ARCHAEOLOGICAL SOURCES FOR THE RECONSTRUCTION OF THE HISTORY OF SCIENCES OF INDIA*

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I. INTRODUCTION

Archaeology has long been accepted as a scientific discipline providing tangible evidence for building up the superstructure of history. In fact, its claim is accepted as supreme especially in such periods where written records are absent or have remained undeciphered. Where, however, written records exist, the material remains turned up by the spade convey in a telling manner the import of the written word.

Archaeological material, however, has to be interpreted with a view to determining its real character and significance. Such an interpretation often tends to be subjective vitiating the very purpose of scientific enquiry. The precondition, therefore, is of complete objectivity aided only by such reasoned and controlled speculation as is warranted by facts. To the extent objectivity is sacrificed the results are bound to be erroneous. This will also largely depend on the field of experience or versatility of the interpreter, for a person with limited knowledge and experience is likely to overlook or misinterpret the facts.

Among the varied range of archaeological material that will be useful for the reconstruction of the History of Sciences of India, the following may be mentioned:

(i) Excavated material and other antiquities;
(ii) Standing monuments;
(iii) Sculptures, reliefs and paintings on monuments and other objects; and
(iv) Inscribed records.

Of these, the last-mentioned item, viz. inscribed records, is, in fact, a sort of a literary record and could, therefore, be classified as archaeo-literary source material. Perhaps this source has one speciality inasmuch as it reveals its date or probable period and generally belongs to the region where it is found unlike a manuscript which is copied from time to time, liable to be transferred from one place to another, and is susceptible to interpolation, diminution or alteration. Hence, inscribed records, especially those found on

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stone, rock or copperplates, are more reliable though in the last-named variety spurious records are also sometimes met with.

Coming to the subject proper, archaeological source material for building up the history of sciences is proposed to be dealt with in a chronological order, highlighting the archaeological evidence that is available during prehistoric, protohistoric and early historical periods. The consideration of the historical period is generally left out, for, it is during this period that written records are available and archaeological sources assume supplementary and secondary character. It is quite evident that, during the prehistoric period, Man was rather a helpless creature struggling to adapt himself to the natural environment, his technological skill being limited to fashioning of stone tools. It is really in the protohistoric period that he commences his supreme effort to master the environment when the foundation of science and technology was laid.

II. Prehistoric Science and Technology

A. *Early Palaeolithic*

Peering in the dim prehistoric past we discern, on the evidence of old Stone Age tools, the existence of prehistoric communities in different parts of India. The story of their progress from savagery to a settled way of life as a food-producing community can be construed largely on the evidence furnished by the stone tools left by Man in a variety of geological environment. Broadly speaking, the Himalayan foothills comprising the high periglacial terraces of the Indus-Soan-Jhelum[1] valleys of West Punjab (West Pakistan) and the Sutlej-Sirsa and Beas-Banganga valleys of the Punjab and Himachal Pradesh (India) provided a habitat for the prehistoric man. The lithic tool industry found in this region ascribed to the Mid-Pleistocene is characterized by choppers and chopping tools on rough oval pebbles. Very recently R. V. Joshi located in Himachal Pradesh a developed Acheulian industry in the lower Beas valley characterized by cleavers—a tool type usually accompanied by hand-axes in Peninsular India. The relationship of this industry with chopper-chopping tool-complex is being investigated. In the rest of India, Stone Age tools chiefly consisting of hand-axes, cleavers, discoids, etc., have been reported from different river valleys in Bihar, Orissa, Rajasthan, Malwa, central India, Gujarat, Maharashtra and Madras.[2] The geological environment observed in these parts and especially in Madras area indicated a succession of pluvials and interpluvials. All these stone tool industries indicate a continuous struggle for survival on the part of the prehistoric man, and a slow technological development in regard to fashioning of tools. This technological development can be studied, stage by stage, from his early efforts in fashioning crude pebble tools to the elaborately worked and beautifully shaped hand-axes of Acheulian type. It is difficult to discern, nay even to think, of any scientific advancement during this period. Early Man during this epoch was making, more by accident, such fundamental discoveries as of fire that burnt forests and left him helpless. It may have taken an enormously long period of time to know the boon fire and heat could bestow on him. Nevertheless, it is possible to observe certain very basic tendencies that led to the development of scientific ideas at a much later stage of Man's progress. Early Man was able to select the right type of rock material for making tools he required. He used the stick to lever up the stone blocks. He watched the behaviour of the animal world and thought of ways and means for overpowering them. He knew the season when he could get the right type of edible roots or wild fruit. All these activities involving observation of the recurring natural phenomenon bear the germ of the birth of science.

Further, there is evidence to suppose that tools were hafted to enhance their utility and early Man must have, therefore, made several experiments for firmly fixing the tools to the wooden or bone handles. During this stage, Man may have used, specially in the Himalayan region, hides and bark for protecting himself from the severity of cold but such a development has to be imagined on the basis of evidence provided by tribes living in similar circumstances and in semi-savage conditions.

As with other prehistoric communities, medicine and the related science of gynaecology[3] may also have originated in India in the Stone Age period, for, in the latter case, some specialization in attending on childbirth is absolutely necessary. Care of wounds caused in skirmishes between rival groups or animal chase, setting of broken bones and massaging may have had a very early beginning.

As a result of observation of the heavenly bodies lasting over centuries, early Man may have at some stage of progress developed a sense of directions and seasons. The idea of number may also have occurred to early Man but all this surmising would not fall in the realm of archaeological source material. As pointed out above, the source material of this period is only in the form of stone tools and we do not possess even a scrap of evidence to know even the physical aspect of the Stone Age Man. Observations and deductions about the environment in which the ancient man lived and struggled are, however, possible on the basis of palaeontological studies and the geological strata in which the tools have been found, sometimes in association with skeletal remains of extinct animals.

B. *Middle Palaeolithic*

The old Stone Age industry is succeeded by what is known as Middle Stone Age tools ascribable to late pleistocene times. This industry was first recognized at Nevasa[4] in the Pravara valley in Maharashtra. The tools were made on flakes and were smaller in size being made of fine-grained material such as chert, agate and chalcedony, and comprised of scrapers, points, awls or borers, blades, etc. These, however, are not associated with any pottery and the economy of the period still continued to be at the food-gathering stage. As regards the use of these tools, observations made by Sankalia who brought this industry to light may be quoted:

> 'The straight-edged scrapers may have been used for dressing skins and barks of trees; the hollow or concave scrapers, for smoothing the hafts or spears or arrow-heads(?); the knives for cutting and chopping; and the pointed tools, for piercing (in wood and bone). It may, therefore, be inferred that at this period there were larger tools and weapons of more perishable material, such as bone and wood.'

C. *Mesolithic*

The small stone (microlithic) industries of India, which we now intend to examine, have come to light as a result of recent explorations in different parts of India. These are widespread and await closer analysis and examination. The *teri*[5] sites in South India appear to have been associated with sea level which once stood seven to eight metres higher than the present level. An attempt to correlate these sites *vis-à-vis* ancient sea levels and to establish a chronological sequence, if any, is in progress. Provisionally, Dr. Zeuner has placed this industry around 4000 B.C.

It was at Langhnaj[6] in Gujarat, however, that pottery was first found in association with microliths. The pottery and tools assemblage consisted of hand-made, ill-fired sherds, and geometric microliths of quartz, jasper and chert. Sandstone slabs, flattened on one side and used for grinding, and mineralized human skeleton of dolichocephalic type were found associated with the tools. The fauna included the Indian rhinoceros, hog, deer, nilgai (antelope), black buck, bovines, mongoose, pig, horse, dog or wolf, tortoise and fish. The economy was primarily of hunting and fishing and the community supplemented its meat with grass and herbs. Sankalia has dated the microlithic industry to a period ranging from 2500 B.C. to 2000 B.C. In this context, Wheeler's[7] surmise, regarding the cultural nexus and distribution of this culture, is worthy of note as it may have a good deal of bearing on the diffusion of technology and scientific ideas. He states that:

> 'There is slight but accumulating evidence that Arabia formed a cultural, as indeed it forms a geographical extension of the Sahara zone, and may have constituted a central link between northern Africa and western Asia on the one hand and India on the other.'

D. *Neolithic*

The next stage in the development of Man in India is very significant. This may be termed as the 'Neolithic Revolution' when he made a determined attempt to control his environment and started settling down in small villages. This period forms the basis of technological and scientific development of later times for it marks the beginning of agriculture, domestication of animals, use of pottery, grinding and polishing of stone tools and settled life.

The evidence furnished by excavations at Burzahom,[8] near Srinagar in Kashmir, is very interesting. The earliest inhabitants of this valley lived in circular or oval pits dug into the *Karewa* soil. Evidence of post-holes along the edge of the pits indicated a timber superstructure covered over by a thatched roof. The pit-dwellers provided landing steps to reach down the floor of their house, where stone hearth and small-sized storage pits were met with. In the succeeding period, red ochre was found used as a colouring material for the floor. As regards the technology of pottery, it is worth noting that the pottery of Period I was hand-made and crude in appearance with basket impression on the base. Wheel was, however, employed for the first time in the production of more utilitarian pottery in Period II.

The stone tools of the neolithic folk consisted of polished axes, harvesters, polishers, pounders, chisels and mace-heads. The use of harvesters and pounders and mace-heads would suggest primitive agriculture, though no actual grain has been encountered in the excavation. The bone-tool assemblage consisting of small daggers, small and large points, awls, scrapers, chisels, needles with eyes and harpoons would suggest hunting, fishing and tanning as their principal occupation. The tool-complex with peculiarities of its own calls for closer examination of neolithic cultures in the Pamir region. The use of hides perhaps sewn by bone needles as covering for the body and as protection against wind and snow may also be postulated. The antler's horn found in the excavation may also suggest its medicinal use as was possibly made in other parts of the world. The most interesting evidence provided by the human skeletal remains of the Neolithic period Phase II is of trephining marks on the skull. It is reported by A. K. Sharma[9] who examined the skeletons that the skull bore seven finished and four unfinished holes in the normal lateralis position on the parietal between bregma and lambda. None of the holes disclosed any sign of healing. They were made in order to obtain fetishes. He further suggests that some sort of surgical operation cannot be ruled out. This culture has been dated, on the evidence of C^{14} dating[10] to a period ranging from *circa* 3500 B.C. to 2300 B.C.

The neolithic culture of eastern India is characterized by the use of tanged or shouldered hoes of stone (chert or schist) with angular or sloping shoulders. This tool type is widely distributed in Bengal, south Bihar, Orissa, Banda District (U.P.), and one from Chittor[11] (Rajasthan) and would suggest its extra-Indian affiliation to South-East Asia. The use of the hoe, a specialized agricultural tool, may have served the needs of rice cultivation better than any other tool. Excavations at Kuchai in Orissa and Daojali Hading in Assam have for the first time revealed use of pottery in the neolithic culture of eastern India. At the latter site the implements comprised celts (including one of shouldered variety), hoes, corn-grinders, mullers, pestles, etc. The pottery which was greyish in colour bore basket impressions on the exterior.

The South Indian neolithic complex,[12] as revealed by excavations at Brahmagiri, Sangankallu, Piklihal, Maski, Nagarjunakonda, Utnur, T. Narsipur, Tekkalkotta and Hallur, is generally characterized by the use of polished stone-axes, adzes, pounders, chisels, polishers, sling stones and microliths. The pottery with minor variations from site to site is hand-made, dull grey in colour showing burnishing. The painted pottery with linear pattern in brownish purple colour is also met with. The economy of the neolithic folk was pastoral as indicated by the remains of domesticated cattle, buffalo, sheep and goat. The ash-mounds at Utnur, when excavated, revealed remains of cattle-pens. The culture is put in a large date bracket of *circa* 2300 B.C. to 1650 B.C.

III. Protohistoric Science and Technology

While southern India and Kashmir were in a neolithic stage, Rajasthan and Punjab were the scene of a comparatively superior and scientifically advanced stage. With the excavation at Kalibangan[13] a pre-Harappan Chalcolithic culture, designated as Kalibangan culture by the excavators, has come to light. This culture marks the formative stage of an urban civilization, having a mud-brick fortification wall enclosing the habitation remains and mud-brick houses. The use of copper axes clearly shows the beginning of metallurgy as early as 2450 B.C. Side by side stone tools, such as blades, sometimes serrated and backed, continued to be used.

The Harappan civilization presupposes a good deal of scientific advancement. The use of burnt-brick in the construction of houses and drains, the grid-pattern of streets and house-blocks, a script, employment of weights and measures, use of metals like gold, silver, lead, copper, bronze, casting of bronze statues and above all commercial contacts with the Middle East would indicate a high degree of technological skill and scientific advancement. As the script has remained undeciphered, the full import of the seals and writings thereon is not known to us. The economic basis of the civilization was undoubtedly of surplus agriculture which must have fostered the development of related technological processes. It will be worth while to examine the available evidence to determine their progress in different branches of science.

A. *Agriculture*

As agriculture was the primary occupation and the entire civilization flowered forth as a result of surplus agricultural economy, it is but appropriate that an attempt is made to know its various aspects.

The wherewithal of the community in terms of agricultural equipment that we get at Mohenjo-Daro and Harappa consisted of a solitary large hoe (Mackay, Mohenjo-Daro, pl. CVI, 56) made of flint, parallel-sided blades used for cutting corn and sickles. This evidence is supported by the possible use of wheel-carts for transporting agricultural produce, actual find of wheat, barley, peas and sesame grains, the employment of humped bull for agricultural operations, use of large storage jars for stocking grain and remains of large granaries. The sickle type beads[14] of magico-fertility significance would also tend to suggest that Harappa Civilization was founded on prosperous agriculture.

It may, however, be said that the three provincial capitals—Harappa on the Ravi, Mohenjo-Daro on the Indus and Kalibangan on the Saraswati—and Lothal and Suktagendor as seaports exemplify urban and administrative centres where market produce was stocked or exported. There must have been many other smaller farm-units in the far-flung villages where men must have been busy in agricultural operations. Excavation of such smaller sites is a desideratum to know more about the way of life, methods of agriculture employed by them. In fact, an effort should also be made* to locate ancient fields around bigger habitations and to uncover the furrowed land to know more about their farming methods.

Coming to details about the Indian wheat found in the Indus valley, it may be stated that it belonged to a variety of *Triticum sphaerococcum*. Experts who have studied morphological, genetic and archaeological aspects of the wheat have stated that the Indian wheat which is called club-wheat, a climatically resistant, short and dense-eared plant, is found, besides Harappa, at El-Omari (near Helwan, Egypt, Neolithic *circa* 3500 B.C.).[15]

The specimens of charred barley[16] found at Harappa belong to a small-seeded variety of *Hordium vulgare* L. var. *hexastichon* (six-rowed barley). Besides, the find of sesame and peas have been also reported. Though no date-seeds have been found at Harappa but its presence has been surmised on the basis of the shape of two tiny faience seals shaped like date-seeds. Mention may also be made of the find of vestiges of the seeds of melon. Lemon was also known as could be surmised from a well-made pendant in the form of a lemon-leaf made of burnt steatite. Two polychrome earthenware vases shaped like a pomegranate and coconut fruit perhaps would also indicate the cultivation of these fruits.

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* Subsequent to the reading of this paper the Archaeological Survey of India has brought to light an agricultural field belonging to pre-Indus period at Kalibangan ascribable to the first half of the third millennium B.C. This is ploughed on a grid pattern and is perhaps the earliest ploughed field so far excavated anywhere in the world. The plough marks conform to the arrangements of furrows similar to those encountered in the present-day crop pattern, according to which mustard is planted in horizontal rows and black gram in the vertical ones.

It is not unlikely that cotton was also cultivated by Harappans, for two scraps of textile were found at Mohanjo-Daro preserved on a silver vase and a copper razor. Some pieces of string of cotton and fibre were also met with. Cotton[17] (Genus *gossypium*) was used for spinning threads from early times. Recently, the author came across an oval terracotta disc in Ochre Coloured Ware Pottery deposits of Ambkheri, District Saharanpur, which must have been used for making strings of multiple strands. This age-old method of making the strings is still practised in India and the strands of hemp or cotton are passed through the holes of the disc and are held at the other end by a person who gives a revolving motion to produce a string of multiple strands.

The picture of the irrigation methods adopted by the Harappans is not quite clear. The evidence recently provided by Shri S. R. Rao as a result of his excavations at Lothal[18] would suggest that ancient Harappans fed the dockyard by cutting a channel and joining it with the river that joined the sea. If they can be credited with the wisdom of providing an artificial channel to feed the dockyard, it is quite likely that they had also employed such means for irrigational purposes. Their engineering skill in constructing drains would also suggest sufficient skill in draining water for such a use. Use of wells as the source of drinking water is attested to in all the cities and it is not unlikely that lift irrigation was also practised.

B. *Astronomy*

As agriculture must have largely depended on the rains, the knowledge of seasons and a calendar cannot be ruled out. The regularity of the movement of the heavenly bodies could not have escaped the attention of the Harappans. The priest dominated political hierarchy postulated in respect of this civilization may have strengthened its position on this specialized knowledge. The priests may have kept accurate astronomical records and forecast celestial events and advised the farmers on the time of sowing, harvesting and perhaps the flooding of the rivers so as to forewarn them of the possible catastrophe, which in the end is supposed to have contributed to the destruction of Harappan cities. It is, however, not possible to say with certainty whether they followed the solar or the lunar calendar, though the meagre evidence at our disposal would suggest the adoption of the solar calendar, for the representation of the moon is conspicuous by its absence while a solar symbol is present in the form of painted motif on pottery and in the form of urus-like animal[19] which according to Mackay may have been a solar deity with the head of the beast taking the place of the sixth ray. In the absence of depiction of the moon and stars Mackay had suggested that inhabitants of Indus valley—an agricultural people—did not pay that attention to stars which, according to Smith, is a distinguishing feature of the agrarian population. Such an inference would not hold ground if we consider the following facts: The Harappans must have possessed the knowledge of stars for, without it, it is difficult to account for the rigid north-south and east-west orientation of the streets and lanes. In the burials the bodies of the dead were oriented; head pointing to north and feet towards south. The identification of the pole-star for this purpose has to be credited to the Harappans. Besides, the depiction of a boat on one of the seals and a potsherd and the recent evidence of a dockyard at Lothal would definitely point that the Harappans were navigators and ships laden with goods plied along the western coast as far as Bahrein Islands and perhaps beyond. In the circumstances we may have to conclude that the Harappans possessed sufficient knowledge of astronomy involving angular measurements of heavenly bodies.

C. *Mathematics*

The monumental remains of fortifications, granaries, public-baths, roads and house-blocks excavated at Harappa, Mohenjo-Daro and recently at Kalibangan and remains of dockyard at Lothal imply a good deal of arithmetic and knowledge of geometry. Keeping of accounts for the construction of public buildings such as of labour and material would entail complicated calculations. Unfortunately, direct evidence of such accounting is not available. As regards the knowledge of geometry besides the few measuring rods and other instruments which have come to light, to which reference will be made later, we have largely to depend for such deductions on the data supplied by the buildings themselves. It is obvious from the meticulous care the Harappans took in planning the city with well laid-out streets that they knew fundamentals of surveying. This would include knowledge of levelling as without detailed measurements it would not have been possible to plan the sewage system. The use of standardized bricks having plain rectangular faces, parallel sides, sharp, straight, right-angled edges including wedge-shaped bricks in the construction of circular wells so as to produce the inner and outer circumference would presuppose knowledge of geometry of parallels and circles.

Other fundamental aspect of the mode of measurement revealed by the size of bricks is very interesting. The size of Harappan bricks[20] generally conforms with the ratio of 1 : 2 : 4 in respect of its thickness, width and length. Curiously enough similar binary system was also followed in respect of weights of Harappa and Mohenjo-Daro, the succession of weights being in the ratio of 1, 2, 8/3, 4, 8, 16, 32, 64, 160, 200, 320, 640, 1600. It will, thus, be clear that the system is binary in smaller weights while decimal system was limited to a few bigger numbers.

Coming to the actual finds of mathematical instruments, the following objects need mention.

1. *A neatly finished piece of shell from Mohenjo-Daro showing in its extant form nine divisions*—Mackay[21] observes that the divisions were a multiple of five, for the rod is divided up on a decimal system; groups of ten divisions were marked off by circles and were halved into sub-groups of five. The scale was beautifully made and then finished and its accuracy is remarkable; the division-lines were very carefully cut with a thin saw and average 0·02 in. wide and deep. This portion whose divisions average 0·264 in. is now 6·62 inches long by 0·62 wide by 0·27 in. thick. Only one side of it is marked. In conjunction with the system of weight, it shows the people of Mohenjo-Daro to have reached an advanced stage of mental development with capabilities of precision and mathematical accuracy in thought and work.

He has further observed:

> 'The decimal system of linear measure is known in Egypt as early as the Fourth Dynasty, and a decimal division of the cubit in the Twelfth Dynasty has been noted at Kahun. Both the decimal and the sexagesimal system were in use in early Summer, though it is not yet known which came first. According to Langdon, both systems were in use at Jemdet Nasr; and on the Fara tablets, also, which must be dated to the Early Dynastic period, the two systems were used. We are told, however, that a purely decimal system is found on the Proto-Elamite tablets; and it may be that it was from Elam that the system was introduced into N.W. India, though on the basis that every man has ten fingers it seems to me that the decimal system should be more primitive than the sexagesimal, and that it may have had independent origins. There is no evidence at present from either Mohenjo-Daro or Harappa of a sexagesimal system having also been used. Mr. Hemmy has found amongst the weights that he has examined that the system employed was either binary or decimal. I am inclined to think that possibly a second system of measurement may have been in use, for few of the widths of the doorways are actual multiples of the unit marked on the scale that has been found.'

2. *A bronze rod from Harappa*[22] *1·5 in. long broken at both ends, a little over 1/8 in. diameter bearing only four complete divisions marked by 'V'-shaped indentations*—The values of the divisions were 0·960; 0·905; 0·945; 0·925; average, 0·934 cm = 0·3656 in. Vats has related this to Egyptian system on the standard cubit of 20·62 inches which was termed 'Royal cubit' throughout history.

3. A small measuring rod of ivory from Lothal,[23] about 7 inches long, graduated along the upper margin, each division 1·7 mm.

4. A peculiar object also from Lothal was probably used as a compass for measuring angles.

5. Terracotta plumb-bobs of different sizes from Lothal with or without vertical rods are also reported from Mohenjo-Daro and Harappa.

6. A graduated scale[24] intended perhaps for measuring has also been reported from Kalibangan.

D. *Metallurgy and Mining*

The metals known to Harappans were gold, silver, copper and bronze of which the last item played an important part in the economic and technological advancement of the community. The varied range of copper and bronze implements, weapons, household utensils and ornaments points to large-scale exploitation of metals and would presuppose a flourishing industry of mining and metallurgy. It is unfortunate that all the copper samples from Harappa have not been analysed so as to pinpoint the copper mines from which the ores were extracted. The few ancient bronze samples from Harappa analysed by Archaeological Chemist[25] indicated the following composition:

		Specimen No. X (chisel)	Specimen No. 277a/21 (celt)
Copper percentage		87·42	91·10
Tin	,,	10·45	7·85
Arsenic	,,	1·10	0·42
Lead	,,	0·52	trace
Nickel	,,	0·17	0·22
Iron	,,	0·34	0·41

The micrographic examination of the samples revealed that the sample 'X' was a sample of bronze in the annealed condition. It appears that after casting the metal was subsequently heated and hammered until it reached low temperature.

Sample 277a/21 was bronze in the cast condition and was not subjected to heat treatment.

As regards analysis of copper and bronze samples from Mohenjo-Daro, we have substantial data, for a large number of samples were analysed by the Archaeological Survey of India and Prof. C. H. Desh and Mr. E. S. Carey Mackay. From the chemical composition of the bronze objects it would be seen that the presence of tin, 4·5 to 13·0 per cent, was not accidental but was added intentionally to produce an alloy suitable for production of tools and other purposes. It must be also pointed out that the pure copper tool and weapons persisted along with those of bronze. Marshall is of the opinion that simultaneous use of copper and bronze points to the fact that the supply of bronze was limited and its use was therefore confined to objects of special nature, for example, tools, razors, jewellery or ornamental vases. Regarding the source of copper, Marshall[26] has pointed out that the nearest place could have been the copper mines near Ajmer, in Sirohi, Mewar and Jaipur, notably those at Khetri and Singhana which have been worked from very early times. The presence of a very small quantity of silver and absence of tin in copper lumps point to the use of the sulphide ore, which abounds in these mines for the extraction of copper. It is also likely that copper ores associated with lead found in Afghanistan and Baluchistan may have also been used. Tin which is an ingredient of bronze is scarce in India, the only Indian deposit worth mentioning exists in the Hazaribagh District and may have been worked in ancient times. But the relative geographical isolation of Hazaribagh would indicate that tin source for the Indus valley lay towards the north-west.

Recently, Mohammad Zia-ud-din,[27] of the Geological Survey of India, working on the clues provided by Dr. Heyne in 1814, studied the ancient copper-workings of Agnigundale in Guntur District, Andhra Pradesh. He noticed numerous pestles and mortars of fine gritty quartzite, washing-pans, slag-dumps, crucibles and remains of furnaces near the locality, the old workings being as deep as 100 feet in some cases. Intensive work by the team of archaeologists and geologists is a desideratum for further study of ancient metallurgy in India.

Coming to the technique employed in making metal vessels, tools and bronze figurines, it may be stated that along with the easier method of preparing a vessel by beating them out of sheet bronze, the process known as *cire perdue* or the lost wax method was known to them. The well-known dancing girl, a bronze statuette from Mohenjo-Daro, is a classic example of this process which presupposes a high degree of technological skill.

The antiquity of gold is attested by its occurrence at Harappa and Mohenjo-Daro in the form of gold beads and other ornaments. F. R. Allchin suggested that the first discovery of the gold-bearing beads was during neolithic period (which in the Deccan is now established as between the third millennium B.C. and the first half of the first millennium B.C.).[28] He further states that the work in the beginning was restricted to the surface as the tools available were too limited for deep mining. Later, stone picks and copper chisels came to be employed and settlements may have flourished around gold-fields. The arrival of iron more particularly of carburized steel must have given further impetus to gold mining, which was organized under the

Mauryas. Kautilya's Superintendent of mine is called upon to examine not only new sites but old abandoned workings. Allchin has also illustrated the objects from old workings in Hutti gold-mines probably belonging to the beginning of the Christian era. It may, however, be mentioned that exploitation of alluvial deposits preceded vein mining.

E. *Alchemy and Chemistry*

Very little positive evidence is available about the knowledge of Harappans in the field of alchemy and chemistry. We are forced to deduce that the Harappans knew elementary chemistry from some of their arts such as bead-making, glazing processes, use of bitumen as building material and the use of cosmetics. The preparation of etched carnelian beads[29] involving chemical process, use of soda carbonate and other glazing techniques point to this conclusion.

F. *Medicine and Surgery*

This branch of science which must have had prehistoric beginning and which developed in a regular science known as Āuyurveda in the historical period must have made considerable progress in the Harappan period. It is not known what experiments were conducted on the medicinal qualities of herbs and plants. Among the trees depicted on the seals, mention may be made of *pipal* and *neem*. The *pipal* has primarily sacred significance but *neem* is regarded both as medicinal and sacred. We have very slender evidence about the use of other medicines. *Śilājātu*, which is reported from Mohenjo-Daro, is well known as an ancient Indian medicine. Marshall has quoted Caraka as saying 'there is hardly any curable disease which cannot be controlled or cured with the aid of *śilājātu*.

Arsenic is also reported from Harappa. It is a piece of yellow arsenic (*hartal*). It was probably used as medicine and poison and also as an alloy to harden copper tools.

Coral has also been found at Harappa and Mohenjo-Daro. It has been regarded as a specific against various ailments. It is powdered and used as medicine.

Stag horns found at Mohenjo-Daro may have been used as a medicinal object and appear to have been specially imported from other regions like Kashmir. Similarly, rhinoceros horns have also been reported from Mohenjo-Daro and were used for medicinal purposes on the analogy of their use in eastern Asia.

The vast range of copper objects like knives, needles, borers, small chisels calls for detailed examination by a surgeon. In respect of leaf-shaped blades with curved tips, Mackay has suggested their probable use as surgical instruments especially on account of their comparative rarity. Recent excavation at Kalibangan has furnished evidence of trepanning,[30] showing six circular holes on a child's skull. This useful information on palaeopathology is indeed important.

The yawning gap between the end of the Harappan period and the historical period has been partially filled up by the post-Harappan chalcolithic cultures of Rajasthan, central India and the Deccan which are placed in a time spread of *circa* 1750–1000 B.C. The chalcolithic culture of Rajasthan is characterized by the white-painted black-and-red and cream wares and copper tools such as flat axes, the latter along with other copper objects and copper slags indicating smelting operation at the excavated site of Ahar. The availability of copper was responsible for the early colonization of Banas valley.[31] The picture of the central Indian chalcolithic man is that he was essentially a farmer and supplemented his living by hunting and fishing. He cultivated rice, two kinds of wheat, *masur*, lentil, *kulathi* and beans and oil-seeds like linseed. According to Sankalia the distribution in antiquity of wheat, lentil and linseed would suggest western Asiatic contact whereas rice was indigenous to India. No remains of plough were found but a number of heavy stone-rings that were discovered might have been used as weights for digging sticks. The stocks of grains were probably cut by sickles set with stone teeth.

The Deccan Chalcolithic cultures characterized by the use of parallel-sided blades made chiefly of chalcedony, by the sparing use of copper and painted black-on-red pottery, bespeak of a community which practised agriculture as their basic occupation. The recent evidence from Nevasa and Chandoli[32] would suggest that the spinning of cotton and even (wild) silk and true flax was also known. Presumably garments of all these materials must have been made. The metal tools of this period are usually of copper though at Jorwe[33] a low-grade bronze axe (tin 1·78% and copper 98·04%) was reported.

In so far as northern India is concerned the gap mentioned above is partially bridged by what is known as the Ochre-coloured Pottery[34] assigned on circumstantial evidence to the people who were responsible for the production of the Copper-hoards found in the Gangetic valley and eastern India. The ochre-coloured pottery culture of the upper Ganga-Yamuna Doab appears to be contemporaneous with late Harappan Culture. The remains of late Harappan Culture excavated at Bargaon and also at Alamgirpur show similarity in pottery types found in the ochre-coloured pottery deposit at Ambkheri. It is unfortunate that not a single type-tool of Copper-hoard Culture has so far been found in the stratified O.C.P. deposit, though there has been mounting evidence to suppose the identity of these two cultures. The wide range of copper tools such as flat-and-shouldered axes, low-celts, rings, harpoons, antennae swords and anthropomorphic figure (tool ?), etc., would indicate hunting and fishing as the occupation of the people. The finds of Ambkheri would, however, endow this culture with an agricultural bias.

One thing is, however, very surprising and almost inexplicable when we notice that there is a technological set-back after the Harappan period had come to a close. Bronze technology which was developed by the Harappans deteriorated and there is general reversion to the use of copper tools. It is not known whether the tin import from Baluchistan had ceased or became scarce. There may have also been some natural catastrophe which may have struck a crippling blow when Harappan Culture was at its peak. In the present state of our knowledge it is not possible to explain the full implications of how the clock of progress was set back for there is degeneration in all departments of life. Houses of wattle and daub-walls replaced brick structures, the township is reduced to a cluster of huts, the beautifully painted thick and sturdy pottery is no more to be seen, the script is forgotten, the richness and variety of life is replaced by poverty and drabness.

In tracing the history of science and technology further, we must take into account a culture known as the Painted Grey Ware which stands on the threshold of history. A large number of sites of this culture have been brought to light in the Gangetic valley but no site has so far been subjected to area digging so as to obtain a complete picture of the achievements of these people in the field of art, architecture and technology. We, however, know from the excavations at Hastinapura[35] and Atranjikhera and as a result of field-observations that the people of this culture lived in mud-walled houses sometimes reinforced with reeds. The most significant contribution of this culture is their knowledge of iron metallurgy. This culture in a way provides a firm foundation for the grand emergence of the city-states, the *mahajanapadas* of the pre-Mauryan times.

IV. Sciences and Technology of the Historical Period

This period marked by the advent of iron roughly coincides with the end of the Upanishadic period and the emergence of Buddhism and Jainism and flowering forth of the literary prakrits. The early books of the Jaina and Buddhist canon give us a picture of an organized society based on *catur-varṇa* and numerous arts practised by the *vaiśyas*. These arts presuppose advent of new scientific ideas and technological progress. Infiltration of Hellenistic ideas in the wake of Alexander's invasion further accentuated the process. The Mauryan dynasty with Asoka (*circa* 273–236 B.C.) epitomizes the moral and material advancement of the period.

During the Mauryan period, coins make their appearance for the first time thereby suggesting that large-scale trade and commerce had supplanted barter.

Ancient Indian literature especially the Vedic literature which had survived as an oral tradition received further momentum with the emergence of the *Brāhmi* script. A script for the codification of the written word is one of the characteristics of civilization and it undoubtedly provided a vehicle for the promotion of science and literature. The Mauryan empire brought under its suzerainty almost the whole of North India and major portion of southern India. The natural resources of the country came to be exploited in an organized fashion. Kauṭilya in his monumental work, *Arthaśāstra* (*circa* 300 B.C.), describes the southern country (*Dakṣinapatha*) as yielding conch-shells, *vajra* or diamonds, gem stones, pearls and gold. He further states that the southern route has many mines (*bahukhāni*, *Arthaśāstra*, vii. 12). Allchin[36] summarizing this point analyses the location of Asokan edicts *vis-à-vis* the mines as follows:

> 'The minor Rock Edict at Maski is actually on the gold-field; the two Koppal edicts are no more than 30 miles from the Gadag band of gold-mines; the three at Brahmagiri are equally near to several mines in north Mysore and Sandur; while the other two sites of inscriptions at Yerragudi and near Pattikonda are in the centre of country long famous for diamonds. Viewed in this light the Asokan edict of the south reflect a very material interest in the area, and though they may also proclaim the sincere Buddhism of their author they tempt us to ask whether this was not rather a case of the banner of Dharma following the prospectors than vice versa?'

He further suggests that the town of Suvarṇagiri mentioned in the Brahmagiri edict could be identified with the golden hill of Maski.

The long narrative of Indian history after the Mauryan period has not unfortunately been studied in the proper perspective. The emergence of different dynasties was not merely a coincidence but a historical necessity born out of several factors of which principal one must have been the regional exploitation of the natural resources of the land. It is hoped that such an orientation to the study of history will lend the correct perspective to the study of Indian history. Exploitation of natural resources calls for technological and scientific advancement and we may, therefore, take a brief review of the chief landmarks in scientific advancement as revealed from archaeological sources of the historical period.

A. *Iron Age Metallurgy*

The chief contribution of the historical period is the mastery of iron metallurgy and its use in different departments of life. Even though iron came to be exploited from about the beginning of the first millennium B.C. in India (Atranjikhera, District Etah, 1025 ± 125 B.C.; Hallur, District Dharwar, 1085 ± 105 B.C.), it may have taken some time before high-grade steel sufficiently hard and capable of producing sharp-edge could have been produced.

Unfortunately, the various processes of carburization, quenching and tempering are not adequately represented or studied. It is not possible in the present state of our knowledge to detail the various stages of development of iron metallurgy from the humble beginning up to the period when the great iron pillar of the Gupta period was cast.

The excavations at Ujjain[37] furnish evidence for the use of iron in period I, datable from *circa* 700 B.C. to 500 B.C. Similar evidence is also available from Bahal in the Deccan. In period III of Ujjain, a large number of pointed crucibles having a vitriolic surface along with contractions for blowing air into them have been found. Some of these crucibles contain residue of copper and lead, pointing to workings in those metals during the period.

N. R. Banerjee in his book entitled *The Iron Age in India* has given a good survey of the smelting practices of primitive tribes in contemporary India as an index of the early methods of iron working in India. Special mention may, however, be made of the recent excavation of an Asura site at Saradkel,[38] District Ranchi, by S. C. Ray. The excavation brought to light astonishingly a large number of iron objects along with iron slags, suggesting the existence of a full-fledged iron smelting factory at the site. The objects include arrow-heads, axe with double or single cutting edges, chisels, nails, longitudinal ploughshare, caltrops, door-hinges, rings, knives, etc. N. R. Banerjee who visited the excavations has recorded that 'the excavations at Saradkel have also revealed sections of several vertical pits laid into the earth, each about a metre in width uniformly, and 2–3 metres in depth. These contain ash and slags, etc., and have been described by M. K. Ghosh as smelting furnaces'. This important evidence about iron smelting is datable to first–second century A.D.

The date for the occurrence of iron at Hallur, referred to above, heralds the vigorous development of iron metallurgy in South India. The numerous megalithic monuments spread throughout the southern States of Mysore, Andhra Pradesh, Madras and Kerala with a large variety of iron implements found therein suggest a widespread exploitation of iron during the whole of the first millennium B.C. While a large number of megalithic monuments have been excavated, habitation sites of the builders of the megalithic monuments and factory sites where iron ores were smelted have not been thoroughly explored or excavated. Such a planned work will throw valuable light on the development of iron metallurgy.

The process of carburization of iron appears to have been completely mastered about the third century B.C., for, without hard steel chisels and picks, it would not have been possible for the Asokan craftsmen to excavate into the hard quartzose gneiss of the Barabar hills of Bihar or to chisel, smoothly finish and inscribe the long circular shafts of Asokan pillars of Chunar sandstone. The monumental activity of rock-cut excavation in western India which commences from the second century B.C. also presupposes perfection in iron metallurgy. The culmination in regard to large-sized casting is, however, reached with the manufacture of the Gupta Iron Pillar[39] of solid wrought iron located at Qutb, Delhi. It is unfortunate that the foundry where it was cast has not yet been located.

Iron Age tools may have helped agriculture to a great extent, though by and large the Indian farmer appears to have remained conservative in his outlook. The State, no doubt, helped by harnessing resources of water as can be surmised from the inscriptional reference to the artificially damming of the courses of the streams of Palasini and other rivers to form a lake of Sudarśanā at Junagadh (Gujarat). The lake was equipped with well-provided conduits, drain, etc. This measure ordered by the provincial governor of the Maurya King Chandragupta also indicates of the interest the State took in agricultural needs of the community.

B. *Glass Technology*

Though strictly not a science, the history of glass technology in India is of great importance for glass objects, besides being of utilitarian and decorative in character, may have proved an asset as containers of chemicals which could not have been stored in metal pots. It is generally supposed that glass was introduced in India by the Romans. Archaeological evidence from Hastinapura[40] and Alamgirpur,[41] however, points out that the antiquity of glass may go back to the beginning of the first millennium B.C. The users of the painted grey ware, who had also known the use of iron, were responsible for developing glass technology. Such a development is not at all unlikely for glass was essentially the outcome of glaze. According to Lucas[42] observations of glassy frits formed on pottery waster or in the process of smelting metal may have led man to the use of glazes, and this may have led to the production of glass. Ancient Indian literature, including *Śatapathabrāhmaṇa*,[43] mention glass. The archaeological evidence from Alamgirpur and Hastinapura which is of the nature of variety of glass objects, such as bead, bangles and discs, would imply indigenous inspiration for the manufacture of glass.

C. *Medicine*

During the Mauryan period, foundations of the Ayurvedic system of medicine were laid. In fact, during the period of Buddha, we get reference to Jivaka,[44] the royal physician of Bimbisar and Ajatasatru who was sent to Ujjain to treat king Pradyota for jaundice. The traditional site of the mango-grove of Rājāgṛha[45] (Rajgir) which he presented to Buddha has been excavated in recent years and has yielded elliptical buildings, possibly of a monastic nature. A very interesting archaeological discovery in this regard is the location of a monastery known as *ārogya vihāra* at Kumrahar (ancient

Pataliputra). A clay sealing found at the place bears the legend *Śri ārogya-vihāre bhikṣusaṅghasya* below a spreading tree. The monastery existed as late as the third-fourth century A.D. Earlier, we have the second rock edict of Asọka, mentioning the establishment by the king of dispensaries[46] for the medical treatment of men (*manusa-cikicha*) and of the cattle (*paśu-cikicha*). It also states how the State established botanical gardens for the cultivation of medicinal plants, herbs, roots and fruits or imported them and acclimatized them for future use. The inscription (second century B.C.) in the *chaitya* cave at Pitalkhora[47] mentions the gifts of the royal physician (rāja-vejja) of Pratishthan, the capital of the Satavahana kings. More inscriptional references of this nature can be multiplied but, as pointed out in the introductory portions, inscriptions tend to be in effect literary records and are left out of the scope of the paper for obvious reasons.

D. *Mathematics*

It is accepted that 'the Hindus were the greatest calculators of antiquity. They could raise the numbers to various powers'.[48] Archaeologically, however, we know from the inscriptions of Asoka that the numerals were in use in India from the third century B.C. For the reconstruction of the History of Mathematics recourse has to be taken to literary resources.

E. *Other Technological Advances*

In the field of other sciences we do not have sufficient archaeological data calling for detailed treatment. We may, however, refer to a few technological specialities of the period, viz. production of de luxe ware, manufacture of beads and use of colouring pigments as indicative of all-round progress.

The Mauryan period is characterized by the distinctive pottery known as Northern Black Polished Ware. The pottery is wheel-made, thin in texture with steel-like finish, the colours of the glossy slip varying from the common coal black shade to steel blue, silvery, golden and pinkish. The pottery is dated on the basis of stratigraphic evidence and C^{14} datings from *circa* 600 B.C. to 200 B.C. It has been studied by several scientists and the recent study undertaken by K. T. M. Hedge[49] suggests that the lustrous coal black slip of the ware was due to the presence of magnetic oxide of iron and the formation of glass-like soda-allumina-silicate is responsible for its lustre. An electron microscopic study of the slip has confirmed the analytical studies.

Fashioning of beads was a very ancient craft in India. The excavations at Ujjain have brought to light a full-fledged workshop for the manufacture of beads with sandstone grinding slabs marked by deep and long grooves and several long and deep channel furnaces evidently used for heating beads.[50] This corroborates reference to Ujjayani (Ozeni in Peripplus) as an emporium, from where semi-precious stones were exported to the West.

Painting as an art was practised in India from ancient times. The oldest paintings still surviving at Ajanta go back to about the second century B.C. The pigments[51] used for the purpose show a wide variety, such as yellow, red, blue, white, black and green along with a mixture of these various shades. All these with the exception of black are of mineral origin while the red and yellow pigments are red and yellow ochres and black pigment was obtained from lamp black. Lapis lazuli, used for blue, was alone imported, while all other pigments were locally extracted from mineral deposits from the neighbourhood of Ajanta. These were evidently residual products of the volcanic rock.

Ajanta murals show a wide range of coloured garments used by men and women of the times. The paintings of the classical period of *circa* fifth-sixth century A.D. are specially full of examples of such coloured textiles. Exploitation of natural resources for purposes of pigments for paintings or dyeing of fabrics is borne out by the above evidence.

V. Conclusions

The brief survey of the contribution of archaeology for the building of History of Sciences of India cannot be considered as complete or exhaustive. All that has been attempted is to present an over-all picture mentioning the known landmarks. It would be apparent that there are many avenues where the evidence is very meagre. The presentation thus emphasizes the lacuna in our knowledge as also the contribution archaeology has made in this field. I will be gratified if the present paper forms a basis for future research planning and thereby helps in shedding light on the hitherto unknown aspects of the History of Sciences in India.

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