

Placer chromite along south Maharashtra, central west coast of India

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We describe here the onshore occurrence of placer chromite, its mineralogy, geochemistry and reserve potential from a 12.5 km stretch (Pirwadi–Talashil) of south Maharashtra coast, India. The sediments in the area are moderately well to very well sorted. The heavy mineral concentration ranges between 0.69% and 98.80% (av. 18.87%), increases from north to south, and comprises of ilmenite, magnetite and chromite, whereas garnet, pyroxene, amphibole, zircon, tourmaline, rutile and staurolite are in minor proportions. The concentration of chromite within the heavy mineral fraction ranges between 0.64% and 12.35%, whereas in the bulk sediment it ranges from 0.05% to 10.90%. The chromite grains are rounded to sub-rounded, marginally altered along their border and are ferro- and magnesio-chromite varieties with 32.06–48.3% Cr₂O₃, FeO + Fe₂O₃ between 23% and 27%, and MgO between 3.31% and 14.86%. The chromite grains have been derived from ultrabasic rocks and chromitites present at the upper reaches of the Gad river. The observed occurrence and variation in the distribution of chromite is due to the differences in the sediment supply from the Achara and Gad rivers, their sorting and associated oceanographic processes. The inferred reserve of chromite is about 0.032 mt.

Keywords: Genesis, heavy mineral concentration, placer chromite, sediments.

HEAVY mineral placers containing variable proportions of ilmenite, magnetite, garnet, zircon, rutile, monazite, tourmaline and staurolite have been reported from beaches as well as nearshore areas along the Indian coastline (refs 1 and 2, and references therein). The area of study is along south Maharashtra coast, central west coast of India (Figures 1 and 2).

The work is based on a study of the surface and sub-surface beach sediment samples collected between Pirwadi (16°12'N lat.) and Talashil (16°06'N lat.) beaches. Chromite has not been noticed before as placer in the above area, and hence this report of workable chromite deposits from India's mainland is an additional input to the available database. Chromite placers along the Indian

coastline and elsewhere are meagre^{3–14}. Details of these occurrences and mineralogy are shown in Table 1. Among the reported locations, the chromite placers along the Rutland coast (Andaman and Nicobar group of islands) is the only occurrence from India, where the placers are exposed in a stream along a small stretch (85 m long, 26.5 m wide, 30 cm thick) and this deposit was studied for the platinum group of elements¹⁴.

In this article we describe the occurrence, mineralogy, geochemistry, transport mechanisms, provenance and economic feasibility of the chromite deposit of south Maharashtra coast.

Methodology

Surficial and sub-surficial samples from various physiographic domains of the beach, including foreshore (intertidal) and backshore (supratidal) were collected. Sampling was done in a grid pattern at intervals of about 500–800 m from the foreshore (low- and mid-tide levels) by inserting a transparent acrylic tube (5 cm dia.) up to a sediment depth of 20 cm. A shell-type hand auger was used to collect samples in the backshore zone (high-tide, berm and dune levels) and sub-surface samples at various levels (0–20, 20–40, 40–60, 60–80, 80–100 cm). A Van-Veen grab (surface area 0.04 m²) was utilized to recover samples from the river mouth to the upstream region. A total of 89 samples were collected along the beach and 19 samples from the river bed, i.e. two from the Achara and 17 from the Gad river (Figures 1 and 2).

Sedimentological parameters were obtained following standard procedures^{15,16}. Using bromoform, the heavy minerals were separated into three size fractions: medium sand (500–250 µm), fine sand (250–125 µm) and very fine sand (125–62.5 µm). Heavy mineral separation of river-bed sediments was carried out only for the bulk samples. Following Hutchinson¹⁷, a hand magnet and an isodynamic separator (S.G. Frantz, Model L-1) were used to separate the fractions into magnetite, ilmenite and chromite. The separated minerals were weighed and their weight percentages were determined.

Representative non-magnetic fractions were examined under a microscope to identify the transparent heavy minerals. Selected opaque and heavy mineral fractions from the bed load of the rivers were analysed by X-ray

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was determined by titration method²⁰. To decipher the surface textural features and the chemistry, a few chromite grains were studied under the scanning electron microscope (SEM, JEOL JSM-5800) coupled with an Energy Dispersive System (EDS LINK). The surficial textural features were then identified following Krinsley and Doornkamp²¹.

The study area is characterized by a narrow submergent coastal plain about 12.5 km long located between two rivers – Achara in the north and Gad in the south (Figure 2). The coastal strip is between 90 and 150 m wide, has a moderate to gentle foreshore backed by a narrow berm and sand-dune ridges of variable dimensions.

The disposition of the rivers Achara and Gad (Figure 1), their tributaries specially Janoli river, the main tributary joining the Gad river at Varvada (Figure 1), and the entrenched drainage pattern imply the vital role of tectonic lineaments (S. N. Karlekar, unpublished). Compared to Achara, the Gad river has a steeper graded profile in the upper reaches and a steep slope in the mid-profile (S. N. Karlekar, unpublished)²².

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Table 1. Occurrence of placer chromite along the world coastline

Country and source	Location and type of sediments	Mineralogy
India ¹⁴	Rutland coast in the Andaman islands, at the confluence of two streams with the sea (nearshore)	Chromite, spinel, olivine
Greece ^{3,4,6}	Gulf of Corinth, Eastern Mediterranean Sea, Euboikos Bay, Mediterranean Sea, metalliferous muds from offshore, Touzla cape, coastal sands	Hematite, rutile, chromite (Cr_2O_3 , 0.016–0.374%) Metalliferous sediment with Fe, Ti and Cr Ilmenite, magnetite, garnet, zircon, rutile, pyroxene, sillimanite, tourmaline. Chromite occurs only as inclusions.
Oregon (USA) ^{5,7}	Modern beaches and Pleistocene terraces along Cape Arago, beach sands, Continental shelf of southern Oregon, offshore sediments	Chromite, magnetite, ilmenite, chromiteferous magnetite. Chromite (up to 6%)
Ireland ⁸	East coast of Arklow, beach sands	Ilmenite, garnet, rutile, zircon, chromite, monazite
Newfoundland (Canadian Province) ^{9,10}	Fox Island River and East Central Port au Port bay, offshore and nearshore sediments	Chromite (Cr_2O_3 , 33–55%), magnetite, ilmenite, pyroxene, garnet, amphibole, olivine, rutile, staurolite, epidote
Alaska ¹¹	Northeastern Chukchic, off north Alaska, nearshore sediments	Ilmenite, chromite, garnet, magnetite, epidote, rutile
China ¹²	Narra-Teresa area, south coast of Palawan island, nearshore sediments	Titaniferous magnetite, zircon, monazite, tin, gold, chromite (Cr_2O_3 , 35–45%)
South East Africa ¹³	Beach sediments	Chromian-spinel, ilmenite, magnetite

The study area receives precipitation of the order of 2500–3500 mm from the SW monsoon from June to September. The wave climate does not change much along this area. The tidal range in the area varies from 1 to 2 m. The predominant wave direction is from the south–west, west and west–north–west, with periods²⁴ ranging from 6 to 14 s. The longshore transport rates are variable from the north to south. However, on the whole transportation of sediments is greater towards south than to north²⁵ (Figure 2).

The hinterland rocks are of Pre-Cambrian, Mesozoic and Quaternary age and comprise ultrabasic rocks, quartzite, schists, dolerite, granite, sandstone, basalt and laterite. The Pre-Cambrian formations occupy a major part of the drainage basin of the Gad river (Figure 1). At places these formations have lateritic capping of variable thickness at different altitudes. The geological formations and the associated characteristic heavy minerals are given in Table 2.

Results

Heavy mineral distribution

The heavy minerals are predominantly opaque (ilmenite, magnetite and chromite) and transparent (garnet, amphibole, zircon, tourmaline, rutile and staurolite). The concentration of heavy minerals in the surficial and sub-surficial (up to 1 m depth) sediments ranges from 0.69% and 98.80% (av. 18.87%; Table 3) and varies considera-

bly between intertidal and supratidal zones. In the intertidal zone, the concentrations are low (0.69–17.48%, av. 5.76%), vis-à-vis the supratidal zone (4.45–98.80%, av. 31.98%; Table 3). Surficial concentration of heavy minerals occurs near high-tide regions covering the berm, river banks and dunes (Figures 3 *b–d*), whereas within the dunes, heavy mineral laminations of variable thickness are distinct (Figure 3 *e*).

The heavy mineral content increases with decreasing grain size and the distribution in the supratidal sediments is characterized by discrete laminations with concentrations reaching up to 98.80%. The laminae range in thickness from 2 to 150 mm and are separated by white sands of variable thickness (8–400 mm) and laterally their continuity is noticed up to 500 m (Figure 3 *f*). Such depositional patterns are typical of beach placers and result from grain segregation due to selective sorting within the bed flow during the process of wave backwash²⁶. Such laminations of heavy minerals also occur in the intertidal zone, but these are of lesser thickness (2–5 mm) and limited lateral extent (10–15 m). The heavy mineral content in the Gad river is 13.19–34.32% (av. 24.84%), whereas in the Achara it is low, 0.74–0.79% (av. 0.76%)²⁷.

The opaque heavy minerals in the beach sediments consist of ilmenite, magnetite and chromite. The content of ilmenite is between 0.03% and 33.64% (av. 5.51%), whereas magnetite ranges between 1.16% and 58.15% (av. 13.00%) and chromite between 0.05% and 10.90% (av. 1.62%). The transparent heavy minerals (pyroxene, amphibole, garnet, zircon, rutile and staurolite) range between 1.93% and 29.48% (av. 7.09%).

Table 2. Hinterland stratigraphic sequences and their associated characteristic heavy minerals in the study area

Stratigraphic sequence	Rock type	Characteristic heavy mineral (source reference)
Pleistocene to Sub-Recent	Laterite	Hematite and goethite ^{33–35}
Upper Cretaceous to Lower Eocene	Deccan Trap basalt	Ilmenite, magnetite, titanite-magnetite, olivine, augite (A. R. Gujar, unpublished)
Pre-Cambrian	Sandstone	Tourmaline, zircon, rutile, staurolite, kyanite, sillimanite, epidote, garnet, ilmenite, magnetite, pyrite ³⁶
	Archeans and Dharwars (phyllite, quartzite, schists) and intrusives like dolerite gabbro, granite pegmatite, aplite and quartz vein	Tourmaline, staurolite, garnet, sillimanite, zircon, chromite ^{31,37}



Figure 3. *a*, Pebbly sediment of the Gad river at tidal limit in the upstream region at Maladi. *b*, Surficial enrichment of heavy minerals along the high tide (HT) line, Talashil. *c*, Surficial enrichment of heavy minerals along right bank of the Gad river. *d*, Enrichment of heavy minerals in a dune, Talashil beach. *e*, Heavy mineral laminations in a dune cut, Tondavali beach. *f*, Sub-surficial heavy mineral laminations in a pit along a berm, Talashil beach.

Characteristics of chromite grains

XRD of chromite grains shows patterns for ferrochromite (FeCr_2O_4), magnesio-chromite (MgCr_2O_3), spinel, ilmenite and chrome-bearing spinel (Figure 4*a*). This mineral association is common in ultrabasic rocks¹⁹. The other minerals include hematite, ilmeno-rutile, anatase and garnet. The presence of chromite with other heavy minerals, mainly ilmenite, is also confirmed in the samples from the Gad river (Figure 4*b* and *c*). Similarly, samples from lenses around Janoli mine (Kankavali), the

upstream of the Gad river also show ferro- and magnesio-chromite (Figure 4*d*)²⁸. Ore microscopy of polished detrital chromite grains reveals their rounded to sub-rounded forms. Partial alteration in the form of breakages along the rim of the grains and the effects of mechanical weathering are also noticeable (Figure 5*a* and *b*). Such features could result during different transportation cycles after the release of chromite grains from the host rocks²⁹.

An examination of the electron photomicrographs revealed several features of the chromite grains (Figure 5*c* to *f*). Grains display mechanical breaking such as conchoidal to sub-conchoidal fractures, V-shaped impact depressions and irregular cracks, openings and step-like irregular breaking (Figure 5*c*, *e* and *f*). Conchoidal to sub-conchoidal breakage patterns develop mainly due to an intense action of waves in a high-energy environment in the nearshore areas²¹. These broken surfaces smoothen out with time by attrition (Figure 5*d*). The V-shaped impact depressions generally form on raised surface of grains under sub-aqueous high energy, fluvial and littoral environments. Similarly, irregular cracks and openings are generated during high-energy conditions in the littoral environment by re-working of the grains. The absence of etching indicates that the chromite grains are freshly derived from the source rocks and have undergone limited transportation and less residential period in the depositional basin.

ICP-OES analysis of chromite grains from the Talashil beach shows an appreciable Cr_2O_3 content ranging between 32.06% and 48.30% (av. 39.25%), $\text{FeO} + \text{Fe}_2\text{O}_3$, 23% and 27% (av. 25.79%) and 3.31% and 14.86% (av. 11.25%), whereas EDS analysis shows 48.3% Cr_2O_3 and 33.65% FeO . The ICP-OES analysis of chromite from Janoli mine shows 33.62% Cr_2O_3 and 25.88% $\text{FeO} + \text{Fe}_2\text{O}_3$. Similarly, EDS of chromite grains from Janoli and Wagda mines show 43.08–53.78% (av. 48.99%) Cr_2O_3 , 22.59–32.55% (av. 28.78%) FeO and MgO 5.32–7.48% (av. 6.63%; Table 4). The composition of detrital chromite from the Janoli and Wagda mines is comparable and suggests the derivation and transportation of chromite grains from these sources.

Table 3. Range and average of heavy minerals and chromite in surface and sub-surface sediments of the study area. Weight percentage in total bulk sediments and weight percentages within heavy minerals fraction. Values in parentheses indicate average. *s*, Number of sampling stations and *n*, Number of analysis

Area	Physiographic zone	Heavy minerals	Chromite	Chromite % in heavy fraction
		Percentage in bulk sediment		
Pirwadi	Supratidal (<i>n</i> = 10) (<i>s</i> = 2)	4.45–54.36 (15.91)	0.06–1.19 (0.34)	0.64–6.39 (1.53)
	Intertidal (<i>n</i> = 1) (<i>s</i> = 1)	(1.91)	–	–
Hirlewadi	Supratidal (<i>n</i> = 5) (<i>s</i> = 1)	9.39–17.93 (12.04)	0.18–1.08 (0.48)	1.60–5.88 (1.87)
	Intertidal (<i>n</i> = 5) (<i>s</i> = 3)	1.36–7.52 (3.72)	–	–
Bagwadi	Supratidal (<i>n</i> = 3) (<i>s</i> = 3)	12.60–16.09 (14.90)	0.56–0.97 (0.76)	4.29–5.74 (3.34)
	Intertidal (<i>n</i> = 10) (<i>s</i> = 7)	0.69–9.70 (3.01)	–	–
Tondavali	Supratidal (<i>n</i> = 19) (<i>s</i> = 7)	7.97–86.83 (44.37)	0.12–6.58 (2.10)	0.53–12.53 (2.59)
	Intertidal (<i>n</i> = 13) (<i>s</i> = 7)	2.10–6.61 (3.77)	–	–
Talashil	Supratidal (<i>n</i> = 20) (<i>s</i> = 8)	23.76–98.80 (72.70)	0.05–10.90 (2.71)	0.11–12.35 (2.54)
	Intertidal (<i>n</i> = 3) (<i>s</i> = 3)	15.68–17.48 (16.42)	Up to 0.46 (0.15)	Up to 6.28 (2.09)

Table 4. Geochemical analysis of chromite grains. Rows 1–5 represent bulk analysis of separated chromite grains by ICP-OES, and 6–8 represent EDS analysis of chromite grains from Janoli and Wagda mines

Area	Station no.	TiO ₂	CaO	Cr ₂ O ₃	Fe ₂ O ₃	FeO	ZnO	V ₂ O ₅	NiO	MnO	MgO	Al ₂ O ₃	SiO ₂
Chromite													
Talashil	46	0.03	1.48	47.52	4.73	19.13	0.26	0.98	0.72	1.94	14.86	11.70	2.68
Talashil	97	0.79	3.75	34.76	4.36	23.52	ND	1.96	0.09	0.09	12.29	12.06	2.31
Talashil	48	0.48	3.86	32.06	4.32	21.32	0.42	2.46	0.15	3.35	13.16	10.86	3.60
Janoli	111 b	0.05	2.25	33.62	3.54	22.34	0.03	0.12	0.34	0.76	12.61	14.96	5.32
Talashil	49	0.64	ND	48.30	ND	33.65	1.13	ND	ND	0.69	3.31	10.34	ND
Janoli (altered)	Mine sample	0.28	0.27	43.08	ND	32.55	ND	ND	ND	0.42	7.48	8.20	3.16
Janoli (fresh)	Mine sample	0.37	0.06	53.78	ND	22.59	ND	ND	ND	0.64	7.08	10.78	4.72
Wagda	Mine sample	0.42	0.12	50.12	ND	30.98	ND	ND	ND	0.35	5.32	11.07	1.58

ND, Not determined.

Discussion

Formation and deposition of chromite placer

There are several pre-requisites for the formation of coastal placers, such as the presence of source rock, liberation of placer mineral grains from the rocks through weathering, transportation of the loosened grains to the marine environment and presence of a depositional sink which is conducive for selective sorting of mineral grains to form economically viable placer deposits. These processes are discussed with respect to the chromite placer in the study area.

As stated previously, the hinterland consists of Pre-Cambrian, Mesozoic and Quaternary formations (Table 2) that are drained by the rivers Achara and Gad (Figure 2). The area falls under a humid tropical climate and weathering, a dominant process, liberates heavy minerals from the source rocks.

The occurrence of chromite placer is limited to the beaches that lie south of Bagwadi (Figure 2), in contrast to those in the north. The percentage of chromite in the

bulk sediments from Bagwadi to Talashil varies from 0.05 to 10.90, whereas north of Bagwadi, i.e. between Pirwadi and Hirlewadi it ranges between 0.06 and 1.19 (Table 3). The chromite concentrations within heavy-mineral fractions also show noticeable variations in the area between Bagwadi and Talashil. It varies from 0.11% to 12.35%, whereas north of Bagwadi (between Hirlewadi and Pirwadi) the variation is from 0.64% to 6.39%. This variable distribution could be due to differences in the sediment supply, sediment sorting and density differences between the Fe- and Mg-rich chromite. Additionally, differential transportation or deposition may have resulted due to a disparity in the coastline configuration, nature of the beach gradient and associated oceanographic processes like wave energy, littoral drift, rip currents, etc.

The study area is drained by the river Achara in the north and Gad in the south, that have limited length (Gad, 74.51 km and Achara, 44.67 km) and catchment area (Gad, 973.62 km² and Achara, 263.37 km²). The sediment supply through these rivers is also limited and thus, overall the sediment budget is low. According to Sutherland³⁰, littoral concentrations of heavy minerals are best developed

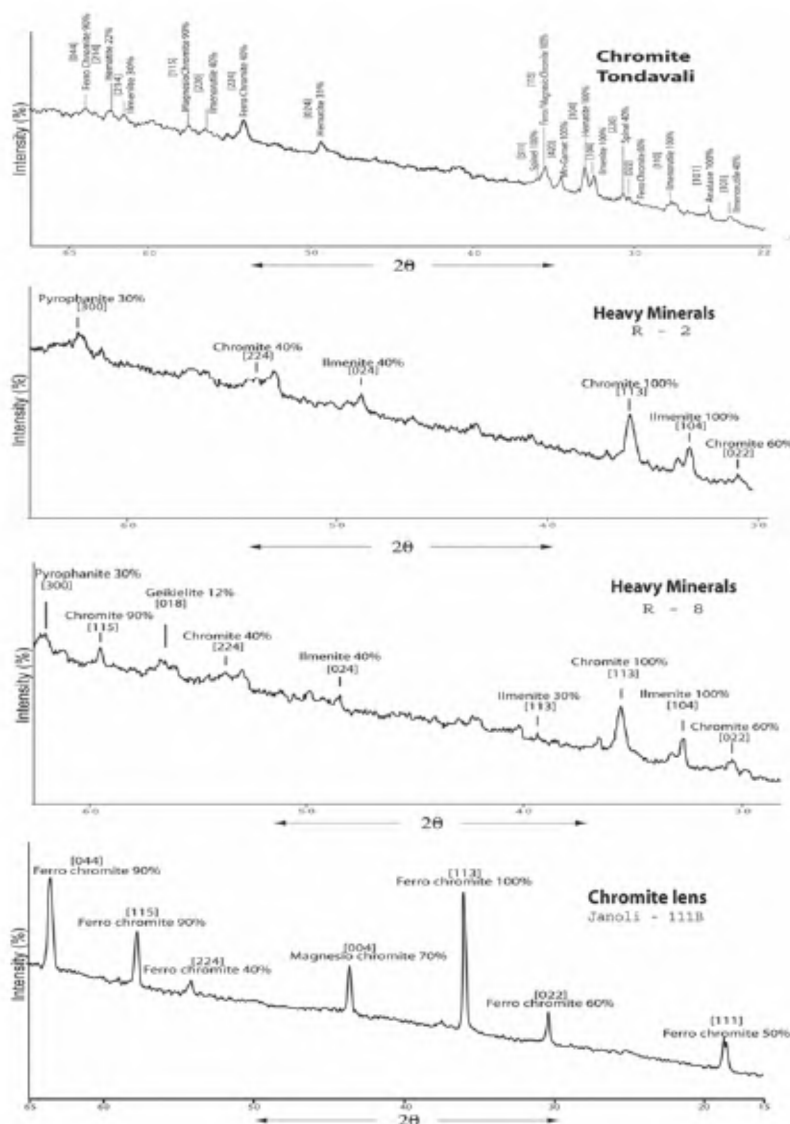


Figure 4. X-ray diffractograms of chromite grains from (a) Tondavali (station 46), (b, c) Gad river (stations R2 (b) and R8 (c)) and (d) chromite lens at Janoli mine (111 B).

along the coast where the overall sediment budget is low. Analysis of the Achara and Gad river bed sediments shows that the area receives substantial heavy minerals from Gad. The heavy mineral concentration in the Gad river sediments from the mouth to close to the source (Songad, Figure 1) ranges between 11.90% and (at Varvada Bhandara R12, Figure 1) and 90.72% (at Hadi R107, Figure 2), with an average of 38.5%. The percentage of ilmenite ranges between 2.33 (at Varvada Bhandara) and 19.89 (at Hadi), with an average of 9.3. The percentage of magnetite ranges from 6.9 (at Varvada Bhandara) to 48.27 (at Hadi), with an average of 31.5. The concentration of chromite ranges up to 8.15% (at Janoli river R13, Figure 1), with an average of 6.06%. On the contrary, the Achara river sediments have negligible heavy minerals (av. 0.7%, Figure 2).

This indicates that the Gad river is mainly responsible for transporting the heavy minerals rich in chromite grains. This is because the Gad river and its main tributary, the Janoli, flow through a rocky terrain which contains chromite lenses of variable dimensions (Figures 6 *a-d*) in the upstream region near Kankavali (Figure 1)^{28,31}.

Chromite grains are also present in the ultrabasic rocks such as serpentinite-talc-tremolite and hornblende schists that occur in the upper reaches of the Gad river around Kankavali²⁸. During weathering of these rocks and the associated chromite lenses occurring at Janoli and Wagda mine areas, chromite grains were prised out and subsequently transported down the Gad river to the depositional areas along with the other associated minerals. In due course of time the deposited chromite grains have formed a workable placer deposit.

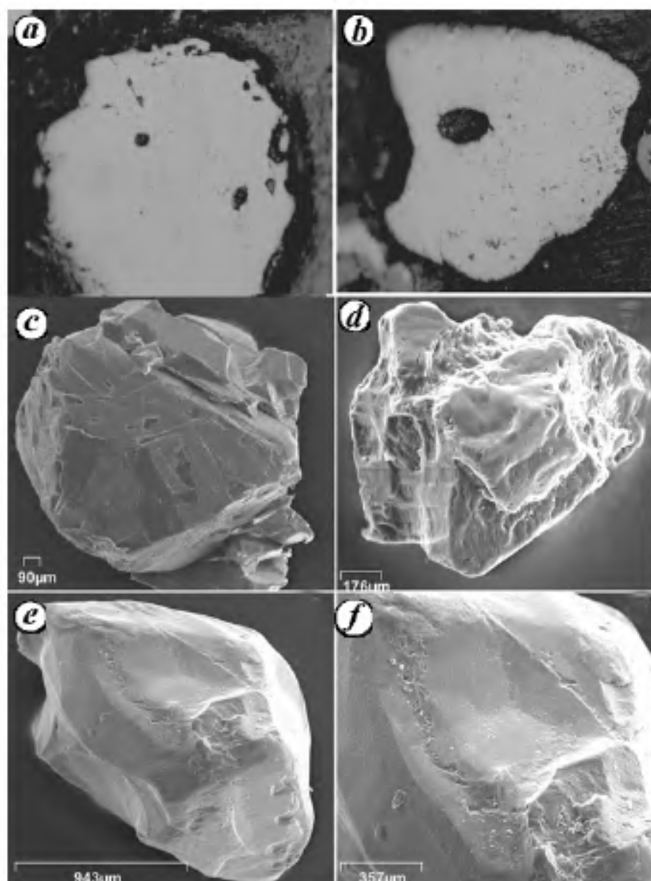


Figure 5. Ore microscopy (*a, b*) of chromite grains and electron photomicrographs (*c–f*) of detrital chromite grains. *a*, Rounded to sub-rounded grain with breakage along the border. *b*, Sub-rounded grain showing rounding of the edges. *c*, Broken octahedral, fresh chromite grain from the Janoli mine showing impact pits. *d*, Sub-rounded grain with conchoidal fractures, impact V-marks and smoothened surface. These features probably formed in a high energy zone. *e*, Sub-rounded grain with conchoidal breakage fracture. *f*, Conchoidal fracture and irregular curved impact marks developed in a high-energy fluvial zone.

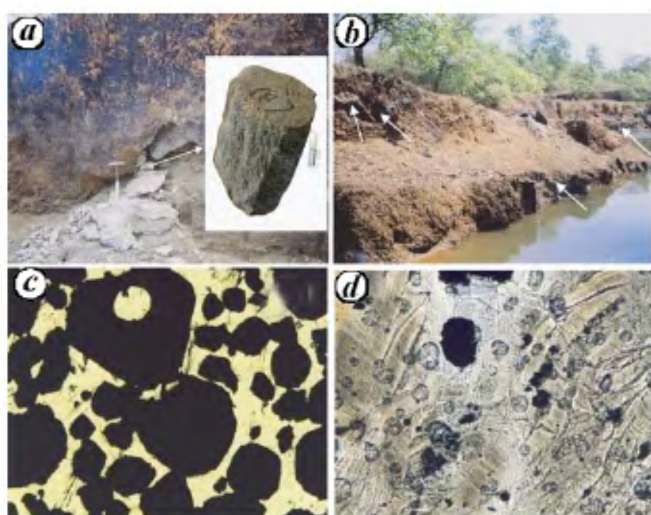


Figure 6. Chromite occurrences from source rocks in the hinterland and their photomicrographs. *a*, Chromite lump from the Janoli mine. *b*, Ultrabasic rocks containing chromite lens (white arrows), Wagda mine. *c*, Thin section showing rounded grains of chromite, Janoli mine. *d*, Thin section of rocks showing dispersed chromite grains, Wagda mine.

Beach morphodynamics

The sorting of sediments varies between the northern and southern areas. In the north, the sediments are moderately well sorted (av. 0.56), whereas in the south they are well to very well sorted (av. 0.42). During the tidal cycle, selective sorting of the grains leads to removal of the lighter minerals. Consequently, an enrichment of the heavy minerals occurs around the high tide line²⁶ (Figure 3 *b* and *f*). The density values of the chromite grains (Fe chromite 5.1 and Mg chromite 4.2, av. 4.65) do not vary significantly and may result in minor variations in the settling of the grains during this process.

The coastline configuration of the study area shows minor differences, whereas the gradient of the beaches shows significant variations. The area north of Bagwadi has a moderate beach gradient (1 : 15 to 1 : 35), whereas that between Bagwadi and Talashil shows a relatively lower gradient (1 : 26 to 1 : 40). The wave refraction patterns indicate the predominance of wave convergence and higher wave energy in the area north of Bagwadi and wave divergence and moderate wave energy south of Bagwadi. This wave divergence with moderate wave energy may be responsible for the deposition of sediments south of Bagwadi vis-à-vis the area north of Bagwadi, which has undergone comparatively more erosion and has less sediment deposition. As indicated earlier, the net littoral transport in the area is towards south^{25,32} and this results in a greater degree of segregation of heavy minerals – both normal to shore and alongshore – in the direction of littoral transport³⁰.

Reserve evaluation

Although the occurrence of chromite is noted up to the northern boundary of Pirwadi, the main concentration is located between stations 106 and 42. In this study the ~110 m wide coastal zone was broadly divided into intertidal (45–50 m) and supratidal (45–55 m) zones, with the latter extending between high tide and vegetated stabilized line dunes (Figure 2). Since the work involved sampling up to 1 m depth, the reserve was tentatively estimated, and is only indicative (i.e. inferred), using the following formula

$$\text{Reserve} = \frac{\left[\frac{\text{Area} \times \text{thickness} \times \text{bulk density} \times \text{concentration}}{100} \right]}{100}$$

The bulk density of the sediments was calculated by considering the average weight of 100 cm³ representative dry samples from the area, and the number of weights was averaged. This average value (1.9 t/m³) was used to calculate the reserve estimation. Based on the above calculation, the inferred reserve of chromite is about 0.032 mt.

Conclusion

Beach sediments between Pirwadi and Talashil, south Maharashtra, are fine-grained and moderately well to very well sorted in nature. The heavy mineral concentration varies in the intertidal and supratidal zones, with higher concentration in the latter and an increasing trend from north to south. The chromite grains are derived from weathering of the ultrabasic rocks and chromite lenses that occur in the hinterland. The inferred reserve of chromite appears promising for exploitation along with ilmenite and magnetite.

- Gujar, A. R., Nagendernath, B. and Banerjee, R., Marine minerals: the Indian perspective. *Mar. Min.*, 1988, **7**, 317–350.
- Mohan, P. M. and Rajamanickam, G. V., Indian beach placers – a review. *Handbook of Placer Mineral Deposit*, New Academic Publishers, New Delhi, 2001, pp. 23–52.
- Varnavas, S. P. and Papatheodorou, G., Marine mineral resources in the eastern Mediterranean Sea I. An iron, titanium, chromium and nickel deposit in the Gulf of Corinth, Greece. *Mar. Min.*, 1987, **6**, 37–70.
- Voutsinou, F. and Varnavas, S. P., Marine mineral resources in the eastern Mediterranean Seas II and Fe–Cr–Ni deposit in the northern Euboikos Bay, Greece. *Mar. Min.*, 1987, **6**, 259–290.
- Peterson, C. D., Gleeson, G. W. and Wetzel, N., Stratigraphic development, mineral sources and preservation of marine placers from Pleistocene terraces in southern Oregon, USA. *Sediment. Geol.*, 1987, **53**, 203–229.
- Filippidis, A., Misaelides, P., Clouvas, A., Godelitsas, A., Barbayannis, N. and Anousis, I., Mineral, chemical and radiological investigation of black sand at Touzla Cape near Greece. *Environ. Geochem. Health*, 1997, **19**, 83–88.
- Kulm, L. D., Potential heavy mineral and metal placers on the southern Oregon continental shelf. *Mar. Min.*, 1988, **7**, 361–395.
- Geoghegan, M., Gardiner, P. R. R. and Keary, R., Possibilities for commercial mineral deposits in the Irish offshore area. *Mar. Min.*, 1989, **8**, 267–282.
- Emory-Moore, M., Solomon, S. and Dunsmore, D. C., Chromitiferous placer accumulations, Fox Island River and East Central Port, Newfoundland: a preliminary examination. *Mar. Min.*, 1989, **8**, 139–154.
- Emory-Moore, M., Scott, W. J., Davis, L. and Solomon, S., Detrital chromite concentrations, nearshore Port au Port Bay. *At. Geol.*, 1992, **28**, 233–241.
- Luepke, G. and Escowitz, E., Grain size, heavy mineral and geochemical analysis of sediments from the Chuckchi Sea, Alaska. United States Geological Survey Bulletin, US Govt Printing Office, Washington, 1989, pp. 1–16.
- Chang, L. and Clark, A., Marine mineral resources of the South China Sea. *Mar. Georesour. Geotechnol.*, 1993, **5**, 101–126.
- Pownceby, M. and Bourne, P., Detrital chrome-spinel grains in heavy mineral sand deposits from South East Africa. *Mineral. Mag.*, 2006, **70**, 1–64.
- Pal, T., Chakraborty, P. P. and Ghosh, R. N., PGE distribution in chromite placers from Andaman ophiolite and its boninitic parentage. *J. Geol. Soc. India*, 2003, **62**, 671–679.
- Folk, R. L., *Petrology of Sedimentary Rocks*, Hamphil, Austin, Texas, 1968, p. 182.
- Blott, S., Grain size distribution and statistics package for analysis of unconsolidated sediment by sieving or laser granulometers. Gradistat version 4, 2006, pp. 1–6.
- Hutchinson, C. S., *Laboratory Hand Book of Petrographic Technique*, John-Wiley, New York, 1974, p. 527.
- Anon., Powder diffraction file inorganic phase, alphabetical index, chemical and mineral name. JCPDS, USA, 1981, p. 1021.
- Berry, I. G., Mason, B. and Dietrich, R. V., *Mineralogy – Concept, Description, Determinations*, CBS Publishers, New Delhi, 1985, p. 553.
- Shapiro, L., Rapid analysis of silicate, carbonate and phosphate rocks. Geological Survey Bulletin, No. 1401, US Govt Printing Office, Washington, DC, Revised edition, 1978, p. 74.
- Krinsley, D. H. and Doornkamp, J., *Atlas of Quartz Sand Surface Texture*, Cambridge University Press, 1973, p. 91.
- Dixit, K. R., Drainage basins of Konkan – forms and characteristics. *Natl. Geogr. J. India*, 1976, **22**, 79–105.
- Jagtap, T. G., Untawale, A. G. and Inamdar, S. N., Study of mangrove environment of Maharashtra coast, using remote sensing data. *Indian J. Mar. Sci.*, 1994, **23**, 90–93.
- Reddy, M. P. M., Wave refraction on relation to sediment transport – tendency along West coast of India. *Indian J. Mar. Sci.*, 1976, **5**, 152–162.
- Chandramohan, P., Sanil Kumar, V., Nayak, B. U. and Pathak, K. C., Variations of longshore currents and sediments transport along South Maharashtra coast, west coast of India. *Indian J. Mar. Sci.*, 1993, **22**, 115–118.
- Komar, P. D. and Wang, C. Process of selective grain transport and formation of placers on beaches. *J. Geol.*, 1984, **92**, 637–655.
- Gujar, A. R., Ambre, N. V., Mislankar, P. G. and Iyer, S. D., Ilmenite, magnetite, chromite beach placers from South Maharashtra, Central West Coast of India. *Res. Geol.*, 2010, **60**, 71–86.
- Iyer, S. D., Babu, E. V. S. S. K., Mislankar, P. G., Gujar, A. R., Ambre, N. V. and Loveson, V. J., Occurrence and emplacement of chromite deposits in Sindhudurg District, Maharashtra, India. *Acta Geol. Sinica*, 2010, **84**, 515–527.
- Ramdhor, P., *The Ore Minerals and their Intergrowths*, Pergamon Press, Frankfurt, 1980, vols 1 and 2, p. 1202.
- Sutherland, D. G., Placer deposits of the nearshore and coastal zone: the role of littoral processes and sea level changes in their formation. In *Sea Surface Studies – A Global View* (ed. Devoy, R. J. N.), Croom Helm, London, 1987, pp. 569–588.
- Chari, G. N., Marwar, S. A., Bobade, G. P., Kulkarni, G. A. and Bhagwatkar, D. A., Ilmenite. *Geology and Mineral Resources of Maharashtra*, Directorate of Geology and Mining, Government of Maharashtra, Nagpur, 1975, pp. 136–144.
- Sanil Kumar, V., Pathak, K. C., Pednekar, P., Raju, N. S. N. and Gowthaman, R., Coastal processes along the Indian coastline. *Curr. Sci.*, 2006, **90**, 530–536.
- Anon., *Geology of the Ratnagiri District, Maharashtra*, Geological Survey of India 125th Anniversary Publications, 1976, pp. 1–8.
- Sahasrabudhe, Y. S. and Deshmukh, S. S., The laterites of the Maharashtra State. In *Proceedings of the International Seminar on Lateritization Processes*, Oxford-IBH, New Delhi, 1979, pp. 209–220.
- Gujar, A. R. and Srinivas, K., Contributions from coastal laterites to the nearshore placers of central west coast of India. *Giornale di Geologia*, 1991, **53**, 65–70.
- Sarkar, P. K. and Soman, G. R., Heavy mineral assemblage from Konkan, Kaladgi sediments. In *Proceedings of the Indian Geological Congress, Pune*, 1984, pp. 19–23.
- Kelkar, K. V., On some Archean rocks in southern part of Ratnagiri district. *J. Univ. Pune*, 1959, **10**, 85–101.

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