

Tamil Nadu shelf ranged from 2.6 to 5.6 m with run-up distances of the order of 150–800 m. Inundation caused due to the surge was higher over the Nagapattinam–Cuddalore part of the Tamil Nadu shelf, resulting in loss of human life of the order of a few thousands, in addition to heavy loss of property. Analysis of geophysical data of Tamil Nadu margin indicates that the higher amplitudes of tsunami surge and inundation are mainly due to the concave morphology of the shelf, apart from the fact that this part of the east coast of India is relatively at close proximity to the source of the tsunami. The straight nature of the coast with a gentle shelf/slope gradient, and the fault controlled structure of the basin resulting in concave shelf morphology, are some of the major factors that might have helped the rapid surge into this part of the shelf.

Similar analysis of bathymetry, magnetic and gravity data of the entire ECMI might help to demarcate risk-prone zones for tsunami surge and also in identifying zones of coastal seismicity which may be potential sources for local tsunamis. The fact that even ten months after the Sumatra event, aftershocks (>5.0 M) still continue in the Andaman and Nicobar segment of the Sunda trench, stresses the importance of these studies over the ECMI, which is now faced with a new type of natural hazard in the form of tsunamis, unusual to this part of the Indian Ocean.

1. Gupta, H. K., Early warning system for oceanographic disasters in Indian Ocean (tsunami and storm): The Indian initiative. *J. Geol. Soc. India*, 2005, **65**, 639–646.
2. McCloskey, J., Nalbrant, S. S. and Steacy, S., Scientist issue Indonesia earthquake warning. *Nature*, 2005, **434**, 291.
3. Satish Singh, Disastrous Sumatra earthquake: Sea monster – a post-mortem mitigation study for future mega-thrust earthquake in the Indian Ocean. Paper presented at the Indo-French Collaboration Meet on Sumatra Earthquake, New Delhi, 22 February 2005.
4. Sieh, K., Aceh-Andaman earthquake: what happened and what next? *Nature*, 2005, **434**, 573–574.
5. Radhakrishna, B. P., Devastating tsunami strikes coastline of India. *J. Geol. Soc. India*, 2005, **65**, 129–134.
6. Stein, S. and Okal, E., Speed and size of the Sumatra earthquake. *Nature*, 2005, **434**, 581–582.
7. Murthy, K. S. R., First oceanographic expedition to survey the impact of the Sumatra earthquake and tsunami. *Curr. Sci.*, 2005, **88**, 1038–1039.
8. Subramanian, B. R., Report submitted to DST, New Delhi on seismic and tidal pattern in Andaman and Nicobar Islands, 2005, pp. 1–77.
9. Chadha, R. K., Latha, G., Yeh, H., Peterson, C. and Katada, T., The tsunami of the great Sumatra earthquake of *M* 9.0 on 26 December 2004. Impact on the east coast of India. *Curr. Sci.*, 2005, **88**, 1297–1301.
10. Murthy, K. S. R., Subrahmanyam, A. S., Lakshminarayana, S., Chandrasekhar, D. V. and Rao, T. C. S., Some geodynamic aspects of Krishna–Godavari basin, east coast of India. *Continental Shelf Res.*, 1995, **15**, 779–788.
11. Murthy, K. S. R., Malleswara Rao, M. M., Venkateswarlu, K., Subrahmanyam, A. S., Lakshminarayana, S. and Rao, T. C. S., Marine magnetic anomalies as a link between granulite belts of east coast of India and Enderbyland of Antarctica. *J. Geol. Soc. India*, 1997, **49**, 153–158.
12. Murthy, K. S. R., Rao, T. C. S., Subrahmanyam, A. S., Malleswara Rao, M. M. and Lakshminarayana, S., Structural lineaments from the magnetic anomaly maps of the eastern continental margin of India and NW Bengal Fan. *Mar. Geol.*, 1993, **114**, 171–183.
13. Subrahmanyam, A. S., Lakshminarayana, S., Chandrasekhar, D. V., Murthy, K. S. R. and Rao, T. C. S., Offshore structural trends from magnetic data over Cauvery Basin, east coast of India. *J. Geol. Soc. India*, 1995, **46**, 269–273.
14. Murty, G. P. S., Subrahmanyam, A. S., Murthy, K. S. R. and Sarma, K. V. L. N. S., Evidence of fault reactivation off Pondicherry coast from marine geophysical data. *Curr. Sci.*, 2002, **83**, 1446–1449.
15. Raval, U., Some factors responsible for the devastation in Nagapattinam region due to tsunami of 26 December 2004. *J. Geol. Soc. India*, 2005, **65**, 647–649.
16. Subrahmanyam, C., Gireesh, R. and Gahalaut, V., Continental slope characteristics along the tsunami-affected areas of eastern offshore of India and Sri Lanka. *J. Geol. Soc. India*, 2005, **65**, 778–780.
17. Varadachari, V. V. R., Nair, R. R. and Murthy, P. S. N., Submarine canyons off the Coromandel coast. *Bull. Natl. Inst. Sci.*, 1968, **38**, 457–462.
18. Rao, L. H. J., Rao, T. S., Reddy, D. R. S., Biswas, N. R., Mohapatra, G. P. and Murty, P. S. N., Morphology and sedimentation of continental slope, rise and abyssal plain of western part of Bay of Bengal. *Geol. Surv. India, Spec. Publ.*, 1992, **29**, 209–217.

ACKNOWLEDGEMENTS. We thank Dr Satish R. Shetye, Director, NIO, Goa for encouragement. Thanks are also due to the reviewer for his suggestions. This is NIO contribution no. 4134.

Received 2 December 2005; revised accepted 7 February 2006

Acheulian cave at Susroni, Konkan, Maharashtra

Ashok Marathe

Deccan College Postgraduate and Research Institute,
Pune 411 006, India

The discovery of a Late Acheulian cave occupation at Susroni in Palshet near Guhagar, on the banks of a small perennial stream, near a waterfall, at a height of 85 m amsl and 2 km inland is the first of its kind on the more than 7500 km long coastline or on the Deccan plateau. On the basis of observations made on tool typology, geomorphology and lithostratigraphy, it is shown that early man occupied the cave during early Late Pleistocene.

Keywords: Acheulian, Maharashtra, Palaeolithic, Susroni.

THE Acheulian tradition forms a distinctive facies of the Lower Palaeolithic. The tradition derives its name from

e-mail: pranav@pn2.vsnl.net.in

Saint Acheul (Amines, France) on the river Somme where it was first recognized in 1850. In European terminology, the term Acheulian refers to bifacially flaked stone artefacts having varying proportions of large cutting tools – handaxes, cleavers, picks and other tools^{1,2}. The Acheulian is the first industrial complex to have attained and attempted standardization and symmetry of form. The earliest Acheulian tools date back about 1.6 to 1.5 myr ago, the tradition lasted till about 0.1 myr ago. During this period the stone tool assemblages betray an evolving trend towards finer forms and they can be subdivided into three chronological stages, namely, Early, Middle and Late Acheulian. Each stage is characterized by the relative frequency of certain tool types and predominance of specific manufacturing techniques³⁻⁷.

The first discovery of the Acheulian in India was the Palaeolithic artefact discovered by Robert Bruce Foote^{8,9} at Pallavaram near Madras in Tamil Nadu. The discovered find was an Acheulian handaxe which was recovered from the detrital laterite gravel deposit. Since then the Palaeolithic research in India is more than 130 years old, however, noteworthy developments in the Palaeolithic studies began only from 1950 onward. There was intensification of regional studies and they established the existence of different cultural stages in various parts of India. Especially, the coastal regions of India provide much scope for the Acheulian studies. The west coast continues to be a promising area as the data from Kerala, Karnataka, Goa, Konkan, south Gujarat, Saurashtra and Kutch¹⁰ have shown. The earliest Palaeolithic discoveries on the west coast of India were from Kandivli (Mumbai) by Todd in 1932. With the exception of Saurashtra¹¹, all the Palaeolithic artefacts discovered so far from the Western littoral are surface collections, and further work is essential in documenting well-preserved sites, particularly cave sites such as those described in this paper.

The previous work carried out on the Palaeolithic of Konkan can be summarized as follows. The first survey of the Palaeolithic sites in the Konkan was carried out by Todd. He collected a number of artefacts from surface sites from Worli Point, Kandivli (Mumbai) to as far south as Jaygad. The former comprised of choppers, handaxes and cleavers of the Chellean/Acheulian stages. He also found Mesolithic artefacts at several sites in Mumbai and Salsette¹²⁻¹⁴. This work was resumed in Konkan two decades later by Malik. His discoveries were the finds of a handaxe at Nala Sopara and Ghodbundar^{15,16}. Sankalia explored Kandivli and surrounding regions with Zeuner in 1949, with McCown in 1958 and again in 1960 with Misra and Mohapatra¹⁷. Guzder began work in north Konkan in 1970. She discovered Palaeolithic sites around Malvan in south Konkan¹⁸. Joshi and Bopardikar on behalf of the Archaeological Survey of India also explored the region around Kolaba and Ratnagiri districts. Their major discoveries were of Mesolithic cave sites at Pachad (District Raigadh) and Hatkhamba (District Ratnagiri). Lower

and Middle Palaeolithic artefacts were discovered around Mahad (District Raigadh) as surface finds¹⁹. After 1972, no further work on the Palaeolithic studies was carried out in the Konkan region until the author began work in 2001. Under such circumstances, this is the first discovery of a coastal Acheulian cave site on the coast of India.

Fieldwork was carried out by a number of field visits during 2001 and 2002 around Guhagar (17°30'N, 73°14'E), a town on the coast, 15 km south of Anjanvel, the headquarters of Guhagar taluka of Ratnagiri District (Figure 1). The initial explorations were confined to Guhagar, Palshet and Hedvi and were aimed at locating the Palaeolithic sites either on surface or in the caves. Three important sites were discovered: (i) Two Early Acheulian cleavers were collected on the surface near the cave at Susroni in Palshet (17°26'N, 73°15'E). (ii) A few Early Acheulian choppers and a cleaver were collected on the surface near a cave at Mandavkarwadi in Palshet; (iii) A good number of cattle bones with chopping marks on them, were collected inside a cave near Hedvi (17°21'N, 73°16'E).

After the explorations, because of the occurrence of two Acheulian artefacts on the surface, it was decided to carry out an excavation at Susroni in Palshet. Palshet is a small village, 12 km south of Guhagar. A number of minor streams originate on the lateritic plateau at a level of 120 m amsl and they have a steep gradient. All such streams flow through deep, narrow gorges; meet the main stream near Palshet; and finally drain into the Arabian Sea. On the bank of a small perennial stream, near a waterfall, at a height of 85 m amsl and 2 km away from the sea there is a cave in the laterite (Figure 2). The cave has developed as a result of karstic weathering process operating within the heterogeneous mass of coastal laterite and later on, it was occupied by early man. This location is known as Sus-

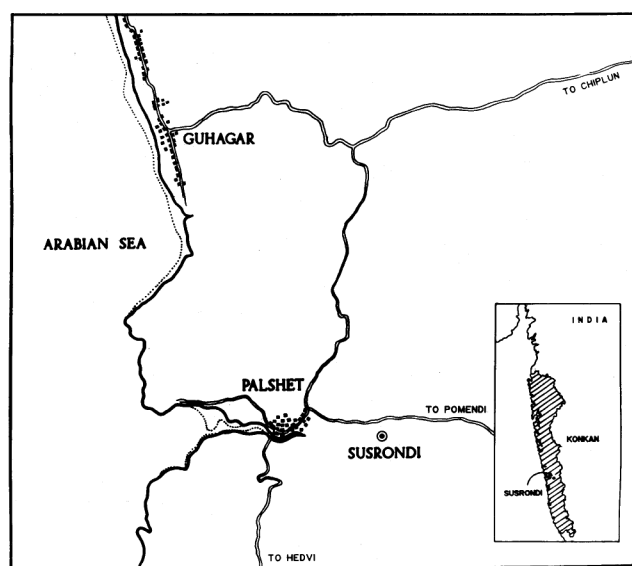


Figure 1. Location map.

rondi, 1 km east of Barbhai, in Palshet. The entrance of the cave is facing the south, it is rectangular in shape, 1.5 m wide and 2.5 m in height. There was a huge boulder (more than 3.5 m high) at the front of the entrance and therefore, it was difficult to enter the cave. It was necessary to clear the entrance for removing the debris from inside the cave. The boulder was cleared with the help of multiple mine blasts. The cave was completely filled with lateritic pebbly gravel and the ceiling was only 1 m high from the surface of the gravel. The area after entering the cave was 5 m × 4 m, further there were two passageways towards east and north. It is believed that the north passageway is very deep in the laterite and runs many metres towards the end of the laterite plateau, while the eastern passageway is 2 m deep.

Two trenches were dug into the floor of the cave (Figure 3). The trench (Figure 4) measuring 2 m × 3 m was oriented in the east west direction. Samples of the deposit were collected at every 50 cm level from the top. Upper 1.5 m was angular lateritic pebbly gravel with blocks of laterite. It was underlined with 0.6 m angular lateritic gravelly



Figure 2. Acheulian cave.

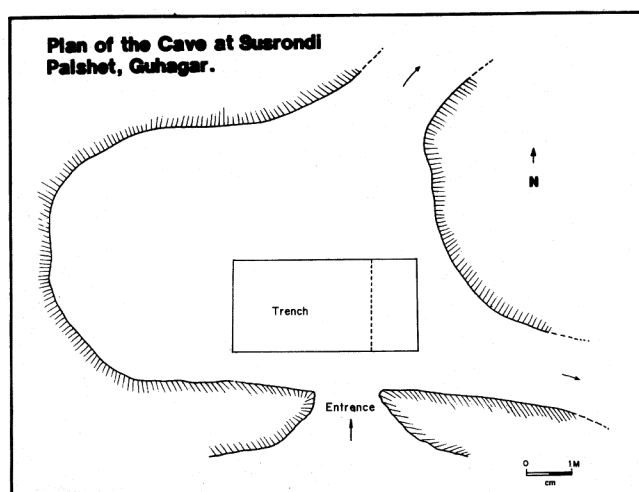


Figure 3. Plan of the cave.

silt with blocks of Deccan Trap and gradually grading into silty clay up to the bottom of the trench, i.e. 2.7 m from the top. The deposit is considerably finer and graded. Acheulian artefacts were discovered at a depth of 2.4 to 2.7 m level from the top. Below 3.2 m subsurface water-level was encountered and the deposits grades into reddish brown mottled clay. Therefore, a 1 × 1 m step trench was dug towards the eastern side at 1.2 m below the first trench. It was dug to a depth of 2.2 m from the top and at this level subsurface water-level was encountered and therefore, it was not possible to dig further.

During the survey an interesting and useful section was observed near Velneshwar, 12 km from Palshet, 110 m amsl and 2 km away from the sea. A well has been dug in the laterite. In this freshly dug section fluvio-estuarine sediments containing ironstone bands, white kaolinite claystone, gravel bed with laterite pebbles and greyish green clays were observed. The sedimentary sequence is capped by ferruginous laterite crust, thereby suggesting ferricretization of fluvio-estuarine sediments which occur 90 m amsl and 2 km inland from the present shore.

The collection comprises of both flake (76%) and core (24%) tools (Figures 5 and 6). The majority of artefacts are on flakes. Among the flakes, end-struck types predominate over the side-struck ones in the ratio of 5:1. There is a clear indication that man has utilized the natural shapes of the raw material. The ventral surface was left comparatively untouched and larger primary flakes were struck off from the convex dorsal surface. Subsequently, the margins were retouched by removing finer flakes. Thus minimum work has been done only along the lateral sides.

The collection consists of 54 artefacts (Table 1), and as noted earlier, were collected from the strata at the depth of 2.7 m in a layer of 30 cm thick deposit.

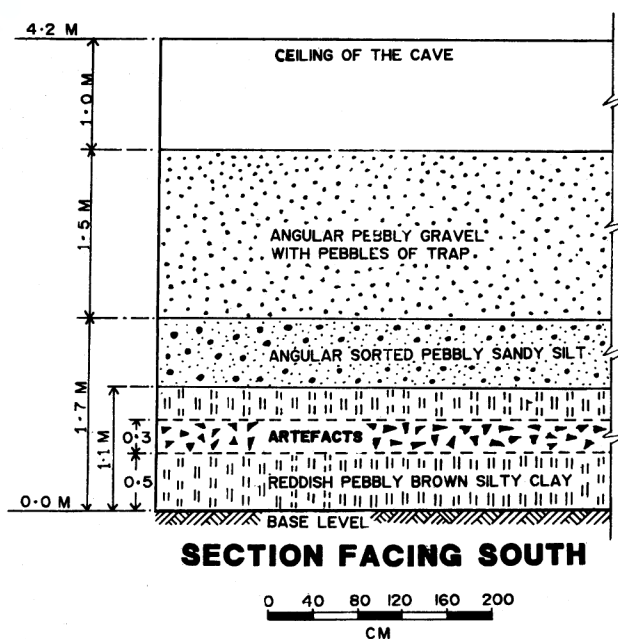


Figure 4. Section of the cave.

Stone artefacts are made on acidic derivatives of the locally occurring Deccan Trap basalt, with a glossy, lustrous colour, varying from greyish-green to dark grey to brown and buff colour. The material is fine-grained and has typical conchoidal fracture. The artefacts are extremely fresh with clear flake-scars and betray razor-sharp margins. The freshness of these specimens suggests that after the desertification of the site by early man, artefacts were preserved because of the sediment cover.

Typologically, the assemblage shows a higher proportion of shaped tools (92.5%) than the simple artefacts (7.4%). Handaxes, cleavers, picks, choppers and scrapers are the five major components which comprise of shaped-tools.

Handaxes: Typologically there are two of ovate-group and one of limande-group of handaxes. The ovate-group

of handaxes are small in size, symmetrical and broad. The transverse cross-section is biconvex. The handaxe of the limande-group is small and shows less workmanship as compared to the ovate-group. The transverse cross-section is plano-convex. The specimen is also mint fresh.

Cleavers: Both the specimens belong to divergent-edge and pointed-butt type. Both are fashioned on side-struck flakes. In one example, the dorsal surface shows secondary working and in another both dorsal and ventral faces are beautifully worked with shallow, skimming scars. The working edge is trimmed from both sides. The transverse cross-section is biconvex.

Picks: These implements occur as a component of the Acheulian assemblage. None of these picks exceed 100 mm. Three picks are spatulated-picks and one is a beaked-pick. Two each are made on end-struck flakes and on chunks. The transverse cross-section is plano-convex.

Choppers: Choppers form the second largest shaped-tool group and comprise of the following types as side-choppers, end-choppers, two-edged choppers, circumferential choppers and pointed choppers. Dorsal and ventral faces are worked. The working edge extends for nearly the whole length of the lateral edge. The butt ends are mostly rounded or irregular and are usually without working.

Scrapers: In the collection, the scrapers form the largest group and bi-faces form the second largest group when grouped together. The typological distribution of the scrapers is as follows: end scrapers (4), side scrapers (10), double scrapers (9) and circumferential scrapers (4).

The tool kit composition of the collection shows the following techniques: Stone-hammer; cylinder-hammer; and prepared-platform.

The stone-hammer technique was employed to manufacture a negligible proportion of implements, which includes cleavers, choppers and scrapers. Flaking may be partial, unilateral, apical or all round the periphery. Some

Table 1. Artefacts collected during the study

Tool type	Number	%
Handaxes	3	5.5
Cleavers	2	3.7
Picks	4	7.4
Choppers	14	26
Scrapers	27	50
Flakes	2	3.7
Cores	2	3.7
Total	54	100

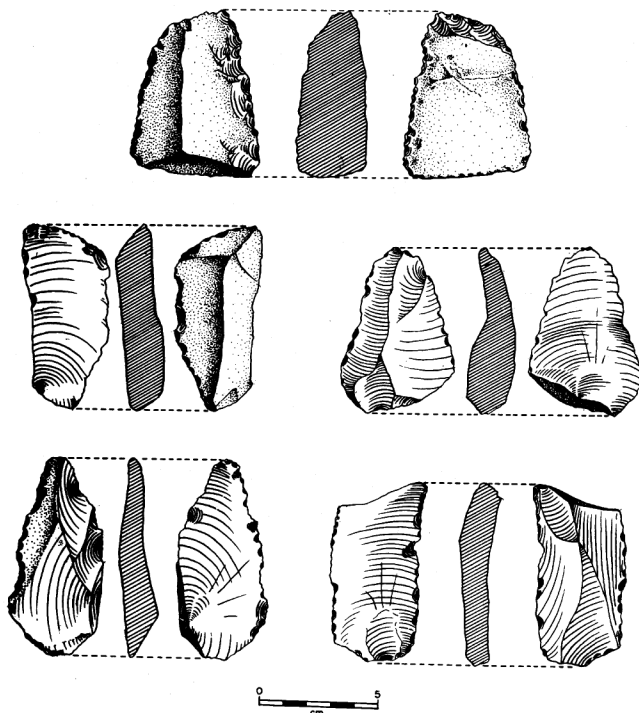


Figure 5. Tool drawings.



Figure 6. Artefacts collected in the cave.

specimens are flaked from both surfaces but the nature of flake-scars for the product of stone-hammer technique are always deep and large, outlines irregular and surfaces uneven and in certain cases retain the cortex.

The collection indicates an overall preponderance of cylinder-hammer technique in the manufacture of cleavers and in the secondary work of cleavers and other implements made on flakes. All implements produced by the cylinder-hammer technique exhibit small, shallow flake-scars, symmetrical outlines, thin sections and even surfaces, especially the handaxe and cleavers showing secondary scars, around the entire circumference. Several flake-scrapers display the type of edge-retouching which generally is common in the Middle Palaeolithic group of scrapers. A small number of diminutive flake implements denotes the presence of prepared-platform technique, but none shows faceted platform. The skimming scars, invariably shallow and usually rounded on the dorsal surface(s) have been obtained due to subsequent working but not because of special preparation beforehand.

Kleindienst⁸ has pointed out that 'a large composite Acheulian collection (random sample) should include 40–60% of handaxe/cleavers/knives; 20–45% of small implements and varying percentages of other components. As such, variability within the Acheulian assemblage(s) in India has not been worked out, albeit the Acheulian occurrence from a few excavated sites; open air as well as cave-like or rock-shelter sites, tend to represent preponderance of bifaces at some assemblages and proportionate abundance of 'chopper-chopping tools' at others.

The total number of excavated Acheulian sites in India is 22. The Acheulian sites with geological context are: Anagwadi, District Bijapur, Karnataka²⁰; Mahadeo Piparia, District Narsingpur, Madhya Pradesh^{21,22}; Hiran valley, District Junagadh, Gujarat²³; Samadhiala, District Bhavnagar, Gujarat²⁴; Madhuban, District Bhavnagar, Gujarat²⁵ – and those with archaeological context are: Adamgarh, District Hoshangabad, Madhya Pradesh²⁶; Bhimbetka, District Raisen, Madhya Pradesh^{27,28}; Chirki, District Ahmednagar, Maharashtra^{29,30}; Hunsgi, District Gulbarga, Karnataka^{31,32}; Lalitpur, District Jhansi, Uttar Pradesh³³; Isampur, District Gulbarga, Karnataka^{34,35}.

The sites at Adamgarh and Bhimbetka are cave-like or rock-shelter occupations. The industries recovered from Lalitpur, Mahadeo Piparia, Adamgarh, Chirki, Anagwadi, Hunsgi and the Hiran valley represent the earlier phase or Early Acheulian; Madhuban represents Middle Acheulian and Samadhiala represents Late Acheulian in India. However, there are considerable inter-industry, typological and technological variability as well as temporal differences.

Against this background the occurrence at Susroni is considered in a primary archaeological context and shows preponderance of bifaces (handaxes, cleavers, small-picks together forming 52.5%), of which picks are 11.5%, a low percentage of choppers (12.2%) and high percentage of

scrapers (35.3%). Of the long sharp edge tools, handaxes (number: 2) and cleavers (number: 3) do not, as at some of the Early Acheulian collections in India, vary in proportionate representation so greatly. Characteristic handaxe forms are ovate and limande; cleaver-forms are restricted to divergent edges group. Picks also smaller in size as well as choppers. The light duty tools, viz. scrapers are exclusively fashioned on flakes. The bifaces from Susroni clearly show 'Advanced' Acheulian characters. The assemblages include refined forms of bifaces. Therefore, considering the characters and stylistic techno-morphological features, the assemblage from Susroni is assigned to the Late Acheulian tradition in India.

The evidences of man-land relationship are only in the form of geomorphic features. In the absence of precise work, particularly in the off-shore zones, it is not possible to establish accurately the trend and nature of the eustatic changes. The picture of the sea level changes during the Quaternary is hazy. The laterite, the gravels, the alluvium and the littoral deposits are the relict indicators of the palaeoprocesses. In the same way, erosional/depositional activities and weathering/leaching processes have varied in the intensity and extent from time to time. Similarly, the hypothesis of the polycyclic origin of the landscape perceives minimum five cycles of lateral planation and intermittent incision during Neogene and Pleistocene period (Figure 7). The deep weathering and stripping of laterite presumes a major episode of dissection and stripping during late Neogene or early Pleistocene period. The succeeding erosional history of mid- and late Pleistocene period is totally blank, as no records exist in the landscape. During the terminal phase of Pleistocene the intensity of erosion was high due to low sea level. The episode terminated with the widespread deposition during the early Holocene epoch. At present, all the rivers are incised, most likely due to ubiquitous mid-Holocene rejuvenation. In the absence of high level gravel and due to the absence of raised beaches, beach rocks, oysters on the coast, it is difficult to comment on the depositional history.

On the basis of above-mentioned background of the palaeoprocesses in the region, stratigraphy of cave deposits and tool typology, it can be deduced that: The stratigraphy in a well section near Velneswar shows that the entire coastal fringe area around Guhagar and Palshet was at a low elevation during the Late Tertiary. The region attained its present elevation of 120 m amsl due to Neogene/Early Pleistocene uplift. Thus, the drainage and the karstic caves in this region are therefore of the early mid-Pleistocene age. These observations are in concurrence with the outcome of earlier studies carried out around Ratnagiri³⁶. The cave sediments bring to light interesting stratigraphy and contemporary palaeoenvironment. The cave was occupied by early man during the early Late Pleistocene (approximately earlier than 90 Ka BP) when the sea level was slightly higher than that today. This is explained by the lower fine-grained mottled clay (about 80 cm thick).

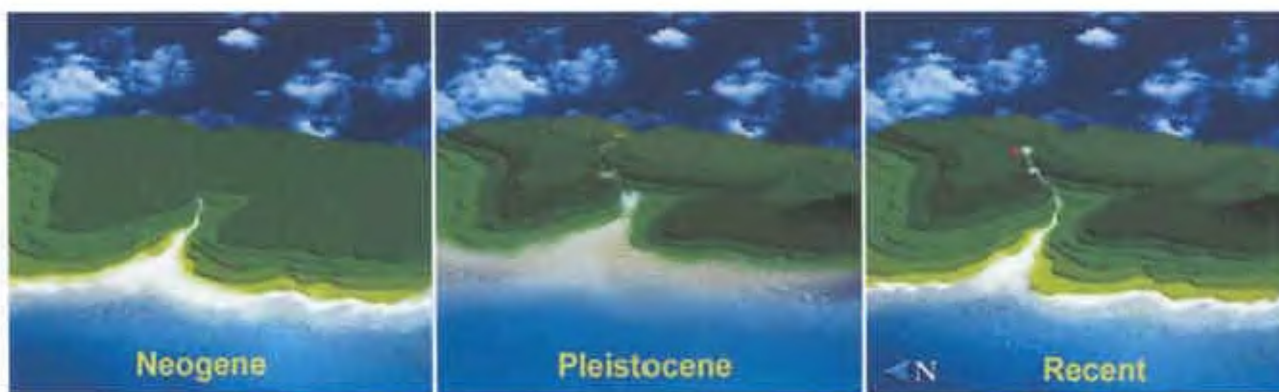


Figure 7. Block diagram showing palaeo processes through time.

Acheulian man occupied the cave during this phase. The situation continued even during his occupancy. Immediately after this phase, a rubble deposit (1.5 m thick) occurred, capping the artefacts-bearing layer. The rubble deposit indicates increased intensity of mechanical weathering in response to relative degree of aridity prevailing in the area during the Last Glacial Maxima, when the sea level was low by at least 100 m and the climate was largely cold and dry³⁷.

There were sincere efforts by several workers during the last seventy years in the pursuit of early man, on the Indian coast. However, this is the first convincing discovery of Late Acheulian coastal cave occupation on the more than 7500 km long coastline of India. The discovery of Palaeolithic artefacts from a cave site in a stratified context is of great significance for deducing the chronology of Early man, related sea level and environmental changes in the Konkan region. The picture presented here, as based on geoarchaeological data is certainly incomplete but the prospects of achieving the record of man-land relationship are enormously tantalizing. The reconstruction of coastal environment during the early Late Pleistocene in this humid tropical part of Western India will provide innovative perception of man-land relationships in this part of India.

1. Bordes, F., *Typologie du Palaeolithique Ancien at Moyen, Bordeaux*: Delmas, 1961.
2. Bordes, F., *The Old Stone Age*, WUL009, Weidenfeld and Nicholson, London, 1968.
3. Clark, J. D., *The Prehistory of Africa*, Thames and Hudson, London, 1970.
4. Clark, J. D., A comparison of the Late Acheulian industries of Africa and the middle East. In *After the Australopithecines* (eds Butzer, K. W. and Issac, G. L.), Mouton, Chicago, 1975, pp. 605–659.
5. Clark, J. D., The Acheulian industrial complex in Africa and elsewhere. In *Integrative Paths to the Past: Palaeoanthropological Advances in Honour of F. Clark Howell* (eds Corruccini, R. S. and Ciochon, R. L.), Englewood Cliffs, New Jersey, 1994, pp. 451–469.

6. Howell, F. C. and Clark, J. D., Acheulian hunter-gatherers of sub-Saharan Africa. In *African Ecology and Human Evolution* (eds Howell and Bourliere, F.), Methuen, London, 1964, pp. 458–533.
7. Kleindienst, M. R., Variability within the Late Acheulian assemblage in East Africa. *South Afr. Archaeol. Bull.*, 1961, **XVI**, 35–52.
8. Foote, R. B., On the occurrence of stone implements from various parts of Madras and North Arcot Districts. Reprinted in 1966 in *Studies in Prehistory* (eds Sen, D. and Ghosh, A. K.), Firma K. L. Mukhopadhyay, Calcutta, 1866, pp. 1–22.
9. Foote, R. B., *The Foote Collection of Prehistoric and Protohistoric Antiquities*, Government Museum, Madras, 1916.
10. Marathe, A. R., Prehistory and Quaternary sea level changes along the West Coast of India: A summary. *Quaternary Environments and Geoarchaeology of India* (eds Wadia, S., Kovisettar, R. and Kale, V. S.), 1995, No. 32, pp. 405–413.
11. Marathe, A. R., Rajaguru, S. N. and Deodhar, P. G., Coastal Miliolite Formation and history of early man in Southern Saurashtra. In *Quaternary Deserts and Climatic Change* (eds Alsharhan, A. S., Glennie, K. W. and Whittle, G. L.), A.A. Balkema Publishers, Netherlands, 1996, pp. 701–711.
12. Todd, K. R. U., Prehistoric man around Bombay. *Proc. Prehist. Soc., East Anglia*, 1932, **7**, 35–42.
13. Todd, K. R. U., Palaeolithic industries of Bombay. *J. R. Anthropod. Inst.*, 1939, **LXIX**, 257–272.
14. Todd, K. R. U., The microlithic industries of Bombay. *Anc. Ind.*, 1950, **6**, 4–17.
15. Malik, S. C., *Stone Age Industries of the Bombay and Satara Districts*, M.S. University Arch. Ser. 4, Baroda, 1959.
16. Malik, S. C., Studies in the prehistory of western India with special reference to Gujarat, Unpublished PhD thesis, M.S. University, Baroda, 1963.
17. Sankalia, H. D., Stone age industries of Bombay: A re-appraisal. *J. Asiat. Soc., Bombay*, 1962, **34/35**, 120–131.
18. Guzder, S. J., *Quaternary Environments and Stone Age Cultures of the Konkan, Coastal Maharashtra, India*, Deccan College, Pune, 1980.
19. Joshi, R. V. and Bopardikar, B. P., Stone age cultures of Konkan. In *Archaeological Congress and Seminar Papers* (ed. Deo, S. B.), Nagpur, 1972, pp. 47–57.
20. Pappu, R. S., *Pleistocene Studies in the Upper Krishna Basin*, Deccan College, Pune, 1974.
21. Supekar, S. G., Pleistocene stratigraphy and prehistoric archaeology of the Central Narmada basin, PhD dissertation, University of Poona, Pune, 1968.
22. Supekar, S. G., Some observations on the Quaternary stratigraphy of the Central Narmada valley. *Recent Advances in Indo-Pacific*

- Prehistory* (eds Misra, V. N. and Bellwood, P.), Oxford-IBH, New Delhi, 1985, pp. 19–28.
23. Marathe, A. R., *Geoarchaeology of the Hiran Valley, Saurashtra, India*, Deccan College, Pune, 1981.
 24. Chakrabarti, S., The Prehistory of Bhavanagar District, Saurashtra, Gujarat State, Ph D dissertation, University of Poona, Pune, 1978.
 25. Marathe, A. R., Deodhar, P. G. and Rajaguru, S. N., Miliolite Formation and history of early man in Southern Saurashtra. *Quaternary Deserts and Climatic Change* (eds Alsharhan, A. S., Glennie, K. W. and Whittle, G. L.), A.A. Balkema Publishers, Netherlands, 1995, pp. 701–711.
 26. Joshi, R. V., *Stone Age Cultures of Central India: Report on the Excavations of Rock-shelters at Adamgarh, Madhya Pradesh*, Deccan College, Pune, 1978.
 27. Misra, V. N., The acheulian industry of rock shelter III F-23 at Bhimbetka, Central India: A preliminary study. *Puratattva*, 1978, **8**, 12–36.
 28. Misra, V. N., The acheulian succession at Bhimbetka, Central India. *Recent Advances in Indo-Pacific Prehistory* (eds Misra, V. N. and Bellwood, P.), Oxford-IBH, New Delhi, 1985, pp. 35–48.
 29. Corvinus, G., *A Survey of Pravara River System in Western Maharashtra, India*, Institute for Urgeschichte, Tubingen, 1981, Volume I.
 30. Corvinus, G., *A Survey of Pravara River System in Western Maharashtra, India*, Tubingen, Institute for Urgeschichte. 1983, Volume II.
 31. Paddayya, K., Excavations of an Acheulian site at Hunsgi, South India. *Curr. Anthropol.*, 1976, **17**, 760–761.
 32. Paddayya, K., The acheulian culture of the Hunsgi–Baichbal valleys, Peninsular India: A processual study. *Quartar*, 1991, **41/42**, 111–138.
 33. Singh, R., *Palaeolithic Industries of Northern Bundelkhand*, Ph D dissertation, University of Poona, Pune, 1965.
 34. Paddayya, K. and Petraglia, M. D., Isampur – an Acheulian workshop site in the Hunsgi valley, Gulbarga District, Karnataka. *Man Environ.*, 1997, **XXII**[2], pp. 94–100.
 35. Paddayya, K. and Petraglia, M. D., *Acheulian Workshop at Isampur, Hunsgi Valley, Karnataka: A Preliminary Report*, Bulletin of the Deccan College Research Institute, 1998, vol. 56–57, pp. 3–26.
 36. Rajaguru, S. N. and Marathe, A. R., Chronology of early man in Saurashtra, Gujarat. *Proceedings of the Symposium on Quaternary Episodes*, Department of Geology, M.S. University, Baroda, 1984, pp. 1–10.
 37. Hashmi, N. H., Nigam, R., Nair, R. R. and Rajagopalan, G., Holocene sea level fluctuations on Western Indian continental margin: An update. *J. Geol. Soc. India*, 1995, **46**, 157–162.

ACKNOWLEDGEMENTS. I thank Dr S. N. Rajaguru and Dr R. S. Pappu for visiting the site and for valuable discussions. I also thank Sri Chandrashekhar Joshi, Superintending Engineer, PWD, for valuable help during the excavation. I am grateful to Dr V. Shah, Sri Phule and Sri Dighe for help in the field.

Received 14 September 2002; revised accepted 23 December 2002

Editor's note: The delay in publication of this article is due to a regrettable error at the journal office.

FTIR signatures of type-II clathrates of carbon dioxide in natural quartz veins

P. S. R. Prasad*, K. Shiva Prasad and N. K. Thakur

Gas Hydrates Group, National Geophysical Research Institute, Hyderabad 500 007, India

***In situ* FTIR spectroscopy is used to probe the clathrate formation in H₂O–CO₂ inclusion in quartz veins by monitoring the spectral variations in 300–93 K. The characteristic spectral signatures of asymmetric stretching mode (ν_3) of CO₂ clathrates in both structure-I and structure-II are doublets at 2336, 2348 cm⁻¹, and 2337, 2349 cm⁻¹ respectively. Further, structure-II for CO₂ clathrate is metastable (it is stable in 93–215 K range), and it transforms into structure-I before melting.**

Keywords: Carbon dioxide, clathrates, FTIR, quartz veins, spectral signature.

METHANE hydrates (clathrates) are the non-stoichiometric inclusion compounds encaging a small, normally a polar (guest) molecule in the framework of hydrogen-bonded, ice-like host molecules, and exist as a stable solid phase at high gas pressures and/or low temperatures. Methane hydrates occurring in marine sediments are considered as an alternate energy source. Two main crystallographic structures of gas hydrates, cubic structures-I and II, are distinguished¹. The basic difference between these two types is in the occupancy ratio of the cages. The ratio of large to small cages in structure-I (sI) is 3 : 1, while that in structure-II (sII) is 1 : 2. Guest molecules such as methane (CH₄) and carbon dioxide (CO₂), most abundant in natural gas hydrates, are not known to form sII hydrates under moderate temperature and high-pressure conditions. Generally it is accepted that these guest molecules form sI in natural gas hydrates and in synthetic hydrates grown under conditions of similar geological occurrence. It is well known that Raman spectroscopy has distinct signatures of gas hydrates. Raman spectroscopy and infrared (IR) spectroscopy are complimentary tools. Use of IR in case of gas hydrates (IR) is difficult because of stronger nearby water modes. But, for CO₂ clathrates, as the modes of CO₂ and H₂O are well separated, IR spectroscopy provides vital information^{2–5}.

Some Raman spectroscopic investigations² on synthetic methane hydrates, in the pressure range 3.0–9.0 MPa and temperature range –15 to 15°C, have shown the signature of sII. Staykova³ observed transient formation of sII CO₂ hydrates during the growth of pure CO₂ hydrates on grains of ice. Fleyfel and Devlin⁴ have reported sII CO₂ hydrates on tetrahydrofuran (THF) hydrate in cryogenic condition

*For correspondence. (e-mail: psrprasad@ngri.res.in)