

caria followed by chilli–garlic (2.42), sorghum–berseem (2.32) and rice–wheat (2.14) cropping systems (Table 5). These results confirm the findings of Roy Bardhan *et al.*<sup>12</sup>.

Among the cropping systems tested in the experiment, maximum reduction in soil pH<sub>2</sub> after three years of experimentation was recorded with sweet basil–matricaria followed by rice–wheat, chilli–garlic and sorghum–berseem (Table 3). This is because matricaria absorbs higher amount of cations, especially sodium at a faster rate<sup>13</sup>. The organic carbon status in the soil was slightly higher in the sweet basil–matricaria cropping system over the traditional rice–wheat system.

From this study it is concluded that in partially reclaimed sodic soils, cultivation of rice–wheat cropping system for a longer period may not be an economically viable proposition. Diversification of rice–wheat cropping system with other highly remunerative crops like sweet basil and chilli in kharif, and matricaria and garlic in rabi may be adopted by the farmers to get higher returns per unit area and to save the natural resources.

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## Elemental oxides analysis of the medieval period glazed ware from Gogha, Gulf of Khambhat, Gujarat, India

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**During an inter-tidal zone exploration in the Gulf of Khambhat region, a large number of glazed and non-glazed sherds were recovered along with stone anchors dating back to the late medieval period. Four representative specimens were analysed for elemental oxides using scanning electron microscope and energy dispersive spectrum. The results indicate that silicon oxide content of the glazed sherds varies between ~73 and 77%, forming three-fourths of the total composition, while it ranges from 42 to 47.5% in non-glazed sherds. Its content is more than half that in the ordinary sherds. It is difficult to understand the origin of these sherds on the basis of chemical analysis, as this study focuses only on the Gogha area. Therefore, similar studies from different regions in the Gulf of Khambhat will help to understand the origin and divergence in the manufacturing techniques used.**

**Keywords:** Elemental oxides, glazed ware, medieval period, stone anchors.

GENERALLY pottery with a glossy layer is termed as glazed ware. The glaze is primarily composed of fine glass-forming oxides, mostly silica (SiO<sub>2</sub>), which on vitrification melt and fuse to form an impermeable glassy layer over the surface of a vessel. The oxides found in glazes have a unique role in determining the final properties such as texture and colour on fired ware. Excavations and explorations at different locations on the Indian sub-continent have yielded a variety of glazed ceramics from various time-periods.

The earliest examples of glazed ware were reported at Mohenjo-Daro<sup>1</sup> and Desalpur<sup>2</sup>. Excavations at a Kushana Period site in Shah-Ji-Ki-Dheri near Peshawar<sup>3</sup>, yielded an inscription over which a glaze coating was observed. Similar studies at another Kushana Period site in Harwan near Srinagar, revealed a pavement of glazed tiles.

During the medieval period use of glazed ware increased manifold with several variations and decorations, and many sites of the medieval period in India yielded the remains of glazed ware<sup>4</sup>. A few important sites among these are Hastinapur, Fatehpur Sikri, Purana Qila, Adilabad, Ujjain, Atranjikhhera, Nevasa, Sanghol, Qila-ri-Pithora, Ropar, Chirand and Kurukshetra. Glazed ware is also re-

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ported from the early historic and the medieval period coastal sites such as Arikamedu, Pattanam and Sanjan.

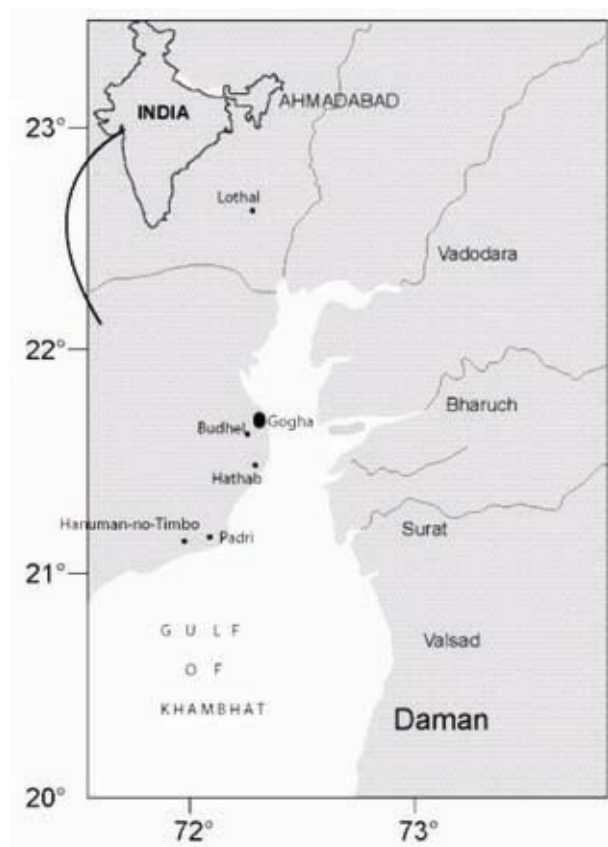
Gogha, on the western bank of the Gulf of Khambhat, Gujarat, was an important town during the medieval and British periods (Figure 1). Because of high tidal range in the Gulf, a large area gets exposed during low tide and a number of archaeological artifacts, such as stone anchors and various type of ceramics can be observed in the inter-tidal zone areas.

The pottery is being studied to understand the cultural sequence and also the expansion of a particular culture in a specific time-bracket. However, it was also felt necessary to carry out scientific analysis to get accurate information on manufacturing techniques, composition and firing. The present communication mainly deals with elemental oxide analysis of glazed, non-glazed and ordinary sherds of pottery recovered from the Gogha region, to understand the relationship between the specific characters of glazes and non-glazes and their basic oxide chemistry used. Approximately half of the total collected pottery is turquoise-coloured followed by green and brown. Non-glazed sherds are limited in number.

In order to determine the variations of chemical composition of glazed, non-glazed and ordinary sherds, scanning electron microscope (SEM) and energy dispersive

spectrum (EDS) studies were carried out at spots on these inter-granular specimens. The clear specimens (size 3–5 mm) obtained from potsherds were placed on a carbon conductive tape stuck on a nylon stub. Each specimen contained both glazed and non-glazed parts. The specimen was mounted on the stub in such a way that the surface to be analysed faced upwards. The specimen was then sputter coated with about 20 nm thick gold coating using a gold sputter coater. The coated specimen image was analysed by SEM (model JSM 5600) with an EDS attachment (model JOEL 5800 LV).

Of the total 20 sherds recovered, three clean glazed sherds (Figure 2) having brown, green and turquoise colours and one ordinary sherd were selected for SEM and



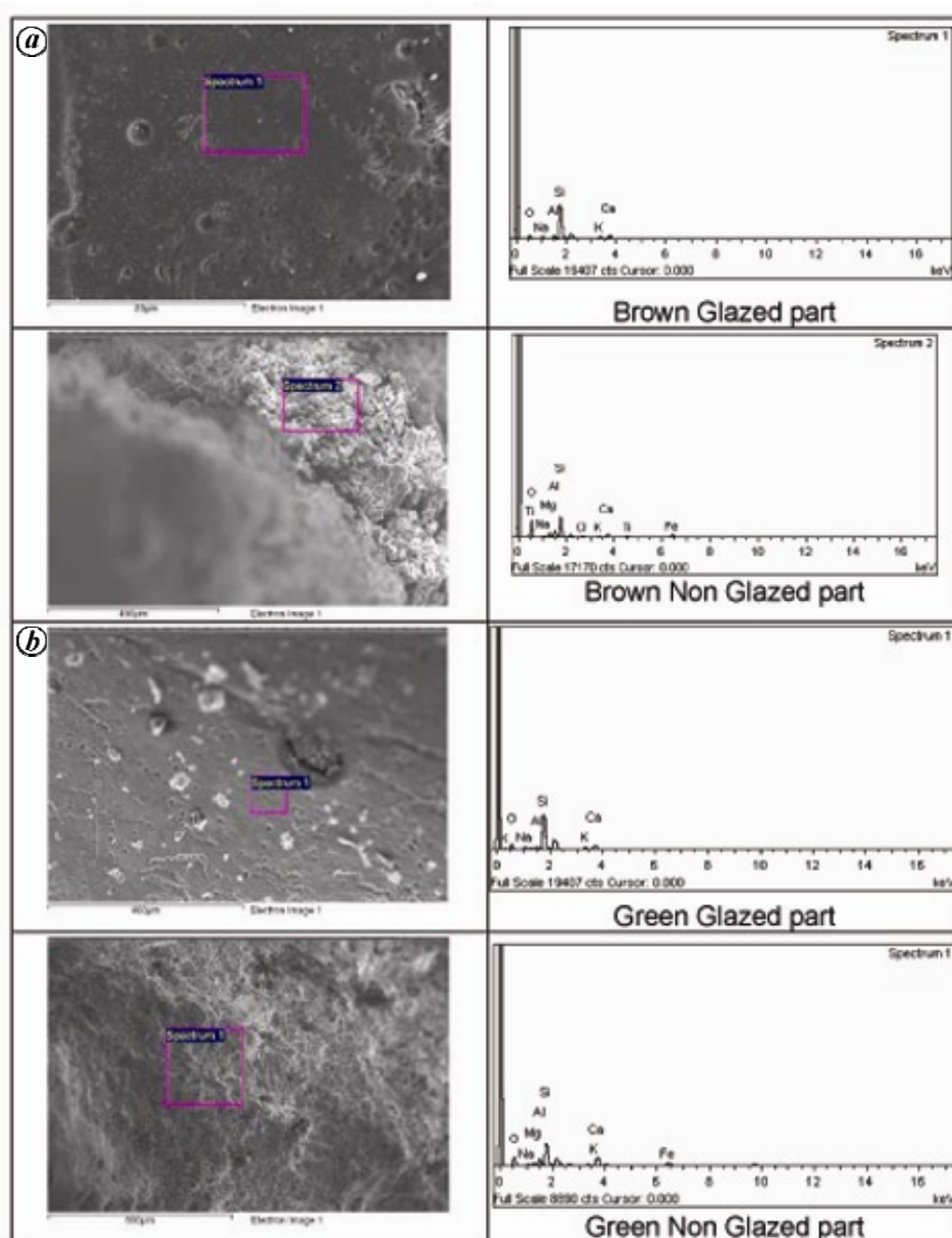
**Figure 1.** Location of sites along the western coast of the Gulf of Khambhat.



**Figure 2.** *a*, Brown, *b*, Green, and *c*, Blue glazed ware (scale: 25 cm).

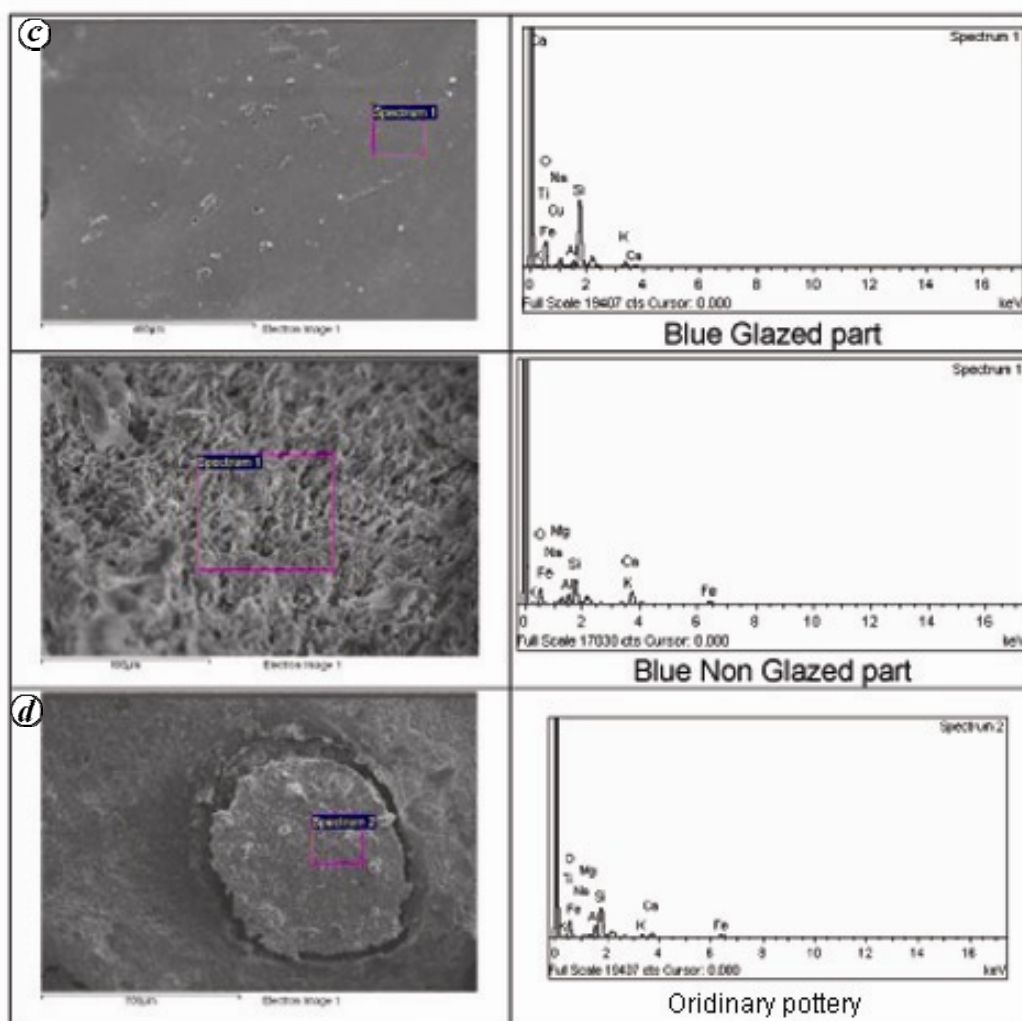
**Table 1.** Weight per cent of elemental oxides in different pottery sherds collected from Gogha

Elemental oxide	Glaze brown	Glaze green	Glaze blue	Non-glazed part (brown)	Non-glazed part (green)	Non-glazed part (blue)	Ordinary sherd
Na <sub>2</sub> O	6.30	5.35	8.91	2.32	3.10	2.52	1.52
Al <sub>2</sub> O <sub>3</sub>	5.13	4.91	4.79	13.62	11.56	13.05	16.93
SiO <sub>2</sub>	73.27	73.49	76.92	47.42	46.62	42.45	54.22
K <sub>2</sub> O	4.76	3.85	4.49	1.49	1.66	1.31	2.48
CaO	7.57	8.11	1.19	6.42	16.52	18.93	5.4
FeO	2.97	2.34	0.70	12.72	15.02	12.57	13.60
CuO	–	1.95	2.31	–	–	–	–
TiO <sub>2</sub>	–	–	0.69	3.98	–	–	1.83
MgO	–	–	–	9.99	5.51	9.17	4.03



**Figure 3.**

(Contd)



**Figure 3.** Properties of (a) brown glaze and non-glaze, (b) green glaze and non-glaze, (c) blue glaze and non-glaze and (d) ordinary sherds.

EDS studies. Glazed and non-glazed portions of each glazed sherd were analysed for elemental oxides (Figure 3) and the results are presented in Table 1.

The results indicate that silicon oxide ( $\text{SiO}_2$ ) content of the glazed sherds varied between ~73 and 77%, forming three-fourths of the total composition, while for non-glazed sherds it varied between 42 and 47.5%. This is more than half that in the ordinary sherds. Silicon is a principal glass-forming oxide in the glaze and cannot be replaced with any other oxide.

Alumina ( $\text{Al}_2\text{O}_3$ ) coating was low (4.79–5.13%) in glazed sherds and high (11.56–13.62%) in non-glazed sherds. Its concentration in ordinary sherd was 16.93%. Alumina mainly retards crystal formation and controls the viscosity in all types of pottery. It also gives strength to the glazed sherds. A similar trend was seen in FeO concentration, being low for glazes and high for non-glazes. Presence of CuO (~2%) was noticed in the glazes, perhaps to obtain the green and blue colours.

Oxides of alkaline earth metals (CaO and MgO) were predominant in the non-glazed portion, with concentrations varying from 16.41 to 28.10%. Their content in ordinary sherds was 9.43%. Whereas glazes have only CaO ranging from 1.19 to 8.11, with no MgO content.

Base oxides (CaO, FeO, CuO, MgO,  $\text{Na}_2\text{O}$ ,  $\text{K}_2\text{O}$ ) content ranged from 17.6 to 21.6% for glazed sherds, from 33.0 to 44.5% for non-glazed sherds, while it was 27.03% in ordinary sherds. These base oxides help lower the melting point of silica, alumina and other refractories in glazes and also colour response. Each of these fluxing oxides brings its specific texture, particularly in the non-glazed portions.

Sodium oxide (NaO) was present in significant quantities (5–9%) in colour glazes, while it was low (1.5–3%) in non-glazed and ordinary sherds. This provides colour or opacity to the glazes. Similarly, potassium oxide ( $\text{K}_2\text{O}$ ) is higher in glazes than non-glazed portion and ordinary sherds, which may be due to feldspar admixture in the glazes.

Archaeologically, the Gulf of Khambhat is rich, as a large number of sites are located around it. On the basis of a comparative study, stone anchors from Gogha were found to be similar to those reported from other sites on the Saurashtra coast, which were dated to the medieval period<sup>5-7</sup>. Stone anchors have also been found associated with the medieval period glazed ware. Similar type of glazed ware has been reported from Kamrej, dated to the 9th–10th century AD<sup>8</sup>. Excavations at Sanjan also yielded though in small quantity glazed ware dating back to the 9th–12th century AD<sup>9</sup>. From the east coast of India, particularly at Kottapattanam<sup>10</sup> and Mantai<sup>11</sup>, late medieval period glazed ware has been found in significant quantities. A factory site producing glazed ware during the medieval period was located at the head of the Gulf of Khambhat at Lashkarshah<sup>12</sup>.

Several metallic oxides such as iron, sodium, potassium, lead, calcium, magnesium, zinc and aluminium have the ability to act as fluxes to produce a stable glaze<sup>13</sup>. Clays with significant quantity of silica have been extensively used to produce a glazed layer over the ceramic surface. When fired under oxidizing conditions, iron oxide imparts glazes of yellow, red or brown colour depending upon the quantity present<sup>12</sup>, whereas in reducing conditions, it produces green glaze.

Glaze usually contains three-fourths of silica and the same composition dominated in samples from Gogha (Table 1). Interestingly, copper oxide is present in blue and green colour glaze and completely absent in brown glaze, non-glaze portion of sherds and ordinary clay vessel. Therefore, to obtain green and blue colour, copper oxide was added while preparing the glaze. Calcium and iron oxide are less in blue glazed sherds compared to brown and green glazed sherds. Calcium is a dependable glaze ingredient at high temperature. It reduces viscosity and produces matt surfaces in glazes. Calcium in the glaze tends to react with the non-glazed body under the glaze to promote a good interface and provide the clay-glaze fit. Its content is low in glazes compared to non-glazes and ordinary sherds, probably to avoid the formation of crystals (calcium feldspar). Potassium oxide is negligibly present in ordinary clay.

The finding of glazed ware from the inter-tidal region of Gogha indicates that pots of glazed ware were frequently used during overseas voyages in the medieval pe-

riod. It is difficult to understand the origin of these sherds on the basis of chemical analysis, as this study focused only on the Gogha area. Therefore, similar studies on such ceramics from different regions in the Gulf of Khambhat and west coast of India will help to understand the origin and divergence in the manufacturing techniques used.

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