Geological Field Guide: Malvan (Maharashtra, India)

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Abstract We present a geological field guide for a lesser known location to (Indian) geologists from Maharashtra (India): Malvan. Geomorphological and structural geology exercises have been explained, and a few results have been shown from the 2016 field report of the third author.

1 Introduction

Fieldwork has been conducted by faculty members of the Department of Geology at St. Xavier's College (Mumbai) in Malvan for the last 25 years. Yet this exciting field location is much less known among geologists in India and abroad. One of the reasons is being that there have been no major research publications on this area despite there being a very good scope of undertaking structural geology and geomorphological studies. Various types of geological training can be conducted with students in and around this area. The place is free from political disturbance and is relatively less known to tourists. Through this chapter, we publish to the "world" an exciting field location and encourage researchers and academicians to explore it. One can watch the YouTube video (https://www.youtube.com/watch?v=Fpd84rADuC8) to have a more vivid look.

Third Year B.Sc. fieldwork is conducted over a period of 12 days out of which 10 days are allotted for the actual fieldwork and two days for travelling between Mumbai and Malvan by train. Some M.Sc. part 2 students also go to Malvan if they choose this area for their dissertation. The fieldwork is mandatory and is spread across fifth and sixth semester. In fifth semester, students prepare a pre-field report, which is evaluated out of 100 marks equivalent to 4 credits (spread across all courses). In the sixth semester, students are evaluated for actual performance during field work and the field report that they generate later on.

Malvan is situated on the Indian west coast within the Konkan coastal belt and comes under Sindhudurg district of Maharashtra. The extent of Malvan taluka may be

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approximately delineated with Gad River in the north, Kolamb and Tarkarli Beach in the west, Karli River in the south, and the Konkan railway track in the East (Fig. 1b).

The area has a considerable exposure of continental flood basalts. Vigorous rainfall has created extensive lateritic (soil) horizons; metamorphic and igneous rocks also occur locally.

Malvan is connected to adjacent talukas and towns like Kankavli, Ramgad, Devbag, and Kudal by road. There is no direct rail connectivity for Malvan. By road, while travelling from Mumbai, take Mumbai–Goa highway (NH-17) and exit toward Malvan to the right at Kasal. By rail, board the train going toward Goa and get off at Kudal station, then take a public transport (state transport bus/rickshaw) from Kudal to Malvan. It takes around 15 hrs to reach Malvan from St. Xavier's College, Mumbai. The distance between Kudal and Malvan by road is 30 km. One can also

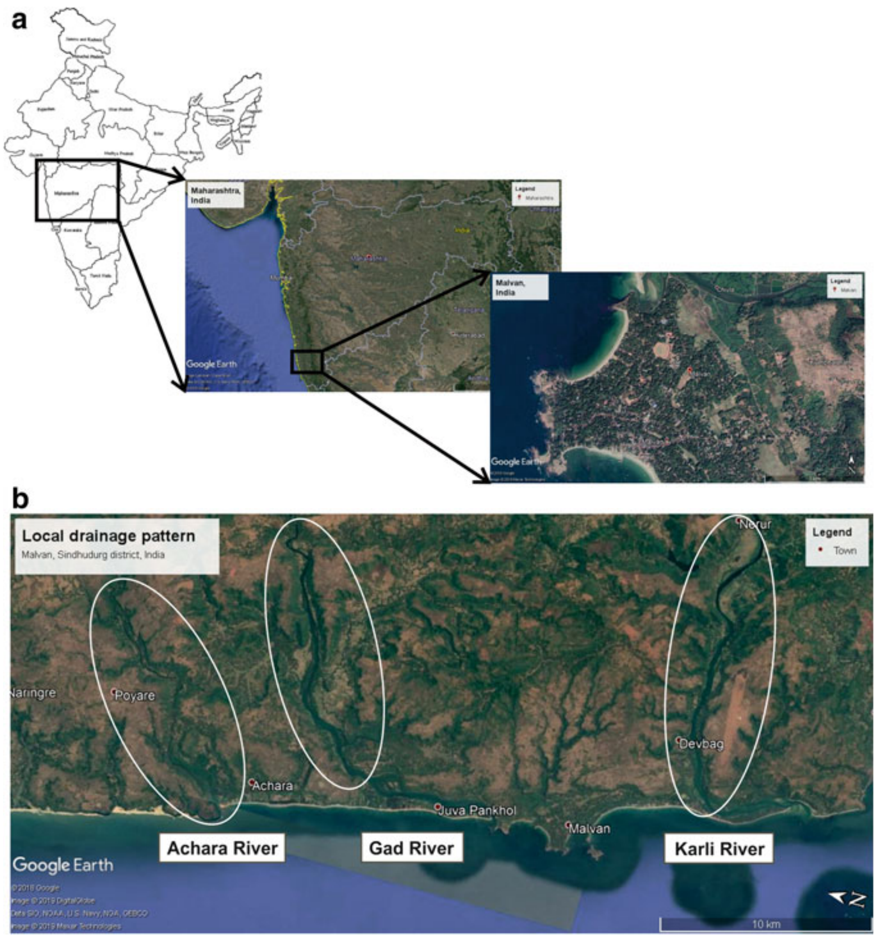

Fig. 1 **a** Location of study area. **b** Local drainage pattern, Malvan and the surrounding areas

travel by air, by taking a flight to the newly constructed airport at Chipi, Vengurla. The distance between Chipi Airport and Malvan by road is 21 km.

St. Xavier's College students and faculty members stay at Om Shraddha Lodge, near Chivala beach—this has been a tradition for the past 23 years. Om Shraddha Lodge is a clean, safe, and reasonably priced accommodation. There are a number of other hotels and resorts in the area, viz Hotel Chivala Beach and Sea Island Beach Resort, with dynamic pricing. The locals are cordial and welcoming, and some also provide home stay facilities for tourists. Malvani cuisine boasts a wide variety of vegetarian and nonvegetarian foods, especially seafood. Food is readily available in all local hotels.

Topography of the area under study is relatively rugged, it does house several detached residual hills with the lowest elevation being MSL and the highest being ≤150–230 m (Gupta and Rai 1987). The hills are outliers that are underlain by basalts. The first- and second-order river valleys are not very deep, although prominent in field. Several sand dunes are present along the coast. The area is characterized by dendritic to sub-dendritic drainage-pattern reflecting thereby impervious nature of the formations. At places, Karli River shows braided geometry in proximity to the coast, which may be due to fall in current velocity and increase in sediment load. Just south of Ramgad, small bar deposits occur on the right bank of Gad River. Drainage system of major rivers in the district is mostly sub-parallel while their tributaries have a rectangular drainage pattern (Mishra 2014).

About half the area of Sindhudurg district has a hilly terrain. The district has three major physiographic divisions: (i) the eastern strip close to Western Ghats highly dissected with deep valleys; (ii) the middle strip of the district occupied by flat-topped hills having elevations up to 300 m above the MSL covered by laterite; and (iii) the coastal plain in the western part with elevation 100–150 m above the MSL (Fig. 2). The physiographic features have given rise to five characteristic landforms viz (i)

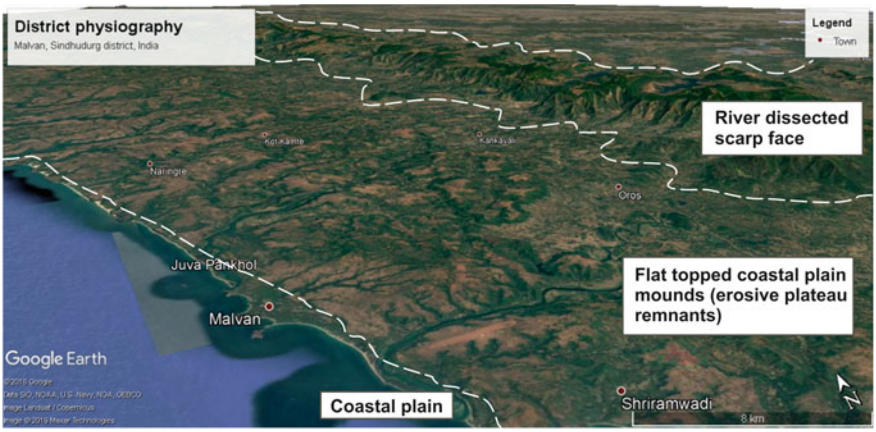

Fig. 2 Local physiography, Malvan and the surrounding areas

the coast line; (ii) the estuarine alluvial plains; (iii) the lateritic plateau; (iv) highly eroded remnant hills; and (v) scarp faces of Sahyadri hill ranges (Fig. 2).

2 Geomorphologic Exercises

2.1 Beach Profiling

A beach profile survey is a topographic/bathymetric survey of a beach carried out perpendicular to the shoreline at various points along the shore. Profiling is repeated multiple times at the same locations across long time periods. It is usually carried out during low tide so as to get the longest possible profile.

A beach profile survey serves as a way of cataloging effects on topography of beaches by long periods of heavy rainfall, floods, strong wave action, construction of manmade structures, etc. It serves as a means to determine total sand budget of the beach over a considerable amount of time. Preservation of beaches is important as it plays a major role in protecting shorelines from strong wave action and thus preventing the sea from encroaching landward.

Equipments required to carry out beach profiling are (i) measuring tape, (ii) clinometer/Brunton compass, (iii) pole/staff (taller than the Brunton bearer), and (iv) marker/bright colored ribbon. The procedure for beach profiling is as follows:

- The pole is held vertical, right against the Brunton bearer's eye, and a mark is made with a marker or a ribbon tied on the pole at the same height as the person's eyes distinct enough to be spotted from a distance.
- The survey begins with the Brunton bearer who logs readings of gradient also carrying the loose end of the tape, with the other end held up by the pole bearer who logs the distance.
- The Brunton bearer initially stands at the low tide line while the pole is held at the point where gradient changes from that on which the Brunton bearer is standing.
- The Brunton bearer at the low tide line sights the mark on the pole using the Brunton at eye level and adjusts the clinometers level. The gradient is directly read in degree and logged. At the same time, the Brunton bearer holds up the tape's loose end at his eye level while standing in the same stance as he was while the pole was marked. The pole bearer notes down the tape reading which corresponds to the length of patch of coast with a particular gradient (Fig. 3)
- The entire process is repeated after the Brunton bearer stands on the spot that the pole was placed previously, and the pole is shifted further landward to the very next point where the slope changes.
- When pole bearer reaches the end of the beach on the landward side and readings are taken, one set of beach profile is completed. Multiple sets are recorded in a similar fashion over a decided stretch of the shore line (Table 1).
- A graph of gradient versus distance along profile is plotted (Fig. 4).

Fig. 3 Positions of the Brunton bearer and pole bearer during beach profiling exercise

Table 1 Beach profiling readings

SET 1		SET 2		SET 3	
Gradient (in degrees)	Length (m)	Gradient (in degrees)	Length (m)	Gradient (in degrees)	Length (m)
14	11.10	9	9.64	2	4.55
4	6.50	7	3.83	5	9.30
9	1.35	12	2.40	9	3.32
-4	10.40	−1	9.50	−1	6.27
5	4.45	2	6.30	3	8.2

Sets 1, 2, and 3 consist of readings taken on parallel points on the beach ~50 m apart. A negative gradient indicates depression which could be caused due to removal of sand on the beach (this is a probable site for heavy mineral deposition), whereas positive gradient indicates that the land is elevated

3 Understanding Coastal Geomorphology

Coastal landforms are formed primarily due to *wave action* and *salt wedging (Davidson-Arnott, 2009).* The shore-features observed in Malvan are dominantly created by waves. The following features are observed at the locality in Malvan called 'Sarjekot' (16° 05′ 12″ N 73° 27′ 48″ E), in a 1.5km traverse along the coastline.

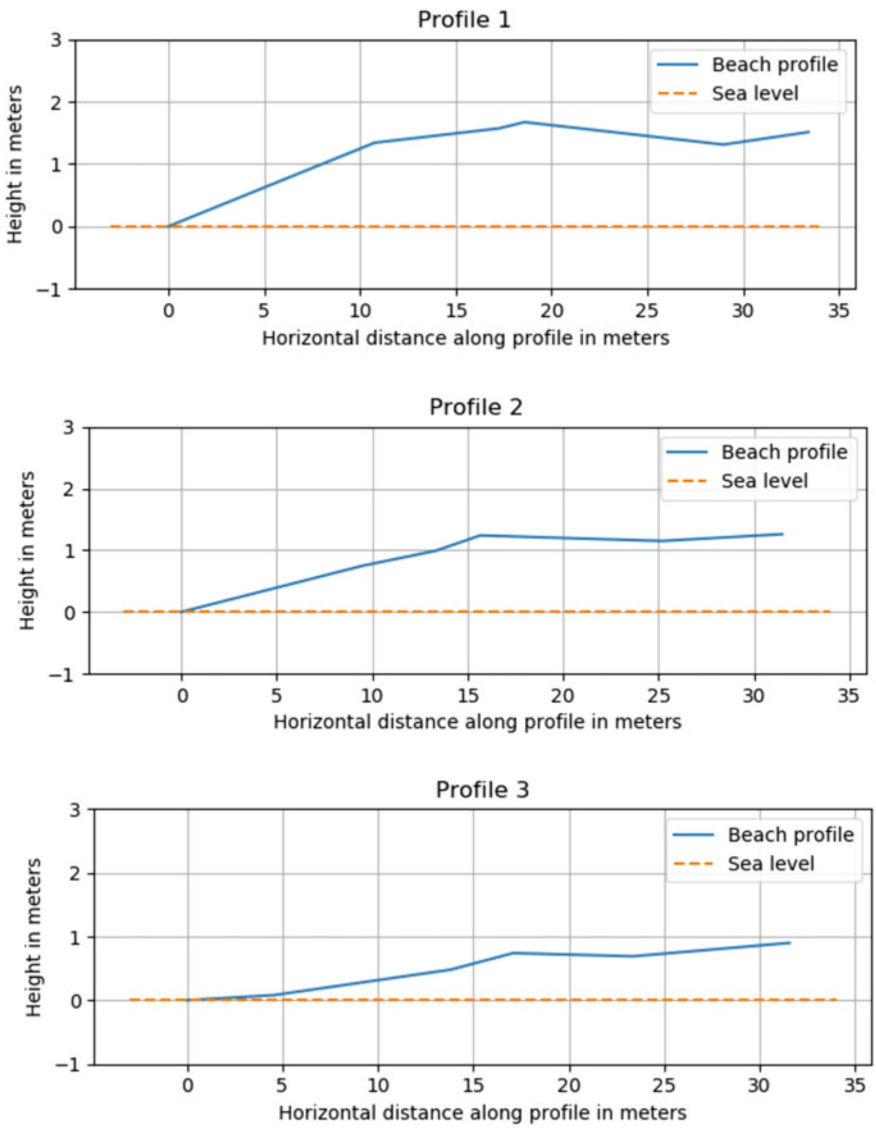

Fig. 4 Three sets of beach profiles

3.1 Sea Cave

A sea cave is a hollow excavated by waves in a zone of weakness on a cliff face (Fig. 5). A mature cave is deeper than its entrance width. Sea caves are likely to form in places of geological weakness such as bed contacts, bedding planes, joints, and

Fig. 5 A sea cave and headland

fault planes (Hugget 2007). Once a tiny part of the cliff face is wedged out, the rate of erosion becomes higher (Fig. 5).

3.2 Headland

A headland is a cliff of resistant rock strata projecting into the sea deeper than the surrounding coastline, with a tall scarp face and a rocky beach at its base formed primarily by erosion due to wave action. Such a structure is seen at Sarjekot (Fig. 5). The cliff is made up of secondary laterite.

3.3 Sea Corridor and Sea Stack

When a sea cave starts forming at two places in close proximity, the caves tend to meet at a certain distance inside the rock mass. The depth at which these caves meet is proportional to thickness of rock above the cave. When the caves meet, it forms a semi-circular hollow called a *'sea corridor'* (Fig. 6).

The corridor widens temporally leaving a narrow bridge like structure connecting the main rock mass to the one across the corridor. This narrow connection is called the *'sea arch'*. A sea arch becomes slimmer at a considerably fast rate and finally

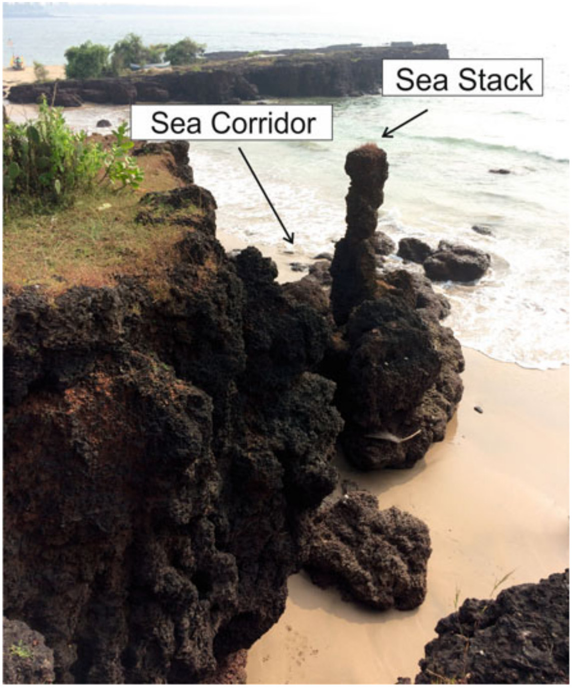

Fig. 6 Sea corridor and sea stack at Sarjekot

collapses leaving a rock mass detached from the main cliff called a 'sea stack'. It looks like an obelisk with a broad base and narrowed top (Fig. 6). These two structures discussed above form when height of cliff face is low, roughly, few tens of meters above the high waterline (Hugget 2007).

3.4 *Pothole*

Potholes are restricted to fluvial environments. They form due to swirling motion of stones and pebbles within depressions. The abrasive material is swirled due to flowing water in the river which enters the depression and induces circular motion to material within the depression. Over time, the depression deepens and forms a cylindrical hole that can go several tens of meters deep.

A large number of potholes were observed near Tarkarli in a dried river channel of the tributary of river Karli (Figs. 7 and 8) near a village named Devli (16° 00′ 59″ N 73° 29′ 52″ E). The tributary follows a NNW–SSE trend along a fault plane.

Fig. 7 A pothole north of Tarkarli, length of hammer marker ~25 cm, the pothole has a lenticular geometry owing to a high aspect ratio

Fig. 8 A giant pothole; students standing in the pothole for scale. Shiba Nikalje at right, waist to head height ~90 cm

3.5 Beach Barrier—Spit

Spit forms by the combined action of river and sea. When a river meets the sea, its velocity is countered by the action of waves in the opposite direction from the

Fig. 9 Satellite imagery of Kolamb Creek's double spit

sea. This leads to a sudden drop in velocity of water entering the sea and abrupt deposition of sand, silt, and sometimes clay. In case of the spit at 'Talashil' in Malvan, as deposition progressed, the pile of sediments has been reworked and reshaped by longshore current (Samant 1989). The final shape of the spit is a linear, elongated landmass running parallel to coast separated by the river also running parallel to the coast. This particular type of situation is called a *'bar-built estuary'*.

3.6 Beach Barrier—Paired Spit

A situation similar to the one observed at Talashil (Malvan) is also observed at the Kolamb Creek (Malvan). Also, the point where the river joins the sea is blocked partially by two spits projecting from either side of the river bank. Such spits are known as 'paired spit' (Fig. 9). The bay is filled with water throughout the year, even during low tides.

Paired spits form commonly in bays where frontal waves generate convergent longshore drifts from the headland on both sides of the bay. Thus, the spit grows evenly from either side of river bank rather than biased on a single side as in the case of Talashil. The influence of long-shore currents on Kolamb Creek's barrier system is absent as they are obstructed by the headland at Sarjekot (Fig. 9).

3.7 Tombolo

A tombolo connects Sindhudurg Fort to the mainland (Fig. 10). Tombolo forms due to splitting and deflection of waves around an island of considerable size in

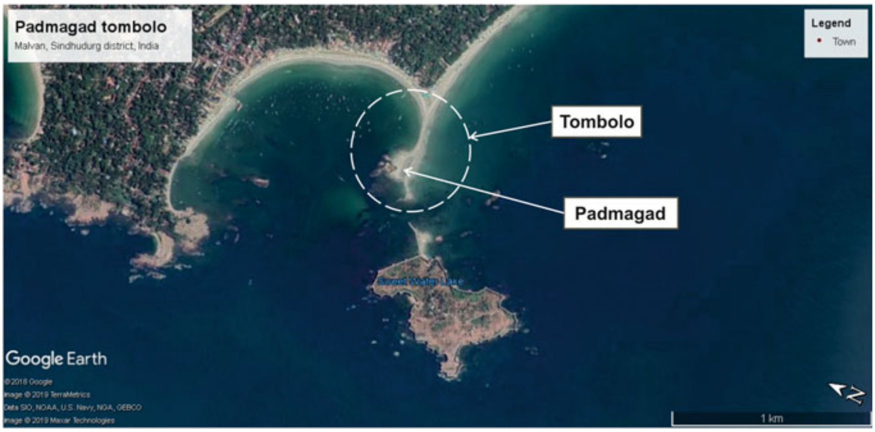

Fig. 10 Satellite image of Padmagad Tombolo

close proximity to the mainland. The waves meet again between the island and the mainland. As waves converge, water velocity suddenly drops leading to deposition of sand and silt. Continued sedimentation finally forms an elongate stretch of land connecting the island to mainland.

4 Geological Setting

Sindhudurg District exposes Peninsular Gneissic Complex, Sargur Group, Bababudan Group, Kaladgi Supergroup, and Deccan Trap Basalts, overlain by laterite and alluvium (Deshpande and Pitale 2014; Sarkar and Soman 2010; Duraiswami and Patankar 2011). The basement is defined by feldspathic gneisses and granites of Peninsular Gneissic Complex along with enclaves of Sargur Group. Sargur Supracrustals are represented by schistose amphibolites, metaconglomerate, quartzite, banded magnetite quartzite), graphite schist, mica-garnet schists, staurolite-kyanite-biotite schist, and calc-metasediments (Duraiswami and Patankar 2011). These rocks are intruded by chromite-bearing ultrabasic rocks near Vagda and Janavli (Kamble 1993). The contact between gneisses and Sargur Supergroup is gradational, indicating that the gneisses are much younger than the Sargur supracrustals (Koregave 1980). The metaconglomerate-quartzite sequence of the basal member of Bababudan Group (Walkunje Formation) extends along the coast of Malvan to Nivti (Sarkar and Soman 2010; Sarkar and Soman 1986) for >20 km. These rocks have been intruded extensively by basic to ultrabasic intrusives along with granites and pegmatites (Kamble 1993; Duraiswami and Patankar 2011). The Peninsular Gneisses and Dhawar Supergroup rocks are overlain by Kaladgi Supergroup with a prominent unconformity. The Kaladgi sediments are represented by

Fig. 11 Quartz veins in staurolite schist, Ramgad. Scale is 15cm

pebbly conglomerate, sandstones, and shales. Sarkar and Soman (2010) have recognized them as Achra Formation, which is subdivided into three members viz Golvan Sandstone, Bagayat Shale, and Poyra Sandstone Members in the order if decreasing antiquity. These rocks are cut by several faults. Faults are seen extensively concentrated more toward the coast than in the internal parts. This is also generally true for Deccan Trap rocks in and around Mumbai (Misra et al. 2014; Misra and Mukherjee 2017; Mukherjee et al. 2017 etc.). The general trend of fault planes is NW. Therefore, it may be stated that the coastline in Malvan is structure-controlled. The Deccan Trap Basalts occur in small patches and rest unconformably over the Archean rocks and the Kaladgi sediments. These basalts are sparsely/moderately porphyritic and occasionally contain (sub) rounded volcanic glass blebs. Occasionally, Early Holocene red and grey clays along with mollusc shells, wood, amber and peat are seen in dugwell sections along the coast (Kumaran et al. 2004). The area around Malvan is dominantly covered by lateritic capping, irrespective of the rock types under them. The alluvium is seen along the banks of rivers, estuaries, and streams. Beach sand and costal dunes are commonly seen throughout the stretch of coastline. Table 2 presents the stratigraphic succession as given by Gupta and Rai (1987), Samant (1989) Kumaran et al. (2004), Sen et al. (2012), and Prusty and Sarkar (2014).

5 Field Observations

5.1 Sargur Group

A traverse can be taken along the southerly flowing second-order stream near Ramgad [16° 14′ 28″ N, 73° 36′ 33″ E. Deformed staurolite-garnet-biotite schist belonging to Sargur Group is observed all along the stream bed. Staurolite schist shows prominent porphyroblasts of twinned staurolite with 5–12 cm size, with subordinate garnet porphyroblasts of ~5 mm size (Fig. 14). Schistosity is defined by parallel orientation of biotite flakes, and staurolite porphyroblasts make an angle to the schistosity. The foliation dips 30–40° toward ESE. The schist is intruded by two varieties of amphibolites namely schistose and granulose. Intrusions of quartz and pegmatite veins (Fig. 11) cut across the foliation of staurolite schist, and all intrusions trend E–W. Schistose amphibolites almost entirely consist of hornblende, while granulose amphibolites exhibit mineral composition Hornblende + Plagioclase + Quartz + Garnet. Garnet porphyroblasts in amphibolites are 5–6 mm in size and seen along with well-defined acicular hornblende. An outcrop of migmatized amphibolites of Sargur Group (?) exists near the Hanuman Mandir (temple), Kunkavle [16° 05′ 24″ N, 73° 34′ 51″ E]. The migmatites exhibit superposed folding: Type-2 and Type-3 of Ramsay (1967), Fig. 12 and parasitic folds (Fig. 13). Inliers of graphite schist, migmatized amphibolite, metaconglomerate, metapelites and dumortierite quartzite belonging to Sargur Group (Duraiswami and Patankar 2011) are seen in the areas around Sangam Maruti temple, Kankavli [16° 15′ 10″ N 73° 39′ 56″ E; ~48Km NE of Malvan] along Gad River Channel.

6 Peninsular Gneissic Complex

Feldspathic augen gneiss representing Peninsular Gneisses is well exposed at Ghumda [16° 03′ 57″ N, 73° 30′ 13″ E] near Kumbharmathi, in the stream bed of Anand Vahal (Fig. 15). The gneisses contain augens of feldspar (e.g., Mukherjee

Table 2 Regional stratigraphy of the Sindhudurg district, Maharashtra (Gupta and Rai 1987; Samant 1989; Kamble 1993; Kumaran et al. 2004; and Prusty and Sarkar 2014)

Alluvium (Holocene)
River terraces, beach dunes and sand ridges.
Local clay deposits with peat, plant remains, and mollusk shells.

Laterites (Plio-Pliestocene)
Primary laterite, reworked or secondary laterite.

Deccan Trap (Cretaceous-Paleogene)
Compact massive basalt, amygdaloidal basalt,
sparsely to moderately porphyritic basalt,
development of pillows at few localities.

----------------------*Unconformity*------------------------

Kaladgi Supergroup (Meso-Neoproterozoic)
Quartzite,
Ferruginous and carbonaceous shale
Ferruginous quartzite (at places grading to grit)
Conglomerate

----------------------*Unconformity*------------------------

Late intrusives Acidic rocks
Metabasic/ultrabasic intrusives

Bababudan Group (Archean)

Fuschite quartzite, Metapelites and Metavolcanics
Banded magnetite-quartzite
Polymict conglomerate-Quartzite
----------------------*Unknown contact*------------------------

Gneisses and Granites of Peninsular Gneissic Complex
----------------------*Unknown contact*------------------------

Sargur Group (Archean)

Kyanite-Staurolite-Biotite-Garnet Schist

Graphite schist

Ultrabasic intrusive

Dumortierite Quartzite-Metaconglomerate

----------------------*Basement not seen*------------------------

Fig. 12 Type '2' Superposed folding pattern in migmatite at Kunkavle. Length of marker ~13 cm

2017). Gneissosity is defined by parallel preferred orientation of biotite and hornblende (Fig. 16). Gneissosity trends N12° and dips steeply toward southeast. These gneisses exhibit three sets of joints trending N182°, N300°, and NE. Several ~ 15–75 cm wide meta dolerite dykes intrude the gneisses (Fig. 17). The metadolerite dykes intruding the gneisses at Kumbharmathi have an attitude of N322°/74, and show schistosity defined by parallel orientation of hornblende (Fig. 18). Another outcrop of Peninsular Gneiss is exposed near railway bridge at Kankavli [16° 15′ 14″ N, 73° 43′ 03″ E].

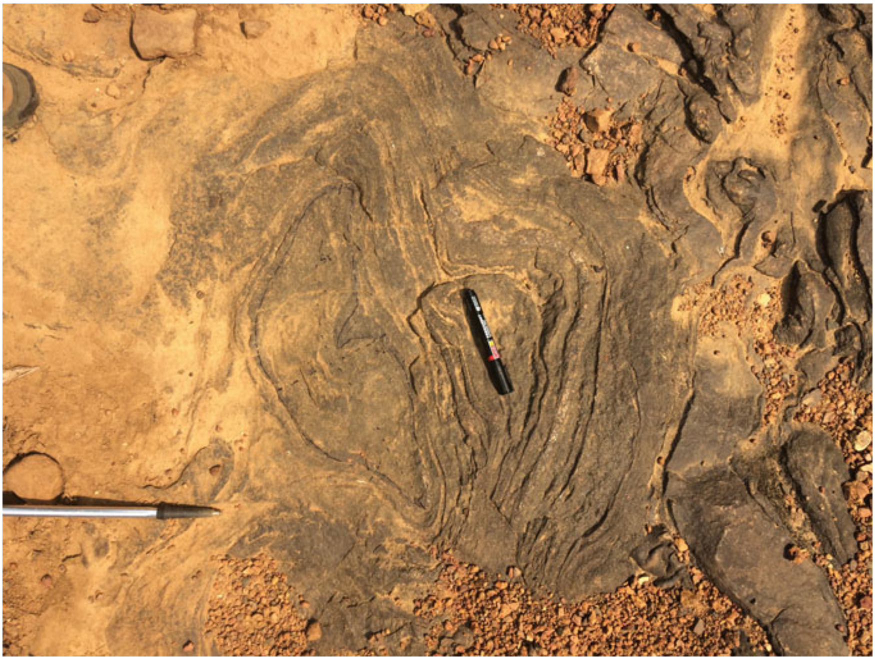

Fig. 13 Folds in migmatized amphibolites (Sargur Group?) seen at Kunkavle. Scale 15cm.

6.1 Dharwar Supergroup

The conglomerate-quartzite sequence of basal member of Bababduan Group (Sarkar and Soman 2010) is exposed on the coast near Santacruz Chapel, Rajkot [16° 03′ 19″ N, 73° 27′ 20″ E], and near the Rock Garden, Malvan, and can be traced for ~20 km toward S up to the coast of Nivti. Quartz grains in the quartzite show a preferred orientation defining locally a crude schistosity. These conglomerate-quartzite sequences are, folded into open, broad, doubly plunging folds (Fig. 19a) with axes plunging towards NNW and SSE. The folds near Rajkot are tight, while the folds near Rock Garden are open. Quartzites exhibit a variety of sedimentary structures, e.g., large-scale tabular and trough cross bedding (Figs. 19b and 20), hummocky cross bedding, festoon bedding, wedge cross bedding, sub-horizontal bedding, parallel bedding, climbing ripple laminations, and parallel laminations indicating their deposition in near-shore transition to inner-shelf environment (Sarkar and Soman 2010). The paleocurrent direction determined from large-scale tabular cross bedding is northwesterly. These quartzites also show soft sediment deformation structures such as convolute bedding (Fig. 21), syn-sedimentary faults, and slump folds. Along the syn-sedimentary faults, drag folds (different from tectonic drag folds as in Mukherjee 2014; Mukherjee et al. 2015) exist (Fig. 22).

Fig. 14 Staurolite schist outcrop in Ramgad, swiss knife for scale, length ~10 cm

Fig. 15 Peninsular Gneiss outcrop, Ghumda

Fig. 16 Peninsular gneiss sample, Ghumda

Fig. 17 Metadolerite dyke intruding in augen gneiss. Hammer ~25 cm in length for scale

Fig. 18 Metadolerite dyke sample, Kumbharmathi. Coin for scale, diameter ~2 cm

Interbedded between the quartzites are thick layers of polymict pebbly conglomerates, which show clasts of quartz, amphibolite, banded magnetite-quartzite, granite, gneiss, and varieties of quartzite, bounded by fine to medium sandy matrix containing fuschite mica and ferruginous cement (Figs. 23 and 24). The pebbles range in size from 5 to 10 cm and are preferentially bedding parallel. Pebbles are commonly elongated along NNW–SSE. The conglomerates are mostly parallel bedded, occasionally exhibiting wedge cross bedding (Sarkar and Soman 2010). Crude foliation defined by parallel preferred orientation of fracture cleavage is observed in these conglomerates. These sequences are cut by numerous E-W trending, near vertical faults. A strike slip fault can be observed behind Santacruz Chapel, Rajkot (Fig. 25). Alternating beds of these conglomerates and fuschite quartzite are well exposed within Sidhudurga Fort (Fig. 26) [16° 02′ 31″ N, 73° 27′ 36″ E].

The Dharwar metasediments represented by pebbly metaconglomerates, quartzites, and chlorite-sericite-schists are seen to be displaced by a NNE-trending fault, which is well exposed about 500m west of Devli [16° 01′ 00″ N, 73° 29′ 50″ E]. These metasediments dip steeply toward NNW and show a significant deformation.

Another outcrop of quartzites occurs near Deulwada [16° 03′ 30″ N, 73° 28′ 53″ E] Malvan, where it is overlain by laterite capping. The quartzites here show a large number of joints and fractures. Near vertical beds of quartzite strike ~N340°. These are cut by numerous small scale left-lateral strike slip faults trending ~N352° with up to 10 cm slip.

6.2 *Kaladgi Supergroup*

The Meso-Neoproterozoic Kaladgi Supergroup sediments are represented by ferruginous quartzites interbedded with ferruginous and carbonaceous shales. These crop out near Amdos-Wahalwadi [16° 06′ 09″ N, 73° 33′ 08″ E], Kuperi Ghat, and Shravan.

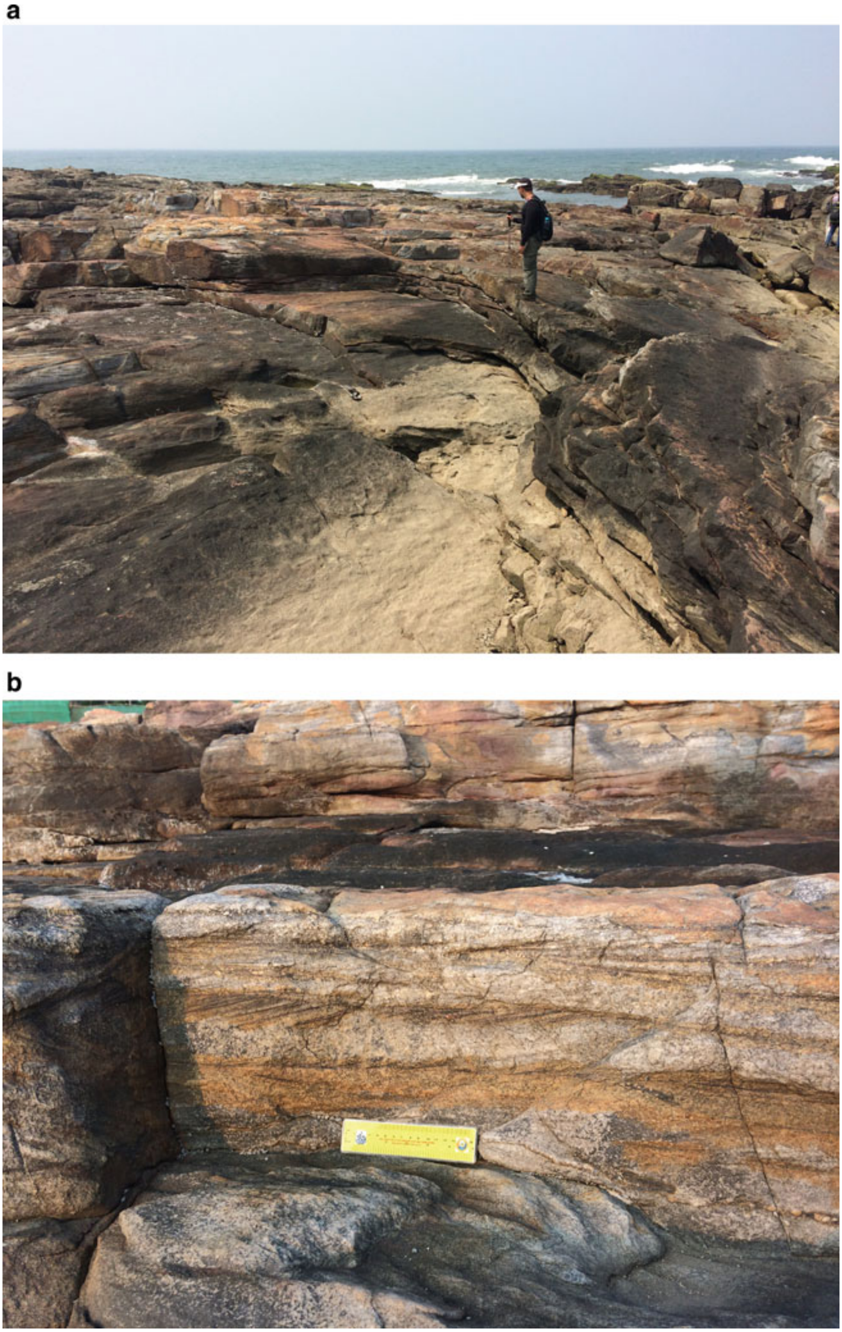

Fig. 19 **a** Open, plunging folds in quartzite near Rock Garden, Malvan. Ashwin Pundalik standing on the outcrop, height 163cm. **b** Tabular cross bedding, near Rock Garden, 15 cm scale as marker

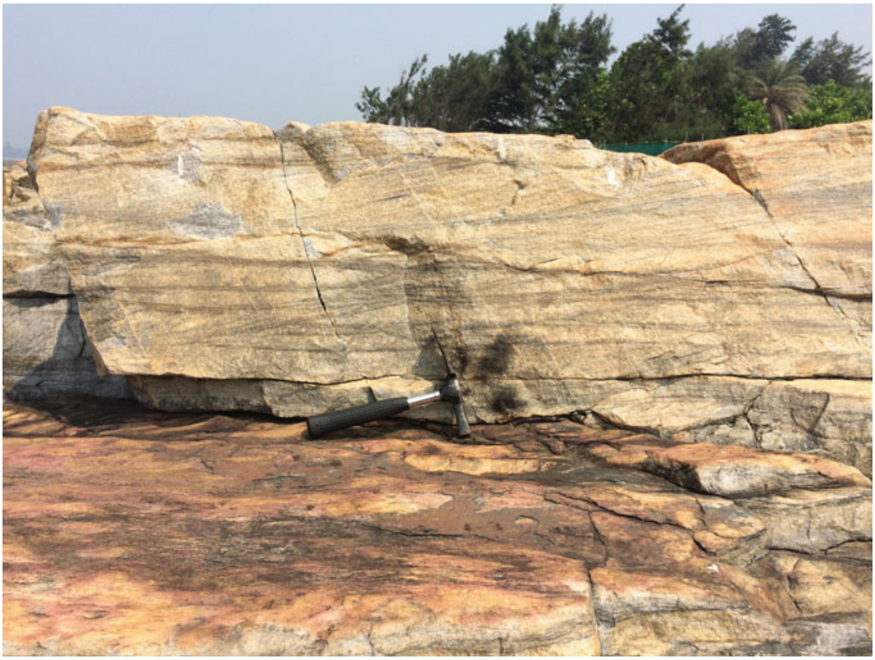

Fig. 20 Large-scale trough cross bedding near Rock Garden, 25 cm hammer for scale

Fig. 21 Convolute bedding, near Rock Garden

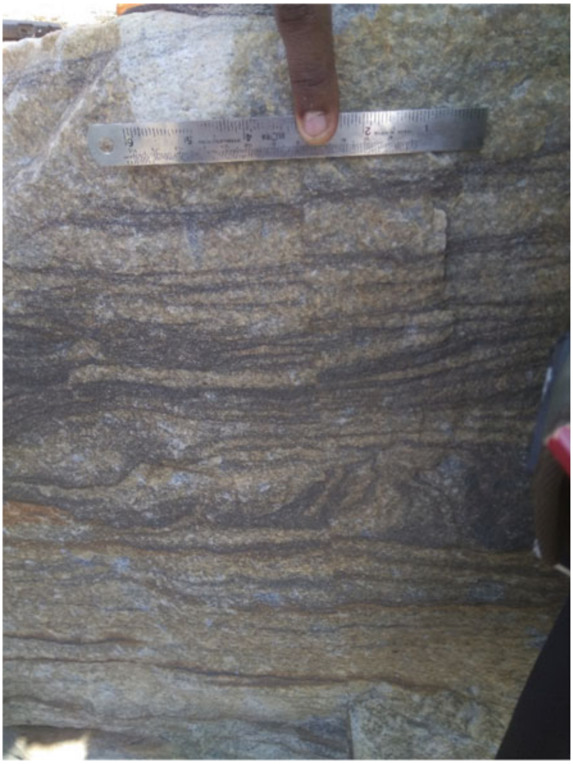

Fig. 22 Syn-sedimentary faults in quartzite, Rock Garden, Malvan. Scale is 15cm

Fig. 23 Sample showing quartzite and conglomerate contact, Rajkot

Fig. 24 Field photograph of polymict conglomerate outcrop at Rajkot, 15 cm scale

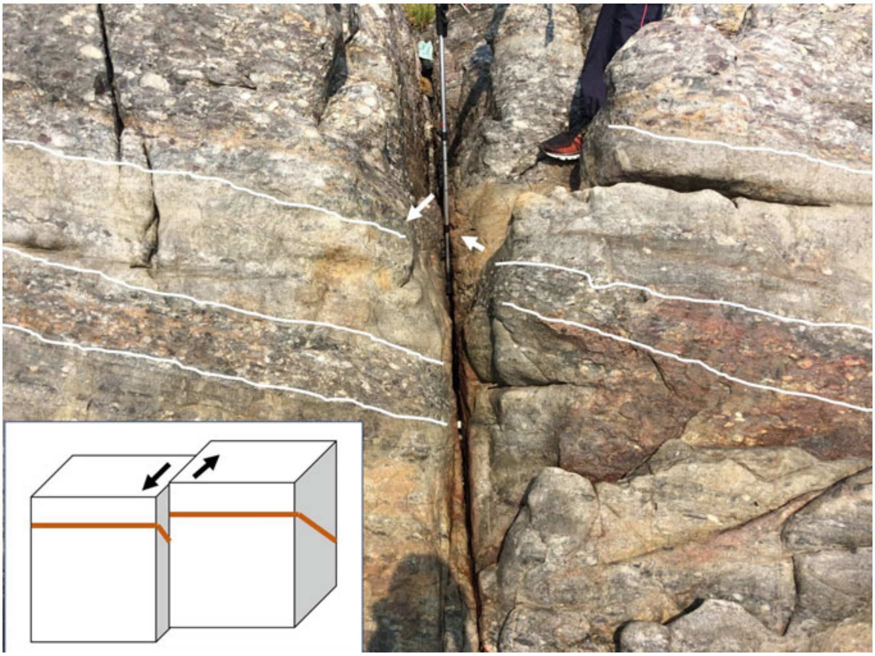

Fig. 25 Strike slip fault, displaced conglomerate bed marked in photograph and inset shows the box diagram, Rajkot

Fig. 26 Bedding in fuschite quartzite of Bababuddan Group, Sindhudurg Fort

Laminated shales (Fig. 27) alternating with ferruginous quartzite in turn capped by a thick laterite body occur near Vahalwadi. These are exposed in open, broad folds plunging gently toward north. These can easily be inferred from the topographic map, where the two cuestas can be seen with dip slopes facing toward east and west. The Kaladgi sediments form the elevated portion of the Kuperi Ghat section, where

Fig. 27 Thinly laminated shale sample, Vahalwadi

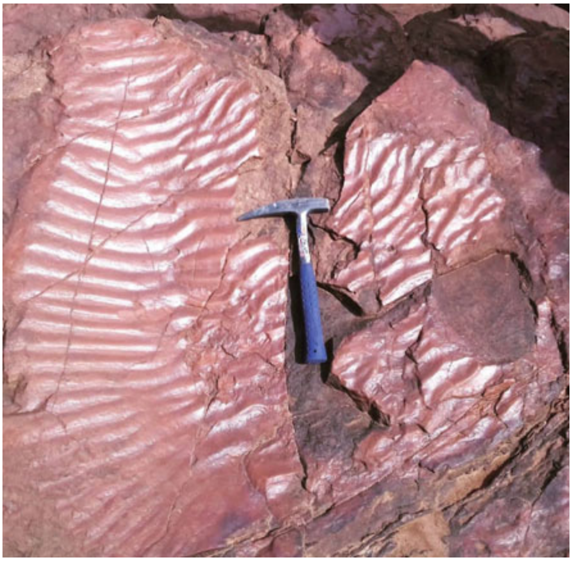

Fig. 28 Well-preserved wave ripples, Shravan. Hammer 25 cm, length

they seem to be resting unconformably on migmatized amphibolites of Sargur Group (?) exposed near Kunkavle.

The Kaladgi sediments overly sericite phyllites of Dharwar Supergroup with a prominent nonconformity near Rathiwde and in Gad River bed near Belna and Shravan. Here, they are represented by thin layers of ferruginous oligomict pebbly conglomerate passing upward into ferruginous coarse- to fine-grained sandstones with occasional buff-colored shale. These sandstones show sedimentary structures viz parallel bedding, tabular and trough cross bedding, and very well-preserved, well-defined wave ripples (Fig. 28).

6.3 Deccan Trap Basalts

The Deccan basalts occur as patches in the study area. These are massive and mostly aphyric (Fig. 29).

Locally, basalts with blebs of volcanic glass (Fig. 30) occur in a laterite quarry near Devli [16° 00′ 5″ N, 73° 30′ 0″ E] where basalts are seen underlying the laterite.

6.4 Primary and Secondary Laterite

Laterites in Malvan are of two types—primary and secondary/reworked. The primary laterite has formed from varieties of rocks (Fig. 31), and it constitutes a thick capping

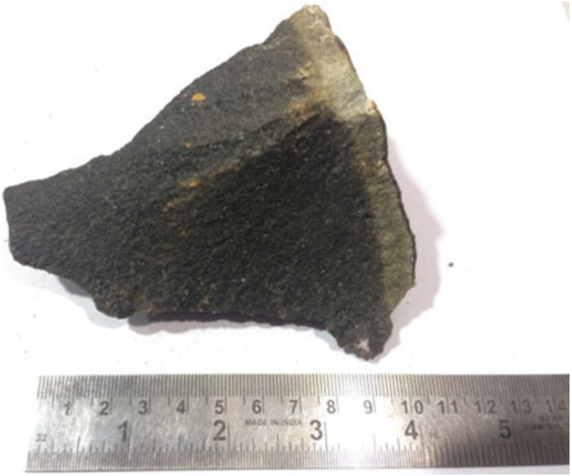

Fig. 29 Basalt sample from a quarry, Devli

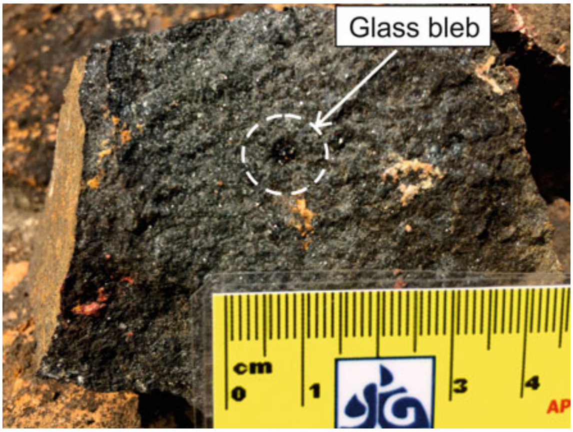

Fig. 30 Basalt sample with a glassy bleb in it (pointed by arrow)

on large areas forming flat-topped hills. Due to this laterite capping, underlying rock types can only be seen in valleys or stream beds. A complete laterite profile can be seen in abandoned laterite quarries near Deulwada, Malvan, where laterites overly Dharwar quartzites. However, due to dense vegetation and risk of rockfall, the outcrop must be approached with great caution. Excellent quarry sections of primary laterites can be seen in the areas around Amdos (Fig. 32) and Kumbharmathi. Secondary laterite having conglomerate-like appearance (Fig. 33), due to re-lithification of the lateritic and other rock debris, has formed all around the coast of Sarjekot [16° 04′ 58″ N, 73° 27′ 29″ E] and is well exposed in coastal cliffs, exhibiting variety of coastal geomorphic features discussed earlier (Sect. 3) (Fig. 34).

Fig. 31 Laterite sample, Devulvada

Fig. 32 Laterite quarry, Amdos

6.5 *Holocene Clays*

Early Holocene clays are seen in a pile of dug well debris near Ozar [16° 05′ 43″ N, 73° 28′ 52″ E]. Amber, pyrite, and lignite/peat (Kumaran et al. 2004) are found—all

Fig. 33 Secondary laterite sample, Sarjekot

contained within clay. Plenty of ferruginized pneumatophores along with other plant remains are also found (Figs. 35 and 36).

Fig. 34 Sea arch formed in secondary laterite, Sarjekot

Fig. 35 Amber collected during 2010 fieldwork

Fig. 36 Amber collected during 2018 fieldwork

6.6 Beach Sand

The Malvan area has extensive stretches of scenic beaches at Tarkarli, Malvan, Chivla, Talashil, and Deobag. The beaches show well-developed beach profiles as already described in Sect. 2.1. Various types of primary sedimentary structures such as horizontal parallel bedding, horizontal parallel lamination, ripple lamination, and wave ripples can be observed and studied in these sands (Figs. 37 and 38). On Tarkarli beach, a small stream merges with the sea and exhibits variety of current ripple

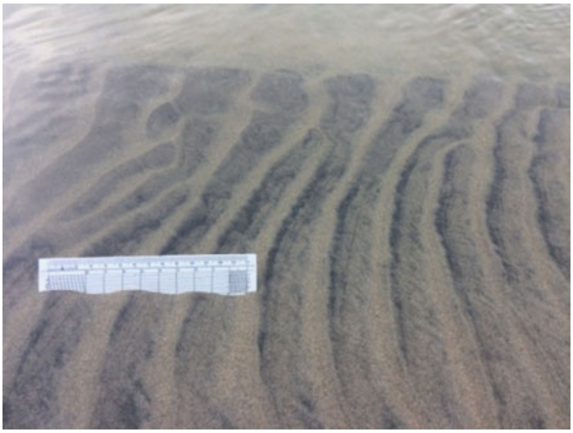

Fig. 37 Wave ripples, Tarkarli Beach, 15 cm scale

Fig. 38 Current ripples, Tarkarli Beach, 15 cm scale

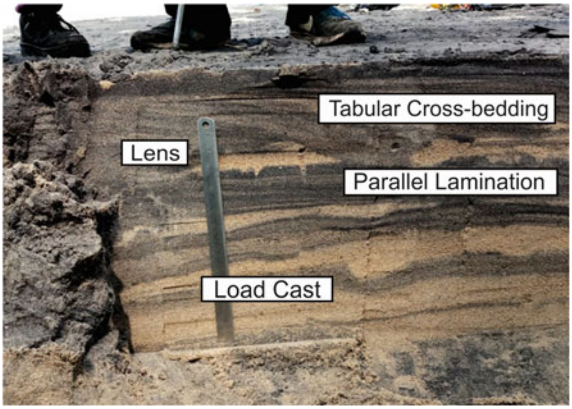

Fig. 39 Syn-sedimentary deformation structures in a dug up trench, Tarkarli Beach, 30 cm scale

geometries such as straight crested, linguoid, cuspate, lunate, etc. (Fig. 37). The physical processes leading to formation of these structures can be studied and observed by the students here.

Besides, the beach sands show a variety of syn-sedimentary deformation structures, e.g., convolute bedding, syn-sedimentary faults, load casts, and ball and pillow structure (Fig. 39). These structures can be seen in beach dune deposits at Tarkarli and Talashil, and have been studied occasionally in the trenches dug by students at Talashil Beach. The beach sands around Malvan host a rich assemblage of heavy minerals, which can be observed in dark sands, with help of hand lens, or with a binocular microscope in laboratory. These heavy minerals include zircon, tourmaline, rutile, magnetite, garnet, ilemnite, augite, occasional kyanite, staurolite, biotite, hornblende, and chromite (Gujar et al. 2010), indicating a mixed provenance of Precambrian metamorphics, granites, gneisses, and Deccan Trap Basalts for the beach sand. Lithic fragments of laterite are also commonly seen, at places imparting red color to the sand.

In this fieldwork, students also carry out R_f/ϕ, center-to-center, and Fry method of strain analyses of deformed clasts of conglomerates of Bababudan Group and Sargur Group. They also map the area using Plane table, auto level, RTK-GPS, Total Station. A permanent benchmark has been established by the graduating batch of 2017, near Rock Garden [16° 03′ 41.55846″ N, 73° 27’21.20767″ E] at the rocky beach, near Malvan Court using RTK-GPS on 27th October 2016 (Fig. 42).

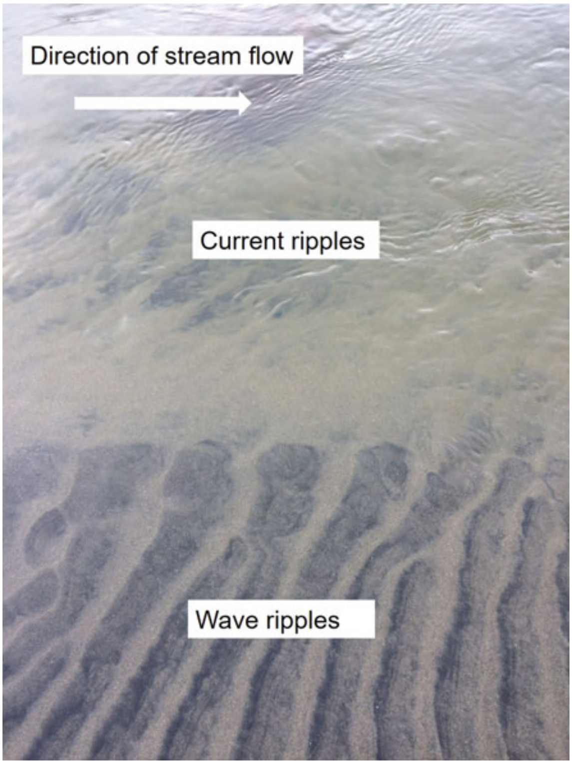

Fig. 40 Formation of current and wave ripples, Tarkarli Beach, 15 cm scale

Fig. 41 Rocks in Malvan and surrounding areas marked on Google Earth image

Fig. 42 Permanent benchmark established by students of St. Xavier's College, near Malvan Court, Malvan

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