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Indigenous Glass Manufacture in India: An Ethnographic Approach

Alok Kumar Kanungo and Laure Dussubieux

The production of glass was a major technological development in the ancient world. It required vast knowledge of pyrotechnology and engineering to build furnaces, to maintain the furnace temperature for weeks, and to be able to mix the correct proportions of raw materials. Archaeologists have spent considerable time and energy investigating ancient crafts to understand ancient communities.

The antiquity of glass in India is 3,500 years. Indian glass beads and bangles have been major exports all over the Indian Ocean and beyond for more than 2,500 years. The bulk of the glass available in India was primarily produced from Indian indigenous glass. Although different recipes were certainly used, the major raw material for this glass, called *reh*, was locally available. The furnace for the melting of *reh* was developed indigenously and the pyrotechnology involved is an important component of ancient Indian knowledge. The traditional production of *reh* glass was abandoned by the end of the twentieth century. This mode of glass production was certainly very ancient and could have been used even before the beginning of the Common Era.

This paper attempts to ethnographically document the production mode of indigenous Indian glass in western Uttar Pradesh, with comparisons to archaeological data. The paper also evaluates the ethnohistorical data based on scientific analyses.

THE EVIDENCE of glass in Indian archaeology is both temporally and spatially widespread. The discovery of glass from as many as 34 sites in association with Painted Grey Ware and the Megalithic culture during the Iron Age (1200–600 BCE) clearly suggests that glass was locally known to Indians before Roman contact and could have been an indigenous innovation. Subsequently, an increasing number

of sites with the presence of glass were identified, with 40 sites belonging to the Northern Black Polished Ware culture (600–300 BCE) and 135 sites dating from the beginning of the early historic phase, particularly from the early centuries CE, suggesting a large-scale glass use and production at that time. Evidence of glass has also been found at 85 early medieval (400–1300 CE) sites and 58 late medieval (1300–1800 CE) sites.

Acknowledgments. The first author acknowledges the Indian National Trust for Art and Cultural Heritage (INTACH) Research Grant (Indian Citizen) 2016 for the project “Mapping Purdampur: The Final Stage of One of the Most Predominant Glass Bead Industry of the World,” which led to this paper. We also acknowledge the National Science Foundation project “Reconstruction of Manufacturing Patterns through Elemental and Isotopic Characterization of Raw Materials,” during fieldwork for which we were able to revisit Purdilnagar-Susamayee-Jalesar-Akrabad (PSJA) and enrich our understanding. We are indebted to Shri Ashok Gupta for letting us use his good offices and

contacts for the local hospitality in the field. Our heartfelt thanks to all glass craftspeople of the PSJA villages where we carried out fieldwork, for their readiness to provide ethnographic information and their interest in our work. We are grateful to Drs. Trupti More and Mudit Trivedi for quickly making available the cited colonial literatures; to Scott Staszak for his help with the English; to Chinmay Kulkarni for help with the map; to Drs. Vikas Kumar and Oishi Roy for their review of the paper. Discussion over the years with Dr. Shahida Ansari has broadened generally the ethnographic insights which are the basis of the paper.

During the latter periods, glass was commonly used for utensils, decorations, and other daily activities.¹

We have little information about the method of glassmaking in ancient India. There are few mentions in ancient literature about the people involved, techniques, tools, furnaces, and trading of the product. No excavation reports have discussed the glass manufacturing techniques and no site has yielded any tools used for glass production.

Ancient Indian texts have not described furnace construction for glassmaking and/or glassworking; neither the details about the recipes for producing glass nor the different compositional elements required for varied colors has been provided. However, there are numerous references to the use of glass products in different social contexts. The existence of glass and glassmakers are cited in some great Indian texts such as *Māhabhārata* and *Rāmāyaṇa*. Starting from the twelfth century BCE, the ancient Indian texts (from *Yajurveda* to *Arthaśāstra* through *Brāhmaṇa*, *Sūtras*, *Samhitās*, and *Vinaya Piṭaka*) categorize glass as a luxury item; this continued until about the third century BCE, when it had become a popular mercantile commodity.²

Ethnographic research has established that there was a very specific way glass was produced in India. A substance called *reh* is used in single-ingredient glass recipes. It is a silica-rich soil, containing a natural mix of immature sand with high alumina concentrations and a sodic efflorescence that produces a vitreous material when heated in a glass furnace.³

For this article we focused our attention on clues to understanding ancient indigenous glassmaking found in archaeological evidence of ancient furnaces, on information reported in the colonial literature, and on the knowledge of living craftspeople in western Uttar Pradesh who formerly practiced this production technique. Chemical analysis of recently produced native glass adds to the story from ancient craftspeople and provides additional information about glassmaking.

ANCIENT FURNACES IN THE ARCHAEOLOGICAL RECORDS

Information on glass furnaces in ancient India is meager. Only seven excavated sites have produced evidence of glass furnaces: Kopia and Sarethi in Uttar Pradesh; Porunthal, Karaikadu (also known as Kudikadu), and Padavedu in Tamil Nadu; Karakambadi in Andhra Pradesh; and Nevasa in Maharashtra (Fig. 1).

Kopia (26° 52' N, 83° 4' 45" E) is located in the Sant Kabir Nagar district of Uttar Pradesh. At Locality II a glassworking furnace (made of clay) was unearthed, dating to the first century BCE/CE (Fig. 2a). The diameter of the excavated furnace is 1.35 m at its outer periphery, 1.10 m at its inner periphery, and 80 cm at the bottom. The height of the surviving part of the furnace is 65 cm. Its upper portion was possibly dome shaped.⁴ Innumerable pieces of glass, glass slag, tuyeres, and crucible fragments with molten glass adhering to them were recovered in a stratified context (Fig. 3). Although glass beads with the same chemical composition as glassworking remains are found in Locality I layers dated from the fifth century BCE to 200 CE, no evidence suggests that glass production happened at Kopia prior to the first century BCE.⁵ Discoveries of Kopia glass in Southeast Asia in general and at the sites of Khao Sam Kaeo and Khao Sek, Thailand, in particular, dating back to the fourth to second century BCE, suggest an earlier production.⁶

Sarethi (26° 44' 19" N, 82° 12' 45" E) is located in the Faizabad district of Uttar Pradesh. A glassmaking furnace was found from period II (dated to 200 BCE–300 CE). The inner portion of the furnace was well burnt (Fig. 2b). The area was strewn with slags, charcoal, and ash. A good

1. Kanungo 2016, 3–8, and references therein.

2. Dikshit 1964–1965; Engle 1976; Govind 1970; Kanungo 2008; Singh 1989, 235.

3. Brill 2003; Gill 2017; Kock and Sode 1995.

4. Kanungo 2013, 445.

5. Kanungo and Brill 2009; Kanungo and others 2010; Kanungo 2013.

6. Dussubieux and Bellina 2017.



FIG. 1. Evidence of ancient glass-furnace and glass-working (bead-producing) sites, and indigenous glass furnaces in present-day India. (Map: Alok Kanungo)

number of glass beads and bangles were also found at the site.⁷

At Porunthal (10° 22' 58" N, 77° 28' 38" E) in the Dindigul district of Tamil Nadu,⁸ an oval-shaped glassworking furnace was unearthed (first century CE) on a 20 cm-thick hard floor made of gravel mixed with lime. The furnace was crumbled on the inside. Two probable bellows holes, a number of tuyeres, and a flat stone were noticed. On the southern end of the furnace, the base of a 0.3 m thick wall was found,

7. Singh and others 2018, 69.

8. Rajan and others 2013.



FIG. 2. Remains of glass furnaces: (a) Kopia, (b) Sarethi, (c) Porunthal, (d) Karakambadi. (Photos: [a, d] Alok Kanungo; [b] courtesy Pushp Lata Singh, Banaras Hindu University; [c] courtesy K. Rajan, Pondicherry University)



FIG. 3. Remains from Kopia: (from top, rows 1–3) glass pieces, (row 4) tuyeres, (row 5) crucibles. (Photos: Alok Kanungo)

which probably regulated the natural air flow (Fig. 2c). Several smoothened triangular terracotta pieces were found, which could have been used as polishers or encrustation removers. The size of the postholes around the furnace suggests that perhaps a few poles supported a large roof. The mound that yielded this evidence is known as *Paci-medu*, which locally means “bead mound,” and has yielded more than 2,000 Indo-Pacific glass beads, out of which 60 were found in the furnace.

Karaikadu (10° 35' 18" N, 79° 15' 50" E), in the South Arcot district, was initially excavated by the Southern Circle of Archaeological Survey of India in 1966 and later by the University of Madras in 1989, each time under the supervision of Kunnavakkam V. Raman.⁹ The early historic level (dated to the first century BCE/CE) has revealed four glassmaking/glassworking furnaces. The inference that “[t]he occurrence of a large number of finished as well as unfinished glass beads, together with an equally large quantity of shapeless vitreous slags, indicated local manufacture of glass for making beads”¹⁰ was proved right during the 1989 excavation, when two trenches (KDU I and KDU II) revealed four furnaces. In trench KDU I, three furnaces were found. Furnace 1 was built of mud, and it had evidence of glass slag. Furnace 2 was made of brick fragments and pottery. It was 0.6 m long and 0.4 m wide and was rectangular in shape. Furnace 3 had a mouth on the top with a diameter of 0.3 m, and it most likely produced glass beads. It was 1 m long and 0.16 m deep. The fourth furnace in Trench KDU II was 0.7 m in diameter and 0.16 m deep. Glass manufacturing activities probably continued in the medieval period at this site.¹¹

At Padavedu (12° 39' 36" N, 79° 6' 45.36" E), Tiruvannamalai District, Tamil Nadu, blow-pipes and crucibles for glassmaking were found in levels dated to the thirteenth to fourteenth century CE.¹²

At Karakambadi (13° 39.6' N, 79° 30.5' E), Chittoor District, Andhra Pradesh, a portion of a furnace with in-situ crucibles, tuyeres, and

glass chunks was found. The findings were dated to the fourth to fifth century CE on the basis of associated pottery finds (Fig. 2d).¹³

Nevasa (19° 34' N, 74° 54' E) is located in the Ahmednagar district of Maharashtra. A glass-making furnace dated to the third to fourth century CE was unearthed.¹⁴ It was a circular furnace, 0.75 m in diameter and 48 cm deep, and was made of burnt clay. Bichrome glass, slag, lime, cow dung, etc., were found in abundance around it.¹⁵ At one of the points near the periphery, there was a channeled projection, which was evidently used for inserting the pipe for the bellows.¹⁶

COLONIAL LITERATURE

More information about glassmaking is available in the colonial literature, including British government accounts of glass industries in India from the nineteenth century.¹⁷ Moreshwar Dikshit observed that through these documents, the British Government tried to investigate the indigenous methods of glass manufacturing in India with the objective of determining whether foreign goods could be introduced in the Indian market to oust local production.¹⁸ This approach of the empire did succeed, and the glassmakers and glassworkers of India were marginalized. However, local mastery in the art of making indigenous glass beads and bangles, and centuries of end-users' association with and attachment to the indigenous product, allowed the glass crafts to survive unchanged in certain corners of the country. Unfortunately, what the British administration could not achieve, independent India

9. Raman 1991.

10. IAR 1966–1967, 21.

11. Selvakumar 2021.

12. IAR 1993–1994, 98.

13. Kanungo 2003.

14. Sankalia and others 1960.

15. Dikshit 1969.

16. Deo 2000, 11.

17. Hallifax 1892; Dobbs 1895; Mukharji 1895; Government of Central Provinces 1895.

18. Dikshit 1969.

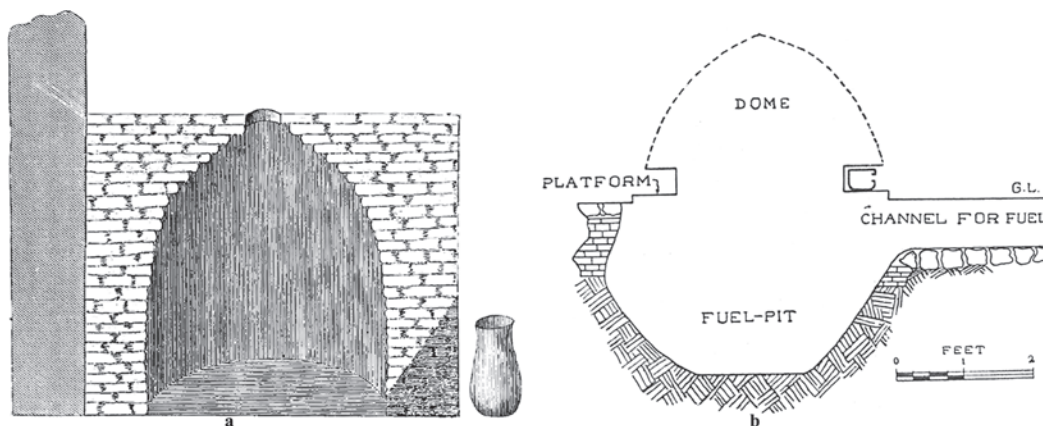


FIG. 4. Glass furnaces: (a) Seringapatam, (b) Asre. (Drawings: [a] from Buchanan 1807, 2:459, plate 33, fig. 81; [b] from Dikshit 1969, 144, fig. 25)

did accomplish in quick time by not protecting the interests of the Indian crafts. This led to the closure of all remaining indigenous glassmaking workshops by the end of the twentieth century.

Furnaces

The colonial literature shows that technology and recipes varied across the country. One of the earlier details about indigenous production of glass in India comes from South India,¹⁹ recording that the preparation of *reh*, the prime raw material for glass, was conducted in the villages of Chenapatna²⁰ and Seringapatam.²¹ At both locations, the prepared *reh* was mixed with quartz sands and melted in crucibles placed in a furnace to produce glass.

At Seringapatam, the furnace was built on a high terrace against the inside of the town wall. It was dome shaped with a diameter of 2.5 m and a height of 3 m. The dome of the furnace was constructed by stacking rows of stone in circles of decreasing diameter, leaving a hole about 45 cm in diameter on top (Fig. 4a). On the side opposite the town wall, at the base of the furnace, the fuel (one-year-old sticks and burning coal) could be introduced through a small aperture. Oblong crucibles with a 4.6 L capacity were filled with raw materials before being lowered

into the furnace through the hole at the top. Workmen used the same aperture to get into the furnace. Crucibles were placed in rows around the furnace, with their bottoms to the wall and their mouths sloping inward. They were then covered with clay so that they could stay in place, leaving only their open mouths exposed. Four rows of crucibles were stacked on top of each other. Depending on the size of the furnace, 50 to 100 crucibles were used simultaneously. Fuel was added night and day until full vitrification of the content of the crucibles. After a cooling period, the workmen would remove the crucibles from the furnace through its top aperture and would break the crucibles to expose their content, which would be melted again with colorant in order to obtain black, green, red, blue, and yellow glasses.²²

The furnaces at Chenapatna are slightly different. They are long, measuring 4 by 2 m, and they are 2 m high. They are arched with a round opening on top with a diameter of 65 cm. A stone with an aperture covers this opening, and

19. Buchanan 1807, vols. 1 and 3.

20. Buchanan 1807, 1:150–151.

21. Buchanan 1807, 3:371–373.

22. Buchanan 1807, 3:371–373.

a platform inside the furnace creates a space for the fuel at the bottom. Crucibles are introduced into the furnace through the top opening and placed in a circle on the platform. The opening is then covered with the stone and moist clay, leaving the hole open. Wood is used as fuel and the process takes eight to nine days.²³

The discovery of stacked crucibles in layers with their mouths sloping inward at a late medieval glass furnace at Karkambadi in the Chittoor district of Andhra Pradesh,²⁴ in South India, appears to have striking similarity to the description given by Buchanan.²⁵

Henry Dobbs described very different furnaces where the glass is produced without the need of a crucible. In Aligarh and Bulandshahr, furnaces were built from sun-dried brick, in the shape of a cone “with a semi-circular section taken out of it.”²⁶ The furnace was approximately 2 m high, and its base was 0.9 m below the surface of the ground. Its diameter was 3.6–4 m. Inside the furnace, at ground level, a clay flooring created two compartments: at the lower level was the “furnace” (firing chamber?) and the *reh* was placed above. The fuel was stored in a pit in front of the furnace, right below the stokehole. Another aperture was used to clean the ashes into an ash pit. Opposite the stokehole, also at ground level, was an aperture for introducing the *reh* into the furnace. Two smaller openings on each side of this aperture allowed workers to watch and stir the *reh*. These three holes were covered while the fusing was in progress. Air circulation was insured through four additional holes, three around the dome and one on top.

In Mainpuri, Etawah, Rae Bareli, and Feyzabad, furnaces were different and only had one chamber. They consisted of a dome made of clay with a diameter of 6 m and height of 2.5 m. The fire burned in the center and was surrounded along the walls inside the dome by pits or earthenware vessels connected to each other by channels, in which the *reh* would be fused. The *reh* was melted in some of the pits and was then channeled to adjacent ones for cooling.

Raw Material

In general, the literature mentions the use of *reh* or sodic soils as the only ingredient necessary to melt glass. Depending on the region, *reh* is also called *usar*, *kalar*, and *oos*, which are terms designating either the efflorescence itself or the sodic-rich soil. *Reh* is the most common term and is why we are using it here. Generally, *reh* is a soil efflorescence containing large amounts of sodium salts (carbonate, bicarbonate, and sulphate) and varying proportions of calcium and magnesium salts. It is usually seen as a disadvantageous occurrence as it results in soil that is unsuitable for agriculture. It occurs in areas where rivers draining mountains contain dissolved salts that percolate through the subsoil until saturation. Rains dissolve these salts, which travel upward through the soil during the dry season by capillary action and form white efflorescence on the surface.²⁷ They are present in arid or semi-arid regions and can be exacerbated by poor irrigation methods and poor drainage, which accelerate water logging and salt accumulation in soil.

James Mill’s “rude glass” was made in a manner unique to India.²⁸ This “country glass” was made from gathering soil encrustation after the rains. The encrustation often contains enough silica to avoid adding any sand. It was fired for a couple of weeks, producing a bubbly, semi-translucent green or black glass, colored by the carbonization of goat dung added to the batch. The glass could be used directly or could be refined by being crushed, colorizers added, and fired again, driving out the bubbles and producing a fine glass.

23. Buchanan 1807, 1:150–151.

24. Kanungo 2003.

25. Buchanan 1807, vols. 1 and 3.

26. Dobbs 1895.

27. Wadia 1975, 489, 501, 502.

28. Mill 1826.

Edward Balfour indicates that “wherever *reh* occurs over clean sandy soil, there is naturally formed a mixture of sand and alkali, which fuses into coarse lumps of bottle-green glass.”²⁹ Elsewhere he describes how glass is made in the Bihar (Bihar) district:

The efflorescence of the soil [. . .] is collected and thrown in a cistern lined with clay. This is then filled with water, which is afterward allowed to evaporate. When dry the bottom of the cistern is found covered with a thick saline crust [. . .]. This soda makes glass without any addition as it still contains a sufficient portion of siliceous matter.

The Administration Report number 480G of 1882, Department of Agriculture and Commerce, North-Western Provinces and Oudh, describes “the native fashion” in the Aligarh and Etah districts, Uttar Pradesh, of producing glass by loading a closed furnace with *reh* soil. After eight days, a colored glass full of bubbles and impurity is obtained. Rogers, referring to glass manufactured in Gujarat, wrote: “Glass is already made at Kapparvanj (present-day Kapadvanj), in the Thásra Talúka, in Kaira, from a surface efflorescence of carbonate of soda and the silica with which it is mixed, but as the materials are crude and impure, the glass produced is naturally very coarse and bad. It is used mostly for women’s bangles and rough glass and bottles.”³⁰ In southern Andhra Pradesh, “the soil mixed with the soda is found to supply the necessary amount of quartz” for the manufacture of glass.³¹ Such a traditional method of manufacturing glass was in practice until recently; Jan Kock and Torben Sode describe how the bead-makers in the village of Purdilnagar “just had to dig” a sandy ground with a high natural sodium carbonate content “to get their raw material.”³² The same raw material was used by the glass workshops in Firozabad, located a few kilometers south from Purdilnagar.³³

Both Dobbs³⁴ and Dikshit³⁵ have recorded that the most frequently used chief ingredient in the local industry is *reh*. Dobbs described the

production of *reh* in what is now western Uttar Pradesh, in plots of land divided in shallow tanks by small ledges of mud that are then flooded. The water evaporates, bringing to the surface saline efflorescence that is then scraped off and stored for future use. An alternate technique to collect raw materials for glassmaking consists of forming small heaps of *reh* soils surrounded by a low wall of dirt. Water is added to the heaps. After evaporation, the pure *reh* that migrated at the surface is collected and rolled into balls. Dikshit more or less echoes the opinion of Dobbs and adds that the soda contained in the soil is gathered after four to five days in the form of flakes of an encrustation called *papri*. These flakes are turned into balls and stored in a place called *reh-ka-bata* to be used as raw material to produce glass.

Additional Information about Traditional Glassmaking throughout India

Moreswar Dikshit, while describing the glass industries in Maharashtra, referred to the glass furnace at Asre (see Figure 4b) in the Kolaba district, which worked for 200 years but closed down in 1945 because it could not compete with the glass products of Firozabad.³⁶

Trailokya Mukharji found very little evidence of traditional glassmaking and sparse evidence of glassworking in Bengal.³⁷ At places in Calcutta, perfumery bottles, kerosene lamps, ink-bottles, and bangles were made from the recycling of broken glass.

In Bihar, green glass was produced from Son River sand mixed with carbonate of soda. At

29. Balfour 1871, 331.

30. Rogers 1900, 584.

31. Cox and Stuart 1894–1895, 165.

32. Kock and Sode 1995.

33. Kock and Sode 1995; Brill 2003.

34. Dobbs 1895.

35. Dikshit 1969.

36. Dikshit 1969, 142–144.

37. Mukharji 1895, 10–11.

Bhagalpur, a coarse black glass (primarily used in the manufacture of glass bangles) was made of *khari*, or impure carbonate of soda. In Patna, some articles like *surahis* (water goblets), bottles, and *lotas* (pots) were made out of recycled old, broken glass. Green-colored glass is obtained by adding peroxide of copper, prepared by putting salt and turmeric into a moistened copper plate. Blue glass is produced by adding an oxide of tin or indigo or sulphate of copper. By the time Mukharji visited Patna for collecting data about the glass industry, it was on the verge of extinction, and the remaining two or three families still engaged in glassmaking specialized only in specific glassware on order.³⁸

C. J. Hallifax had reported the manufacture of glass bangles and bottles, chimneys, and other materials from Punjab province (now divided between Pakistan and India).³⁹ It is interesting to note that almost all glassworkers were known as *churigars*, literally “bangle makers.” They were distributed across 17 districts. Hallifax recorded that glass was produced by mixing equal parts of powdered sandstone and *saji* (carbonate of soda), which were melted together. This method was followed in Lahore, Jhelum, Panipat, Mooltan (present-day Multan in Pakistan), and Dera Ghazi Khau. In Gurgaon, *reh* would be mixed with saltpeter and heated for one night over a slow fire, after which it was subjected to fierce heat for a day for glassmaking. While Hallifax was carrying out his survey, glassmakers of Hisar were engaged in remelting broken bangles rather than making glass from raw materials.

The *Gazetteer of the Province of Oudh* (1875–1876) refers to six large ovens for the manufacture of glass bangles in Rampur in the Saharanpur district. The gazetteer gives an elaborate description of raw materials, glass production, and bangle making at Jasrana and Armara Kirar in the Mainpuri district. It is stated that bangles were made from an efflorescence usually found in *usar* plains, which is separated by intentionally making furrows in the ground. The furrows are filled with water and the resultant earthy compound is well mixed and dried at length, giving rise to *reh*. Next it is placed in an oven,

whose fire is continuously fed, to produce glutinous *kanch* (glass).

The Manihar community in the southwest of Hasanpur (district Moradabad) manufactured a small quantity of rough glass. Bagpat (Meerut district) was reported to be working in *kanch*. At Nagina, Bijnor district, the glassware manufactured by indigenous methods was exported to Calcutta (Kolkata). Being made from *reh* and saltpeter, it is said to have a bluish color.

At Nagina glass phials were made for pilgrims to carry Ganges water.⁴⁰ This area lies on the huge alluvial plains south of the Ganges River. Through a quirk of nature, this barren plain has a high natural content of easily soluble alkali carbonates, crystallized under the subtropical sun, as well as natural lime content. The composition of the sand makes it suitable for glass-making.

Henry Dobbs’s report indicates that an industry of substantial proportions was thriving in a much larger area in the western half of the Gangetic plains in Uttar Pradesh.⁴¹ Nine districts of the state—namely Aligarh, Agra, Bulandshahr, Etah, Etawah, Fysabad (Faizabad), Mainpuri, Meerut, and Rae Bareilly—are mentioned by him as being locations of manufacture of crude “native” glass. Among these, Aligarh, Etah, and Mainpuri are mentioned as being centers where considerable manufacturing happened. Besides catering to the local needs of beads and bangle workshops, their products were also transported and distributed as blocks of crude glass by the railways all over India. The chief reason for the engagement of these nine districts in crude glass manufacture, according to Dobbs, was the network of canals that crisscrossed their lands, causing the efflorescence of a natural carbonate of soda on the soils that they irrigated, as well as the local availability of a sufficient supply of fuel.

38. Mukharji 1895.

39. Hallifax 1892, 23.

40. Birdwood 1880, 168.

41. Dobbs 1895.

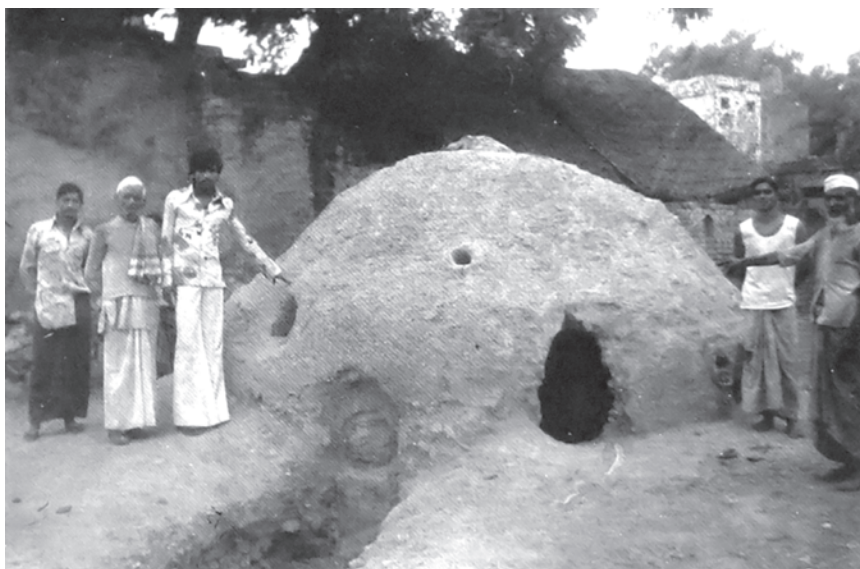


FIG. 5. *Abandoned glass furnace at Purdilnagar. Probably 1981.*
(Photo: from Francis 1982, 12, plate 3)

ETHNOGRAPHIC RESEARCH

The Region of Native Glass Production

In present-day North India, native glassmaking was abandoned as recently as the end of the twentieth century. By that time, native glassworking had become limited to the Purdilnagar-Susamayee-Jalesar-Akrabad (PSJA) region in western Uttar Pradesh. Jalesar and Purdilnagar are on the road between the glass city of Firozabad and the Indian capital, New Delhi. The town of Jalesar (Etah district), which was famous for traditional glass production until the recent past and is still a major center for glass products, is located at a distance of about 40 km from Firozabad. Purdilnagar (Hathras district) is located at a distance of 65 km from Firozabad. The village of Susamayee, which lies adjacent to an abandoned glassmaking area of the late twentieth century, is on the route from Hathras to Rati ka Nagla station, about 5 km before Rati ka Nagla station. Farther, 42 km away from Purdilnagar to the northwest, is the small settlement of Akrabad (Aligarh district) (see Figure 1). The glass furnace that was documented by Kock

and Sode in 1995 (which the first author visited along with Torben Sode in 2017) is now an abandoned, barren land and the pit is full of plastic waste.⁴² The last surviving abandoned furnace, in the village of Purdalpur (Purdilnagar), for making “country” glass (Fig. 5), which was reported by Francis in 1982, is no longer traceable.⁴³

Nowadays much of the glass activity in the area takes place at Firozabad, which constitutes one of the most important Indian hubs for glassmaking and is the Indian epicenter for bangle making. Fuel-efficient furnaces, modern ingredients, and increasingly automated processes allow for a better-quality production at lower costs that quite likely precipitated the demise of the traditional glass workshops nearby. Ironically, there was a time when the factories in Firozabad were dependent on the glass production of those same traditional workshops. Records show they acquired large amounts of cheap blocks of

42. Kock and Sode 1995.

43. Francis 1982.



FIG. 6. Pit-line of the last glassmaking furnace at Purdilnagar. (Photo: Alok Kanungo)



FIG. 7. Abandoned glass-furnace pit at Jalesar. (Photo: Alok Kanungo)

opaque glass from Purdilnagar, Akraabad, and other places manufacturing *reh* glass.⁴⁴

The PSJA region retained many traditional methods, and the remains of the native glass production hold the key to many puzzles about the history and the technology of Indian glass. Most of the techniques of this craft were passed from parents to children. With each family that abandons the glass crafts, some part of this ancient Indian knowledge system slips into oblivion.

For more than 15 years, the first author has visited the famed PSJA region to investigate the remains of the traditional glass industry. Glass-makers from this area had effectively dominated

the world jewelry market at an unprecedented scale until the late twentieth century. In 2016–2017, the author could locate a few craftspeople on the way to Purdilnagar from Jalesar, north-east of Agra, who were still able to produce glass in the traditional way. Again in 2019, we met at Purdilnagar a glassmaker named Heider Ali, who owned the last-known traditional *reh*-glass furnace (27° 39' 28.38" N, 78° 22' 13.30" E). The outline of the furnace is visible next to his present chevron bead furnace (Fig. 6), and Ali has not forgotten the secret of traditional glass-making. A chunk of glass, which Ali claimed to be 50 years old and made out of *reh*, was analyzed and the results are presented below.

In 2017–2018 in Jalesar, the first author met the members of M. G. Mittal Group (the four Mittal brothers Prashant, Vikas, Manoj, and Aditya), who had been producing saltpeter for gun powder for generations and have more recently added brass-bell making to their existing business. Their father had established a glass factory (27° 28' 11.7" N, 78° 17' 54.6" E), which closed down in 1984. The abandoned glass furnace can be seen today in the compound adjoining the brass-bell making (Fig. 7).

In 2019, guided by the Akraabad villagers who are present-day glassworkers, the authors surveyed the scattered abandoned glass furnaces (27° 48' 16.14" N, 78° 16' 19.00" E) on the outskirts of the village of Akraabad. The furnaces had been abandoned for the preceding 50 years. The local informants, in their 60s, had seen the furnaces in use during their childhood.

In 2019 and again in 2020, the family of Heider Ali, the craftsperson mentioned above from Purdilnagar Hasain Bhai, and the villagers of Kalupura guided us to the site of Susamayee (27° 40' 14.19" N, 78° 16' 34.22" E), which is situated adjacent to a heap of glassmaking leftovers. The local informant was 65 years old and had grown up hearing about the glass production there but had never seen these furnaces in action.

44. Indian Tariff Board 1934, 139–140.

Raw materials and glass samples from the above-mentioned abandoned furnaces were collected for elemental composition analyses (Fig. 8).

The Furnace

Although furnaces using crucibles as well as tank furnaces (where the glass is melted directly in a compartment of the furnace without using any kind of other containers) are reported in the colonial literature, only tank furnaces seem to have been used for the production of raw glass in the PSJA area. Based on the accounts of Sode and Kock and Gill,⁴⁵ a description of the furnaces built for the purpose of making glass from raw materials is given below, enhanced by details collected by the first author. This additional information is based on Mittal family interviews and observations of abandoned furnaces.

The circular dome-shaped furnace was about 2 m tall, and its external diameter varied from 4 to 6 m. The furnace chamber was dug 70–100 cm into the earth, and the furnace dome was constructed as a closed vault with the help of unfired mud bricks. The bricks were 25 cm wide and 5 cm thick, with 2 cm-thick joints. The furnace vault was plastered with a thick layer of sandy clay. The interior was divided into two compartments by a semi-circular mud-brick wall. The larger compartment, occupying two-thirds of the furnace, was the melting chamber, while the other part of the furnace constituted the firebox.

Outside the furnace a pit ($3 \times 1.5 \times 1.25$ m) faced the firebox. Its width diminished gradually towards the firing chamber. It was used to remove the ashes from the combustible placed in the firing chamber and helped with air circulation to improve combustion. Combustible to fuel the fire was introduced into the firing chamber through two stokeholes placed on either side of the pit. A second pit (3×1.5 m) on the side of the furnace led to an opening (60×50 cm) at the base of the melting chamber. This pit, which was used for filling and emptying the furnace when the sand was dried and roasted, was located



FIG. 8. Glasses from (a) Purdilnagar, (b) Jalesar, (c) Akabad, (d) Susamayee. (Photos: Alok Kanungo)

at the same level as the bottom of the melting chamber. At ground level, the part of the dome that covered the melting chamber was supplied with inverted U-shaped work openings, the so-called windows that also ensured the even distribution of heat within the chamber. The number of windows (5) varied from furnace to furnace.⁴⁶ Each window had an extension with a piece of clay at the bottom, on which a movable hatch, also of clay, was placed. The extensions are equipped with air vents at the top. Ingredients for the manufacture of the glass were introduced through a rectangular aperture on top of the furnace, opposite the firebox (Fig. 9).

A precise description of the partition wall was omitted by previous researchers. This wall was hollow and measured 55 cm in height. Vertical

45. Sode and Kock 2001; Gill 2017.

46. Gill 2017.



FIG. 9. Prepared batch is introduced into the furnace through rectangular filling-hole. (Photo: from Sode and Kock 2001, 166, fig. 10)

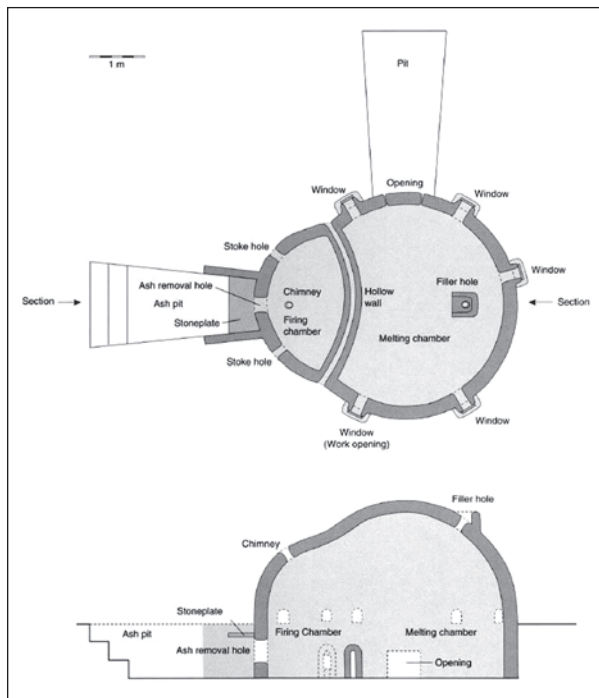


FIG. 10. Schematic plan of native glass furnace at Jalesar. (Drawing: Sven Kaae, from Sode and Kock 2001, 161, fig. 5)

air slots through both sides of this wall where it met the furnace wall allowed air to circulate and cool the hollow wall. In the furnace wall, just above each air slot, there was another opening



FIG. 11. (a) Stored prepared batches and (b) abandoned glass chunks and bottles at Jalesar. (Photos: Alok Kanungo)

25 cm wide into the firing chamber (Fig. 10). To facilitate melting, it was necessary to control the supply of air, and this was accomplished, in part, by means of these openings. At the top of the dome, there was a round hole 10 cm in diameter that acted as the chimney. In the furnace, the glass was melted primarily by the flames licking the raw material, and by the heat that was reflected from the dome.

At Mittal's glass furnace, the structure is no longer intact. The ash pit is clearly exposed, and although the partition wall is no longer visible, the Mittals confirmed that it used to be there. The inner diameter of this furnace was 6 m. There are two additional structures which were meant for drying the collected raw materials (Fig. 11a). The area was littered with wastes of glass and finished products (Fig. 11b).

Raw Material

Ancient glass is generally the result of melting sand (which is mostly silica) and a flux (an alkali or alkali earth-based ingredient), necessary to keep the melting point of the mix reasonably low. A sodium-based flux could be used; it was generally obtained either from mineral deposits (e.g., natron) or from soda plant ash, the former being purer than the latter. Potash or lime-based flux can also be used. Saltpeter (potassium nitrate), a mineral efflorescence, provides a rather pure potash flux, while forest plant ash, containing both potash and lime along with other elements (chlorine, phosphorus, etc.), has a more mixed composition that can vary according to the species.⁴⁷ In India, ancient glass was sodium based and it is generally thought that it was produced from *reh*. Two informants of Gill stated that *reh* used to be gathered from the surface upon its natural efflorescence.⁴⁸ Large expanses of salt-affected soil can be found in the Gangetic region.⁴⁹

The information the first author could gather from local craftspeople, who have produced glass in the recent past at Jalesar and Purdilnagar, reveals more diverse sources of raw materials. It is not possible to say whether they have been in use for a very long time or whether they were more recently developed. The latter option would explain why some of these recipes were not mentioned in the colonial literature.

1. The craftspeople scrape the *reh* from the surface during the winter, when the entire region becomes covered with a salty, whitish-color efflorescent material (Fig. 12a). They store it for the entire year and use it by mixing a proportion with the silica or with fallen mud-wall plaster or post-flood riverbed sand. Over time large soap companies started monopolizing the *reh* collection. In early winter they would arrive with trucks and scraping machines to harvest all the *reh*, leaving almost nothing for the glass craftspeople. According to the Sisgar family of Kapadwanj, a similar situation has arisen in Kheda, Gujarat.⁵⁰ In earlier days,



FIG. 12. (a) Reh exposed on the right bank of the Ami River; (b) raw materials on section of the Ami River after the flood recedes; (c) fallen plaster. (Photos: Alok Kanungo)

Kapadwanj housed both glass and soap factories, perhaps due to the abundant availability in the nearby area of *reh* (called *oos* in that region). Although neither the glassmaking factory nor the soap factory is operational

47. See Henderson 1985; Turner 1956.

48. Gill 2017.

49. Singh and others 2010.

50. Pers. comm. with Alok Kumar Kanungo, 2018–2019.

at present, every winter people from soap factories of other cities still come here regularly to exploit the *oos/reh*. The living artisans who had produced glass out of *reh* in their youth say that they always mixed *reh* in a proportion with silica for producing glass. Perhaps in the days of Dobbs, because *reh* was produced in North India in a customized manner specific to the region, there may have been cases when glass was only produced from *reh*.

2. Glassmakers collect the riverbed sands just after the floods recede (an annual occurrence in this region; Fig. 12b). Then it is dried and used as the main raw material after cleaning the waste. When the floodwaters recede, the banks are covered with natural soda and lime in the form of foam and shells. Thus, these sands become natural ingredients for glass and need no flux.
3. The third source of raw material used by glass producers is the fallen plaster of mud walls (Fig. 12c) that is mixed with some amount of *reh*. Every week a worker moves around the villages and collects the fallen plaster, which is plentiful in this region (although today plastered mud walls are quickly being replaced with plastered cement walls). For a faster melting, the craftspeople mix some amount of old glass with the mix of *reh* and plaster to produce raw glass. It is important to mention that the same fallen plaster is also used as an ingredient for producing saltpeter.

All of the above propositions need experimental studies. In the future, analyses of the glass produced through such experimental studies and of ancient glass will contribute to and bring to light an important dimension of the field of glass studies by connecting technology and glass compositions.

Batch Preparation

Before the collected raw materials can be used for glass production, they must be cleaned of all organic impurities. Complete removal of organic

impurities aids in producing an oxidized glass that is chemically easier to control in the furnace and is also easier to manipulate under rudimentary conditions. Even small amounts of organic impurities would create a reduced batch. The cleansing process is accomplished by roasting or burning and takes place in the same furnace that is later used for the melting of raw glass.⁵¹

Color

The preparation of the batch described above is important, as it will have a significant influence on its color. The raw material contains iron, and depending on its oxidization state, will produce different nuances of green, blue, or brown. An environment free of organic materials that would have a reducing effect on the glass batch will produce a greenish glass. The two informants opined that no other materials were ever added to achieve a green color.⁵² However, the Mittal family very categorically stated that some amounts of saltpeter are added to the batch for producing green glass. The first author saw that most of the glass leftovers near their furnace were sky blue in color with a greenish tint. Dobbs also reported the adding of 4% saltpeter for green glass.⁵³

Dobbs and Francis report the use of goat or sheep dung in similar proportions to make a relatively inferior version of black glass.⁵⁴ This is confirmed by Gill, who indicates that “to produce black glass, one part of roughly mashed goat dung was added to four parts of unroasted raw material, and these were mixed well to make the batch before it was placed in the furnace.”⁵⁵ For better quality glass, 1–4% black iron oxide and a small quantity of saltpeter were added to the scorched raw material.⁵⁶

51. See Gill 2017.

52. Gill 2017.

53. Dobbs 1895; Francis 1982, 32.

54. Dobbs 1895; Francis 1982.

55. Gill 2017.

56. Dikshit 1969.

Green and black raw-glass samples were analyzed, and the results will be discussed later in light of the different information reported above.

Traditionally only these two colors were produced. Additional colorization of green glass, if necessary, was done separately at a later stage. Black glass, which could not be further colored, was an end product in itself.

Dikshit updated the list of Dobbs by adding the materials used by the then-indigenous glass-makers of Uttar Pradesh to produce glasses of different colors rather than the rudimentary black and green glasses (Table 1).

Melting

The batch was introduced into the furnace in stages over three to four days and melted accordingly, which concurs with the information reported by Sode and Kock.⁵⁷ Gill claims that the entire batch is added all at once.⁵⁸ With such a procedure, the result would be more than 60% of glass not fusing completely and less than 40% glass yield. Moreover, the period of firing would require much more time than the usual three to four weeks.⁵⁹ Adding the full batch at once would not be economically viable for the glass-makers.

The introduction of the batch into the melting chamber is done at regular intervals. Only the clay plate coverings are removed during the stirring of the batches, two to three stokers at a time. The batch is stirred to ensure that the heat penetrates it evenly. The glassmakers work in shifts to watch the fire and monitor the melting.

After the melting is complete and no bubbling in the molten glass is observed, Gill opines that a large fruit or vegetable such as a pumpkin is skewed at the end of a long iron rod and inserted into the molten mass, causing it to bubble violently for a while as the fruit burns and decomposes.⁶⁰ However, no such incident has been reported during the first author's fieldwork of more than one and half decades. Rather, glass-makers avoid any such external agency in order to obtain fine, bubble- and impurity-free glass.

TABLE 1
Coloring Agent Used by the Craftspeople
from Uttar Pradesh (from Dikshit 1969, 131)

Transparent dark green	Di-oxide of copper	1 tola
Opaque light green	Di-oxide of copper Lead Tin Yellow shale	2 tolas 1 chhatak 1 chhatak 1 chhatak
Light blue	Sulphate of copper	1 chhatak
Sky-blue	White Ferozabad glass Chep, a white stone Patra, a stone	1 seer 2 chhataks 1.2 tola
Indigo violet	Chep	2 chhataks
Opaque lemon yellow	Pilli, a powder of lead, tin, and yellow shale	3 chhataks
Opaque brown	Black glass	4 chhataks
Opaque ochre	Tin Lead Goramba, a red stone	1 chhatak 1 chhatak 1.5 chhatak
Dark red	Lead Zinc	1 chhatak 1 chhatak
Light red	Copper oxide Black glass	1 tola 4 chhataks or 1 seer
Uda (purple)	Anjani	10 chhataks for one maund

Fifteen to twenty days are necessary to create a batch of glass. The glass is extracted from the furnace by creating a hole in its wall and breaking chunks from the glass slab. Only a little more than half of the raw glass is of acceptable quality. The bottom portion of the cake, which is poorly fused and invariably contaminated through

57. Sode and Kock 2001.

58. Gill 2017.

59. Pers. comm., Heider Ali and his family, 2020.

60. Gill 2017.

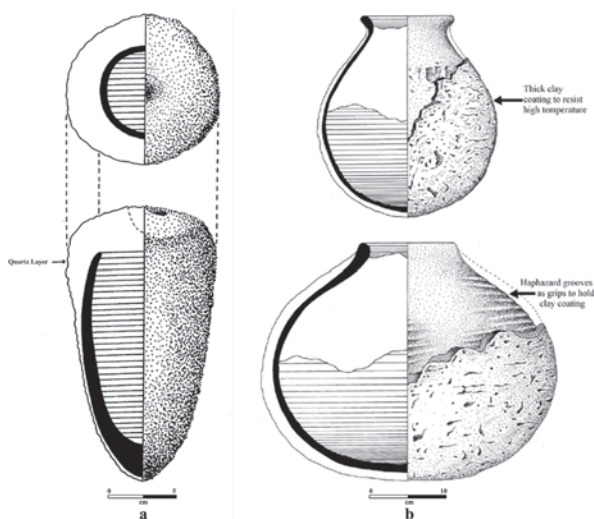


FIG. 13. Reconstructed crucibles: (a) Karakambadi, (b) Kopia. (Drawings: Devadatta Phule)

contact with the earthen floor of the furnace, is crushed and reused in the next melt. When it is time to melt a new glass batch, the craftspeople either build a new furnace or replace the clay base of the furnace for a depth of about 60 to 90 cm. They then repair the damaged wall.

Fuels

Wooden logs (mango, neem, lovestick, sheesham, and babul; never the logs of trees whose sap has an appearance like milk and is toxic in nature) are put on the floor of the firing chamber first, which keeps the temperature in the furnace constant. For the entire period of glass melting, when the temperature needs to be raised, the preferred fuel is dried stalks of mustard, maize, and lentil plants, which produce strong flames when burnt.⁶¹ They are continuously fed into the furnace, 24 hours a day, through the two firing holes. The process thus consumes enormous amounts of stalks, which lie in huge piles next to the furnace.

The glass at the bottom of the furnace that is imperfectly melted is broken and added to the

new batch. These added pieces of vitreous material facilitate the melting process because glass that has already been melted reacts at a lower temperature. Glass has a melting interval rather than a specific melting point. Using an extremely long melting period, the local glassmakers can successfully complete their work at the lower end of the melting interval. When the sand is brought to the glowing point, a molten phase of 800–850°C results, and as the soda decomposes, gas bubbles are formed in the melt.

Primary and Secondary Melting

The British Empire's investigative team and Buchanan reported the use of pot crucibles for melting glass in many places.⁶² In addition, Dikshit provides several other examples for the use of effloresced alkaline deposits as the principal ingredient in glass manufacturing at other places in India in the nineteenth and early twentieth centuries.⁶³ All of these require heating the alkali in earthen pots or crucibles to melt and form glass.

In this context, it is interesting to note that excavations at the Karakambadi and Kopia glass-producing sites have yielded pot crucibles that apparently were employed for manufacturing glass (Fig. 13).⁶⁴ Although the locals at Kopia declared that they saw a large floor of glass and furnace domes, the first author's attempt at locating them was in vain. Nevertheless, there is no reason not to believe the locals, as not one or two but most of the elders in the village, who used to dig the mound in Locality II in search of hard clay for making floors in their respective houses, gave identical reports. Perhaps this supposedly large floor was that of some ancient tank furnace. Thus, the production process in

61. Gill 2017.

62. Buchanan 1807.

63. Buchanan 1807.

64. Kanungo 2003; 2013, 445.

PSJA could be just a continuation of a dome-shaped glass furnace tradition which is more than 2,000 years old. It is also interesting to note that the riverbed of Ami is rich in *reh*, and Kopia stands on the dried horseshoe bank of this river.

There is always a possibility that glassworkers at Kopia used two furnaces, one to produce frit in a tank furnace and the other to produce glass out of powdered frit in a pot crucible. In such a case, glass can be produced by generating a lower temperature than the required 1,000+°C, which is difficult to achieve. Use of tuyeres (which is a common find at the site) and blowers might have helped raise the temperature.

On the other hand, ethnographically, the kind of tank furnace used in the PSJA region is still in use at Kapadwanj.⁶⁵ Although the Kapadwanj glass craftspeople no longer melt silica with *reh* to produce glass, they remelt broken glass for their needs. The furnace in use has been the same for the last 150 years. They not only describe the process of glassmaking to be the same as that of PSJA but also use the same batch material (a mixture of *reh*) that they used to produce glass 60 years ago in the same furnace. The shape of the furnace is not circular but barrel topped, having a rectangular base (Fig. 14a). Abandoned furnaces are also seen just behind the present one, some of which are hundreds of years old (Fig. 14b). The present furnace is used for remelting glass over the first four days, after which the craftspeople produce their lead-coated glass balls for 45 days. Then they let the furnace cool for 15 days and repair the furnace over 30 days before starting the next cycle.

ELEMENTAL COMPOSITION

Scientific analysis of recent glass produced by traditional methods can add to the information obtained from archaeological excavations, from the literature, or collected from craftspeople.

The scientific analysis of glass finds from ancient Indian sites establishes that it has high soda content and high alumina concentrations,



FIG. 14. (a) Glassworking furnace and (b) abandoned furnace at Kapadwanj. (Photo: Alok Kanungo)

suggesting the use of a high-alumina sand.⁶⁶ Scientific experiments by Brill and Gill indicate that this composition is the result of using *reh* as the single-ingredient recipe for glass production.⁶⁷ The same composition has been recognized in a context as early as the fourth century BCE, indicating that this unique glass recipe certainly has a very ancient origin.⁶⁸

The following glass and raw-material samples collected during the fieldwork in the PSJA area were analyzed for elemental composition (Table 2) by the second author using a Thermo ICAP Q Inductively Coupled Plasma–Mass Spectrometer

65. Pers. comm. to the first author from the only family, i.e., Sisgar family, which continues to engage in glasswork at Kapadwanj. See Kock and Sode 2021, 2002.

66. Abdurazakov 1987; Brill 1987; Brill 1993; Brill 1995; Brill 1999, 1:150–176, 2:358–362, 364–367; Brill 2009; Brill, Fenn, and Lange 1995; Dussubieux and Kanungo 2013; Kanungo and Brill 2009; Lal 1958; Lal 1987.

67. Brill 2003; Gill 2017.

68. Dussubieux, Gratuze and Blet-Lemarquand 2010.

TABLE 2
Elemental Composition of Analyzed Samples

		<i>PNGG</i>	<i>SMGG</i>	<i>SMBG</i>	<i>ABGG</i>	<i>ABBG</i>	<i>JSGB</i>	<i>JSGG1</i>	<i>JSGG2</i>	<i>JSPB</i>
wt%	SiO ₂	72.9%	59.1%	62.4%	62.1%	62.0%	73.1%	59.1%	59.2%	76.5%
	Na ₂ O	16.36%	24.21%	20.78%	22.14%	22.62%	13.77%	19.19%	19.27%	0.66%
	MgO	0.82%	1.07%	1.04%	0.93%	0.89%	3.21%	1.32%	1.32%	1.29%
	Al ₂ O ₃	3.56%	8.69%	9.21%	8.45%	8.13%	1.32%	1.65%	1.66%	10.37%
	P ₂ O ₅	1.52%	0.27%	0.34%	0.27%	0.20%	0.02%	4.89%	4.81%	0.78%
	Cl	0.04%	0.17%	0.11%	0.23%	0.28%	0.02%	0.34%	0.33%	0.09%
	K ₂ O	1.55%	2.49%	2.16%	2.13%	1.63%	0.50%	0.67%	0.67%	2.09%
	CaO	1.18%	1.72%	1.68%	1.67%	2.20%	7.80%	12.40%	12.26%	5.34%
	MnO	0.03%	0.09%	0.04%	0.04%	0.05%	0.01%	0.09%	0.09%	0.04%
	Fe ₂ O ₃	0.71%	2.16%	2.21%	2.02%	1.85%	0.14%	0.22%	0.22%	2.65%
	CuO	0.65%	0.002%	0.002%	0.002%	0.005%	0.002%	0.002%	0.003%	0.02%
	SnO ₂	0.0031%	0.0004%	0.0004%	0.0005%	0.0004%	0.0092%	0.0003%	0.0003%	0.0031%
	PbO	0.27%	0.00%	0.00%	0.00%	0.05%	0.03%	0.03%	0.03%	0.01%
ppm	Li	58	17	17	15	17	3	4	4	47
	Be	1	2	2	2	2	0	0	0	2
	B	1663	163	171	124	156	126	338	339	52
	Sc	8	10	10	10	10	2	2	2	13
	Ti	1547	2349	2509	2515	2870	434	352	362	2245
	V	34	78	86	79	76	5	5	6	69
	Cr	1388	45	54	49	63	5	6	6	62
	Ni	17	14	15	13	11	3	3	3	37
	Co	16	6	5	5	5	3	1	1	8
	Zn	2886	33	39	29	107	16	73	72	723
	As	462	33	48	37	28	88	506	507	12
	Rb	27	74	83	71	59	25	19	18	86
	Sr	59	123	116	113	138	61	134	134	246
	Zr	79	560	255	280	313	111	87	89	166
	Nb	9	9	10	10	11	2	1	1	7

(ICP-MS) connected to a New Wave UP213 laser for direct introduction of solid samples:

1. a piece of green glass collected from the last native glass furnace owner/glassmaker at Purdilnagar, Heider Ali, labeled as PNGG;
2. a piece of green and a piece of black glass from the glass abandoned in Susamayee's furnaces, labeled as SMGG and SMBG;

3. a piece of green and a piece of black glass from an abandoned furnace on the outskirts of Akrabad, labeled as ABGG and ABBG; and
4. a glass bottle, two pieces of green raw glass, and a sample of prepared batch from the abandoned glass furnace of the Mittal family at Jalesar, labeled respectively as JSGB, JSGG1, JSGG2, and JSPB.

TABLE 2 (cont.)

		<i>PNGG</i>	<i>SMGG</i>	<i>SMBG</i>	<i>ABGG</i>	<i>ABBG</i>	<i>JSGB</i>	<i>JSGG1</i>	<i>JSGG2</i>	<i>JSPB</i>
ppm	Ag	1.8	0.2	0.1	0.1	0.2	1.1	0.2	0.2	1.5
	In	0.32	0.05	0.05	0.05	0.04	0.25	0.11	0.10	0.25
	Sb	30	6	6	5	2	3	66	66	2
	Cs	1.9	3.1	3.9	2.9	2.0	0.8	0.7	0.7	6.9
	Ba	122	313	318	297	265	447	828	859	332
	La	10	35	37	38	47	9	8	8	144
	Ce	22	71	75	79	99	23	22	22	327
	Pr	3	8	9	9	11	2	2	2	35
	Ta	0.6	0.9	1.0	1.0	1.1	0.2	0.2	0.2	0.6
	Au	0.04	0.01	0.01	0.01	0.01	0.01	0.01	0.02	3.1
	Y	9	25	26	26	30	5	5	5	45
	Bi	1.4	0.3	0.2	0.3	0.1	0.2	0.3	0.3	1.4
	U	2	120	247	165	206	0.7	0.8	0.8	8
	W	1.7	1.7	2.4	1.4	1.3	0.3	0.4	0.4	4.4
	Mo	1.5	11.0	18.3	8.3	8.3	0.3	1.2	1.3	7.0
	Nd	9.4	28.2	29.7	30.7	36.0	6.7	6.2	6.2	116.9
	Sm	2.1	5.8	6.0	6.2	7.2	1.3	1.2	1.2	18.9
	Eu	0.5	1.0	1.1	1.0	1.2	0.2	0.2	0.2	3.3
	Gd	1.9	4.9	5.2	5.2	6.0	1.0	1.0	1.0	11.5
	Tb	0.3	0.8	0.8	0.8	1.0	0.2	0.2	0.2	1.5
	Dy	1.8	4.4	4.8	4.7	5.3	0.9	0.8	0.8	8.2
	Ho	0.4	1.0	1.0	1.0	1.2	0.2	0.2	0.2	1.7
	Er	1.0	2.5	2.7	2.6	2.9	0.5	0.5	0.5	3.9
	Tm	0.2	0.4	0.4	0.4	0.5	0.1	0.1	0.1	0.5
	Yb	1.0	2.8	2.6	2.6	2.9	0.5	0.5	0.5	3.5
	Lu	0.2	0.5	0.4	0.4	0.5	0.1	0.1	0.1	0.5
	Hf	2.5	17.6	7.6	8.1	9.1	3.1	2.4	2.5	4.6
	Th	6	17	18	18	23	3	3	3	171

Although we expected that the results would show the use of a high soda–high alumina raw ingredient that is connected to the use of *reb*, more contrasting results were obtained.

Four samples had high soda (21–24%)–high alumina (8–9%) compositions (SMGG, SMBG, ABGG, and ABBG) with high trace elements (e.g., U = 120 to 247 ppm). Overall, the compositions of SMGG, SMBG, ABGG, and ABBG

are very similar to that identified in archaeological glass such as the glass from Kopia. Such a composition indicates the use of *reb*.⁶⁹ The difference in the composition of the glass based on the color is very small. For SMGG (green) and

69. Dussubieux and Kanungo 2013.

SMBG (black), the potash concentrations are 2.5 and 2.2%, and the iron-oxide concentrations are 2.2% for both samples. This indicates that salt-peter (which would add potash to the glass) or iron was not added to the glass batches to influence their color. For the ABGG and ABBG glass samples, the values differ a little more, with potash concentrations of 2.1% for the green glass and 1.6% for the black glass, while iron oxide is 1.7% for the green glass and 2.2% for the black glass. The very small variations for these two constituents might reflect a variation in the overall composition of the raw materials.

Sample PNGG from Purdilnagar has a different composition. It is a soda glass (16.4%) but contains much lower alumina (3.6%) and trace-element concentrations ($U = 2$ ppm) than SMGG, SMBG, ABGG, and ABBG. Copper with a concentration of $CuO = 0.65\%$ was added purposefully as a coloring agent. This glass does not seem to have been manufactured from *reh*, which contradicts what our informant told us.

For the samples from Jalesar, we expected that the raw material (JSPB), the raw glass (JSGG1 and 2), and the glass bottles (JSGB) would yield compositions indicating that they were part of the different steps of the manufacturing process at the abandoned workshop where they were collected. The composition of the sandy raw material (JSPB) is high in silica (76%) and high in alumina (10.3%). It is low in alkali ($K_2O = 2.1\%$ and $Na_2O = 0.7\%$). The composition is not suitable for the production of glass. Mixed with the appropriate amount of soda, JSPB could have produced a high soda–high alumina glass.

The glass bottle JSGB and the two fragments of raw glass JSGG1 and 2 have a high-soda composition with $Na_2O = 13.8\%$ in JSGB and 19% in the JSGG1 and 2. Alumina concentrations for the three samples are low ($< 2\%$). Phosphorus and lime are particularly high in the raw-glass samples ($P_2O_5 \sim 5\%$ and $CaO \sim 12\%$). In ancient glass the concomitant presence of higher phosphorus and calcium concentrations is associated

with the addition to the batch of bone ashes that opacify the glass and give it a milky look. Trace elements for the raw glass and the bottle samples are similar, suggesting the use of a common low-alumina sand mixed for the three objects, but a different flux was used for the two types of objects. The composition of the raw material, raw glass, and bottles are different and were part of different manufacturing processes. No logical explanation can be proposed as far as a possible connection between the raw material, raw glass, and glass bottle. The fact that the results of our analysis do not match what former craftspeople told us about the material that we collected and analyzed reveals that memory is a very volatile thing and that there is an urgency to record details about traditional glass technology in India before the techniques have totally vanished.

CONCLUSION

The understanding of Indian indigenous glass production requires looking at different lines of evidence coming from archaeological research, literature, ethnography, and chemical analysis. Although there is mention in the literature and by craftspeople of different glass recipes to produce glass in India, the single-ingredient recipe was certainly the most widely used from ancient times until the mid-twentieth century. It has now disappeared, although some craftspeople still remember how this glass was manufactured. The single-ingredient recipe used *reh*, a mix of sand and of an alkali-rich efflorescence, which was melted in tank furnaces that were still in use in the western part of Uttar Pradesh until very recently. This recipe produced either greenish or black glass that was then colored elsewhere before being transformed into objects.

The chemical analysis of different glass samples obtained from various glass workshops operating a few decades ago can be compared to the information obtained elsewhere. We found

occasional inconsistencies between the information provided by craftspeople and analytical results. This might indicate that the memory of these traditional practices is deteriorating rapidly and will soon disappear.

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