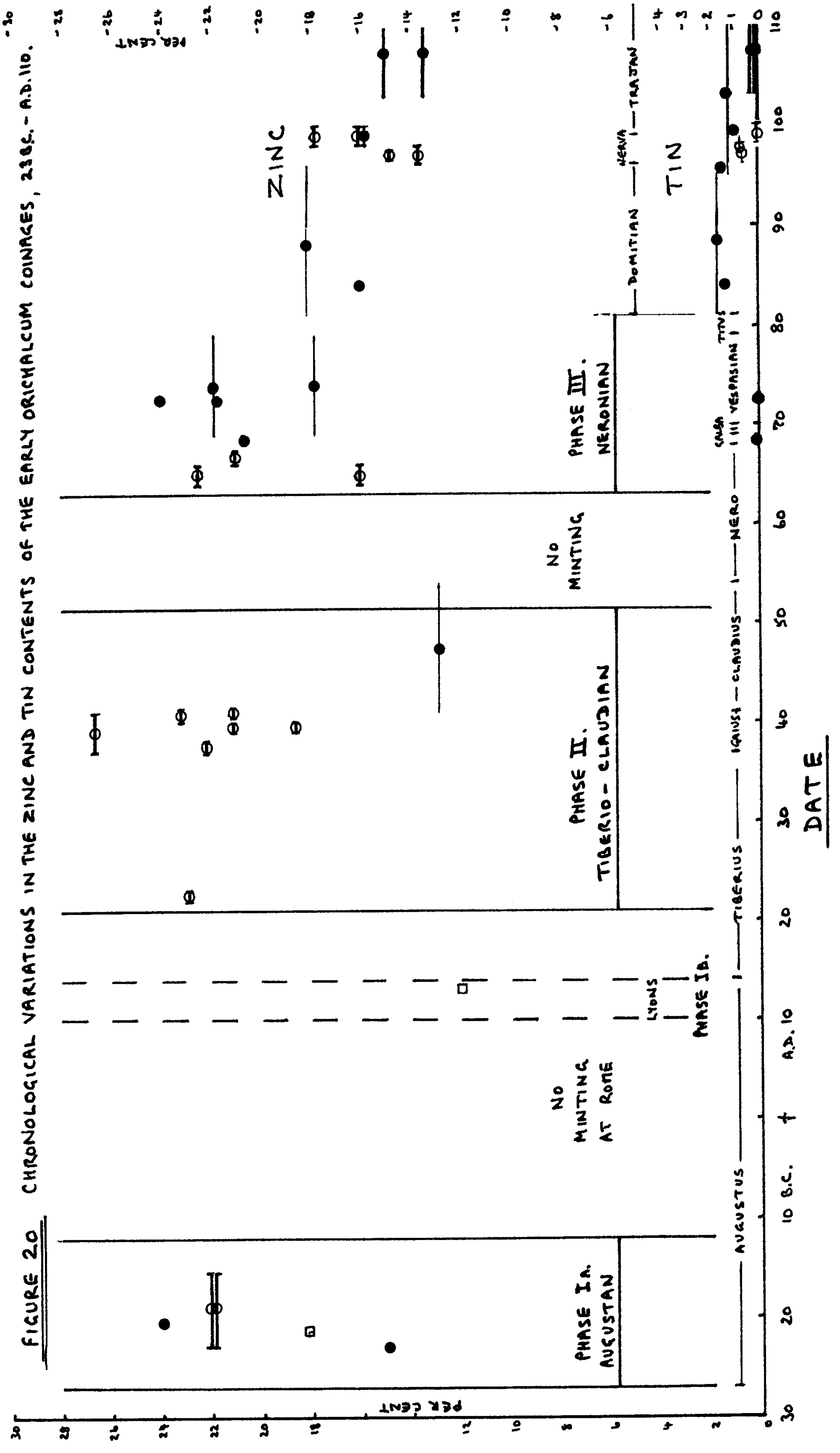


FIGURE 20 CHRONOLOGICAL VARIATIONS IN THE ZINC AND TIN CONTENTS OF THE EARLY ORICHALCUM COINAGES, 23 B.C. - A.D. 110.

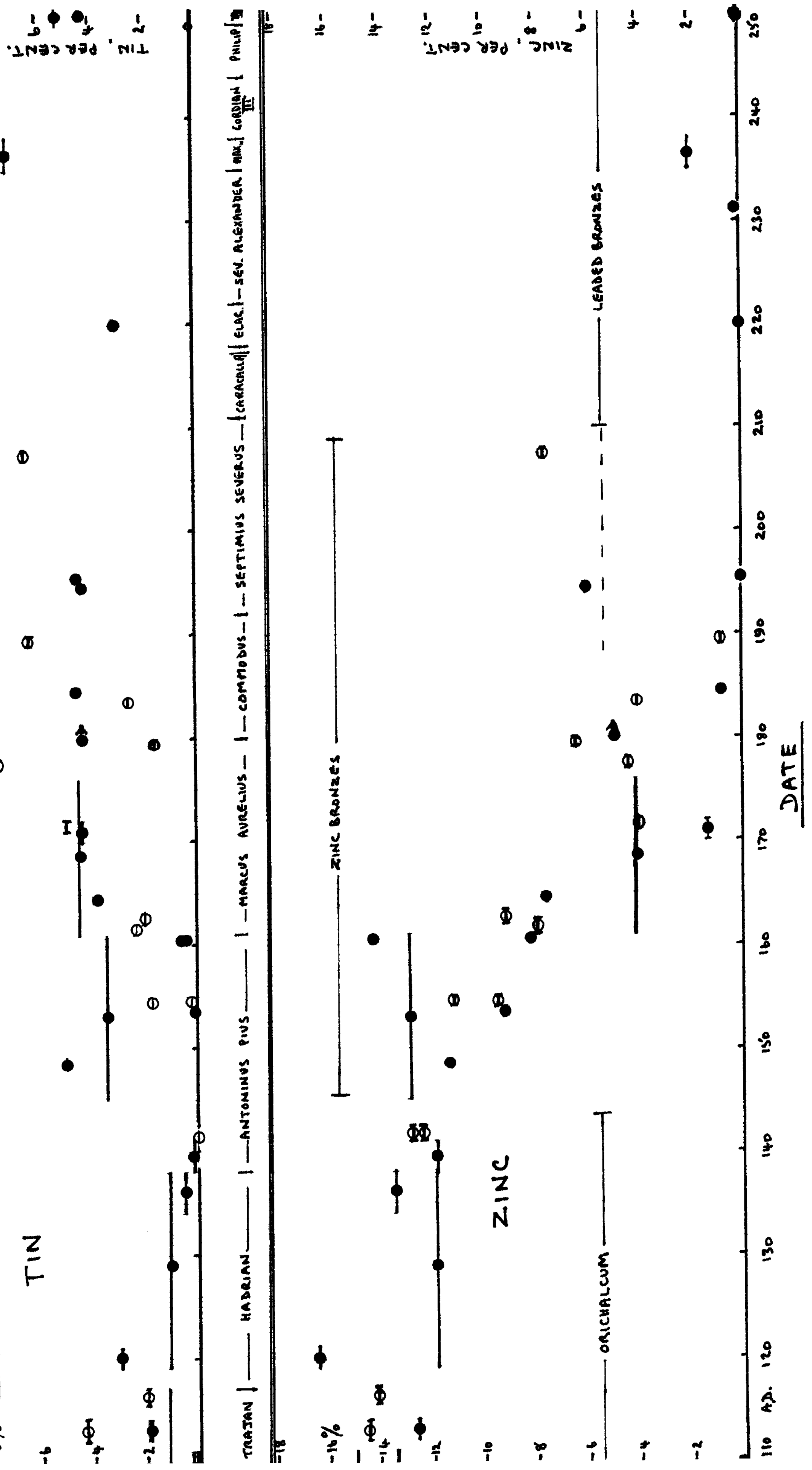


FIGURE 21 CHRONOLOGICAL VARIATIONS IN THE ZINC AND TIN CONTENTS OF THE LATER ORICHALCUM COINAGE, A.D. 110-251.

TABLE XVI

New chemical analyses of Imperial sestertii and dupondii

Code No	Coin Reference (RIC)	Date of Issue, AD	Composition - weight %				
			Copper	Tin	Lead	Iron	Zinc
SL35	71	23 BC	83.99	0.12	nil	0.04	14.96
SL36	91	21 BC	74.41	trace	nil	0.09	24.12
LHC74	Claudius 82	41-54	79.84	0.01	6.34	0.22	12.93
LHC84	Antonia	69-79	80.58	0.01	0.43	0.87	17.82
B.49	739	72-73	75.56	0.02	nil	0.29	23.96*
R.1	Domitian	81-96	78.84	1.70	0.50	-	18.10
B.12	246	84	81.86	1.35	0.05	0.30	15.97
Ch.1	417	95-96	85.97	1.53	0.36	nil	11.74
B.63	Trajan	98-117	82.15	1.16	-	-	16.74
B.21	1093	117-138	82.89	0.27	2.26	-	14.31
B.40	1716	145-160	83.56	3.47	0.09	-	12.90
B.37	1715	180+	81.00	4.37	8.45	-	5.03
B.32	1001 or 1029	Dec 170-Dec 172	84.31	4.20	9.42	-	1.31
B.43	561	190	79.2	6.09	13.98	0.04	0.02
B.73	Maximinus	235-238	74.1	7.30	18.30	-	2.01

*Mint of Lugdunum.

constant for over half a century. The second was a period of progressive decline in zinc content, judged to begin with Nero - or if not, then Caley was certain that it did with the reign of Vespasian (AD 70-79). These groups terminated with the introduction, under Marcus Aurelius (AD 161-180) of a third series of alloys "radically different in composition from those of Antoninus Pius and his predecessors".

Caley postulated that the steady decline in zinc content during the second phase was probably due to the zinc volatilisation losses occurring when worn coins from earlier reigns were remelted for new mintings; whereas in the period from Augustus to Claudius the coinage metal had been always produced as virgin alloy by a standard metallurgical process. For the extensive coinage of Trajan and Hadrian, issued over nearly four decades, he suggested that both new and re-melted alloys were used, leading to a generally lower but wide range of zinc contents. Caley’s comparison does not allow, however, for the true width of scatter which the early orichalcum really possesses (Figure 20); indeed he veiled the evidence for this by his rejection of the lower-zinc analyses, already reported for first-century orichalcum, which he considered to be doubtful analyses. There is little doubt that the Romans would have had great difficulty in batch-producing brass to a fixed composition - even by a standardised metallurgical procedure - because of the highly volatile nature of zinc, and their lack of close pyrometric control. That it was far from a precise process is confirmed by the new analyses of Carter, and the author, which show that some of the moderate-zinc alloys which Caley regarded as typical of the post-Neronian era occurred also in the earlier reigns. Looking at this another way, Figure 20 depicts the present known range of scatter, based on the best analyses, and shows that some of the post-Neronian coins have as much zinc in them as the earliest pieces. Any decline must now be placed later. Similarly it can be shown that there is not the clear distinction in 'quality' between the Lugdenese and Roman mintings which D W MacDowall(290) suggests, since Vespasian's later orichalcum from Lugdunum is as rich in zinc as any of the earlier Roman orichalcum. Despite a few years gap in minting the art had not been lost; and our evidence is that it was revived soon after the discovery of the Stollberg calamine deposits in Upper Germany, between AD 57 and 74, when Pliny was governor there.

It is rather unfortunate that Caley equates a high zinc-content with a better orichalcum, and regards subsequent reductions to about 15% zinc as a "decline in quality". This is not metallurgically correct because alloys over the whole range of alpha-brasses are mechanically suitable for coining. In fact, brasses with the lower proportions of zinc much more nearly resemble gold in colour and are far less prone to corrosion in service - especially when they contain a small proportion of tin, such as is present in most of the early second-century orichalcum, but not before the reign of Domitian. R G Collingwood(291) has noted that the coins of Trajan had a long life; and one of the metallurgical reasons could well be their better alloy optimisation for resisting wear and corrosion, for it is the earlier coins which are more often found in a dezincified condition. H Mattingly's footnote to Collingwood adds that "the restored issues of Titus and Domitian seem to show that about AD 80-81 a great deal of worn aes was withdrawn from circulation"; and this coincides with our analyses which show that Domitian made the first small but deliberate additions of tin to his orichalcum to create a new family of alloys which was then adopted by his successors. He thus adumbrated the development of British Admiralty brass, which is characterised by a good resistance to marine corrosion. Could it be that a partly naval Empire, for which the Mediterranean was almost an internal lake, had to compensate for the devastating effects which sea-water and salt-spray could have on the golden appearance of its high-zinc brass coinage?

A fundamental problem has been introduced by Caley's own explanation of the chronological decline in the zinc content of the two orichalcum denominations - between which there is no alloy distinction at any one time. He is convinced that it was due to a regular mint practice of remelting earlier worn coins; and he provides seemingly acceptable calculations of attendant zinc losses, based on brass-works experience with crucible melts. But, while this seems to provide a satisfactory metallurgical explanation there are, nevertheless, two important factors which militate against the acceptance of the general conclusion.

The first, which has already been demonstrated with the analyses of the copper asses, is that there was no official system for recovering the base-metal coinages after issue. The second, and more powerful argument in this case, is that the chronological variations in the proportions of the elements other than zinc do not support the re-melting hypothesis. On the contrary, they give evidence for fresh alloy - containing increasing proportions of some hitherto negligible alloys and impurities - being prepared for new mintings, at least until well into the second century.

As historical evidence we recall that even Caligula's damnatio memoriae(292) did not cause the official withdrawal or destruction of his coinage, for overstruck pieces are to be found with his successor's countermark. Similarly, substantial numbers of worn Augustan sestertii and dupondii have been discovered at the Rhine forts, with Tiberian, Claudian, and Neronian countermarks, dating as late as AD 64(293). The last marks were used to revalidate orichalcum coins of Tiberius - some 40 years after their original minting; so the official intention must have been to extend their useful lives without remelting them. Such practice points to an acute shortage of aes coinage in northern Europe in Nero's day, and it indicates that, since the mint production of new orichalcum was insufficient to keep pace with overall needs, no furnace capacity could be spared for unnecessary remeltings.

We are driven to the conclusion that the remelting of recovered coins was not normal practice, and that Nero’s own orichalcum coinage must have been minted in virgin alloy. The one analysis which Caley judges as representing secondary metal really falls within conventional ranges for both its zinc level and its minor impurities. Perhaps we should now treat as genuine some of the earlier analyses with low zinc levels, which Caley rejected, and take them as correctly revealing some of the scatter which pertained to the manufacturing process itself.

For the post-Neronian orichalcum Caley attempted to simplify and smooth the regularity of the chronological descent in zinc content by taking averaged zinc values for sequential fifty-year periods(294). But a proper plot of his own results (as open circles in Figures 20 and 21) together with our more recent results (as filled circles) shows that the decline follows a much less regular pattern, There is, for instance, more of a plateau between AD 100 and 150, which might be better explained as the consequence of a modified procedure being developed for orichalcum manufacture towards the end of the first century, coincident with the deliberate addition of tin to the alloy. We can positively date this period from Domitian (AD 81) – but not from Nero.

A final point against the application of Caley's remelting theory to this second phase of orichalcum derives from his own observation that "when the proportion of tin begins to increase in orichalcum it does so in excess of the associated proportion of lead". If some older asses had been occasionally used in orichalcum remelts (as Caley also suggests) then - although they would have lowered the zinc levels by dilution, apart from any volatilisation – one would expect the resultant orichalcum lead content (because lead is generally much higher in the Republican leaded bronze than is the tin) to exceed the tin content, which it does not. The tin contents and other compositional characteristics of the orichalcum minted after Domitian cannot be explained by any theory which states that the earlier (tin-free) orichalcum was simply remelted, or that it was melted with additions of earlier copper or bronze. We have to admit a new phase of deliberate alloy development for the last two decades of the first century, thus rejecting Caley's view that the orichalcum coinage was "repeatedly remelted and reissued".

The next metallurgical phase which appears is the transition to zinc-bronzes, commencing c. AD 150, before a final period of overlap and replacement with highly leaded (and eventually zinc-free) tin bronzes in the mid third century. This was brought about, undoubtedly, by the exhaustion of the zinc ore deposits known to the Romans, which, as Caley observes, is the most likely explanation for the ultimate stoppage of orichalcum coin manufacture – which happened, however, well before its two denominations ceased to be minted, so alternative alloys had to be found.

The zinc-bronze period, extending over the latter half of the second century, was one in which many metallurgical experiments with alternative compositions requiring less zinc must have taken place, commencing early in the reign of Marcus Aurelius - as Caley observes. This is illustrated quite clearly in Figure 21 by proportions of zinc scattered between 10 and 1%, in association with increases in tin to 5% or more. It is quite possible that at this stage some attempt was made to conserve orichalcum by the recovery of secondary metal; but the general trend is rather one of unrestricted alloy developments involving first the more liberal use of tin, and then lead and tin together building up to quite substantial proportions. The coin analyses convey a superficial impression of lax metallurgical control; but there is some system in the progress as the orichalcum-related alloys pass from zinc-bronzes, to gun-metals, and finally to simple leaded tin bronzes containing no zinc at all. One then encounters just an occasional coin in which zinc is an essential component of the alloy - right up to the reign of Philip (AD 244-249).

Some of these later coinage alloys contain so much tin and lead that it is difficult to imagine that they were suitable for striking; yet their microstructures invariably reveal well-annealed structures which have been definitely struck in the final minting operation, and perhaps prepared by hot-forging close to form. X-ray studies of some of these pieces, however, reveal lead segregations which are consistent with the initial thicker coin blanks having been cast on edge; and often the remains of the casting sprue is evident, upon visual examination of that part of the coin edge which the striking hasn't reached. Some of the squarish shapes of these pieces are due to the original contours of their individual cast forms, or of cast notched bars from which they were parted before being shaped into blanks. There is no positive evidence that the coin blanks were ever sheared from sheet metal, as is sometimes supposed.

No satisfactory technological explanation has yet been given for the fact that ancient orichalcum is rarely found to contain 30% zinc, or more, although various writers have remarked upon it. The highest recorded zinc content for an Imperial coin which has been carefully analysed is Caley's determination of 26.71% in a dupondius of Caligula: the two next highest are H N Billingham's (24.13% zinc in a dupondius of Augustus) and the author's (23.96% zinc in a Lugdenese dupondius of Vespasian) - both reported in this work.

The question arises whether the Romans deliberately attempted a limitation - thus keeping all their coinage alloys within the more malleable single-phase alpha-brass range seen in Figure 22 - or whether there was a

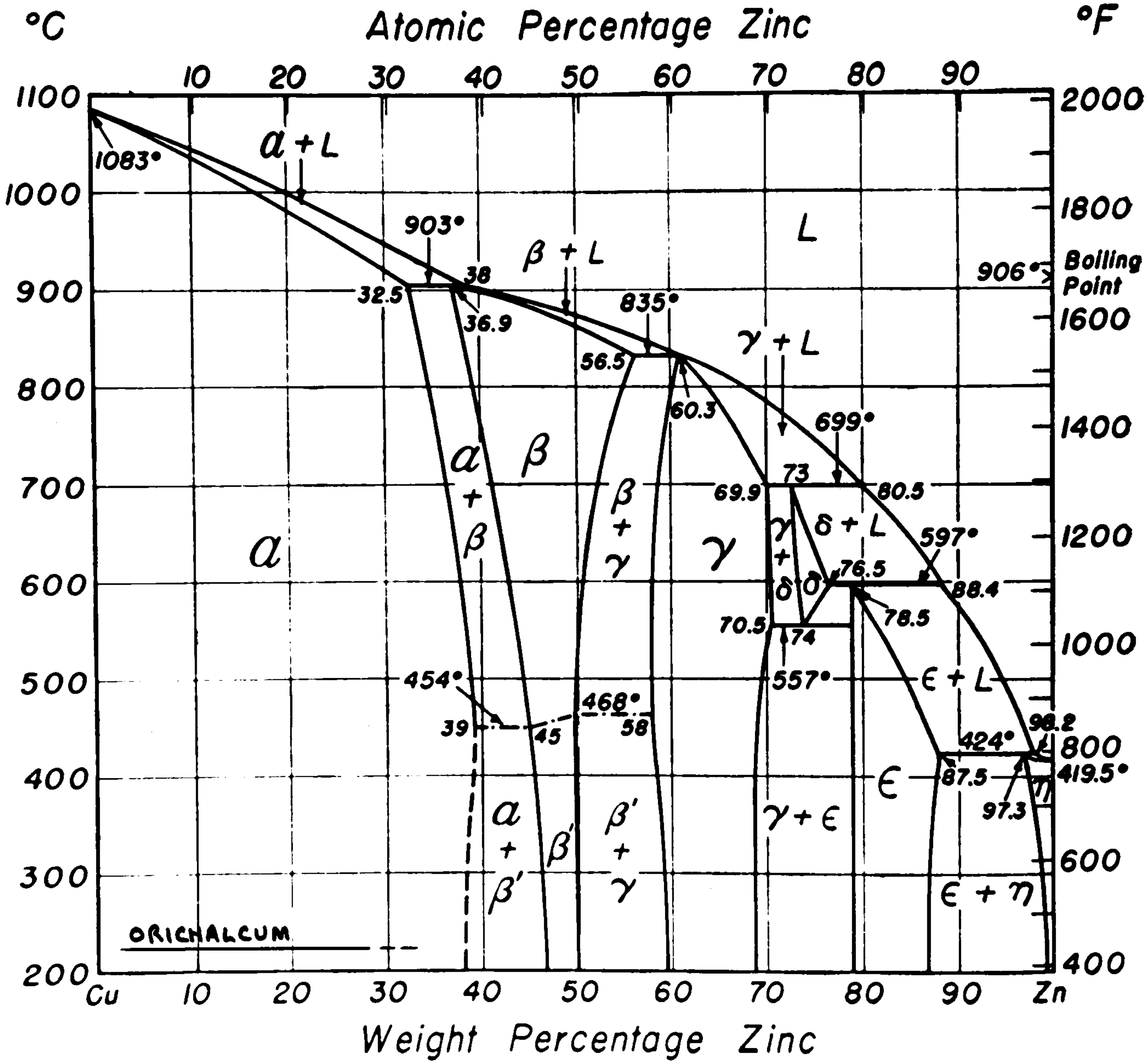


FIGURE 22.

COPPER - ZINC
ALLOY
SYSTEM

zinc content which could not be exceeded because of technical limitations to their brass-making process, of which they were unaware. Recently O Werner(295) conducted some experiments, one of which, roughly simulating calamine brass-making at 1000°C, showed that the reduction of zinc-oxide with charcoal in contact with a boat containing metallic copper would not raise the zinc content above 28%. In another experiment a 42% zinc brass heated in contact with the same mixture fell to 28% zinc after 2 hours. Werner concluded that the equilibrium between copper and the zinc vapour formed by the reduction of the zinc oxide is the limiting factor, and that only when the zinc vapour pressure is of such a level as that of molten zinc can brasses of higher zinc content be formed. But, as a reviewer(296) of his paper remarks, at higher temperatures (which were attainable without difficulty) such an equilibrium would be expected to move in favour of higher zinc contents; and it is possible, in the calamine process, for metallic zinc to condense at the cool end of the crucible and run (or be put back later) into the alloy beneath.

We should examine this matter, however, also from the points of view of chemical thermodynamics and binary alloy equilibria as they could affect the kinetics in a practical situation which might never be able to reach equilibrium. The Roman orichalcum is said to have been produced by heating together copper and calamine. Although carbon is not mentioned in the ancient manuscripts it must have been present in some form as the necessary reducing agent. This vital piece of 'know-how' might have been kept secret so as to preserve the State monopoly and frustrate any other attempts to 'purify' copper with 'cadmea' alone. A crucible charge would have contained small pieces of copper embedded in a mixture of zinc oxide and carbon (as perhaps charcoal) somewhat in excess of the total zinc requirements for a particular brass. The zinc oxide would have been obtained either from roasted carbonate or sulphide ores, or from flue deposits of the fumes from previous furnace charges. Heating the (preferably luted) crucible to a bright red-heat would have reduced the zinc, whose vapour would then diffuse into the copper, first in the solid state, to form a liquid brass alloy. The diffusion time allowed at zinc reduction temperatures would have been an important secret of the process, as would the rate of heating, because heating too rapidly to too high a temperature could cause copper to melt and descend to the bottom of the crucible before it had taken up enough zinc.

The free-energy diagram for oxides (Figure 4) reveals that at ordinary pressures zinc is gaseous at the temperature necessary for the carbothermic reduction of its oxide. Zinc normally boils at 906°C, but the lines for CO and ZnO intersect at 935°C for 2 atmospheres total pressure for the following reaction:-

$$\underset{\text{(solid)}}{ZnO} + \underset{\text{(solid)}}{C} = \underset{\text{1 atm}}{Zn_{(gas)}} + \underset{\text{1 atm}}{CO_{(gas)}}$$

At one atmosphere total external pressure, however, the minimum possible reduction temperature is 897°C - which is still well above the reduced boiling point of zinc (840°C) at the relevant 0.5 atm partial pressure. In practice, therefore, the process will only work to produce zinc gas, and a temperature more in the region of 900°C is required to maintain continuous reduction at a reasonable rate. Some of the zinc gas escapes from the crucible and reoxidises to oxide fume, but much of it diffuses into the copper pieces distributed within the crucible charge. If we assume that there is a sufficient excess of calamine and charcoal the copper will become enriched with zinc until it melts when it reaches the zinc concentration which matches the applied temperature according to the Cu-Zn binary equilibrium system shown in Figure 22. There it will be seen how the melting point of copper (1083°C) is reduced by zinc; so that if 900°C is the lowest possible temperature for brassmaking the zinc cannot rise beyond about 37% in any piece of the original copper without its becoming a molten brass droplet which can descend to the bottom of the crucible. Once there it is no longer surrounded by freshly generated zinc vapour, and it can only lose zinc by distillation if the heating is prolonged or if the temperature is raised. In Roman practice, with no critical temperature control, it is not an unreasonable assumption that crucible temperatures were nearer to 1000°C, and that on occasion these could rise higher. At 1000°C incipient melting starts at 17% zinc, and the zinc content for a completely liquid brass is almost exactly 20%. So one could expect the compositions of normal calamine-brass practice to fall between 17 and 37% zinc, with occasional lower levels if pots were overheated; and indeed the majority of the early orichalcum coinage (Augustus to Vespasian) depicted in Figure 20 is seen to be well within this broad range, with 20-24% zinc.

Now 2% tin will reduce the melting point of copper much more than 2% of zinc; so if pieces of low-tin bronze were put in the crucible charges, from the time of Domitian onwards, the more fusible ternary Cu-Zn-Sn alloys formed according to our description would possess an even lower potential zinc maximum and a lower average zinc content, in general. This is what is observed in moving from Figure 20 to 21; and when the tin content later exceeds 4% it is rare to find an 'orichalcum' with as much as 10% of zinc in it. In fact the highest zinc recorded for a coin minted after AD 130 (14.24% in a sestertius of Faustina II) is associated - as might now be expected - with an unusually low tin content (0.59%) for its day, as is a 13.38% zinc alloy of Hadrian (AD 134-138).

Tin-bearing orichalcum, or zinc-bronze as Professor Caley prefers to call it, may have become easier to make than plain orichalcum; and while helping to conserve zinc reserves as they dwindled it would have enabled the mints to preserve substantially the golden-yellow colour for which the older orichalcum coinage was renowned. Eventually, however, it would have become literally impossible to keep up appearances, and the leaded bronzes came into being out of simple necessity.

Lead does not appear as a regular alloying element in orichalcum until late in the reign of Antoninus Plus - c. 145 AD. A possible explanation could be the ultimate use of mixed zinc-lead ores before the known sources of zinc were completely worked out. Superimposed on an existing bronze-based orichalcum technology the result would have been the production of very fluid alloys of low zinc content, similar in composition to modern leaded gun-metals; and these coinages occur during the reigns of Marcus Aurelius and Commodus before the more highly leaded bronzes almost completely displace them.

Returning briefly to the early orichalcum process; Pliny's remark about the selection of particular coppers for their ability to "reproduce the excellence of orichalcum", and the rejection of Cyprian copper as suitable only for minting asses, calls for metallurgical comment, because all well-refined coppers should have been suitable, and our analyses show no trace alloy differences which should have hindered any stage in the calamine brass process. The one exception could be the residual oxygen, which is manifest within the metallographic structure of copper asses as oxide films or inclusions. Since zinc is a powerful deoxidiser it would meet such inclusions as it diffused into the copper and reduce them to their metallic state while replacing them in situ with zinc oxide. Poorly deoxidised copper would, therefore, provide a series of insoluble diffusion barriers, limiting the zinc penetration and thus preventing the formation of any high-zinc alpha brass. Maybe Pliny's remark on the metallurgical selection made in his day was an indirect comment on different achievements in deoxidising copper at the different refineries, It is perhaps significant, in this context, that the highest oxygen level found in any early copper coin was 0.15%, in an As of Vespasian (B. 151 in Table XIV) which was minted during Pliny's lifetime – in AD 71.

Pliny remarks that there was an Imperial brass industry in Cyprus; but O Davies(297) comments that the necessary calamine was apparently imported for the treatment of the local copper. D MacDowall, basing his judgement on Pliny's statements on ore sources, divides the early orichalcum coinages into three successive categories which he relates to each of the major sources of zinc exploited. For convenience these three chronological categories are shown by the vertical bands separating them into Augustan, Tiberio-Claudian, and Neronian issues, in Figure 20; but in his interpretation MacDowall may be confusing what Pliny intended as a list of contemporary sources of copper with successive ones for zinc - thus artificially dividing (but on an unreal metallurgical basis) three principal phases of early orichalcum by two periods of mint inactivity which he attributes to periodic exhaustions of the known zinc ore deposits. There is a chance, however, that some distinctive metallurgical features might yet be found for these groups. MacDowall's own judgement, that the middle Julio-Claudian issues are visually brassier than the rich golden issues of Nero from AD 63-64, is far too subjective for proper classification; and so far even the fullest analyses available do not show any consistent distinguishing metallurgical characteristics, for either the alloy or impurity contents, before Domitian. This is clearly a matter for deeper investigation in the future, but it will always be complicated by the influences of the separate zinc and copper characteristics upon the combined trace element patterns of the resultant orichalcum coins.

c) Sulphur in Roman copper and brass

The proportions of sulphur to be found in the early Imperial Roman copper and brass coins are more relevant to sources of copper, refining techniques, and the continuity of aes coinage production, than might be supposed. Sulphur is never present as an element, but it is usually found either as simple or complex insoluble metallic sulphides or oxysulphides fairly uniformly dispersed and recognisable within the microstructural phases of the finished coins. Sulphur originates in the minerals present in many copper, zinc, and lead ores and (because it is not feasible carbothermically to reduce the common metallic sulphides, most of which are also fairly soluble in liquid metals and in each other) some sulphides persist to the coin stage unless the original ores were adequately oxidised by weathering or roasting before reduction, or the metal was drastically oxidised in refining.

Today almost all copper is extracted from sulphide ores; but those ancient coppers which were extracted from the then more freely available, easily recognisable, and readily smelted oxidised ores are virtually sulphur-free. The exhaustion of these ores in the western world seems to have occurred quite early in the Imperial era, with important effects on the base-metal coinage metallurgy which we shall now reveal in connection with their numismatic implications.

In 1869, when chemical methods for analysing metallurgical materials were still at a primitive stage, E von Bibra(298) reported the discovery of determinable proportions of sulphur in three coins minted in the second century AD but no more than traces of sulphur in a few coins minted earlier. This remained the limit of knowledge of this facet of Roman metallurgy for nearly a century - until, in 1961, E R Caley(299) published seventeen new and thoroughly reliable determinations of the sulphur content of some first and second century Roman brass coins. He was, indeed, prompted to make this study by his earlier confirmation of suspected chronological variations in the composition of Roman brass; for he rightly judged that Bibra's results - although quantitatively suspect - provided qualitative evidence that the proportions of sulphur in Roman brass might also be variable in some chronological way. Aided by advances in metallurgical chemistry since Bibra's day Caley prepared uncontaminated and representative coin sector samples for accurate gravimetric determinations of the sulphur present in a range of closely dated orichalcum coins issued between 22 BC and AD 179. He devised a specially modified method to cater for the usual variety of alloys involved; and the author has independently endorsed its simplicity, precision, and accuracy, although it is a laborious process.

It is interesting that Caley's results - although much more reliable, and statistically significant - did not alter Bibra's original findings; but they firmly substantiated the previous slender evidence for the virtual absence of sulphur in the copper-based coins minted in the first century AD, and for its presence (up to as much as 0.31%) in all seven samples of brass coins minted between AD 116 and 179.

From these results Caley reasoned that the only likely sources of sulphur in Roman coinage brasses were the sulphide ores of copper, or zinc, or both; but that since sulphur had not been found to occur in more than traces in the plain copper coins - even those of the second century AD - the copper used in the manufacture of both the Roman copper and orichalcum issues was obtained only from oxidised copper ores in both centuries. Therefore the principal or sole source of sulphur in the second century brass coinage was a sulphide ore, or ores, of zinc, which came to be mixed with the oxidised ores of zinc, in increasing proportion, during the second century AD.

But the fundamental weakness in Caley's reasoning was his tacit acceptance of the demonstrably false premise that the second-century Roman copper coins are free from sulphur. Uncharacteristically he quoted no previous analyses in support of this, nor did he produce any new analyses of the copper coins to establish the basis of his hypothesis.

In recent studies of the second century Roman copper asses, however, and, using Caley's own method for sulphur determination, the author has discovered much higher general levels of sulphur in the Roman copper coins than in any of the contemporaneous issues of orichalcum, while generally confirming Caley's results for the latter. These sulphur determinations have been confirmed and supplemented by other analyses involving alternative reliable techniques already described in the section on analytical methods. Altogether sixty-six new sulphur determinations have been made of the different early Imperial <u>aes</u> coinage denominations as follows:-

Analysis technique for sulphur	Copper and bronze Asses	Brass and bronze Sestertii and Dupondii	Totals	Symbols used in Figure 23
Fusion-combustion	18	8	26	▲
" (LECO instrument)	11	9	20	■
Gravimetric (Caley's method)	7	5	12	●
Mass spectrometry	7	-	7	●
Hydrogen reduction	1	-	1	●
	44	22	66	

These results are plotted on a chronological basis for each of the two families of denominations, together with Caley's seventeen analyses of sulphur in orichalcum (plotted as open circles), in Figure 23. The forty-four results for sulphur in the Roman copper and bronze asses, quoted to the

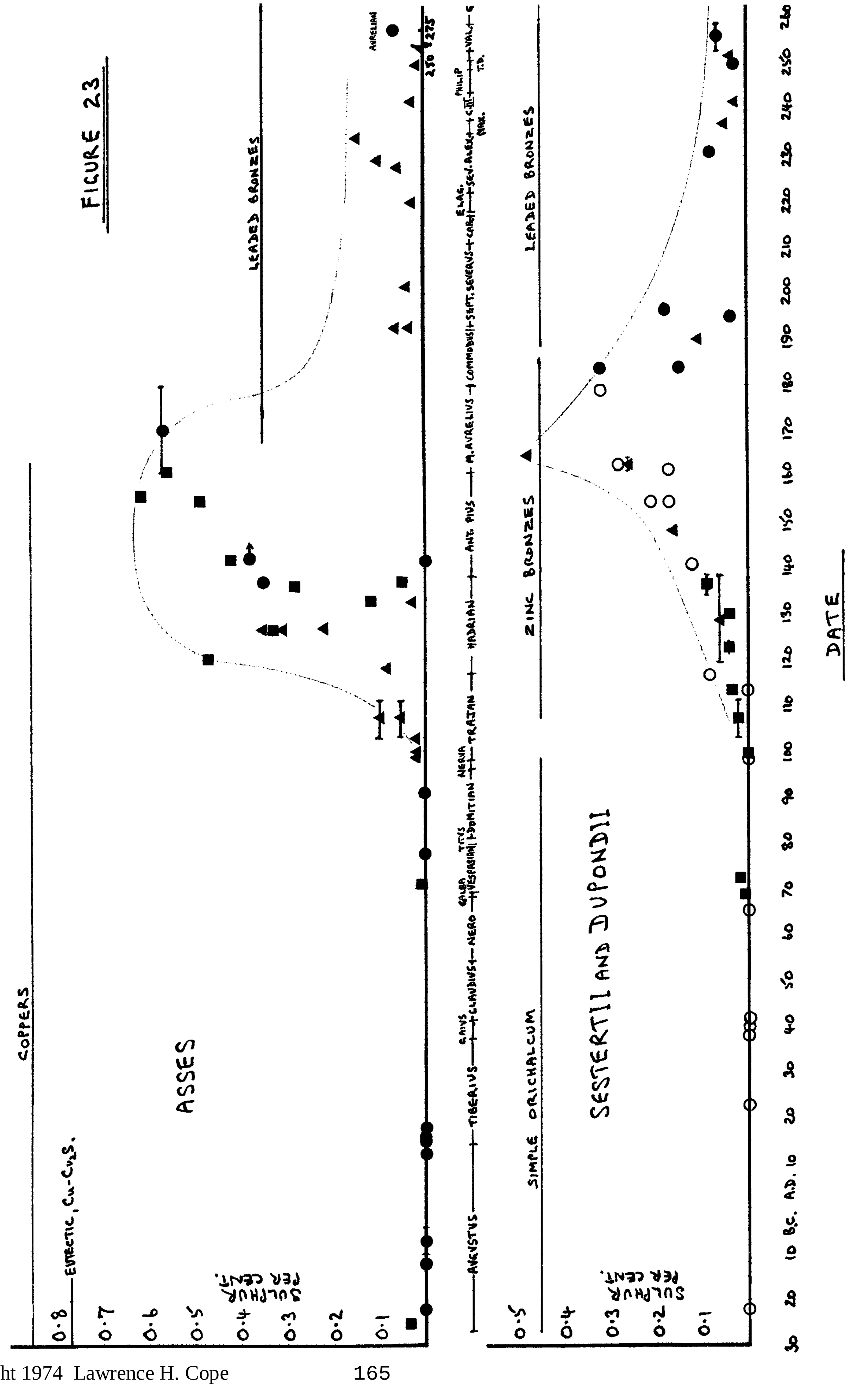


FIGURE 23
ASSES
SESTERTII AND DUPONDII
COPPERS
EUTECTIC, Cu-Cu$_2$S.
LEADED BRONZES
ZINC BRONZES
SIMPLE ORICHALCUM
LEADED BRONZES
SULPHUR PER CENT.
SULPHUR PER CENT.
0·8
0·7
0·6
0·5
0·4
0·3
0·2
0·1
0·5
0·4
0·3
0·2
0·1
AUGUSTUS
TIBERIUS
GAIUS
CLAUDIUS
NERO
GALBA
VESPASIAN
TITUS
DOMITIAN
NERVA
TRAJAN
HADRIAN
ANT. PIUS
M. AURELIUS
COMMODUS
SEPT. SEVERUS
CARA
ELAG.
SEV. ALEX.
MAX.
G.III
PHILIP
T.D.
VAL.
G
AURELIAN
250 TO 275
30
20
10 B.C. A.D. 10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170
180
190
200
210
220
230
240
250
260
DATE

degree of accuracy claimed for each determination, are detailed in Table XVII: the twenty-two new results for orichalcum and its related coinage alloys are given, similarly, in Table XVIII. The results - particularly those for the copper asses - really establish that sulphide ores of copper were, indeed, smelted in increasing proportions during the whole of the second century; for substantial sulphur levels are to be found first in the copper As coinage and much later in the bronze coinages of both denominations which contain no zinc at all.

Caley's opinion that the sulphur in second century orichalcum derived entirely from zinc ores has now to be rejected in view of the positive evidence for copper having been extracted from its sulphides, and the probability that sulphide ores of copper - rather than of zinc - provided the principal source of sulphur in orichalcum coins which - as Figure 23 clearly shows – have generally lower sulphur contents than their contemporaneous coppers. One must allow that eventually the sulphide ores of both metals might have been contributory, as both their oxidised ore deposits became depleted - but even then the influence of any zinc sulphide ores would still appear to have been less than those of copper.

A final point which refutes Caley's view is that if he had been correct, either in his assumption that the second century copper coins were free from sulphur, or that the sulphur in the contemporaneous orichalcum originated in the zinc alone, then one would not only expect to find negligible proportions of sulphur in the plain copper coinage of the second century but also no sulphur in those second century leaded-bronze coinages of both series which happen to be zinc free. Neither of these is so. The author and R Warren(300) have confirmed the presence of 0.18% sulphur in a completely zinc-free leaded bronze sestertius of Septimius Severus (AD 195-6), and 0.028% in a mid-third century sestertius of Trajan Decius (AD 249-51). The 0.085% sulphur present in a sestertius of Severus Alexander (AD 231), in a leaded-bronze containing only 0.25% zinc, would have represented an extremely high concentration of sulphide in the tiny amount of zinc in the alloy had the sulphur originated with the zinc rather than the zinc acting as a 'getter' for sulphides derived from the copper. These coin sulphur analyses (listed with others in Table XVIII) point to their coppers being derived from deeper mined sulphide ores – the weathered and purer oxide ores nearer to the surface having been mostly exhausted by their dates of issue.

It is most improbable that any other alloying component could have

TABLE XVII

Sulphur in Roman Copper and Bronze Asses

Coin Code No	Emperor	Date of Issue	Sulphur- wt.%		RIC No	Analysis technique
			Sample 1	Sample 2		
MAZ.1	Augustus	27-24 BC	0.0309	0.0321	Cohen 706	LECO, Bronze As (Spain).
B.2	"	22 BC	none	-	RIC.81	Hydrogen reduction.
B.3	"	12 BC	0.3 ppm	0.1 ppm	189	Mass spectrograph
LHC.34	"	10-4 BC	1 ppm	3 ppm	360	" " (Lyons)
LHC.73	Divus Augustus	AD 14-15	25 ppm	25 ppm	1	" "
MAZ.6	Tiberius	AD 14-17	10 ppm	25 ppm	Cohen 140	" "
MAZ.3	"	AD 14-21	10 ppm	2 ppm	Cohen 216;2	" " (Spain)
B.5	"	AD 22	15 ppm	20 ppm	RIC.16	" "
LHC.82	Vespasian	AD 71	0.0121	0.0131	482	LECO
B.10	"	AD 77-78	10 ppm	10 ppm	764b	Mass Spectrograph
U of S.3	Domitian	AD 90-91	slight trace	-	395	Gravimetric.
MAZ.16	Trajan	AD 98-99	0.02	0.02	395	Combustion.
B.174	"	AD 99-100	0.02	0.02	417	"
SL.31	"	AD 103	0.02	0.02	458	"
BM.462	"	AD 103-11	0.10	0.10	584	"
BM.463	"	AD 103-11	0.05	0.06	466	"
B.17	Hadrian	AD 118	0.08	0.07	546a	"
LHC.91	"	AD 119-21	0.457	0.465	616	LECO
B.122	"	AD 125-28	0.328	0.333	678	"
MAZ.19	"	AD 125-28	0.35	0.35	669c	Combustion
BM.464	"	AD 125-28	0.33	0.30	674	"
BM.465	"	AD 125-28	0.23	0.21	673	"
MAZ.18	"	AD 125-28	0.33	-	664	Gravimetric.
LHC.95	Sabina	AD 132-4	0.02	0.03	1039	Combustion.
LHC.93	Hadrian	AD 132-4	0.1143	0.1138	716	LECO.
LHC.92	"	AD 134-8	0.2864	0.2822	975	"
B.20	Aelius Caes.	AD 137	0.0508	0.0501	1067a	"
MAZ.20	"	AD 137	0.35	-	1068	Gravimetric.
B.66	M. Aurelius	AD 140-4	none	-	Ant.Pius 1238	"
B.29	"	AD 140-4	0.4186	0.4173	Ant.Pius 1232a	LECO.
LHC.96	Diva Faustina I	AD 141 +	0.38	-	1157	Gravimetric.
LHC.97	Ant. Pius	AD 154-5	0.4847	0.4988	934	LECO.
Ch.4	"	AD 155-6	0.6131	0.6142	936	"
MAZ.21	Lucius Verus	AD 161	0.5568	0.5677	1289	"
B.38	Lucilla	AD 161-80	0.57	-	M,Aur. 1741	Gravimetric.
B.47	Sept.Severus	AD 193	0.03	0.04	706	Combustion.
LHC.102	" "	AD 193	(0.06	0.07)	656	" (Top section)
			(0.07	0.07)		(Bottom ")
MAZ.26	Julia Mamaea	AD 220	0.02	0.02	674	Combustion.
SL.53	"	AD 228	0.06	0.06	677	"
Ca.41	Sev.Alexander	AD 229	0.10	0.11	498	"
SL.45	"	AD 234	0.16	0.14	540	"
B.173	Gordian III	AD 242	0.03	0.03	306b	"
MAZ.25	H.Etruscilla	AD 249-51	0.02	0.02	134b	"
AJHG.4	Aurelian	AD 274-6	0.066	-	80	Gravimetric.

TABLE XVIII

SULPHUR IN ROMAN BRASS AND BRONZE SESTERTII AND DUPONDII

Coin Code No	Emperor	Date of Issue	Sulphur- wt.%		Denom.	RIC No	Analysis technique
			Sample 1	Sample 2			
BM.199	Galba	AD 68-69	0.0111	0.0100	S	Uncertain	LECO
BM.200	Vespasian	" 72-73	0.0122	0.0111	Dp	739	"
LHC.86	Trajan	" 98-99	0.0074	0.0073	Dp	386	"
MAZ.17	"	" 103-11	0.0227	0.0247	Dp	545	"
B.64	"	" 112-4	0.0417	0.0420	Dp	603	"
LHC.90	Hadrian	" 119-21	0.0445	0.0409	S	569	"
LHC.89	"	" 119-38	0.06	0.06	S	610	Combustion
B.19	"	" 134-8	0.0900	0.0878	S	786d	LECO
B.25	Ant. Pius	" 148-9	0.16	0.16	S	855	Combustion
MAZ.22	Faustina II	" 161-4	0.25	0.27	Dp	1629	"
B.30	M. Aurelius	" 164-5	0.48	0.49	S	902	"
B.41	Commodus	" 183-4	0.32	-	S	400a	Gravimetric
B.42	"	" 184-5	0.1460	0.1288	S	440,452 or 459e	LECO
B.43	"	" 190	0.11	0.11	S	561	Combustion
Ch.5	Sept.Severus	" 194-5	0.0404	0.0399	S	678	LECO
U of S.4	"	" 195-6	0.18	-	S	706	Gravimetric
U of S.5	Sev.Alexander	" 231	0.085	-	S	515	"
SL.50	Maximinus I	" 236-8	0.05	0.05	S	82	Combustion
Ca.42	Gordian III	" 242	0.03	0.03	S	307a	"
U of S.6	Trajan Decius	" 249-51	0.028	-	S	112	Gravimetric
W.1	Treb. Gallus	" 251-3	0.04	0.04	S	116a	Combustion
B.121	Diva Mariniana	" 253-9	0.07	-	Dp	9	Gravimetric

contributed sulphur, since both the alloyed lead and tin present would have become sulphide-free by the normal extraction and purification processes; and this is testified by the purity of extant metal pigs. Although galena – mineral lead sulphide - was (and still is) the principal lead ore, it was usual for the Romans to smelt it alone and then to extract the silver from the virgin metal before reducing 'EX-ARG' lead from the recovered lithage. Cupellation is so powerful an oxidising process that it would have removed any trace of the original lead sulphides which, well below 1000°C, are virtually insoluble in extracted lead in any case; and the extremely low residual silver contents of the leaded orichalcum and bronze coinage alloys are confirmatory evidence that desilvered - and hence desulphured - lead was used for their manufacture.

So far as tin is concerned there is no evidence that it has ever been extracted from sulphide ores at any time: the principal source in all ages, has always been the oxide concentrate.

A remarkable feature of Caley's previously published sulphur determinations, and all the new ones listed in Tables XVII and XVIII, is that duplicate analyses are so close in value - even when (in the case of LHC 102) the X-radiograph of the coin shows an obvious severe lead segregation. This would not, at first, be expected, when one considers the high levels of sulphur discovered and the potential which would seem to exist for its segregation; but a general uniformity of sulphide distribution is indeed verified by the microstructures of quite dissimilar coinage alloys of the period. It is rare that such good fortune attends the work of the metallurgical sampler and analyst. The explanation is probably the ease with which the sulphides present form particles or eutectics having densities similar to those of their copper-alloy matrices of closely similar fusion ranges - thus diminishing both the gravitational and thermal segregation effects of sulphides which so bedevil iron and steelmaking.

The present work reveals two outstanding facts concerning the sulphur contents of early Imperial Roman copper, orichalcum and bronze. The first is the definite occurrence of high levels of sulphur in most of the early second century Roman copper asses - in spite of uncorroborated statements to the contrary: the second is a similar (but somewhat lower level) chronological trend for the sulphur content of second century orichalcum, extending into the subsequent - and previously unexplored - leaded bronze coinage era. Figure 23 illustrates these features graphically, and shows quite a dramatic step-change, from the analyses which are confirmatory of Caley's own for sulphur-free first century copper, to the highly sulphur-bearing coppers of c. AD 120 onwards.

It would appear that the principal sources of oxidised copper ores available to the Romans became exhausted early in Trajan's reign, and that his and Hadrian's moneyers were then forced to use increasing proportions of copper extracted from sulphide ores for new mintings of both the copper and orichalcum coinages. The trend continued, and the highest sulphur contents yet recorded for Roman coins - of about one half of one per cent - belong to both coin series towards the end of the reign of Antoninus Pius and the beginning of that of Marcus Aurelius (ie between 155 and 170 AD). Thereafter, metallurgical techniques for producing lower sulphur coppers from sulphide ores seem to have been developed coincident with the transition to leaded zinc bronzes. Then, in the third-century leaded bronze era, it is rare to find either an As or a Sestertius with much more than 0.1% of sulphur in its alloy. Apart from possible improvements in raw copper refining, there are good thermodynamic and metallurgical reasons to believe that it was these alloy developments which led to the lower sulphur levels found in the resultant coinages.

The effect of residual sulphur upon copper is to render it gassy and unsound, and rather difficult to coin. In modern copper refining practice sulphur is kept below 0.003% - which was the standard for most of the base-metal coinage before c. AD 90, according to both the new analysis data and Caley's. The visual effect of increased sulphur is a poorer surface quality, due to external blisters and spewing, and lower workability caused by the presence of internal embrittling eutectic films. These features are, indeed, manifest even on the selected second-century copper asses in the British Museum trays; and this was established after their potentially high sulphur contents were indicated by the analyses listed in this work. In general Hadrian's asses are dumpier, have rougher edges, and are less well finished than those of earlier or subsequent reigns.

The elimination of sulphur in copper refining requires a fine balance in the fire-oxidation of smelted metal, which the Romans would have found difficult to achieve; so it is possible that they would have made empirical attempts to compensate for the experienced loss in the coining quality of sulphided metal. Fortuitously, sulphides in copper affect the working properties only if the copper is otherwise of such high purity that substantial proportions of Cu-Cu_2S eutectic films can form at the grain boundaries. The presence of quite a small proportion of lead renders even high proportions of sulphur in copper comparatively innocuous by providing a physical means of entrapping widely dispersed sulphides as coarser globules of insoluble Cu_2S-PbS eutectic. It is perhaps quite significant that leaded coinage coppers make their first appearance during Hadrian's reign. It can hardly have been an accident because the contemporaneous orichalcum alloys of this reign - based on the same raw coppers - are found to be virtually lead-free; and so Hadrian's metallurgists can be credited with the discovery of the beneficial effects of adding small proportions of lead to the sulphur-bearing copper intended for coining.

Now in the case of the orichalcum of this era we have to consider the more effective purgative power of zinc which renders any additional treatment with lead quite unnecessary. Thermodynamically (see Figure 7) we know that of all the normal elements present in Roman copper-based coinages zinc is the one with by far the greatest chemical affinity for sulphur at metal-melting temperatures, and this is confirmed by the electron probe analyses made by R Warren(301). Furthermore, when copper is desulphurised by zinc the resultant zinc sulphide is of lower density than the melt and has an appreciable volatility - for it can sublime at 854°C or boil at 1182°C – and so it can rise to the top of the melt and transfer some of the sulphur from the metal to the slag and to the furnace atmosphere. Any residual zinc sulphide then exists within the solidified metal as a comparatively harmless $ZnS-Cu_2S$ eutectic, often isolated and entrapped in small globules of the lead-phase when this is present. This could provide the explanation for the facts that the sulphur-bearing orichalcum alloys depicted in Figure 23 show no signs of having been difficult to coin and that - while showing similar chronological trends - they contain much less sulphur than the contemporaneous asses. This is the exact opposite of what might have been expected if zinc sulphide ores had been the principal or even an additional source of sulphur in second century orichalcum. Alternatively the earliest phase of sulphur-bearing orichalcum (say, from AD 100-150), when much lower sulphur contents are manifest than in the coppers, might be explained by the diluting influence of zinc in a period in which it was still being derived from oxide ores while copper was starting to come from new sulphide ore deposits.

Thereafter, the increase in orichalcum sulphur content follows rather more closely the copper coinage trend. But in whatever way we consider the present evidence there is no certainty that sulphide ores of zinc, as such, were ever used for making Roman coinage alloys, whereas it is clear that copper sulphide ores were - from just before the end of the first century AD. Moreover, the manifest increases in the sulphur contents of both forms of aes coinage point to the regular preparation of virgin metal for minting – rather than the reclamation, remelting, and re-minting of earlier coinages – for that very period for which Caley postulated that re-melting explained the lower zinc contents. All pre-Nervan first-century orichalcum was virtually sulphur free; but no sulphur-free orichalcum has yet been found after AD 113, and Caley's own results confirm this.

Although zinc was the best practical and fortuitous desulphuriser for ancient copper, we have already seen that the Romans kept orichalcum quite separate from the metal for their asses at all times. Yet by the end of the second century there appears (in Figure 23) a dramatic reduction in the sulphur content of both series of coins - and this coincides with the general adoption of highly leaded tin-bronze alloys.

Now lead can be used as a mild desulphuriser of copper, but it is much more effective when present in the high concentrations typical of the coinage of this later era. Zinc refiners have long been aware of the volatility of lead sulphide, which readily finds its way into the fume concentrates produced by the Waelz rotary kiln process for treating mixed zinc-lead ores and furnace slags. Any prolonged heating of the leaded coinage bronzes could, therefore, have reduced their sulphur contents to more acceptable levels for minting purposes whenever sulphur posed a problem; and this might have become the regular treatment when difficulties were still being experienced in extracting and refining low-sulphur coinage coppers from sulphide ores, and when the known supplies of zinc for the alternative treatment of the orichalcum-related alloys were becoming exhausted.

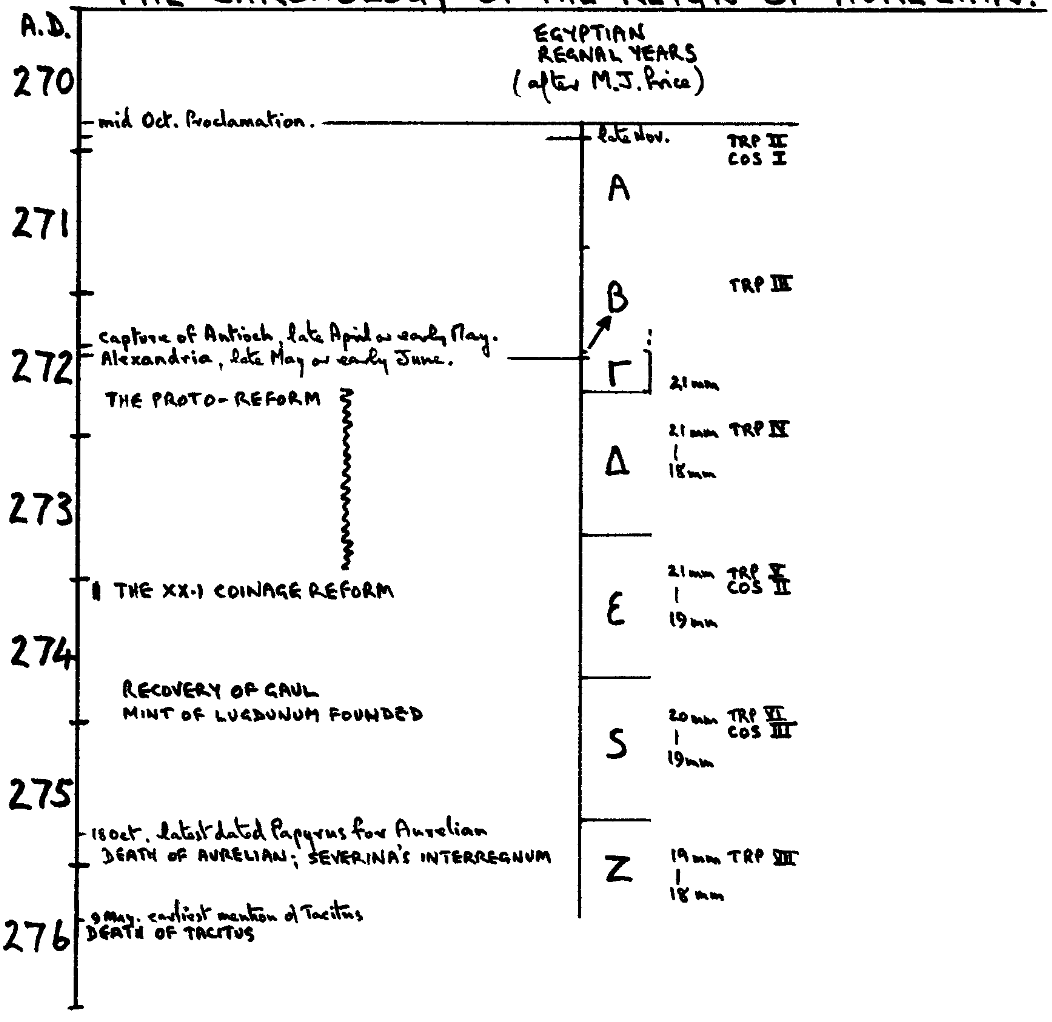
We might conclude, perhaps, that it was principally the metallurgical problem of spewing and porosity which encouraged the change from low-leaded coppers to the sounder zinc bronzes and highly leaded bronzes from which the remaining sulphur was partly volatilised or rendered relatively inert by chemical reaction with zinc or by physical entrapment in a comparatively innocuous form in the mixed lead phase which was the last to solidify. Nevertheless, all the metallurgical evidence for change is compatible, not with remelting, but with the continued issue of new aes coins, until they ceased to be minted in the mid third-century. By then it would appear that techniques for refining coppers to low residual sulphur contents had been developed.

From Aurelian to the Tetrarchs: the restored Imperial coinage, and the Alexandrian tetradrachms

Aurelian inaugurated a new numismatic era which, continuing for twenty years, established the basis upon which Diocletian's major coinage reform was possible with a minimum of complication. The dates of his reign, and the exact sequence of the events which affected his coinage, have long been the subject of conjecture; but these are now closer to resolution in consequence of the works of R A G Carson(302) and M J Price(303). Their combined historical sequence is taken here as fundamental, and it accords with the author's observations of the two metallurgical stages of the antoninianus reform and some parallel changes in the Alexandrian tetradrachms of the reign.

FIGURE 24

THE CHRONOLOGY OF THE REIGN OF AURELIAN.



Aurelian inherited an antoninianus coinage which had passed beyond its nadir under Claudius II to a recent improvement in quality with respect to both the fineness and its basic metallurgy. It is this coin which attracts attention as the principal object of the reform, because Aurelian's other measures amounted to little more than the adoption, at a more regular weight, of the 1/60 libra gold pieces previously introduced by Claudius, and the restoration of the old imperial aes denominations - now minted in leaded tin-bronze rather than in orichalcum.

The sequence of dimensional and intrinsic changes which took place in the Roman antoninianus between AD 270 and 274 may be most conveniently summarised as follows:

Date	Emperor	Coin Module	Weight Standard	Fineness
AD 270	Claudius II	19-20 mm	1/96 libra (ill kept).	6 scrupula per libra.
Sept-Oct 270	Quintillus	20-21	- ditto -	- ditto -
Oct 270-mid 272	Aurelian	20-21	- ditto -	- ditto -
Mid 272-273	" (proto reform)	22	1/84 libra	8 scrupula per libra
Beginning of 274	Aurelian (major reform)	20-21	- ditto -	10 " " "

Aurelian's first task after his proclamation was to secure and restore a financially and territorially impoverished Empire. This he managed, before falling an early victim to a base conspiracy. The matter of Imperial coinage reform may have been in Aurelian's mind quite early in the reign but, if so, it had to wait until he had established dependable frontiers along both the Rhine and the Danube, freed himself from the liabilities of Trajan's Dacian province, and concentrated upon regaining the Eastern provinces from the Palmyrene rulers and putting down a subsequent revolt in Egypt. Then came the opportunity for the coinage restoration and its western reform and the ultimate recovery of Gaul and Britain. This historical sequence of events, and not least the influence of Aurelian's familiarity with the East, is undoubtedly relevant to the interpretation of the reforms of both the antoninianus and the Alexandrian tetradrachm - whose inter-relationship at this stage will need to be worked out anew when more statistically significant assays and dimensions of both types of coinage spanning the reform periods can be obtained.

Aurelian created no radically new coinage system but rather set the older Imperial one on a new footing: the enigma surrounds the interpretation of the improvements made to the intrinsic value of the common radiate pieces which were minted at an improved weight standard - the module re-adjustments being perhaps for metallurgical convenience only - and in particular the denominational value ascribed to his final reformed antoninianus bearing the XX.I, XXI, XX, or KA symbols, and its relationship with the gold coinage.

R A G Carson(304) has suggested that the synonymous Latin or Greek numerical symbols indicated, perhaps, a content of two sestertii of ten libellae each. C H V Sutherland(305) preferred the view that XXI signifies 20 sestertii, ie 5 denarii; while S Bolin(306) (following W Brambach(307)) preferred the explanation that it meant one part of silver in twenty of copper, ie a 5% silver alloy. From a sound etymological point of view, however, H Mattingly(308) considered that the numerous variants of the XX.I mark can all mean 'twenty to one' or 'twenty and one', but they cannot all mean 'twenty one'; and he expressed the view that these marks on the Aurelianic reformed antoniniani - which are identical with those which appeared much later on the larger Diocletianic folles of c. AD 300 - almost certainly meant that the coin was a unit containing twenty smaller units. The problem is to identify the different units with reasonable certainty, and in the correct order, so that an explanation can be offered which is compatible with the similar alloys now identified for such widely different coins as the radiates of Aurelian and his successors and the large folles of Diocletian.

There are sufficient coin analyses now available to dismiss Brambach's interpretation of the marks meaning a 5% silver-copper alloy - yet we can retain his broad concept. The coinage alloy finenesses mostly fall short of 5% silver, but are consistent with a rather poorly maintained lower fineness standard.

Sutherland's reasoning for a 5d piece is cleverly based on a continuity of Roman tradition, the certain persistence of the sestertius as a unit of account long after the minting of sestertii ceased, and a parallelism of usage for the puzzling symbols. But its weaknesses are that it equates denominationally such widely dissimilar coins, minted a generation apart, and that the parallelism of usage argument can now be applied to the coinage alloy fineness with much more force than simply to the denominational value upon which Sutherland concentrated,

The Author's explanation(309) follows Brambach in the basic concept that it is the alloy fineness which is declared by the identical symbols on both the antoniniani and folles; but it reverses the order and the values of the units involved so as to match the assay evidence. Remembering that Aurelian would have become used, while in the East, to the obol (a half scrupulum) as a basic unit of weight, the finenesses of both reformed coinages can be explained as having been first decreed at twenty obols of silver to the libra (ie 3.47%). The XX.I and contemporaneous eastern folles of AD 299-306 are all very close to this norm(310). The alternative X ET I symbols which appear on some intermediate antoniniani of Carus and his family create no problem if the X is taken as the simple representation of the same alloy fineness in terms of the more familiar western scrupula, rather than obols; but the rarity of these pieces has precluded confirmatory assays yet being made.

The opponents of the author's explanation have attempted to argue that the coinage assays do not really support such a conclusion (especially for the antoninianus); but in one case(311) the published results are simply treated with unexplained prejudice, and in another(312) no allowance is made for the silver enrichment of the finished coins which would have been much more severe in the fabrication of the smaller module antoniniani than in the case of the large folles having lower surface to mass ratios for preferred base metal oxidation during processing.

In view of the controversial opinions, however, the matter must be re-examined in the light of further coin analyses now available. There seems to be no question that successive emperors, after Aurelian, preserved the reformed antoniniani at their 1/84 libra weight standard, and generally with their XX.I markings, right into the tetrarchic era and to the brink of Diocletian's reform. Thereafter the marks were never used on the subsequent radiate pieces, which can then be significantly shown to be void of silver.

In 1972 P Bastien(313) published twelve new analyses of Lugdenese antoniniani - one being selected from each of the twelve successive phases of minting which he identified and dated between AD 285 and 294. Their silver contents range from 2.88 to 5.10%, embracing a norm which (despite its mathematical impracticality to the Romans) Bastien considers to be about 4% silver, and therefore rather higher than, and disproving, the theoretical standard proposed by the author. In fact Bastien's assays vary widely and unevenly from 17% below to 22.4% above the nominal level for an XX.I alloy standard. What is most interesting is that their average silver content is about 5% on the high side of that norm - which is very close to the level of silver enrichment to be expected from the base metal melting losses attending a double melting procedure - first for the bulk melt and then for the coin buttons made from a divided cast strip, as described by the author(314) and demonstrated by D C C Potter(315). Furthermore, the coin weight statistics compiled from Bastien's own weight data for the identical families of Lugdenese coins (plotted in Figure 25) confirm a typical weight loss of about 4% from a theoretical 1/84 libra standard.

So; a reasonable metallurgical assessment of Bastien's own analytical evidence and coin weight data shows that the pre-reform Diocletianic antoniniani can really conform to an XX obols to I libra silver fineness standard for the original crucible melts. By way of confirmation the author's additional assays of Lugdenese antoniniani of the same reign fall into an even closer range, but with the almost identical average fineness value explained above:

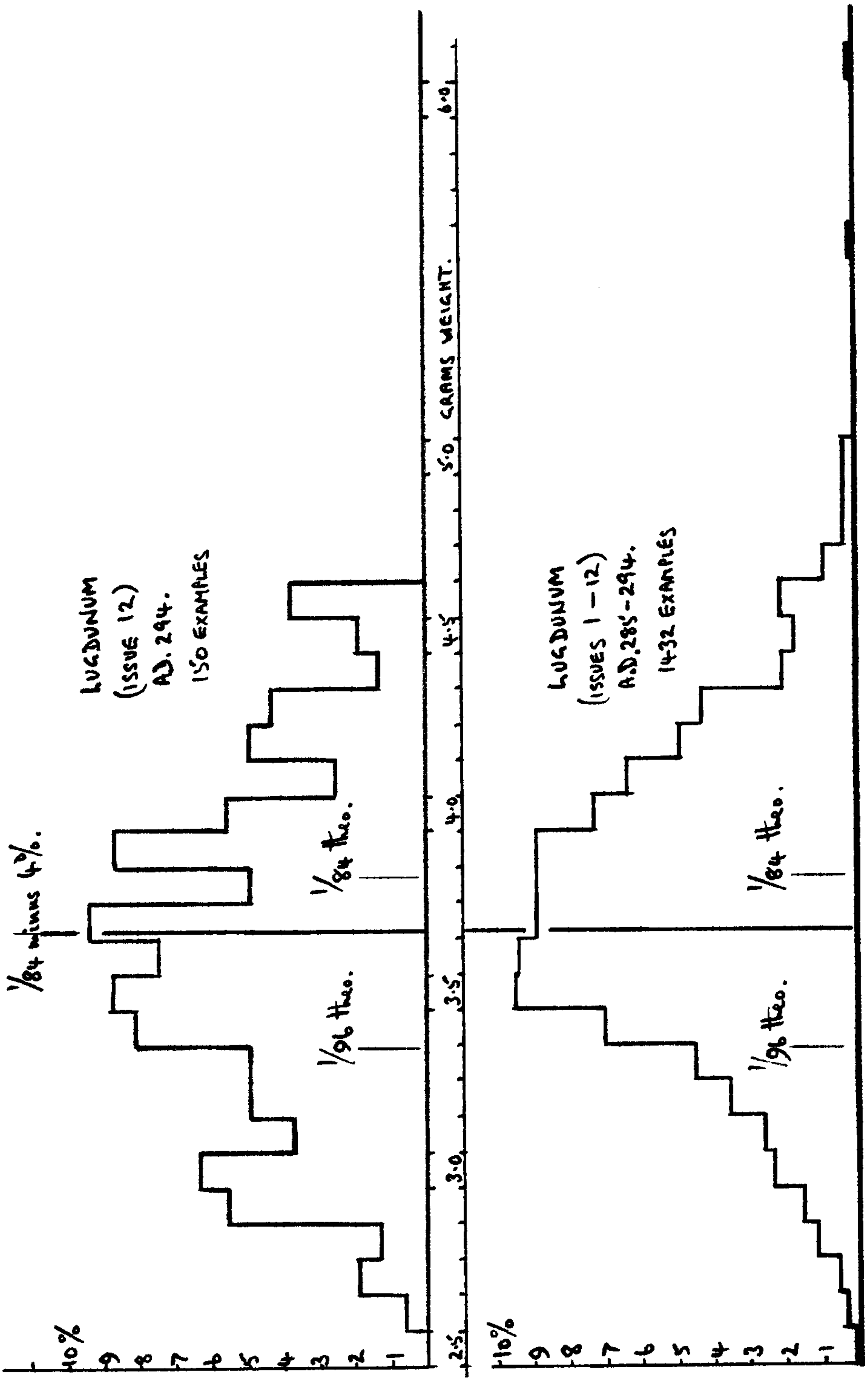
BM 177	4.13% silver	Average 3.99% silver
BM 178	4.08%	
BM 179	4.23%	
BM 180	3·57%	
SL 22	3.92%	

By no real stretch of imagination can these coins be properly attributed to a practical fineness standard higher than an improbable odd one of 11 scrupula per libra. A twelve scrupula standard could just be postulated in a few instances; but generally it would then be necessary to accept that serious weighing deficiencies with the silver alloy addition occurred and that there was negligible oxidation loss of base metal in processing. All the most recent assay evidence therefore strengthens the probability that the Aurelianic to Diocletianic antoniniani were based upon a 10 scrupula per libra fineness standard, predictably enriched by the nature of the metallurgical processes of minting.

In retrospect all the previously available reformed Aurelianic coin assays can be viewed in the same light - as can most of those minted between the reigns of Aurelian and Diocletian, which are listed in Table XIX. We meet, however, an inexplicable situation with the only available examples of Diocletianic XXI antoniniani from the mint of Rome. The coins appeared

FIGURE 25

WEIGHT DISTRIBUTIONS OF PRE-REFORM LUGDENESE ANTONINIANI



genuine enough to experts, but their finenesses match none but the first issues of the British usurper Carausius - with which they were just contemporaneous. Without further pieces for confirmatory assay the problem of their composition cannot be resolved. We know that Diocletian reopened the mint of Rome with a limited number of officinae; but what his special policy there was, if these coins are genuine, is difficult to discern. So profound is the difference in silver content compared with his antoniniani from other mints that there is just the possibility that the Roman mint issues were specially devalued.

If we take a strictly literal interpretation of the term 'Italikon nomisma' in the Rylands Papyrus(316) - as meaning the coinage actually minted in Italy, and at Rome, and not the Imperial coinage minted in general at places other than Alexandria - then we have here examples of coins which could correspond with the stated halving of the denominational value, and also a measure of the selected adjustments in intrinsic worth. But their dating seems to be much too early for this interpretation, for XXI coins at the normal standard continued to be minted in the East for at least another 8 years.

A metallurgical feature of the Imperial coinage issued between the reigns of Aurelian and Diocletian - and evident in Table XIX - is the much narrower and more optimised range of basic coinage alloys employed than before; and there is visible improvement in the quality of existing coins compared with the issues of the Gallienus-Claudius period. There are slight differences in mint preference, particularly with respect to the lead contents of the alloys. Bastien has also noted that his analyses of twelve Lugdenese coins reveal rather less tin than the present author had already shown to be present in Aurelian's coins and in some Lugdenese coins of different archaeological provenance but of the same broad period as those examined by Bastien. But nothing of numismatic importance hinges on this matter: Bastien's results simply show fairly consistent low tin proportions in coins all taken from one hoard, and the author's results match at least the observed extremes. The evidence simply reveals that in pre-reform days there was a certain laxity in general metallurgical practice at Lugdunum which has already been observed for its folles minted more than a decade later(317). One thing seems certain: the Lugdenese metallurgists probably preferred to put more tin in their coinage alloys, but for ten years they were prevented from doing so by the shortage of supplies due, no doubt, to

TABLE XIX

Analyses of antoniniani, Aurelian to Diocletian

Emperor	Mint	Die Module	RIC No		Composition - weight %			
					Copper	Tin	Silver	Lead
Aurelian AD 270 Pre-reform coinage								
LHC 13	Rome	20, 21	141		-	0.70	3.26	1.25
Aurelian AD 272-274 Proto-reform coinage								
BM 68	Milan	22	128		91.01	3.09	2.57	3.05
BM 69	Siscia	22.5;22	216		93.49	1.07	2.71	2.00
Aurelian AD 274 onwards Post-reform coinage								
BM 71	Rome	20;20.5	62		92.73	2.70	4.36	nil
BM 72	Rome	20.5;20	62		93.51	2.47	3.61	0.65
BM 70	Ticinum	21.5;20.5	151		93.69	2.13	3.89	0.24
AJHG15	Ticinum	21;20.5	154		-	-	4.52	-
Probus AD 276-282								
Ca 59	Ticinum	22	351		-	-	4.25	-
Carinus AD 283-284								
B 168	Rome	20.5	247		89.01	5.25	2.76	2.72
Diocletian and Maximian: Pre-reform coinage								
BM 182	Rome	21.5	506	AD 285-6	91.47	2.73	0.12	4.92
BM 181	Rome	21.5	162	AD 285-6	-	-	1.36	-
BM 183	Antioch	20	623	AD 285	88.55	2.21	3.56	5.33
BM 177	Lyons	21	43	AD 286	90.43	2.81	4.13	2.18
BM 178	"	21.5(est)	53	AD 289	92.07	0.69	4.08	2.76
BM 180	"	21.5	386	AD 292	91.62	2.02	3.57	2.29
BM 179	"	21.5	407	AD 292-3	92.66	0.45	4.23	2.03
SL 22	"	21.5	417		-	-	3.92	-
M3	Antioch	21	306	AD 284-294	92.33	2.43	3.10	0.81
BM 186	"	20.5	322	AD 293-4	-	-	2.30	-
BM 203	"	22,21.5	323	"	-	-	3.00	-
Diocletian: Post-reform radiate								
BM 205	Rome	20.51, 20	82	AD 297-298	90.68	3.62	0.13	5.38

the loss of Britain and its tin mines to the usurpers Carausius and Allectus.

We do not know the contemporary name of Aurelian's reformed 'antoninianus', nor can we be certain about its denominational value. Daniel Sperber(318) has narrowed the origin of the Greek term "follis" to the period AD 260-275, which includes Aurelian's reform. Originally the Latin word "Folsa" meant a bag – or to metallurgists the skin bag which was used for a furnace bellows - but Sperber points out that from AD 274 onwards the term could have been first used in a numismatic context to mean a bag containing a set number of coins, or their blanks; then (between AD 280 and 300) the individual blank units; and finally (from AD 300 on) a particular coin struck in copper (alloy). Later coinage laws contained in the Codex Theodosianus(319) seem to use the word in the context of either a bronze-based coin or, what might seem (from the quantity involved) a bag of them. Eventually the description fitted a single bronze piece; and the term is nowadays carried backwards from that certain time to describe the 1/32 libra argentiferous bronze piece of Diocletian's reform.

It is at this point, perhaps, that we should introduce the concept of contemporaneous intrinsic compatibility for considering the denominational relationships between the different types of silver-bearing alloy coinage which were to circulate in the later Roman Empire, because any Emperor had the choice - whatever the relationship between the lower denominations and his gold pieces - to distribute his silver between contemporaneous denominations in similar or different fineness alloys. Although the cost of the diluent base metals cannot have been negligible, the major value lay in the silver which could (if necessary) be recovered, refined and re-used for another issue of coinage. Accordingly, the nominal investments of silver – by weight - in parallel issues, can be used to determine unknown denominational relationships on a surer footing than hitherto. In this context the pre-reform XXI antoniniani of Aurelian to Diocletian, minted at 1/84 libra, would have each contained a theoretical silver investment of 10/84 = 0.119 scrupula, or 0.134 grams. These figures are important in the context of the later pieces with which they had to circulate over at least some period of transition, and with the tetradrachms of Alexandria with which they would have had to be interchangeable at some rate of exchange not far removed from comparative intrinsic worths.

The Tetradrachms of Alexandria

From the beginning of Empire until the completion of Diocletian's coinage reform the mint of Alexandria enjoyed the special privilege of minting its silver tetradrachms. Professor Caley(320) had made a detailed study of the metallic compositions of the earlier series - for they suffered similar, though not identical, debasements and weight reductions to those of the Imperial denarius which they outlasted by half a century. Caley's own results actually terminate with the analysis of two tetradrachms minted in Aurelian's fourth regnal year, and therefore in association with his proto-reform Imperial coinage at Rome. It is noteworthy that the levels of fineness which Caley determined (1.37 and 1.43% silver) are significantly less than those recorded by A Markl(321) (2.10-2.75%) for bulk coin analyses pertaining to the first three regnal years of his predecessor Claudius II. Otherwise all these coins were minted in argentiferous leaded tin-bronzes, of good general metallurgical quality, similar to each other and to the Imperial antoniniani of Aurelian.

An examination of the Aurelianic tetradrachms in the British Museum trays belies the quality of their materials, for many of them are struck on crudely shaped flans of widely differing weights without careful die-size control. There are indications, however, of changes in module which could signify that the tetradrachm was subjected by Aurelian to reforms paralleling those of the antoninianus. This remains to be investigated in detail when material can be made available. So far the author has obtained two pieces minted in regnal years 6 and 7 which do show that Aurelian approximately doubled the fineness standard of his later tetradrachms minted at the time of the XXI reformed antoniniani. This is an important numismatic matter which requires deeper investigation using closely dated Imperial coins for assays to compare with those of earlier dated Alexandrian coins - since it is not yet possible to be certain of either the weight or fineness standards of the reformed tetradrachms for the determination of intrinsic ratios and the possible denominational relationship established in AD 274 with the reformed antoninianus.

An analysis of an isolated Diocletianic tetradrachm of regnal year 6, published by W F Brazener(322) in 1934, and containing no silver, was at first regarded as suspect (or of a forged coin) in view of its exceedingly high lead content of 22.84%. But when the author's own analyses began to reveal similar alloys for undoubtedly genuine Diocletianic pieces the necessity of analysing other tetradrachms minted between the reigns of Aurelian and Diocletian became apparent - since it is numismatically important to determine the reasons behind the known undisturbed overlap of Diocletian's tetradrachm coinage with his major reformed Imperial pieces at Alexandria, and also the point at which the Aurelianic intrinsic-worth relationship between the two coinages broke down. The material available for assay is scarce; but the change from argentiferous bronze to a virtually silver-free and excessively leaded bronze for the tetradrachms has now been narrowed (as shown in Table XX) to the period August 277 to c. 284 - and probably to within the reign of Probus.

TABLE XX

Alloys of the later Alexandrian tetradrachms, Aurelian to Diocletian

Code No	Emperor	Ref No	Regnal Year	Date of Issue	Silver, wt %
Ch 9	Aurelian	Milne 4453	S (6)	Aug 274-Aug 275	2.11
W2	Severina	" 4480	Z (7)	post Aug 275	3.14
A 24	Probus	" 4516	A (1)	Aug 276-Aug 277	2.92
A 25	Numerian	" 4719	2	c. 284	0.35
LHC 120	Diocletian	BMC 2529	2	Aug 285-Aug 286	0.19;0.36;1.95*
LHC 118	Maximian	BMC 2555	2	Aug 286-Aug 287	0.26; 0.12
A 21	Diocletian	Milne 4877	4	Aug 287-Aug 288	0.28
SL 21	Maximian	" 4922	5	Aug 289-Aug 290	0.20
A 20	Maximian	" 4932	5	" "	0.10

* A highly-leaded and much segregated bronze (see analysis below).

Alloy compositions:	wt % Copper	Silver	Tin	Lead	Iron	Nickel
LHC 120	76.23	0.19-1.95	4.26	16.99	0.07	0.01
LHC 118	76.86	0.12-0.26	5.07	17.27	0.04	trace
A 21	(77.40)	0.28	4.93	17.49	-	-

It is now abundantly clear that long before Diocletian began to rule there was no official intention of allowing the Alexandrian tetradrachm to be an intrinsic-worth coin in the manner of the contemporaneous XXI antoninianus minted elsewhere. It was probably the Emperor Probus – previously a governor in the East - who, for reasons not yet apparent, originated the Imperial policy to mint the tetradrachm henceforth as a purely token silver coinage, thus paving the way for Diocletian to treat the antoninianus alloys later in exactly the same way.

The disparity thus created between the tetradrachm and the antoninianus must have deeply undermined public confidence in the interchangeability of the two coinages - at whatever official rate was decreed. We can see now why the tetradrachm was so easily absorbed into Diocletian's major coinage reform, and could continue to be minted for a further two years (with whatever value was given to it) while having no permanent place in the new system. In contrast the argentiferous Imperial radiate was precipitously halved in value, and further issues interrupted, until they also emerged as token plain bronze pieces.

The disrepute into which the most debased tetradrachm fell, in Egypt itself, is manifest between the lines of the Greek text of the Rylands Papyrus(323); for we note that the Alexandrian official - having prior knowledge of the forthcoming devaluation of the Italian 'silver' coinage - required his subordinate to exchange his holdings of such coin into goods, and not (as might have been more easily accomplished) into current tetradrachms which, by reason of their negligible intrinsic worth, the official would have known to be vulnerable to either an identical devaluation, or even demonetisation, by the same pending Edict.

The Coinage of an Independent British Empire: Carausius and Allectus, AD 286-296

In the summer of AD 285 Diocletian charged a Menapian, Carausius, with the defence of northern Gaul, the control of the Saxon shore, and the suppression of piracy in what is now known as the English Channel. In fact he made it so, for, encouraged by his success, his ambition, and his appreciation of the Channel as a means of both communication and defence, by the end of AD 286 he established himself as Emperor of Britain and part of northern Gaul. He struck his coinage at two British mints ('L' and 'C' - now commonly regarded as London and Colchester, although there is some uncertainty about the latter) and also in Gaul at, perhaps, Boulogne and Rouen.

Compared with the Imperial radiates the antoniniani of Carausius, and especially those of his assassinator and successor, Allectus, are rare; and there is no record of any piece having been previously analysed. Metallurgically, some of the earliest ones in particular are rather crudely executed in comparison with their Imperial counterparts; but they are really found to be minted in better quality bronzes - of superior weight standard though of inferior fineness - made from purer raw materials.

With control of the British lead mines, and hence of their silver output, Carausius was in a good position to inaugurate a fine silver coinage a few years ahead of his continental tetrarchic rivals, Diocletian and his new colleagues Maximian, Constantius, and Galerius. It is, however, the metallic composition of the British 'antoninianus' and 'quinarius' coinages which are of greatest interest for comparison with the Imperial issues of their day – and the now available analyses are listed in Table XXI.

G C Boon(324) has advanced the theory that Carausius would have been short of skilled mint workers when he assumed power in these islands; and that, in consequence, he would have had to recruit a variety of metal craftsmen whose work is manifest in the rough, robust, and vigorous style of his British coinage. Furthermore, his desperate needs of coin could have led to the production of numerous 'unofficial' local official issues. There is some support for such a theory in the variety of alloy finenesses to be observed in some of the suspected forgeries and apparently official issues - whose basic alloy compositions are otherwise so similar.

There are some remarkable features of the British coinage which throw light upon the complete independence of the monetary policies of the usurpers, Carausius and Allectus, during Diocletian's dyarchy with Maximinian and well into the first tetrarchy.

The first important distinction is that the antoniniani of both British emperors were struck at a weight standard of 1/72 libra compared with the Imperial standard of 1/84 libra. This is abundantly clear from a comparison of the author's histograms for the almost unworn coins of the unpublished Burton Latimer hoard from Northamptonshire (Figure 26) with those for Lugdenese antoniniani, of almost the same period, which were weighed by Dr Bastien(325) and are depicted in Figure 25.

The second is that Diocletian's monetary reform of AD 294 prompted no parallel action in Britain - where Allectus minted as before except for the striking of an unusual smaller piece (a 'quinarius') in the final year of his reign. The only concessions to Imperial tradition were the general design features of the antoniniani and the use of XXI markings by Carausius between AD 290 and 293. Unfortunately, it has not been possible to obtain one of these pieces for comparative assay to discover whether the symbols were a metallurgically meaningless political device, or not.

The third feature is that the finenesses of the British coinages are significantly lower than those of the majority of the contemporaneous Imperial pieces in the pre-Diocletianic reform era, but their standard was continued well into the continental post-reform period when the Imperial radiates became silverless.

TABLE XXI

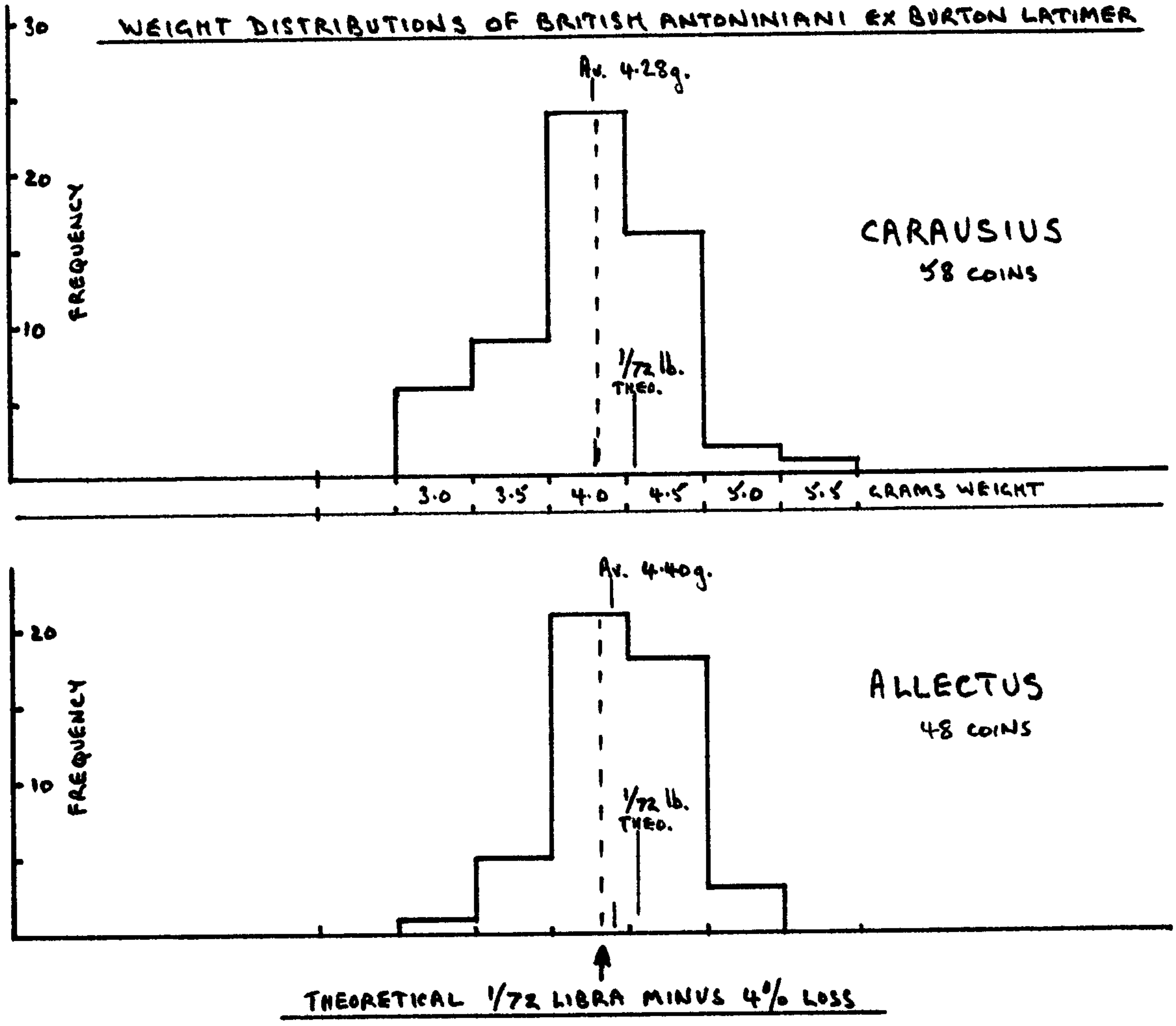
Analyses of the coinage alloys of the British Emperors Carausius and Allectus, AD 286-296

Code No	Reverse Type	RIC No	Data of Issue AD	Mint Mark	Composition, wt %			
					Copper	Tin	Silver	Lead
CARAUSIUS (AD 286-293) British 'L' and 'C' mints:								
LHC14	Moneta Aug	? 287	286-7	-/C	-	trace	1.46	0.91
Ca.60	Pax Aug	101	288-9	FO/ML	-	-	2.37	-
L.5	Illegible	Uncertain	291	S C/-	-	2.51	1.60	low
Boulogne mint:								
CJ018	Pax Aug	879	286-290	Unmarked	86.42	4.29	0.08	8.78
Ca.1	Pax Aug	880	287-290	"	94.88	1.23	0.17	3.24
NMW48	Pax Aug	880	"	"	97.70	0.48	0.16	1.58
Ca.61	Pax Aug	895	286-290	"	-	-	0.21	-
ALLECTUS (AD 293-296) British 'L' and 'C' mints:								
CJ021	Pax Aug	28	294	SA/ML	91.81	2.63	1.96	3.46
CJ020	Laetitia Aug	79	293/4	SP/C	94.01	1.43	1.16	2.90
Small Galley issues of quinarii								
CJ024	Virtus Aug	55	296	(QL)	-	2.37	0.06	3.38
NMW52	Laetitia Aug	124	296	QC	93.30	2.03	1.75	2.88
CJ023	" "	125	296	QC	94.23	1.80	1.54	2.77
CJ025	Virtus Aug	55	296	QL	91.72	2.14	1.07	2.93
Suspected forgeries:								
CJ019	Pax Aug	cf. 878ff			Rem.	1.11	0.74	1.74
NMW49	Sol Invicto	Copy of Victorinus Invictus type			"	2.28	1.88	0.22
H.7	Pax Aug	cf. 893ff			"	2.22	nil	moderate
H.9	" "			C/-	"	3.94	nil	present
H.8	" "			S C/-	"	3.02	1.44	low
NMW51	" "	cf 855			"	3.06	0.32	25.34

Note, that by virtue of their silver contents, NMW49 and H.8 might really have been genuine pieces: whereas CJ024 might be a forgery which looked genuine.

FIGURE 2b.

WEIGHT DISTRIBUTIONS OF BRITISH ANTONINIANI EX BURTON LATIMER



Finally, apart from the rough appearance of some, the British antoniniani were much better optimised than the western Imperial pieces to produce a tougher and more corrosion resistant coinage. The nominal impurities of the analysed coins listed in Table XXI have been determined but they are exceptionally low; and Dr R H Brill has obtained some lead-isotope abundance ratios for the author which indicate that the small proportions of alloyed lead present are of British geological origin.

The most comprehensive survey of the sequence and dating of the coinages of Carausius and Allectus is that of R A G Carson(326) - in which he reiterates, with additional evidence, his earlier view that the distinctive coinage of Carausius without mint-mark was most probably struck at his naval base of Gesoriacum (the modern Boulogne) to supply the needs of his territory in northern Gaul until the city was wrested from him by Constantius Chlorus in

AD 293.

The four analyses of the supposed Boulogne-minted pieces listed in Table XXI now provide added confirmation of R A G Carson's other arguments, for this coinage has quite a distinctive metallurgy. The tin and lead contents are more variable than those of the British minted pieces; but the absence of deliberate silver addition is by far the most important, in a period which preceded Diocletian's reform by at least three years. It shows a deliberate difference of monetary policy, by Carausius, for his continental territories and his island fortress.

The assay evidence suggests that it would have been most profitable for Carausius to receive infiltrating argentiferous Imperial antoniniani, to extract their silver (or simply to melt and dilute them with a similar proportion of copper), while re-issuing similar (yet larger) pieces of much lower intrinsic worth in Gaul. It raises the question of Diocletian's awareness of this problem, and whether the low-grade silver issues which we have already encountered as anomalous issues from the mint of Rome at about this time were specially minted for circulation in the fringe territories of northern Gaul in an economic attempt to frustrate Carausius. An obvious objection to this idea is the close proximity of the mint of Trier - from which northern Gaul would normally have received its coins. The Treveran coinage might have been similarly minted, for all we know; but the investigation of this point must await the availability of suitable material for assay.

The position of the fractional Q-marked pieces amongst the later coins of Allectus have long been a matter for conjecture. Their analyses indicate that they were minted in alloys of similar composition to the British antoniniani, and so their denominational value could be judged to be simply in proportion to their weight standards. They could well be true half-pieces; but if their accepted average weight of 2.68g (1/120 libra) is to be taken for precise comparison, the intrinsic-worth ratio would then lead to a two-thirds relationship.

The 1/72 libra British antoniniani of both Carausius and Allectus seem to have been minted at a fineness standard of about 5 scrupula per libra – or half that of the current Imperial alloy standard. On this basis the British Emperors would have benefited in silver from any interchanges with the normal Imperial coinage, at home as well as abroad, while offering more sizeable pieces for transactions in the opposite direction.

When we consider next the matter of Diocletian's coinage reform it is apparent that although three of the Colleagues later minted radiate and other fractional follis pieces there seem to be none at all for Constantius from his own mints in Gaul and Britain. It is suggested here that in AD 296 the existing lowly-argentiferous British radiate pieces, and 'quinarii', could easily have provided ready-made halves and quarters without the intrinsic-worth problems which attended the sudden devaluation and subsequent disappearance of the older Imperial antoniniani in the Central and Eastern territories.

Diocletian's coinage reform, and after; AD 294 to 309

So much has been written about Diocletian's major Imperial coinage reform and its consequences that it would be unnecessarily tedious to review it here in fine detail, for the known facts are few and tantalising, and the numismatic speculation has been extensive. The vital metallurgical issues involved, however, need to be discussed, because in the past they have either been overlooked, discounted, or treated in a superficial manner, largely because of the dearth of analyses of the different near-contemporaneous denominational pieces involved. Yet it is the coinage assays in particular which can throw clear light on many important aspects of the reform - and especially upon the much-debated matter of its quantification.

The certain facts are that, c. AD 294, Diocletian and his tetrarchic colleagues introduced a high quality silver piece into the coinage system in association with a much more plentifully-minted large laureate piece in argentiferous bronze. The leaded-bronze tetradrachm continued to be minted at Alexandria for a while; but the pre-reform argentiferous bronze antoninianus was soon replaced by a plain bronze radiate piece of similar dimensions, and a tiny bronze laureate piece also made its appearance. The new system was headed by an already established 1/60 libra gold piece.

R A G Carson(327) has aptly described Diocletian’s coinage reform as "one of the great landmarks in the history of the coinage"; for, although it was comparatively short-lived in its fullest original form, it set a fundamental pattern upon which the Imperial coinage was henceforth based.

New mints were created so that each of the four rulers could strike new coins at key points within his own territory, while matching the overall Imperial monetary policy and showing a spirit of concord by honouring his Colleagues (by inscription) on a proportion of his own mintings. The advantages of the trimetallic coinage system of earlier Imperial days was thus restored; and the opportunity was provided for a return to a flexible and controllable monetary economy in place of the local systems of barter, and cumbersome payments to the Government in kind, which had developed in the late third century.

There is little doubt that the system worked well for a little while; but an overall economic policy which - either ignorantly or willingly – disregarded economic laws, led to gathering inflation and an official attempt within five years to control both wages and prices by a Price Edict which P M Bruun(328) has fittingly described as "A monument of complete failure".

The basic problem has occurred repeatedly in the world's history - and not least in our own day - due, in the main, to the prevalence of human cupidity; but a proper understanding of the detailed factors involved in the case of Diocletian's coinage can only be obtained by a study combining the literary evidence with both the metallurgy and the metrology of the old coinage in comparison with the new. The latter had been much neglected as primary sources of critical data until, in 1966, Professor Bruun(329) adumbrated some of the intended coin weight reductions by suggesting that they "become intelligible when assessed in (Roman) carets". More recently, however, D R Walker(330), P Bastien and H Huvelin(331), the author(332), and his son(333), have all published data of increasing statistical reliability upon which calculations of the comparative intrinsic worths of the early Diocletianic and the weight-reduced fourth century argentiferous bronze coinages can be reliably based when their intended fineness are also determined from assays.

The unestablished facts about Diocletian's coinage reform concern the denominational relationships which existed between the various pre- and post-reform pieces, and the transitional and subsequent chronological changes which occurred. These have been partly gleaned from extant literary and inscriptional evidences - although not assuredly, for they have to be re-examined in their right sequences and contexts together with reliable information on metal-worths. It is this more comprehensive review which will be attempted here, using quantitative criteria wherever possible and restricting conclusions to those which can be most reasonably drawn in the light of the coinage assays and mensuration.

The brothers N & D Lewis(334) severely handicapped progress in dealing with some of the fundamental metallurgical principles behind the reform, for over 30 years, by their insistence - apparently supported by reliable chemical analyses - that the large follis was simply a plain bronze coin. D Lewis still insists(335) that the Seltz hoard coins which he analysed contained no silver and that his results were not affected by chloride corrosion. But the author has traced some of the remains of his sampled coins to the Archives et Bibliotheque de la Ville de Strasbourg, and in each cleaned coin there was found to be determinable silver and there were also chlorides present in the residual surface corrosion products which overlay a definite surface-silvering.

One of the first coin samples obtained from Strasbourg (Seltz no. 159 or 194) had obviously been previously sampled but was not listed amongst the published coin analyses: it was found to contain 1.63% silver. When challenged with this latest information D Lewis admitted that he did find 1.31% silver in his portion of that coin but says that he cannot now recollect why he omitted the analysis from the list. The remainder of the analysis is not unusual - except for a low analytical total:-

Code No. S2 (Possibly RIC vi Trier 671)

	D Lewis Unpublished Analysis (c.1937) Seltz hoard follis	H N Billingham Analysis (in 1969) of part of coin remains
Copper	85.87	85.45
Tin	5.61	5.81
Silver	1.31	1.63
Lead	4.57	6.90
Iron	0.08	0.04
Nickel	0.04	0.05
Cobalt	-	0.01
Zinc	-	0.02
	97.48%	99.91%

Ironically, it was the author's original impression of the importance of Lewis' results - in view of their obvious conflict with an opposite school of numismatic opinion - that stimulated his own studies aimed at confirming Lewis's conclusions; but after the completion of thirty-nine follis analyses – all of which contained alloyed silver - it became necessary completely to refute them(336), together with H L Adelson's(337) subsequent endorsement which had been based on no additional scientific evidence. The later works of M R Harold and C H V Sutherland(338), and of A Ravetz(339) - all involving neutron-activation assays, and showing the early folles to contain distinct proportions of silver - were, therefore, confirmed by the new chemical assays; and these authors also made the first analyses showing that the two smallest post-reform denominations are, in fact, the only ones in plain bronze.

A convenient comparison of the coinage system on each side of the first Diocletianic reform may now be made as follows:

Denominations (original names not all known with certainty)	c. AD 294	
	Pre-reform coinage (into 294)	Post-reform coinage (completed by early 296)
1. GOLD (also in multiples and fractions of the unit)	1/60 libra pieces (since Spring 286)	1/60 libra pieces (sometimes marked ≤, for '60')
2. FINE SILVER	NONE	1/96 libra pieces (sometimes marked XCVI) - the "nummus argenteus".
3. LARGE 'SILVER' LAUREATES (argentiferous bronze) c. 25 mm dies.	NONE	1/32 libra 'folles' pieces (not marked XXI until the second reform c. 299).
4. SMALL 'SILVER' RADIATES c. 21 mm dies.	1/84 libra antoniniani (some marked XXI)	NONE; but earlier argentiferous bronze coins (devalued?) overlapped in circulation, until replaced by virtually plain bronze radiates of similar die module but somewhat lower weight, c. 3g.
5. FRACTIONAL 'SILVER' PIECES	Rare 'denarii' in argentiferous bronze	Small laureates (c. 1.3g and c. 14 mm dies) in plain bronze - the new basic unit of the system, the "denarius communis" itself.
6. TETRADRACHMS (Egypt only)	1/40 libra leaded bronze	1/40 libra leaded bronze

On the basis of significant differences discovered in the finenesses of the eastern and western folles minted after AD 299 - when the XXI and KA marks first appeared on these large laureates - the author(340) has identified the principal metallurgical features of a second Diocletianic coinage reform which C H V Sutherland(341) had already suspected as having occurred c. 300-1.

Much confusion in the numismatic literature can now be seen to derive from the frequent assumption that there was only the one major reform, with the consequent application to it of the Price Edict and XXI marks of later date which, in any event, strictly pertain to the Eastern coinage only.

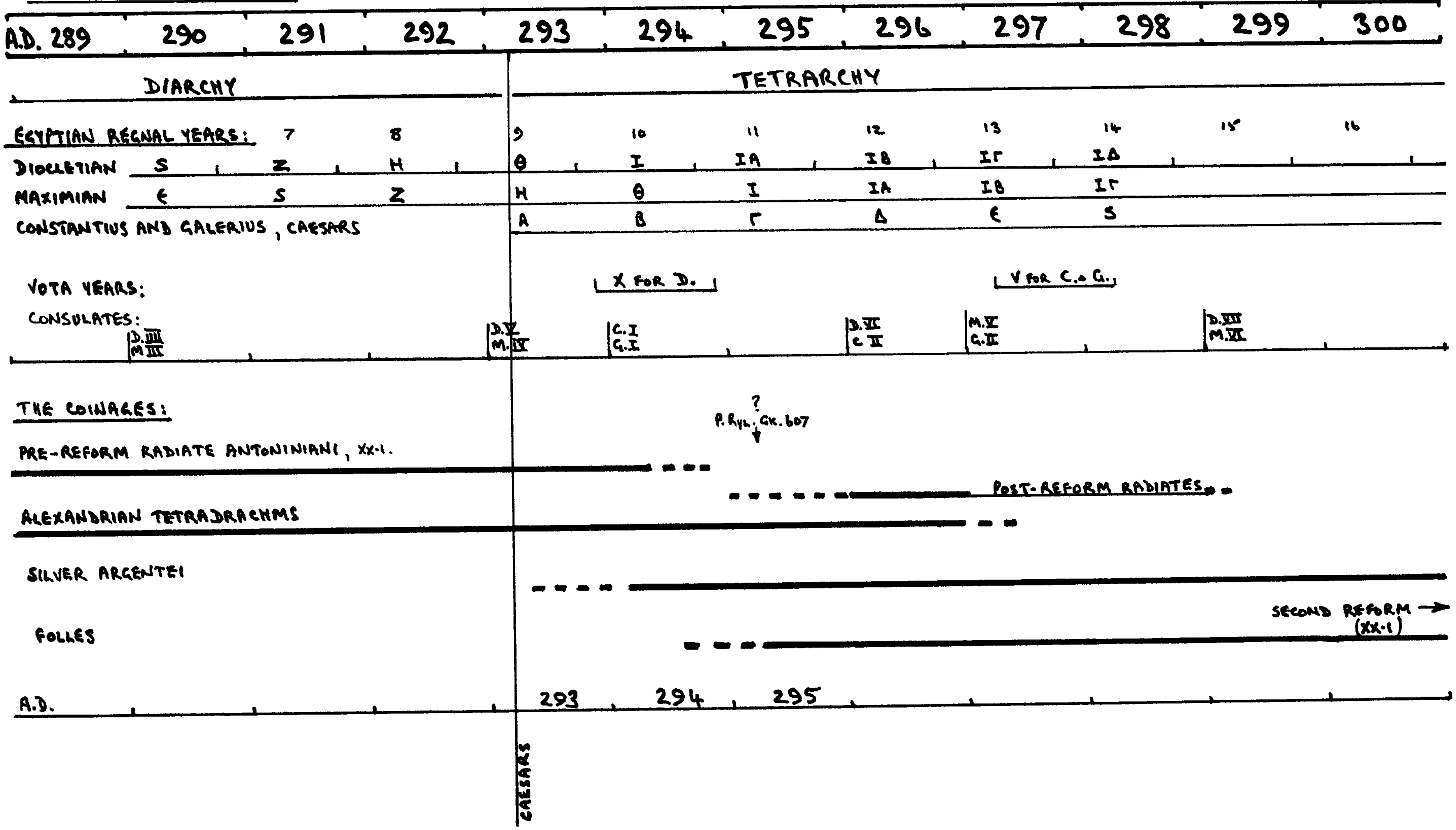
It is necessary, therefore, to divide carefully the chronological sequences of the numismatic events so as to keep the historical and metallurgically distinct matters apart for a new assessment of the original and the subsequent denominational relationships. The chronological progress of the coinage reform is depicted in Figure 27 to assist in our discussion of its elements; and it is immediately apparent that a major coinage reform affecting an Empire extending from the Channel coasts to Egypt could not have been a precipitate event, but rather a transition, phased, as circumstances would permit, from one coinage system to another.

While the mint workers would have found it delightfully easy to begin minting fine silver pieces to dimensions close to those with which they were already familiar, there would have had to be an experimental stage for the new follis, which was made larger than any coin minted for more than a generation. This could explain the variations in the quality of the earliest pieces, until more standardised production techniques were established; and it could also point to the origin of the different mint preferences (in basic bronze compositions) which the author has already observed, for each mint would have had to find an empirical solution to the tin and lead proportions which (in local opinion and according to availability) best facilitated, the mass fabrication of such sizeable coins.

But the most restricting factor would have been the time necessary to physically replace the old coinage with an adequate supply of new pieces, throughout the Empire, while the older pieces were being recovered for their substantial silver content. It must be taken as fundamental, therefore, that both the silver argenteus and the argentiferous follis, at their inception, would have had to fit neatly into the monetary system already operating, and bear at least simple transitional relationships with the existing pieces in circulation. It is these relationships which we shall attempt to determine, sequentially, using the principle of contemporaneous comparative intrinsic worths.

There has been much confusion in the past in applying the few extant pieces of coinage legislation to the folles reform. Thus H L Adelson(342), following N and D Lewis(343), applied the text of Codex Theodosianus ix.21.6 -

FIGURE 27. THE CHRONOLOGICAL DEVELOPMENT OF THE DIOCLETIANIC COINAGE REFORM



which pertains strictly to the quite different post-AD 348 coinage - to the follis of more than half a century earlier. Similarly, P Oslo III 83 - which most probably describes the coinage of AD 318 - has been associated(344) with the devaluation mentioned in P Ryl 607; while K T Erim, J Reynolds and M Crawford(345), in an effort to reconcile the assumed contemporaneous evidence of P Ryl 607 and the Aphrodisias inscription (to explain the doubling of one coin value with the halving of another) conceive that the writer of P Ryl 607 "doubtless believed" that a doubling of a higher piece effectively halved the radiate coinage whereas, in fact, the knowledgeable official concerned positively states that a particular coinage is to be halved in value. The lesson is to give more consideration to literal renderings of ancient texts than to postulated thoughts which might lie behind them. The simple acceptance that P Ryl 607 refers to a true situation some five years before the cutting of the Aphrodisias inscription, and that the document refers to the first reform and the inscription to a second one, requires no distortions in the light of the comparative coin assays. What could be more natural than that the old 'silver' radiate piece - because of its intrinsic worth - truly possessed geminata potentia after having been inappropriately halved at an earlier date?

An undertaking as great as the founding of a tetrarchic system of Imperial government; the provision of adequate mint facilities for each ruler to be militarily self-sufficient in his administrative territory; and a matching reform of the coinage, would have necessitated considerable deliberation and at least one joint consultation between Diocletian and Maximian. Yet there is no record that they met more than twice after their initial division of dominions - once in AD 288, and again at Milan in early January 291. So it was probably on the latter occasion that the defence of the Empire; the recovery of Britain; and the foundation of the tetrarchy, were agreed, in circumstances which would have necessitated consideration of new mint cities to enable each of the tetrarchs to mint a universally acceptable coinage. This would have left two full years for the choice and training of colleagues, and extra mint personnel, and for the development of a new coinage system and minting experiments with the larger pieces selected to replace the radiates as the principal coinage.

Dr Bastien(346) has established that the 1/60 libra gold piece became the standard one early in 286 - at the commencement of the diarchy - and it continued to head both the old and the new coinage systems. This presents no problem - except that its nominal value at each stage cannot be determined exactly.

The pre-reform XXI antoniniani continued in issue for at least a year beyond the foundation of the tetrarchy (on 1 March 293) because they are known for the two Caesars. Beyond that, VOT X pieces are known for Diocletian's tenth year of reign which commenced on 17 September 293, and antoniniani bearing consular busts are known for both Constantius and Galerius - who became Consuls on 1 January 294. Dr Bastien extends the known minting of these coins even to the saecular celebrations of 21 April 294; but beyond that date lies uncertainty, although it would seem that the last antoniniani were struck before the end of the Vota year on 17 September 294.

The new folles and silver pieces were entirely tetrarchic in their inscriptions and imagery (thus post-dating 1 March 293) but they bear no reference whatsoever to the Vota year. This strengthens the probability that neither of these denominations were issued before 17 September 294. One or other of Diocletian's Sarmatian victories - which commenced in mid 294 - is, however, celebrated on an issue of silver which is obviously not the first; and so some argentei may have been issued before the end of the Vota year despite inscriptional proof.

The first phase of the reform, therefore, was the introduction of the 1/96 libra piece into the existing monetary system. No chemical assay of these rare silver pieces has ever been made, but the visual impression is that they are of quite fine silver. They resemble Nero's first debased coinage in weight and module, but whether they are of similar alloy is not known at present.

On the assumption of the highest possible fineness we can calculate a maximum intrinsic (silver) ratio of the silver piece, with the existing XXI antoninianus, of 25.2 to 1. In practice an exact 25 to 1 ratio might have been reasonably accepted - especially if a small proportion of base alloy is present in the original silver pieces. A value of 100 denarii communes – which from the Aphrodisias inscription we know the coin certainly possessed later - would have exactly matched a 4 d.c. antoninianus on silver-worth alone. This is close to the 5d value which has been postulated for the XXI antoninianus (on the old assumption that the numbers mean that it was a 5d piece, of XX sestertii) but it avoids the intrinsic worth problem of having to accept an identical 5 d.c. value for the much larger and later XXI follis on the basis of the same reasoning.

The date of issue of the first folles is difficult to ascertain. At Antioch their mint officina marks show that they were issued with the first silver pieces; but at some mints the silver would appear to have been first. That they were planned to go together in the new system is certain, and so we should compare their intrinsic worths for an estimation of their intended denominational relationship. Pieces are known, from Alexandria, for Maximian's 12th Egyptian regnal year and the coincident 5th regnal year of Constantius, ie 29 August 296 - 28 August 297. Dr Sutherland shows, however, that several undated issues have to be accommodated earlier than these – including some for Domitus Domitatus whom Diocletian had to suppress in AD 295. The first folles were undoubtedly earlier than this, because Domitus copied them; and so Dr Sutherland(347) correctly deduces that a date within AD 294 is wholly compatible with the numismatic evidence for the reform. Evidently the transition from the old system to the new was accomplished in but a few months, with enough overlap of pieces to allow the new system to be grafted neatly into the stem of the old.

Now the early follis, being a 1/32 libra piece, had the weight-equivalent of just over 2.6 antoniniani. If made in the same alloy at the beginning – as some neutron-activation analyses due to M R Harold(348) and C H V Sutherland indicate - the follis would have had to bear at least 2.6 times the nominal value of the antoninianus in order to be a viable proposition. This corresponds with a value of at least 10 d.c. for it to circulate immediately amongst antoniniani of 4 d.c; and this is the lowest initial value which ought to be placed upon it, rather than (for example) the 5 d.c. value which Dr Sutherland(349) derived without knowing the relative intrinsic worths of the contemporaneously circulating pieces.

New analytical evidence does not, however, quite support the use of the XXI fineness alloy for the early folles. Until the second coinage reform of c. AD 300 even the eastern pieces do not appear to have been made to quite so high a standard(350) but closer to one of 8 scrupula per libra. Six additional assays of the early coins minted between the two follis reforms, given in section A of Table XXII, indicate (with only one exception) that this lower standard was soon effective, even if not the first selection.

Several large inter-reform hoards deposited between AD 297 and 300(351) show that there was a mixed coinage circulated in this period, but that there was a tendency in the West to hoard antoniniani in preference to folles:

TABLE XXII

New assays of the large folles of AD 294-308

Code No	Date of Issue AD	Mint	RIC vi No	Die Module (mm)	Silver, wt %
A. First-reform coinage:					
BM249	c. 294	Trier	137a	24	2.99
BM250	296-7	Ticinum	32a	24.5;25	3.64
BM258	"	Trier	181a	25;25.5	3.13
Ca.66	"	"	213a	25	2.14
BM260	c. 298	Lyons	31a	26; 27	3.18
BM257	"	"	53b	26	3.09
B. Second-reform coinage:					
a) Eastern					
BM259	c. 299	Siscia	109a	27	3.50
BM253	"	Alexandria	33a	25	3.48 An 'XX·I' marked piece
b) Western					
SL33	300-1	Rome	100a	26	2.49
BM264	c.300-3	Ticinum	43b	25	2.08
BM255	c.301	Aquileia	31b	25.5	1.91 A 'V' marked piece
PB1	c.300+	London	15	25	2.17
PB2	"	"	22	25	2.44
PB3	c.303	"	23b	26.5	1.67
PB4	303-5	"	32	26	1.70
C. Post-abdication coinage:					
PB5	305-6	London	77a	26	1.87
Ca.64	307	"	85	24; 23	1.61
BM422	307	"	86	25;24.5	1.60
BM267	307-8	Lyons	253	25	1.48
LHC110	"	Trier	781	24.5	1.48
BM268	"	Trier	768 or 769	24.5;25	1.45
S.1	305-7	Trier	671	-	1.63 ex Seltz hoard
S.3	307-8	Trier	768	Possibly 25	0.86 " " "

Hoard	Date of Burial AD	Number of Coins in the Hoard		
		Antoniniani	Folles	Denarii
Thibouville	297-8	3215	31	10
Fresnoy-les-Roye I	"	1393	418	3
Clemont	300	655	131	0
Ettelbruck	300	1859	123	0

This situation changed after AD 300; for eighteen western hoards deposited between AD 300 and 318 contain pre-reform and tetrarchic antoniniani in diminishing proportions which indicate that they continued in circulation for a long while, and that they were certainly considered worth hoarding at all times. Their intrinsic worth, and their absorption into the new system are the most relevant factors, for, at the time of the first coinage reform, in late AD 294, the following pieces (plus, in Egypt, the tetradrachms) could have circulated together, without any problem:

	Old XXI antoninianus	New follis	New argenteus
Theoretical weight	1/84 libra 3.87 grams	1/32 libra 10.15 grams	1/96 libra 3.39 grams
Silver content	0.134 grams	0.353 grams (if XX·I alloy)	3·39 grams (if pure silver)
Silver ratio	1	2.6 (2.1, if 8 scrupula alloy)	25.2
Appropriate denominational relationships	4 d.c. (1 nummus)	10 d.c. (2½ nummi)	100 d.c. (25 nummi)

With the rapid proliferation of mints, however, and continued military activity and expenses in almost every territory, Diocletian (presumably with the cognisance if not the full agreement of his fellow Augustus) appears to have taken the drastic deflationary step of which the Rylands Papyrus is the positive evidence. Much silver would have been invested in the huge volume of pre-reform antoniniani circulating in the Empire, which needed to be recalled and issued more economically as 8 scrupula folles or as somewhat debased argentei. The method adopted seems to have been the halving of the denominational value of the Italikon nomisma to a half-nummus - so that, precipitately, all holders (except those like the *officialis* who had prior privileged information and time to get rid of them) would have found themselves with heavy losses of savings they might have made in pre-reform radiates in preference to the new issues of folles. The tetradrachms would have been immune by virtue of their negligible intrinsic worth, and their minting could have continued in deference to eastern sentiment at any convenient exchange value which the emperors cared to place upon them. Hence the temporary refuge which Dionysius sought for his money, in goods rather than in alternative coin.

Hoping for better days some folk would have hoarded their antoniniani: but those recovered to the fiscus would have had their silver extracted or could have been reprocessed after further alloy dilution into replacement folles of higher total nominal value. The outcome would have been a shortage of antoniniani and some measure of frustration of Diocletian's plans for bullion recovery. Dionysius' subordinate, Apion, made a note on P Ryl GK.607 that he had received the letter on 8th Pharmuthi (4 April) in what might well have been the year AD 295. (This may have been a self-protective move in case he didn't have sufficient time to do as he was told before the Edict was published.) Experts agree, however, that the coinage mentioned must have been the Imperial radiate. The circumstances could match its swift reduction from a 4 d.c. antoninianus to one of 2 d.c., with deflationary intent. Perhaps rather too hopefully, since the radiate was not actually demonetised, Diocletian expected its voluminous return to the Treasury in settlement of outstanding debts as well as future taxes.

The replacement of the disappearing coins with a suitable substitute for small change would have necessitated the minting of still-recognisable radiates of less intrinsic worth - and this is exactly what happened in 295 when the silver-free radiate coins began to appear in association with an even smaller laureate - perhaps the *denarius communis* itself. The analyses of the post-reform radiates of AD 295-8 bear ample testimony to the change in this traditional denomination from an intrinsic worth to a token-value coinage while it retained its recognisable physical characteristics. On the basis of known intrinsic worths the different coins of the system after AD 295 could have been:

Small bronze laureate = 1 denarius communis
Bronze radiate (and devalued antoninianus) = 2 denarii communes
Follis (of 8 scrupula silver per libra) = 10 " "
Nummus argenteus = 100 " "

The gathering inflation and consequent rising prices of the next few years would have led to a diminishing need for the small token pieces so that, by AD 298, they had ceased to be minted. When new fractional folles were next required - after AD 300 - they were quite different in style, and indicative of a revised coinage system based on folles of higher denominational value than before.

Diocletian's measures of AD 295 must have been only partly effective in recovering the silver he so much needed for the flood of new folles being minted. Effectively he had moved towards a much more debased main currency comprising the over-valued follis and a token radiate, which would have stimulated the disappearance of the argenteus, as well as the old radiates, as repositories of value. By AD 301 it became necessary to strengthen flagging confidence in the new currency.

Although the preamble of the Aphrodisias inscription gives the impression that Diocletian, Maximian, and their Caesars, were acting unanimously in a revision of the coinage system which was to be effective from the beginning of the new fiscal year, 1 September AD 301, the analyses of their subsequent folles show differences in fineness which amount to a loss of unity in monetary policy and the beginnings of political rifts yet to come between the Eastern and Western rulers.

The Price Edict has been dated to mid-301 and so we can accept that both records definitely refer to an Eastern coinage reform, if not to one which was completely paralleled in the west.

If the opening word of the Aphrodisias inscription can really be finalised to read Bicharacta m(oneta) we have a prime reference to some coinage which has been struck twice, and which was then the subject of a revaluation, perhaps because of its geminata potentia. There were actually two possibilities, and not just the follis as Crawford et al(352) suppose. First, there were the old Imperial antoniniani - still extant in circulation, as the hoards reveal, despite their earlier halving in value - which had been subject to a second striking as current plain bronze radiates; secondly, there were the 8 scrupula fineness folles which were about to be struck at the higher eastern standard which the author's previous work, supported by the additional assays in Table XXII, reveal. They both possessed 'doubling potential' of a kind.

The restoration of the old antoninianus to a valuation more in keeping with its current intrinsic worth would have brought some hoarded pieces back into circulation, and to the Treasury; while the doubling of the follis, at the cost of only a 25% increase in its silver content, would have been economically attractive. The other denominations could have withstood the change. It seems certain from the Aphrodisias text that the argenteus was established at 100 denarii communes - a value which (intrinsically) would have roughly matched an XXI alloy follis of 20 d.c. or could be made to do so if slightly debased at this stage.

It is suggested that the coinage system established in the Eastern dominions in AD 301 can, on known intrinsic worths, be compatible with the following system in which only the new XXI follis was significantly overvalued:

Small laureate bronze = 1 denarius communis) as
Radiate plain bronze = 2 denarii communes) before
Old XXI radiate, in argentiferous bronze = 4 " " (even, perhaps, 5)
Former follis of 8 scrupula per libra = 10 denarii communes
New XXI follis of 10 " " " = 20 " "
Nummus argenteus (perhaps debased) = 100 " "

This proposed system can be tested in various ways. The 'V' portion of the 'KV' symbol on the Antiochene folles can be taken to mean the fraction of the argenteus which the new follis represents; while the alternative 'K' and 'XX' symbols represent the alloy standard which has been determined by several assays of this coinage. The retention of the old follis as a 10 d.c. piece matches, in particular, the immediate Western change to a 5 scrupula per libra-fineness for the subsequent western pieces which do not bear any sign of the XXI marks to which they never became entitled. Maximian, in fact, set his revised follis standard at exactly one half of the new Eastern silver standard (see Table XXII), and matching the harmonious continuation of a 10 d.c. follis in the West.

In relation to an XXI follis of 20 d.c. the old antoninianus would have been a perfect intrinsic match at 7½ d.c. A rise from 2 d.c. to 4 d.c., although helping to bring it back, into circulation, would have still undervalued it somewhat in relation to the new follis; but a rise to 5 d.c. would have been more acceptable, and especially in relation to the folles then in circulation. We could match such a revision quite well with the *.... ri quinque den(ari) orum potentia* portion of one of the Aphrodisias blocks. Diocletian's newer bronze radiates would have also been sufficiently distinguishable by their reverses to avoid any confusion between the radiates: indeed, no more were minted, and it would seem that the new fractional pieces were halves and quarters of the follis - again matching a transition to a 5 d.c. piece for the smallest eventual fractional denomination of the large follis.

The proposed new system is also compatible with L C West's(353) statistical analysis of the frequency of prices found in the Price Edict. It is evident from these that a unit denarius piece was still necessary after AD 301, while the seven most common prices which we can extract from West's list show that coins minted with 2 d.c., 5 d.c., and 10 d.c. units (or their multiples) would have been the most convenient for everyday use:

Ranking Order	Price, in Denarii Communes	Frequency of Occurrence
1	4	87
2	100	51
3	50	38
4	200	31
5	30	30
6	20	28
7	2 and 16	23 each

L C West argues that these strongly support the need for a 4 d.c. piece. This would conveniently match the monetary system derived above for the post-301 coinage; but it must be admitted that two 2 d.c. pieces would have been equally useful for such small transactions - as they are in our own coinage today. We cannot deny, however, that a 4 d.c. price is by far the most frequent in the Price Edict, and this might have been deliberately arranged to foster the use of the older antoniniani still in existence. If we extract the occurrences of 4 (87), 8 (22), 12 (21), and 16 (23) denarii from the List, we encounter, in fact, as many as 153 instances. A 20 unit piece can also be seen to have been of great convenience at the time, while the common occurrence and multiples of 100 d.c. are self-explanatory in the light of the Aphrodisias description of the argenteus.

Assays of the large folles minted between c. AD 300 and the occasion of their first weight-reductions in AD 307 show quite plainly a sharp division between the monetary policies of the Eastern and Western rulers after what can now be judged to be rather unilateral action on Diocletian's part in AD 301. The differences in folles finenesses were illustrated by the author(354), in 1968, in the manner depicted in Figure 28, and are confirmed by the extra assays listed in Table XXII.

At Aquileia and Siscia the number 'VI' replaces the 'V' on folles

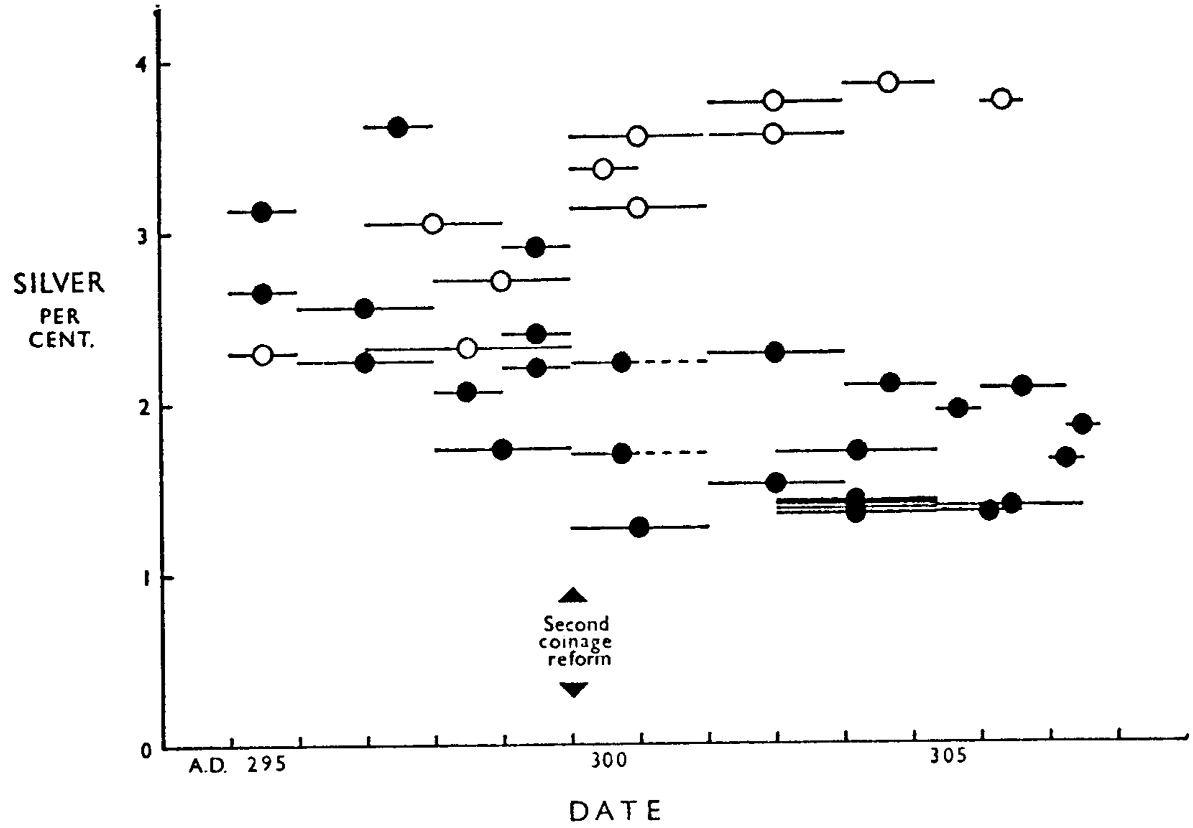


FIG. 5. Chronological variations in the proportions of silver in eastern and western follcs.

FIGURE 28.

minted in the middle of the period, but its exact significance is not known; furthermore, it has not been possible to obtain juxtaposed issues for analysis. It is possible, however, that the follis became a sixth part of the argenteus at this time - in the West if not in the East. This would have given it the not altogether inconvenient value of 120 d.c. which would accommodate the known increasing inflation and declining intrinsic value of the Western follis, for, although it seems to have been set originally at a 5 scrupula per libra standard in parallel with Diocletian's new standard pieces of exactly double the silver-worth, the standard soon fell to what was later to become the Constantinian and Maxentian standard of 4 scrupula of silver per libra. Eventually, therefore, Maximian came to invest only two-fifths of the silver which his fellow-Augustus was using in a seemingly identical coinage after the XXI markings ceased, and in addition he might have effected a 20% gain in the nominal value of the argenteus without changing the denominational value of the follis itself.

The large Eastern folles issues, even beyond the XXI marked pieces, seem to have maintained their fineness standard of 10 scrupula per libra to the end of the series - in early 307. In contrast a few issues of the large Western folles, minted near to the brink of the first weight-reductions in mid-307, fell to a standard of no more than 3 scrupula per libra (see Table XXII). It is interesting that one of these most debased issues was amongst the Seltz hoard pieces whose analyses were reported by D Lewis; but the author has confirmed their positive - though exceptionally low - silver values with assays of coins of other archaeological provenance which were minted at Trier.

Little is known of the coinage affairs of this era, except that the folles continued in issue in great volume, together with a small proportion of fractional pieces of undetermined fineness; but issues of the argenteus virtually ceased. Thus folles of two widely different standards became the principal coins of the Empire.

Diocletian's willing abdication, together with Maximian's more reluctant one, on 5 May 305, passed without any significant change to these coinage systems in the East and the West. From a point of metallurgical interest both families of folles alloys were made with almost equal, though widely ranging, proportions of lead and tin in them - as illustrated in the following graph (Figure 29) taken from the author's previous work on the alloys of the tetrarchic folles, in which the eastern folles are distinguished by the open circle symbols.

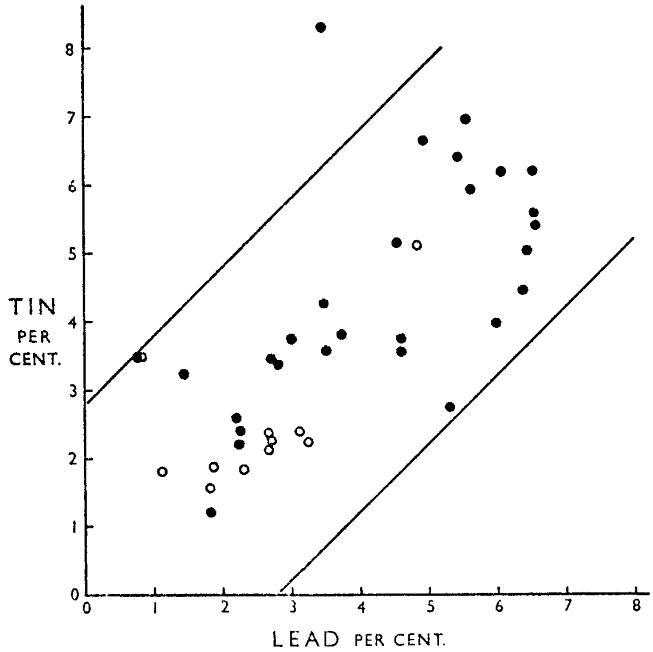


FIG. 3. Relationship between the tin and lead proportions of the large folles.

FIGURE 29.

The explanation offered is that adding a 50:50 Pb-Sn intermediate alloy to molten copper, to form the basic bronze, would have been the simplest method for introducing the more expensive tin in a form in which it would sink and dissolve, instead of floating and being subject to greater oxidation losses. In the West there was easier access to British tin - particularly after the recovery of Britain to the Empire in 296 - and it is from that date that the western folles alloys tended to degenerate, especially at the mint of Lugdunum, with the lavish use of tin and proportionately high lead levels which have made the western coins much more susceptible to corrosion than their metallurgically well-optimised eastern counterparts.

THE CONSTANTINIAN AND LICINIAN ERAS, AD 309-324

The revolt of Maxentius, son of the retired Maximianus, at Rome on 28 October AD 306, marked the beginning of violent disturbances in Italy in AD 307 which brought in their wake a heavy military expenditure and the emergence of an independent Maxentian follis coinage which lasted exactly 6 years.

The revolt was fostered by strong public resentment in Italy at the enforcement of severe tax-assessment measures which might have stemmed inflation for a while: in the event a necessary western coinage reform was precipitated, and minting ceased in the East until a more compatible – though still not identical - system could emerge in early 308.

In practice the follis was simply reduced in size - but not, presumably, in denominational value, in the West. Between mid-307 and mid-313 this process was repeated, in what have been identified as five western follis weight reductions(355) - although this number is uncertain because of the overlap of coin weights and variability in module, particularly in the earliest stages of reduction. In the East the temporary cessation of minting between the Spring of 307 and early 308 skips this problem.

Until quite recently numismatists had not appreciated that these weight reductions were in fact in fractional Roman libra steps, nor was it realised that groups of coins in overlapping weight categories can be separated more precisely by considering the additional criterion of die-module. In 1966 Professor P M Bruun(356) observed that "the development was one of gradual lowering of weight standard without any clearly defined steps on the way down"; and in the following year Dr C H V Sutherland(357) carefully plotted chronologically what he regarded as the "sliding" weights of folles, for each mint. When these graphical data were superimposed by the author – to obtain the rather narrower commonly applicable weight ranges - it became immediately obvious that these matched simple fractional libra weight standards which had been subject to normal metallurgical losses of oxidation during minting and subsequent coin wear. These superimposed weight data are shown in Figure 30 alongside a scale representing theoretical weight standards reduced by up to 10% to allow for reasonable combined losses of processing and use. Different time-scales apply for the adoption of identical standards in the East and the West; but four weight standards (1/32, 1/48, 1/72 and 1/96 libra), each of more than 3 years duration, are clearly identified, and the confusion which still applies to the weight-standard(s) of small numbers of coins minted in mid-307 is revealed. The 1/41 libra standard which J Lafaurie proposed for these issues on an average weight basis is questionable - for it matches no really practical fractional standard for minting operations; so Dr Bastien(358) has attempted to rationalise this to a similarly 'difficult' 1/42 libra standard, and has more recently suggested(359) that there was an additional 1/36-libra standard. A closer examination of the basic weight data quoted by both Lafaurie and Bastien, however, reveals that the imagined 1/41 and 1/42 fractions cannot be justified either metallurgically or statistically: they could just as readily match either 1/36 or 1/40 libra standards. Furthermore, the application of die-module criteria in this instance is only partly useful because of the small differences which obtain, which are found to be less than the scatter shown by groups of adjacent coins within individual mint-marked series. The matter is still one of conjecture - but of no great metallurgical or numismatic importance. If one has to locate a single weight standard for mid-307 the most convenient at the time might have been one of 1/36 libra.

Since the coins of this period were mass produced, and of such low intrinsic worth that individual weighing at the mint would not have been a practical proposition, the author(360) has postulated that the simplest combined production route and accounting procedure would have been to cast one-libra melts in the form of long strips - then to sub-divide these (estimating weight division by eye) by dichotomy or trichotomy based on the duodecimal system of weight, and subsequently to re-melt into individual sessile drops for the final coin-striking operations. The type of Iron-age coin moulds described by Dr R F Tylecote(361) - although not positively known for the later Roman period - would have been admirable for the purpose

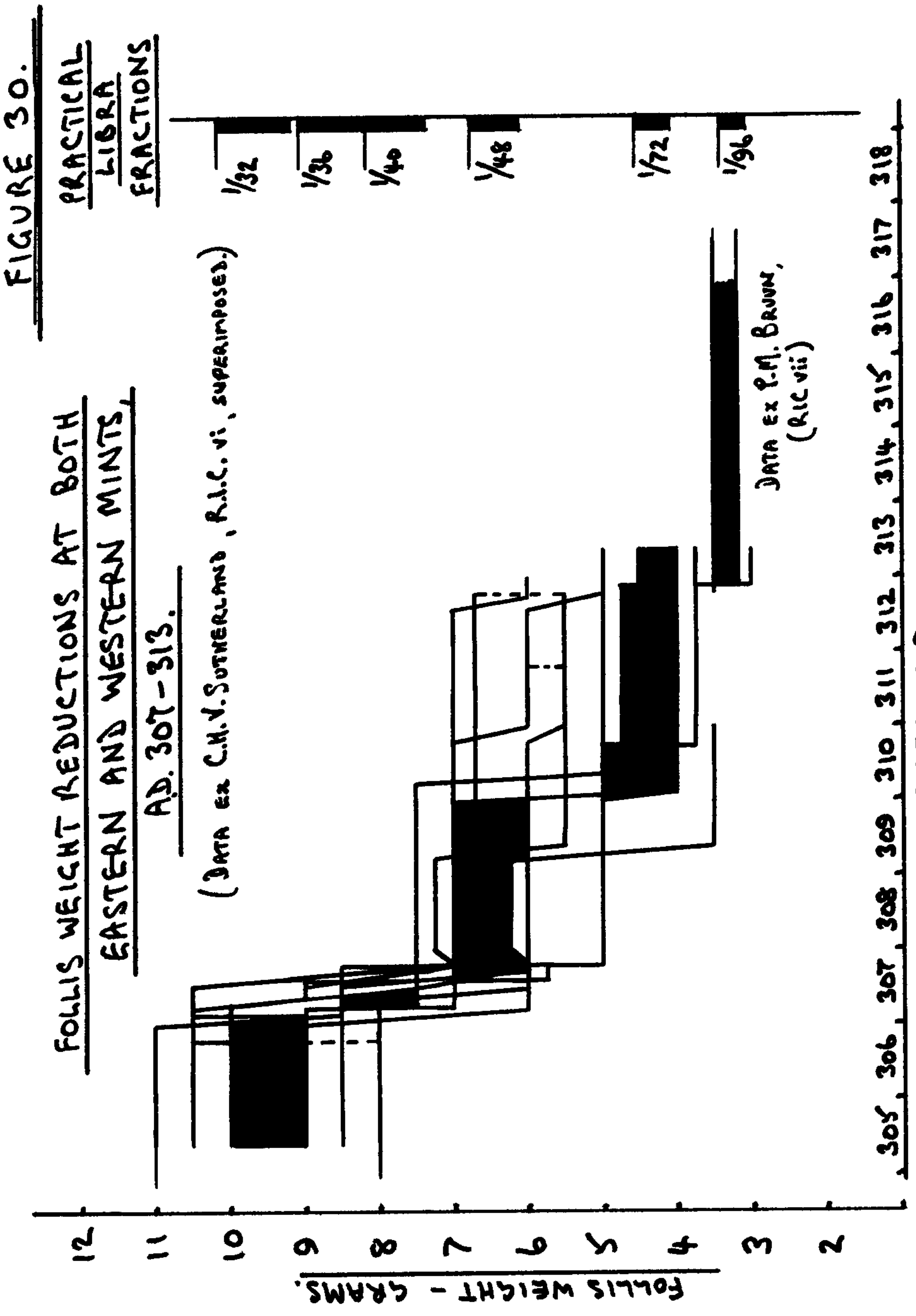


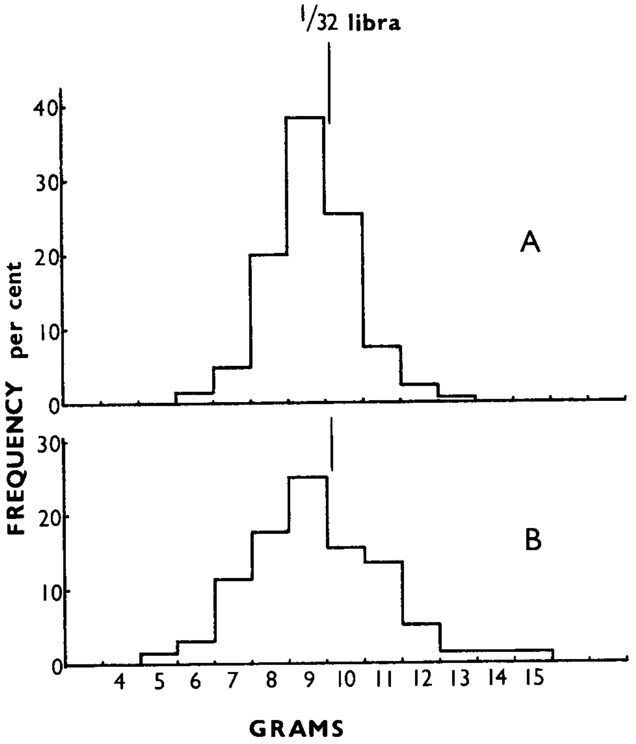
FIGURE 30.

FOLLIS WEIGHT REDUCTIONS AT BOTH EASTERN AND WESTERN MINTS, A.D. 307–313.

(DATA EX C.H.V. SUTHERLAND, R.I.C. vi, SUPERIMPOSED.)

of preparing small metal buttons from irregular-shaped pieces chopped from an initial cast strip.

This postulated method of fabrication was put to the test by D C C Potter(362), in 1969, using synthesised alloys of a typical Treveran follis composition. The 'coin' weight-distribution obtained from three one-libra melts is shown at 'B' in Figure 31, for comparison with folles from an actual hoard. There are remarkable similarities, and even the average weight for both populations is about 4% below the theoretical norm. Furthermore, the 'coins' made by this route - using comparatively unsophisticated techniques possible in the fourth century - possessed both the external form and appearance and the internal microstructural features of genuine 1/32 libra folles of identical composition(363).



A. Weight-distribution of the large Treveran folles found in the Domqueur Hoard. (Compiled from data recorded by P. Bastien and F. Vasselle, 1965.)

B. Weight-distribution of synthesised folles prepared by D. C. C. Potter according to the fabrication route postulated by the author (University of Surrey, 1969).

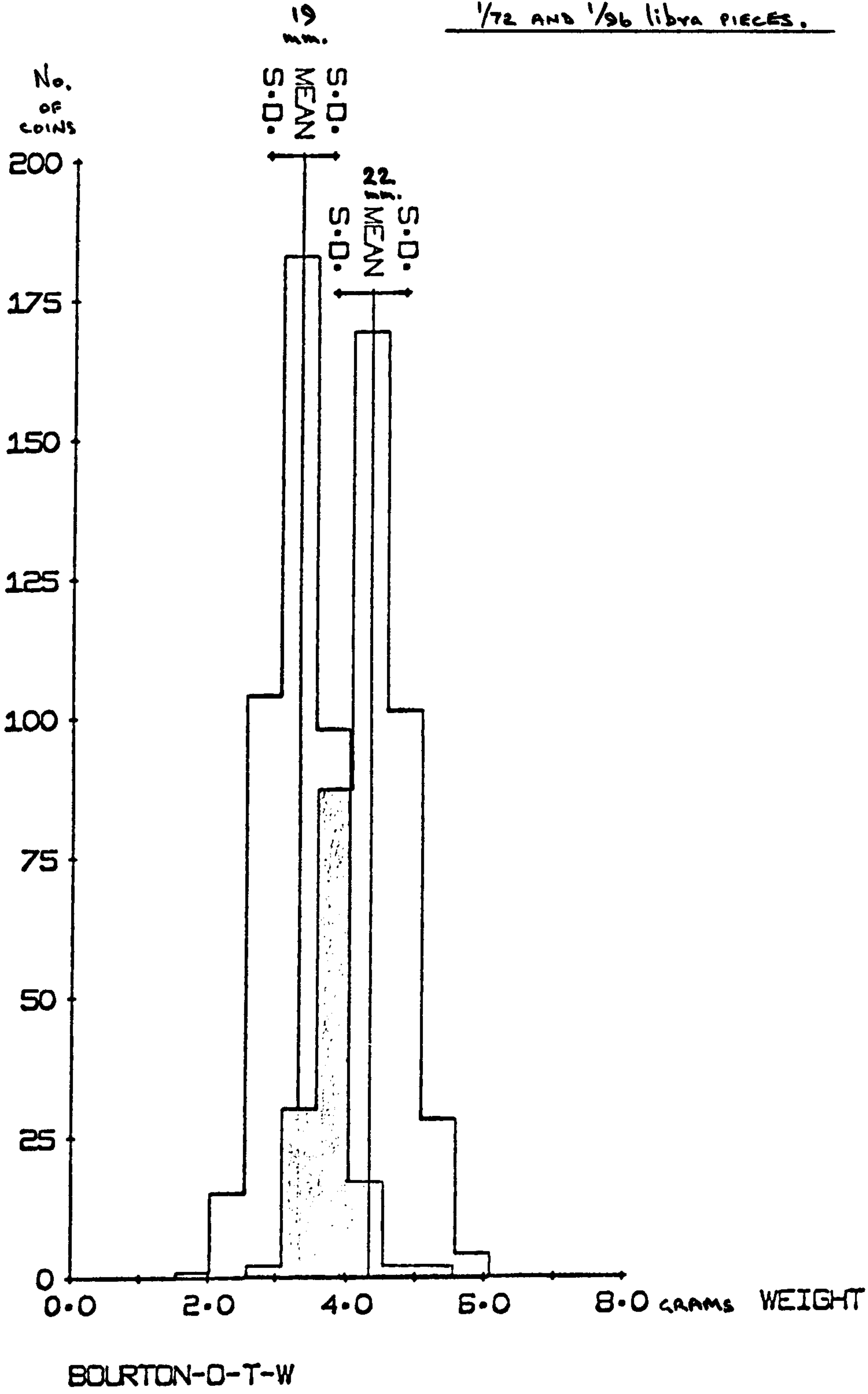
FIGURE 31.

The extent to which folles of adjacent weight standards in the discovered sequence can overlap is illustrated by the superimposed histograms (Figure 32) of the 22 mm and 19 mm Treveran pieces found in the 1970

FIGURE 32.

TREVERAN FOLLES.

WEIGHT DISTRIBUTIONS OF 1/72 AND 1/96 libra PIECES.



Bourton-on-the-Water hoard(364). Their coefficients of variation are 11.51% and 13.97%, respectively, which results in a substantial proportion of the coins falling in a range of uncertain weight-standard attribution unless the die-module criterion is used as a more positive indication of the standard intended.

By applying the technique of die-circle measurement to the small folles of Ostia and Arelate in the British Museum collection the author(365) has established that both the 1/72 and 1/96 libra folles (having 22 mm and 19 mm dies, respectively) were struck at each mint, in proportions which reveal an overlap in the operation of these mints rather than the simple transfer of the mint from Ostia to Arelate. By the application of other numismatic criteria it has been possible to determine that Arelate was opened in late December AD 312 or very early in AD 313 before the closure of the mint of Ostia. From the compositions of the coinage alloys of these issues it is obvious that the mint personnel took with them their preferred metallurgical practice of minting more highly-leaded bronzes than were in use at the existing Gallic mints of Trier and Lyons. Within the last year D W Burge(366) has reported that the coins of Ostia and Arelate in the Bourton-on-the-Water hoard confirm these findings.

The author and H N Billingham(367) have made a detailed study of the chemical composition of the folles minted by Maxentius at the central mints of the Empire between AD 306 and 312. The coins were made in the typical moderately leaded argentiferous bronzes of their period. They show the spirit of Italian independence by their dimensions being upheld out of phase with the weight-reductions taking place in the rest of the Empire during the 6 years of issue; but they show better metallurgical conformity in the maintenance of a consistent and carefully controlled fineness standard of 4 scrupula per libra throughout.

A metallurgically distinctive feature of the Maxentian coinage is the start of the bad practice, at Carthage, of alloying exceptionally high proportions of lead (c. 12%) with about half that proportion of tin to make the basic coinage bronzes. The practice spread to Rome, and Ostia, and thence to Arelate and most of the western mints of the succeeding Constantinian era, with the sad consequence today that many of the coins made in these alloys have corroded deeply in the course of time. The analysis of a contemporaneous Siscian follis is of special significance in that its quite different fineness and distinct alloy composition provide metallurgical evidence for the independence of Siscia - which supports the historians' view that Maxentius never managed to extend his territory to include control of the mint of Siscia.

In the western territories Constantine gained complete control and he eventually defeated Maxentius and acquired his territories at the heart of the old Empire. Forty-three analyses(368), mostly made for the author by H N Billingham (and of both the 1/72 and 1/96 libra folles) together with numerous assays of the same issues by the author, confirm that the western standard follis fineness, set at the 'solidus-follis' reform of c. mid-310, was 4 scrupula of silver per libra for both of these coin weight standards as well as for the Maxentian coinage during the whole of this period. There is some indication that a 3 scrupula per libra Constantinian standard was used in emergency just after the Italian campaign, towards the end of AD 312, but the 4 scrupula standard was soon recovered and continued until the termination of the Sol coin series of 1/96 libra folles c. 318. The intrinsic worth of the western coinage moved, therefore, in direct proportion to its weight standards - which dropped dramatically by a factor of three, in just seven years, from 1/32 to 1/96 libra.

A fractional follis assay, of a coin paralleling the 1/72 libra issues, indicates that Constantine's original policy was to mint fractions in an alloy of identical fineness:

Code No BM272; RIC vi Trier 893, 1.54% silver;

but later (AD 317-318) when higher silver standards began to be adopted for pieces of higher denomination, he changed this policy for the fractional pieces:

Code No BM470; RIC vii Rome 106, 18 mm, 0.07% silver
" " BM471; " " " 116, 15 mm, 0.34% silver.

The VICTORIAE LAETAE PRINC PERP and the VIRTVS EXERCIT issues of Constantine - usually dated AD 318-320 - show marked metallurgical differences from the long run of small Sol folles. They are argentiferous bronzes containing almost equal proportions of lead and tin between lower optimised levels of 2 to 5%, which is more characteristic of the normal eastern coinage of the period; but the most significant feature is the return to the 10 scrupula per libra fineness of former days. This was adumbrated in an earlier publication(369) by a few analyses, and is now supported by another result:

Code No BM285; RIC vii Ticinum 93, 17 mm, 3.43% silver.

That this standard was not maintained for long, however, is shown by the later issues of the same types in AD 320-321:

Code No BM295; RIC vii Lyons 75, 18 mm, 2.37% silver
" " MAZ30; " " London 188, 18.5 mm, 2.65% silver
" " AJHG10; " " " 185, 18 mm, 2.48% silver

Nevertheless, these coins represent the issue of a higher Constantinian 'silver' denomination contemporaneous with at least the later issues of the Sol folles.

Professor P M Bruun(370) is now of the opinion that the VICTORIAE LAETAE issues were first issued earlier than AD 318 - and perhaps immediately after Civil War I against Licinius, as a parallel to the Jil bust issues of the latter (at an identical standard) which we will discuss below. There is metallurgical support for this view, although the hoard evidence follows a pattern which seems to be difficult - though not impossible - to reconcile with it. There is an earlier issue of this type which can be dated to AD 312, but this is so very rare that it must be quite a different experimental silver denomination(371) first issued in AD 312, several months before the 1/96 libra follis reform.

Constantine did make an early attempt at a short-lived higher denomination base-silver coinage contemporaneous with his 1/72 libra folles. A thorough metallurgical examination of a rare 1/96 libra piece (RIC vi Trier 826), attributable perhaps also to the year AD 312, was announced on behalf of the author at a Symposium in Oxford in 1972 and has since been published(372). The fineness standard was clearly 3 unciae of silver per libra - corresponding with a theoretical content of 0.846 g silver and an intrinsic worth 13½ times that of the contemporaneous follis. It is just possible that this was a 100 d.c. piece - after the manner of the tetrarchic argenteus which it somewhat resembles - and that, in metal-worth, it matched a 10 d.c. follis created by Constantine in the 1/72 libra 'solidus-follis' reform in the spring of AD 310. Dr J P C Kent's view(373) that it might have been the original 'centenionalis' - literally containing 100 parts (of denarii communes) - is an attractive possibility, although an alternative etymologically satisfactory explanation is presently preferred by the author in the context of the post-AD 348 coinage.

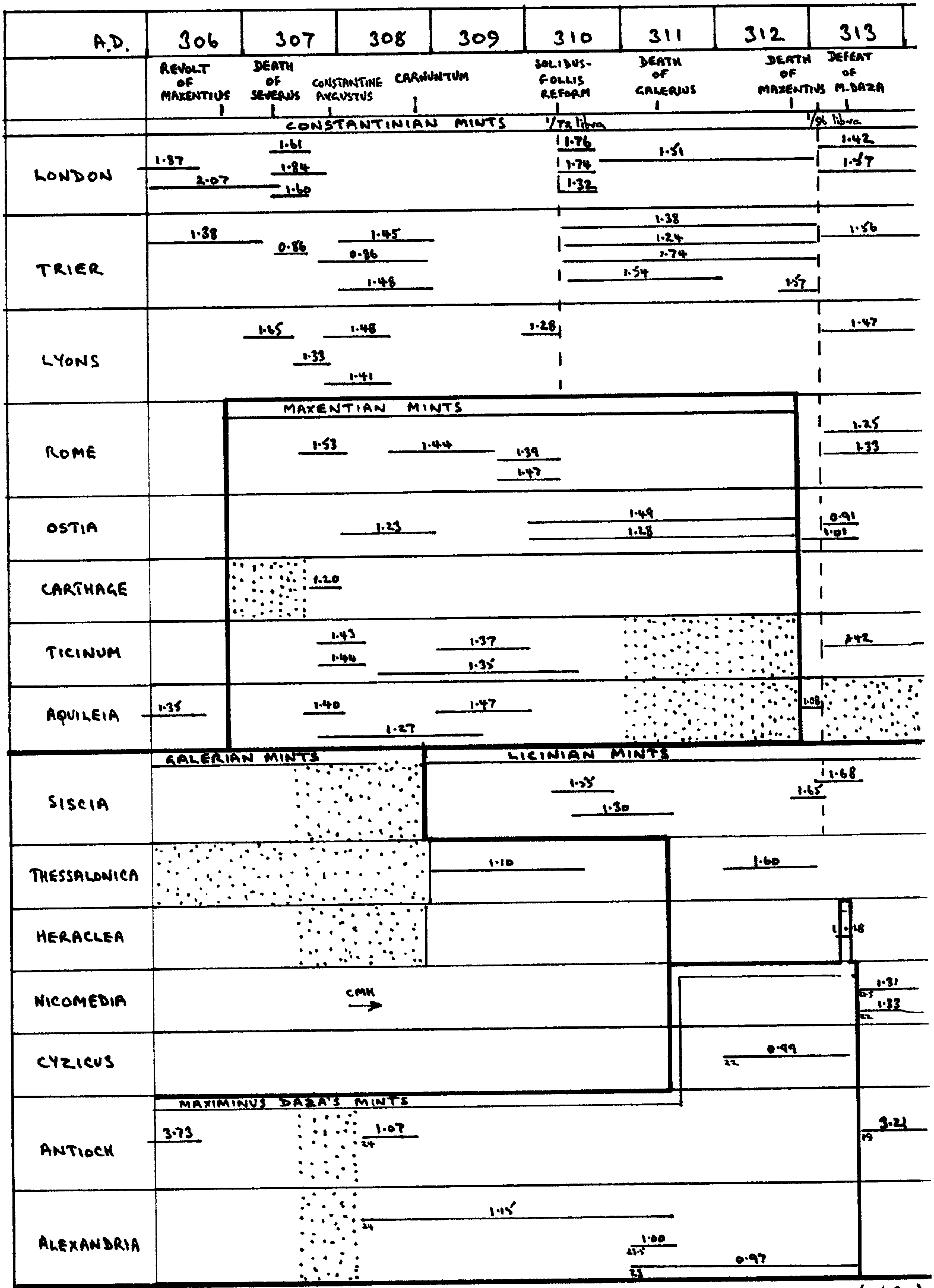
The Balkan and eastern coinages of the period of the folles weight-reductions show a rather different pattern of coinage alloy policy from the West. Since several of the mints came under the control of different rulers during these turbulent years the differences are most conveniently illustrated by a chronological display of the coinage finenesses (Figure 33). Balkan and eastern pieces are rather difficult to acquire now, in the West, but sufficient coins have been assayed to delineate the general sequence of change.

The most obvious difference pertains to the eastern issues when Maximinus Daza resumed the minting of folles early in AD 308. Although a large Antiochene follis of AD 306 assayed 3.73% silver (ie 10 scrupula per libra) a new issue of AD 308 was found to contain only 1.07% silver. This reduction in standard - down to 3 scrupula per libra - which is confirmed by all the subsequent issues of Daza, is not in accord with the 4 scrupula standard then extant at the western and central mints for ostensibly the same 1/48 libra coinage. It marks an appreciable revision of the nominal value of the eastern follis - perhaps down to a 10 d.c. piece again, as the 'X' marks on some of the earliest Alexandrian pieces of this fineness suggest. All the assays of the coinage of Maximinus Daza reveal that his mints were most consistent in their application of the new standard, for the six results are contained within the narrow limits of 0.97% and 1.18% silver. The last piece mentioned is a Heraclean coin of considerable interest because it reveals that Daza operated his fineness standard in preference to any other during his short tenure of the captured mint early in AD 313.

The Balkan mints are rather poorly represented; but, with the exception of the one post-Carnuntum issue from Thessalonica, for Galerius - who would, on that evidence, seem to have changed to the 3 scrupula fineness of the eastern Empire - the Licinian coins, down to the 20 mm die-size of AD 313, all match the 4 scrupula per libra western standard of Constantine, with whom he was then in concord.

Galerius placed the CMH symbol on his reduced Nicomedian folles in late 307, and subsequently on other issues from that mint and from Cyzicus. Dr J P C Kent has expressed the view that this Greek epigraphy could simply mean "a standard of 48". The weight range and die module would certainly support that view; and, together with the fineness standard revealed by assay, we can now determine the theoretical intrinsic worth of the Balkan and eastern follis of AD 309 to mid-311 as 0.0705g silver. That the coinage was seemingly identical, and exchangeable at par with the Licinian coinage of Siscia and the contemporaneous Maxentian and Constantinian 1/48 libra issues - all, early in AD 309, of 4 scrupula per libra (ie 0.094 g silver) -

FIGURE 33.



THE FINENESSES OF THE WEIGHT-REDUCED FOLLES OF A.D. 306-313. (% Ag).

is remarkable. The need for reform in the west seems to have become inevitable if any intrinsic balance had to be preserved.

Maxentius, perhaps feeling isolated yet secure, effected no change; but Constantine's action was not to reduce the fineness of his issues but to reduce the weight and module instead. By introducing a 1/72 libra follis, in the reform of early 310, at his existing 4 scrupula per libra fineness, he reduced the precious metal worth of his follis to only 0.063 g silver. But by the parallel introduction of the gold solidus (at 1/72 libra), while the East retained its aureus (of 1/60 libra), he established a gold to silver ratio nearly 7% below that of his colleagues Galerius and Daza - thus over-valuing his new 1/72 libra follis by the same proportion, in any direct follis exchange, while enabling 6 of his solidi to equate in gold-worth with 5 aurei.

Licinius showed no sign of following Constantine's lead with his own gold issues, which he continued to mint at Siscia at 1/60 libra - but without any inscriptional recognition of Constantine before the summer of AD 311. Thus the personal feelings which were to bring later conflict were, despite the formal acts of union in early 313, manifest in the earliest coinage of Licinius. Even well into AD 312 Licinius maintained the 1/48 libra follis standard and its module at Siscia, Thessalonica and Heraclea. These, together with the 4 scrupula fineness, made it the most silver-rich follis coinage of the period mid-311 to autumn 312, with 0.094 g silver.

The defeat of Maximinus Daza, at the beginning of May 313, left only Constantine and Licinius to rule the Empire; and a new era of follis coinage began. A lack of precision in the datings of several of their main issues has thus far prevented the direct correlation of contemporaneous issues, but these are beginning to emerge as a result of new coin analyses.

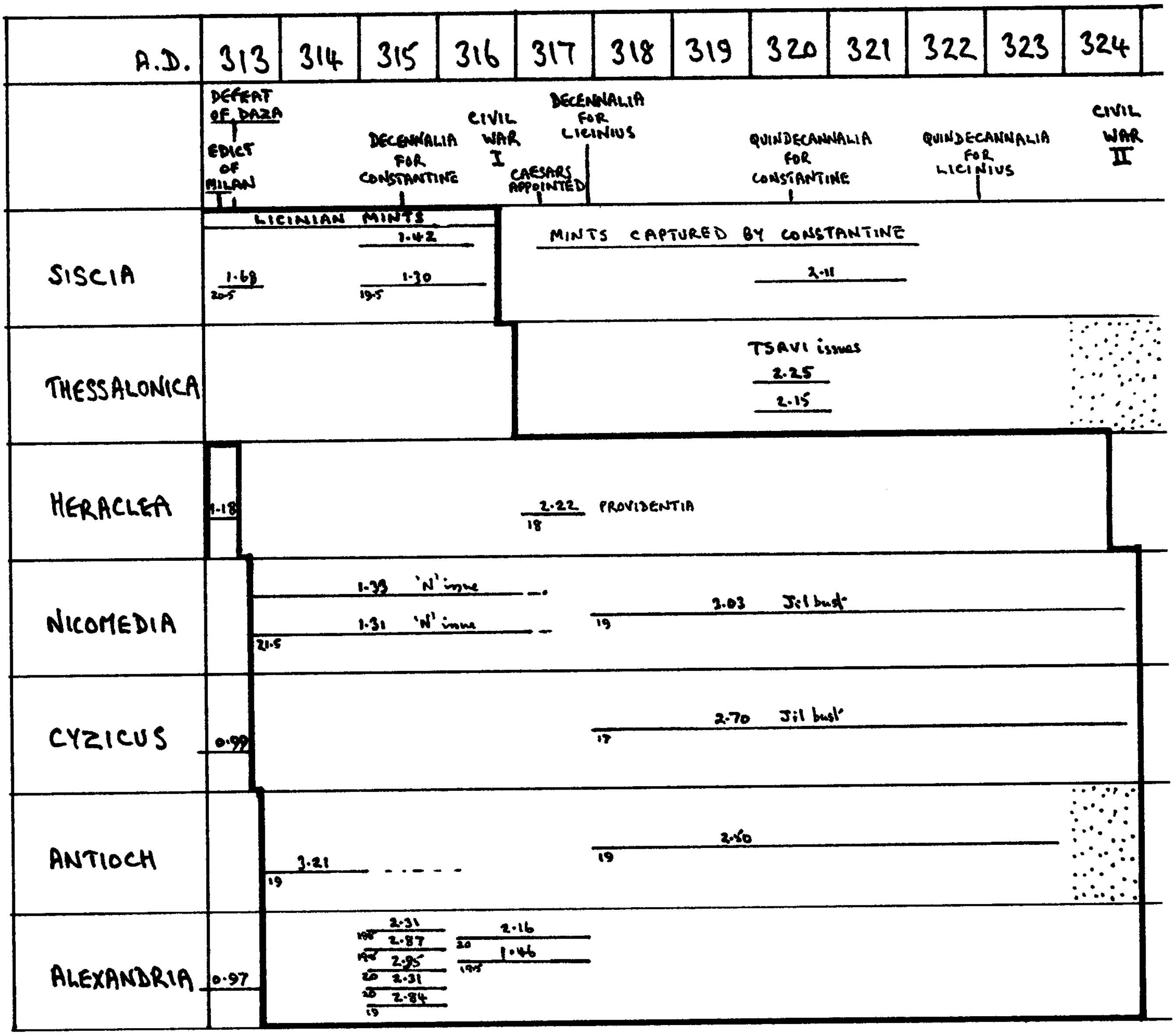
Despite their adoption of a common 4 scrupula fineness standard for their folles from the middle of AD 313 the coinages of the two emperors show both similarities and differences over the next decade. The author(374) has already published some analyses of Constantine's coinage, and a few others in this work. In Table XXIII the first analyses yet made of the Licinian coinage are reported for comparison. They are divided into pre-Civil War I and post-war categories because it was the first war which brought the more strained relationships, in an unsatisfactory peace settlement, which manifested themselves in somewhat independent minting practices between late AD 317 and 324. This is illustrated, in so far as the chronological changes in fineness are concerned, in Figure 34.

TABLE XXIII

Analyses of the Licinian coinage, AD 313-324

Code No		RIC No	Date	Die Module	Composition (wt %)			
					Copper	Tin	Silver	Lead
I. Pre-war issues; AD 313-Nov 316								
a) Larger module								
NMW30	Siscia	234a	c. early 313	23;22.5	91.11	3.32	1.65	3.74
BM88	Thessalonica	23	c.312-May 313	23	91.47	2.90	1.60	3.53
BM84	Nicomedia	15	313-317	21.5	93.07	2.02	1.31	3.06
LHC36	"	"	" "	22	-	-	1.33	-
b) Smaller module								
BM89	Siscia	231a	c.early 313	20.5	90.55	3.42	1.68	4.22
NMW36	"	17	315-316	19.5	91.54	2.93	1.30	3.82
MAZ29	"	15	" "	19.5	-	-	1.42	-
BM467	Antioch	7	313-314	19	-	-	3.21	-
c) 'N' series								
R.11	Alexandria	9	315	19.5;20	89.99	3.37	2.31	3.85
R.2	"	10	"	19	90.76	2.79	2.87	3.47
R.3	"	10	"	20	91.39	2.65	2.95	2.66
R.5	"	10	"	19.5;20	92.60	3.00	2.31	1.85
R.7	"	10	"	19.5;19	-	2.48	2.75	1.60
R.8	"	10	"	19	91.70	2.36	2.84	2.85
R.9	"	10	"	19.5	-	-	3.12	-
d) 'K/X' series								
R.10	Alexandria	18	316-317	20	89.02	2.67	1.73	6.24
BM96	"	18	" "	19.5	84.84	3.55	1.46	9.68
II. Post-war issues; AD 317-320								
B.55	Heraclea	20	AD 317	18	93.87	2.71	2.22	1.51
BM100	Nicomedia	24	"	19;18.5	90.99	2.88	3.03	2.89*
BM99	Antioch	29	"	19;18.5	90.59	3.62	2.50	3.08*
BM466	Cyzicus	8	"	17	-	-	2.70	- *
* Jil busts: AD 317-320 (Bruun); AD 317 (Bastien, NC 1973)								
III. The XIIM coinage; AD 321-324 (Bruun); AD 318-324 (Bastien NC 1973)								
NMW43	Heraclea	52		18	-	0.51	trace	2.49**
NMW44	"	52		19	92.80	0.78	0.12	4.52
NMW45	Cyzicus	15		19	91.64	0.96	0.13	6.09
BM144	Alexandria	27		18.5	-	traces	trace	-
BM111	"	28		18.5;18	95.31	0.65	trace	2.23
** Outer silvered layer, filed from NMW43					-	1.7	4.8	-

FIGURE 34.



THE FINENESSES OF THE CONSTANTINIAN AND LICINIAN ISSUES OF A.D. 313 to 324.

(PERCENTAGES OF SILVER. SUB-SCRIPT NUMBERS ARE DIE DIAMETERS.)

The general metallurgy of the Licinian folles calls for little comment other than the observation of his continuation of the traditional well-optimised tough and more corrosion-resistant eastern alloys of tetrarchic days. Both the tin and the lead contents fall into similar narrow ranges matching the equal-proportion additions noted earlier. A change is observed however with later issues: an Alexandrian follis with 9.68% lead (BM96 in Table XXIII) marks an exceptional departure from previous standards; but the XIIM coinage is significantly different from all others in that the products of three separate mints show a metallurgical policy of using only minor proportions of tin in non-argentiferous alloys containing the usual (or somewhat higher) proportions of lead.

It is the proportions of silver, however, that provide the major guidance to minting policy. It is evident that after his acquisition of the Balkan mints (following the death of Galerius in May 311) and of the eastern mints (following the demise of Maximinus Daza in May 313) Licinius established for a while the 4 scrupula per libra fineness already used by Constantine and himself. The Siscian pieces show that, like Constantine, he reduced the module while keeping the fineness standard; but this step seems to have been taken rather more slowly at the mints east of Siscia.

Dr P Bastien(375) has quite recently remarked that "Licinius' coinage needs to be completely reconsidered, not only from the chronological point of view, but also from the typological and metrological points of view". The analyses listed in Table XXIII help to advance this knowledge, and their variations support Bastien's view. By dividing the issues represented there into smaller categories some of their unique features become apparent, which will necessitate re-arrangements on a metallurgical basis in future revisions of the works of reference.

The first item of note is the Antiochene piece (BM467) whose enhanced fineness seems quite out of place amongst the early pre-war issues to which it is presently assigned. Because of portrait links with an earlier period Professor P M Bruun(376) felt compelled to put this issue first, despite the evidence of legends and mint marks which he admits would have otherwise persuaded him to invert the three series of Antiochene coins struck within the period August 313- 1 March 317. Taking into consideration the papyrological evidence for a significant change in the eastern gold to follis ratio, in the period 314 to 316, we should indeed invert the series in RIC vii and re-date this coin perhaps to the brink of Civil War I, in AD 316. On their internal evidence the Alexandrian 'N' series belong to the same period; and their assays, although spread so that it is difficult to be certain which fineness was intended (between the limits of 6 and 9 scrupula per libra) point to a positive reform and revision of the silver standard just before Civil War I.

The mint of Alexandria also gives a clue to a further change - the return to a 4 scrupula standard - with the 'K/X' series which followed in 316-317. Then came another reform, shortly after the war, with a reduction in module combined with a raising of standard to a special Licinian one of 6 scrupula per libra. These issues appear to have been followed within a year (according to Bastien’s(377) latest work) by the XIIᴍ pieces. Indeed they might have been issued at the same time from the same reduced number of Licinian officinae. Numismatists have shown some reluctance, hitherto, to accept the almost obvious meaning that the XIIᴍ coin was one of 12½ denarii. But the Jil-bust folles, if regarded as contemporaneous with at least the first issues, are now shown to have silver proportions which would identify them as the 25-denarius pieces which we seek as those of higher denomination just preceding or running parallel with the XIIᴍ coinage. The latter, although minted in almost silver-free leaded bronzes of low tin content, were certainly intended to be regarded as a silver denomination because of the obvious silver "plating" which remains on some of them to this day. In Table XXIII an assay of the surface filings from one of these coins confirms the application of a silver coating to the virtually silver-free coinage bronze base.

The position of the rare and slightly larger (20-21 mm) double-effigy Licinian coins, unique to the mints of Nicomedia, Cyzicus, and Antioch at the time of the reduction in the number of the eastern officinae in 318, now needs to be determined. According to Bastien(378) their average weight (3.95g) far exceeds that of the other silvered bronze coins of the period. They could be pieces of, say, 1/80 libra; but it will not be possible to locate them in the series and to suggest a denominational value until their fineness can also be judged - perhaps by some non-destructive method such as neutron activation assay, in view of the rarity of the material.

New assays now provide an insight also into Constantine's minting policy as he advanced eastwards. After the first Civil War the peace settlement at Serdica deprived Licinius of all his European territories except Thrace, and left him controlling only the mints of Heraclea, Nicomedia, Cyzicus, Antioch, and Alexandria. When Constantine began to consolidate his position and to prepare for the final thrust he set up headquarters at the mint city of Thessalonica, where his issues of AD 320 bear the enigmatic exergual marks TSAVI and TSAVII for which a metallurgical explanation can now be offered.

Bearing in mind that by AD 320 Licinius was operating a 6 scrupula fineness standard with his own Jil-bust folles, it would seem that Constantine, in deference to local feeling (and perhaps personal pride), could hardly mint his 4 scrupula fineness alloys without the coinage being regarded by its recipients as inferior to that already circulating in the Balkans and the East. So, while keeping his 4 scrupula standard in operation in the extreme West, he struck at a special campaign and 'eve of battle' standard of 6 scrupula at Siscia and Thessalonica, and declared it on the coinage after the manner of the XXI mark of earlier days: only this time the mark was 'VI' or 'VII' - the latter being properly read as VI.I. The fineness of these coins - which would have found immediate acceptance in conquered territory – is clearly 6 scrupula of silver to the libra, as shown by the following assays:

Code No	BM108	Siscia 160		2.11% silver
" "	MAZ27	Thessalonica	114	2.15% "
" "	BM114	Thessalonica	123	2.25% "

There is reason to believe that apart from these campaign issues, Constantine revised his coinage system during the four years which preceded the second Civil War in which Licinius was finally defeated. Between c. AD 320 and 324 the assays of the later issues of the VICTORIAE LAETAE and VIRTUS coinages, and the new BEATA TRANQVILLITAS and VOTA issues, indicate (as R A G Carson(379) suggests) a possible attempt to introduce a new kind of follis which begins to degenerate in fineness with VIRTVS, is worse with BEATA, and drops to its lowest level with PROVIDENTIAE.

THE COINAGE OF THE LATER ROMAN EMPIRE

a) The issues of the House of Constantine, AD 324-346

With his final defeat of Licinius, at Chrysopolis, on 18 September AD 324 Constantine found himself the undisputed master of the Roman world, and able to unify the Imperial coinage and to consider its future pattern of development. He made no change to his gold - which continued to be minted principally as the 1/72-libra solidus, and its multiples, for the rest of the

Imperial era and even into Byzantine and later days. In AD 325 he restored the 1/96-libra (siliqua) piece, of seemingly high fineness, and introduced a 1/72-libra 'light' miliarense in association with it. For the common 'silver' he retained the argentiferous bronze follis, which he minted mainly with PROVIDENTIAE and SECVRITAS inscriptions until the next reform of AD 330. It is this 'silver' - degenerating eventually to an aes coinage - which shows much compositional variety in the following years and reveals most positively the substance of subsequent reforms. Yet it is from this point onwards that there has been the greatest dearth of metallurgical information.

The much-debated Feltre inscription (I.L.S. 9420) dated 28 August 323, provides the earliest record of the word "Siliqua" and has been used to interpret that the silver-rich coins of that name were introduced by that date. The use of the singular inscription 'AVG' on the coins dates them later than AD 320, but so early a date - or even AD 323 itself - cannot be justified on any other grounds.

The vicennalia celebrations of 25 July 325 would have been really more suitable as the occasion for the first issues of siliquae, for they are known at Thessalonica in 325, and at Siscia and Rome in 326, although at the Gallic mints they were not minted until ten years later. By 325 the PROVIDENTIAE and associated follis coinage was well-established; so we can derive an intrinsic-worth ratio for the follis and the two fine silver denominations in issue between AD 325 and 330, on the assumption (in the absence of actual assays) of a high fineness for the siliqua and the miliarense and the sure knowledge of the fineness of the follis.

Constantine's complete victory removed any necessity to continue minting folles deliberately to the 6 scrupula per libra standard, and he became free to unify the Imperial coinage on the well-established basis of his existing western standard of 4 scrupula per libra. His only concession to Licinian innovation appears to have been his adoption of the PROVIDENTIAE legend (which Licinius had introduced at Heraclea in AD 317) for the bulk of the post-war follis issues. The assays in Table XXIV show the metallurgical characteristics of the issues of AD 324-330.

It will be noted that the highly-leaded 'western' alloys of AD 313-318 were replaced everywhere by the much better coinage bronze compositions which were originally characteristic of the eastern tetrarchic mints, and of Britain under Carausius. But a seemingly inexplicable feature is the occasional incidence of an unmistakable 6-scrupula fineness amongst the

TABLE XXIV

Analyses of the follis coinage of the House of Constantine, AD 324-330

Code No	RIC No		Die Module	Composition, (wt %)			
				Copper	Tin	Silver	Lead
LHC7	London	295	18.5	-	-	1.76	-
B150	London	293	18.5	88.80	4.16	1.70	4.85
BM290	Lyons	225	18	-	-	1.70	-
BM291	Rome	287	19, 18.5	-	-	1.72	-
BM276	Rome	291	18	-	-	2.00	-
Ch 13	Arles	338 or 339	uncertain	88.29	4.52	1.66	5.24
MAZ42	Siscia	218	18.5	-	-	1.97	-
MAZ41	Thessalonica	153	19, 18.5	-	-	1.77	-
LHC8	Heraclea	77	18	-	-	1.63	-
CJ028	Heraclea	79	18	91.79	2.77	2.31	2.64
AJHG9	Constantinople	25	18.5	-	-	2.38	-
Y2	Cyzicus	34	18.5	89.61	4.36	1.31	4.05
BM2	“	44	19	86.09	4.56	1.45	8.66
LHC28	Antioch	67	18.5;18	92.53	2.29	2.39	2.35
CJ014	Antioch	63	19	-	-	2.07	-

otherwise unified coinage.

According to the statistics compiled by D R Walker(380) the weight standard for PROVIDENTIAE appears to be 1/96 libra; and on this basis a 4-scrupula standard piece would have contained 0.047g silver and possessed a silver equivalent of exactly 1/72 of a pure silver siliqua, or 1/96 of a light miliarense. On a pure silver basis the siliqua was therefore the equivalent of 72 folles, or very close to 50 on a total metal-worth basis. The settlement of Army veterans, with 25,000 folles each in cash, in addition to a yoke of oxen and 100 measures of assorted grains - as mentioned in a Constantinian law of 13 October AD 320 or 326 (C. Th. 7.20.3) - would have been fairly generous: the folles themselves would have contained 3.6 libra (nearly 1.2 Kg) of silver, but worth much more as coin.

It is not known to what extent earlier coinages were recovered to the Treasury and re-used. Because of the silver invested in the folles there would have been a constant drain on Imperial resources unless some coins were recovered as tax-payments and the alloys, or their silver, re-used. The now established fact that they were intended as a silver denomination lends support to a view that they would have constituted 'silver' for the purpose of paying taxes at a time when there were no finer precious-metal denominations other than gold.

The puzzling feature of 6-scrupula alloys being minted contemporaneously with indistinguishable issues of 4-scrupula alloys possessing identical mint-marks can be explained if it is accepted that Constantine's moneyers simply re-melted the Licinian folles returned to the Treasury and then recoined them. If no alloy dilution were specified there would have been some concentration of silver, due to base metal oxidation, which would have raised the nominal 2.08% silver to, say, over 2.2%. And if worn coins were weighed into the melting pots (rather than counted) it is easy to account for the occasional silver proportions now determined in excess of 2.3% for some of the coins listed in Table XXIV.

There would have been a negligible circulation of Licinian coins in the extreme West, and so fewer would have been consigned to the melting pot. But, again, the remelting of 4-scrupula material would account for the apparent approach to a 5-scrupula standard due to the combined influences of oxidation and any topping up of worn batches to full librae by the addition of extra pieces.

Therefore, although there appears to be a double fineness standard for Constantine's folles of AD 324-330, it can be explained metallurgically in the context of normal re-minting plus a grand re-minting of Constantinian pieces following the unification of the coinage of the Empire. Apart from a desire to recover the silver value of circulating folles Constantine would have also had a personal incentive to extract the remaining coinage of his former rival, and to turn it to his own use.

This matter needs deeper investigation when further coin material is forthcoming for analysis. As the analyses stand at present they provide assay figures mainly for PROVIDENTIAE from the western mints and for SECVRITAS from the eastern ones. If better-grade Licinian issues, after re-minting, account for the higher finenesses of SECVRITAS (at eastern mints) one would expect the PROVIDENTIAE issues from the eastern mints to be similarly affected(381), and this needs to be tested on a larger scale. A start has been made with item CJO14 in Table XXIV: it is an eastern PROVIDENTIAE issue, from Antioch, and it does indeed match the 6 scrupula alloy standard re-melted.

Within the period 324-329 there was the intrusion of a scarce Dynastic follis issue which D R Walker(382) has dated to AD 326, and for which he suggests a lower weight standard - corresponding to perhaps 1/120 libra. The author sought and purchased one of these pieces for assay, because the fineness issue is of special numismatic interest. The coin (LHC76) appeared genuine to experts; but if it is typical of its issue (RIC Cyzicus 32) the fineness is at the inexplicable low level of 0.48% silver, matching no known standard. Other oddities of composition are a low tin content for the suggested period of issue (0.99%) and 0.46% arsenic.

Constantine celebrated his 25th anniversary on 25 July AD 330, and his 30th in AD 335. On both occasions there were reductions in the module of the follis coinage and alterations to the fineness standards which effected overall reductions in the amount of silver per coin. The enormous cost of the donatives due on these occasions, plus the cost of building Constantinople (from AD 328-330) as the new Imperial capital, and the consequent heavy drain on bullion reserves, were undoubtedly contributory to these coinage reforms. The coin assays now enable the effects on the intrinsic worths of the new issues to be determined.

The coinage reform of AD 330 involved a complete change in Reverse types, as well as in module and fineness. The new issues exalted the Roman Army and honoured both the Cities of Rome and Constantinople in issues united everywhere by a community of mint-mark. The VRBS ROMA and CONSTANTINOPOLIS issues came first and were closely followed by the first of the GLORIA EXERCITVS issues showing, on the reverse, two Roman Army standards supported between two soldiers. D R Walker's weight statistics indicate a reduction in weight to 1/120 libra - compared with the PROVIDENTIAE 1/96 libra issues - and the analyses listed in Table XXV reveal a drop in fineness to 3 scrupula of silver per libra.

The silver-worth of the new issues was thereby reduced to 0.028 g; but the increasing circulation of the finer silver siliquae and miliarensia eliminated the need for a large-scale issue of an intermediate base-silver denomination. There were, however, a few large VRBS ROMA issues, (of 32 mm die diameter and weighing about one uncia) in issue in this period. Such a piece (Ca. 68; RIC vii Rome 315; and attributed to AD 327-333) has been analysed and found to contain 0.86% silver, together with 0.34% tin and 2.85% lead. Although medallic in character it was apparently minted with the same fineness standard as the common coins of its day and could have served as a 10-follis piece by virtue of both its weight and fineness.

A noticeable metallurgical development was the re-appearance of the much more leaded alloys of a decade or two earlier - particularly in the West – combined with a much more sparing use of tin. These factors led to an

TABLE XXV

Analyses of GLORIA EXERCITVS (2 standard), VRBS ROMA, and CONSTANTINOPOLIS issues, AD 330-335

Code No	RIC No	Die Module	Composition (wt %)				Reverse Type
			Copper	Tin	Silver	Lead	
SL28	Lyons 257	17	-	-	1.06	-	UR
B113	Lyons 256	16.5	-	-	0.91	-	Cp
Ca13	Trier 529	16.5			0.98		UR
Ch14	Trier 522	17	86.93	2.41	0.96	9.15	UR
BM313	Arles 380	17.5;17	-	-	0.72	-	Cp
B149	Thessalonica 198	18	-	-	0.99	-	G.II
BM3	Constantinople 59	18	93.24	1.98	1.17	3.29	G.II
BM310	Constantinople 78	18	-	-	1.09	-	UR
PMB5	Antioch 86	16.5;17	-	-	1.06	-	G.II
BM314	Alexandria 64	17	-	-	1.09	-	Cp
LHC113	Uncertain	-	-	-	0.99	-	G.II

inevitable drift downwards in metallurgical quality, particularly at the western mints. The follis coinage from this period onwards becomes increasingly difficult to sample for analysis because of the depth of corrosion often encountered in quite small pieces. For the best results resort has often had to be made to the fusion-reduction of cleaned coins to provide sufficient metal for analysis.

The reform of AD 335 affected the parallel issues of VRBS ROMA and CONSTANTINOPOLIS but is most apparent in the case of the GLORIA EXERCITVS pieces where the reduction in module seems to have forced the engravers to place one Army standard between the soldiers in place of two. This coinage spans the death of Constantine, on 22 May 337, and needs metallurgical consideration in two separate phases - AD 335-9 September 337 and 9 September 337-mid 341.

Although there is a measurable fall in module Dr J P C Kent(383) has obtained similar average weights for the two series: 199 examples of Gloria 1-standard coins minted in AD 335-337 averaged 1.58g, and 749 post-337 issues averaged 1.64 g. The weight-standard of both would thus appear to have been set at one half of that of the much earlier 1/96 libra folles, ie 1/192 libra. Taken in conjunction with the apparent restoration of the higher 4-scrupula fineness - on the evidence provided in Table XXVI - the theoretical silver content of each new follis became 0.0236 g in AD 335.

The initial improvement in fineness was, however, more than compensated by the reduction in weight, so that the silver invested in each coin was actually reduced by 16% compared with the previous Gloria 2-standard coinage.

TABLE XXVI

Analyses of the Gloria Exercitus (1-standard) coinage of AD 335-337

Code No	RIC No	Die Module	Composition (wt %)			
			Copper	Tin	Silver	Lead
H18	Lyons 281	16	-	-	1.41	-
BM340	” 286	16;17	-	-	1.22	-
BM358	Trier 591	16;15.5	-	-	1.27	-
LHC50	Aquileia 145	16;16.5	-	-	1.58	-
LHC49	Arles 396	16	-	-	0.89	-
H23	Arles 413?	15.5	-	-	0.91	-
BM337	Rome 393	16	-	-	0.92	-
BM336	Constantinople 139	15	-	-	1.55	-
BM24	Alexandria 66	16	91.15	3.85	2.09	3.08

There is some confusion, in the two main works of reference on this coinage, with respect to the parallel issues which bear identical mint marks to the Gloria 1-standard and span the reform. Since their weight is no real guide these issues need now to be classified on the basis of die module so that they can be more surely located in their correct periods. A notable example is a Constantinopolis issue, Code No BM314. In L.R.B.C.I it could be allocated to either coin reference 1432 or 1441: in RIC vii it might be either Alexandria 64 or 71. The die diameter of 17 mm is a guide to its correct position in the earlier of these series; and this is confirmed by the assay value of 1.09% silver, which pertains to the AD 330-335 eastern mint issues but certainly not to the post-335 ones.

After the death of Constantine and the appointment of his three surviving sons as the new Augusti, on 9 September AD 337, a new pattern of change in the finenesses of the issues of a seemingly unified Empire took place; and this is most clearly demonstrated by the arrangement of the assays in Table XXVII. The weight standard continued despite the slight reduction in module; but the outstanding feature is the emergence of two fineness standards for eastern and western issues or, rather, a fall in the western standard while the eastern coinage remained remarkably constant at the 4 scrupula per libra standard.

TABLE XXVII

Analyses of the coinage minted after the death of Constantine the Great, AD 337-341

Code No	LRBC I No	Die Module	Composition (Wt %)		
			Tin	Silver	Reverse Type
Western and Central mint issues:					
H24	Trier 113	15	-	0.65	Pietas Romana
W5	“ 117	15	3.21	nil	Virtus Aug NN
H25	“ 112 or 119	15	-	0.88	Pax Publica
BM351	“ 127	15.5	-	0.53	Gloria 1-std.
H27	“ 132	16	-	1.41	“ “
BM341	“ 132	15.5;16	-	1.66	“ “
H17	Lyons poss 242	15	-	0.76	“ “
H20	“ 242	15	1.98	0.56	“ “
H23	Arles 417	15.5	1.55	0.91	“ “
BM352	Rome 591	15.5	-	0.72	Securitas Reip
BM315	“ 594	15.5;15	-	0.92	Constantinopolis
BM316	“ 617	16;16.5	-	1.01	Pietas Romana
Balkan and Eastern mint issues:					
LHC48	Thessalonica 845	16.5	-	1.42	Gloria 1-std.
BM345	“ 856	16	-	1.50	“ “
BM323	Constantinople 1046	15	-	1.53	Pax Publica
BM320	“ 1046	16	-	1.57	“ “
Y3	Antioch 1374	15.5	-	1.65	Quadriga
BM349	“ 1382	15	-	1.55	Gloria 1-std.
BM338	Alexandria 1465	14.5	-	1.44	“ “

If the 'M'-marked varieties in Table XXVII (Items H27 and BM341) are isolated as being either special issues or ones which need re-attribution to an earlier date, the entire Western coinage shows a descent to standards of 3 scrupula per libra and less. This trend was adumbrated at Rome and Arles before AD 337, when Trier and Lyons were still operating the 4-scrupula standard (see Table XXVI), but all the western and central mints appear to have lowered their coinage alloy finenesses between 337 and mid-341. The new types of PAX PVBLICA, SECVRITAS REIP and PIETAS ROMANA were all introduced when lower standards prevailed in the west; but the eastern PAX PVBLICA and the Quadriga issues for DIVUS CONSTANTINE, conformed to the extant eastern alloy standard which continued.

Thus began again the inexorable drift from a 'silver' to a plain bronze denomination. Hints of the lower official opinion of the much-debased follis are contained in a law of Constantius II (C. Th. 6.4.5), issued at Antioch on 9 September 340, and concerning the prescribed expenditure and outlay on the Games, by Praetors, on attaining office:

First	Praetorship:	25,000	folles	and	50	librae	of	silver
Second	"	20,000	"	"	40	"	"	"
Third	"	15,000	"	"	30	"	"	"

From the text it would appear that the folles began to be distinguished from silver coin in its finer form. The quantities of coin are seen to be in proportion, and there is just the possibility that their values might have equated. If so, the siliqua would have been equal to 5 folles - which would have attached a most inflated value to the baser coins.

In July AD 341 came a further follis reform involving the introduction of altogether new types in both the East and the West. Dr Kent's(384) average weight of 1.63g for 223 of the western VICTORIAEDDAVGQQNN coins shows no change in weight-standard from the existing 1/192 libra, and his very similar average of 1.66g for 280 eastern issues of VN MR and VOTXX types confirms the apparent intention of operating a unified coinage over the period 341-348. The die-module, however, shows some reduction from the previous issues; and the actual module is such that many pieces of this period are dumpier and do not extend to the full circle of the dies. Metallurgical degradation is also revealed by the fracture and by the analyses of the coinage presented in Table XXVIII.

TABLE XXVIII

Analyses of the follis coinage of AD 341-348

Code No	Mint	LRBC I No	Die Module	Composition (Wt %)			
				Copper	Tin	Silver	Lead
SL54	Trier	138	16	-	-	0.65	-
BM26	“	166	15.5	77.59	6.03	nil	16.13
Ca34	Arles	462	16	-	-	0.18	-
BM458	Aquileia	703	15.5	-	-	0.64	-
BM29	Thessalonica	864	16.5	-	-	0.44	-
BM360	Nicomedia	1150	14.5 +	-	-	0.37	-
BM364	Cyzicus	1308	16	-	-	0.01	-
BM31	Antioch	1399	15	-	-	0.52	-
W4	Alexandria	1473	15.5;16	80.94	2.87	0.40	15.53
BM325	“	1476	15.5;16	-	-	0.41	-
W3	“	1477	16	78.09	3.87	0.40	17.55
POP ROMANVS issue							
BM387	Constantinople	1067	13	-	-	2.27	-
BM469	“	1067	13	92.86	1.76	1.82	5.69

At this stage the Imperial follis coinage descended to the smallest practical size for convenient handling - down to one or two millimetres less in diameter than the modern British halfpenny - but the presence of its 'silver' character persisted. The analyses show the descent to a 1 scrupula per libra fineness in the East - which just maintained the token silver tradition, but in the west the few results are so scattered that it is difficult to discern what the policy was there. Everywhere, however, the highly leaded tin bronzes were adopted.

An intriguing issue at this time is the little POP ROMANVS coin, of which two examples have been assayed and are listed in Table XXVIII above. The fineness standard could have been, say, 6 scrupula per libra; but whatever it was it is apparent that it was intended as a higher denomination than the common follis despite its smaller dimensions. It was an issue peculiar to Constantinople, and finds no counterpart at the mint of Rome or elsewhere.

b) The FEL. TEMP. REPARATIO and associated coinages, AD 348-357

In an incisive reassessment of the numismatic and historical evidences in association with traditional Roman religious thought Dr J P C Kent(385) has established 21 April AD 348 - the Natalis Urbis - as the likely, though unproven, date for the commencement of a new coinage marking the 1100th year and the tenth saeculum of the foundation of Rome. Over 40 years ago Dr Mattingly(386) had attributed the inception of the 'Fel. Temp. Reparatio' coinage to AD 348 in that its theme related to the Golden Age, with a unifying emphasis on renewal and on the use of time-honoured inscriptional slogans, but an earlier date (346) was suggested by others. Now Dr Kent concludes that the little VOT XV MVLT XX coins - for which an assay (BM 31) is included in Table XXVIII - were struck with the VOT XX MVLT XXX variants, as a whole, to coincide with the 'Silver Jubilee' of Constantius II in and after the second half of AD 347, so they provide an absolute terminus post quem for the 'Fel. Temp. Reparatio' coinage and firm support for Mattingly's original concept.

The new coinage - which is here established as minted in various argentiferous bronzes - was struck for Constantius II and Constans in three denominations and with five principal reverse types, as follows:-

Large, AE2 (c. 22.5 mm)	:	'Galley', and then 'Falling Horseman'
Small, AE2 (20-22 mm)	:	'Hut', and 'Emperor with two captives'

Smaller, AE3 (c. 18 mm) : 'Phoenix', (and rarer 'Galley')

These issues were soon to suffer a fate similar to their no less ambitious predecessors of earlier periods; and since it is found that the numismatic 'AE' classifications lack sufficient precision for a metallurgical study of closely similar sequential issues of diminishing size the author prefers to re-classify them according to their measured die modules.

In the standard work of reference now being compiled by Dr J P C Kent(387) the weights of good specimens, principally in the BM and ANS collections, will be reported. They are useful for determining the hitherto uncertain weight standards to which these issues were minted, as follows:-

Type	No of Coins	Average Weight (grams)	Apparent Weight Standard
Large AE2s ('A' denomination)			
Galleys and Falling Horseman	750	5.26 (Poor spread)	1/60 libra
Issues of Constantius II and Gallus	618	5.26 (Poor spread)	1/60 libra
Small AE2s ('N' denomination)			
Types with left-facing busts	415	4.25	1/72 libra
AE3s			
Phoenix, and AE3 Galleys	82	2.42	1/120 or 1/144 libra.

There are two metallurgical factors which probably contributed to the poor weight distribution of the largest pieces and the present uncertainty about the smallest weight-standard. The first was the general use of fairly substantially leaded alloys for all the pieces minted - particularly at the western mints; and the second would have been the difficulty of making the final cast-strip division by five when working with a new 1/60 libra fraction for bronze. We must remember also that these were the largest common coins minted for 38 years, and so a new generation of mint-workers had to gain experience in the weight control of their issues.

The weight fractions for the smallest issue is actually an improbable 1/135 libra; consequently it might be either a light 1/120 standard or a heavy 1/144 standard. Until the author can examine the weight histogram for their issues it cannot be more closely judged. But in due course the highest denomination was discontinued, and then a 1/144 libra working standard for the lower denomination and a 1/72 libra standard for the remaining higher one become more obvious:

Type		No of Coins	Average Weight (grams)	Apparent Weight Standard
Reduced AE2s of Constantius and Gallus:		670	4.34	1/72 libra
Reduced AE3s:	'M' variety	137	2.26	1/144 libra
	Types sans 'M'	679	2.48	1/144 libra

In any case we can correlate the weights and (21.5 mm) module with the later Aquileian and Siscian 'LXXII' marked issues which provide the standard; and from these it would seem that a 1/144 libra piece existed as a true half-piece.

The coinage assays can lead to much confusion because of the common intrusion of apparently genuine pieces which are actually good contemporaneous forgeries, and the considerable variety of silver standards used between AD 348, and the complete demise of the Fel. Temp. coinage about AD 357. It is found necessary, therefore, to classify the coinage, according to its type and module, into narrow chronological periods of issue, so as to determine the key dates and features of reform, as follows:-

Series I Constantius II and Constans

Ia (from, say, 21 April 348 to 19 January 350)

Issues for Constantius II and Constans from the pre-Magnentian western mints only.

Ib (from 19 January 350 to 18 March 351)

Issues for Constantius II alone - before the appointment of Gallus - including Constantius and Vetranio (1 March 350 to 25 December 350) and Nepotian (3 to 30 June 350); and the earliest issues of Magnentius.

Series II Constantius II and Gallus - from all mints (18 March 351 to Autumn 354)

IIa (from 18 March 351 to the recovery of Italy in September 352)

This series includes eastern mintings and issues of Siscia and Sirmium in the late summer of 351.

IIb (from September 352 to 11 August 353)

Issues of the mints of Rome and Aquileia, under Constantius II and Gallus; and parallel eastern issues.

IIc (from 11 August 353 to Autumn 354)

Issues of the re-captured western mints, and parallel eastern issues. (A key period of change).

IId (from Autumn 354 to 6 November 354)

Issues for Constantius II alone, after the death of Gallus.

Series III Constantius II and Julian (Caesar) - from 6 November 354 to mid-357

Issues from all the Imperial mints.

Apart from the true Imperial series the Gallic and Central-mint coinage of Magnentius, and then Magnentius and Decentius, extending from 19 January 350 to 18 August 353, call for separate attention because the coinage alloys point to both similarities with and differences from the coinage policies of the rest of the Empire.

If the Imperial issues are displayed, as in Table XXIX, according to their module and in sequence, the chronological progress of their diminution in size becomes apparent. It is then necessary to correlate them with fineness.

TABLE XXIX

The dimensions of the various FEL. TEMP. REPARATIO coinage issues

Series	Date	Large AE2 c. 22.5 mm	Small AE2 20-22 mm	AE3 c. 17.5 mm	Reduced 1 21.5 mm	AE2 2 19.5 mm	AE3 3 18 to 16.5 mm	AE4 4
		1/60	1/72	1/144	1/72	?	1/144	
Ia	April 348- January 350	*	*	*				
Ib	January 350-March 351	*	*	*				
IIa)	March 351	*	*	?				
IIb)	to				*			
IIc)	Autumn 354				*	*	*	
IId	Autumn 354-November 354						*	
III	November 354-mid-357						*	*

Those few coin analyses which have been reported by the author and H N Billingham(388) reveal little metallurgical novelty except for their proportions of silver. It would seem that the fairly conventional argentiferous leaded tin-bronzes used much earlier in the fourth century were repeated – the new difference being that both the eastern and western issues were minted in fairly highly leaded alloys.

The assays of the initial FEL. TEMP. REPARATIO issues - listed in Table XXX - completely endorse Dr Kent's concept of a new three-denominational system from the start of this coinage; and it is now possible to calculate their relative intrinsic worths for an appreciation of their denominational relationships. Dr A Ravetz's(389) neutron activation assays had indicated that there might be significant differences between the coin types, but these can now be quantified by the more accurate chemical assays.

The highest denomination is not only the largest coin but the one which contains the highest proportion of silver. The range 2.17% to 2.96% silver (for seven coins), makes it difficult to be absolutely sure of the standard, but one of 8 scrupula per libra would seem to match most closely the average fineness.

The sixteen assays of the middle denomination types - clearly distinguishable by their left-facing obverse busts when their flan modules were occasionally similar - show that a change in fineness standard was effected very soon after the first issues. Early issues are scarce, but all three which have been obtained for assay point to an original fineness standard of 4 scrupula per libra which was then revised to one of 3 scrupula. This is the denomination which the author thinks might have been the original centenionalis, because, if one takes a literal rendering of 'containing 100 parts' as meaning that the coinage alloy contained 100 wheat grains of silver per libra, the nominal composition (1.39%) is identical with the 4 scrupula per libra standard which the original coin alloys appear to possess. The term centenionalis is not known in any coinage legislation or literature earlier than AD 348. That it was the name of a common coin, already in circulation but disappearing, is attested by an edict of AD 354 (c. Th. 9.23.1) which forbids any trading in them (for personal profit). The assays in Table XXX now help us to distinguish between the larger Imperial coins (maiorinas) and the 'commonly called' centenionales, and to identify the similarly argentiferous but officially unmentionable ceteras (listed in Table XXXII) as the Magnentian coinage; to overcome the ambiguity of the Latin text ".... maiorinas vel centionales communes appellant, vel ceteras ...." whereby, since vel can be either conjunctive or disjunctive, the two different coin terms have often been taken to be synonymous; and to appreciate that the

TABLE XXX

Assays of the initial FEL. TEMP. REPARATIO coinage
(Series Ia; April 348-19 January 350)

Code No	Mint	LRBC II No	Reverse Type	Die Module	Silver (wt %)	Remarks
A. The highest ('A') denomination						
Ca 14	Trier	40	Galley	22	2.64	
B 146	"	41	"	22	2.52	
BM 5	"	46	"	22.5	2.25	'A' behind bust.
BM 17	"	43	"	22.5	2.17	
BM 224	Arles	410	FH(2)	22.5	2.56	) Parallel issues,
NMW 1	Aquileia	893	"	23	2.62	) all with 'A'
BM 227	Siscia	1169	Hoc Signo Victor Eris	24;23.5	2.96	) behind bust
B. The middle ('N') denomination						
BM 9	Trier	26	Hut	21.5	1.45	Earliest issue
BM 8	"	29	Hut	22	0.99	
BM 247	Rome	596	Hut	20.5	1.08	'N'-marked
BM 218	"	604	Hut	20.5	0.99	
BM 10	"	"	Hut	21	1.79	
BM 219	Constantinople	2017	Hut	20	1.05	First 'Γ' issue
BM 226	"	2018	E and 2C	20.5	0.89	
BM 225	"	2026	FH(3)	22.5	0.94	Last 'Γ' issue before Gallus
NMW 21	Cyzicus	2474	E and 2C	21	1.26	Earliest issue
BM 61	"	2481	Hut	21	1.00	
LHC 37	"	2484	FH(3)	22.5	0.81	First issue in Series Ib
BM 223	Antioch	2615	Hut	20.5	1.09	
BM 215	"	2616	E and 2C	21;20.5	0.92	
BM 217	Alexandria	2816	E and 2C	20.5	1.24	Earliest issue
BM 220	"	2818	Hut	20.5;21	1.11	
BM 221	"	2820	Hut	20	1.15	
C. The lowest denomination						
NMW 17	Trier	35	Phoenix	16.5	0.29	
BM 21	Cyzicus	2483	"	17.5	0.27	
AJHG 5	Rome	626	Galley	19	0.32	

silver-worths of all these 'forbidden' pieces were superior to any <u>follibus</u> issue current on 8 March AD 354.

The lowest denomination in the triple FEL. TEMP. REPARATIO series is distinguished by its small module, lowest weight, and lowest level of fineness. The standard (1 scrupula per libra) would seem to be at the lowest practical level of any significance; but the assays are supported by those of A Ravetz and are too consistent for the level of silver to be regarded as either an impurity or as the residue from a bronze-desilvering operation applied to any earlier coins recalled to the Treasury. The small AE3 'Galley' issue is deemed by Dr Kent to belong to the coinage at the start of the period, and the assay confirms that it does.

Consideration of the intrinsic worth of the coinage of AD 348 leads to the useful comparisons made in Table XXXI with respect to feasible denominational relationships:

TABLE XXXI

Coin Type	Weight Standard (libra)	Fineness Standard (scrupula per libra)	Theoretical Silver Content (grams per coin)	Total Metal Worth in Equivalent Silver*	Possible Range of Comparative Values
Large AE2 'Galley' and 'Horseman)	1/60	8	0.151	0.204	25-10
AE2 'Hut' and 'Emperor and captives'	1/72	4	0.063	0.108	10-5
AE3 'Phoenix' and small 'Galley'	1/144	1	0.0078	0.031	1½ or 2
Previous Vota coinage	1/192	1	0.0059	0.021	1

*assuming the base alloy to be 1/100th of the worth of the silver - which was its approximate value in AD 396 (C. Th. 11.21.2)

On a pure-silver basis the highest argentiferous bronze denomination would have equated with, say, 1/20 siliqua; and the lower denomination with approximately 1/50 siliqua. They could not have represented smaller fractions otherwise there would have been no economic incentive to mint them instead of siliquae. It is postulated that the 'N' symbol could have meant, simply, '50 to the siliqua'. The 'A' symbol really allows no other interpretation than that it was the principal denomination in this (and later) issues of argentiferous bronze. The now established fact that the 'A' piece had not only twice the alloy fineness but a greater weight and module than the 'N' piece suggests that a value ratio of more than two was intended - and that a ratio of 2½ (thereby equating 20 of the larger coins with the siliqua) would have been quite satisfactory at the outset.

This new coinage had been in issue perhaps no longer than 8 months when, on 12 February AD 349, Constantius published an edict forbidding the separation of silver from the 'bronze' pecunia maiorina. The term suggests a larger coin (than the centenionalis?) as being the particular denomination from which silver was being extracted; and it is clear that the mint-workers themselves were the principal offenders, and at least at the mint of Rome itself.

The edict throws considerable light on the metallurgical practices and abilities of the time. First, it provides official confirmation that the bronze coins were deliberately made in argentiferous alloy, and that this arrived at the mint in ingot form and was there processed into coins. Otherwise the mint-workers would have found it easier to steal any silver intended for alloying on the premises, rather than to engage in the more laborious practice of extracting it from the coin alloy off the premises (and presumably returning the desilvered bronze for minting the quota of coins expected by the Treasury in return for the issue of ingot alloy). Secondly, it indicates that there were other coins (the lower denominations), which, although argentiferous, were less attractive for their yield of silver and not subject to the same abuse. Thirdly, it proves that a simple 'home-industry' silver-extraction process for treating low silver alloys was known and practised, and that it could have been also used by the government for desilvering older argentiferous bronze issues which were either recovered or recalled.

A simple treatment of the melted bronze with lead, followed by slow cooling to separate a silver-rich lead bullion by gravitational segregation – with subsequent liquation of the lead-rich material - would have been a feasible process. A second treatment would have sufficed to remove nearly all the silver, and, since the original alloys were well-leaded anyway, the desilvered leaded bronze ingots could have been taken back to the mint and processed into coin as if nothing had happened. The nefarious activity would have been revealed by cupellation assays conducted on coin samples at the Treasury; and perhaps this is how it become known to the Emperor, and was traced to its source by the mintmark.

In 1967 W F Smith, a student at the Wednesbury College of Technology, explored the postulated silver extraction route on an alloy compounded to simulate a typical 'Galley' coin which had been already analysed. It was found that the mediaeval process described by Agricola(390) in 'De Re Metallica' was quite effective in removing the silver into a separated lead-phase which could be cupelled in the normal manner. There was no difficulty in extracting more than half of the available silver by two simple treatments with lead. But when the residual highly leaded bronze was cold-hammered, and then reheated to below red heat, it was found possible to collect further droplets of exuded lead-rich material containing silver. The process could then be repeated until the final bronze contained less than 15% of residual lead, and over 90% of its silver had been extracted.

Quite a substantial proportion of the large 'Galley' coins obtained by the author for assay have been found to be almost void of silver, and highly leaded. Some are fairly obvious forgeries - and a coin of such value would have been tempting for contemporaneous counterfeiters to reproduce - but some assayed coins which have passed expert scrutiny, as genuine, are perhaps official mint products made in the illegally desilvered bronze. Characteristically, they are highly leaded.

The vulnerability of the highest 'A' denomination quickly led to its replacement by 'Falling Horseman' issues of the same dimensions but lower-fineness; and in parallel (or perhaps a little earlier) the <u>centenionalis</u> was also reduced in fineness. The assays listed in Table XXX show that well before the death of Constans the issues with the left-facing bust were minted in an alloy with a 3 scrupula per libra fineness, and that before the appointment of Gallus (18 March 351) the same alloy was in use for the larger denomination also (Item BM 225).

The interesting feature of the revised issues is the introduction of the 'gamma' symbol - especially on the eastern coinage. Dr J P C Kent is of the opinion that this simply denotes a third issue, despite the fact that it is difficult to establish this for several mints. The author postulates that it signifies a fineness standard of 3 scrupula per libra, and this is justified by all the assays yet made of the earliest issues so marked.

Constans was killed on 18 January 350 and Magnentius obtained control of Gaul and part of Italy for nearly four years. Upon accession he made a short-lived attempt to create 'Fel. Temp. Reparatio' coin varieties for himself; but he quickly abandoned the idea in favour of his own themes struck on what appears to be a single-denomination argentiferous bronze coinage. The coin assays listed in Table XXXII show the extent of his independence and yet the degree of his metallurgical conformity. His FELICITAS REIPVBLICE type for the early 'A' denomination conforms in both module and fineness with the Imperial large 'Galley' issues - as does the isolated example of his special

TABLE XXXII

Assays of the coinage of Magnentius, AD 350-353

Code No	Mint	LRBC II No	Type	Die Module	Silver (wt %	Remarks
A. Issues of 19 January 350 to, say, May 350:						
BM 34	Trier	50	Felicitas Reipublice	22	2.71	
BM 35	"	51	" "	23	2.51	
B 84	Lyons	211	" "	22	2.85	
BM 246	Rome	632	Victoria Aug Lig Romanor	24	2.05	Laminated metal
B. Issue of, say, May 350 to Autumn 350:						
BM 33	Trier	54	Gloria Romanorum	22.5	1.69	)'A' behind
Ca 70	Lyons	214	" "	21.5;21	1.53	)bust
C. Issue of, mainly, September 351 to September 352:						
B 116	Amiens	5	Victoriae DD NN Aug et Cae	20+	1.33	)
SL 46	Lyons	221	" "	21	1.21	)'A' behind bust
BM 330	"	223	" "	21.5	1.27	)
BM 334	"	228	" "	21.5	1.18	
BM 432	Amiens	8	" "	23	1.08	)
SL 24	Trier	58	" "	22.5	0.95	)'A' behind bust
Ca 69	"	60	" "	22	0.99	)
BM 37	Lyons	217	" "	22	1.06	
BM 331	Rome	652	Vict DD NN Aug et Caes	22	1.08	'B' behind bust
BM 433	"		"	21.5	1.28	'Γ' behind bust
BM 333	"		"	21.5	1.39	'Γ' behind bust
BM 332	"		"	22	0.13	A forgery?
BM 39	Arles	437	Victoriae DD NN Aug et Cae	21	0.75	
LHC 65	Amiens	9	" "	22	0.43	
D. The AE1 special coinage of Gaul, September 352 to August 353:						
B 85	Uncertain	-	Salus DD NN Aug et Caes	27	nil	
AJHG 11	Trier	56	"	19	0.58	
E. Coinage of the revolt of Trier against Magnentius, AD 353:						
BM 40	Trier	67	Salus Aug Nostri	23(est)	0.51	

VICTORIA AVG LIB ROMANOR issue from the mint of Rome. But the next (GLORIA ROMANORVM) 'A' issue, which was introduced before June 350 and lasted not much beyond the middle of the year, is clearly of the true 'centenionalis' composition but the coins possess the larger or an intermediate module. The fineness was maintained with the introduction of the VICTORIAE DD NN AVG ET CAE series in September 351 - although the module was reduced; but later issues in this series (corresponding with 'B'-marked issues at Rome) are of maintained module but with their fineness at last reduced to the extant

Imperial standard of 3 scrupula per libra.

Before the final defeat of Magnentius (11 August 353) the mint of Trier staged a revolt and issued coins of lower standard (Item BM 40 in Table XXXII) in the name of Constantius - of full module yet matching his current coin fineness. The unique AE 1 coinage, struck only in Gaul and dated between September 352 and August 353, is enigmatic in that the only two assays conflict: one would suggest that the universally current alloy standard was used, and the other that this magnificent coin was a show-piece of little intrinsic substance - a distorted appeal, perhaps, to Christian support for a lost cause.

The Imperial coins of Series Ib (for Constantius only) and those of IIa (for Constantius and Gallus before the re-capture of Italy) are comparatively scarce, yet it was within this latter Series that some fundamental metallurgical changes were effected, for the 'A'-marked denomination reappeared – with associated LXXII marks - at Siscia and Aquileia. The weight standard of these pieces is undoubtedly 1/72 libra, and the die-module of representative pieces in the British Museum collection varies within the narrow range of 21 to 21.5 mm. They were introduced before the autumn of AD 352 and lasted well into AD 354, when some issues became contemporaneous with the 'S'-marked coins of the 'A' denomination - bearing all of the identification marks – at Aquileia.

The assays of the coinage of the legitimate emperors for Series II are given in Table XXXIII, in which the progressive reductions of module and western-mint finenesses can be seen. It is remarkable, however, that the fineness of the Alexandrian pieces was maintained at between 2 and 3 scrupula per libra throughout all the dimensional transitions. As one looks westwards the other mints show similar initial standards, descending eventually to 1 scrupula per libra, with the onset of debasement appearing to commence earliest at the most western mints. Amongst the profusion of issues it is difficult to follow the exact trends at each mint, but there is no doubt that important changes were effected in the year before the Roman world was re-united on 11 August 353, and that these continued with severe restrictions throughout 354.

The assays are entirely compatible with the dating of C. Th. 9.23. 1 to 8 March 354. Pharr(391) places the origin of this edict as Constantinople, in either 353 or 356: Pearce (in RIC ix) reads the place as Constantia (ie Arles), and suggests alternative dates of 348 or 352. The latter city is the more likely, so AD 354 is more consistent with Arelate regaining its dynastic

TABLE XXXIII

Assays of the Imperial coinage of AD 351-354 (Series II)

Code No	Mint	LRBC II No	Type	Die Module	Silver (wt %)	Remarks
A. The larger 'Γ'-marked issues:						
LHC 37	Cyzicus	2486	Falling Horseman	22.5	0.81	) First issues
BM 46	Heraclea	1893	" "	22	0.62	) of Constantius and
BM 437	Nicomedia	2300	" "	22.5;23	0.81	) Gallus
B. The smaller LXXII weight-standard pieces (First die-diminished series):						
BM 240	Rome	662	Falling Horseman	21;21.5	0.64	'B' behind bust.
BM 438	Cyzicus	2490	" "	20.5	0.68	'Δ' " "
BM 236	Alexandria	2481	" "	21.5	0.48	" " "
BM 241	Rome	666	" "	21.5	0.32	" " "
BM 18	Amiens	25	" "	21	0.19	'A' " "
C. Second die-diminished issues:						
SL 26	Cyzicus	2492	Falling Horseman	20.5;20	0.57	'E' behind bust
BM 237	"	2493	" "	19;19.5	0.53	" " "
BM 238	"	2495	" "	19;19.5	0.44	'S' variety.
LHC 54	Nicomedia	2308	" "	19	0.43	" "
BM 243	Rome	672	" "	19.5	0.26	" "
BM 41	"	676	" "	18	0.50	" "
LHC 103	Arelate	455	" "	18.5	0.55	'D'-marked
SL 27	Constantinople	2039	" "	18;17.5	0.89	
BM 449	"	2039	" "	17(est)	0.41	
BM 381	"	2041	" "	18;17.5	0.49	
BM 442	"	2041	" "	18(est)	0.59	
LHC 55	Aquileia	930	" "	17.5	0.30	
BM 439	Cyzicus	2497	" "	18(est)	0.66	last issue for Gallus
BM 377	Alexandria	2845	" "	16;16.5	0.83	" " " "
D. Bridging issues between Series II and III, late 354:						
BM 19	Siscia	1222 or 28	Falling Horseman	18.5	0.76	
MAZ 47	"	" " "	" "	18	0.71	
BM 439	Cyzicus	2497 or 98	" "	18(est)	0.66	
BM 379	"	" " "	" "	17(est)	0.46	
BM 378	"	" " "	" "	17;16.5	0.26	
BM 443	Alexandria	2844 or 46	" "	18	0.84	
BM 446	"	" " "	" "	17;17.5	0.81	
BM 239	"	" " "	" "	16.5;17	0.72	

name of Constantia shortly after its occupation by Constantius II in 353. The new D/PCON post-Magnentian coinage then issued by Constantius is represented by one assay (LHC 103) in Table XXXIII. At 1½ scrupula per libra fineness it matches the contemporaneous issues from the other Imperial mints and clearly illustrates and quantifies the purpose behind the edict - that no trader may transport more than 1000 of these folles, on his animals, for the payment of expenses, and that trading in maiorinas, common centionals, and other forbidden (Magnentian?) coinages, then extant in Gaul, was forbidden. In other words Constantius intended to recover the much more silver-rich coinages from circulation and private use, and to substitute the current inferior AE3 coinage of perhaps identical nominal value to the centenionalis.

By comparing the assays of the Magnentian pieces listed in Table XXXII with those of the Imperial issues listed in Tables XXX and XXXIII it is apparent that part of Magnentius's public appeal would have been his continuation of the 'A' denomination alloy fineness in face of the lower standards substituted in the East, and his persistence with a true centenionalis composition long after the standard had been reduced elsewhere by Constantius. Even the later fineness reductions by Magnentius had produced a coinage of superior worth; and this is what Constantius decided to forbid once he had eliminated Magnentius, because the existing centenionales were an embarrassment and a loss to him in the context of none of his coinage being then minted in 354 to match the quality of either the centenionalis or the pecunia maiorina.

The final issues of the "Falling Horseman" type of Fel. Temp. Reparatio coinage descended to a c. 17 mm module, with a 1/144 libra weight standard, either in late AD 354 and early in 355. The fineness standard at this stage does not seem to have had other than local importance, for the assays listed in Table XXXIV show much variation from mint to mint. Characteristically, Antioch maintained the eastern standard - of, perhaps, 2½ scrupula per libra; but the other mints reveal silver at impurity levels rather than typical of positive addition.

These 'M'-marked pieces probably indicate an official attempt at revaluation - perhaps to stem the enormous amount of counterfeiting which was then common, for the small 'Falling Horseman' is one of the commonest of ancient forgeries. Sometimes these appear with much-diminished weights and flans and are then termed minimi or minimissimi according to their dimensions. Surprisingly, one which was obtained for assay still contains 0.42% residual silver. These enigmatic issues provide a whole field of metallurgically unexplored territory at present, although it is obvious from their fractures that they were minted in very poor quality leaded bronzes.

The Fel. Temp. Reparatio coinage ended about 357, but not before the

TABLE XXXIV

Assays of the joint coinage of Constantius II and Julian Caesar (AD 354-360)

Code No	Mint	LRBC II No	Type	Die Module	Silver (wt %)	Remarks
A. Series III, AD late 354 to mid-357						
BM 244	Antioch	2637 variant	Falling horseman	16.5	0.78	'M'-marked type.
BM 452	"	2637	" "	15;15.5	0.52	" " "
BM 451	Rome	687	" "	16.5;17	0.44	
BM 245	Cyzicus	2500	" "	18	0.28	
LHC 53	Siscia	1236	" "	17	0.04	'M'-marked types.
B. Falling Horseman, minimus						
Ch.16	?	?	" "	15 (est)	0.42	Coin weight, 1.10g.
C. Series IV, AD 355-360						
BM 388	Cyzicus	2506	Spes Reipublice	17;16.5	0.19	
BM 43	Arles	460	" "	16	0.10	
B. 89	Aquileia	952, 4 or 6	" "	16.5	nil	
B. 87	Cyzicus	2504 or 06	" "	uncertain	nil	
BM 42	Rome	692	" "	16	nil	

introduction of an even smaller (1/168 libra?) AE4 SPES REIPVBLICE coinage in AD 355. The Series IV assays in Table XXXIV show that these pieces were essentially void of silver. Some analyses of the earlier 'Fel. Temp' issues have revealed occasional lead proportions in excess of 20%(392); but the little 'Spes' issues are found to have at least that amount of lead in them, and even 35.06% lead has been determined. The tin proportions descend to impurity levels in some instances; so it is with these issues that a new metallurgical era of leaded-coppers really began.

After the death of Constantius II Julian revived the practice of a double-denominational series in bronze, with the enlargement of the AE3 leaded-bronze to c. 19 mm and its weight to perhaps 1/96 libra, and the introduction of a rather larger AE1 coinage (c. 28 mm) than even Magnentius had attempted. The contemporaneous smaller coins however, still remained silver-free; but the apparently 1/40 libra AE1 pieces - two of whose assays are given in Table XXXV - show the revival of a 4 scrupula per libra fineness standard for the larger denomination. This piece was also minted by Jovian, and later (in a slightly smaller form) for Valentinian, but it has not been possible to obtain one of these pieces for assay to determine if the fineness was preserved by the later emperors.

TABLE XXXV

Assays of the issues of Julian Augustus

AD 361-363

Code No	Mint	LRBC II No	Type	Die Module	Silver (wt %)
A. The large AE1 coinage:					
NMW 22	Nicomedia	2319	Securitas Reipub	28	1.33
BM 391	Antioch	2640	" "	25.5	1.55
B. The small AE3 coinage:					
BM 327	Antioch	2642	Vot/X/Mult/XX	18	traces
BM 389	Constantinople	2060	" "	20(est)	0.04
AJHG 6	Siscia	1255	" "	19	0.08

On the assumption of the weight and fineness standards given above, the Julianic AE1s would have each contained 0.113 g. silver, which is approximately one-sixteenth of the actual silver present in a typical slightly debased contemporaneous 1/168 libra siliqua. If we take the substantial amount of base metal diluent into consideration the metal worths of the two coins fall almost exactly in a 10 to 1 relationship. There is just the possibility that this coin was the basic decargyrus which, with its Valentinianic successors, was demonetised in AD 395.

The Julianic silver is rather more plentiful than the earlier issues, and it has been possible to obtain a few pieces (and one obvious cast forgery) for the assays now listed in Table XXXVI. It will be noted that there is a small but definite proportion of copper in each coin; and the alloys seem to have been based on a norm of 12 scrupula of copper per libra. It is interesting that the compositions of the genuine coins are similar to that of a one-libra silver ingot of the type which Julian donated (together with five gold solidi) to each soldier on his accession, in AD 361, in conformity with the words "quinos omnibus aureos argentique singula pondo promisit"(393). K S Painter(394) obtained an analysis of such an ingot - found in Kent, and acquired by the British Museum in 1970 - and found 4.10% copper, 0.81% gold and 1.22% lead. The overall composition is so close to that of the coinage

TABLE XXXVI

The fineness of the Julianic siliquae

Code No	Coin Weight (grams)	Die Module (mm)	Coin Reference	Silver	Gold	Copper	Lead	Mint and Date, AD
*NMW47	2.08	17	Coh. 343	91.79	0.577	6.55	1.02	Arles, 354
BM 155	1.64	17.5	-	93.26	0.323	5.60	0.61	Lyons, 360
BM 399	1.89	17	-	94.51	0.81	4.55	0.47	Arles
Cast forgery:								
BM 398	1.55	16.5	-	27.40	traces	71.59	0.16	Copy of Arles.

*Struck earlier for Constantius II.

that we can regard the ingot as a simple officially authorised remelt of a libra of current coins returned to the Treasury as tax payments. Alternatively, such ingots made up as virgin alloy could have provided the basis for each libra batch of new coins to be minted. The point of metallurgical interest is that there does not seem to have been any attempt in this era to refine the recovered silver coinage back to purer bullion for re-alloying; and so each donative libra conveniently equated in quality with current coin.

c) The Valentinianic coinage, AD 364-378

On 25 February AD 364 Valentinian succeeded Jovian, as Augustus. A month later he appointed his brother Valens as his Imperial colleague - giving him responsibility for the eastern provinces while he attended to the defence of the West.

Only three previous bronze coin analyses are known for Valentinian's issues, plus one which Brazener broadly attributed to AD 366-376. These results indicate that leaded low-tin bronzes, or leaded coppers, came into general use at this period for both the larger and the smaller pieces. Two unusual features which it has not yet been possible to confirm are presented by the silver and zinc contents reported, respectively, by Bibra and Sabatier, for two Valentinianic issues:-

Coin weight	Cu	Sn	Pb	Ag	Zn	Fe	Ni	Loss %
4.20g	87.08	-	9.99	2.02	0.61	0.2	0.1	-
?	92.94	0.70	2.11	-	2.23	-	-	2.02

From the numismatic point of view the first analysis is the more important, since it implies that Valentinian deliberately issued an argentiferous bronze at a time when that type of alloy would otherwise appear to have been abandoned. If the identification and the assay are correct the explanation might be that the coin assayed was an exceptionally light-weight AE1, and a continuation of the Julianic *decargyrus*. It is unfortunate that Bibra does not record the type in sufficient detail; but this present work confirms that no subsequent AE2 or AE3 coinage for Valentinian or Valens contains deliberately added silver, except maybe the special GLORIA NOVI SAECVLI type issued in honour of young Gratian when his father appointed him an Emperor in the West.

Despite the true *aes* nature of the smaller pieces of his coinage Valentinian was not more generous in his use of base metal. His AE3 coinage descended in module from c. 18 to c. 17 mm during the reign and, according to 691 pieces for which Dr J P C Kent has determined an average weight of 2.32 grams, the weight-standard was reduced to 1/144 libra in comparison with the 1/96 libra of the two earlier reigns.

Valentinian instituted a bronze coinage reform either late in 364 or early in 365 - perhaps while resident at Milan between October 364 and September 365. Essentially he tidied up the system which, into the early months of his reign, had involved the continued circulation of his own and earlier AE1 pieces; existing 'Fel. Temp', Julianic, and Jovian, AE3 pieces; and the quite recent AE4 'Spes Reipublice' issues. Some of these contained recoverable proportions of silver, and so help us to explain a Valentinianic edict which was to be issued nearly 6 years later. In their stead Valentinian introduced a new c. 18 mm 'RESTITVTOR REIP', (AE3) coinage in leaded bronze, and followed this by a long double series of 'GLORIA ROMANORVM' and 'SECVRITAS REIPVBLICAE' issues of slightly larger (19 mm) AE3 module, from all mints. In 367 he struck an AE2 version of 'GLORIA ROMANORVM' which has not yet been assayed. The two common AE3 issues, however, all in leaded bronze, were to provide a rather monotonous but profuse series of mintings for the next 19 years. The author has completed sixteen assays of these issues of AD 364-378, and found them to contain principally residues of silver in the following proportions, although it is just possible that a one-scrupula fineness might have been adopted for the 'Gloria Novi' specials:

zero to 0.09% ********
0.10 to 0.19% ****
0.20 to 0.29% ***
0.30 to 0.39% *

The basic coinage alloys vary considerably - from coppers with large and small proportions of lead in them, to low-tin bronzes with either large or small proportions of lead. There is no typical alloy of the period, but the western mints appear to have used an abundance of lead so that nearly all the coins are corroded and have to be fusion-reduced for a full metal analysis. One merely patinated coin of particular interest gave the following analysis:

Code No B 120; LRBC II 523a (RIC ix Arelate 15) GLORIA NOVI SAECVLI issue, from Arles, AD 367-375.

Composition, wt %:

Copper	78.50
Tin	0.54
Silver	0.21
Lead	18.59
Iron	2.02
Nickel	0.04
Zinc	0.03
Oxygen	0.08
	100.01

The first three Valentinianic coinage edicts listed in the Codex Theodosianus are concerned with the details of tax payments in gold. They are of some metallurgical significance relevant to possible abuses by both the public and the emperors' officials - which is no small reflection on the trustworthiness of the Roman civil servants!

C.Th.12.6.12, of 10 November 366 states that when solidi were collected, they had to be reduced to a firm and solid mass of pure gold. In this way the emperors sought to prevent either the public or their officials from incorporating base brass counterfeits or adulterated gold forgeries in the bullion delivered to the Treasury. That it was slow to be put into practice is revealed by the subsequent edict (C.Th.12.6.13 of just two months later) which stresses that the actual solidi shall not be delivered, because adulterated coins are often substituted for such solidi, but either the solidi shall be reduced to a mass, or .... a mass of fine gold shall be despatched (instead). And a pound of gold (either as dust or as a mass) shall be credited for 72 solidi.

It would seem that this latter edict was issued without metallurgical advice, or the careful legal forethought which we generally expect to have been applied to edicts, because later on the very same day (8 January 367)

C.Th.10.19.4 was issued to say that "... fourteen ounces of gold dust shall be paid for each pound" (due, of pure gold). These two laws are not juxtaposed in the Codex, nor in its translations, and the discovery of their identical dating was only made when the author extracted the existing scattered coin legislation and placed it in chronological order of issue. It would appear that the first law was only just 'in the post' when someone pointed out that gold in granular form was even more open to adulteration than if received as coin. So an arbitrary decision appears to have been swiftly taken to demand fourteen ounces of gold dust for each pound of gold due. The penalty of paying 16.7% extra on gold in this form would have fallen heavily on honest men; yet there is no certainty that the law would have prevented abuse by those who sought to adulterate to a greater extent than it apparently allowed so as to account for potential losses in eventual melting and refining by the State. There was really a complete metallurgical naivety about the possibilities.

A most important edict (C.Th.l1.21.1) was issued by Valentinian I, Valens, and Gratian Caesar on 7 April AD 371. It laid down that "not only shall the bronze called '<u>dichoneutum</u>' henceforth be (not?) delivered to the Imperial largesses, but it shall be completely withdrawn from use and circulation, and no person shall be allowed to have it publicly. Capital punishment shall overtake the '<u>conflatores</u>' of coined bronze as well as the counterfeiters of money". In other words, in the middle of their long series of apparently unaffected issues the emperors called for the complete withdrawal from circulation of a now enigmatic coinage, and forbad it to be retained privately or melted down unofficially. It is rather unfortunate that the two rare technical words - whose precise interpretation is essential for a complete understanding of the law - make their first and only appearance in extant classical literature in this law; but '<u>dichoneutum</u>' appears to be a definite metallurgical term and '<u>conflatores</u>' describes a special occupation connected with the preparation of bronze coin alloy melts.

Clyde Pharr(395) attempts to translate '<u>dichoneutum</u>' as 'twice-smelted'; but this makes metallurgical nonsense because smelting is really a primary metal-extraction process and, in its edict context, since it refers to an existing bronze coinage, the reprocessing described must fail to resemble or repeat an original smelting. The word has Greek roots, however, which more literally means 'twice digested' or 'twice-stewed' - in a cookery sense(396). Furthermore, '<u>conflatores</u>' means a 'kindling' - perhaps in the sense of a 'hot stirring up'. If, therefore, we place these words in their context with the now established knowledge that pre-Valentinianic argentiferous coinages were still in circulation with recent comparatively silver-free leaded bronze issues in early AD 371, and our awareness of an existing process for melting with lead to extract the silver, it is possible to provide a completely satisfactory explanation of the edict. The emperors were actually forbidding the unofficial final desilvering of an already twice-digested bronze coinage (probably the later Fel. Temp. issues) from which they wished to recover the silver themselves - after withdrawing it from circulation. Had it been a plain bronze then simple demonetisation would have sufficed; but here is the positive intention to recover it for its residual precious metal content. The conflatores could, conceivably, have been those skilled in stirring up the 'kindled' lead-treated melts, and liquating the weak bullion for later cupellation. These workers would have had previous experience in 'twice-stewing' the much more silver-rich earlier 'Fel. Temp.' issues so as to produce partly desilvered metal for the later 'Falling Horseman' issues whose silver contents we find to be so varied, and their operations were sufficiently well-known for the coin issues to be popularly known as '<u>dichoneutum</u>'.

This edict is also important for the evidence it provides for the practice of paying some taxes in argentiferous bronze, or for its formal re-purchase by the Treasury, at a time when it is thought that the bronze was issued with almost gay abandon in a great inflationary process, and for its formal declaration of the intended practice of issuing pure <u>aes</u> coins.

For the purposes of quantification it is worth noting that the loss of two librae of coins containing, say, only 0.3% residual silver, would have meant a loss to the State of the equivalent of a current silver siliqua – making its extraction a worth-while proposition in view of the essential simplicity of the process.

The current coin in AD 371 was no doubt minted in '<u>multichoneutum</u>' bronze - if one may coin such an unknown ancient term - and assays of the later AE3 coinage of the reign confirm that this was so:-

zero to 0.09%	silver	****
0.1 to 0.19%	"	***
0.2 to 0.29%	"	-

It is noteworthy that the hoards of the Valentinianic coinage reveal the almost complete disappearance of the familiar 'Falling Horseman' pieces during the reign; and the continuity of the existing coin types for seven years after the edict, apparently quite unaffected by it, lends support to the metallurgical explanation offered above.

In AD 378 Gratian effected a coinage reform involving the introduction of a small AE4 denomination and, later in the year, a 'REPARATIO REIPVB' AE2 denomination of 22.5 mm module in addition to 'CONCORDIA AVGGG' AE3 issues of 17.5 mm module. Two of the largest coins have been assayed, but at present it is not possible to judge whether a nominal 1 scrupula per libra fineness was intended, or not. One coin assay revealed 0.31% silver, and the other no silver, in leaded bronze-base materials. The distinctive metallurgical feature of all the issues is, however, the negligible proportion of tin present in most of the coinage alloys. From about this period to almost the close of the Imperial era in the West the coinage alloys were really leaded coppers - as shown by the new analyses of the issues listed in Table XXXVII.

TABLE XXXVII

The Valentinianic reformed AE2 coinage of AD 378-383

Code No.	BM 62	BM 63	LHC 69	B 155
Emperor	Gratian	Gratian	Valentinian II	Theodosius I
LRBC II No.	376	750	1065	1067
Mint	Lyons	Rome	Aquileia	Aquileia
Composition, wt.%				
Copper	80.37	94.65	93.56	94.10
Tin	0.88	0.62	0.03	0.14
Silver	0.31	nil	0.04	0.01
Lead	17.73	3.74	5.34	4.55
Iron	0.22	trace	0.23	0.28
Nickel	0.09	0.11	0.07	0.13
Zinc	-	0.01	0.05	-
Sulphur	< 0.01	-	-	-

d) The Theodosian aes coinage, and that of the declining Empire

Theodosius was created an emperor by Gratian on 19 January 379 and given charge of the East. Politically, he soon began to show his independence of Gratian, and his attitude is manifest in the coinage. In AD 383, shortly after the accession of Arcadius on 19 January, Theodosius initiated a rival eastern bronze coinage with 'GLORIA ROMANORVM' and 'SALVS REIPBVLICAE' inscriptions on the principal AE2 pieces, and later (c. AD 385) these were replaced by a 'VIRTVS EXERCITI' type. The question arises whether he intended these issues to be in plain or argentiferous bronze.

J Hammer recorded only six analyses of Roman coins minted in the entire post-Valentinianic period, and none has been published since. The available analyses, however, confirm the true aes character of the 'bronze' coinage of these closing decades of the western empire, and the adoption of leaded low-tin bronzes or coppers (sometimes contaminated with zinc) as follows:-

Emperor	Coin Weight, g	Chemical Analysis, wt %					
		Cu	Sn	Pb	Zn	Ag	Total
Theodosius I	1.17	98.30	nil	1.76	-	-	100.76
"	3.75	96.62	3.38	trace	-	-	100.00
"	?	90.04	1.25	6.11	2.60	trace	100.00
Arcadius	4.50	95.97	1.22	1.00	1.31	-	99.50
"	4.30	96.29	0.93	0.90	1.50	-	99.62
"	3.70	96.68	1.00	1.02	0.80	-	99.50

In consequence both chemists and numismatists have shown little or no interest in the metallurgy of this late Imperial coinage during the last sixty years, and no further investigation was made until this present work. The discovery is made, however, that there is a not insignificant proportion of silver to be found in the first large 'rival' bronze pieces issued by Theodosius in 383, but not in the smaller denomination, as follows:

Code No	Reverse Type	Coin Reference	Silver	Tin	Lead	(wt %)
BM64	Gloria Romanorum	LRBC II 2152	0.31	0.69	4.89	
BM201	" "	" 2550	0.29	-	-	
B136	Vot/X/Mult/X	" 2159	trace	0.65	6.60	

Whether this does or does not represent a deliberate 1 scrupula per libra addition of silver is still open to question, because at this date the proportions discovered in just the two coins could so easily be residues from the incomplete desilvering of re-minted alloys.

Gratian was murdered in Gaul on 25 August 383 and Theodosius became the dominant Augustus in the remaining partnership. In July 383 Magnus Maximus arose as a usurper in the West, and was not put down until 28 July 388. No analysis of his coins has been previously reported, but two of his AE2 coins are now shown to be virtually silver-free.

Beyond 388 it appears that all the Imperial bronzes became true aes, since the need for argentiferous bronzes decreased as increasing supplies of only slightly alloyed silver began to meet the needs of more convenient denominations between the bronze and the gold. The AE2 Virtus Exerciti coinage of Theodosius in this period is almost silver-free - as indicated by one assay (0.01% silver) and the following full analysis:

Code No MAZ 52; Theodosius I, (c. 385); 22 mm AE2 of 427 grams.
VIRTVS EXERCITI, Mint of Cyzicus, LRBC II 2565 (RIC ix 25b).
Composition (wt.%)

Copper	93.20	
Tin	0.93	
Silver	0.15	(0.09% on the other coin half)
Lead	3.89	
Iron	0.39	
Nickel	0.29	
Cobalt	trace	
Zinc	0.28	
Antimony	0.06	)
Arsenic	0.18	) (By neutron activation analysis of a co-
Gold	10.2ppm	) precipitate with iron)
Sulphur	nil	
Oxygen	0.12	(By reduction, without fusion, in hydrogen)

TOTAL	99.49%	

After the death of Valentinian II, and the accession of Honorius on 10 January 393, new 'GLORIA ROMANORVM' pieces were issued in both AE2 and AE3 dimensions. These are also found to be silver-free, and an edict of 12 June 393 (C.Th.11.1.23) confirms that the current coin was intended to be a completely base alloy for it refers to an additional tax in *aes* which "shall be completely removed". This is important because it reveals that some tax payments had been accepted in bronze; and so it strengthens the case for believing that earlier argentiferous bronzes had been treated as (dilute) silver for the same purpose - sometimes, even if not regularly.

Upon the death of Theodosius I, on 17 January 395 (or very shortly afterwards, and certainly by early April 395) a reform of the eastern *aes* coinage was effected when Arcadius re-divided the rule of the Empire with his brother Honorius. An edict of 12 April 395 (C.Th.9.23.2) demonetised the '*decargyrus*', stopped the minting of a '*maior pecunia*', and declared that "only the '*centenionalis*' shall be handled in common use. Now the '*maior pecunia*' is easily identified, as the plain bronze AE2 coinage which is known to have been completely discontinued after the death of Theodosius: it is not to be confused with the similar module but metallurgically different 'pecunia maiorina' which earlier edicts show to have been in issue in AD 349 and 'forbidden' in AD 354. The 'centenionalis' of this edict must, therefore, have been the current AE3 coin, which was retained in common use, and also the new and larger AE3 piece which is represented by item LHC 71 in Table XXXVIII. But at this stage it had become a 'centenionalis' in name only, and not in silver content. Perhaps with some deference to tradition Arcadius improved the module of the VIRTVS EXERCITI pieces to match those of the diminished (18 mm) Falling Horseman of earlier days.

TABLE XXXVIII

Analyses of the bronze coinage spanning the reform of early 395

Code No	BM 67	MAZ 55	LHC 71
Emperor	Honorius	Theodosius I	Arcadius
Date of issue	393-395	393-395	395-408
Module	AE2*	AE2*	AE3**
Die diameter (mm)	21	21.5;21	17.5
LRBC II No	2188	2571	2791
Mint	Constantinople	Cyzicus	Antioch
Composition (wt %)			
Copper	93.36	96.18	97.21
Tin	0.33	0.33	0.30
Silver	0.07	0.25	0.29
Lead	5.00	2.68	1.83
Iron	0.93	0.28	nil
Nickel	0.14	0.13	0.06
Cobalt	-	nil	trace
Zinc	-	0.10	0.03
Antimony	-	0.06	0.06
Arsenic	-	0.18	0.17
Gold	-	22 ppm	24 ppm

* The maior pecunia of C.Th.9.23.2.

** The new centenionalis.

The 'decargyrus' of the edict remains something of a mystery. It was obviously frozen; and if found in use it was obviously deemed to be of sufficient value to the State for it to be confiscated. It is suggested that the term is not at all synonymous with the 'maior pecunia', but that it refers to the few older AE1 pieces of Julian still apparently in use by those who preferred their bronze coins to possess some real silver worth. The edict was a final attempt to ensure that only a true aes coinage remained for the lowest denominations; and this is substantiated by assays of some of the latest Imperial leaded-copper issues which could be obtained for this work:

Code No	Emperor	Date of Issue AD	LRBC II No	Mint	Silver (Wt %)
Ca 71	Theodosius I	393-395	2198	Constantinople	0.10
MAZ 59	Honorius	" "	2573	Cyzicus	0.06
MAZ 54	Theodosius I	" "	2779	Antioch	0.18
AJHG 7	Arcadius	395-408	2205	Constantinople	0.09
BM 461	Honorius	410-423	823	Rome	nil

The last piece is a little AE4 - the pathetically tiny bronze coinage with which the western empire closed. This particular coin, however, possesses a moderate tin content, such as one would hardly expect at this time. It is a matter for further investigation in due course. Some measure of the effect of the persistent inflation which had brought the common Imperial coinage to its unworthy state is revealed in an edict of Honorius and Theodosius II, of 29 July AD 419, in which the price of pork is fixed at 50 denarii per libra. Fifty years or so earlier Julian had fixed it at 6 folles per pound (C.Th. 14.4.3).

On 18 January 445 the Emperors Theodosius II and Valentinian III issued an edict declaring that "... never shall a (gold) solidus be sold for less than 7000 nummi if it was bought from a money changer for 7200 nummi". By then the little AE4 must have been the nummus - for it was the only bronze coin in issue. If, as is probable, it was a 1/288 libra piece, there would have been 518,400 (or 1800 librae) to the libra of gold. This is exactly the same relationship as that created by the edict (C.Th.11.21.2) of December 396, stating that 25 librae of bronze were to be rendered for one solidus.

And so, at its close, and a half millennium later, the Roman Empire had completed a most elaborate metallurgical cycle with its coinage and returned to the simple tri-metallic intrinsic-worth system of Republican days.

ACKNOWLEDGMENTS

The Author is deeply indebted to those many friends who have allowed their imaginations to be caught and enthused with the fascinations and scientific possibilities of this research, and wherever possible they have been mentioned in the text and references in connection with their specific contributions. By way of special appreciation, however, the author's thanks are due to Mr R A G Carson of the British Museum for his most valuable guidance of the work through its maze of numismatic complexity, and for the provision of the bulk of the material without which a study in any depth would not have been possible; and to Dr M A Zammitt who has not only acted as the Supervisor concerned with the more purely scientific aspects but has so generously donated Roman coins in his own personal possession to fill important gaps in the analysed series.

Mr H N Billingham, of West Bromwich College of Technology, has kindly allowed the quotation of a number of complete routine analyses which he has freely contributed; and Dr G R Gilmore, of the Universities Research Reactor, has shown a similar generous spirit in the provision of several neutron-activation assays which required both skills and facilities to which the author had no other access. Mr E P Cook, of the Warrington Technical College, is to be thanked especially for his encouragement and for the provision of all the local facilities for classical metallurgical analyses and assays.

Those who have kindly provided the essential coin material are acknowledged individually, in the Appendix. They include the Directors and Curators of nearly all the principal Museums in the United Kingdom possessing Roman coin collections - and others abroad. Their reward will be the information of numismatic worth which has now been extracted from their secondary material, and in the routes which have been opened up for further scientific study.

Thanks are also due to Mrs S S Dean for her patient acquisition of previously unfamiliar classical and numismatic phraseology in the process of converting a rough manuscript into an excellent typescript. Any errors which now exist are entirely the author's.

In conclusion, this work is dedicated to Ione - a most patient and self-denying wife without whose whole-hearted support and encouragement it might never have been commenced, let alone completed.

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APPENDIX

Donors of the coins whose analyses are contained in this work

Coin Code No.	
A	Ashmolean Museum, Oxford, Dr C H V Sutherland.
AJHG	Mr A J H Gunstone, Birmingham.
B	City Museum and Art Gallery, Birmingham, Mr A J H Gunstone.
Br	The City Museum, Bristol, Mr L V Grinsell.
BM	The British Museum, Mr R A G Carson.
Ca	Carlisle Museum and Art Gallery, Mr Robert Hogg.
Ch	Grosvenor Museum, Chester, Mr D F Petch.
CJO	A donor who wishes to remain anonymous.
EHR	Mr E H Redfern, Gravesend, Kent.
H	Hereford Museum, Mr J F W Sherwood.
HDG	Colonel H D Gallwey, Faithlegg, Eire.
L	City and County Museum, Lincoln, Mr J B Whitwell.
LHC	The author.
Ls	City of Leicester Museums and Art Gallery, Mr J F L Norwood.
M	The Manchester Museum, Professor F C Thompson.
MAZ	Dr M A Zammitt, Liverpool.
NMW	National Museum of Wales, Mr G C Boon.
PB	Dr Pierre Bastien, Dunkirk, France.
PMB	Professor P M Bruun, Turku, Finland.
R	County Borough of Reading, Museum and Art Gallery, Mr T L Gwatkin.
S	Archives et Bibliothèque de la Ville de Strasbourg, M. J Fuchs.
SL	Schweizerisches Landesmuseum, Zürich, Dr H-U Geiger.
U of S	University of Surrey, Professor M B Waldron.
W	Municipal Museum and Art Gallery, Warrington, Mr J R Rimmer.
Y	The Yorkshire Museum, York, Mr G F Willmot.