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India's Contribution to the Mining, Extraction and Refining of Gold: Some Observations Related to the Pre-Christian Era

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ABSTRACT

India has a very old and fascinating history of gold. Various aspects of the mining and metallurgy of gold were known to the Indians since time immemorial. In this paper, different types of the gold ore deposits, and the technique used in the extraction and refining of gold in ancient India as obtained from the literary sources composed in the pre-Christian era and some archaeological findings are discussed. The recovery of a novel variety of high purity gold powder, known as Pipilaka Gold, from the auriferous soil of ant-hills, as stated in the Mahābhārata, has also been discussed.

Key words : Alluvial placer gold, Vein gold, Liquid ore of gold, Panning, Deep mining, Cupellation, Solid state refining of gold, Ants' gold.

INTRODUCTION

Man and metal have an age-old relationship. Out of all metals known to man in ancient times, perhaps gold was the first with which man became acquainted. Indians had, and still continue to have, great fascination for gold. Its special attributes, such as pleasing and untarnishing colour, excellent corrosion and oxidation resistance, ease of forming, and limited availability made it an ideal metal for ornaments, decoration, currency, and store of wealth in ancient India.

Its characteristics also made it a symbol of sacredness in ancient times in India. The attributes of gold influenced the mind and heart of early Indians so deeply that they conferred upon the supreme spirit the designation of "Hirnyagarbha". It was so called because, He remains in a golden egg as an-embryo.

In the present paper the literary and archaeological evidences related to the gold ore deposits, and the mining, extraction and refining of gold in India in ancient times up to the beginning of the Christian era have been discussed, and the contribution of India in these areas have been analysed.

The literary evidences cited in the present paper are mainly derived from the following texts: R̥gveda^[1], Atharvaveda^[2], Śaṭapatha Brāhmaṇa^[3], Pañcaviṃśa Brāhmaṇa^[4], Rāmāyaṇa^[5], Mahābhārata^[6], Kauṭilya's Arthaśāstra^[7], and Anguttara Nikāya^[8]. A brief description of these texts are given in the Appendix. Although scholars differ on the exact date of composition of these texts, a representative date of their composition is given in Table 1.

Table 1 : Dates of composition of ancient Indian literary sources

Text	Date
R̥gveda	4500 BC
Atharvaveda	Later part of 4500-2500 BC
Saṭpatha Brahmana	3000 BC
Pancavimsa Brahmana	3000 BC – 2000 BC
Ramayana	Before 500 BC
Mahabharata	600 – 500 BC
Kautilya's Arthasastra	300 BC
Anguttara Nikaya	500-300 BC

DEPOSITS OF GOLD IN ANCIENT INDIA

In the Atharvaveda, the earth has been referred to 'hiranyavaksa', i.e., the one containing gold in her chest –

viśvaṃbharā vasudhāni pratisthā hirnyavakṣā jagato niveśanī |
vaiśvanaram bibhrati bhūmiragnimindrarishbha draviṇe no dadhātull
(Atharvaveda, 12.1.6)

The above hymn implies that the earth has mines of gold. The word 'bhumi' in the above hymn does not denote merely the surface of the plain land, but it also includes banks and beds of rivers, hills of mountains, together with the interior of the earth.

In ancient India, the following types of gold deposits were known:

1. Alluvial Placer Deposit
2. Vein Deposit, and
3. "Liquid" Ore

Alluvial Placer Deposit

There is a considerable amount of reference to the alluvial placer deposit of gold and the recovery of gold from such deposits. The R̥gveda (10.75.8) mentions that the river Sindhu (Indus) contains gold –

svaśvā sindhuh surathā suvāsā hiraṇyayī sukṛtā vajinivātī |
urṇāvātī yuvatīḥ śilamāva tyutādhi vaste subhagā madhuvṛdham ||

The greatest commentator of the R̥gveda – Sāyana has given the following commentary on the above hymn –

“This is the river Sindhu which is full of horses, chariots, cotton, gold, grains, and wool (i.e., these materials are either produced or found on the banks or the nearby area of the river Sindhu).

Its banks contain ropelike plants which are used to tie down ploughs. It bestows fortune on people, and such plants are grown on its banks that help in producing greater amount of honey”.

In another reference in the R̥gveda (8.2.18), it has been mentioned that the path, i.e., both banks, of the river Sindhu contains gold –

ut syā śvetayāvārī vāhisthā vām nadīnām |
sindhurhiraṇyavartaniḥ ||

According to Sāyana, the translation of the above hymn is as follows –

“And moreover, the river Sindhu having white (i.e. clean) water flow, and path (i.e., both banks) containing gold, praises you (Ashwin)”.

It is noteworthy that Sāyana has translated, ‘hiraṇyavartani’ as ‘hiraṇyamayobhayakūlā’ (i.e., both banks containing gold). The famous lexicon Amarkośa (2.1.15) mentions that ‘vartani’ is one of the twelve words used to denote the word path.

The above hymns of the R̥gveda are some of the earliest indirect references to the alluvial placer gold deposit, and throw light on the antiquity of such deposits in India.

In another Vedic text Śatapatha Brāhmaṇa, it has been stated that gold is found in water, apparently referring to alluvial placer gold found from rivers –

atha hiraṇya sambharati | retastāsmadapsu vindantyapsu hi
.....tasmādhiraṇya sambharati | (Satapatha Brāhmaṇa, 2.1.1.5)

The classical Sanskrit literature, notably the Rāmāyana and the Māhābhārata, has also given references to alluvial placer gold. The Mahābhārata (2.28, daksinatya recension) mentions that sand and mud of the Jambu river contains gold –

meruṃ pradakṣiṇaṃ kritvā parvatapravaraṃ prabūḥ |

The gold obtained from the river Jambū was known as Jāmbūnada, meaning literally "the produce of the river Jambū". In the Mahabharata (Drona, 68.11), it has been stated that the Jāmbūnada gold was considered to be a highly pure variety of gold and was very famous –

jāmbūnadasya śudhasya kanakasya mahāyaśaḥ |

There is another reference in the Mahābhārata, which states that the water flowing in the rivers of the kingdom of the king Suhotra contained gold, thus justifying the name of the earth as vasumati, i.e.,

satyanāmā vasumatī yām prapyaṣijjanadhipam |
hiranyamavahan nadyastasmīñjanapadeśvare | |
(Mahābhārata, Śānti, 29.26)

The relationship between rivers and gold was so strong that the names of many rivers producing alluvial placer gold started with the word meaning gold. Some notable examples are as follows. The Mahābhārata (Bhisma, 8.5) states a river named Hairanyavatī. Various Puranas have also stated similar such river names – Hirnyaskandavaha river (Varaha Purāna, 82.35), Kāñcanakṣi river (Vamana Purāna, 37.8), Hairanyavati river (Vayu Purāna, 45.10), etc. The famous lexicon Amarkosa (1.10.34) states that the Hiraṇyavāhu is another name for the river Soṇa.

Vein Deposit

Vein deposits are the important deposits of gold. The rocks of mountains are the important source of vein deposits of gold.

The Ramayana mentions various mountains, which contained gold. These were: Udai and Saumanasa mountains in the eastern, Soma, Pariyatra and Varaha mountains in the western, and Kala mountain in the northern direction of India. In the Mahābhārata (Vana, 104.2), it has been stated that the Meru or Sumeru mountain contained gold. –

adriṛājan mahāsailam meruṁ kanakaparvatam |
udayāstane bhanuḥ pradkshīṇamavartata ||

The identification of the Meru or Sumeru mountain has been subject of a number of studies. In the Mahābhārata (Aswamadrik, 4.25/26), it has been stated that the Meru mountain is situated to the north of the Himālayas–

meruṁ parvatamasadya himavatparsva uttare |
kāñcanāḥ sumahān padastatra karma cakārsaḥ | |

Harshe^[9] believes that the Meru mountain is no other than the Altai mountain in the Central Asia. Altai is the name given to a vast system of highlands and lofty mountains of southern Siberia and Mongolia^[10]. In the older geographical system the Altai included nearly the whole of the entire northern mountain system of Asia, extending through the Yablonoj and Stanovoi ranges to the N.E. extremity

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of the continent^[10]. The name Altai has been derived from the Turkish – Mongolian 'altan', meaning 'golden'^[11] and resembles with the description of Meru as gold mountain in Sanskrit texts. Pathak^[12] believes that the complex mountain chains from the Altai to the Upper Himalayas are variously termed as Meru.

Liquid Ore of Gold

In ancient Sanskrit texts, there is a mention of certain naturally occurring special liquids containing gold, which may be considered as 'Liquid' ores of gold. Such references are unique to Indian Sanskrit texts, which have not yet been noticed in ancient texts of other part of the world.

The Atharvaveda (5.28.6) mentions in a very concise (Sūtra) manner that one type of gold is the essential (sara) of powerful liquids –

apāmekam vedhasam reta ahustat te hiranyam trivrdastvāyushe |

The above hymn refers to the liquid in which gold is present in the dissolved form. Kautilya in his Arthasāstra has stated that one of the origins of gold in nature is in the form of solutions, referred to "rasavidhha", which is formed by the dissolution of gold present in veins of the rocks, in the liquid flowing through it. Kautilya (2.28.12) further states that this type of liquid emanates from the holes and fissures of mountains, and is of various colours, such as those of rose apple (jāmuna), mango, palm fruit, turmeric, red arsenic (manahsila), yellow orpiment (haritala), honey, vermilion (hingula), lotus, parrot, peacock, etc, and is unctuous and of high density –

parvatanamabhījnatoddeśanam
bilaguhopatyakalayanagūdhakhateṣvantaḥprasyandino
jambūcutātālahalapakvahariḍrabhedaharitalakṣaudra
hingulakapundrikasukamayura-patravarṇaḥ
savarnodakausadhiparyantaścikkana visada bharikaśca rasah
kāñcanikāḥ |

Kautilya (2.28.12) has exemplified the characteristics of such solutions containing gold. When such solutions are mixed in water, it spreads over the water surface like oil. Alternatively, it settles to the bottom of the vessel containing water, indicating a high density immiscible liquid. Kautilya has further given a very important characteristic of such solutions, which indicates that it contains gold. He says that one pala (a measure) of such solutions converts 100 palas of silver or copper into gold, which refers to the cementation of gold on the surface of less cathodic copper or silver (2.28.12) –

apsu niṣṭhyūtastastailavadvisarpiṇaḥ pañka malagra hiṇasā tāmrarūpyayoḥ
śatadupari veddhāraḥ |

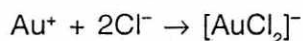
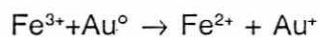
The conversion of silver or copper into gold by such liquids, in fact, refers to the deposition of gold particles on the surface of less cathodic metals such as silver, copper, etc., when these metals are immersed into such liquids containing gold.

It is not possible to identify the chemical nature of the liquid ore of gold as stated above by Kautilya, due to the limited data available. However, it is possible to visualize the chemical processes which must have been responsible for the dissolution of gold in nature into the liquids available in its surroundings under specific conditions. Some of these are discussed below.

Gold may be complexed and rendered soluble by the products of certain organic compounds, e.g., H_2S produced by bacteria that gives rise to $[AuS]^{[13]}$. The oxidation of sulphides and sulphosalts may produce a variety of species such as thiosulphate, sulphite, polythionate and sulphate depending upon the Eh and pH^[13]. A number of other complexes may also be formed, e.g., HS^- , HSO_3^- , H-S-O species, etc.^[13]. Gold may dissolve in many of these species forming complexes such as $[AuS]^-$, $[Au(HS)_2]^-$, $[Au(S_2O_3)_2]^{3-}$, $[Au(SO_3)_2]^{3-}$, $[Au(SO_4)_2]^-$, etc. Gold may also dissolve as chloro complexes, as per the following reaction^[13].



Ferric salts such as sulphates dissolve gold in the presence of dissolved chlorides under the acidic condition^[13]. The ferric ion renders the gold in an oxidized state, which then combines with the chloride to form soluble complexes –



MINING OF GOLD

Mining of gold is perhaps as old as the human civilization in India. It is reasonable to believe that the small scale mining or working of alluvial placer gold deposits preceded vein gold mining in ancient India. This hypothesis gets credence in view of the fact that the Vedic civilization was river based, and the people must have noticed the shining nuggets and particles of gold in the sand and gravels of rivers. However, the concurrent working of these two types of deposits must also have continued throughout the ages.

Unfortunately the literary evidences of the ancient alluvial placer gold mining are very few, and that too are not "direct" ones. As stated earlier, many rivers of India in ancient times have been stated to have gold, indirectly referring to the availability of alluvial placer gold from these rivers. It has also been stated earlier that the names of many rivers in ancient India started with the word meaning gold. This is another indirect evidence of the availability of alluvial placer gold in these rivers.

Several veteran geologists of the Geological Survey of India and mining engineers recognised numerous ancient working of vein gold deposits in South India in the nineteenth century. It was this recognition of old gold mining sites that induced prospecting for gold in South India, which eventually led to the establishment of numerous gold mining companies. It is interesting to note that almost all the working mines in India in the last 120 years have been established only on deposits indicated by the existence of old gold working sites. An examination of old gold workings in South India would give some insight into the mining practice

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used in ancient times. The work of Bruce Foote, L. Munn, J.M. Maclaren, and others of the Geological Survey of India, carried out in the later part of the nineteenth century throws light on the vein gold mining in ancient India.

Foote^[14] reported old gold workings including pits and small shafts and passages choked with debris at Belli-Betta (Silver Hill) situated 20 miles NW of Seringapatam, and Sonnahalli situated 18 miles SW of Mysore. On the banks of a stream near Belli-Betta, Foote^[14] noticed many small saucer shaped depressions on the hard quartz rocks, which was an indication of the sites of the rock pounding in the process of gold extraction. At Kempinkote about 45 miles NW of Mysore, Foote^[14] observed a huge pit, which according to him was the 'largest excavation of its kind' that he has seen in India. Bosworth Smith^[15] has reported a large number of old gold workings NW of Halebid and at Woolagiri, situated 20 miles SW of Mysore.

Several old gold workings have been reported in the Dharwar area of South India. Important old gold workings have been found between the town of Gadag and the river Tungabhadra by several workers. Maclaren^[16] has mentioned two dozen pits of 18-25 ft in depth on the top of Jalgaragudd Hill (Goldwasher's Hill). He has described the old workings as often characterized by no more than shallow depressions where the grass was greener; all that remained of a pit of 80-100 ft in vertical depth. The upper part of the old workings had been packed with large rocks and debris after the work was complete; the reasons for which are discussed later. On nearby rocks, evidences for the two types of crushing mill have also been observed, which are discussed later.

Foote^[17] reported the details of various old workings and mines lying between Hutti and Maski in the Raichur district of the present time Karnataka state, which are perhaps the most remarkable and interesting group of old gold workings. In an area of about 200 square miles several hundred old workings have been located. The entire area is covered by a thick blanket of black cotton soil, which has been drifted into the old pits thus obscuring them to surface view. As a result the pit areas appear as shallow depressions in the ground. Foote^[17] has reported numerous old shafts of up to 50 ft in depth in this area. He found that all these were filled with water and thus he could not explore deeper. Munn^[18], quoting from Maclaren's report submitted to the Government, has stated that the first modern gold mining started at Budini in 1887 AD, and in the very first year's survey some 300 old gold workings were discovered. The concerned mining company sank 5 shafts at Wandalli. The old workings were reached at different depths in different shafts, and in one shaft the old working had not bottomed even at 380 feet depth^[18]. At the Hutti mines, about 10 miles to the west, modern gold mining operation started in 1902. Here old gold workings were encountered at depths of up to 640 feet^[18]. Similarly at Maski, about 15 miles from Hutti, 13 old gold working sites were encountered; of which one mine extended upto a depth of 117 feet.^[18]

The above description gives the details of the number and size of some of the old vein gold mines in the Karnataka state. It is necessary to examine the

evidence they have on the antiquity of vein gold mining in India, and the method employed in mining. Timber, semi-charred timber, ashes and iron gouges have been found in many of these old gold workings^[19]. Timbering was used in supporting the galleries, and lengths of babul (*Acacia arabica*) were found. Some of the babul lengths had the irregular marks of adze cutting, while some had been rounded off at the ends to fit into uprights. The availability of timber, semi-charred timber and ashes in old workings point towards the fact that rock faces were fire set, which were subsequently quenched with water. This enabled the rocks to fracture which subsequently fell into pieces. Alternatively, the fracturing of rocks makes easy breaking of hard rocks from the main body. At depth of hundreds of feet in some old workings, the deposit of as much as 10 ft of broken water pots at the bottom of old workings has been reported. This indicates that here the miners came across a spring, and further mining was abandoned in the shaft.

Munn^[19] has observed that the upper parts of the old workings had been carefully hand-packed with large rocks and debris after any section was completed. Munn suggests that this was done with a view to prevent the surface water to flow into the mine, and perhaps also to prevent the collapse of the excavation. He is also of the view that the ancient miners were doing it to conceal the mines from the observation of invaders in time of war.

In 1955 AD C¹⁴ analysis of two specimens of timber found at a depth of about 250 feet in the old workings at Oakleys shaft of Hutti mine were carried out in New Zealand^[20]. The results were as follows: Sample No. 1 – 1890 ± 70 years BP and Sample No. 2 – 1810 ± 70 years BC. Allchin^[20] has quoted the dates of other objects, such as small pots of coarse pink-red earth ware, cylindrical grinding stone of pink sand stone, small stone discs of green chlorite schist, etc., found from the old workings and preserved at Hutti, which is in the range of 1st century BC to the 3rd century AD. This date is consistent with the dating suggested by the C¹⁴ analysis. The above archaeological evidences from the Hutti field suggest that the gold mines were being worked at depths of 250 feet during the 1st century of the Christian era.

On the basis of the above description of old gold workings, one may reconstruct the method employed in the mines of Hutti in ancient times, which may be considered as a representation of the method used in other areas also. The various steps used in deep mining were as follows. The first step consisted of going down the dip of the reef with a small shaft or series of shafts. The ore was extracted laterally from the shaft resulting in a flat back open overhand stope. Excavation was achieved by means of fire setting. Auriferous rock was removed and hauled to the surface in bags or baskets by ropes and windlasses for the recovery of gold.

This is supported by the appearance of smooth sides of the rock face in the shafts caused due to prolonged rubbing with ropes, as observed in old workings. Timbers were used for supporting the galleries. The water from spring found at greater depth of mines was hauled to the surface by means of water pots passed

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hand-to-hand to surface by a human chain. Such mines were subsequently abandoned due to severe problems faced in mining. The upper parts of the old workings was carefully hand packed with large rocks and debris after any section was completed. It is rather interesting to compare the gold working in Hutti area of the South India with that of the following verse quoted by Kautilya in his famous Arthasashtra (7.116.12).

sthalapathepi | "haimavato dakshināpathācchreyaṃ,
hastyashvagandhadantājīnarūpyasuvārṇapaṇyaḥ saravatrāḥ" ityācāryaḥ |
neti Kautilyaḥ | Kambājīnāshvapaṇyaḥ
sankhavajramanimuktāsuvārṇapaṇyaśca prābhutataṛā dakshīṇapāthe ||

Kautilya mentions that the earlier scholars have stated that among the land routes the Northern route (Uttarāpatha) passing through the Himalayas had been better than the Southern route (Dakṣiṇāpatha), which ran southwards from the Ganges valley, as superior quality of elephants, horses, musk, elephant teeth, skin of deer, silver, and gold are available in plenty. But then Kautilya explains that it is not so, and except woolen rug, skin of deer, and horses, huge quantities of conches, diamond, pearls, precious stones and gold are available in the Southern route. It is clear from this reference of the Arthasāshtra that in the time of Kautilya Southern route had occupied an important place for the availability of gold, which corroborates the archaeological findings reported earlier.

The question now arises as to when the very first gold mining activity started in the South India. Allchin^[20] has reviewed the various stages of the gold mining in the South India, and has traced the antiquity of gold mining in this area to the Neolithic period. He has stated that the first discovery of gold bearing reefs was during the Neolithic period, which in the Deccan is now established at between the end of the 3rd millennium BC and the first half of the 1st millennium BC. The mining work in this period would have mainly on the surface, i.e., open cast mining and alluvial placer gold mining. The tools available were too limited for any deep mining: stone picks are found in local Neolithic assemblages. However, due to availability of gold people started settling near the gold fields. On the basis of archaeological findings, Allchin has stated that small scale and local extraction of gold was taking place in the Neolithic period in the Wandalli and Hutti zones. The next stage must have been marked with the arrival of tools made of carburised steel, which must have increased the scale of operation. Allchin^[20] believes that this would probably coincide with the spreading of the fame of South India as rich source of gold to distant Magadh, as described in the Kautilya's Arthasāstra. According to Allchin^[20], the deep shaft mining represents a separate phase of the work, and it followed at some time about the beginning of the Christian era.

EXTRACTION OF GOLD

The Anguttara Nikaya (3.10.10) has described the process for the recovery of gold from the alluvial placer. According to this reference, the process consisted of agitating the auriferous sand along with water in a pan. The lighter sand

particles were drained out along with water, leaving behind heavier gold particles and some residual sand. This rougher concentrate was further panned several times resulting into gold dust having very little sand or other impurities. The persons engaged in gold washing were called "pansudhavaka", and were different from goldsmith.

The basic process for the recovery of gold from alluvial placer deposit, popularly known as gold washing, has not changed since the antiquity, although some details must have been changing with time and place of operation. Documentary evidences for the washing of gold from the alluvial placer deposits in the medieval and pre-modern periods are available in plenty. On the basis of all these references gold washing process may be summarized as follows.

Early recovery methods for gold from alluvial placer deposit were based upon the use of dish shaped pans made of wood or iron, and the technique was known as panning. The techniques differ according to custom and pan design. Most pans have one common characteristic – a large internal surface area and shallow depth. Basically, however, all methods relied upon a thorough puddling of the alluvial placer deposit mass by hand and agitation, using an oscillatory motion. As a result the heavier gold particles settled preferentially. A swirling motion of the pan under water continuously washed the top layer of light particles away until only a small amount remains. This rougher concentrate is a mixture of gold particles and lighter sand or mineral particles. Rougher concentrates from various runs were collected and further panned to a product in which the percentage of gold was high. Repeated panning resulted into gold dust having very little sand or other impurities. However, the success of the process greatly depended upon the skill of the washer. Alternatively, the gold and sand mixture was subjected to amalgamation, wherein gold combined with mercury, which was separated from the sand. The amalgam was heated in a suitable container to evaporate mercury, leaving behind gold. Recovery of crucibles containing mercury from the archaeological evidences has been discussed later.

If the alluvial placer deposit contained very coarse size gravels and pebbles, then the deposit was put over a sieve, made of bamboo or similar material, laid over a trough. Water was poured upon the heap of deposit, and also the deposit was stirred until all the sand was carried through the sieve into the trough. The remaining coarse particles lying on the sieve were rejected. The sand collected in the trough was panned for gold, as described earlier.

The run-of-mine gold ores obtained either from the open cast mining or deep mining was crushed in the batteries of crushers on the ground level. Several explorers have noticed the evidence of such crushers near many old gold workings in the Karnataka state in the nineteenth century. Two types of crushing mills have been sighted by these explorers. The first type, which Maclaren^[21] called "rock breakers", consisted of small depressions of about 6" broad and 4" deep, in which rocks were placed and crushed to about the size of a walnut. Maclaren^[21] has reported over 200 such rock breakers at old gold working site situated near Sangli. The second type crushing mill, used huge "rocking boulder" of size about

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30" x 18" x 18", weighing on an average 6 cwts. Maclaren^[21] has reported that many such rocking boulders were found lying near Kabulayakatti. Similarly, many small saucer-shaped depressions on the hard quartz rocks near a stream at Belli Betta 20 miles N.W., of Seringapatam have been noticed by Foote^[14], which was obviously a site for the crushing/grinding of the rocks to extract gold from the ore. The sand produced by the crushing was taken to a suitable place where water was available in plenty, and washed in wooden pans of the kind used for alluvial placer mining, as described earlier. The subsequent steps of extraction were similar to those used in the extraction of gold from alluvial placer deposits.

Munn and Mahadevan^[20] discovered ancient crucibles near Wandalli and Honkunni workings. The analysis of these crucible proved beyond doubt that they had been used for gold extraction. It was most interesting to note that in both instances they showed the presence of mercury, which indicates that amalgamation process was used at some stage of the extraction of the gold from the ground ore.

REFINING OF GOLD

There are references in the early Vedic literature, which throw light on the pure form of gold. For example, it has been stated in the Rgveda (4.10.6) that the fire glows like pure form of gold and the word used in this context is "suci hiranyam". There is also a mention of the best variety of gold in the Rgveda (1.25.2) – "suhiranyah". In the Atharvaveda (19.26.2), gold having pleasant colour (hiranyam suvarnam) has been mentioned, which is also an indication of pure gold. All these references indicate that pure form of gold, whether naturally occurring or intentionally prepared after refining impure gold, was known to the Vedic people.

In some of the Vedic texts of the later Vedic period, a clear mention of the refining of gold has been made. In Pañcaviṃśa Brāhmaṇa (17.6.4), there is a mention of how gold refining was carried out, when it is stated that the Agnistut purifies him by heat just as he (the smith) would purify the gold by the heat (of the fire).

The Arthasāstra of Kauṭilya has given two formulations for gold refining. According to the first formulation, pure gold is obtained by heating impure gold in liquid state along with lead. It is an example of the cupellation process. The second formulation is based on the heating of thin sheets of impure gold containing essentially silver and copper, along with salt and soil in the solid state. These two methods of gold refining are discussed below. Both of these formulations are indication of the fact that the ancient Indian knew the fact that gold does not oxidize in air or oxygen.

Kauṭilya has stated the following –
"taścaturguṇena śisena śodhayet"

[English translation: Impure gold should be melted with four times of its weight of lead for its purification].

Kauṭilya further states that the gold obtained from mines should also be purified in a similar manner –

"ākārodgataṃ śisānvayena bhidyamānaṃ"

Native gold is invariably by no means a pure metal. It contains up to 20% silver, copper, iron, lead, bismuth, platinum group metals, and other metals, as impurities. When impure gold containing various impurities are melted with lead at around 1100-1150°C, all the base metals present in the impure gold, as well as the lead, combine with the oxygen in the air, forming respective oxides, leaving behind gold unoxidised. The above formulation of Kautilya states that the amount of lead should be about four times the weight of impure gold. This is an important factor responsible for the success of the process. Since the concentration of lead is many times more than that of base impurities present in the impure gold, the primary oxidation of lead takes place. PbO does not accumulate in the melt until all the base metals have oxidized. Subsequently it begins to pass into the melt at a high rate. In other words PbO serves as a carrier of oxygen from the primary oxidant air to the impurities.

Subsequently a liquid solution between PbO and respective oxides of the base metal impurities present in gold is formed. If the crucible in which the gold was melted is porous, then these oxides of base metals together with that of lead would get absorbed by the porous crucible. There is a very large difference in the surface tension of Pb and PbO, and molten lead is not absorbed in the porous crucible. Elements such as Sb, As and Zn, when present in impure gold are, in part, volatilized as oxides and in part, absorbed in the porous crucible. If the crucible did not have enough porosity, then the liquid slag consisting of lead oxide and the oxides of the base metals present in the impure gold would float on top of the liquid metal, which can be tapped off leaving behind purified gold in the crucible.

The panning process, which is used for separating gold particles from the sand-gold mixture, whether obtained from alluvial placer deposit or obtained from crushing and grinding of auriferous rocks, is a very skillful operation demanding dexterity and ingenuity at each step. It is very difficult to remove all the traces of undesirable fine sized sand and soil from the gold particulate even after repeated washing without incurring heavy losses of gold. Kautilya was aware of this problem, and has suggested that the gold obtained from mines should also be purified by lead. As a result, not only the base metals present in the impure gold, but also the sand and soil present along with it are removed. The nature of soil and sand impurities present in the gold particulate would depend upon the location of the deposit, but the most frequently encountered oxide impurities would be SiO₂, CaO, FeO, Fe₂O₃, Cu₂O, ZnO, As₂O₃, Sb₂O₃ and Al₂O₃. When impure gold containing these oxide impurities is heated along with lead, say at 1150°C, then the lead and also the base metals present in the gold are oxidized as discussed above. The lead oxide combines with the above stated oxide impurities and also with the oxides of base metals present in gold formed during melting, leading to the formation of low melting point slag. This slag can either get absorbed in the porous crucible, or can be tapped off leaving behind purified gold in the crucible.

The treatment of impure gold with lead does not allow the separation of silver from gold. Hence if the starting impure gold contains silver as an impurity, which

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is usually the case, then almost all the silver would remain along with the gold after treatment with lead. Kautilya was aware of this fact, and it is against this background that the second formulation prescribed by him is very important, which was used for the further refining of gold, especially with respect to silver content. Kautilya has stated that the thin sheets of impure gold should be heated with the soil of Sindhu state –

“pākapatrapakvaṁ saindhavikyojjvālitaṁ I”

The soil of Sindhu state had been known to contain salt. It is interesting to note that the rock salt from the state of Sindhu had been known as Saindhava salt. The above process prescribed by Kautilya is a solid state process, in which the impurities such as silver, copper, etc from their respective chlorides by reacting with NaCl present in the soil. Subsequently these chlorides are absorbed in the soil with which the impure gold was being heated. The statement of Kautilya that the starting impure gold must be in thin sheet form is of special attention, as this would improve the kinetics of the solid state refining process as discussed above.

RECOVERY OF A NOVEL VARIETY OF GOLD POWDER FROM AURIFEROUS SOIL: THE ANTS' GOLD OF THE MAHABHARATA

In the famous Sanskrit epic Mahābhārata, there is a mention of a “Pipilaka” gold. Pipilaka is the Sanskrit word for ants. In the Mahābhārata (2.52.2-4) it has been stated that Pipilaka or ants' gold was presented to the king Yudhisthira at the time of the Rājasuya Yaṅna ceremony by the kings of various groups of people. The reference in question is as follows –

meruṁmandaryomdhye śailodāmbhito nadīm I
yete kīcakaveṇunāṁ chāyām ramyāmupāsate I
khasā ekāsānā hyarhah pradārā dīrghavenvahl
pāradāśca kulindāśca taganah parataṅgañāhll
tad vai pipilikam nama uddhrtam yat pipilikaihl
jatarupam dronameyamaharshuh punjaso nrpahl

According to the above reference, the kings of Khasa, Ekasana, Arha, Pradara, Dirghavenu, Parada, Pulinda, Tangana, and Paratangana groups of people, who resided beneath the pleasant shade of bamboo trees making sound like that of Venu musical instrument owing to air filling the pores of the bamboo, situated on the banks of Sailoda river flowing in between Meru and Mandaracala mountains, presented to the king Yudhisthira heaps of Pipilaka gold drawn up by ants.

The gold was in such a large quantity that it was measurable by Drona. Dube^[22] has discussed the theory of Ants' Gold in detail elsewhere. The fact that heaps of ants' gold was presented to the king Yudhisthira, and it was measured by the unit Drona is of importance in understanding the nature of such a gold.

Drona was a vessel, generally made of dried and seasoned timber, and was used to measure granular, powdered and liquid materials^[22].

Ant is a generic name representing various types of similar small creatures. Depending on the colour there are brown, black and white ants. Depending upon the size, there are big and small ants. All types of ants have been, and still continue to be, known to dig out soil from beneath the earth, and make soil heaps of various sizes, popularly known as "ant-hills". The size of these ant-hills would depend upon the type of ant making the hill. Brown and black coloured ants, whether small or big, make very small ant-hills, which are very fragile. On the other hand, white coloured small ants having reddish tip, also known as termite, make big size hills. The size of such ant-hills or termite mounds, which may be anything up to 5m high and 20m broad, depends largely on the kind of soil and climatic conditions. Hesse^[23] has reported ant-hills (termite mounds) as large as 84cu.m. in volume which had weight of about 185 tons of soil above ground at Ngomeni in East Africa.

In the light of the above discussion related to the ant-hills, one may reconstruct as to what is meant by ants' gold. Ants, in particular white ants, were digging out auriferous soil present in the alluvial placer deposit, and stored it at various places. Such soils were collected from these ant-hills by people. Subsequently, gold was separated from the soil constituting ant-hills by the usual process of panning, and such a gold was designated as Pipilaka or Ants' gold (powder). It is not unreasonable to believe that Pipilaka or Ants' gold must have been fine in size as the ants can carry only very small size gold particles in view of the higher density of gold. From the description cited in the Mahabharata it seems that the banks of river Sailoda or the area nearby were highly auriferous, and were the source of this gold.

The moot question that one may ask is as to what is so novel about the Pipilaka or Ants' Gold that it was considered to be the most appropriate item for presentation to the royalty at the time of Rajasuya Yagna ceremony. In order to answer this question, it is necessary to throw light on the nature of alluvial placer gold deposits. It has now been firmly accepted that the purity of alluvial placer gold is greater than that of the primary gold deposit from which it was derived. Further, the purity becomes greater with increasing distance from the primary source, is greater in small grains than in large ones, and greater on the out side of the grain than in the core of them.

The purity or fineness of alluvial placer gold varies from 500-900; that of vein gold from 500-850 (1000 is pure gold)^[24]. For example, Lindgren stated that the gold in California veins averages 850 fine, whereas the tertiary placer gold averages 930 to 950^[25]. McConnell^[26] showed that Klondike nuggets and grains have greater fineness on the outside than on the inside. In nature gold is alloyed with silver, copper and other base metals. Depending upon the suitable environment, silver, copper and other base metals are selectively leached from the gold alloy particles, e.g., as soluble sulphates or carbonates, during the transport. As a result, alluvial placer gold obtained from far removed locations from its parent source tends to become purer than the original material. More importantly, the outer surface of such gold particles becomes much purer due to the easy dissolution of silver, copper and other base metals from the surface,

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leading to greater shine. Similarly, the purity of alluvial placer gold increases with the decreasing powder size. For reasons described above, the alluvial placer gold powder is generally of more pleasing colour, having natural deeper colour than the mountain gold^[27]. Some authors^[28] have suggested that the natural deeper colour of alluvial placer gold can also result from the precipitation of pure gold from the solution containing gold on the relatively impure gold particles during transport.

In view of the fact that ants have limited capacity and strength and hence are unable to carry bigger particles of higher density gold, it is reasonable to envisage that the average size of the Pipilaka gold powder must have been very fine, and smaller than that of the average size of the alluvial placer gold powder produced by the washing of auriferous sand dug by human beings, and hence of greater purity as described earlier. Thus the ants were carrying out sizing of the gold powder present in the auriferous soil. It is because of the greater purity of the Pipilaka gold powder that it was considered to be a novel variety of gold and was thought to be the most appropriate item for presentation to the royalty. The amount of Pipilaka gold powder presented was so large that instead of weighing, it was measured by the Drona measuring vessel.

Greek historians and geographers, such as Herodotus, Pliny and Strabo have also referred to the ants' gold, which was different than that described in the Mahabharata. This has been discussed in detail elsewhere^[22]. Thus, the Pipilaka gold of the Mahabharata was high purity and fine sized gold powder obtained by panning the auriferous soil of ant-hills formed by the real ants as a part of their nature on the land containing alluvial placer deposits in the Meru and Mandara mountains region.

CONCLUSIONS

The present paper is an attempt to trace the antiquity of the knowledge related to the gold deposits, and the mining, extraction and refining of gold in India, mainly from some important literary sources composed in the pre-Christian era, and archaeological findings. From the foregoing discussion it is apparent that Indians acquired the knowledge related to the mining and metallurgy of gold at a very early date.

In ancient India there have been two important sources of gold, namely banks and bed of rivers, and mountains, having alluvial placer deposits, and vein deposits respectively. On the basis of literary evidences, it is apparent that the Indians had recognised these deposits as early as Rgvedic period. In addition, there was another interesting naturally occurring source of gold, which was in liquid form, and can be considered as "Liquid" ore of gold. Literary references are available in ancient Indian texts, which gives the details of the special liquids flowing through the holes and fissures of some mountains, which contained gold in dissolved form. Although Kautilya has given a detailed description of such naturally occurring special liquids containing gold, there is a mention of such liquids in sutra (concise) style in the period as early as when Atharvaveda was composed.

The early Indians have recognised an unique naturally occurring liquid solution as a source of gold. Alluvial placer gold was known as early as the time of the Rgveda. It is not surprising since the Vedic civilization was river based. It is reasonable to believe that alluvial placer mining of gold started first followed by open-cast mining in mountains. Later, deep mining of gold must have started.

On the basis of the archaeological evidences, it has been found that small scale and local extraction of gold was taking place in the Neolithic period in the Wandalli and Hutti zones of the South India. Large scale gold mining in these areas started around 4th century BC which spread the fame of the "Southern" route as a rich source of gold to distant Magadh in the North India, as stated by Kautilya in his Arthasastra. It must be remembered that both "Northern" and "Southern" routes were famous for their richness in gold during different periods of time. Deep gold mining up to depth of 250 feet was prevalent in the Hutti area of the South India during the beginning of the Christian era. For separating pieces of rock from the main body, the ancient Indians were using fire-setting on the rock face, followed by quenching with water. This shattered the rock so that it can be easily removed from the main body. It must be recognised that all the types of mining of gold must have been in vogue concurrently in different parts of the country. Panning was the most important process of separating gold particles from the sand gravels obtained either from alluvial placer or crushed lode deposits. Some archaeological evidences suggest that amalgamation process was used at some stage of the extraction of gold as early as during the first century BC in the Hutti area in India.

Early Indians had developed different forms of gold refining, viz. refining of gold with lead in liquid state, and refining of thin gold sheets with salt and soil in the solid state. The roots of these processes are available in the Vedic literature. Kautilya has given a detailed account of gold refining in his famous Arthasastra. Kautilya has proposed refining of gold both in molten and solid states. For both, the run-of-mine gold ore concentrate and the recycled gold, the refining in molten state with lead was carried out. As a result most base metals were removed from the impure gold. For removing the silver present in the impure gold, Kautilya proposed solid state refining using a mixture of salt and soil. It is interesting to note that the very first reference to the refining of gold using salt in the classical Greek literature is given by Strabo (63 BC–24 AD) and Pliny (23-79 AD)(29), which are of the period later than that of Kautilya's Arthasastra.

The recovery of a novel variety of gold, known as Pipilaka or Ants' Gold, from the auriferous soil of the ant hills, has been stated in the great epic Mahabharata. This was a high purity and fine sized gold powder obtained by panning the auriferous soil of the ant-hills.

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APPENDIX

Rik, Yaju, Sāma and Atharva Samhitas:

In general Samhitas are collections of hymns narrating prayers, benedictions, and sacrificial formulae. The hymns are written in very concise form, known as Sutra style, and therefore great care has to be exercised in interpreting their meaning. There are four Samhitas – Rik, Yaju, Sama and Atharva, and these are respectively also known as Rgveda, Yajurveda, Samaveda and Atharvaveda. The Rgveda was written first and the Atharvaveda last. Disagreement exists on the dates of composition of these works.

Max Müller^[30] considered the date of Rgveda to be 1200-1000 BC. Upadhyaya^[31] has drawn attention towards a lecture delivered by Max Muller in 1889 AD in which he stated that it is impossible to fix the date of the Rgveda exactly, but was of opinion that the above is the latest possible date. However, Tilak^[32] calculated the date of the Rgveda as 4500–2500 BC on the basis of astronomical evidence given in it; a conclusion that has been corroborated by Jacobi^[32]. On the basis of linguistic evidence, Mishra^[34] puts the date of Rgveda as 5000 BC or earlier, which is in accord with the astronomical chronology.

Brāhmaṇa Literature

The Brahmana literature discusses the spiritual, material and philosophical aspects of Yagna ceremonies. It is generally believed that the Satapatha Brahmana is the oldest Brahmana among all the Brahmanas. Upadhyaya^[35], quoting Dixit, has stated the date of Satapatha Brahmana as 3000 BC and places the Brahmana age in the period 3000-2000 BC. Most of the Brahmana literature has been composed in the period 2500-1400 BC^[36].

Rāmāyana

The Ramayana, the famous epic written by the great Rishi Valmiki, has inspired the Hindus from time immemorial. It describes the life, action and great deeds of Lord Rama; the incarnation of God. The famous war between Rama and Ravana is an important focal point of this epic. The Ramayana consists of about 24,000 verses and is considered to have been composed before 500 BC^[37].

Mahābhārata

The Mahabharata, consisting of about 100,000 verses in its present form, is one of the most important epics, and describes the famous war between Pandavas and Kauravas. Vaidya^[38] has discussed the date of the Mahabharata war in great detail, and is of the view that this war took place in 3101 BC. The Mahabharata was composed by the great Rishi Vedavyasa, and is considered to be a work of around 600-500 BC^[39].

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Pāli Tripiṭaka

The Pali Tripiṭaka is a collection of the sermons and discourses of Lord Buddha, and is considered to be composed during the period of 5th century BC – 3rd century BC. It is an important reference which gives an insight into the economic and social life in India in the 5th century B – 6th century BC. Anguttara Nikaya is a part of the Sutta Pitaka of the Pali Tripiṭaka.

Kauṭilya's Arthasāstra

The Arthasāstra of Kautilya occupies supreme place in the ancient Indian texts dealing with political and economic thoughts. The credit of bringing this great text to light for the first time goes to Dr. R. Shama Sastri, who was then the Librarian of the Oriental Research Institute, Mysore, and he published it in 1909 AD. Shama Shastri⁽⁴¹⁾ has stated that the Kautilya's Arthasāstra was composed somewhere between 321 and 300 BC.