

Luminescence Chronology of a Second Millennium BCE Settlement near Porbandar on the Gujarat Coast, India

— A.S. Gaur, P.J. Thomas*,
K.H. Vora and Sundaresh

An onshore excavation at Bokhira (Porbandar) on the Saurashtra coast has revealed a late Harappan settlement dating back to the early 2nd millennium BCE. Four trenches were dug in an agricultural land where an occupational deposit was noticed up to a depth of 50 cm. A large amount of pottery and other antiquities similar to those reported from other late Harappan sites of Saurashtra have been found here. Chronology of human occupation at this site was obtained through thermoluminescence (TL) and optically stimulated luminescence (OSL) dating of two potshards. The obtained luminescence ages are found to be in agreement with other archaeological findings. We discuss the implications of the luminescence ages on the maritime history of the area and the cultural sequences of late Harappan civilisation.

Saurashtra coast on the western margin of India has been a favourable area for human settlement since the early stone age (Marathe 1981). A large number of sites dating back to the mid 3rd millennium BCE have been discovered and a few of them, for instance, Lothal (Rao 1979), Padri (Shinde 1992), Prabhasa (Sankalia 1974), Bet Dwarka (Gaur et al. 2005) and Nageshwar (Hegde et al. 1990) have been excavated extensively. The excavation of a coastal site at Bet Dwarka yielded the remains of the late or post Harappan period. To understand the settlement pattern of this phase along the Saurashtra coast an onshore exploration

was undertaken and a site was noticed on the western bank of Porbandar creek. To ascertain the archaeological deposits and chronological order a systematic excavation was carried out and a few trenches were laid at different places. There is a remarkable similarity between Bet Dwarka and Bokhira on the location and deposition of human settlements. The potshards such as bowls and jars from both sites closely resemble one another. The chronology of human settlement in these sites is either based on relative dating (comparison with other excavated sites) or through conventional radiocarbon methods. In situations where

National Institute of Oceanography, Goa, India

* Luminescence Dating Laboratory, National Geophysical Research Institute, Hyderabad, India



suitable or sufficient organic materials were not available, thermoluminescence (TL) dating of fired objects like pottery was done (Singhvi *et al.* 1991). TL ages of fired materials were critical to identify the cultural sequences of Harappan civilization in Bet Dwaraka (Vora *et al.* 2002). Recent archaeological excavations in Bokhira, near Porbandar revealed remnants of a protohistoric (post Harappan) settlement. In order to determine the chronology of human occupation and cultural sequences at this settlement, two pottery shards have been dated using thermoluminescence (TL) and optically stimulated luminescence (OSL) methods. We discuss the TL and OSL dating procedures and the implications of the pottery ages in unravelling the settlement structure of late Harappan people and the maritime history of the area.

LOCATION AND GEOGRAPHIC SETTING OF STUDY AREA

The archaeological site, which is partially under cultivation, is located on the western side of the Porbandar creek in the village Bokhira (Figure 1). Further west of the excavated site, a small limestone cliff indicates a higher sea level in the past. There is a well-defined depression around the site towards the creek, which is presently banked by a high metal road. According to local tradition, there was a *Juna Dhakka* (ancient jetty) near the present creek, which indicates that the site was very

close to the creek in the past. The location of the study area apparently favours the utilization of the creek for maritime activities around Porbandar.

EXCAVATIONS

Four locations were selected for the excavations to assess the extension of settlement towards the creek and total occupational deposits (Fig. 1). Trenches TR-I to TR-III contained occupational deposits, upto 50 cm thick (Fig. 2), whereas in the trench dug close to the creek (TR-IV), the thickness of the deposit was 103 cm. A large number of potteries were recovered from these trenches during the excavation. The important ceramic assemblages are red

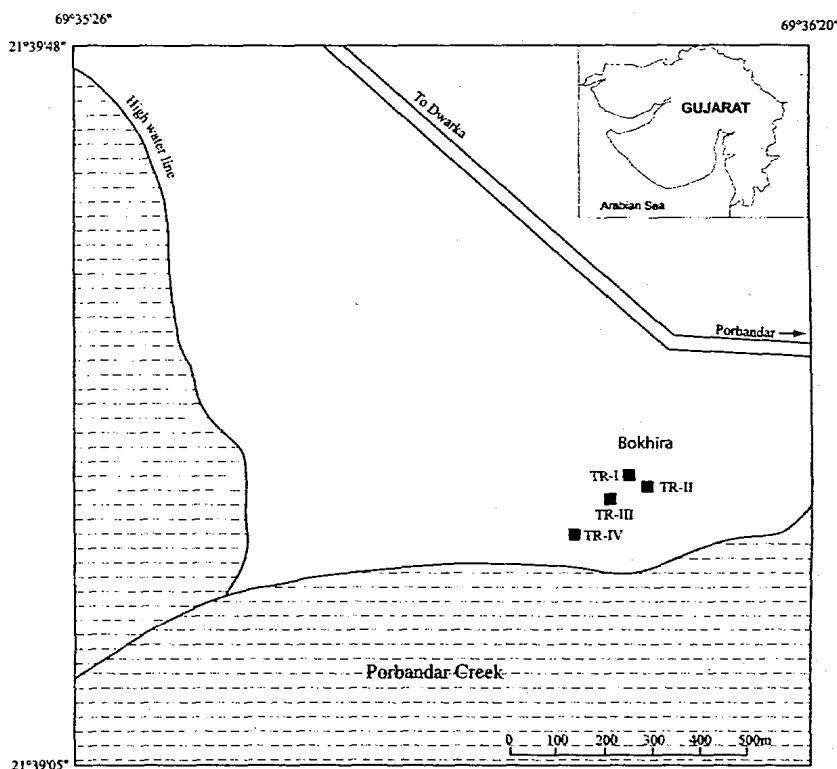


Fig. 1: Location of excavated trenches at a late Bronze Age site near Porbandar creek.



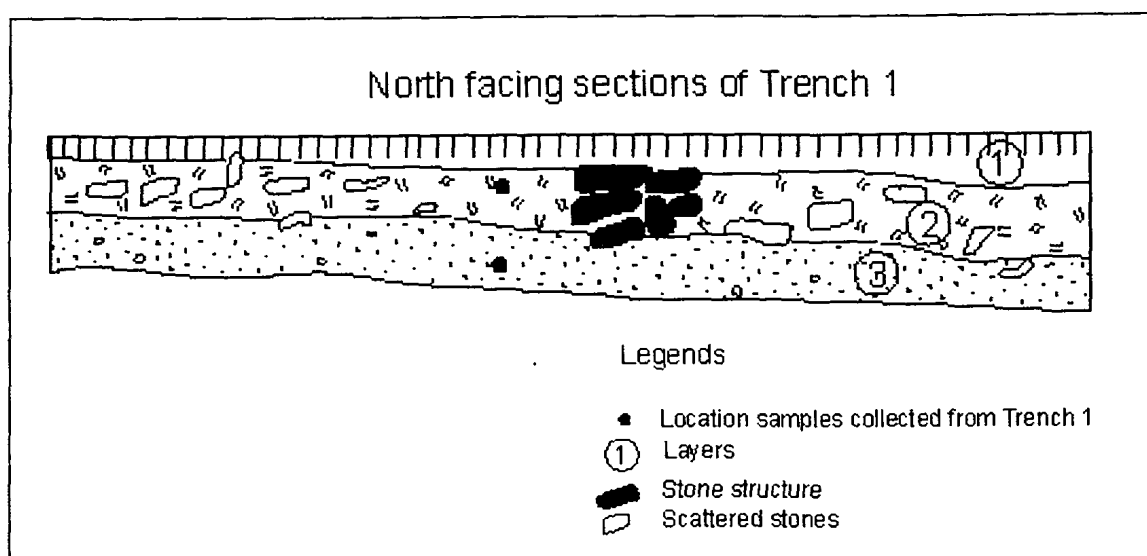


Fig. 2 : Section of trench I, from where samples were collected

ware, black ware, buff ware and grey ware. Varieties of bowls of different sizes are the major attraction of the excavation besides a large number of shards of jars, lids, basins and other pots (Table 1, Fig. 4). The shape, size and paintings are very similar to the pottery reported from Bet Dwarka (Gaur *et al.* 2005), Rojdi (Possehl and Raval 1989), Lothal (Rao 1985) and Kuntasi (Dhavalikar *et al.* 1996). The important paintings on the potshards are roundels, wavy lines, cross lines and thick bands on the rim portions.

Other important artefacts discovered at this site include four stone tools comprising a blade, point, fluted core and flake. Three of these stone tools were made of milky quartz, while the fourth one was made of crystal. Apart from these, four terracotta beads, two balls, three sling balls besides one copper finger-ring and two terracotta artefacts were also recovered during the excavation.

Trench TR-I preserved evidence of the postholes, which are indicative of past constructional activities at this locality (Figure

Table 1. Number of identified shapes of pottery from Bokhira

| Type of vessel | BKR-I | BKR-III | BKR-IV | Total |
|----------------|-------|---------|--------|-------|
| Jar | 39 | 32 | 44 | 115 |
| Bowl | 41 | 37 | 38 | 116 |
| Lid | 3 | 3 | 3 | 9 |
| Dish | | | 1 | 1 |
| Miniature pot | 7 | 5 | 8 | 20 |
| Others | | | 2 | 2 |



3). In order to determine the chronology of occupation and settlement at this site, two pottery samples (NIO-1, NIO-2) were collected from this trench for luminescence dating. Pottery NIO-1 was from layer 1 (at a depth of 15 cm, from surface) while NIO-2 was from layer 2 (at a depth of 40 cm from surface). Sample 1 represents a shard from a bowl, which has a thin section with coarse fabric and a slip applied over the surface. This sample typically represents Sorath Harappan type of late phase. Sample 2 is probably from a jar; is sturdy with fine fabric and made of well levigated clay and well fired. Both samples fall in the category of red ware. Along with two pottery pieces, the soil covering the potteries was collected for estimating the environmental radioactivity.

LUMINESCENCE DATING

TL dating of heated or fired material like pottery is a well established technique (Aitken 1985). It is based on the principle of measuring accumulated charge populations within crystalline materials (e.g. quartz and feldspar) to determine the amount of time that has elapsed since the firing of pottery. The amount of thermally stimulated luminescence observed when irradiated quartz is exposed to artificial heating in the laboratory is used to estimate the total radiation dose derived from naturally occurring radioactivity and acquired since the time of heating of pottery or stone (paleodose). In order to calculate the time that has elapsed since the firing event it is

also necessary to determine the radiation flux (annual dose) in the natural environment. The sample age may then be obtained using the following general equation: Age (years) = Paleodose (Gy) / Annual dose (Gy/year).

Although TL method is the common dating tool for pottery dating, optically stimulated luminescence (OSL) method also has been used for dating heated objects (Aitken 1998). In the case of latter, the luminescence is produced when the mineral grains are stimulated with light of appropriate wavelength (eg. quartz is stimulated with blue/green light, whereas feldspar is stimulated with infrared light). By using OSL, some of the potential disadvantages of TL, incandescence during sample heating and

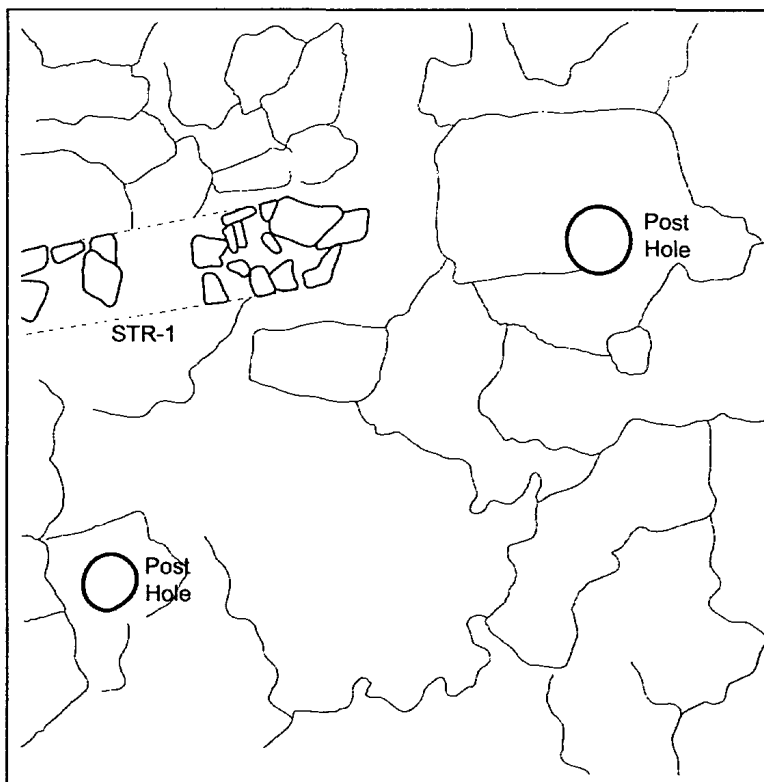


Fig. 3: Post-holes exposed in Trench I, are the remnant of the thatched roof house



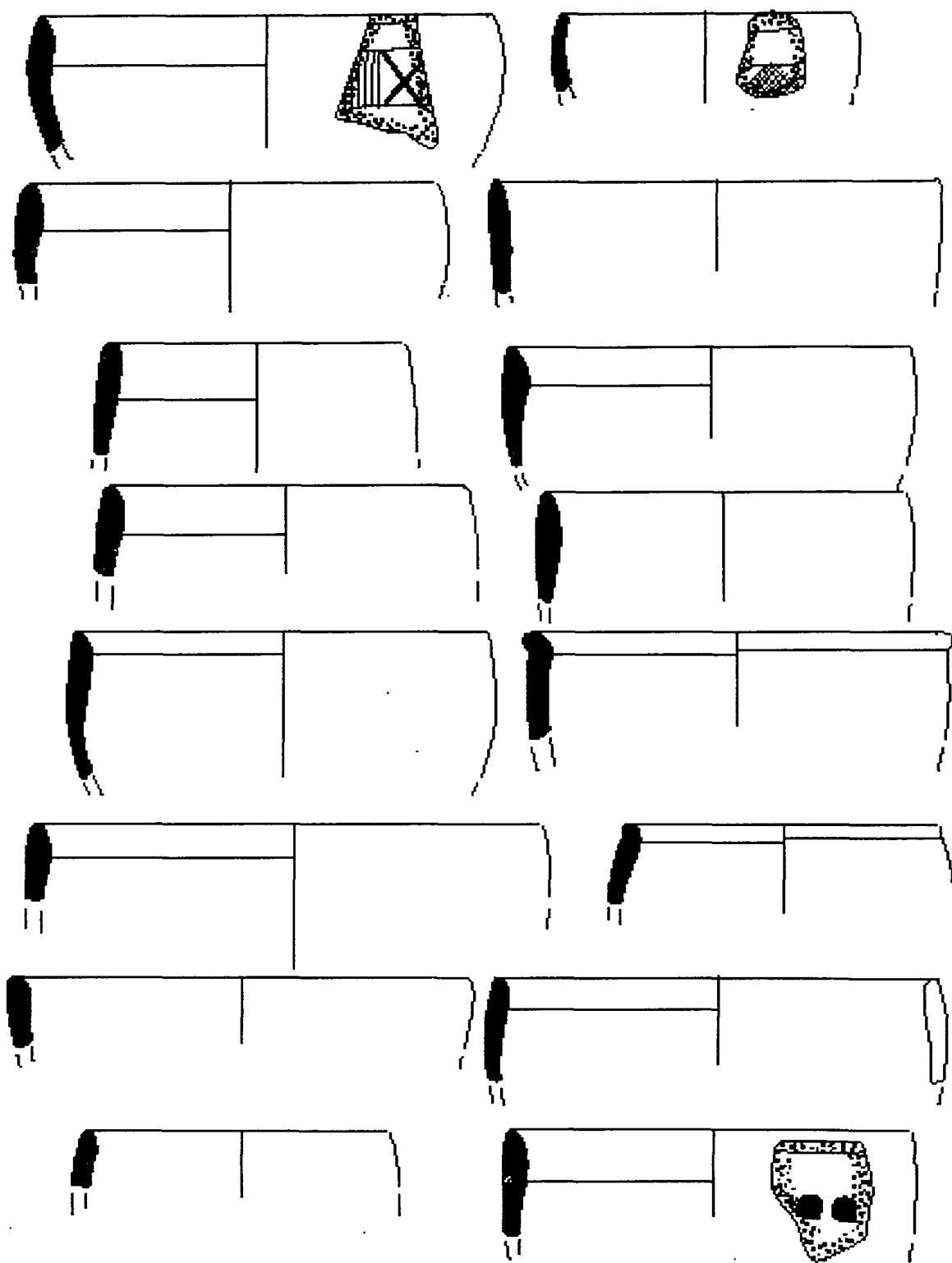


Fig. 4. Late Bronze Age (late Harappan Period) Pottery from the site



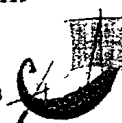
'spurious' luminescence (Aitken 1998), can be avoided. Recent methodological advances in the OSL technique, especially the usage of single-aliquot regenerative-dose (SAR) procedure (Murray & Wintle 2000) enables precise and accurate dating of heated objects (Lamothe 2004). Using SAR-OSL, the paleodose estimation is possible from a single (aliquot) thereby the sample requirement is very less, the estimate is more precise and the procedure is automated and more rapid. On the other hand, to estimate paleodose from TL signal, a minimum of 20 aliquots are required, because it is based on the multiple-aliquot additive-dose (MAAD) procedure. In some cases, availability of datable material will be limited and under such circumstances, TL dating will be difficult and less reliable. Further inter-aliquot variations in luminosity (scatter) between aliquots and the uncertainties due to extrapolation and curve fitting also contributes to less precision and accuracy of TL paleodose. SAR-OSL dating of heated materials collected from different archaeological sites in India has been attempted recently (Thomas *et al.* In Press), and is shown to be a reliable dating method when compared to TL dating.

SAMPLE PREPARATION AND MEASUREMENT DETAILS

Quartz inclusion technique was used for paleodose (or the equivalent laboratory dose, D_e) estimation. Sample preparation was carried out under subdued red light conditions. After removing the outer 2 mm from all sides of the pottery by iron filing,

the pottery fragments were crushed in a vice to liberate the smaller grain sizes in the matrix. A grain size fraction of 70-90 μm was separated by dry sieving, which was then treated with 1N hydrochloric acid (HCl) for the removal of carbonate in the matrix. The feldspar grains in the matrix and alpha irradiated outer layer of quartz grains were removed by etching with concentrated hydrofluoric (HF) acid for 40 minutes. Acid soluble fluoride coatings, if any, on the quartz grains were removed by subsequent treatment with concentrated HCl. The purity of the quartz with respect to feldspar contamination was checked using infrared stimulated luminescence (IRSL) at ambient temperature (30°C); no measurable IRSL signal was observed in both quartz fractions. Pure quartz grains were mounted on 9 mm diameter stainless steel disc using silicon oil resulting in typical aliquots having an average diameter of 6 mm. TL and OSL measurements were carried out at NGRI using an automated Risø reader, equipped with a calibrated $^{90}\text{Sr}/^{90}\text{Y}$ beta source. The luminescence was detected by a 9235QB15 PM tube after passing through a 7 mm thick Hoya U-340 optical filter.

TL glow curves were recorded by heating the aliquots (sub-samples) up to 450 °C at a uniform heating rate of 5 °C/s, in an ultra-pure nitrogen environment. Temperature region comprising 325 and 375 °C TL peaks of the glow curves (325-375 °C plateau) was used for calculation of D_e , using a multiple-aliquot additive-dose (MAAD) procedure (Aitken, 1985). Inter-aliquot scatter in



luminosity was corrected by second glow normalisation. The supralinearity effect (slow growth of the growth curve at low dose region) was measured using the same aliquots, which were used for measuring the natural TL intensity (Leung 2005 and Vora *et al.* 2002). TL glow curves and MAAD growth curve obtained from pottery sample NIO-1 is shown in Figure 5A.

Optical stimulation was carried out using blue LEDs (wavelength 470 ± 30 nm). OSL measurements were performed at 125°C for 40 seconds and the resulting decay curve was collected in 250 channels. The first five channels (0.4s) of the decay curve were used as signal and last 25 channels (4s) were used for subtracting the background. The SAR procedure (Murray and Wintle 2000) was used for D_e measurement. The appropriate preheat temperature was determined through dose recovery-cum-preheat plateau test (Thomas *et al.* In Press). A known laboratory dose was given to previously sunbleached aliquots and was measured using the SAR protocol as a function of different preheat temperature ($160 - 260^\circ\text{C}$ for 10 s), assuming it as unknown. The cut heat was fixed at 160°C . Figure 5B shows that dose recovery (ratio of measured dose / given laboratory dose) is good and not dependent on preheat temperature between 200 to 240°C in sample NIO-2. Further, the sensitivity corrected repeat dose points (recycling ratio) between the preheat temperatures $200 - 240^\circ\text{C}$ are all within the acceptable limits (10%), as suggested by Murray and Wintle (2000). Based on the above test, a

preheat temperature of 200°C for 10 s and a cut-heat temperature 160°C was used in OSL measurements of sample NIO-1 and NIO-2. OSL decay curves and growth curve of pottery sample NIO-1 is shown in Figure 5C. The SAR-OSL D_e distribution in both pottery samples was found to be normal, implying that there was no residual luminescence signal in the crystals after the pottery firing. Typical D_e distribution obtained for NIO-1 is shown in figure 6 as histogram (6A) and radial plot (6B) (Galbraith *et al.* 1999). Since the D_e distribution is normal in both pottery samples, the average value is taken as D_e value, for the respective age calculation.

The annual dose acquired by the pottery was calculated from the elemental concentrations of potassium, uranium and thorium in the pottery material and surrounding soil matrix. The elemental concentrations were measured using a NaI gamma spectrometry at NGRI. Considering the thickness of the pottery (1-1.5 cm) and also the effective range of beta and gamma radiations, it can be considered that the beta dose component of the annual dose rate is contributed solely by the pottery, whereas, the gamma dose is from the surrounding soil matrix. The dry beta and gamma dose rates were corrected for water content attenuation (Zimmerman 1971) using the laboratory measured water content in the pottery (varied between 5-8% by weight) and the soil matrix (~10% by weight). The cosmic ray contribution was calculated as described by Prescott and Hutton (1994) and is added to gamma dose. Allowance has been made



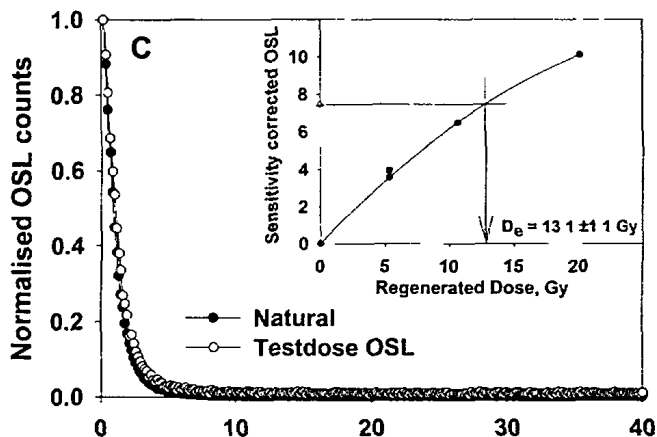
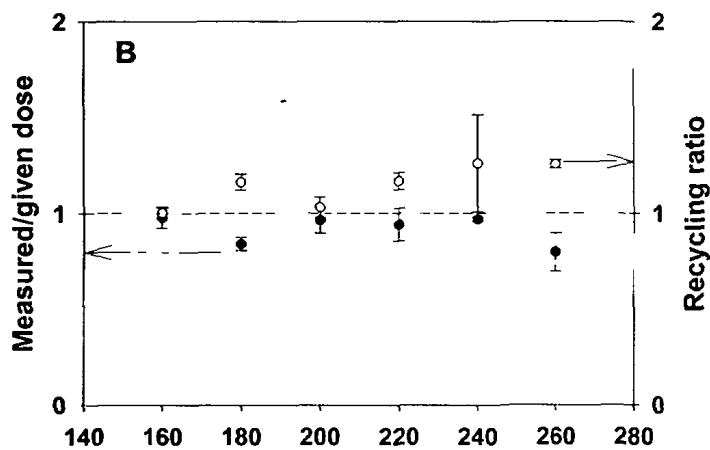
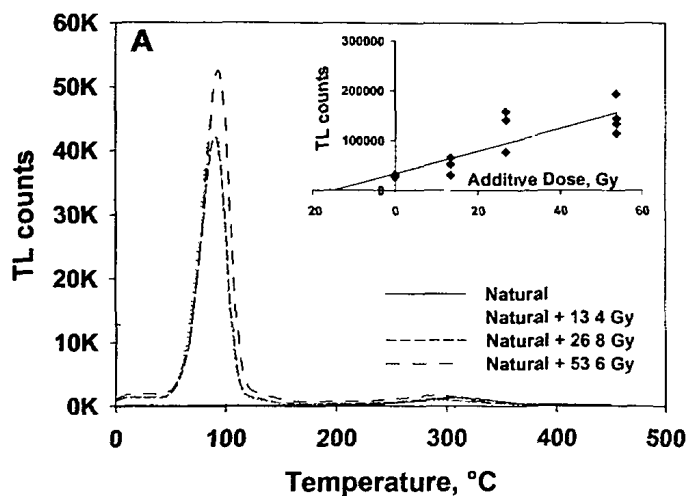


Fig 5 (A) TL glow curves of pottery sample NIO-1 (inset) MAAD TL growth curve of the same sample (B) Dose recovery-cum-preheat plateau measured using a SAR protocol in pottery sample NIO-2 (C) SAR-OSL decay curves and growth curve in a typical aliquot of pottery sample NIO-1

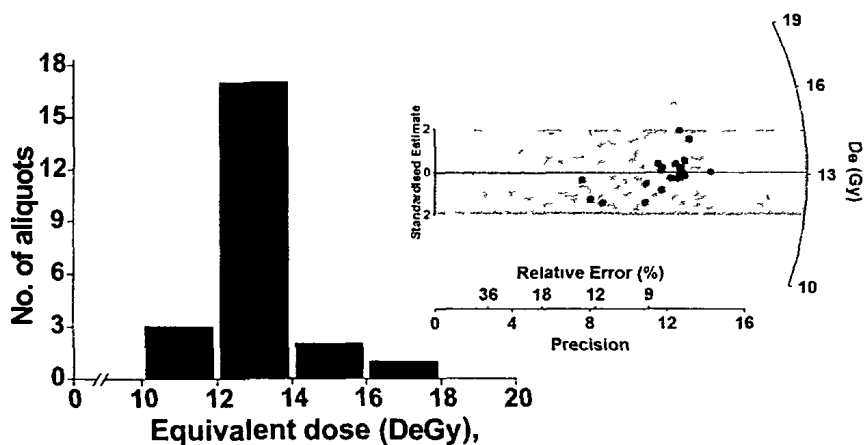


Fig. 6 .SAR-OSL equivalent dose (D_e) distribution in pottery NIO-1, shown as (A) histogram and (B) radial plot



to account for beta dose attenuation within quartz grains (Aitken 1985). In table 2, the beta and gamma annual dose rates, the TL and SAR-OSL D_e values and the calculated luminescence ages of the two pottery pieces are summarised. The agreement between the TL and SAR-OSL ages of the two pottery pieces is good. The TL and SAR-OSL ages of the two pottery pieces are 1395 BCE and 1145 BCE (NIO-1) and 1955 BCE and 1855 BCE (NIO-2), respectively. The datum year for the luminescence ages is 2005, the year in which the measurements are carried out.

DISCUSSION

This is the second site (after Bet Dwarka) discovered on the coastal plains of the south western coast of Saurashtra that contains protohistoric deposits. The excavation revealed the oldest antiquities around Porbandar for the first time, dating back to the beginning of the 2nd millennium BCE. The initial habitation took place on the bedrock and thatched wood houses were built, which were erected on the wooden poles as evident from the postholes noticed on the surface. This is the characteristic feature of the Chalcolithic culture (Allchin and Joshi 1995 and Dhavalikar *et al.* 1988) and rarely noticed in the Harappan Civilization. The archaeological material is very similar to that reported from Rangpur IIB and IIC (Rao 1963), Rojdi C and Bet Dwarka (Gaur *et al.* 2005). The pottery is also similar to the Sorath Harappan suggested by Possehl and Raval (1989) in Rojdi, which has been very well dated between the mid-third

millennium BCE and early 2nd millennium BCE. TL and SAR-OSL dates of two pottery pieces (Table 2) from the excavation suggest a time bracket for the settlement between the early 2nd millennium BCE and the late 2nd millennium BCE. Pottery and other antiquities suggest that site belongs to the Sorath Harappan (indigenously developed in Saurashtra and has strong Harappan influence on pottery and other antiquities). Perhaps they migrated from hinterland area to coastal area in the beginning of the 2nd millennium BCE and the same phenomena has been observed at Bet Dwarka Island also (Gaur and Sundaresh 2003). However they could not sustain themselves for a longer duration and habitation was abandoned around the mid 2nd millennium (Ratnagar 2004).

The new luminescence ages of pottery and other evidences from the archaeological assemblages at Bokhira and Bet Dwarka (Gaur *et al.* 2005) provide some insights into the settlement pattern of the late or post Harappan people on the coastal area of Saurashtra. During the post Harappan period a large number of village settlements came into existence along the coastal area of Saurashtra (Ratnagar 2002).

CONCLUSIONS

Onshore excavations at Bokhira, on the Saurashtra coast, brought to light the oldest antiquity in Porbandar area dating back to the early 2nd millennium BCE. The proximity of the settlement to the Porbandar creek indicates that the early inhabitants engaged



Table 2. Radioactivity data, equivalent dose and luminescence ages of pottery samples from the Bokhira site, Porbander. Beta dose was calculated using the pottery material and gamma dose using the soil matrix. ^a Number of aliquots used to calculate the De value is shown in bracket. ^b The calendar ages are based on the datum year of luminescence ages (2005).

| Sample ID | Radioactivity | | | Dose rate (Gy/ka) | | | De (Gy) | | Age (years BP) | | Ageb (Calendar years BC) | |
|------------|---------------|----------|---------|-------------------|-----------|-----------|------------|-----------------|----------------|----------|--------------------------|--------------------|
| | K (%) | Th (ppm) | U (ppm) | Beta | Gamma | Total | TL | SAR-OSLa | TL | SAR-OSL | TL | SAR-OSL |
| NIO-1 | 3.08 | 16.59 | 3.31 | 3.01±0.13 | | 4.17±0.15 | 14.18±2.35 | 13.13±0.26 (23) | 3400±580 | 3150±130 | 815 - 1975 (1395) | 1015 - 1275 (1145) |
| NIO-1 soil | 1.81 | 8.01 | 2.41 | | 1.16±0.08 | | | | | | | |
| NIO-2 | 1.60 | 2.61 | 4.49 | 1.70±0.08 | | 2.72±0.10 | 10.77±0.99 | 10.49±0.67 (6) | 3960±390 | 3860±280 | 1565 - 2345 (1955) | 1575 - 2135 (1855) |
| NIO-2 soil | 1.77 | 6.33 | 2.61 | | 1.10±0.05 | | | | | | | |

in maritime activities. Luminescence ages of pottery recovered from the excavation have close correspondence with archaeological assemblages and are critical for providing the time bracket for the archaeological sites. The discovery has also indicated that along with the Indus Civilization, regional cultures flourished in the coastal belt of the Saurashtra regions and were engaged in maritime activities. Methodologically, this study has demonstrated the reliability of SAR-OSL dating of heated/fired objects like pottery. The good agreement between TL and OSL ages of pottery from Bokhira suggests that optical dating using SAR protocol can be routinely used for precise and accurate dating of archaeological pottery.

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