Indian Journal of History of Science, **22** (1) : 29–46 (1987)

RASA-RATNA-SAMUCCAYA AND MINERAL PROCESSING STATE-OF-ART IN THE 13TH CENTURY A. D. INDIA

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(*Received 18 June 1986*)

A judicious combination of the literary evidences with the archaeological ones yields fruitful results in revealing the antiquity of science in human civilization. Such an exercise has been carried out in this article centering around the 13th century A.D. Sanskrit alchemical text *Rasa-Ratna-Samuccaya* (abbreviated as *RRS*). The mineral processing and metallurgical state-of-art in ancient India up to the said period has been reconstructed. Special emphasis has been laid towards the end of this article on the pioneering Indian contribution in the field of zinc metallurgy. The rational as well as obscurantist trends in the Indian science, as typified in *RRS*, have been commented upon.

INTRODUCTION

The ancient history of mineral processing in the Indian sub-continent is a fascinating subject. But its pursuit is hazardous for any serious scholar on account of several reasons. The archaeologically discovered artefacts are often finished products, and considerable intelligent guessing is necessary even to hypothesise what raw materials and what technology might have been used to produce such metallic and nonmetallic artefacts. Ancient literatures on mineral processing and metallurgy in India are scanty, and great care must be taken to reconstruct the glory of ancient Indian technology.

Rasa-Ratna-Samuccaya (abbreviated throughout this paper as *RRS*),[1] a 13th century A.D. alchemical treatise, authored by Vāgabhatācārya, is a very useful compilation related to preparation and properties of drugs of mineral origin. The Sanskrit text incidentally throws considerable light on the state of Indian expertise in the fields of minerals and their properties, mineral purification, extraction of metals, fuels, crucibles and furnaces, metals, alloys and their properties, metallic salts, and so on. This paper reviews the Indian progress in the sciences of minerals and metals during the ancient period ending with the era of *RRS*.[1] The curious mixture of rational, alchemical, and obscurantist world-views depicted in the *RRS* and typical of medieval Indian science is also reviewed at the end of this article.

The earliest (5000 B.C.) uses of copper, bronze, lapis lazuli, turquoise, steatite and a steatite-cutting workshop have been reported in connection with Mehrgarh excavations.[2,3] Copper metallurgy was known to the pre-Harappan people of Siddhuwala[4] and Ganeshwar.[5] During the Harappan period, gold, silver, lead, and tin metal were used for fabricating various objects, and specific ores were used.[6,7] During the said period, a large number of gem minerals were used for decorative purposes, and this tradition developed into a specialised Indian expertise as attested by Pliny. There was certainly an overlap between the bronze age and the iron age. Mundigak IV in Afghanistan shows iron buttons and specular hematite nodules as early as 2300 B.C.[8] The megalithic site of Tadakanahalli in Karnataka (1000 B.C.) shows iron objects composed of several layers—some carburized and heat-treated.[9] Thus, the north Indian iron technology of the epic ages need not be considered as an alien gift of the *invading Aryans*. Srivastava has catalogued[10] the various metals and minerals used by the Indians in the successive historical epochs. Table 1 in this paper summarises the minerals and metals used in the Indian antiquity. The pioneering Indian contribution in the area of gemology is clearly borne out in Table 2.

Tables 2 and 3, compiled from *Rasa-Ratna-Samuccaya* show India's state-of-art on gems, non-gem minerals, metallic ores, metals, and alloys, druing the 13th century A.D. Acharya P. C. Ray has characterised *RRS* as 'a typical production of the Iatrochemical period, coming after the extravagance of the Tantric Alchemical texts'.[11a] Although a few more Indian developments took place in the fields of mineralogical, metallurgical, and chemical sciences during the subsequent five centuries of the pre-British period, which would be briefly summarised at the end of this article, the 13th century A.D. text of *RRS* embodies the pinnacle of Indian metallurgy during the pre-modern period.

Minerals and their Characteristics

Garuḍa Purāṇa has meticulously described the physical characteristics of various gem minerals (1.68-1.81). The various defects of the gems have been outlined. Diamond could be distinguished from imitation diamonds through the observations of optical properties, non-reactivity with alkaline solutions and hardness (scratch) tests (1.69, 44-46). Similar specific tests have been described for ruby, emerald, pearl, *etc.* Pliny noted that India was the 'sole mother of precious stones' (9.20) and that the Indians had found out a way of imitating a variety of precious stones by colouring crystals (37.26).

RRS provides a more elaborate catalogue and description of gems as well as of non-gem minerals. The defects of gems such as occlusions (*grāsa*), foreign grains (*trāsa*), black spots (*bindu*), bubbles (*jalagarbhatā*), *etc.* are described in great depth (*RRS*, 4.33). Special mention may be made about the Indian origin of

TABLE 1

MINERALS AND METALS IN INDIAN ANTIQUITY

Source	*Items*	*Reference*
a) Mehrgarh in Baluchistan 5000 B.C.–2500 B.C.	Copper, Bronze, Lapis Lazuli, Turquoise, Steatite.	Jarrige[2] Asthana[3]
b) Charaiwala and Siddhuwala	Copper, Copper ore in crucible.	Stein[4]
c) Ganeshwar-Jodhpura near Jaipur 2800–2000 B.C.	Copper artefacts and production technology.	Agrawala[5]
Harappan Period :		
Mohenjo-daro and Harappa	Gold, Silver, Electrum, Copper, Bronze, Lead, Tin, Galena, Cerrusite (Pb), Lollingite (As, Fe), Steatite, Lead ore (Pb, Sb), Copper oxide and sulphide ore, Lapis Lazuli, Turquoise, Carnelian.	Agrawal[6]
	Agate, Alabaster, Amazon, Amethyst, Jade, Jasper, Chalcedony, Talcose, Steatite.	Marshall[7]
Ahar I 2100 B.C.–1750 B.C.	Iron objects and slag.	
Mundigak IV 2300–1900 B.C.	Iron buttons on bronze objects.	Shaffer[8]
Said Qala Tepe near Mundigak	Specular Haematite nodules.	
Vedic Sources	Copper, Bronze, Gold, Trapu (Tin), Silver, Lead, Collyrium, Red Salt, Gem minerals.	Srivastava[10]
Aṣṭādhyayī	Iron Chain, Emerald, Ruby, Cat's eye.	,,
Buddhist Sources	Brass (*Dhammapada Aṭṭhakathā*), Salt, Marble, Diamond.	
Arthaśāstra	Arsenic (*Haritāla*), Ruby (*Padmarāga*), Spinel (*Saugandhika*).	Srivastava[10]
Epics	Brass.	*Rāmāyaṇa*, III 29.20
	Iron.	*Rāmāyaṇa*, I 37.17; III 47.46
	Cat's eye or *Vaidūrya* from Ceylon.	*Mahābhārata*, II 48.30
	Amethyst pots.	*Mahābhārata*, II 47.14
Pliny and Periplus	Pearl, Oyster, Arsenic, Lead & Tin imported to India.	
	Crystals of various colours.	Pliny, 37.26
	Diamond—India sole exporter, Haematitis.	Pliny, 9.20 Periplus, 56 Pliny, 30.41.60
	Iron exported from India to Arabia & Syria.	Periplus, 17.137
	Obsidian, Onyx, opal.	
Mahābhāṣya Patanjali	Brass.	Vol. III, p. 388
Caraka Saṃhitā	Brass.	Ci 24–154, Ci 3, 7

TABLE 2

GEM MINERALS DESCRIBED IN *Garuḍa Purāṇa* AND *Rasa-Ratna-Samuccaya*

Mineral	Chemical identification	Indian name
Agate	Hydrated SiO_2	Akīk
Alabaster	Transparent $CaSO_4$	Rukham
Amethyst	SiO_2 (Contg. Mn)	Jāmīrā
Aquamarine	Be-Al-Silicate	Pāribhadra
Beryl	Be-Al-Silicate Green colour due to Cr_2O_3	Pānnā, Marakata, Gārutmata, Garuḍodgāra, Harinmaṇi
Carbuncle	*see* Garnet	
Carnelian	*see* Agate	
Cat's eye	*see* Chrysoberyl	Vidūraka
Chalcedony	*see* Agate	
Chlorite	Steatite or Mg-Silicate	
Chrysoberyl	Be-Al-Oxide	Vaidūrya, Lasuniā
Coral	Marine product	Pravāla, Vidruma
Corundum	Al_2O_3	Kuruvinda (Sanskrit, Tamil & Telugu : origin of the Latin word).
Diamond	C	Vajra, Bhidura
Emerald	*see* Beryl	
Emery	Corundum (Contg. Fe)	Tārkhsya
Feldspar	(NaK)-$AlSi_3O_8$	Candrakānta or Moonstone
Garnet	M_3^{2+}-M_2^{3+}-$(SiO_4)_3$	Tāmḍi or Tāmrya *not* Gomed.
Hessonite	*see* Zircon	
Jade	Jadeite, NaAl-Silicate Nephrite, CaMgFe-Silicate	Pīlu, Yasam Jaharmuhrā
Lapis Lazuli or Lazurite	$3NaAlSiO_4$, Na_2S	Rājāvarta, which is *not* Amethyst
Marble	$CaCO_3$ (metamorphic)	Marmara
Olivine	$(MgFe)_2SiO_4$	Puttikā, Jabarjad
Onyx	*see* Agate	Sulemānī
Pearl	Marine product	Muktā
Peridot	*see* Olivine	
Quartz	SiO_2	Sphatika, Billaur
Ruby	Al_2O_3 with Cr_2O_3	Padmarāga (red), Mānikya, Cuṇī Karuṇḍaka (if crimson-yellow)
Sapphire	Al_2O_3 with oxides of Ti, Fe & Co	Nīlā, Nīlakānta, Indranīla (blue)
Spinel	Al_2O_3 with MgO	Saugandhika (red)
Stibnite	Sb_2S_3	Rasāñjana, Surmā
Topaz	Al Fluorosilicate	Puṣparāga (yellow) or Pokhrāja. Quartz containing Fe is 'false' Topaz
Tourmaline	BAl Silicate with Mg, Fe, Na, *etc.*	Vaikrānta
Turquoise	CuAl Phosphate	
Ultramarine	*see* Lapis Lazuli	
Zircon	$ZrSiO_4$	Gomed

TABLE 3

GENERAL COMPOUNDS, NON-GEM MINERALS, METALS AND ALLOYS MENTIONED IN *Rasa-Ratna-Samuccaya*

Item	Chemical identification	Indian name
General Compounds :		
Acid	Plant product organic acids	Amla
Alkali	Plant ash residue; K_2CO_3, *etc.*	Kṣāra (3 types)
	River bed alkaline soil; Na_2CO_3, Na_2SO_4, *etc*	Sarjikā kṣāra
Bitumen		Adrija/Śilājatu
Flux	Like Borax	Drāvaṇa Varga
Metal	Which can be extracted	Loha, from the verb *Luha*
	The essence	Sattva
Metal (low melting point)	Like Pb, Sn	Pūti (furnace) Loha
Salt		Lavaṇa (6 types).
Non-Gem Minerals :		
Alum	M_2SO_4, $Al_2(SO_4)_3$, $24H_2O$	Kāṅkṣī/Sauraśtraja Phaṭkī/Tuvarī
Anglesite	$PbSO_4$	Yellow Mṛddāra Śṛṅga
Galena &	PbS	
Greenockite (?)	CdS	
Arsenopyrite with	FeAsS	
Löllingite	$FeAs_2$	Kāṃsya Vimala or Haritāla (?)
Bismuth ore (?)		Capala
Borax	$Na_4B_2O_7$, $10H_2O$	Saubhāgya, Ṭaṅkaṇa
Calamine	Zn Silicate	
	Zn Carbonate	
Zinc blende or Sphalerite	ZnS	Rasaka/Kharpara
Carrollite	CuS, Co_2S_3	Srotāñjana, Nīlāñjana or Sohtā
Cassiterite	SnO_2	Vaṅga (tin) Ore (Kaṅkuṣtha)
Chalcopyrite	$CuFeS_2$	Svarṇamākṣika
Cinnabar	HgS (black)	Kajjali/Hiṅgula/Darada
Copper sulphate	$CuSO_4$	Sasyaka/Tuṅte
Iron oxide (hydrated)		Gairika
Iron (ferrous) sulphate	$FeSO_4$, Green Vitriol	Kāśīsa or Harā Kāśīsa
Magnesium sulphate	$MgSO_4$	Kamkustham (purgative soil—also Na_2SO_4)
Mercuric chloride	$HgCl_2$	Rasakarpūra
Mercuric sulphide	HgS	Rasasindūra (red)
		Makaradhvaja (medicine)

TABLE 3 (*Contd.*)

Item	Chemical identification	Indian name
Mica		Abhraka
Orpiment	As_2S_3	Tāla/Tālaka
Potassium salt	KCl/K_2CO_3	Navasāra
Pyrite	FeS_2	Mākṣika/Vimala
Realgar	AsS	Śilā/Manaḥśilā
Saltpetre	$(NaK)NO_3$	Sauvrachala (in *Rasārṇava*)
Stibnite	Sb_2S_3	Sauvirānjana
Sulphur	S	Gandhaka
Metals & Alloys :		
Brass	Cu & Zn	Pittala/Rītikā/Kākatuṇḍī
Bronze or Bell-metal	Cu & Sn	Kāṃsya/Ghoṣa
Copper		Śulva/Tāmra
Copper-Lead Alloy		Śulva Nāga
Gold	Au	Suvarṇa
Iron :	Fe	
Wrought		Muṇḍa (3 types)
Cast		Tīkṣna (7 types)
Magnetic		Kānta (5 types)
Lead	Pb	Sīsā/Nāga
Mercury	Hg	Pārada/Rasa
Silver	Ag	Rajata/Raupya
Tin	Sn	Vaṅga/Ranga/Rāng
Zinc	Zn	Yaśatva, Yaśadāyaka, Yaśada, Dastā, Kharpara, Rasaka.

the word Corundum (from *Kuruvinda*). There are conflicting versions with regard to a few equivalents *e.g. Gomed* (Zircon vs Garnet), *Rājāvarta* (Lapis Lazuli vs Amethyst), *etc.*

By the 13th century A.D., Indians became acquainted with large *varieties* of acids, alkalies, and salts as well as of mica, pyrite, quartz, sulphur, and ores of Fe, Cu, Pb, and Zn (*vide* Table 3). They were also familiar with the biochemical alteration products of sulphates such as alum (*tuvarī*), ferrous sulphate (*kāśīsa*), copper sulphate (*sasyaka*) (*vide* Table 3), and their properties as mordants and colouring agents. A mixture of potassium carbonate and chloride, known as *Cullikā Lavaṇa* or *Navasāra*, was used as an alkali (*kṣāra*) (converting Hg into calomel), and as fertiliser (*sāra*). We are not sure about the modern equivalents of many Indian terms of minerals such as *anjanas* (collyrium), *kaṅkuṣṭha* (could be SnO_2 or As_2S_3), *gaurīpāṣāṇa*, *varātikā* (collophane or bauxite ?) *etc. Pināka abhra* which 'expands when heated on fire' (2.5) is clearly vermiculite.

MINERAL DRESSING AND PROCESSING

Mineral Engineering or Beneficiation involves physical (dressing) as well as chemical (processing) methods. *RRS* describes in its glossary, compiled by an earlier author, Somadeva, various comminution equipments such as crusher (*kaṇḍanī*), grinder (*peṣanī, mardanī, gharṣanī*), mortar (*khalva*) of various shapes, hot mortar of iron (*āyasa tapta khalva*), and sieves (*cālanī*) made of bamboo bars, wooden fibres as well as of horse hair or fine cloth piece 'with thousands of minute holes to sieve very fine particles' (7.9-7.10 ; 7.14-7.17). Separation of particles on the basis of size and density used to be done by winnowing (*śūrpa*, 7.13) which involves the principle of non-steady state gravitational settling in air. The practice of hydraulic washing or elutriation was also known (*dhauti*, 8.45 ; *kṣālana*, 7.4). *Kṣālana* might also mean chemical washing with alkali (*kṣāra*). *Garuḍa Purāṇa* describes purification of gems by using alkali (*kṣāra*) and acid (*kāñjika* or *amla drava*).

For centuries, mineral engineering has been practised in India. The ^{14}C dates show that the earliest mining activity is indicated at Dariba Mines, Udaipur District, Rajasthan (64 m depth), as the date goes back to *c.* 360 B.C.[12] Analysis of the pieces of wood, forming part of the timber used as roof support in the Cu-Pb-Zn Ambamata mines, established the earliest mining activity to be in the 2nd century B.C.; ore-artefact correlation has also been satisfactory.[13] Carbon-dating of the timber samples from the Zawar mines suggests that zinc was being mined and smelted there in the second century B.C.[14]

At Agnigundala, Dist. Guntur, Andhra Pradesh, old copper workings dated 1000 A.D., extend over 3 km and up to 30 m depth. The entire flowsheet starting from mining to crushing and smelting is indicated by rock dumps, ore dumps, pounding stones (pestles and mortars), washing tanks, tailing dumps, smelting furnaces, slag dumps, crucibles, *etc.*[15]

Chemical treatments of minerals and other materials (apart from reduction leading to extraction of metals) were practised, of course with very little fundamental insight. Excavation of the Dhatwa site in Gujarat showed that limonite, collected from the surface laterite formation, used to be roasted for dehydration into haematite before smelting.[16] *RRS* refers to removal of impurities from tourmaline and other gems by alkali, acid, and salts in water (2.65-66; 4.60-62), removal of carbonates by acids from zinc ore (2.155-156), liberation of copper from brass through dissolution of zinc by mild acid (5.191), purification of sulphur by boiling in milk and washing with water (3.20-22), *etc.*, such processes being known as *svedana* or dissolution.

A molten metal could be purified by blowing and oxidizing the impurity to form a scum, the process being known as *tāḍana* (8.32). Copper could be regenerated from bronze (*kāṃsya* or *ghoṣa*) by removal of tin with arsenic compound (*tālaka*) and blowing (*tāḍana*) with bent tube (*vaṅka nala*). The metal thus obtained was specially named as *ghoṣākṛṣta tāmra* (8.38). Similarly, iron and lead compound when heated gave lead (8.39).

A novel process was to extract the metallic content of the metabolic product of earthworm (*bhunāga*) (5.225-5.230).

Sulphates of aluminium, iron, and copper were formed in nature evidently on account of bacterial action on sulphide ores. These sulphates used to be commercially leached, and the filtered solution evaporated yielding crystals of alum (*tuvarī*) or ferrous sulphate (*kāśīsa*) or copper sulphate (*sasyaka*).[17] *RRS* describes reduction of copper sulphate (*mayurkanṭha nīla sasyaka*) to coccinella-type red copper (*indragopākṛti*) (2.125-2.134).

Extraction of Metals

The subjects of chemistry and metallurgy in ancient India have been excellently covered elsewhere.[11,18a] In this article we wish to merely highlight some of the metallurgical concepts as outlined in *RRS*.

Like *āyasa* tne word *loha* also stood for metals in general. The second word was derived from the word *luha i.e.* that which is extracted : *dhāturlohe luha iti... karṣārthabācī* (5.1). The word *dhātu* stood for metals as well as minerals : 'that which sustains the body'. The 'essence' of the metallic ore was called the *sattva* meaning the metal itself. Some minerals were described as devoid of a sattva since no metallic residue was left when these were heated. The extraction of the metal (essence) could thus be called *satvapātana* (10.9). *RRS* is full of *satvapātana* recipes for Au, Ag, Hg, Cu Sn, Fe, Pb, Zn, *etc.*

The metallic ores used to be heated with a wide variety of solid fuels such as dried cowdung or charcoal in a crucible (*mūṣā*) or furnance (*koṣṭhi*)—big (*aṅgāra koṣṭhi*) or small (*pātāla koṣṭhi*). Smelter for sulphidic ores was known as *puṭa*, associated with the obnoxious smell of the sulphurous fumes (*putī gandha*). *RRS* lists 51 kinds of metallurgical implements (*upakaraṇas*), 36 kinds of equipments (*yantras*), 17 types of crucibles (*mūṣās*) and 9 types of furnaces (*puṭas*). This compilation excelled all the earlier ones and could certainly claim as an useful metallurgical encyclopaedia of the 13th century world.[1]

Special comments may be made about fluxes and furnace-construction materials. There was a constant attempt to conserve the quantum of heat (*puṭamāna*). Fluidity was improved by the use of flux (*drāvaṇa varga*) such as borax (*taṅkaṇa*) (2.27-2.38; 10.95). It is noteworthy that Na and B have been detected in an East Indian ancient copper slag.[19]

An important adjunct for increasing the furnace temperature was the bag for blowing air (*bhastrikā*) (11.75). Special clays (*toyamṛttikā*) were used for furnace construction. Heat resistant and air-tight fire-clay seals (*vahnimṛttikā*) was poetically compared with the tight embrace of a lustful mature lady (9.64). The change iu colour of the flame from blue (due to carbon monoxide) to white (*suddhāvarta, bijāvarta*) (8.56-57) indicated completeness of reduction and the time when the metal was about to melt.

Decomposition of cinnabar (*hiṅgula*) to produce mercury (*hiṅgulākṛṣta rasa*) was specially studied (8.37). Distillation (*pātana*) of mercury was graphically described as the movement of the vapour upwards, obliquely and downwards (*ūrdham adhaśca tiryak*) (9.12) to move away from tin, lead, and other impurities (*baṅga ahi samparka kañcuka ghnanam*) (8.64). Zinc vapour was described to travel through bent tube (*vaṅkanāla*) and get absorbed (*nirvāpana*) in molten copper to produce brass (8.24-25). For distillation, a special apparatus (*ḍekī yantra*) was recommended (9.10-19).

METALLIC SYSTEMS

The concept of alloying or mixing two (or more) metals in molten state was known *dvandvāna* (*RRS*, 8.46). Additives were used to alloy otherwise incompatible metals, *durmela lohadvaya melanaśca* (2.80). The process of addition was known as *nirvāpana* (8.24-25). Specific alloy systems were known : two kinds of brass (5.191-192), low melting alloys or *pūṭi loha* (5.1), Cu/Pb alloy or *śulvanāga* (8.19), golden coloured alloys such as brass or *suvarṇaka* (8.47), five-metal alloy or *pañcaloha* or *vartaloha* (8.12), Fe/Pb alloy or *varanāga* (8.39), *etc.*

To increase the hardness of metals and alloys, quick cooling or quenching used to be done either by pouring cold water (*abhiṣeka*, 8.53) or dipping hot metal in specified liquids (*parivāpa*, 2.38 ; *nirvāpa*, 8.54). Often, additives were added to produce better colour in the alloy (*anuvarṇaka*, 8.51).

It is now well-established that the iron-making technology in India was indigenous and not introduced by any invading race such as the Aryans. Studies on Tadakanahalli site iron (1000 B.C.)[9] and other Indian materials of antiquity[20] have established that the Indians were skilled in producing wrought iron blooms at temperatures below its melting point, removal of the surrounding slag and forge-welding around 1200°C. Carburisation and quenching techniques were satisfactorily known to the Indian smiths.

RRS provides the *literary* evidence relating to the varieties of ferrous alloys which could be produced by the Indians (5.70-5.95). Wrought iron was known as *muṇḍa loha*, and it is heartending to note that Prakash and Igaki have recently documented the ancient technology of the iron-smiths of Mundia[21] (and Halbi tribes of Bastar, Madhya Pradesh) in whose name the term *muṇḍa loha* was coined. The carburised, quenched and forge-welded variety of iron was known as *tīkṣṇa loha* and hailed as 'hundred times better than other varieties' : *śatottaraṃ* (5.83). *Kānta loha* (5.90-5.94) was the magnetic variety of iron, probably coated with a residual layer of magnetite.

India's Pioneering Contributions to Zinc Metallurgy

We are unable to subscribe to Acharya P. C. Ray's view that 'brass (an alloy of copper and zinc) appears to have been introduced in Northern India quite early, probably *through Chinese trade*'.[11b] As a matter of fact, it is the other way round and the pioneering contribution of Indian zinc metallurgy diffused into China probably through the Buddhist influence not earlier than the first century B.C., and probably much later. Production of zinc and brass in China as described by Partington was a copy of the Indian technology developed several centuries earlier.[22]

Carbon-dating of the timber samples from the excavated site of Zawar, Rajasthan suggests that zinc was being mined and smelted there in the 2nd century B.C.[14, 23] Brass bangles found in the 2nd-5th century B.C. sites of Taxila assayed 13-20% Zn.[11c]

Ray also refers to the 1st century B.C. brass coins of Dhanadeva and Āryavarmā of Ayodhyā, 2nd century A.D. cast brass casket from the Buddhist stupa at Mānikyālaya, 6th century A.D. brass statue of Buddha at Fatehpur near Kangrakot and Hiuen-Tsang's description of a 7th century A.D. (unfinished) brass *vihāra* (convent) at Nalandā.[11d] Evidently, India had a glorious tradition of copper metallurgy,[24] iron metallurgy,[25] as well as of zinc and brass metallurgy.

There are three categories of evidences regarding the antiquity of zinc metallurgy in India : (a) dating of artefacts as discussed above, (b) literary, and (c) archaeological studies on the mining and metallurgical site, equipments and slags.

The Literary Evidences

The literary evidences cover more than fifteen centuries, spanning from the era of Kautilya's *Arthaśāstra* upto that of *RRS* and even beyond. Brass has been named *arakuta* by Kautilya, *rīti* by Caraka and *rītikā* in *RRS* (another variety is *kākatuṇḍī*).

The advent of zinc metallurgy must have started with the chance discovery of golden hued brass. The famous Nāgārjuna stumbled on to this revelation before he wrote in *Rasaratnākara* (1.3): "what wonder is it that *rasaka* (zinc ore)......roasted thrice with copper, converts the latter into gold" (*Rasako......Karoti śulvam triputena kāñcanam*). That was the decisive stage for the onset of alchemy in search of transmutation of elements and of *precious* gold and mercury. Later in the *Rasaratnākara* text (1.31-32) it was recognised that *rasaka* on reduction, without copper, gives a tin-like metal. *Rasārṇava* (7.31-38) recognises three kinds of *rasaka* or zinc ore, and repeats the observations made earlier in *Rasaratnākara*. Yaśodhara lists two types of *rasaka* or zinc ore in his *Rasaprakāśasudhākara*.

Now we come to summarise the detailed informations about zinc mineralogy and metallurgy contained in *RRS* or *Rasa-Ratna-Samuccaya*. Zinc ore or *kharpara* or *rasaka* could be of two types: (a) *durdura* with *dalā* or lamella and (b) *karavellaka* without lamellae. The first variety was good for metallurgical extraction (*satvapātana*) and the second suitable for medicinal purposes (2.149-150).

It is difficult to judge whether one or both of the above types of ores belonged to carbonate or sulphide family. In India, even sulphidic ores of substantial quantities of acid soluble limestone and dolomite. Significantly, zinc contain *RRS* recommends that prior to smelting, the ground ore should be heated with the acidic juice of *kaṭutumbī* or *kāñjika* (lemon juice) or urine, evidently to dissolve some calcium and magnesium carbonates (2.155-156).

Smelting involved reduction-roasting of zinc ore with diverse carbonaceous (vegetable) materials and borax (*ṭaṅkaṇa*) used as flux, in brinjal-shaped crucible called *vṛntāka mūṣā*. Fitted with a 12-*aṅgula* long tube and inverted, it looked like an inverted flower of *dhattūra* (10.22-23) (Fig. 1).

Several techniques of smelting were discussed. According to the first method, the dried charge was to be heated in the crucible, closed and stacked one over another (*mūṣāṃ mūṣopari nyasya*) and the reduction was supposed to be complete as soon as the blue flame (due to carbon monoxide) turned white (*jvāla bhaved nilā sitā yadi*), when the crucible was to be gripped by a pair of tongs and tilted to pour the molten metal (2.157-161). The second method involved mixing the charge thoroughly with binders and putting this in the crucible as pellets (*gutikākṛti*) (2.163-164). The third method involved distillation of the produced zinc metal in the inverted crucible (*adhomukhaṃ mūṣā*) and collection of the condensed vapour in a vessel filled with water kept in a hermetically sealed container below the crucible (*patitaṃ sthālikā nīre sattvaṃ*) (2.165-166). This last method, as we would notice later, was commercially followed in India. China probably followed the first or the second method.[22]

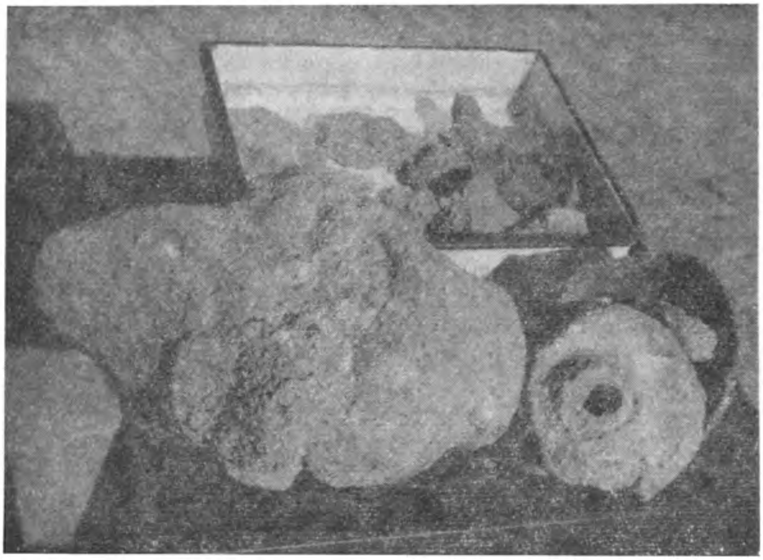

Fig. 1. Photograph showing *Vṛntāka Mūṣā* or the brinjal-shaped Zinc reduction/distillation crucible or retort. Shown an intact retort, contents of the broken retort, and a broken retort with a hole which fitted a clay-tube for the exit of Zinc vapour.

The author of *RRS* was primarily interested in the medicinal value of the product of reaction between zinc metal and orpiment (2.167-168), but has incidentally left for posterity the invaluable and comprehensive text for the extraction of zinc metal. As we have said earlier, *RRS* gives exhaustive descriptions for many other metallic and alloy systems, as well.

Brass (*pittala*) could be made by alloying zinc with copper or by direct reduction of zinc ore in the presence of copper. A good variety of brass was known as *rītikā* which must be soft, smooth, yellow, and malleable (*pītābhā tāḍanakṣamā*). Treatment with hot lemon-water (*kāñjika*) turns *rītikā* copper-red, but turns *kākatuṇḍī*, an inferior variety of brass, black (5.191-194).

To conclude our comments on the literary texts on zinc, we may assert that Nāgārjuna, the father of zinc metallurgy and alchemistry, certainly did not belong to the 9th or 10th century A.D., as wrongly surmised by Al-Bīrūnī[26a] since Hiuen-Tsang had referred to Nāgārjuna's alchemistry in clear terms, much earlier.[27] Renou and Filliozat have proven that Nāgārjuna, the alchemist, lived during the end of the first century A.D.[18b]

RRS records that Nāgārjuna considered both mercury (*rasa*) and zinc (*rasaka*) (salts) as powerful metallic drugs, strengthening the body tissues (*rasa* *rasakaśca śreṣṭha siddharasam dehalohakarau parama*) (2.152). We have earlier referred to Nāgārjuna's observation on the gold-like brilliance of brass. Zinc was named *yaśadāyaka*, *yaśada* or *yaśatva* (Hindi & Bengali : *dastā*) *i.e.* the one which gives fame. These factors as well as the malleable property and ease of fabrication of brass ushered in the art of zinc metallurgy in the world.

The third and last category of evidence regarding the antiquity of zinc metallurgy in India is again archaeological. A century after the first investigation on the ancient Pb-Zn Zawar mines,[28] a survey reported the characteristics of the ancient slags.[29] Recent excavations[14, 23] have unearthed the 2nd century B.C. metallurgical works with two sets of furnaces still containing their charge of 36 retorts. The furnace is divided into two parts, a lower condensing chamber separated by a perforated brickwork from the upper main furnace chamber in the form of a truncated pyramid. In the latter, the brinjal-shaped retorts—the *vṛntāka mūṣā* of *RRS* (Fig. 1)—containing the charge were stacked in inverted position and heated, probably around 1200°C for 4-5 hrs. The clay tubes, fixed on the mouth of the retorts, pointed downwards and carried outgoing zinc vapour. The distilled metal was condensed in the bottom cold portion of the chamber, or collected in cold water as described in *RRS* (2.165-166).

The retorts were closely spaced to each other, and the assembly looked like a honey-combed structure from a distance. The Chinese practice was similar,[22] except that the crucibles did not point downwards, and the produced metal was not distilled, but had to be poured from the crucible as explained in the first and the second procedure of *RRS* (2.163-164).

Huge quantities of retort content (zinc extraction residue) and a separate variety of glassy slag (lead extraction residue) in Zawar contain substantial quantity of zinc,[29] which can now be commercially recovered. The author of this article and his colleagues have carried out X-ray, electron microscopic and DTA analysis to characterise the diverse, micron-size grained, zinc-containing phases.[30] Special leaching techniques have been evolved to recover zinc from the silicate and carbonate phases such as hemimorphite, willemite, hydrozincite, *etc.*[31] The slag contains 0.1-0.3% sulphur, and its siliceous-carbonate composition fully corroborates the postulate that quartz- and dolomite-rich sulphide ore of the neighbouring mines was used to extract zinc at the Zawar site as early as 2nd century B.C.

Mineral Processing in India after 13th Century

After *RRS*, subsequent (post-13th century) texts record some progress in the state-of-art for mineral processing in India, without the emergence of modern scientific tradition as in the West. Paper, opium, and gunpowder were introduced in India, the last one coming much too late, and only after the Muslim conquerors had firm stranglehold on the country. The techniques of gold recovery from wastes, tinning of vessels (*kalāi*), enamelling and *bidery* (Cu-Pb-Sn alloy) metal crafts were developed. Quicksilver and calomel were used as medicines. Although the terms *dāhajala* and *śaṃkha drāvakarasa* were used in *Rudrayāmala Tantra*, *Rasapradīpa*, *etc.*, it is doubtful whether the mineral acids such as H_2SO_4 or HCl were actually produced. The system containing alum, sal-ammoniac, saltpetre and sulphur, *etc.* might have generated chemical species *in situ* which would dissolve conch-shell or copper.[11e]

Alchemy was introduced in Europe during the 12th century A.D., and as recently as the beginning of the 17th century Europe was still debating on the older theories of elements, and Libavius wrote his *Alchymia*. Thus, the Indian record on science was not inferior to the global standard till the balance was finally tilted in favour of Europe during the eighteenth century, when the modern concept of elements, atoms, molecules, and chemical bonds added new understanding to the old techniques, and finally made the ancient science obsolete.

The Nature of Scientific Philosophy Reflected in *RRS*

Rasa-Ratna-Samuccaya or *RRS* typifies entire Indian scientific literature during the ancient and medieval periods, insofar as this text reflects both the rational as well as the obscurantist philosophies in a dialectical fashion.

The spirit of enquiry revealed in the *Ṛgveda* was sustained by Caraka and Suśruta, who claimed that the Vedas were not infallible, a knowledge of the human body is not possible without dissection and inspection, and so on. The casteist Manu changed and mutilated the rational spirit of enquiry.[11] Acharya P. C. Ray pointed out how Śankarācārya had ridiculed Kaṇāda's theory of atomism (*Brahmasūtra Bhāṣyam*, 2.2.17).

Like Āryabhaṭa, Varāhamihira was a great scientist, and yet he decided to indulge in tight-rope walking on issues such as the real reason for eclipses,[26b,32] the origin of minerals and rocks, *etc.* On the latter topic, Varāhamihira wrote in *Bṛhatsaṃhitā* that the gems could have originated either from the bones of gods and demons, or on account of natural metamorphosis of rocks. The two possibilities were given equal emphasis. This ambivalence, reflecting a struggle between the rational spirit of enquiry and theological obscurantism,[32] persisted for centuries, and got reflected in texts such as *RRS*.

We need not criticise the alchemical and empirical nature of *RRS*, since the European science was equally steeped in alchemical extravagance at that time

(13th century A.D.). However, identification of emerald with the bird-god Garuḍa's vomit, of mercury with Lord Śiva's semen (*RRS*, 1.61-67) and of sulphur with Goddess Pārvatī's menstrual discharge (3.2-11) *etc.*, is inexcusable since these were made centuries after Suśruta and Varāhamihira. The *Tāntrik* religion strangely permitted deification of even minerals, metals, and equipments (6.47-6.58).

The concept of hereditary caste system permeated into the subject of classification of minerals. Diamonds, for example, were classified as male, female, and of four types to be selectively used by the people belonging to the four castes! What was worse, such a classification theory for materials, based on caste, was claimed to have universal applicability (*padārtheṣu akhileṣu api*) (4.29-4.31).

The other dangerous trend was the concept of professional secrecy in alchemical and medicinal research, and the astounding claims that 'scientific knowledge remains powerful when kept secret and becomes useless when made public', and that 'the medicine becomes ineffective when its identity is revealed to the patient' (6.71-6.72). In these two *ślokas*, we find the seed for the downfall of Indian science.

On the other hand, *RRS* makes out a brilliant case for systematic and sequential study of alchemistry (*rasaśāstra*) (6.2). In a contemporary text, *Rasaprakāśa Sudhākara*, Yaśodhara declared that he had recorded facts only after personal experimentation and verifications. In the same vein, *RRS* insists on the desirable qualities of an ideal, dedicated student and a hard-working, meticulous research worker (6.5-6.7; 6.67-6.68). To cap it all, *RRS* feelingly describes the environment, lay-out and experimental facilities of an ideal *rasa-śālā*, an alchemical laboratory of 13th century A.D. India (6.11-6.58) (Fig. 2).

That scientific laboratories and scientific enquiry lead to industrial prosperity and health, was well-recognized in our country seven centuries ago. The nadir of Indian science, reached during the medieval period, was bound to be replaced by a new ascent spurred by the positive ideals of our ancient traditions in science.

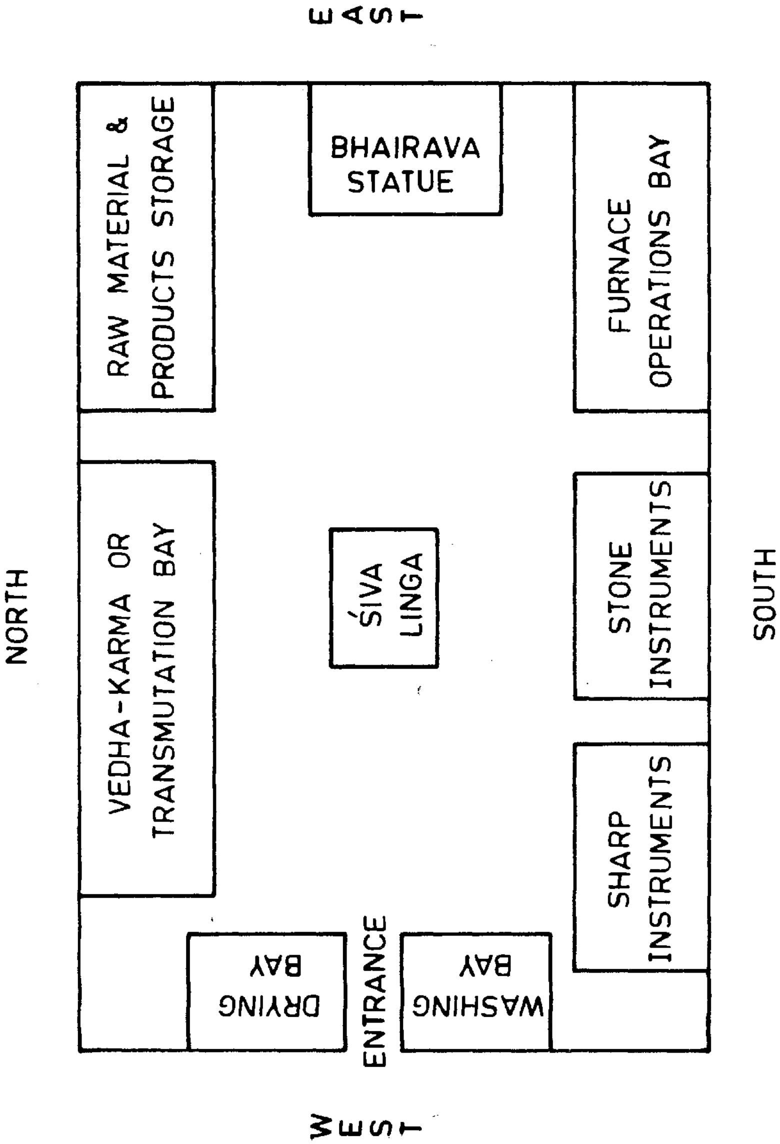

Fig. 2. Rasa Śālā or Alchemical Laboratory described in Rasa-Ratna-Samuccaya (7.1–5).

References

[1]Joshi, D. (edited), *Rasa-Ratna-Samuccaya*, a Project Report submitted to the Indian National Science Academy, New Delhi. The author is indebted to Prof. Joshi for encouraging him to write this critical note, and for allowing citations from his edition of *RRS*. The views expressed in this article, however, are not necessarily shared by Prof. Joshi.

[2]Jarrige, J. F., Excavations at Mehrgarh, *South Asian Archaeology*, Leiden, 1975, pp. 76–87; in *Harappan Civilization* edited by Possehl, G. L., New Delhi, 1982, pp. 79–84; *Scientific American*, **243**, 122–133, 1980.

[3]Asthana, Shashi, *Pre-Harappan Cultures of India and the Borderlands*, Books and Books, New Delhi, 1985, pp. 110–120, 194–196.

[4]Stein, A., Archaeology along Ghaggar-Hakra River, Microfilm, ADI 4861, Washington.

[5]Agrawala, R. C. and Kumar, Vijay, Ganeshwar-Jodhpura Culture, in *Harappan Civilization*, edited by Possehl, G. L., New Delhi, 1982, pp. 125–134.

[6]Agrawal, D. P., Metal Technology of the Harappans, in *Frontiers of the Indus Civilization*, edited by Lal, B. B. and Gupta, S. P., Books and Books, New Delhi, 1984.

[7]Marshall, J., *Mohenjo-daro and Indus Civilization* (3 Vols.), 1931.

[8]Shaffer, J. G., Bronze Age Iron from Afghanistan, in *Studies in the Archaeology and Palaeo-Anthropology of South Asia*, edited by Kennedy, K. A. R. and Possehl, G. L., Oxford & IBH Publishing Co., New Delhi, 1984, pp. 41–62.

[9]Agrawal, O. P., Harinarain and Bhatia, S. K., Technical Studies of Iron Implements from the Megalithic Site of Tadakanahalli, *Purātattva*, **12**, 97–100, 1980-81.

[10]Srivastava, B., *Trade and Commerce in Ancient India*, Chowkhamba Sanskrit Series, Varanasi, 1968.

[11]Ray, Acharya P. C., in *History of Chemistry in Ancient and Medieval India*, edited by Ray, P., Indian Chemical Society, Calcutta, 1956; (a) p. 158, (b) p. 97, (c) p. 96, (d), p. 95, (e) p. 163 and p. 197.

[12]Agrawal, D. P., Margabandhu, C. and Shekar, N. C., Ancient Copper Workings : Some New ^{14}C Dates, *Indian Journal of History of Science*, **11**, 133–136, 1976.

[13]Shekar, N. C., Antiquity of Mining and Metallurgical Activities at Ambaji etc. in Gujarat and Rajasthan, *Indian Journal of History of Science*, **18**, 176–183, 1983.

[14]*The Statesman*, October 4, 1985, page 5. Recent work by Hegde, K. T. M., Craddock, Paul and Gurjar, Lalit on Zinc Archaeometallurgy at Zawar Mines, Rajasthan.

[15]Ziauddin, Mohd., *Indian Minerals*, **15**, 117–120, 1961.

[16]Hegde, K. T. M., A Model for Understanding Ancient Indian Iron Metallurgy, *Man*, **8**, (3, September 1973), 416–421.

[17]Ball, V., *Economic Geology of India*, pp. 419–433; see also ref. 11, pp. 230–233.

[18]Bose, D. M., Sen, S. N. and Subbarayappa, B. V. (edited), *A Concise History of Science in India*, Indian National Science Academy, New Delhi, 1971; (a) pp. 274–349, (b) p. 41.

[19]Dutta, M. L., Spectrographic Determination of Minor Constituents in Ancient Copper Slag, *Trans. Indian Inst. of Metals*, **35**(5), 487–488, 1982.

[20]Chattopadhyay, P. K., Archaeometallurgical Studies in Indian Sub-continent : A Survey on Metallography of Iron Objects, *Indian Journal of History of Science*, **19**, 361–365, 1984.

[21]Prakash, B. and Igaki, K., Ancient Iron Making in Bastar District, *Indian Journal of History of Science*, **19**, 172–185, 1984.

[22]Partington, J. R., *A Short History of Chemistry*, Macmillan & Co., London, 1939, pp. 32–33.

[23]Hegde, K. T. M., *Personal Communication.*

[24]Neogi, P., *Copper in Ancient India*, Indian Association for Cultivation of Science, Calcutta, 1918.

[25]Bannerji, N. R., *The Iron Age in India*, Munshiram Manoharlal Publishing Co., Delhi, 1965.

[26]Sachau, E. C., *Al-Bīrūnī's India*, 1910, Munshiram Manoharlal Publishers Private Ltd., 1983 reprint; (a) pp. 187–195, (b) pp. 107–114.

[27]Filliozat, J., Al-Bīrūnī and Indian Alchemy, in *Al-Bīrūnī Commemoration Volume*, Calcutta, 1951, pp. 101–105.

[28]Brooke, J. C., Notes on the Zinc Mines of Zawar, *Journal of Asiatic Society Bulletin*, **19**, 212–225, 1850.

[29]Straczek, J. A. and Srikantan, B., The Geology of Zawar Zinc-Lead Area, Rajasthan, *Memoirs of Geological Survey of India*, **92**, 47, 1967.

[30]Gangopadhyay, A., Ramachandran, T. R. and Biswas, A. K., Phase Studies on Zinc Residues of Ancient Indian Origin, *Trans. Indian Inst. of Metals*, **37**, 234–241, 1984.

[31]Rakesh Kumar and Biswas, A. K., Zinc Recovery from Zawar Ancient Siliceous Slag, *Hydrometallurgy*, **15**, 267–280, 1986.

[32]Chattopadhyaya, D. P., *Science and Society in Ancient India*, K. P. Bagchi and Co., Calcutta, 1979.