

## Impact of offshore placer mining experiments (PLAMEX) on the sediment size and heavy minerals

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Two offshore placer mining experiments (PLAMEX) were conducted using submersible pumps specially designed by Central Mechanical Engineering Research Institute (CMERI), Durgapur at 8 m water depth in Kalbadevi Bay (PLAMEX-I), Ratnagiri, Maharashtra, and off Paradip (PLAMEX-II), Orissa, to determine the effects on sediment grain size and heavy mineral assemblages. The PLAMEX-I results for the sediments off Kalbadevi Bay showed no major effects on the average sand, silt and clay, grain size, and the heavy mineral percentages. The PLAMEX-II results for the sediments off Paradip showed mixed effects due to the dynamic environmental conditions.

**Keywords:** Environmental impact, grain size, heavy minerals, offshore mining, placer.

INDIA has a long coastline of ~6700 km, and large reserves of coastal placer deposits of garnet, ilmenite, kyanite, monazite, rutile, silliminite, tin and zircon. The coastal beach placer deposits from Maharashtra and Orissa have been reported by many workers<sup>1-11</sup>. It is further considered that the inferred reserves (2 MMT) of the Kalbadevi Bay, Ratnagiri<sup>5</sup> have significantly high exploitation potential<sup>12</sup>.

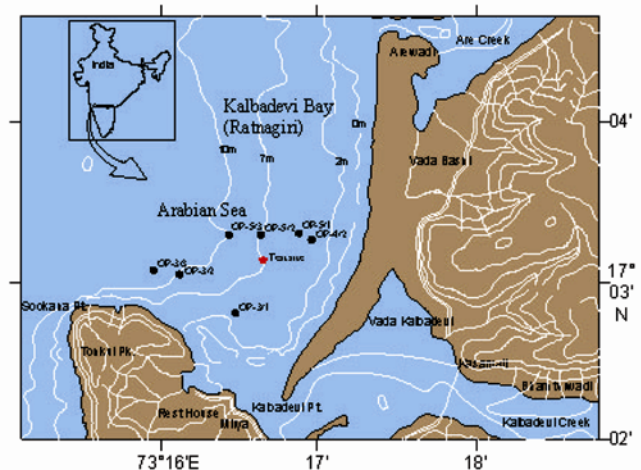
The ilmenite deposits of Kalbadevi Bay and other adjacent bays in Ratnagiri are associated with the sensitive coastal ecosystems which interface between the land and sea interaction, and act as natural filters of runoff and provide breeding grounds for important types of fish. Therefore, the placer mining activities in such (and other) areas are likely to disturb the near-shore environment, navigation channels, fishing and breeding grounds, flora and fauna, etc.

Considering the possibility of onshore and offshore coastal placer mining in future, the NIO, Goa, in 2002, under CSIR network project on 'Capacity Building of Coastal Placer Mining', initiated year-wise systematic environmental study plan and identified a potential site on the west coast (Kalbadevi Bay, Ratnagiri, Maharashtra) and another on the east coast of India (Paradip, Orissa), where sampling for baseline and sand mining tests were carried out in the near-shore area. Baseline and seasonal sampling along three offshore profiles in Kalbadevi Bay were carried out in January, May and October, 2004. Results of the country's first offshore placer min-

ing experiments (PLAMEX-I and II) off Kalbadevi Bay, Ratnagiri on the west coast of India, and off Paradip, Orissa on the east coast of India are presented in this paper. Immediate impacts of PLAMEX-I and II on the sediment grain size and heavy mineral assemblages are discussed here.

The operations of PLAMEX-I in Ratnagiri and PLAMEX-II in Orissa were carried out in February 2006 and December 2007, respectively, using a dredge head mining system<sup>13</sup> which was specially designed, developed and operated by the Central Mechanical Engineering Research Institute (CMERI), Durgapur. Prior to PLAMEX-I in Kalbadevi Bay, seven baseline sediment samples were obtained by Van veen grab in January 2006 along two E-W offshore profiles (OP), one in the north (OP-4/1, 5/1, 5/2 and 5/3) and another in south (OP-3/1, 3/2 and 3/3) of the test location (Figure 1). Pre- and post-test operation samples were collected at the suction (S-01 and S-06), discharge (D-01 and D-06) and reference point (R-01 and R-06) respectively (Table 1). Additionally, 4 mixed slurry samples (MSS-1, 2, 3 and 4) were collected at the end of the test daily for four days. The coordinates of sampling locations were obtained by Magellan GPS model NAV DLX-10.

Similarly, prior to PLAMEX-II in Paradip, Orissa, seven baseline sediment samples were collected by Van



**Figure 1.** Sediment sampling stations off Kalbadevi Bay, Ratnagiri, Maharashtra. Test site indicates location of Pontoon and PLAMEX-I.

**Table 1.** Details of sediment sampling during PLAMEX-I

Sample no.	Remarks
R-01	Pre-test sample at reference point
R-06	Post-test sample at reference point
S-01	Pre-test sample at suction point
S-06	Post-test sample at suction point
D-01	Pre-test sample at discharge point
D-06	Post-test sample at discharge point

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veen grab along three E–W offshore profiles (OP-1/1, 1/2, 2/2, 2/3, 3/1, 3/2, 3/3) in December 2007 (Figure 2). Also, the pre-, during- and post-test samples, and monitoring-I and II samples were collected from reference, suction and discharge points (Table 2). The coordinates of all the sampling locations were obtained by Ceducer DGPS position fixing instrument.

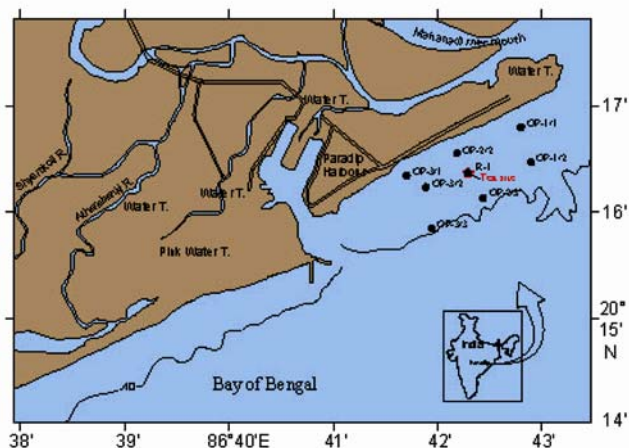
A cost effective and eco-friendly dredge head mining system<sup>13</sup> having submersible slurry pump capacity of 180 m<sup>3</sup>/h developed by the CMERI, Durgapur was used for PLAMEX-I and II. The system included a dredge head, submersible pump, general test pump, data acquisition system (DAS), global positioning system (GPS), dredge head lifting system and diesel generator set, all fitted on Pontoon (39 m length, 11 m width and 2.51 m draft) to carry out first offshore placer mining experiment (PLAMEX-I) off Kalbadevi Bay, Ratnagiri. The Pontoon was anchored around OP-2/2 location. The circular dredge head having 54 nozzles in three rows was lowered on the seabed with a crane (Figure 3), where the sea water under high pressure from heavy duty centrifugal pump entered into the agitation chamber of dredge head, and left with high velocity jet and impinged on the seabed to form sand–water slurry inside the dredge head. The sediment slurry was pumped out by a heavy duty vertical submersible pump mounted on the dredge head (Figure 3). The dredge head was immersed at ~8–10 m water

depth<sup>14</sup>, where the pressurized water from centrifugal pump was supplied at 250 m<sup>3</sup>/h and 70 m head to produce effective water jets from the nozzles ranging from 20 to 130 kPa (ref. 14). The discharge of slurry measured<sup>15</sup> by the magnetic flow meter ranged between 182 to 198 m<sup>3</sup>/h. The bulk/mixed slurry sample (MSS) collection in 50 kg sacks was accomplished by directly pumping the sediment slurry into a storage (Hopper) barge adjacent to Pontoon.

In December 2006, offshore sand mining test (PLAMEX-II) at Paradip, Orissa was carried out using the same dredge head and other machinery developed by CMERI, Durgapur with few modifications on board vessel (47 m length, 13 m width and 2.2 m draft). The large quantity of sand–water slurry pumped from the seabed was stored in two tanks on board the Pontoon. The surface water from the storage tank was discharged back into the sea after most of the sediment had settled down. All the PLAMEX-II samples were collected on the same day by Vanveen grab before, during and immediately after the experiment, and also during monitoring-I and II to evaluate the immediate impacts. The monitoring samples were collected to evaluate restoration at the test site.

The sediment samples were washed repeatedly with ELIX distilled water to remove salt content, and the carbonates, organic matter and ferruginous coatings were removed by treating with 1 : 10 HCl, H<sub>2</sub>O<sub>2</sub> (30% by vol.) and SnCl<sub>2</sub> respectively. The treated samples were dried in an oven at 40°C, and known quantity of representative samples were used for dry and wet sieving separately. The sand, silt and clay percentages were determined by wet sieving following the standard pipette analysis<sup>16</sup>. Similarly, different size fractions were obtained from sieves of 0.5 phi mesh by dry sieving and grouping to determine the heavy mineral content using 2.89 sp. gr. Bromoform, following the standard procedures<sup>17</sup>.

The baseline data show that the major component of the sediment was sand which varied between 95 and 98% (av. 97%; Figure 4a). Comparatively, the silt and clay



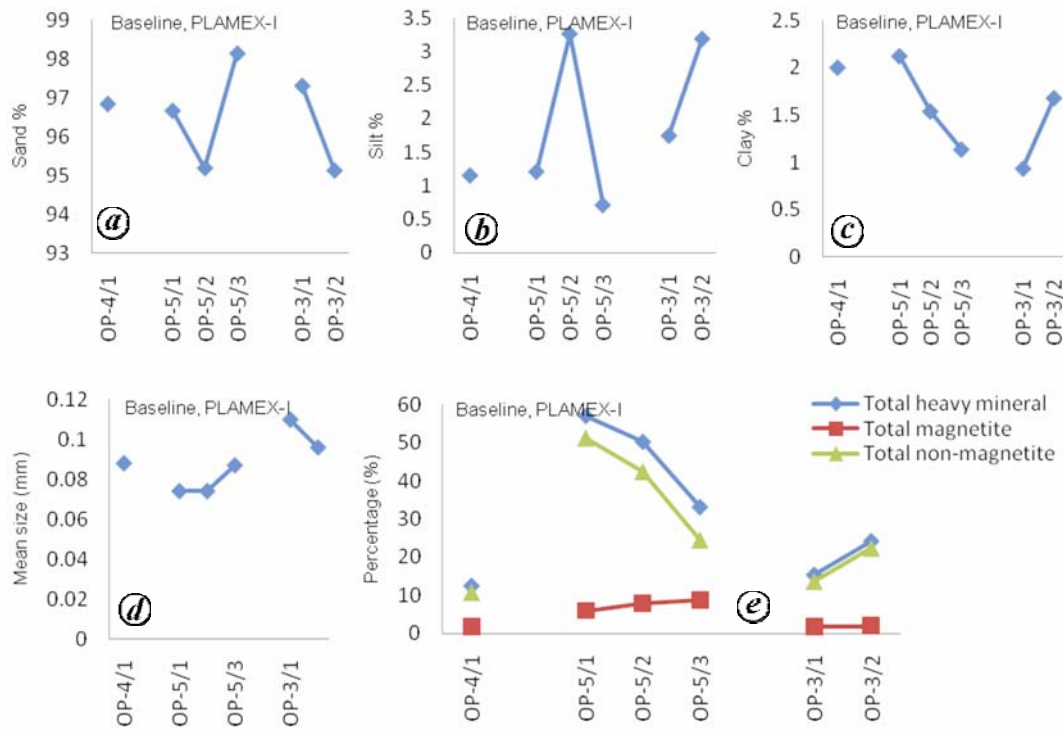
**Figure 2.** Sampling stations off Paradip, Orissa. Test site (R-1) indicates location of Pontoon and PLAMEX-II.

**Table 2.** Details of sediment sampling during PLAMEX-II

Sample no.	Remarks
R-01	Pre-test sample at reference point
R-02 A	Post-test sample at reference point
R-03	Monitoring-I sample at reference point
R-04 B	Monitoring-II sample at reference point
S-02 A	During-test at suction point
D-01	Pre-test sample at discharge point
D-03 B	Monitoring-I sample at discharge point
D-04 B	Monitoring-II sample at discharge point



**Figure 3.** Placer mining experiment (PLAMEX-I) off Kalbadevi Bay, Ratnagiri. Note the suction (station S) and discharge points (station D) are on opposite sides of the Pontoon (left and right respectively), and the photo is taken from the reference point (station R, Photo by ABV).



**Figure 4.** Variations in (a) sand, (b) silt, (c) clay, (d) mean grain size, and (e) total heavy mineral percentages along three baseline profiles off Kalbadevi Bay, Ratnagiri, before PLAMEX-I.

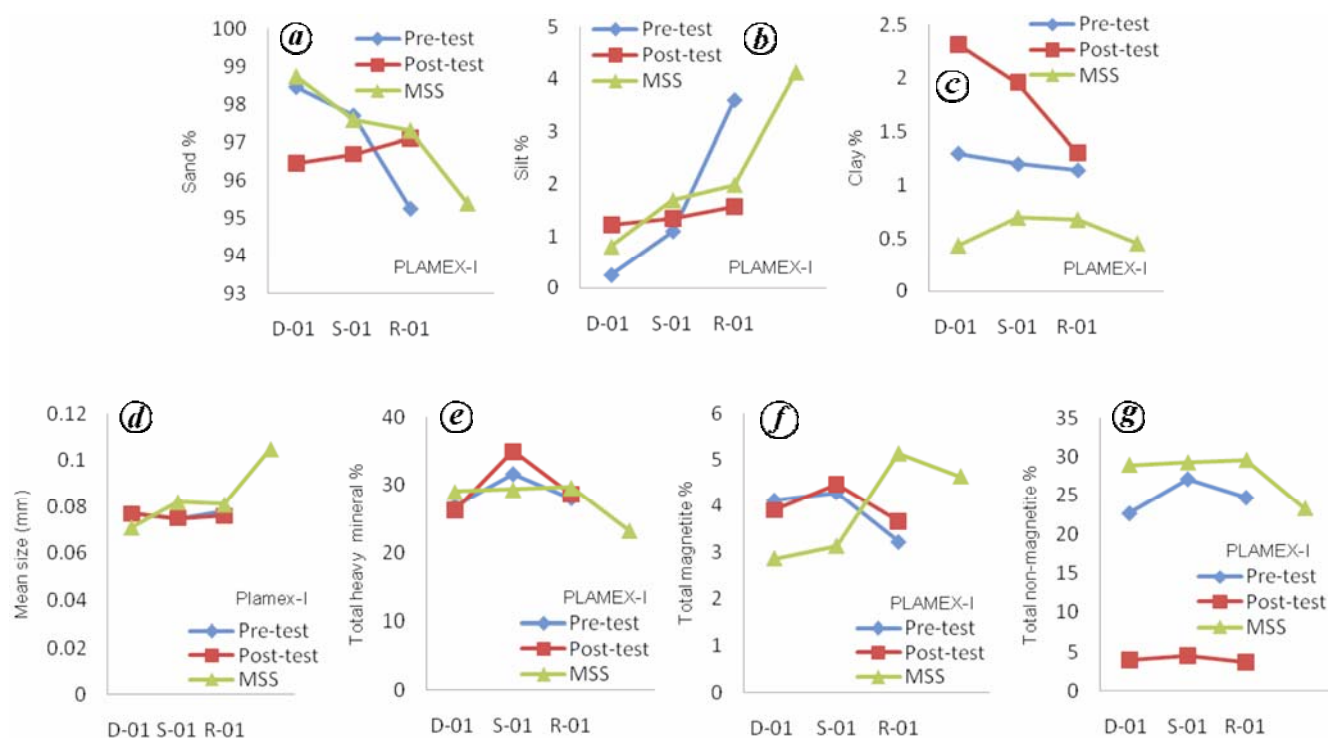
content variation (<1 to 3%; Figure 4b and c) and the average mean grain size (0.07 to 0.1 mm, av. 0.09 mm) were small (Figure 4d). The total heavy minerals (Figure 4e) determined for two baseline profiles varied between 12 and 57% (av. 31%), magnetite from 1 to 9% (av. 4%) and non-magnetite (ilmenite) from 11 to 57% (av. 26%). The pre-test samples collected just before PLAMEX-I at D, S and R points also gave similar results of sand (95 to 98%, av. 97%; Figure 5a), silt and clay content (<1 to 4%; Figure 5b and c), and the average mean grain size (0.08 mm; Figure 5d). Similarly, at D, S and R points, the total heavy minerals in the pre-test sediments varied between 27 and 31% (av. 28%; Figure 5e), magnetite from 3 to 4% (av. 4%; Figure 5f) and non-magnetite (ilmenite) from 23 to 27% (av. 25%; Figure 5g). The samples from D, S and R points collected immediately after PLAMEX-I (post-test; Figure 5a–g) exhibited 96–97% (av. 97%) of sand, 1–3% silt and clay, 26–35% (av. 30%) total heavy minerals, 3–4% (av. 4%) magnetite, 22–30% (av. 26%) ilmenite, and 0.08 mm average mean size. Four mixed slurry samples (MSS; Figure 5a–g) collected from the barge at the end of PLAMEX-I every day displayed sand content from 95 to 99% (av. 97%), silt <1 to 4%, clay <1%, total heavy minerals 23–30% (av. 28%), magnetite 3–5% (av. 4%), ilmenite 18–26% (av. 24%), and the average mean size of 0.08 mm. Comparison of samples from D, S and R points for pre-, post-test and MSS stages is shown in the Figure 5a–g.

Pre- and post-test comparison with reference data during the experiment showed that the sand content reduced

to 2% at discharge (D), 1% at suction (S) and increased by 1.8% at reference (R) point. The MSS showed slight changes at D (0.3% increase) and S (0.1% reduction), but an increase of 2.1% at R point. The silt content increased by 1% at D and 0.5% in MSS, reduced by 2% at R and 1.6% in MSS, but the changes at S point and in MSS were insignificant (0.1 and 0.6% respectively). The clay content at D, S and R increased by 1, 0.8 and 0.2% respectively, but reduced in MSS by 0.9% at D, 0.5% at S and 0.5% at R point. Although variation in the total heavy minerals at D and R was negligible (< 0.7%), it increased at S (3.5%), and in MSS (2.1% at D and 1.6% at R), and reduced at S (2.3%). Changes in the total magnetite content were negligible at D, S and R (<0.4%) but considerable in MSS (1.2% at D and S; 1.9 at R). Similarly, changes in the percentage of non-magnetite minerals were pronounced at S (3.3%) point, and all three points in MSS (6.3% increase at D, 2.1% at S and 4.8% at R). The mean size showed no changes at D, S and R, but in MSS, it was reduced by 0.01 at D point.

The baseline data showed large variation in sand (31–94%; Av. 79%, Figure 6a) and silt (6–67%; av. 20%, Figure 6a) with very low clay (<1–3%). The total heavy mineral concentration varied between < 1 and 13% (Figure 6c), and the mean grain size displayed much variation from 0.06 to 0.1 mm (av. 0.09 mm; Figure 6e). The sediments typically have low magnetite (up to 0.1%, Figure 6c) and non-magnetic minerals (averages to 5% maximum).

The sand mining test off Paradip (PLAMEX-II) was conducted in 8.5 m water depth at R-1 (Figure 2), after



**Figure 5.** Comparison between pre- and post-test (PLAMEX-I) composition for (a) sand, (b) silt, (c) clay, (d) mean grain size, (e) total heavy minerals, (f) magnetite, and (g) non-magnetite.

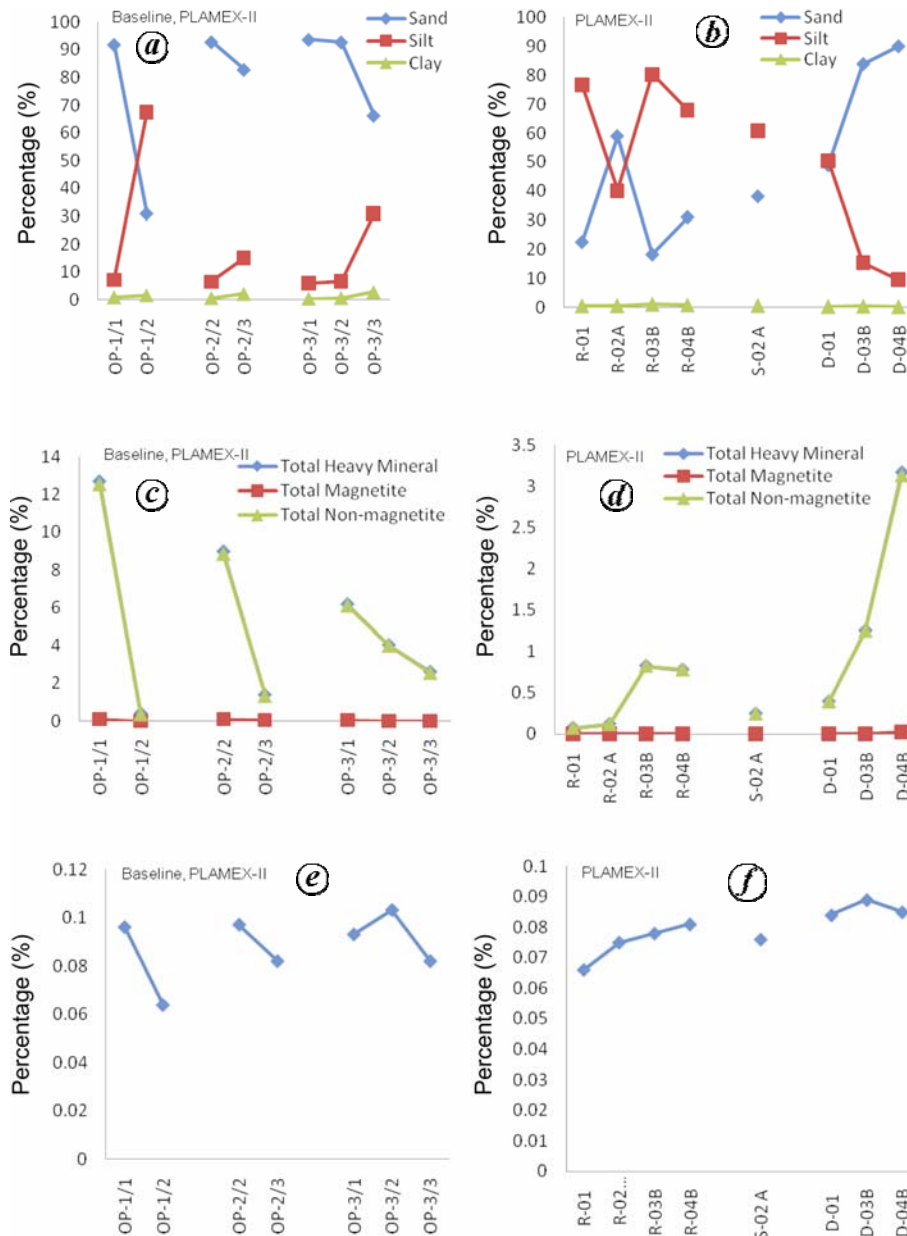
three days of baseline sample collection. The sand composition changed during pre-mining test and varied from 23 to 49% (av. 36%, Figure 6b), silt from 51 to 77% (av. 64%, Figure 6b), and the total heavy minerals were <1% and without magnetite (Figure 6d). Compared to the baseline samples, those collected during various stages of PLAMEX-II (pre-, during-, post-test and monitoring) at D and R points showed noticeable deviation in the sediment texture, grain size and heavy mineral composition (Figure 6b, d and f). The dominating textural class of the sediment changed from 'sand' (in baseline) to 'sandy silt' (during the pre-test). The average total heavy mineral composition and the clay content remained <2%.

The comparison of reference and post-test data during the experiment showed large changes at R and D points for all the parameters. At the reference point (R), the sand content increased (36%) during post-test, decreased (4%) during monitoring-I and increased (8.5%) during monitoring-II. The silt decreased (36%) during post-test, increased (4%) during monitoring-I and decreased (8.7%) during monitoring-II. At discharge point (D), the sand content increased by 35% during monitoring-I and 41% during monitoring-II. The changes in the clay content at D were negligible and 0.6% maximum during monitoring-I. At R, the total heavy minerals increased by 0.05% during post, and 0.8% during monitoring-I, whereas at D, the content increased by 0.8% during monitoring-I. The magnetite minerals were absent in the sediments from D and R during all the phases. However, the sandy silt texture of the sediments from R and D changed to sandy

sand during post-test, which further changed to silt at R and sand at D during monitoring-I. Similarly, the mean size at R increased from 0.06 to 0.08.

The sand variation during baseline, pre-, and post-test remained within 95–98%, indicating no major changes due to PLAMEX-I. Although changes in silt and clay% were minor, the decreasing trend (Figure 5a) probably suggests conversion of some sand into silt size due to the test. Similarly, the average mean grain size, which also showed slight reduction from 0.09 mm (baseline) to 0.08 mm (pre-, post-test and MSS, Figure 5d), suggests deposition of minor silt probably due to the reduction of sand size to silt size. Correspondingly, the average total heavy mineral concentration during baseline (31%), pre-test (29%), post-test (30%), and in mixed slurry samples (MSS, 28%) remained constant. The average magnetite percentage did not vary from baseline (5%) to pre-, post-test and in MSS (4%). The non-magnetite (ilmenite) content equally showed no variation as the average 26% during baseline varied between 25 and 26% for the pre-, post-test, and in MSS. It is thus clear that the PLAMEX-I had no effect on the grain size and heavy mineral content in the sediments of the Kalbadevi Bay, Ratnagiri. Hence, the sand mining at shallow depth in the Kalbadevi Bay is not expected to have drastic effects on the sediment grain size and heavy mineral percentages.

The pre- and post-test comparison of data at D, S and R during the experiment showed slight changes but similar trends of sand, silt, clay, total heavy minerals, total magnetite, non-magnetite and mean grain size supporting the



**Figure 6.** Variations in the grain size and heavy mineral composition during baseline (a, c and e), and pre-, post-test and monitoring phases of PLAMEX-II (b, d and f). R-01 and D-01 = pre-test samples, S-02 A = sample during suction, R-02 A = sample immediately after the test, R-03 B and D-03 = monitoring-I sample, and R-04 B and D-04 B = monitoring-II sample. S = suction point, D = discharge point and R = reference point.

above conclusions that the PLAMEX-I had no effect on the grain size and heavy mineral content in the sediments of the Kalbadevi Bay, Ratnagiri. This behaviour also remained similar for the MSS samples.

The results of PLAMEX-II are not similar to PLAMEX-I. The sand (31–94%; av. 79%; Figure 6a) and silt content (6–67%; av. 20%; Figure 6a) showed large variation during baseline which is also reflected in the range of mean grain size (0.06–0.1 mm; av. 0.9 mm; Figure 6e). Compared to the baseline results, the average sand content at the reference point (R) reduced from 79 to 22% during pre-test, increased during post-test (59%), reduced during monitoring-I (18%) and increased during

monitoring-II (31%) on the same day of the test (PLAMEX-II, Figure 6b). Almost similar results were obtained for the silt variation (baseline 20%, pre-test 77%, post-test 40%, monitoring-I 80%, and monitoring-II 68%; Figure 6b) and average clay showed small reduction from 1.3 (baseline) to 0.06 (pre-test) to 0.8% (monitoring). The sediment texture also changed from sand during baseline to sandy silt (during pre-test and suction), and sandy sand and silt during the monitoring phases. The strong currents in the area are, therefore, responsible for such variations. It has been reported that the currents are parallel to the coast, and tides and local winds in the shallow water region off Paradip which are moderately

high, play an important role in determining the advective process<sup>18</sup>. The current measurements<sup>19</sup> carried out by deploying 2 RCM-72 and DCM-12 current meters in 30 m water depth at about 17 km south of Paradip Port during May–June 1996, showed that the surface current speed varies from 10 to 40 cm/s (E to NE) during summer monsoon, and ranges between 70 and 80 cm/s (NE) during winter monsoon and bottom currents at ~45 cm/s (ref. 20). Off Paradip port, the current velocity increases to 0.8 m/s in NE direction during SW monsoon season (March to May) from 0.3 to 0.4 m/s in SW direction round the year (October to January). The tides off Paradip are semi-diurnal type<sup>20</sup>, with mean high water spring tide of 2.58 m.

Therefore, reduction in the average mean size of the sediments at reference point (R) from 0.09 mm (baseline) to 0.07 mm (pre-test), and steady increase up to 0.8 mm until monitoring-II phase indicates continuous changes in the environment with deposition of silt and clay (Figure 6f). Baseline studies have shown that the sediments are poor in magnetite (<0.1%) and heavy minerals (or non-magnetite; 0.3 to <12.7%), suggesting that the area is not suitable for offshore mining of placer minerals. Further, the PLAMEX-II sediments collected at reference, suction or discharge points were devoid of magnetite, and showed low heavy mineral content (<3%).

Comparison of pre-test data with post-test, monitoring-I and II during the experiment showed large variations (20–40%) in sand and silt content at D, S and R points within 05–30 h against the actual suctioning of sediments for 13 min. The experiment further showed increase in non-magnetite content by 2.7% at D and 0.7% at R with change in sediment texture due to increase in the mean grain size, indicating possibility of strong currents in the area and supports the above view.

The results of the placer mining experiment on the west coast (PLAMEX-I) and east coast (PLAMEX-II) are contrasting due to the different offshore environmental conditions. Although PLAMEX-I showed almost no effect on the grain size and heavy mineral percentage in the sediments off Kalbadevi Bay, Ratnagiri because the Bay is enclosed, the PLAMEX-II off Paradip, Orissa showed diverse changes in the sediment texture, grain size and heavy mineral content mainly due to the dynamic environmental conditions in the area because the test site is exposed to the open sea conditions.

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ACKNOWLEDGEMENTS. We thank the CSIR network project 'Capacity building of coastal placer mining' for financial assistance. We also thank Mr P. Ganeshan and R. Uchil for preparing the sample location map. This is NIO contribution no. 4635.

Received 19 January 2009; accepted 9 September 2009