ARCHAEOLOGICAL CHEMISTRY AND SCIENTIFIC STUDIES

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CONTENTS

1. INTRODUCTION

THE Archaeological Survey of India was re-organized in 1902 with the object of looking after the archaeological remains of this vast country and exploring and excavating new sites with a view to revealing India's ancient past. With the passage of time the activities of the Survey increased rapidly, and the need was felt for putting the preservation of ancient remains, antiquities and museum-exhibits on a firm scientific basis. To meet this need, the Chemical Branch of the Survey was established in 1917 with the appointment of an Archaeological Chemist, whose primary duty was to be the scientific examination and chemical treatment and preservation of museum-objects and other antiquities recovered in the course of excavations and explorations. The laboratory of the Archaeological Chemist, at first organized in the Indian Museum, Calcutta, and later on shifted to Dehra Dun, conducted this work on the lines of the British Museum Laboratory, where Sir Alexander Scott had developed important methods of the chemical preservation of metals, alloys, terracotta, glass, faience, textiles, prints, drawings and other types of antiquities. The application of these scientific methods of preservation of antiquities to the Indian material under the supervision of the Archaeological Chemist yielded satisfactory results and created considerable enthusiasm among art-collectors, museum-curators, archaeological officers and others interested in the preservation of our cultural heritage. The result was a tremendous expansion of the activities of the Archaeological Chemist, and the preservation of antiquities, paintings, rock-cut caves, temples, sculptures, inscriptions, etc., became an important function of the Chemical Branch. Large-scale chemical preservation of monuments was begun in 1937, when the decaying sculptures of the famous caves at Elephanta were chemically treated with very spectacular results. This type of preservation-work has since been extended to a large number of monuments.

The growth and development of archaeological chemistry in India during the period of more than three decades—from 1917 to the present day—could not remain isolated from the scientific progress in other countries, which had made rapid strides in researches in chemistry, physics and geology, as a result of which numerous techniques, of immense use in the scientific conservation of ancient monuments and cultural relics of various kinds, had been developed. Most of these methods were adopted by the Chemical Branch in its own work, for it was soon realized that the interpretation of ancient Indian techniques and materials could be carried out best by the application of the results of research in these various branches of science; consequently, chemical analysis, scientific examination and microscopic investigation of specimens of various kinds, such as mortar and plaster, glass and glaze, terracotta and faience, metals and alloys and pigments and painted stuccos from mural paintings were systematically carried out. Some of the salient activities of the Branch are discussed and the methods and techniques that have been evolved as a result of research in the laboratory and experimental work in the field are described below.

2. ANALYTICAL CHEMISTRY AND ARCHAEOLOGICAL PROBLEMS

The rôle played by analytical chemistry in the solution of archaeological problems, such as the composition of metals and alloys, the techniques of manufacturing glass, glaze, terracotta and faience and other allied problems, was recognized long ago by western scientists, who carried out a great deal of analytical work, the results of which have been admirably summarized in a recent article by Caley.[1] The young science of archaeological chemistry is actually based on the pioneering work done by western scientists; the Archaeological Survey did not lag behind in the application of the methods of analytical chemistry to archaeological problems, and intensive analytical work done during the last thirtysix years has produced important and interesting results.

A. Ceramics

The materials excavated at Mohenjo-daro and Harappā have been chemically analysed and examined in great detail,[2] and the results throw much light on the development of the material civilization of protohistoric India as revealed at these two important sites. Similarly, specimens of glass and glaze unearthed at Taxila and other Buddhist sites have been analysed[3] and much information obtained about the state of technical knowledge that existed in India during the historical period. The results of chemical analysis of glass specimens from Nālandā, Arikameḍu, Ahichchhatrā and other places have already been partly published,[4] and others are in the course of publication. These results are of great value in determining the composition and origin of the raw materials used in their manufacture. An intensive programme of research on ancient and medieval ceramics has been put through recently, and a systematic research on the

[1] E. R. Caley, 'Early history and literature of archaeological chemistry', *Chemical Education*, XXVIII (1951), pp. 64-66.

[2] John Marshall, *Mohenjo-daro and the Indus Civilization* (London, 1931), II, pp. 574-78; M. S. Vats, *Excavations at Harappā* (Delhi, 1940), I, pp. 468-69.

[3] *An. Rep. Arch. Surv. Ind.*, 1921-22 (1924), pp. 125; 1922-23 (1925), p. 158.

[4] B. B. Lal, 'Examination of some ancient Indian glass specimens', *Ancient India*, no. 8 (1952), pp. 17-27.

glaze of various periods has been undertaken; the results of these investigations will be published in due course. As an example of the interesting results that can be obtained by such researches, it may be stated that investigation in connexion with the glazed tiles from Chīnī-kā-Rauzā ('mausoleum of China tiles') at Agra has shown that their composition differs from that of the Chinese glaze and, therefore, it is evident that these tiles were manufactured not by Chinese but Persian craftsmen or their Indian pupils.

Glazed tiles of different colours from Sher Shāh's tomb at Sāsārām and from a mosque at Nārnaul in PEPSU have been analysed and the results published.[1] The results of research into the composition and technique of glazed pottery of Kushan times have also been briefly reported on,[2] and a detailed paper will be published in due course.

This investigation into ancient and medieval ceramics has not been confined to glass and glaze specimens but has been extended to ordinary terracotta and pottery. The Northern Black Polished Ware, with which every Indian archaeologist is familiar (above, p. 119), has presented a difficult problem to the chemist. Some work has already been conducted with a view to determining the technique of fabrication of this Ware, and in the course of this research several analyses have been undertaken. The results of this preliminary investigation have already been published,[3] but the problem cannot be considered to have been solved beyond doubt, and investigations are still under way to determine unequivocally the technique of its manufacture. In this connexion it may be remarked that chemical analysis of a number of glazed celadon ware specimens unearthed in the course of excavation at Arikamedu has helped to fix the date of the fabrication of this ware on internal evidence,[4] and this agrees closely with the date arrived at from the study of the relics of known date found in association with this ware.

The distinctive pottery of different ages and localities, e.g. the Painted Grey Ware of northern India (above, p. 93), the Red Polished Ware of western India (above, p. 158), the russet-coloured pottery recovered from the Āndhra levels at various sites in south India and the Deccan (above, p. 163), and the Black-and-red Ware found in the south Indian megaliths (above, p. 110)—all require scientific investigation and research for the determination of the technique of their manufacture, which will be undertaken shortly.

B. Metallurgy

The application of chemical analysis to archaeological problems, which has proved significant in the study of ancient Indian ceramics, has been found to be equally useful in the investigation of metallurgical and metallographic problems presented by metal- and alloy-specimens recovered in the course of excavations. The results of most of these investigations have already been published. Thus, the analysis of specimens from Mohenjo-daro and Harappā has led to important and interesting results[5] and has shown that the ancient craftsmen had attained a very high degree of skill in metallurgy. Bronze was well-known and used on a fairly large scale, while the technique of its casting and working had also been developed considerably. The chemical composition of the

[1] B. B. Lal, 'Composition and technique of some glazed tiles from historic monuments', *Science and Culture*, XIX (1953), pp. 244-66.

[2] B. B. Lal in *Current Science*, no. 22 (Jan. 1953), pp. 7-8.

[3] *Ancient India*, no. 1 (1946), pp. 58-59.

[4] *Ibid.*, no. 2 (1946), pp. 94-95.

[5] Marshall, *op. cit.*, II, pp. 484 ff.; Vats, *op. cit.*, I, pp. 378 ff.

Nālandā bronzes has been studied, and the results of this investigation are in the course of publication. A systematic metallographic examination of the bronzes is already under way, and the results of this work will be available in due course. It is also proposed to publish the results of analysis recently carried out on a large number of coins from Ahichchhatrā. Although metallographic data on these coins are not yet available, it may be mentioned that most of these coins contain appreciable quantities of antimony, and some contain lead as well. Several objects from Brahmagiri have also been analysed and found to be variously composed of bronze and copper. It is proposed to complete the examination of ancient metals and alloys by undertaking a systematic metallographic investigation, in order to determine the technique of manufacture. It is also desirable to carry out a complete chemical and metallographic examination of datable metal- and alloys-specimens from sites of known dates in order to assess the extent of technical skill and metallurgical development through the ages.

3. PRESERVATION OF ANCIENT MONUMENTS

The problems of preservation of stone monuments, such as rock-cut caves, temples, sculptures, inscriptions, etc., all over the country, exposed that they are to varying elemental forces, are extremely complicated, and their preservation is a very difficult task indeed. The climatic factors, including the temperature- and humidity-conditions, atmospheric pollution and the salinity of soil are different in different parts of the country. In view of the varying factors it is almost impossible to work out uniform methods which will hold good for all monuments in the country. Moreover, the materials used in the construction of ancient monuments are of a widely different nature, and as such the problems of each monument have to be studied and examined with a view to determining the causes of its decay before suitable preservative measures can be devised to arrest the progress of decay and save it from further disintegration. It need hardly be emphasized that petrological investigations are of great importance in such work and microscopic examination of rock-specimens has, therefore, to be undertaken as a preliminary to devising chemical methods of preservation. Consequently, the Chemical Branch has been reinforced by the addition of a petrological section, the primary object of which is to determine the minerological composition of the original rock and the alteration of minerals as a result of weathering. The determination of micro-structure, porosity, water-absorption and saturation-coefficient, the study of which is so necessary for assessing with some degree of precision the weathering properties of building materials, also falls within its purview.

As a result of this development, the chemical conservation of ancient monuments has been based on a firm scientific basis, and it has been found that results of petrographic investigation, coupled with analytical data, give a clear insight into the causes of decay of stonework. In most cases the injurious soluble salts have been found to be responsible for the decay and disintegration of stone used in various monuments. It is proposed to publish brief but complete reports on groups of monuments incorporating therein the results of petrographic investigation and chemical analysis. It may be added that already large-scale chemical preservation has been carried out at Elephanta, Kārla, Bhājā and Kanherī in Bombay State; Konārak, Bhuvaneśwar, Udayagiri and Khandagiri in Orissa State; Nālandā, Lauriyā Nandangarh and Maner in Bihar State; and Agra and Fatehpur Sīkrī in Uttar Pradesh. It is also proposed to undertake extensive work at the temple at Baijnāth in Kāngrā District, Panjab; several temples at Bhuvaneśwar; Khajurāho in Vindhya Pradesh; and Sānchī in Bhopal. The measures adopted by the Chemical Branch have already proved to be highly successful, and as a result thereof many sculptures have been rescued from decay which had assumed alarming proportions.

The techniques and materials employed in these works may now be briefly described. In most cases the chemical preservation has consisted in the elimination of soluble salts from the affected sculptures, the eradication of moss and lichen, the prevention or reduction of the solvent action of rain-water and the preservation with vinyl acetate solution or methyl-metha-crylate resin. The results of large-scale fungicidal treatment carried out at several sites by employing 1-2 per cent solution of zinc silicoflouride have been fully successful and confirm the results reported by western scientists. It can be said with confidence that the problem of eradication of moss and lichen has been effectively solved, and the disfigurement and decay caused by the algal growth can be completely eliminated by this method. The efficacy of this method can be judged from the work done at Bhuvaneśwar, where a number of sculptures belonging to the Paraśurāmeśvara and Mukteśvara temples (pls. XCV and XCVI) were subjected to fungicidal treatment with zinc silicoflouride, and it is gratifying to note that even now, seven or eight years after their treatment, they are in a very good state of preservation and are free from algae.

While chemical work has been conducted at numerous sites, it is desirable to emphasize the complexities involved in the work when temples and structures of colossal dimensions are involved. The Sun temple at Konārak, Shore temple at Mahābalipuram and Temple 3 at Nālandā serve to spotlight these complexities. The gigantic Konārak temple (pl. LXXXVI) is built of a highly ferrugenous khandolite stone, which is a garnetiferous sillimanite schist. The rock has weathered considerably; felspars have been kaolinized, garnets have been limonitized and the alkalis have been leached out as a result of these alterations. Chemical analysis of a large number of rock-specimens in different stages of weathering has confirmed the leaching of alkalis, elimination of silica and concentration of iron and alumina. Petrological investigation has led to similar conclusions. There is, therefore, no doubt that this process of weathering is akin to lateritization. The problem of preservation of the temple has been considerably complicated by its proximity to the sea, for sea-salts present in the atmosphere have been playing havoc with the sculptures. The attrition caused by dust- and salt-laden winds and the disintegration of the rock caused by crystallization and solution of salts have reduced most of the sculptures to mere skeletons, and the weathered rock presents a very ugly appearance on account of distinct patches of white kaolin and brown limonite. While chemical conservation carried out in the past has helped to lessen the intensity of weathering, the stonework has nevertheless been deteriorating slowly. Consequently the Government of India appointed a committee of experts to go into the whole question of the preservation of this unique temple. The findings of the committee are being adopted for the preservation of the priceless sculptures on the temple, but it may be emphasized that so far no rock-preservative has been evolved which can consolidate and strengthen huge monuments exposed to sun and rain and protect them for an indefinite period, and the measures that have been recommended will have to be repeated periodically as need arises. This work is in progress.

Another extremely difficult problem of conservation is that of the Shore temple at Mahābalipuram. This temple is virtually saturated with sea-salts due to the direct beating of waves which has been going on for centuries. The coarse-grained rock of the temple is being reduced to powder bit by bit, and since the supply of soluble salts is perennial because of salt-laden winds and spraying which continue to deposit salts on the temple, all attempts at chemical conservation of this unique monument have been abandoned. In fact the chemical treatment is likely to do more damage than good because of the extreme environmental conditions prevailing in the area.

A third difficult problem of chemical conservation of exposed monuments was presented by the stucco-figures of Temple 3 at Nālandā (pl. LXVII). These figures were found to be impregnated with injurious soluble salts. For their preservation the entire structure was rendered watertight, and the images freed from soluble salts by repeated applications of wet paper-pulp, after which they were preserved with 5 per cent vinyl acetate solution. The treatment has proved quite effective, and these beautiful figures (pl. LXVIII) are likely to remain in a satisfactory state of preservation for some years to come.

The problems of the decay of ancient monuments, the work conducted with a view to determining the causes of the decay and the measures for their scientific conservation may now be briefly described. Generally speaking, the more important causes of decay of stone monuments in India are injurious soluble salts, considerable fluctuations in temperature and heavy rainfall. Some of the monuments are of colossal dimensions, and it is difficult to check the solvent action of rain-water and the attrition caused by winds. Fluctuations in temperature bring about flaking and cracking of the rock, and the salts cause enormous damage due to repeated crystallization and solution under suitable conditions of temperature and humidity. The choice of a suitable stone preservative is extremely limited. Waterproofing materials, such as oil-paint, linseed oil and similar preparations, are out of the question as they cannot be used without disfiguring the monuments. Some of the reagents which can be used on stone monuments have been found to exert deleterious effects on the rock itself, while others cause flaking and exfoliation of the rock. Prolonged fieldwork has shown that neither a thin solution of vinyl acetate or methyl-metha-crylate nor hard paraffin wax can be expected to be of more than limited efficacy. Field-tests have shown that some preservatives possess little adhesion, as they are washed off by the first few showers of rain, and others show very little penetrability and form a superficial skin on the surface of the rock. These results are of a negative character, but a study of literature on the subject shows that no preservative has been evolved which can offer permanent protection to the surface, consolidate the rock as a whole and is suitable in every way in varying climatic conditions. While the quest for a suitable preservative must continue, research is being undertaken by the Chemical Branch with a view to evolving a suitable reagent or formula for the most suitable preservative. For this purpose synthetic resins like vinyl acetate, methyl-metha-crylate and polystyrene, tornesite, hard paraffin wax, etc., are being studied. So far only methyl-metha-crylate has been found to give partially satisfactory results. It is proposed to experiment with aqueous emulsions of some of these resins with a view to determining their preservative properties. The use of silicon ester advocated in some quarters has been found to be of little value.

4. PRESERVATION OF MURAL PAINTINGS

Some of the ancient monuments are embellished with mural paintings which stand in need of treatment and preservation. Considerable work has been carried out on the wall-paintings at Sitābhinji in Orissa; Fatehpur Sīkrī and Madanpur in Uttar Pradesh; Tambekarwāḍā, Aṣār Mahal and Kumutgi in Baroda and Bījāpur Districts of Bombay State; Hoshāngābad, Pachmarhī and Chāndā (pls. XCVII-C) in Madhya Pradesh; Tanjore (pl. CI), Śittannavāsal, Conjeevaram, Tirumalai and Tirumalaipuram in Madras State; Lepākshī in Andhra State; and several other sites. The problems involved in these murals are extremely complex due to several factors, such as the existence of two layers of paintings at Tanjore (pl. CII), Śittannavāsal and Ellora; heavy accretions of smoke and soot at Bāgh, Chāndā, Badāmi and other places; and a general extensive flaking of the pigments on account of the deterioration of the binding medium originally used as an adhesive for fixing the pigments to the ground. Suitable cleansing reagents, detergents and emulsions have been evolved by research and it has been possible to remove heavy accretions of oil, smoke, etc., and expose the paintings in their original colours. The use of such preservatives as mastic in turpentine, shellac in rectified spirit and paraffin wax, which had been used in the past at Ajaṇṭā and other places, for fixing the flaking pigments to the ground had to be discontinued as a result of better materials being placed at our disposal by modern science.

5. THE TECHNIQUE OF PAINTING

Most of the wall-paintings in India, including the world-famous paintings at Ajaṇṭā, Ellora and Bāgh and the lesser known but still important ones at Tanjore, Panamalai, Somapalle and Aihole, have been scientifically surveyed and examined with a view to determining the technique of painting process at each place and evolving suitable preservative methods. As a result of detailed investigations into these paintings, it can now be concluded that the technique adopted at Ajaṇṭā, Ellora, Bāgh, Sitābhinjī, Badāmi, Śittannavāsal and Conjeevaram, which cover a period of nearly half-a-millennium of classical pictorial tradition, was tempera, and the use of water-souble binding medium has been confirmed by laboratory-tests in all these cases. The paintings of the later period, such as the Choḷa paintings in the Bṛihadīśvara temple at Tanjore (pl. CI), the Vijayanagara paintings at Lepākshī and Somapalle and the still later Nāyaka paintings, again at Tanjore, have also been found to have been executed in the same technique. There is, therefore, no doubt that the technique, as revealed by the study of murals dating from the second century B.C. to fifteenth-sixteenth century A.D., was all along tempera, and genuine fresco-technique (Buon fresco), which involves the use of pigments ground in water only without the incorporation of any binding medium on fresh lime-plaster, was not used by ancient artists. The result is in agreement with the technical details about the preparation of surface for wall-paintings and the application of different kinds of colours together with the process of tinting and shading as preserved in Sanskrit texts on paintings, such as the *Vishṇu-dharmottara*,[1] *Śilparatna*, etc. Wall-paintings of a later period, such as those found in the Mughul buildings at Agra and Fatehpur Sīkrī and in the palaces in Kāngrā, Bundelkhanḍ and Rājasthān are being surveyed and scientifically examined along these lines.

6. GEOCHRONOLOGICAL INVESTIGATIONS

A. Soil-profile

Indian archaeology has so far concerned itself solely with the study of cultural aspects of the material remains of the past, and little attention has been paid to the study of environmental conditions in which the various cultures flourished. In the course of excavations various layers of sedimentary deposits are exposed, and a chemical and mechanical study of soils from various layers is of great importance in the reconstruction

[1] S. Kramrisch, *Vishṇudharmottaṛ* pt. iii, 2nd ed. (Calcutta, 1938).

of the conditions under which the various deposits were laid. Similarly, the determination of the phosphate-content of soil from various layers is helpful in understanding the distribution of population. It is, therefore, important that investigations into the soil-profiles exposed in the course of excavations should be systematically conducted. A beginning has already been made in this direction, and soil-samples from excavations at Bahādarābād in Sahāranpur District have been subjected to chemical and mechanical analysis with very interesting results.

B. Fluorine test

In the west considerable attention has been paid to the application of fluorine test to problems of prehistoric archaeology for determining the dates of prehistoric sites and remains. With the exception of one or two stray analyses, no systematic work has been conducted in India on this line. It is proposed to subject bone-materials found at prehistoric sites to fluorine test and collect suitable data which, in the course of time, can be utilized in establishing a chronological sequence and even in dating prehistorical sites. Already there is a growing interest among the Indian prehistorians in the problem of the fossil man, and therefore, it would be in the fitness of things that fluorine test should be applied wherever prehistoric remains of human or animal bones are unearthed.