

A potential phosphorite deposit on the continental margin off Chennai

Phosphorite is one of the world's most important phosphate mineral resources used mainly as fertilizer. The consumption of phosphate fertilizers has increased dramatically over the years in view of the 'Green Revolution'. Of the total 146 m tons of annual production of phosphate in the world (in 1987), the Asia-Pacific region (an agriculture-dominated and thickly populated area), produced only 13 m tons¹. India produced only 4.26% of the total phosphate of the Asia-Pacific region. The major recovery of phosphate in India comes from Mussoorie, Udaipur, Jhabua and Bijawar phosphorite mines and their cumulative annual production is about 0.58 m tons^{2,3}. The total production in India is far less than its demand (2-3 m tons/year)¹. As a result, India is compelled to import about 2 m tons/year (ref. 4). Therefore, in order to support the Green Revolution, India either has to intensify its exploration for the discovery of phosphate deposits of economic importance or pour out large sums of valuable foreign currency for importing phosphate fertilizers.

Phosphorite is defined as a rock composed of 18% P_2O_5 (ref. 5). Sedimentary phosphorites currently provide 82% of the total world production and 95% of the world's phosphate reserves⁶. Phosphorite deposits of marine origin have been identified on land and shallow continental margins and seamounts of the world ocean. Both relict and modern phosphorites have been reported on the continental margins⁷. Phosphatized limestones (< 11% P_2O_5)⁸⁻¹³ and high-grade phosphorites (21-33% P_2O_5)¹⁴⁻¹⁷ have been reported from the continental margins of India. As the occurrence of high-grade phosphorites is sporadic and mostly confined to subsurface depths, their resource evaluation and economic viability could not be accounted.

Cruise 126 of *ORV Sagar Kanya* was mainly organized to deploy meteorological data buoys at pre-determined locations along the east and southwest coast of India and to sample shelf-edge geomorphic features along the central and southwest coast of India. During deployment of data buoys, Peterson grab was operated at 7 stations on the outer shelf and upper

slope off Chennai at water depths between 30 and 293 m (Figure 1). The sediments recovered are clay/clayey sands. Upper portions of the grab sediments are clayey, and phosphorite is largely recovered from the lower portions of the grab, suggesting that phosphorites are buried under clays. Phosphorite/phosphatic sediments were recovered at 6 out of 7 stations. Maximum penetration of the grab is about 20 cm. Although dredging would have given better results on the extent of the deposit, it could not be operated as the main working deck of the vessel was occupied by data buoys.

Phosphorites recovered at different locations are classified into four types (Table 1): Light brown friable phos-

phorites, grey dense phosphorites, phosphorite sands and phosphatized algal nodules/limestones. Phosphorite sands are defined here as phosphate grains and phosphate infillings of planktic and benthic foraminifers and gastropod shells. Green grains are also associated with them. It was observed that more than one type of phosphorite occurs at each station. Friable phosphorites together with a few phosphate grains occur at deeper station (no. 3) on the continental slope which are associated with clayey sediments. Dense grey phosphorites occur abundantly at station 4 (4 kg/sq m) and are in the form of irregular or ellipsoidal nodules and crusts (Figure 2a). Furthermore, the sediments are clayey sands and

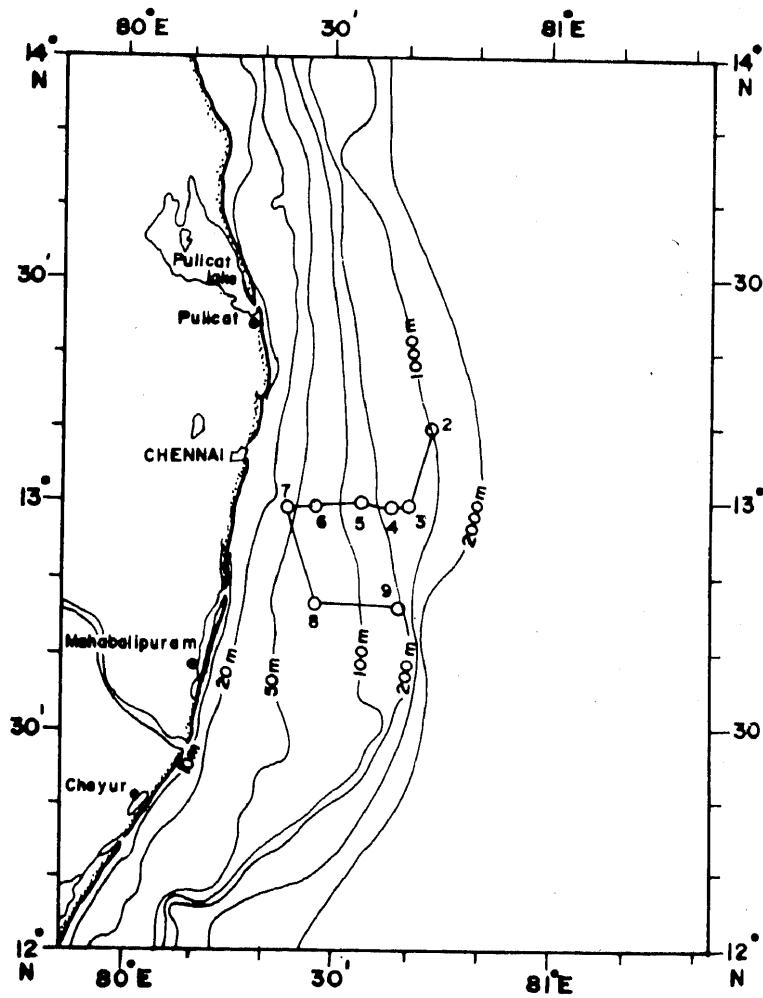


Figure 1. Sample location map. Location map, east coast of India. Station no. 2 is core location and others are grab stations.

Table 1. Details of sediment samples and phosphorites/phosphorite sands off Chennai

Station no.	Depth (m)	Sand in the sediment (%)	Phosphate grains in the sand (%)	Type of phosphorites	Minerals in the phosphorites	Peak height ratios of ICa/ICfa
SK-126/3	293	19	8	Light brown friable phosphorites	Cfa, Imc, qtz, feld	0.3
SK-126/4	186	44	42	Grey dense phosphorites	Cfa, Imc, hmc, qtz, feld	0.61
SK-126/5	124	81	30	Phosphorite grains	Cfa, Imc	—
SK-126/6	58	44	16	Grey irregular phosphatized limestones	Lmc, qtz, feld, cfa	—
SK-126/7	30	37	6	—	—	—
SK-126/8	66	73	21	Grey irregular phosphatized limestones	Lmc, qtz, feld, cfa	—
SK-126/9	160	62	27	White phosphatized algal nodules	Hmc, ara, feld, cfa	8.2

Cfa, Carbonate fluorapatite; Lmc, Low-magnesium calcite; Hmc, High-magnesium calcite; Qtz, Quartz; Feld, Feldspar; Ara, Aragonite.

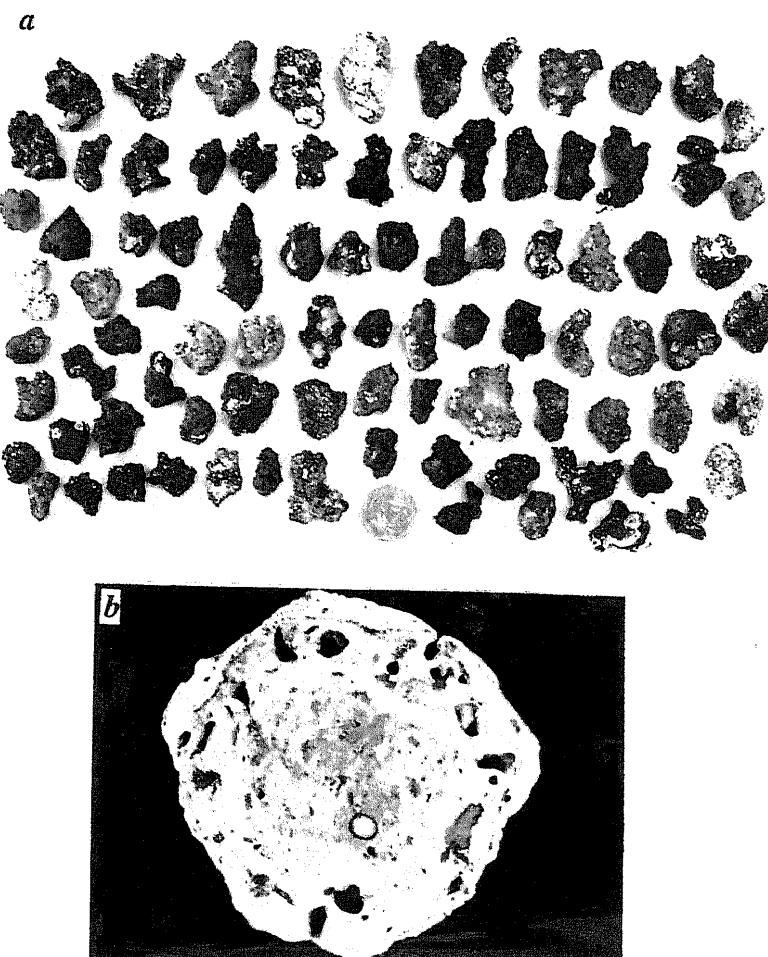


Figure 2. a, Dense phosphorites (scale - see one rupee coin below); b, Polished section of the phosphatized algal nodules (nodule size 1 cm diameter).

about forty per cent of the sand fraction is phosphatic. The sediments recovered from shallower stations are clayey (Table 1) and phosphatized limestones/algal nodules (Figure 2 b) and phosphorite sands occur in the lower portions of the sediments in the grab. It is suspected that due to the lesser penetration of the grab, it hardly collected the phosphorites underlying the clays.

Phosphorite sample powders were analysed from 8° to $40^\circ 2\theta$ on a Philips X-ray diffractometer using nickel filtered $\text{CuK}\alpha$ radiation at $1^\circ 2\theta/\text{min}$. Carbonate fluorapatite and calcite are the major minerals in friable phosphorites, dense phosphorites and phosphorite sands (Figure 3, Table 1). Peak height ratios indicate that the former dominates the latter in all the samples. Quartz, feldspar and high-magnesium calcite are found as accessory minerals. High-magnesium calcite is the most abundant mineral, followed by carbonate fluorapatite in the phosphatized algal nodules. EDAX (Energy dispersive X-ray analysis) studies were carried out for 9 elements on JEOL 840 SEM/EDAX. Measurable S contents (0.9%) occur in only algal nodules. Major element composition of phosphorites (Table 2) indicate

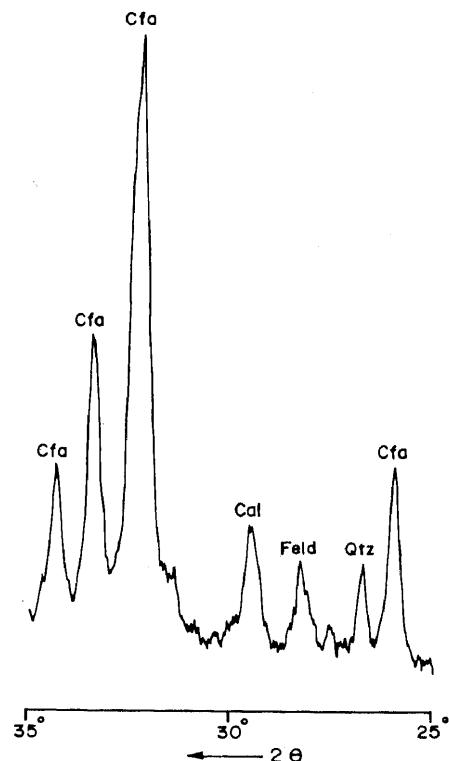


Figure 3. X-ray diffractogram of the light brown friable phosphorites. Cfa, Carbonate fluorapatite; Qtz, Quartz; Cal, Calcite; Feld, Feldspar.

SCIENTIFIC CORRESPONDENCE

that the P_2O_5 content is highest (31%) in phosphorite grains followed by friable phosphorites (27%) and dense phosphorites (21%) and least in algal nodules (9%). The average CaO content is more than 56% (average in sedimentary rocks) in grey dense phosphorites and phosphorite grains. We are unable to explain these high values most probably due to instrumental error. CaO/P_2O_5 content of the phosphorites ranges from 1.72 to 6.2 and is higher than that in pure carbonate fluorapatite (1.54) (ref. 18). For convenience, the average chemical analyses of friable and dense phosphorites and phosphorite grains (average analyses of 1, 2 and 3, Table 2) were compared with the composition of the phosphorites from other offshore regions. Si, Al, Fe, Mg, Na and K values of these phosphorites are significantly higher than the Holocene and Pleistocene phosphorites of the western margin of India (see analyses 5 and 6, Table 2). The phosphorites from the western Indian margin were recovered from carbonate-dominated sediments. Si, Fe and K values of the phosphorites are lower and Ca, P and Al are higher than in the phosphorites of Namibia and Agulhas Bank, South Africa (analyses 7 and 8, Table 2) and, Si, Al, Fe, Mg and Ca are higher and P and Na values are lower than that in the phosphorites of Peru margin, South America (analyses 9, Table 2). Phosphorites from both Namibia and Peru margins were, however, recovered

from diatomaceous muds. P and Ca values are much higher and Si, Al, Fe and K are lower than the phosphorites of the Eastern Australian margin (analyses 10, Table 2) which is a weak upwelling region. This comparison indicates that the initial sediments in which phosphatization has taken place may be neither carbonate-dominated nor diatom-dominated. Phosphatization apparently has taken place in mixed terrigenous and biogenic sediments. These results have to be confirmed by petrographic studies.

The importance of these phosphorites is manifold: (i) As they contain more than 18% P_2O_5 , these can be classified as ore grade phosphorites. The probable continuity of the deposit at different stations along a stretch of 21 km (each) on two parallel tracks perpendicular to the coast would make this the largest phosphorite occurrence so far reported from the continental margins of India. (ii) The area covered by phosphorites is approximately 636 sq km. It is the least estimate area based on a few stations. It is premature to evaluate the resource potential at this stage. If detailed exploration is done, the area covered by phosphorites is likely to be larger and this deposit may serve as an economically viable phosphorite deposit. In order to evaluate the lateral and vertical extent of the deposit and its resource potential, exploration needs to be carried out at closer grid spacing. Offshore area like Chatham Rise

off New Zealand has been thoroughly investigated for their resource potential where exploration was done at 200–300 m grid spacing and sometimes even at 100 m spacing. The results of exploration indicate that the phosphorites on the Chatham Rise are randomly distributed and their abundance at different stations varies from 0 to 100 kg/m² (ref. 19). In spite of this, these are considered as economically viable deposits. (iii) These phosphorites are also of significant academic interest. For example, unlike the phosphorites abundantly reported on the western continental margins of the world ocean, associated with upwelling currents, these occur off Chennai on the eastern margin of India where upwelling currents are unknown. (iv) Type (hardness and colour), mineralogy and geochemistry of the phosphorites recovered here are different, possibly indicating that phosphorites of more than one generation are mixed up. Earlier study on phosphorites in the vicinity¹⁷, however, did not clarify the sources of P for the formation of ore grade phosphorites but identified the fossils of Cretaceous–Eocene age in them. India was situated south of equator during the Cretaceous and moved through the equator to its present position during the continental drift. It is therefore likely that the equatorial oceanic upwelling might have played a major role in the development of organic-rich productivity system on the continental margins that favoured the formation of ore-grade phosphorites. Moreover, friable phosphorites must be younger than the dense grey phosphorites which resemble those off Peru–Chile, where intense upwelling and present day phosphogenesis is taking place²⁰. In contrast to Peru margin, there is no upwelling off Chennai but a southerly current (0.15 to 0.3 m/s) induced by cyclonic eddies prevails on the continental shelf and slope. Several rivers from the east coast of India discharge abundant terrigenous flux annually to the Bay of Bengal and these rivers debouched sediments directly on or very close to the continental slope during the lowered sea levels. Despite this, the phosphorites of Cretaceous–Eocene age in the study region are still exposed on the continental slope and partly buried on the continental shelf. Two possibilities may be considered for various types of phosphorites: The Western Boundary Current (WBC) has been presently traced about 100 nm away

Table 2. Geochemistry of the phosphorites off Chennai (1–4) and their comparison with other offshore phosphorites (5–10)

Element	1 (9)*	2 (11)	3 (3)	4 (4)	5 (24)	6 (15)	7 (46)	8 (12)	9 (21)	10 (4)
SiO_2	16.90	9.72	4.04	16.80	3.40	0.11	19.39	14.79	8.79	24.00
Al_2O_3	5.50	2.62	0.79	5.01	1.53	0.33	1.95	2.13	2.68	3.53
FeO	2.78	2.98	5.00	7.08	1.34	0.39	6.95	6.17	1.28	5.00
MgO	1.49	2.36	1.05	5.15	1.27	0.81	1.41	1.38	0.99	1.31
CaO	46.25	58.16	64.20	54.53	46.30	50.20	37.28	36.87	42.00	31.90
Na_2O	1.20	1.01	0.62	0.68	0.20	—	0.90	0.76	1.08	0.90
K_2O	0.89	0.36	—	0.71	0.30	0.10	1.38	1.55	ND	0.89
P_2O_5	26.93	21.35	31.12	8.80	29.30	33.30	17.42	17.53	27.58	11.00
CaO/P_2O_5	1.72	2.72	2.06	6.20	1.58	1.51	2.14	2.10	1.52	2.90

*Average of number of analyses.

1, 2, 3 and 4, Present study (EDAX analyses on freshly broken surfaces); 1, Light-brown friable phosphorites; 2, Grey dense phosphorites; 3, Phosphorite grains; 4, White phosphatized algal nodules. 5 and 6, Western margin of India (seasonal upwelling region); 5 – Holocene dense phosphorite off Malavan (microprobe analyses) (Purnachandra Rao, V., unpublished data), 6 – Pleistocene phosphorite off Goa (microprobe analyses) (ref. 14). 7 and 8, South African margin (intense upwelling region); 7 – Rock phosphate off Namibia (microprobe analyses) (ref. 21); 8 – Phosphorites on the Agulhas Bank (microprobe analyses) (ref. 22). 9, South American margin (intense upwelling region); Holocene phosphorites off Peru (microprobe analyses) (ref. 23). 10, Eastern Australian margin (weak upwelling region); Non-ferruginous Holocene phosphorite²⁴.

SCIENTIFIC CORRESPONDENCE

from the coast; it is likely that the WBC might have been closer to the coast in the geological past and induced conditions suitable for phosphogenesis. Alternatively, high-energy environment might have prevailed on this part of the margin for a longer time that minimized the deposition of large terrigenous flux and favoured conditions similar to hardgrounds for the formation of various phosphorites. Phosphatized algal nodules (Figure 2 b) provide evidence for such high-energy conditions. In other words, different oceanographic/coastal processes influenced at different times in the formation of phosphorites which requires thorough study. (v) Phosphorites are good host for F, U, REE and V. Fluorine and U are bound to apatite and increase with increasing P_2O_5 content. Similarly, REE contents have been reported to be higher in older phosphorites compared to younger phosphorites⁵. Detailed studies on these phosphorites are in progress which would provide important information on palaeoceanography, age and factors controlling the genesis of phosphorites.

1. Cook, P. J., Banerjee, D. M. and Southgate, P. N., in *Phosphorite Requirements for Sustainable Agriculture in Asia and Oceania*, International Rice Research Institute, Manila, 1990, pp. 97-114.
2. Banerjee, D. M., *J. Geol. Soc. India*, 1989, **13**, 160.
3. Notholt, A. J. G., Sheldon, R. P. and Davidson, D. F., *Phosphate Deposits of the World, Phosphate Rock Resources*, Cambridge University Press, Cambridge, 1989, vol. 2, p. 566.

4. Qasim, S. Z. and Nair, R. R., *J. Mines Met. Fuels*, 1983, **30**, 236-239.
5. Slansky, M., *Geology of Sedimentary Phosphates*, North Oxford Academic, London, 1986, p. 210.
6. Howard, P. F., *Econ. Geol.*, 1979, **74**, 192-194.
7. Baturin, G. N., in *Developments in Sedimentology* 33, Elsevier, Amsterdam, 1982, p. 345.
8. Nair, R. R., *Mahasagar, Bull. Nat. Inst. Oceangr.*, 1985, **18**, 273-279.
9. Borole, D. V., Rajagopalan, G. and Somayajulu, B. L. K., *Mar. Geol.*, 1987, **78**, 161-165.
10. Rao, V. Purnachandra and Nair, R. R., *Mar. Geol.*, 1988, **84**, 105-110.
11. Rao, V. Purnachandra, Natarajan, R., Parthiban, G. and Mascarenhas, A., *Mar. Geol.*, 1990, **95**, 17-29.
12. Rao, V. Purnachandra, Lamboy, M. and Dupeuble, P. A., *Mar. Geol.*, 1993, **111**, 133-158.
13. Rao, V. Purnachandra and Lamboy, M., *Mar. Geol.*, 1996, **136**, 41-53.
14. Rao, V. Purnachandra, Rao, Ch. M., Thamban, M., Natarajan, R. and Rao, B. R., *Curr. Sci.*, 1995, **69**, 1017-1022.
15. Rao, Ch. M. and Rao, B. R., *Curr. Sci.*, 1996, **70**, 308-311.
16. Vaz, G. G., Faruque, B. M., Biswas, N. R., Vijaykumar, P., Misra, V. S., Sankar, J. and Krishna Rao, J. V., *Indian J. Mar. Sci.*, 1996, **25**, 20-24.
17. Vaz, G. G., *Indian J. Mar. Sci.*, 1995, **24**, 8-12.
18. McClellan, G. H. and Lehr, J. R., *Am. Mineral.*, 1969, **54**, 1374-1391.
19. Von Rad, U. and Kudrass, H. R., *Geol. Jahrb. Reihe D*, 1981, Heft 6-5, p. 355.
20. Froelich, P. N., Arthur, M. A., Burnett, W. C., Deakin, M., Hensley, V., Jhanke, R., Kaul, L., Roe, K., Soutar, A. and Vathakanon, C., *Mar. Geol.*, 1988, **80**, 309-343.
21. Bremner, J. M. and Rogers, J., in *Phosphate Deposits of the World, Neogene to Modern Phosphorites* (eds Burnett, W. C. and Riggs, S. R.), Cambridge University Press, 1989, vol. 3, pp. 143-152.
22. Parker, R. J., *J. Sediment. Petrol.*, 1975, **45**, 230-242.
23. Burnett, W. C., *Geol. Soc. Am. Bull.*, 1977, **88**, 813-823.
24. Cook, P. J. and O'Brien, G. W., in *Phosphate Deposits of the World, Neogene to Modern Phosphorites* (eds Burnett, W. C. and Riggs, S. R.), Cambridge University Press, 1989, vol. 3, pp. 98-115.

ACKNOWLEDGEMENTS. We thank Dr E. Desa, Director, National Institute of Oceanography for encouragement. We thank Dr M. Veerayya and M. T. Babu for discussions. V. P. Rao thanks Prof. Vikram Jayaram, Department of Metallurgy, Indian Institute of Science, Bangalore for EDAX analyses. This is NIO contribution no. 2557.

V. PURNACHANDRA RAO
K. MOHAN RAO*
K. H. VORA
F. ALMEIDA
M. M. SUBRAMANIAM
C. GODFREY A. SOUZA

National Institute of Oceanography,
Dona Paula, Goa 403 004, India

*NIO Regional Centre,
176, Lawsons Bay Colony,
Visakhapatnam 530 017, India