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There are many disciplines within archaeometallurgy which examines the production, usage, and consumption of metals from about 8000 BCE until the present. However, the scope of this research is limited to mining and metallurgy in the medieval industrial society of Vasantgarh. Many of the main themes of this literature do relate to current debates in anthropology, even though they were not written with an anthropological audience in mind. Besides working on the social construction of technology in capitalist economies at Vasantgarh, ancient archaeometallurgists were also involved in the social construction of technology in the kingdom. The slags and ores collected during the exploration of the Vasantgarh fort site at Sirohi in Rajasthan were studied to understand the available minerals and their characterisation.

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The Archaeometallurgy of Vasantgarh, Sirohi, Rajasthan

Riddhima Saini^α, Priyank Talesara^σ & Aniruddh Bahuguna^ρ

ABSTRACT

There are many disciplines within archaeometallurgy which examines the production, usage, and consumption of metals from about 8000 BCE until the present. However, the scope of this research is limited to mining and metallurgy in the medieval industrial society of Vasantgarh. Many of the main themes of this literature do relate to current debates in anthropology, even though they were not written with an anthropological audience in mind. Besides working on the social construction of technology in capitalist economies at Vasantgarh, ancient archaeometallurgists were also involved in the social construction of technology in the kingdom. The slags and ores collected during the exploration of the Vasantgarh fort site at Sirohi in Rajasthan were studied to understand the available minerals and their characterisation.

In this research, Chemical characterization of the slags and ores was conducted using Gravimetric analysis by vacuum fusion and X-ray spectroscopy; X-ray Fluorescence (XRF) spectrometry analysis to build a complete chemical element level test, which was conducted on a metal sculpture of Pindwara Jain temple, a part of 240 bronze hoard retrieved from the excavation from Vasantgarh. In this study, the presence of Zinc in the sculpture is reported, which is unique in understanding that sculpture hoards are not bronze but are brass that glitters like gold.

Keywords: vasantgarh, copper, zinc, brass hoards, jain sculpture, xrf, medieval, silk-route trade, metallurgy.

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I. INTRODUCTION

The history of world civilization is connected to the tale of the metals in antiquity in various different ways (Sharada Srinivasan, Srinivasa Ranganathan, 2013, p. 2). Mining and metallurgy have played crucial roles in the development of the world in every scenario (David Killick, Thomas Fenn, 2012, p. 560). The text of *Rasaratnakara* of *Nagarjuna* describes the method of production of zinc (Sharada Srinivasan, Srinivasa Ranganathan, 2013, p. 2).

In ancient India, the commonly used eight metals in antiquity are- gold, silver, copper, iron, tin, lead, zinc and mercury (Sharada Srinivasan, Srinivasa Ranganathan, 2013, p. 2). The minerals and metals tradition of India covers a time of over ten thousand years and extends beyond the current national boundaries of the Republic of India (Sharada Srinivasan, Srinivasa Ranganathan, 2013, p. 1).

As per Indian history, Copper was widely used in India from the 3rd to 4th century BCE, as found in the accounts of the Greek ambassador Megasthenes' visit to India in 302 BCE (Aditya Prakash Kanth, Rajdeo Singh, Buddha Rashmi Mani, 2022, p. 226). In our research, we have found significant metal antiquities from Sirohi and copper-ore mines from the site of Vasantgarh. Based on the scientific analysis, we can undoubtedly say that the copper industry of Vasantgarh had trade links with Zaware. Zinc had been popular in India before the common era, around the 4th to 5th century BCE, being the oldest evidence of the Zinc Industry (Kharakwal, 2011).

A great quantity of copper and bronze sculptures found at similar excavation sites are on display in museums or temples, as an evidence of the practice of using copper to produce different implements after extracting it from its ores.

The western state of Rajasthan (Land of Kings) is the largest state of India which can be divided into nine cultural regions; one of the nine regions is the *Godhwar* or *Gorwar* (cradle) treasuring a rich heritage relating to archaeological antiquities and history of Kings, temple art and architecture and large defence structures from our past (Talesara, Priyank; Bahuguna, Aniruddh, 2020, p. 14). The region is located to the southern of Rajasthan state (Robbins, 2011, p. 193). Human habitation flourished in this district between the middle Palaeolithic to Mesolithic age and still continues (Thakar, Chintan; Patel, Punaram; Kharakwal, Jeewan Singh; Talesara, Priyank; 2019, pp. 123, 124). The kingdom of Sirohi, lying in the *Godhwar*, was known as *Arbuda* - Mt. Abu, *Arbudanchala* or Mt. Abu kingdom - in ancient period.

The immemorial history of Rajputana (Rajasthan) was inclined towards business activities, having a greater significance accorded to the *Vaishyas* (trading class) and Jain folks, who controlled the sale and purchase of goods and commerce over communities (Taknet, 2016, p. 30). Due to the trade and role of the Silk-route, the prosperity of this area was glorified amongst the other cities of contemporary time (Talesara, Priyank; Bahuguna, Aniruddh; 2020b, pp. 302,304).

In ancient-time, the site of Vasantgarh which is situated in the Sirohi District of the State Rajasthan was known for its copper mines and Zawar of Udaipur was an important industrial center of Zinc ore in the state. According to the Sun Temple inscription, Vasantgarh was under *Rajila*, the *Gurjara-Pratihara* king (under the feudatory of *Varmalata* of the *Chappa* dynasty) in AD 625. An inscription of AD 1042 also marked Vasantgarh as a province of the *Parmara* king *Purnapala* and later on, the dated inscription of fifteenth-century records the *Guhil* king *Maharana Kumbha* giving *Mandan* (the architect), the charge of re-establishment of a fort (Bhandarkar, 1907, p. 52). Vasantgarh is believed to be the abode of the sage *Vasistha* and there are many archaeological sites in Sirohi, which are connected with the folklore of sage *Vasistha* like *Vasantgarh*, *Vasa*, *Vastanji*, and *Achaleshwar* (Talesara, Priyank; Bahuguna, Aniruddh; Thakar,

Chintan; 2020, pp. 99, 100) ;Today it only has ruins of the fort.

The inscriptions found from this site belong to the 6th to late 15th century AD (Talesara, Priyank; Bahuguna, Aniruddh; Thakar, Chintan; 2021, p. 5). Vasantgarh is also identified as *Basantgarh*, *Vatapura*, *Vata*, *Vatanagar* and *Vatakara* in different literary and epigraphical sources, wherein the term "*Vatakara*" is connected with the word "*Akara*" which means an important centre of mining and smelting (Talesara, Priyank; Bahuguna, Aniruddh; Thakar, Chintan; 2021, p. 6). From this site 240 Jain bronze idols were found in the excavation which justifies the importance of the copper industrial workshop & also suggests that the site was well known for its trade & commerce, manufacturing large numbers of bronze idols (Talesara, Priyank; Bahuguna, Aniruddh; Thakar, Chintan; 2021, p. 5). The inscription of Samoli (A.D. 646) is inscribed in the *Kutila* script using the Sanskrit language and informs us that - During the time of king *Siladitya*^{1*}, a group of *Mahajana* community (caravan of merchants) headed by *Jentaka* who had migrated from *Vatanagara*^{2*}, started mining at *Aranyakupagiri*^{3*} for livelihood (Halder, 1933, p. 97). In the next line it is mentioned that *Mahattara Jentaka*, at the command of *Mahajana*, found the temple (*Devakula*) of *Aranyavasini* (goddess *Durga*), who was noted for her eighteen *Vaitalikas* (bards), hailing from different parts of the country and was always crowded with moneyed and wealthy people (Halder, 1933, p. 97). In AD 1452, the fortified city was under *Maharana Kumbha* but was later captured by the *Deora-Chauhan* King, *Rao Lakha* with the help of King Qutubudin of Gujarat (Talesara, Priyank; Bahuguna, Aniruddh; Thakar, Chintan; 2021, p. 5). Vasantgarh has a similarity with the exquisite artistic beauty like that of the

¹ * Siladitya – Most of the scholars identified King Siladitya as belonging to the Guhil dynasty, whereas few scholars believe Siladitya VI of Valabhipura.

² * Vatnagara- It is the name of a place. Vatnagara is identified as copper smelting area of 'Vasantgarh' of Sirohi district.

³ * Aranyakupagiri- Scholars believe it to be the name of the place of smelting & mining zone of Vasantgarh, mines of copper or Zawar mines of Zinc.

sculptures of Akota bronze of Gujarat (P.shah, 1959, p. 1).

Our team tried to explore Vasantgarh, the ancient fort site of Sirohi. This research paper deals with the archaeo-metallurgical analysis of antiquities found during the field survey of the site Vasantgarh.

The area has not been geologically surveyed at the time, but we can say that there are numerous quarries near Abu and other places. Marble can be found near the ancient *Puskar tirthas*, as well as between *Utraj & Sheragaon* on Abu hill (Lala Sita, 1920, p. 13). It is an accepted fact that the celebrated Jain temples of Dilwara were somewhat fabricated of marble extracted from these quarries (Lala Sita, 1920, p. 13). The marble mines are also found on the hill of Achalgarh, named *Vansvalla*, and even good quality marble is also found at *Saliwara*, to the west of *Anadra*, *Serua* and *Perua*. Other minerals such as mica mines and arsenic, antimony, alum, sulphur, silver, copper and lead are available in several areas but in limited quantity. Quarry of gold was accounted in some ferruginous belt of quartzose schist close by the Rohera rail line stop in the year 1897 (Dhoundiyal, 1967, p. 17). The geomorphic study of *Godhwar* shows that the hills are highly eroded granite remnants of Precambrian uplift and divide the humid southeast from the arid northwest of the state (Robbins, 2011, p. 193).

The Aravallis besides bearing the flag for the oldest mountain range, is a twisted belt of the Proterozoic period entangled with the Archaean craton and it begins as a part of the state's eastern border.

For this research study - before field exploration- we gathered quantitative data from the archaeology and geography library. One of the important points jotted from the quantitative data is that around 1956 the local site of Vasantgarh was excavated for treasure-purpose - as per details from the ancient ruined Jain temple of *Shantinath*- in the vicinity of which were unearthed 240 bronze hoards of Jain idols, which were gifted to Pindwara Jain Temple (Shah, 1956, p. 55).

Apart from understanding the medieval metallurgy, the main aim and objective of this research is to lionize and exalt the grandeur and significance of the ancient industrial heritage of the site and to endorse to the administration and government, awakening them to acknowledge and safeguard the site from the unfaltering expansion and destruction due to modern mining and industrial activities.

II. METHODOLOGY

For the purpose of our goals and research, we have done an archaeological inquiry, which involved gathering quantitative data and also several field explorations of previously explored sites to discover new findings related to our subject. To determine the dates of the cities, the inscriptions were chronologically studied, various artifacts were collected for relative dating and finally concluded on the basis of observations related to the material culture of these cities, like- the brick size and the evolution of art and architecture. The information was further amalgamated with the discussions and interview of local people and conversations with an eminent historian. For a better understanding, we have used advanced technological applications such as QGIS, Google Earth Pro, Bing Map, Map-Hill and Measure Map software and other Geospatial applications which helped us generate quantitative data related to GIS studies, GPS location of the site, tracing geo-coordinates of sites and tracing MSL data of the sites.

The quantitative lab analysis method is used for archaeo-metallurgical tests; for metal element level testing XRJ laser Fisher SD 515 Advance Energy dispersive via X-ray fluorescence analysis measuring instrument (EDXRF), is used, to analyze precious metals and their alloys in composition and coating thickness; Petrographic examinations and Radical Titration methods with Ethylenediaminetetraacetic acid (EDTA) and redox reactions to establish the nature and composition of materials in a controlled environment of Analyst India Laboratory. The slags and ores collected during the exploration of the Vasantgarh fort site at Sirohi in Rajasthan were studied to understand the available minerals and

characterization of raw ores and the slags. In this research, Chemical characterization of the slags and ores was conducted using Gravimetric analysis by vacuum fusion and X-ray spectroscopy.

For the qualitative purpose, we have collected the data from the library of, “Sahitya Sansthan Shodh Pustakalya, Udaipur”, the Library of “University of Rajasthan, Jaipur”, and other important online archives. Toposheets from “Survey of India” were used for help in the Pedestrian Survey of site location.

III. FINDINGS AND RESULTS

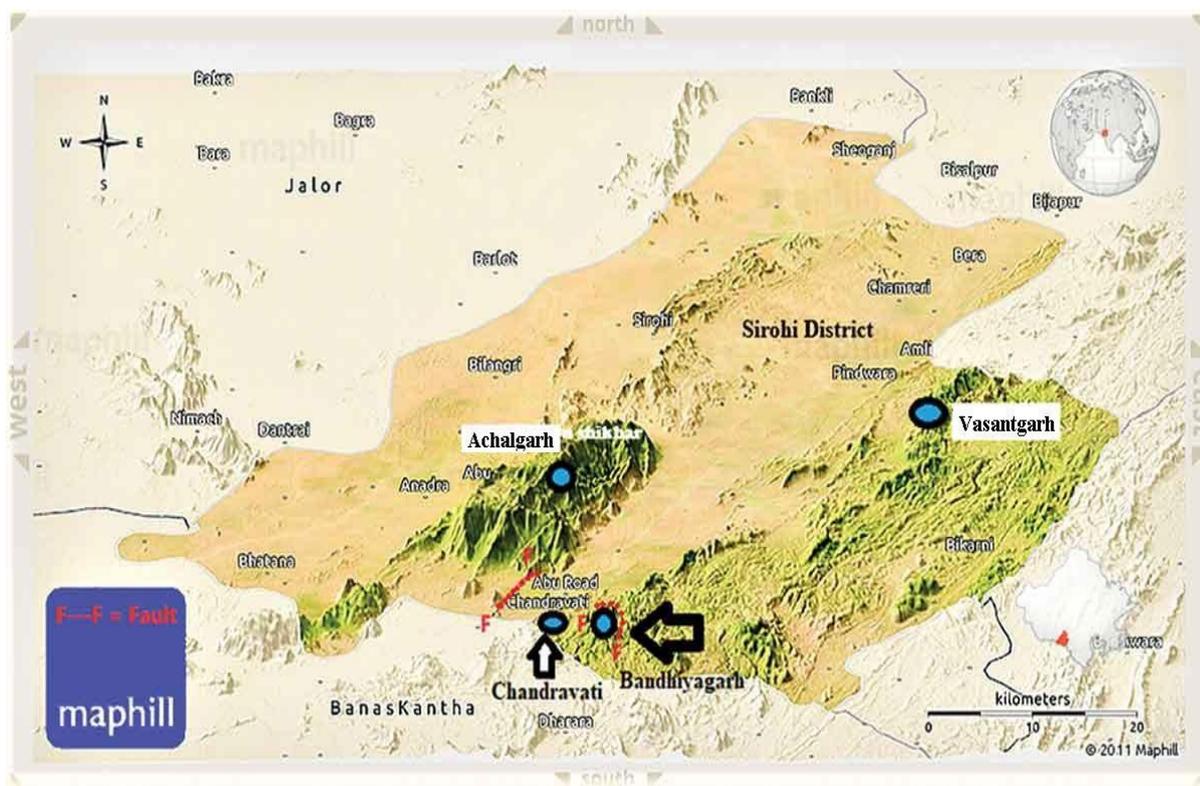


Figure 1: Topographical map of Sirohi District Showing Vasantgarh and other important locations

During the exploration, some slags and ores samples were collected to understand the archaeological data related to metallurgy. The inspection also yielded several sites of stony waste dumps that are also mentioned in the toposheet no G43T2 of the Survey of India indicating ancient mining activity. From the ancient times, *Mata* Temple of Hindu Goddesses are a common feature to be found around or nearby the mines symbolizing the goddess as the deity for safety during mining. In an interview with the priest of the *Ambaji* Temple, it came to light that the sculpture installed in the modern temple, was actually a part of an old mine, and was rescued by the local people who filled up the mine because of

the risk of people, especially children falling inside.

All the slag activities and ore dumps are found near the West Banas River and the supporting tributaries, one site near *Khimel/Khimaj Mata* Temple, and several sites around *Ambaji* Temple. Some inactive modern mines are also found near the *Ambaji* Temple.



Figure 2: (A) Showing Chalcopyrite Sulphite ores of Copper, (B) Showing Malachite Carbonate Ore of Copper.

The Concentrated minerals of copper are broadly divided into sulphite, oxide, carbonate and copper silicate. The action of oxygen and water into oxides, carbonates and sulphites, is also conducive to smelting in pyrometallurgy (Kumar, 2021, p. 52). Such minerals bear eye-catching

colors during the course of oxidation as the Brass Yellow color shown in Fig 2 (A) is Sulphite of Chalcopyrite having CU (Copper) 34.5% approx and the bright greenish color Shown in Fig 2 (B) is Carbonate of Malachite having CU (Copper) 57.3 % approximate.

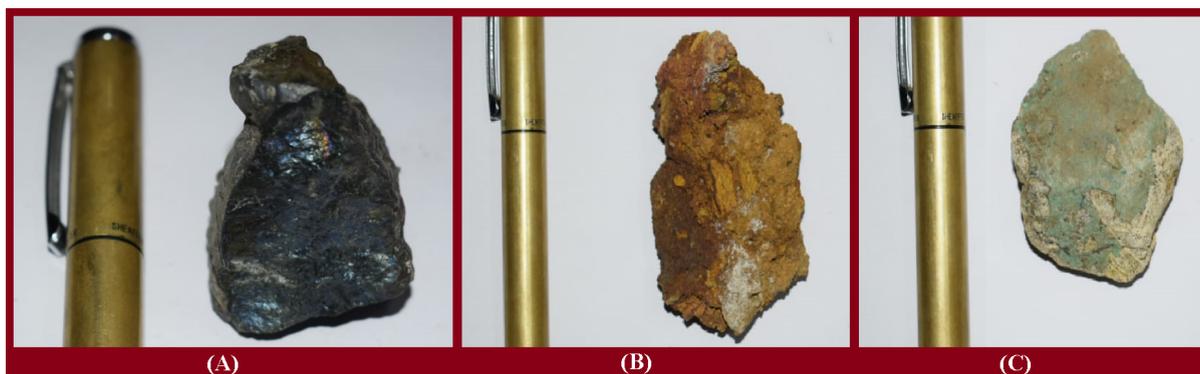


Figure 3: (A) Glassy Slag, (B) & (C) Ore Samples

One collected lump of slag was fine-grained, homogeneous and glassy in appearance. Because of the slag's dark color and glass-like appearance, it was slowly cooled in the open air and possessed a high specific gravity. Slag lumps like this one represent the first layer of slag produced during the smelting process. Fe and Si from 2FeO might have separated due to the high Ca concentration in granulated slag. CaO may also have increased the slag viscosity due to the greater amount of insoluble solids present, resulting in a better slag reduction at high temperatures, but higher Ca has

been shown to reduce slag viscosity at high temperatures.

Other was rising micro bubbles caused matte entrainment in the slag by moving matte droplets onto the slag's surface. The matte entrainment due to the rising gas bubbles depends on two things: first the larger bubble buoyancy force than the matte droplet drag force, and then the thickness of the matte film. It is the bubble buoyancy force that lifts the matte droplets (Cheng X, Cui Z, Contreras L, et al, 2019). The above statement is presented in the equation below:

$$\frac{d_g}{d_{matte}} = \sqrt[3]{\frac{V_g}{V_{matte}}} > \sqrt[3]{\frac{\rho_{matte} - \rho_{slag}}{\rho_{slag}}}$$

(V_g and V_{matte} = the bubble and matte volumes; d_g and d_{matte} = the gas bubble and matte droplet diameters; ρ_{matte} and ρ_{slag} = matte and slag densities).

Since both bottom-blown and side-blown techniques were used in ancient Indian smelting

techniques, likely, the matte was mechanically entrained from the smelting furnace.

The above-mentioned process of sulphur dioxide micro-bubble generation in settlement zone during matte phase is presented below:



Below, gravimetric analysis by fusion methods, shows that most of the eye-catching bright color materials have copper traces; possibly the ancient copper mines exhausted from the upper accessible layers of that time. Also found traces of Aluminium oxide and Titanium in bright yellow Chalcopyrite material. The LOI in the table below is Lost in Ignition, one surprising ore of Iron is

found, but the geology department has never reported iron from this area, so possibly, it travelled from other sites, as many other elements found in the XRF test of sculpture justify commercial trading of other elements from different part of the country as early as 7th century AD, which is also confirmed from the Samoli Inscription.

Table 1: Gravimetric Results of Samples taken from Site, Figures in Percent, BDL is below detection level

Sample Number	Type	SiO ₂	CaO	Mg O	Fe ₂ O ₃	Al ₂ O ₃	LOI	Mn O ₂	CaC O ₃	MgC O ₃	CU	TiO ₂	Na ₂ O	K ₂ O
284/A/2022	Red Ochre	65.25	0.72	0.20	25.00	1.80	6.63	0.05						
284/B/2022	Slag	37.02	0.20	0.30	47.40	0.50	BDL	14.00						
284/C/2022	Slag	9.48	48.72	1.10	0.68	0.20	39.40							
284/C/2023	Slag						11		87.00	2.31	0.05			
1363/A/2022	Brass Yellow	78.04	1.20	0.20	11.90	4.70	3.6				0.05	<0.01	0.10	0.10
1363/B/2022	Green Stone	5.26	50.90	1.30	0.55	0.12	41.40			2.73	0.05		0.12	0.10

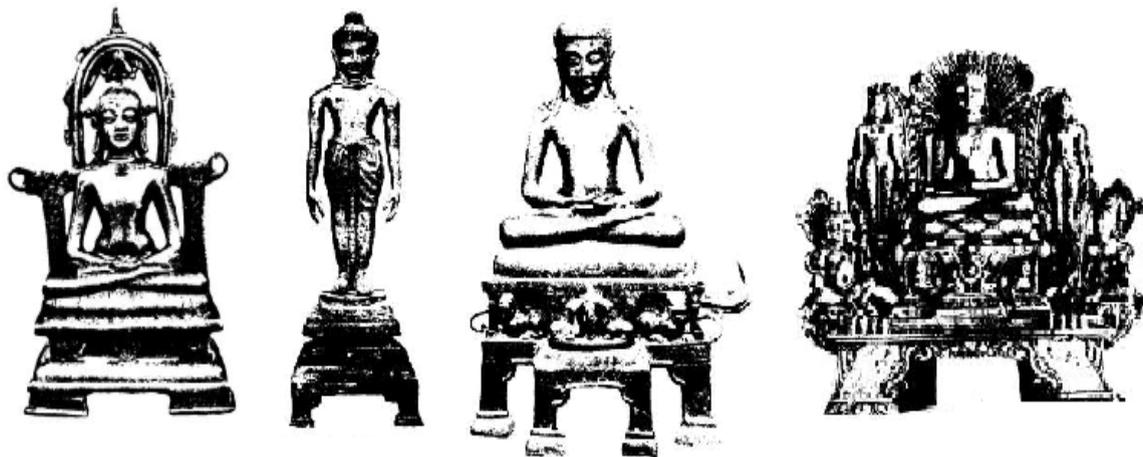


Figure 4: Photography is prohibited in Jain Temple. Here are some sketches of samples of Sculptures found in the excavation from Vasantgarh

The bronze sculpture art of Vasantgarh uses one of the most important ancient techniques called the Lost Wax method. The other important metal joining processes are subject to a more profound archaeometallurgical research, ie. Riveting, brazing, brazing flux, welding and soldering. The Vasantgarh school of art is connected with the industrial production of Metal sculptures that glitters like gold, which is evident from 240 metal sculptures recovered from the unauthorized excavation. All recovered sculptures are related to Jainism (Merchant class floks), this also shows that the region had a prosperous trade and commerce, which is why the city was designed defensively and is consistent with the number of forts and watch-towers to keep the kingdom safe from robbers and other hostile kingdoms.

XRJ laser Fisher SD 515 Advance Energy dispersive via X-ray fluorescence analysis is used to analyze a Lord Parashvnath Jain Trithankar

sculpture from Vasantgarh Hoards. We had to perform two different tests for this sculpture because other than the main body there are several riveting metal points pasted to beautify the sculpture and these minor riveting metals are precious and rare in nature.

A combination of Zinc and Copper found in the main body is the major reason that their sculptures shine like gold; Gold and Irridium rare and precious trace metals which are also present in the beautification features. The available Zinc surely belongs to the ancient Zawar Mines of Udaipur, and Copper is natively available in Malachite and Chalcopyrite forms of Carbonate and Sulphide. Silver with other trace elements is present on the eyes, serpent hood ring, kite on chest and Padma seat, this Silver source is still a question mark and other trace elements are possibly accidentally mixed in the smelting process.

Table 2: XRF result of Metal Sculpture from Vasantgarh School of Art, Value in Percent

Sculpture Part	Siver	Copper	Zinc	Nickel	Iron	Lead			
Main Part	0.103	87.64	10.63	0.08 9	0.606	0.931			
	Gold	Silver	Copper	Zinc	Nickel	Lead	Irridium	Cadmium	Iron
Additional Riveting pieces	0.737	84.52	13.17	0.722	0.224	0.528	0.104	0.201	0.226

In addition, an intriguing petroglyph was found at the high valley on the left side of the main fort. The medieval carving of the face of a warrior (See Fig 5) is possibly carved through a very strong and sharp iron object that shows their expertise in

metallurgy to make weapons. Iron ore present in dumps confirm that they were not only expert in sculpting but also making weapons for war and other utilities.



Figure 5: Petroglyph of Warrior Face carved on Green schists stone

IV. CONCLUSION

Analytical results clearly indicates to the reducing conditions in the smelting process, since dominant mineral phases are present in the sample. Furthermore, the presence of iron in higher concentrations confirmed the existence of a reducing atmosphere. By the gravimetric analytic method, calcium in higher concentration was detected in the granulated slag, which showed a dolomite structure. Based on the EDTA Radical test results, copper has a very low weight percentage in slag, indicating a very strong ancient smelting process pointing towards a highly efficient extraction process. Silica appears to have been used as a fluxing material along with a glassy phase in the slag as a result of the flux, which may have been helpful in efficiently separating the copper from the slag. The slag test also represents the presence of some other metals and minerals such as aluminium, titanium, etc. The slag was also cooled slowly, which made it impossible to recover iron.

The presence of Zinc in the XRF test on sculpture shows that sculptures are Brass hoards, not Bronze hoards as coined by previous scholars and

in comparison to Akota Bronze. The riveting of different metals of varying melting points is still very difficult with modern science, and the fine soldering is subject to a deep metallurgical research in this field.

Conflict of Interest Statement

The authors state that there is no conflict of interest.

Ethical Approval

The data used for the estimates do not include confidential information about individuals or communities that may raise ethical concerns.

Consent for Publication

The authors grant consent for the publication of this paper.

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Data Availability Statement

The data used in this paper is fully available and can be accessed upon request.

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