Cultural sequence of Bet Dwarka island based on thermoluminescence dating

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Earlier studies on the onshore and inter-tidal zone explorations in Bet Dwarka island had revealed the presence of a large number of potsherds and other antiquities that correspond to the protohistoric (2000–1500 BC), historical (3rd century BC to 5th century AD) and medieval (8th century to 15th century AD) periods. Until the present time there has been a lack of absolute chronology. This study therefore attempts to address this deficiency. Accordingly, nine potsherds from four different sites of Bet Dwarka island were dated by thermoluminescence (TL). The ages obtained from site BDK-VI vary between 3870 and 2220 years BP; those from BDK-I vary between 3160 and 830 years BP; those from BDK-II vary between 1780 and 960 years BP, and those from Khuda Dost Dargah vary between 1240 and 880 years BP. When analysed on the basis of their locations, they are in conformity with the expected period. Interestingly, at site BDK-VI and BDK-I a few potsherds, believed to be of protohistoric period, are apparently considerably more recent (2000 years BP), which may suggest the continuation of protohistoric habitation up to historical period at the same site. These TL ages assist in establishing a cultural sequence for Bet Dwarka island.

BET Dwarka island (22°22′ to 22°28′N and 69°05′ to 69°09′E) is situated in the Gulf of Kachchh about 5 km north of the mainland of Okhamandal and to the east of Okha port. Bet Dwarka (also known as Bet Shankhodhar) is famous for temples dedicated to Lord Krishna. The island is a narrow strip of sand and rocks about 13 km long. The eastern part of the island is known as Hanuman point, and comprises sand-hills and bushes. The south-west half of the island is rocky table with relief of + 20 m. Recent geological studies have indicated faults and two prominent structures: the Padmteerth fault running WNW-ESE and the Sonimiyar fault running ENE-WSE, though the dates of the faults are not available at present. It is suggested that these faults caused wedging of the area between them, thus causing subsidence. Evidence of subsequent in-filling and episodes of uplifts during the recent past have been reported[1].

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Bet Dwarka has rich marine resources such as the conch shell, which possibly attracted early man (late Harappan) to establish a colony. Another important site of Harappan period at Nageshwar is located within 15 km in the mainland of Okhamandal. This was one of the active shell industry centres of the Harappan period. Similarly, Bet Dwarka was an important shell-working centre during late Harappan and historical periods. Onshore and offshore explorations in and around Bet Dwarka have yielded a large number of antiquities of late Harappan and historical periods which include pottery, a seal, coins, etc.[2]. To understand the cultural sequence and its continuity, a few potsherds were examined and were scientifically dated using thermoluminescence (TL), when found to be of historic importance the results of which are presented here.

It is important to prepare a chronology of an archaeological site to understand the sequence of events and correlate the same with different sites. Once the chronology is established, it is possible to compare two sites. If two sequences from different chronological events are found together, then that can form the basis to consider the occurrence of neotectonic activity. To obtain absolute dates, generally sedimentary strata provide the proxies for obtaining dates either using ^{14}C or U-series methods. In archaeological explorations, however, antiquities are used to obtain dates based upon cultural association as standard procedure. The dates so obtained are generally reliable and depended upon, but they are subjective. However, at times scientific dates are very important. TL dating of potsherd is now gaining ground to get absolute ages from them. An attempt is made here to discuss the utility of TL ages in identifying cultural sequence from Bet Dwarka.

A number of datable artifacts such as seal, inscriptions, coins and pottery have been reported from the island, which have helped to construct an archaeological cultural sequence for the island[3]. To gain a better understanding of the chronology of the periods, a programme of scientific analysis was undertaken using TL as a dating method. Potsherds from different periods were collected, examined and later dated at the School of Geo-sciences, University of Wollongong, Australia. All potsherds were collected from the surface and have been held in storage since collection (Figure 1). The present paper deals with these archaeological discoveries and their associated TL dating.

TL dating has been used in various disciplines such as earth sciences, archaeological science and space sciences[4,5]. Recently, the use of TL dating has increased significantly in archaeology[6,7]. Potsherds manufactured by man during the ancient period are used in TL dating. It has been observed that application of TL dating in historical archaeology is very effective. In India a few potsherds from Harappan settlements at Sanghol and Hulas and historical period settlements at Sringaverpura and Bagor were dated by this method[6] to confirm their period. A few potsherds from Bet Dwarka were also dated and only one date has been referred as 3520 years BP (ref. 8). Unfortunately, TL dating has not been used extensively for archaeological sites.

Archaeological background

Bet Dwarka island is located at a point from which boats and ships sailing from south enter the Gulf of Kachchh, approach the mainland sailing in a northwesterly direction. The area is also referred to as the Gulf of Barake by foreign travellers[9].

Archaeological evidence testified by the discovery of seal inscriptions and pottery suggests that Bet Dwarka island was inhabited during the Harappan period and habitation has continued with hiatus between protohistoric and historic period, until the present day.

Since 1969–70, onshore explorations at Bet Dwarka have been carried out by the Archaeological Survey of India (ASI), which established the existence of the late Harappan, post Harappan, historical and medieval period settlements in different parts of the island[10]. Rao[11] explored the island extensively and undertook underwater exploration during 1983. During this exploration, many pieces of pottery and sherds with graffiti marks, conch shell bangles, etc. were recovered. Explorations have brought to light the following cultural sequence constructed by comparative studies with contemporary archaeological sites of Gujarat.

Protohistoric period settlement

The protohistoric period in the Indian subcontinent has been bracketed between 5000 and 3000 years BP. Two late Harappan sites have been discovered on the island, these are located on the eastern and southern coast. The eastern site is shielded from tidal effects. However, recent agricultural activities have extensively damaged the site. Important finds from this site include red-ware and grey-ware bowls and sherds of perforated jars[12]. This type of pottery is typical of the Harappan (Figure 2) and late Harappan sites. A major portion of the southern coastal

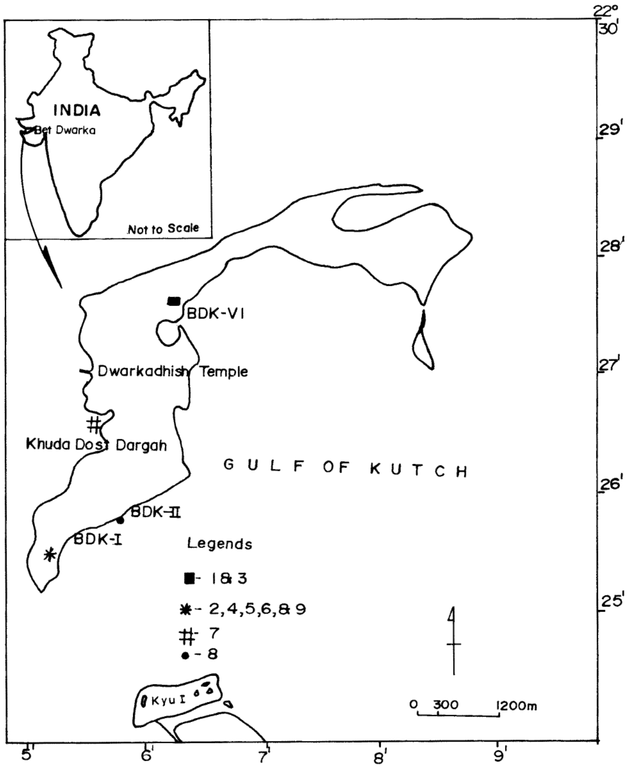

Figure 1. Location of sites and samples.

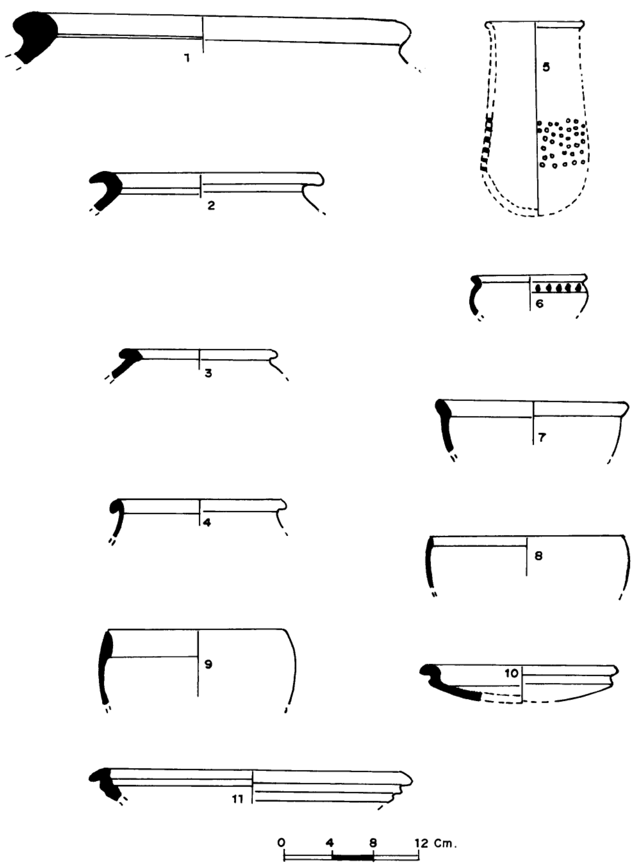

Figure 2. Protohistoric pottery from Bet Dwarka.

site has been damaged by sea erosion (Figure 3). A large number of potsherds and shell bangles lie scattered in the inter-tidal zone and are visible during periods of low tide. Land and underwater excavations at this site have brought to light a seal (Figure 4) made on a conch shell[1] engraved with an animal with three heads. Similar types of seals have also been reported from Mohenjodaro, Harappa and Dholavira from Harappan level. Other important antiquities include potsherds with Indus period graffiti (Figure 5), Harappan pottery[3], shell bangles, chert blades, etc.

Historical period settlement

The historical period represents a time bracket between 2600 and 1400 years BP. Two historical period sites have been identified on the island on the basis of findings like coins and pottery. The first site lies over a late Harappan settlement near Nilakantha Mahadev temple. This site has yielded two Kushana period copper coins and one unidentified historical period lead coin[3]. The second site is on the southwestern coast near Khuda Dost Dargah (Figure 6). This site has natural protection from high sea waves and storms but gets inundated during high tide, suggesting sea-level rise or shoreline retreat on this coast since the time of habitation. The reason for this phenomenon has not been identified as yet. Important artifacts found at this site include amphora sherds, pottery, conch and shell bangles. Recent discovery of amphora and a lead ingot of the Roman period indicate that this site probably was involved in trade with the Mediterranean world.

Medieval period settlement

Medieval period settlement has been identified at a number of places on the island. The majority of present-day habitation is in fact built over medieval period ruins. A number of coins, pottery, iron cannons and stone anchors

Figure 3. Habitational remains exposed in a cliff section in BDK-I.

Figure 4. Harappan seal made on conch shell.

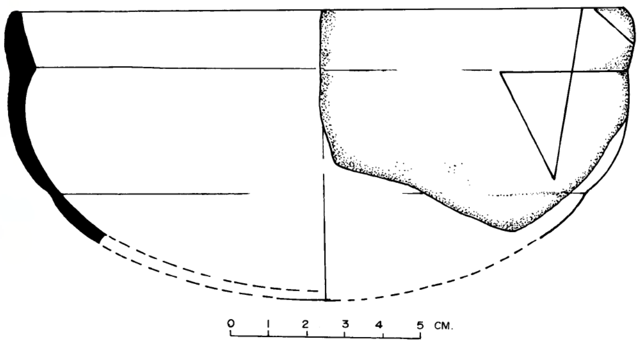

Figure 5. Harappan graffiti over a potsherd.

Figure 6. Archaeological site near Khuda Dost Dargah exposed during low tide.

belonging to this period have been found on the island. The Island had good contact with mainland settlement in the Okhamandal area. In fact, most of the modern villages came into existence during the medieval period. The discovery of five iron cannons suggests that the island was protected with a defence system during the late medieval period. A large number of stone anchors found near present-day Bet Dwarka jetty indicate that this location was used for anchoring boats during the medieval period.

Evidences on sea level/shoreline changes

As stated above, two archaeological sites have been affected by the shoreline changes. One historical period site (Figure 6) becomes submerged during high tide near Khuda Dost Dargah[13]. Another protohistoric site has been severely damaged by the sea and a large number of pieces of pottery and other artifacts can be found in the inter-tidal zone. This evidence suggests that some kind of shoreline change has taken place since 2000–3000 years BP. A geological study by Shakhawala and Shringarpure[1] indicates two faults on the island located near Panchatirtha and also Soni Miyar. At least one of the historical period sites is located upon the Soni Miyar fault. Tectonic activity therefore provides the explanation as to why this site becomes inundated. The submergence of sites near Nilkanth Mahadev Temple, however, requires an alternative explanation and must be further investigated.

TL dating

At the time of firing, any previously acquired TL stored within the crystalline lattice of TL-sensitive minerals contained within a piece of pottery is reset to zero. From that moment onwards the TL signal begins to rebuild at a rate dependent upon the amount of the long-lived isotopes of uranium, thorium and potassium present. Rubidium and cosmic radiation play a smaller contributory role and the entire radiation flux level is modified by the presence of water. Thus, if the amount of stored TL energy induced since firing (archaeological dose) and the radiation flux level are measured, the age of the potsherd may be computed from the basic equation:

$$\text{TL age} = \frac{\text{Archaeological dose}}{\text{Annual radiation dose}}.$$

TL dating methodology

Each of the nine potsherds analysed and reported in the study were dated by means of the fine-grain additive method as described by Aitken[14,15]. This technique utilizes the 1–8 micrometre polymineral grain size fraction extracted from an internal portion of the sherd. This fraction was settled out of a 6-cm column of acetone onto a series of 1-cm aluminium planchettes. Sixteen such sample aliquots were prepared for each sample analysed. Five aliquots were used for the determination of natural TL accumulated since the time of firing. These aliquots were further utilized to determine the supralinearity correction for each sherd[14]. Seven aliquots were serially and incrementally irradiated by means of a calibrated $^{(90)}$Sr plaque radiation source and the remaining four using a calibrated $^{(241)}$Am radiation source, and the subsequent data used to determine the *k*-factor as described by Aitken[14]. All sample aliquots were heated to 500°C at a rate of 20°C/s in a high-purity nitrogen atmosphere. The natural and laboratory-induced TL emitted was detected with an EMI 9635QA photomultiplier fitted with a Corning 9–59 blue transmission filter. All first-glow TL outputs were corrected for aliquot-to-aliquot variation using a second-glow procedure involving a secondary irradiation of approximately 28 greys. In a single case only (W2879) did there appear to be a suggestion of TL sensitivity change due to the laboratory procedure followed. Finally, the archaeological radiation dose accumulated since the time of the last firing was determined from the natural and beta-irradiated data and the alpha-radiation efficiency factor (k) from the natural and alpha-induced TL data. The k value was used in the determination of the amount of radiation received annually by the potsherd under study.

The annual radiation dose received by the sherds was determined by means of thick-source alpha counting to determine the radiation contribution from uranium and thorium, and flame spectroscopy to determine the potassium content of each of the sherds. Smaller, comparatively negligible, contributions from rubidium were included assuming a value of 100 ppm, and an annual cosmic contribution of 185 micrograys was also assumed. As the radiation flux-levels from within the sherds is relatively high (average approximately 5000 micrograys per year) these contributions are comparatively insignificant. The environmental (gamma) radiation dose derived from the soil, etc. in the nearby vicinity of the sherds was computed assuming that the uranium, thorium and potassium levels were the same as those measured for the sherd itself. It was not possible to refine this measurement as soil samples were not available for this purpose.

The final annual radiation flux-level computed for each sherd was corrected for an assumed average water content of 10%. Extremely crude, porous pottery may have a maximum water content as high as 25% (ref. 14), but the pottery studied here is not of a porous nature. However, an underestimation of the pottery moisture content of 1% will result in underestimation in age of approximately 1%. Hence the final age of sample W2879 becomes 1460 years BP assuming a 15% moisture content, as opposed 1380 years BP (uncorrected for fading) assuming a 10% water content.

Because of the polymineral nature of these samples, it is possible that the TL-sensitive minerals may not store TL in a stable fashion over long time periods. Aitken[14] suggests that the first defence against such an effect is the so-called temperature plateau comparison, where the shape of the first TL glow-curves are compared with that of the recently, laboratory-induced glow-curves over a given temperature range (200–500°C). If the trapped electrons are stored in a stable fashion, a plot of the ratio of the natural TL divided by the natural TL plus laboratory-induced TL against temperature should result in a plateau region between 300 and 500°C. Aitken[14] also suggests that all laboratory irradiations should be performed 24 h before TL measurement. In order to further guard against the effect of TL fading, all sample aliquots were preheated to a temperature of 150°C for 5 min prior to TL measurement. Finally, and in addition to the precautions described, the amount of TL fading over a minimum 21-day period at 70°C was actually measured for each potsherd. A series of sample aliquots were irradiated (c. 56 greys) and stored at the conditions specified. Following storage, the TL output exhibited by these aliquots was compared with the output displayed by similar newly irradiated sample aliquots. This procedure is described by Aitken[14] and takes advantage of the fact that most TL fading takes place over the initial storage period. The results of this exercise are shown in Table 1, where sample ages are given in both uncorrected and corrected form.

The analytical technique followed for this chronological exercise differs from that generally adopted in the TL authentication of pottery. Here, annual radiation flux levels are measured using full samples for determination of sample-specific activity and potassium content. In the case of TL authentication, the amount of sample available is prohibited and these measurements must generally be conducted on lesser representative sample amounts. TL fading tests were also conducted, which is generally not the case for TL authenticity analysis.

The sherds analysed in this study were collected 10 years prior to the actual TL analysis and were not collected with the sole purpose of TL analysis. The sherds were properly identified and labelled accordingly before storage under dry, clean, ambient conditions. Given the relatively brief storage period compared to the age of the sherds, the environmental radiation dose delivered to the sherds during this time is relatively negligible. More appreciable is the environmental radiation dose delivered prior to sample collection, as this is totally unknown and can only be assumed to be as that delivered to by each of the sherds internally. This uncertainty is acknowledged and any future TL analysis should include measurement of the environmental radiation dose levels delivered from the burial soil along with the burial depth, to enable the correct cosmic radiation contribution to be made. These sherds should therefore be collected with the purpose of TL analysis in mind. Mindful of the limitations of these present determinations, we are of the opinion that this study forms, at the very least, a first step in the understanding of the chronology of pottery in the study area.

TL dating results

Nine potsherds have been analysed using TL and with the exception of three, all samples are more or less similar to our assumption (Table 1). Two dates, i.e. W2876 and W2877 are very close to, or fall into the protohistoric period if the laboratory TL-fading loss is taken into account. The age of the third potsherd (W2878) is also close to the protohistoric period at the one standard deviation level.

Sample W2876 is from a perforated jar collected from site BDK-VI, which is popularly accepted as Harappan pottery that continued through until late Harappan. The final TL age for this potsherd is 3260 ± 470 years BP. However, after the fading correction this age becomes 3380 ± 490 years BP. Late Harappan culture anywhere in the Indian subcontinent closes around 1500 BC when perforated jars disappear from the archaeological sites[1]. A second potsherd represents a rim portion of red-ware bowl. Similar types of bowls have been found at Rang-

Table 1. Thermoluminescence ages of pottery from Bet Dwarka island

Sl. no.	Site	Laboratory reference	Pottery type	Anticipated age (years BP)	Uncorrected for fading	Corrected for fading
1	BDK-VI	W2876	Perforated jar	4500–3500	3260 ± 470	3380 ± 490
2	BDK-I	W2877	Red-ware carinated dish	4500–3500	2460 ± 330	2790 ± 370
3	BDK-VI	W2878	Red-ware bowl	4000–3500	2300 ± 200	2430 ± 210
4	BDK-I	W2879	Rim portion of a jar	Unknown	1380 ± 150	1440 ± 160
5	BDK-I	W2880	Grey-ware bowl	4000–3500	1960 ± 160	2140 ± 170
6	BDK-I	W2881*	Red-ware lid	2000	740 ± 50	890 ± 60
7	BDK-Khuda Dost	W2882	Red-ware bowl	2000	1000 ± 170	1060 ± 180
8	BDK-II	W2883	Red-ware bowl	2000	1270 ± 380	1370 ± 410
9	BDK-I	W2884	Red-ware bowl	4000	970 ± 120	1060 ± 130

*This sample (W2881) exhibited a TL-fading factor of more than 20% over the period of the test. This casts a degree of doubt upon the reliability of the final TL age computed.

pur, Prabhsa Patana, Lothal and other Harappan and late Harappan sites in Gujarat. This sherd was collected from a site near Balapur which has been designated as BDK-VI. A few sherds belonging to perforated jars and carinated dishes suggest that this was the late Harappan settlement[16]. The TL age for this potsherd is 2460 ± 330 years BP and the corrected date is 2790 ± 370 years BP. At the one standard deviation level, this date falls into the protohistoric period. However, two sherds (W2878 and W2880) appear to be associated with the historical period, although our archaeological records suggest that these should be from the protohistoric period. One of these, a potsherd from a grey-ware bowl again belongs to the late Harappan period and was recovered from BDK-VI, and the other from BDK-I. The remaining pots could have their origin in the historical and medieval periods as jars, basins and bowls continue until the present day. To some extent therefore, this allays concern regarding the results of the dating of other potsherds. However the important point regarding the dating of other sherds is that the results suggest a continuous habitation on the island.

Discussion

The TL analysis of the Bet Dwarka potsherds has provided an opportunity to give a proper time bracket for Bet Dwarka archaeology, without dispute (Table 1). The TL age of one of these potsherds, W2876 (3380 years BP, corrected) falls within the protohistoric time period (5000–3000 years BP), which substantiates a settlement during the late Harappan period. Similarly, the age of another sherd (2790 years BP, corrected) is quite close to the end of the protohistoric period, certainly within one standard deviation (370 years). However, at the lower one standard deviation level, the age of this sherd falls into the historical period. Further, the ages of two sherds, W2878 and W2880, were expected to be within the protohistoric period but they fall into the early historical period (2430 and 2140 years BP). This anomaly could either be due to the fact that this type of pottery continued from the protohistoric period till the historical period, or as the sample was collected from surface it could actually be of a later period. Furthermore, it is also unlikely that the assumptions made regarding the environmental radiation dose received by these sherds could account for this discrepancy, as this forms only 25% of the total annual radiation dose in each case. In our opinion the second option is also eliminated, as nowhere in the vicinity have we found continuance of pottery of this type from the protohistoric period to the historic period. If the first option is taken into consideration, then it will provide evidence of the continuation of Harappan pottery up to historical period in Saurashtra region.

Conclusions

To some extent, the TL ages of the pottery from Bet Dwarka island here endorse the hypothesis on the cultural sequence of Bet Dwarka island established earlier. Accordingly, habitation record at the island begins from protohistoric period (4000 years BP) to medieval period (500 years BP). When seen in conjunction with other finds from the island, i.e. seal inscriptions, large number of anchors, shell working sites, etc., we can suggest that the island of Bet Dwarka was an important active port since ancient times and remained in the limelight for a long time. Bet Dwarka has provided a continuous habitation, which suggests that this island played a vital role in maritime activities since Harappan times. The apparent continuation of the protohistoric pottery into the historical period needs careful study. When confirmed, this will help in unravelling the problem of Okhamandal archaeology, and these present TL ages will provide the initial evidence for a solution to this conundrum.

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