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SOME METALLURGICAL ASPECTS OF GUPTA PERIOD GOLD COIN MANUFACTURING TECHNOLOGY

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The surface features on a standard-type Samudragupta gold coin were studied by scanning electron microscopy. The study indicated that the coin manufacturing process (i.e. by die striking) was performed with the gold coin blank in the cold condition. Analysis of metal flow patterns at high magnification revealed that the die was struck three times in order to produce the impression on the coin. The occurrence of radial cracks from the coin edges at specific locations has been explained by considering the possible clamping of dies at specific locations during the die striking operation. The composition of the coin was determined in the SEM to be 64.10 % Au, 15.65 % Ag and 20.25 % Cu. The SEM is a powerful tool to reveal the manufacturing technology of ancient Indian coins.

Key words: Coin manufacture, Die-striking, Gupta gold coin, Scanning electron microscopy, Surface features

INTRODUCTION

The great varieties and numbers of gold coins of the Guptas that have been discovered so far attest to the prosperity of the Gupta period[1-7]. Moreover, the metallurgical skill that was involved in the manufacture of the gold coins (by die striking) is clearly evident from the fine details available on the coins. It has been rightly said that Gupta gold coins are works of art rather than mere coins used for monetary transactions[8-10]. All important Gupta emperors minted splendid gold coins, which have evoked widespread admiration for their technical and sculptural finesse. Most Gupta gold coins carry *Lakṣmī* (goddess of wealth) on the reverse side of the coin. The symbols, phrasing of Sanskrit legends (written in the Gupta-Bramhi script), size,

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weight and gold content in the Gupta gold coins appear to have been meticulously planned and executed.

The technological aspects of minting Gupta gold coins have not been scientifically explained, although several features of ancient Indian coin-making technology have been addressed in the literature. There are no extant texts from the Gupta period indicating the technical method by which gold coins were minted, while some aspects are available from earlier period. However, it is possible to obtain deep insights into the coin-making technology by careful studies of the available coins at higher magnifications and resolutions. The specific coin-making technology (or, in general, any metal manufacturing technology) leaves behind special imprints and typical characteristics on the surface, which can, therefore, be related to the original methodology. A careful analysis of the surface topological features must be attempted at higher magnifications. It is well known in materials research that the scanning electron microscope (SEM) can be utilized usefully to study topological features. The SEM is very effective because of its high depth of field. It is an ideal tool for the study of ancient coins, especially if fine details on microscopic scale are required. The present study illustrates the use of SEM to elucidate some aspects of the gold coin-manufacturing technology during the reign of Samudragupta, one of the important monarchs of the Imperial Gupta dynasty (300 AD-600 AD).

Coin Description

The coin under study is a standard-type gold *Dināra* of Samudragupta which weighed 7.63 grams (118 grains). The weight standard used in Samudragupta's standard type coins was between 114 and 121 grains[10]. During the reign of his successor, Chandragupta II Vikramaditya, gold coins with standard weights of 124 and 127 grains were introduced. More numbers of coins with the higher weight standard were issued by Kumaragupta I, the son of Chandragupta II. Finally, during the reign of Skandagupta, the successor of Kumaragupta I, coins were also struck to the ancient *suvarṇa* weight standard of 144 grains. Samudragupta was the father of Gupta monetary system. In the fourth century AD, the Kuṣān gold coins were in circulation in north, central and, possibly, in eastern India, the dominion that later comprised of Samudragupta's empire. It was these Kuṣān coins that were the source of inspiration for Samudragupta's coins. The early Gupta coinage were of the same weight standard as that of Kuṣān. The Kuṣān rulers had adopted the Roman standard and minted their coins called as *Dinār̄a*, which is derived from the Roman name for their gold coins, *Denarius Aurius*. Therefore, the Gupta gold coins are referred by the name *Dinār̄a* in most contemporary literature. Samudragupta paid considerable attention to coin minting and left an extensive coinage. Samudragupta minted seven distinct types of gold coins: standard (studied in this report), archer, battle axe, *aśvamedha*, tiger slayer, king and queen (sometimes considered to be minted by his father Chandragupta I) and lyrist.

The most common type of gold coin issued by Samudragupta is the standard type, which is also considered to be the earliest gold coin type minted by Gupta emperors. The coin under study is shown in photograph of Fig. 1. The specimen can be categorized into Class I - Variety A, using Altekar's method of classification, whereas, according to Raven[10], the specimen can be classified as Variety B.6. The description of the coin type provided by Raven aptly describes the minute details. The obverse shows a tall Samudragupta, with a small head, standing facing to the left in a rigid posture. He holds the standard, which has been described as a sceptre by Raven, in his left hand and offers oblation on an altar with his right hand. He wears a cap, belt with dagger, a short tailed coat, which is decorated with rows of beads,

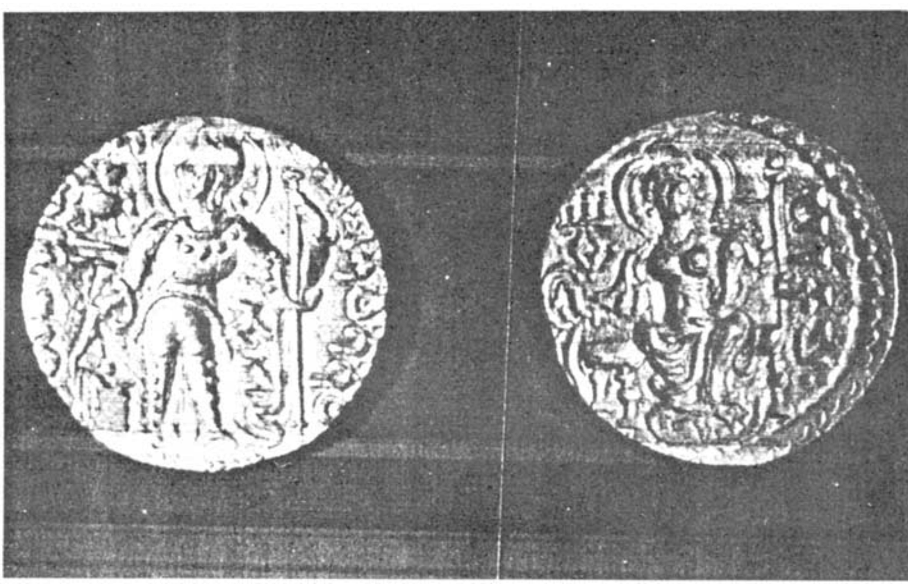

Fig. 1: Standard type gold coin of Samudragupta analyzed in the present study.

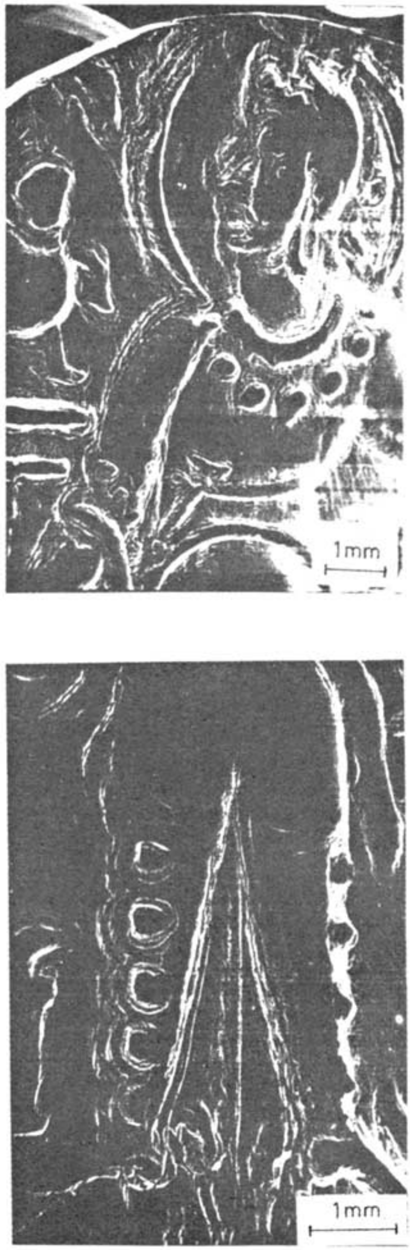

Fig. 2: (a) Top and (b) bottom of the obverse of the Samudragupta gold coin observed in the SEM.

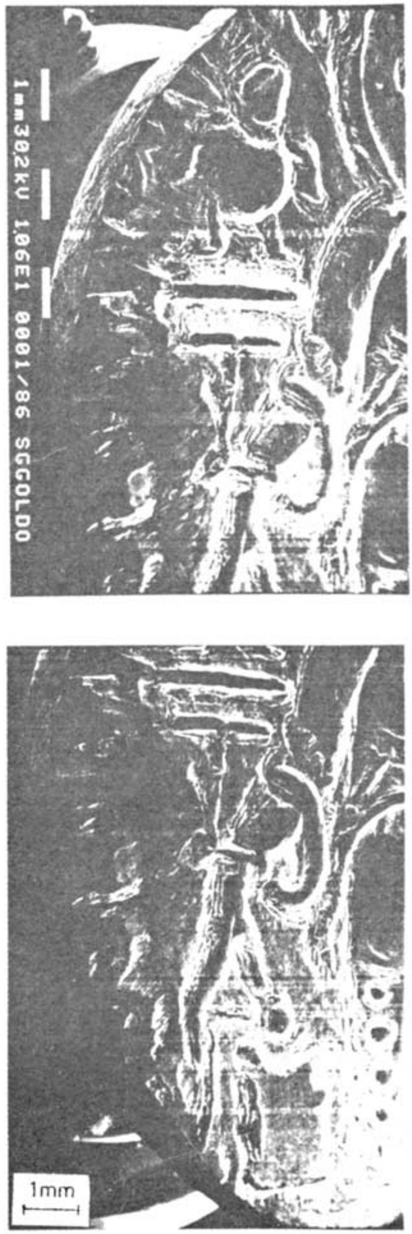

Fig. 3: (a) Top and (b) bottom of the left field of the obverse.

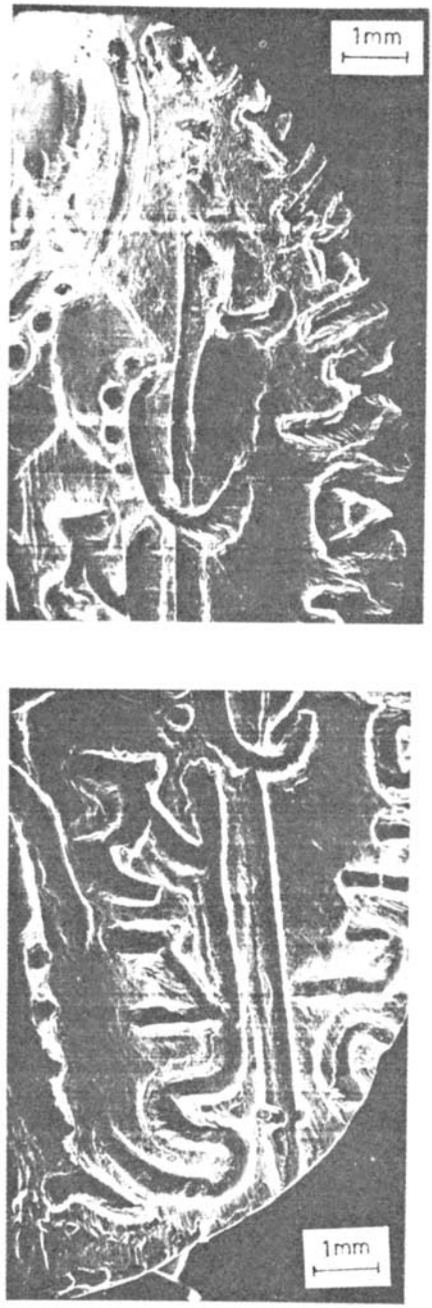

Fig. 4: (a) Top and (b) bottom of the right field of the obverse.

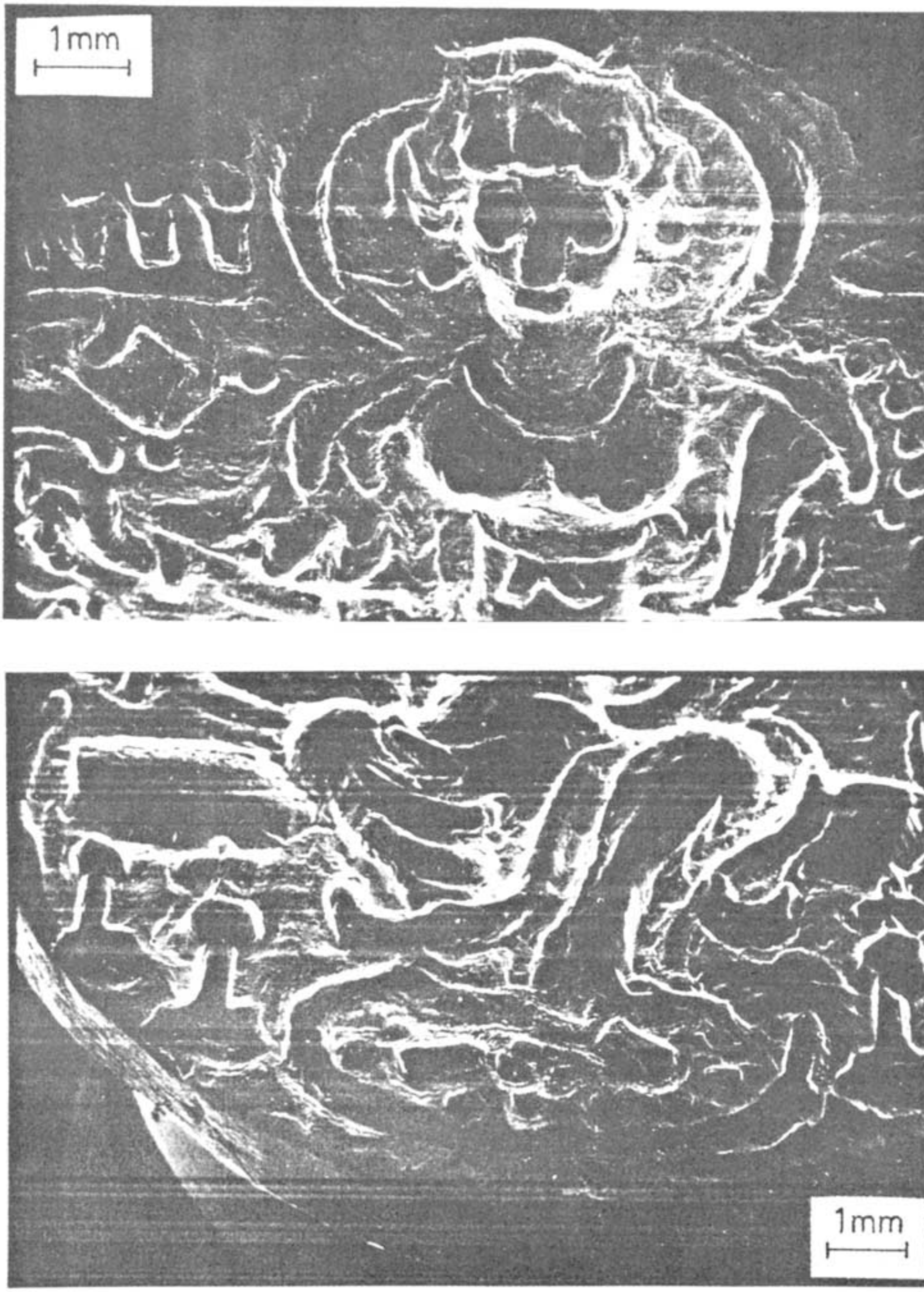

Fig. 5: (a) Top and (b) bottom of the reverse obtained at different perspectives by tilting the sample.

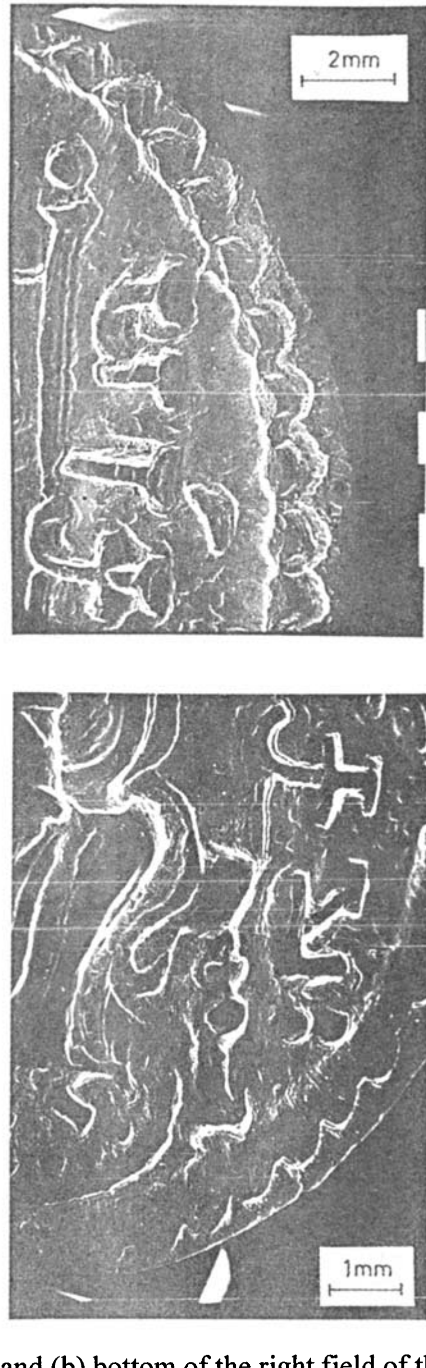

Fig. 6: (a) Top and (b) bottom of the right field of the reverse.

beaded trousers and boots. These details can be appreciated in the SEM micrographs of the obverse (Figs. 2, 3 and 4) and the reverse (Figs. 5 and 6). The short-sleeved coat has beadings along the collar and sleeves, and it comes down to the waist. The tails of the coat curve sideways to the hip. A narrow belt is seen on his coat, in which the dagger is placed with its blade pointing towards the king's right leg (Fig. 2a). In the left field, above the altar, is the Garuda standard. Garuḍa's short wings hang down along his body, with the feet pointing sideways (Fig. 3a). Traces of a small snake lifting its head can be distinguished above the Garuḍa's right wing. Garuḍa stands on a double platform supported by a staff. A banner is usually depicted on the staff on which Garuḍa is placed in Gupta gold coins. As there is relatively little room left for the banner to be shown on the staff in this particular coin, the banner has been indicated unobtrusively by a winding cord tied to the shaft (Figs. 3a and 3b). A crescent is noticed between Garuḍa and the king (Fig. 2a). *Samudra* is inscribed, vertically, beneath the king's left arm (Fig. 4b). The circular legend begins from I (clockwise position considering the position at the king's head to be XII, as per numismatic convention) and is not fully engraved. The legend reads *samara śata vitata vijayo jitaripur ajito divam jayati* meaning "the invincible (king), who has won victories on a hundred battle fields and conquered the enemies, wins heaven."[10] In the reverse (Fig. 5), *Lakṣmī* is seen sitting on a throne, which possesses four legs. In the left field, the symbol can be distinguished, which can be classified as symbol 9/14 as per Raven's classification. It is interesting to note that the throne is shown in perspective from the left (Fig. 5a). The upright of the backrest, along with cross-strut, has been provided (Fig. 6a). She holds a curving fillet in her right hand and a *cornucopia* in her left hand. She is depicted with earrings, necklace and armlets. Her feet are resting on a circular mat (Fig. 5b). The word *Parākramaḥ* (literally "bold advance" or "heroic courage"[10]) appears on the right of *Lakṣmī* (Fig. 6a and 6b). The border is adorned with a pearl chain.

Observations and Discussion

The fine details that are available when ancient coins are viewed in the SEM can be noted in the SEM images of the observe and reverse (Figs. 2 through 6). These figures also reveal the power of utilizing SEM, namely, the higher depth of field at higher magnifications. Different perspective views can be easily achieved by specimen tilting operations in the SEM. The nature of dresses and assorted allied objects can

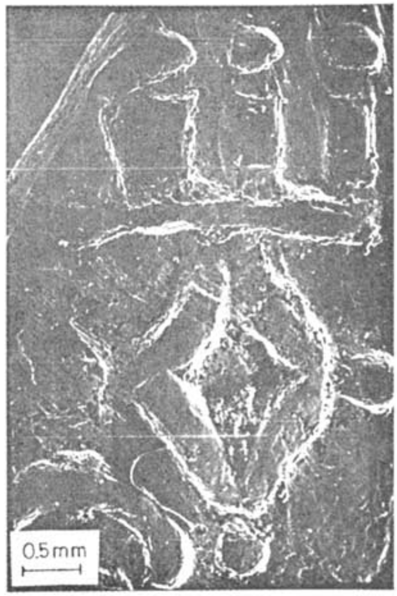

Fig. 7: High magnification view of the Gupta symbol on the reverse. The mark is incompletely imprinted on the coin. There are actually four vertical lines above the horizontal cross line.

be clearly distinguished and appreciated. The high magnification view of the Gupta symbol on the reverse, seen on the left of Fig. 5a, is shown in Fig. 7. It clearly indicates that the mark is incompletely imprinted on the coin and that there are actually four vertical lines above the horizontal cross line. Therefore, careful analysis of coins in the SEM can also help in the proper identification of symbol types and varieties, in a rigorous manner. Some of the contentious issues involved in the classification of these symbols can be sorted out. For example, Raven[10] provides that the variety B.6, to which this coin belongs, can have three different types of symbols, which she labels as 7/4, 7/7 or 9/14. There is only a minute difference between the groups 7/4 and 7/7. The symbol actually observed in the coin belongs to the classification 9/14 by considering the fourth vertical stroke, but can be misinterpreted to belong to either the 7/4 or 7/7 group because symbols in these groups have three vertical strokes.

Some features of ancient Indian coin making have already been discussed before.[11-14] Metallurgical aspects of coin-manufacturing technique of course may be obtained by observing the fine details to the left of the monarch's figure on the obverse at higher magnifications. It is interesting to note that one side of the monarch's facial image appears blurred, as seen Fig. 1. The blurring effect in the left field of the obverse is also evident in the SEM images in Fig. 3a and 3b. This blurring effect is due to the presence of multiple die marks, because observation at higher magnifications reveals river-line patterns, with three distinct striations (Fig. 8a). This high magnification view was obtained from the left side of the neck region of the monarch. A part of the Garuda can also be seen in the left of this figure. A typical river-line pattern, with three distinct striations, can be noticed on all the features. An allied important observation is that the right field of the reverse also exhibits this typical river-like pattern, with three distinct striations (Fig. 8b). This is logical because the left side of the reverse corresponds to the right side of the obverse. These observations are indicative of the fact that the coin-die was struck precisely three times. The possible reason for the appearance of the river-line pattern on only one side of the coin can also be proposed. The river-line pattern was created during the three times the die was struck, due to the small relative motion of the coin blank. This indicates that the one of the edges of the coin was not held rigidly between the dies during the coin-striking operation, resulting in the three visible river-line markings observed clearly. Interestingly, this kind of river-line markings was not observed on the right field of the obverse or on the left field of the reverse. As a result, the coin image does not appear blurred in these portions of the coin. Therefore, based on detailed fine structure analysis in the SEM, it can be concluded that the die containing the gold blank was struck three times in order to manufacture the coin. One side end of the blank was not clamped tightly during die striking.

Another interesting metallurgical, as well as aesthetic, aspect regarding the coin is the presence of cracks near positions XII and VI. One of the cracks can be clearly seen near the monarch's head in Fig. 2a. The other crack cannot be distinguished in the images of the obverse. It is evident in one of the SEM images of the reverse, emanating from the edge (Fig. 6b). It is worth noting that similar cracking features can be observed in several other Gupta gold coins, where radial cracks originate from near the XII or VI positions. Cracking must be related to the stresses created in the coin blank during striking of the dies. The presence of these cracks first indicate that the coin blanks must have been in the cold condition during minting. Therefore, the metallurgical operation can be precisely termed as cold working rather than hot working. Previous metallographic analysis of some Gupta gold coins also confirms this conclusion[15]. A detailed analysis of the stresses and strains in clamped circular

Fig. 8: River-line patterns, with three distinct striations, evident on all features on viewing at higher magnifications (a) the obverse at the left side of the neck region of the king, and (b) the reverse at the top of the right field, where the upright of the back rest is partially observed.

metal blanks under compressive loading (the situation that obtains in die striking process) was undertaken to provide further insights into the clamping and coin-making aspects of Gupta gold coins. Calculations revealed that the maximum tensile stresses are created in the coin plane at 90° to the clamped position, when the compressive stresses are applied normal to this plane[16]. It is well known that cracking is caused readily by tensile stresses rather than compressive stresses. In view of the above, the crack locations in the Gupta gold coins indicate the positions of maximum tension created during the die striking process. It appears probable that the dies were clamped at the III and IX positions during the die striking operation. The relationship between the clamping methodology and the subsequent edge cracking is schematically shown in Fig. 9. The types of dies used for coin making in the Gupta period are not known with

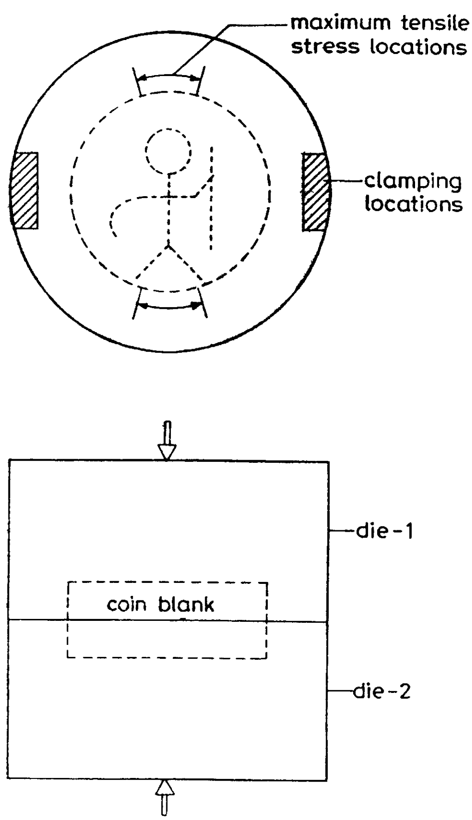

Fig. 9: Schematic showing the plan and elevation of possible clamping of the dies and the locations of maximum tensile stresses on the coin plane.

certainty and in the schematic, the bottom and top dies have been indicated without specifically stating the method by which they were positioned (for example, the lower die in an anvil and the upper die in a punch). The method of clamping of the dies is also not known.

It is appropriate at this juncture to understand the probable method by which the coins were die-struck during the Gupta period. The article by Mukherjee (ref. no.13) can be consulted for further detailed references. It is clearly established that the Gupta die- struck coins were struck from two separate dies, used probably simultaneously. The negative impression of the obverse and reverse types had to be first engraved on these two separate dies. It has been suggested that the dies could have been made of either bronze or steel. It has also been proposed that after engraving the die when the material was in the annealed condition, hardness could have been achieved by quenching heat treatments. In the absence of any coin-making dies from the Gupta period, it is not possible to verify the above statements on metallurgical basis. Two other methods have also been suggested for die production. First, the dies could have been made by pouring molten metal on fired terracotta patterns, which contained the fine details of the coin design. Secondly, it has been suggested that the positive design in high relief was cut on the lower end of a punch and this was stamped on a soft metal to produce the die with the negative impression (a method that was known as hubbing). High magnification observation of the coin in this study indicates that both these methods were not followed because microscopic features at the base of the raised coin features indicate evidences for the die having been engraved. It appears that the die from which the coin was minted was inscribed using sharp instruments. Some ideas about the kind of tools utilized to carve the fine details on the die can be obtained based on SEM observations. Higher magnification views of the depressions on the coin surface revealed fine scratch marks (Fig 10). Sharp tipped tools (most probably made of hardened steel) were probably used to inscribe the die. Once the dies were produced, one of them was fixed or embedded on an anvil, while the other die was fixed or engraved on a punch. After placing the carefully weighed coin blank on the bottom anvil-die, the punch-die was placed atop the blank, and the punch was struck with a hammer.

As several die struck coins were found double struck or partly out of flan, Mukherjee has argued that the regular use of mechanical devices or instruments (like the hinge connecting the dies) was not used in the Gupta period minting to position the upper die while die striking[13]. However, the regular alignment of the obverse and reverse impressions indicates that special care was taken in aligning the upper and lower die before striking. The present analysis of cracking in the gold coin indicates that the upper die (called the trussel die) and the lower die (called the pile die) were aligned with each other before the die striking operation, and that this alignment scheme involved some method of mechanical fixation between the anvil-die and punch-die such that the blanks were apparently clamped at the III and IX positions. The method of mechanical fixation of coin dies during the Gupta period is not known because of lack of archaeological evidences. However, there are archaeological evidences to suggest that Roman mints used hinges to connect the obverse and reverse dies[17]. In some cases, the upper die was so constructed that it fit at particular locations on the lower die.

Defects are not noticeable on a large number of Gupta gold coins and this is one of the reasons that they have been referred to as works of art. The production of high quality die struck coins depended upon the artistic skill of the die maker (who was a designer cum engraver), selection of die and blank materials, proper heat treatment of the dies as well as blanks, efficiency of die minting technique and the resources of the mint[13]. The die striking method continued in the post-Gupta age. However, there was deterioration in the system of coinage during this period[18]. Literary evidences from the reign of Allaudin Khilji (1296-1316 AD)[19] and Akbar (1556-1605 AD)[20] indicate that the same die-striking method, described above, was followed during the Sultanate and Mughal period.

One of the important benefits of the study of ancient metallic objects is understanding long-term corrosion processes and mechanisms. The destannification of an ancient Indian Mauryan – period high tin bronze, studied in detail using microscopic techniques[21], provided insights on the mechanism of destannfication. A common form of corrosion that is observed frequently in noble metal alloys (like gold and silver alloys) is dealloying of the baser alloying additions, like Cu. Features of long term dealloying can also be studied in the SEM. Typical surface features from the gold coin (Fig. 11) provide information about the localized nature of dealloying mechanism. The creation of a relatively porous surface at the dealloyed locations is indicated. Specific aspects of dealloyed surface structures will not be discussed here.

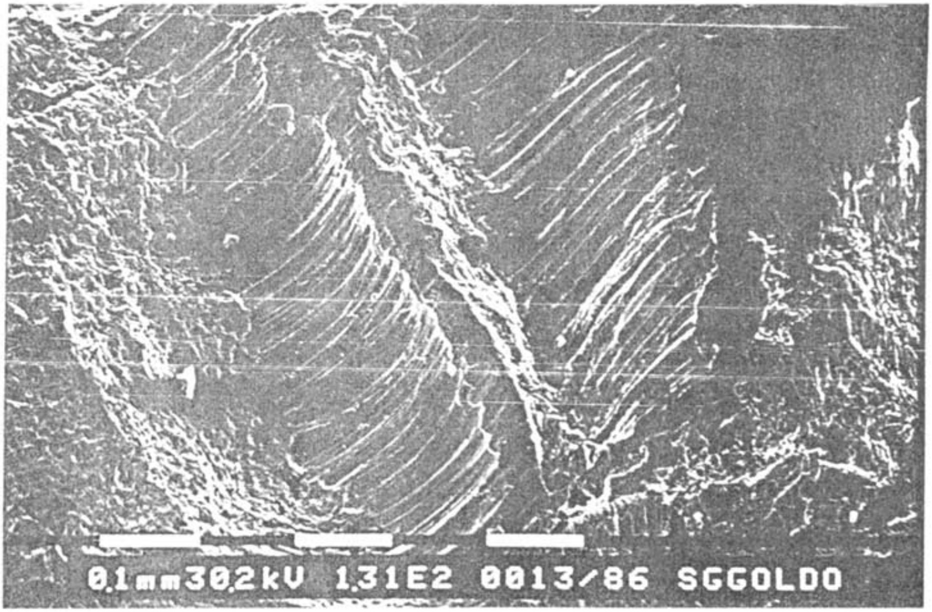

Fig. 10: High magnification view of one of the details on the surface, indicating that fine tools were utilized to carve the coin impression on die.

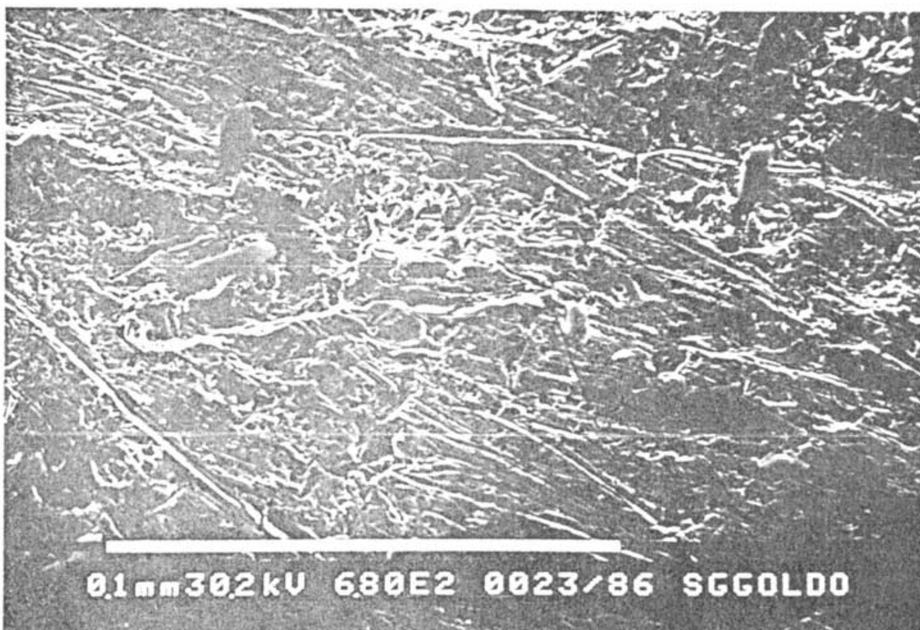

Fig. 11: Porous surface corrosion features indicative of dealloying.

Another advantage of utilizing the SEM for the study of ancient coin is that the composition of coin can be simultaneously obtained using the composition analysis unit, generally attached to the SEM. The elemental compositions can be determined utilizing either the wavelengths or energies of X-rays that are emitted, when the rastering electron beam in the SEM interacts with the surface of the metallic object. Utilizing such a procedure, the composition of the gold coin was determined to be 64.10 % Au, 15.65 % Ag and 20.25 % Cu. Interestingly, this is the first report of the composition of the B.6 variety of the Samudragupta standard gold coin. Maity has provided the average gold content of 83.93% for the standard type gold coins in the Indian museum,[22] and 83.5% for the coins in the British museum[23,24]. However, Raven[10] has pointed out that this may be grossly inaccurate because all the sub-varieties of the standard type coin were not available in either cabinet and that only a few coins had been compositionally analyzed. The additional power of the SEM compositional analysis is that local compositions (i.e. spot analysis) from specific locations can be obtained, which is very useful to study corrosion processes and products.

Conclusions

The surface features of a standard-type Samudragupta gold coin were studied by scanning electron microscopy. The analysis revealed that the coin die-striking operation was performed with the gold coin blank in the cold condition. Microscopic analysis revealed that the die was struck three times in order to produce the impression on the coin. The occurrence of radial cracks from the coin edges at specific locations has been explained by considering clamping of the upper and lower dies during the die-striking operation. The method of clamping is not known. The composition of the coin was determined in the SEM to be 64.10 % Au, 15.65 % Ag and 20.25 % Cu. The SEM is a powerful tool to reveal the manufacturing technology of ancient Indian coins.

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References

1. V.A. Smith, "The Coinage of the Early or Imperial Gupta Dynasty of Northern India," *J. Roy. Asiat. Soc. of Great Brit. and Ireland*, New Series, **21** (1889) 1-158.

2. V.A. Smith, *Catalogue of the Coins in the Indian Museum Calcutta including the Cabinet of the Asiatic Society of Bengal*, Vol. 1, Clarendon Press, Oxford. 1906.

3. J. Allan, *Catalogue of the Coins of the Gupta Dynasties and of Śaśāṅka, King of Garuḍa*, British Museum, London, 1914.

4. A.S. Altekar, *The Gupta Gold Coins in the Bayana Hoard*, Numismatic Society of India, Bombay, 1954 and *The Coinage of the Gupta Empire and its Imitations*, Corpus of Indian Coins 4, The Numismatic Society of India, Varanasi, 1957.

5. *Catalogue of the Coins of the Guptas, Maukharis, etc. in the Provincial Museum, Lucknow,* The Committee of the Museum, Allahabad, 1970.

6. P.L. Gupta and S. Srivastava, *Gupta Gold Coins*, Bharat Kala Bhavan, Varanasi, 1981.

7. B.C. Chhabra, *Catalogue of the Gupta Gold Coins of the Bayana Hoard in the National Museum, National Museum*, New Delhi, 1986.

8. P.L.Gupta, *Coins*, India – The Land and the People, National Book Trust, New Delhi, 1969.

9. B.N. Mukherjee, *Gupta Numismatic Art*, Agam Kala Prakashan, New Delhi, 1991.

10. E.M. Raven, *Gupta Gold Coins with a Garuḍa Banner*, Volumes I and II, Egbert Forsten, Groningen, 1994, pp. 201-251 and 460-464.

11. B. Sahni, *The Technique of Casting Coins in Ancient India,* Bhartiya Publishing House, Varanasi, 1973.

12. S. Prakash and R. Singh, *Coinage in Ancient India: A Numismatic, Archaeological and Metallurgical Study of Ancient Indian Coins,* The Research Institute of Ancient Scientific Studies, New Delhi, 1968.

13. B.N. Mukherjee, "The Technique of Minting Coins in Early and Medieval Periods,' in B.N. Mukherjee and P.K.D. Lee, *Technology of Indian Coinage,* Indian Museum, Calcutta, 1988, pp. 11-39.

14. T.P. Verma, "A Study on Manufacturing of Coins in Ancient India as revealed from the Arthaśāstra," *J. Numis. Soc. Ind.*, **33** (1971) 25-36.

15. H.C. Bharadwaj and S. Misra, "A Metallurgical Note on Gupta Period Gold Coins from Rajghat (Varanasi) Excavation", *J. Numis. Soc. Ind.*, **33** (1971) 122-127.

16. R. Balasubramaniam, *unpublished research.*

17. G. Macdonald, "Fixed and Loose Dies in Ancient Coinage," in Corolla Numismatica – Numismatic Essays in Honor of B.V. Head, Oxford University Press, Oxford, 1906, p. 178.

18. B.N. Mukherjee *Art in Gupta and Post Gupta Coinages of Northern India,* Lucknow State Museum, Lucknow, 1985, pp. 39-49.

19. Thakkura Pherū, *Dravyaparikṣā (Thakkura Pherū Viracitā Dravya-Parikṣā aur Dhātūtpatti)*, Ed. Nahata, Vaisali, 1976, vv 4-47 and 5-7.

20. Abu'l-Fazl-i'Allāmī, *Ain-i-Ākbarī,* Translated by H. Blochman, Ed. S.L. Goomer, Aadiesh Book Depot, New Delhi, 1965, **I**, 6-7 and plate III..

21. M. C. Srivastava and R. Balasubramaniam, "Destannification of Ancient Indian High Tin Bronze," *Practical Metallography*, **34** (1997) 573-583.

22. S.K. Maity, "The Gold Content of the Gupta Coins from the Indian Museum," *J. Numis. Soc. Ind.*, **80** (1958) 183-188

23. S.K. Maity, *Early Indian Coins and Currency Systems*, Munshiram Manoharlal, New Delhi, 1970, pp. 62-63.

24. S.K. Maity, *Economic Life in Northern India in the Gupta Period*, Motilal Banarsidass, New Delhi, 1970, pp. 263.