fuel burning in this region, as also reported by other independent studies.

1. Tripathi, J. K., Bock, B., Rajamani, V. and Eisenhauer A., XVI Inqua Congress, Reno, Nevada, USA, 2003, Abst. 5–7, p. 75.
2. Ashara, Y., Tanaka, T., Kamioka, H. and Nishimura, A., *Earth Planet. Sci. Lett*., 1995, **133**, 105–116.
3. Eisenhauer, A. *et al.*, *Chem. Geol*., 1999, **158**, 173–188.
4. Sillen, A., *J. Hum. Evol.*, 1992, **23**, 495–516.
5. Blum, J. D., Taliaferro, E. H., Weisse, M. T. and Holmes, R. T., *Biogeochemistry*, 2000, **49**, 87–101.
6. Jacobson, A. D., Blum, J. D, Chamberlin, P., Poage, M. A. and Sloan V. F., *Geochim. Cosmochim. Acta*, 2002, **66**, 13–27.
7. Quade, J., Chivas, A. R. and McCulloch, *Palaeogeogr. Palaeoclimatol. Palaeoecol*., 1995, **113**, 103–117.
8. Kennedy, M. J., Chadwick, O. A., Vitousek, F. M., Derry, L. A., and Hendricks, D. M., *Geology*, 1998, **26**, 1015–1018.
9. Vitousek, P. M., Kennedy, M. J., Derry, L. A. and Chadwick, O. A., *Oecologia*, 1999, **121**, 255–259.
10. Capo, R. C. and Chadwick, O. A., *Earth Planet. Sci. Lett*., 1999, **170**, 61–72.
11. Yadav, S. and Rajamani, V., *Geochim. Cosmochim. Acta*, in press.
12. Liebetrau, V., Eisenhauer, A., Gussone, N., Wörner, G., Hansen, B. T. and Leipe, T., *Geochim. Cosmochim. Acta*, 2002, **66**, 73–83.
13. Hoernle, K. A. and Tilton, G. R., *Swiss Bull. Mineral. Pet. V*, 1991, **71**, 3–18.
14. Galy, A. and France-Lanord, C., *Geology*, 2001, **29**, 23–26.
15. Srivastava, P., Shukla, U. K., Mishra, P., Sharma, M., Sharma, S., Singh, I. B. and Singhvi, A., *Curr. Sci.*, 2000, **78**, 498–503.
16. Kar, A., Proceedings of the Seminar of Geology of Rajasthan–Status and Perspectives (ed. Kataria, P.), Geology Dept., Udaipur, 1999, pp. 175–212.
17. Tripathi, J. K. and Rajamani, V., *Chem. Geol*., 1999, **155**, 265–278.
18. Dhir, R. P., *Mem. Geol. Soc. India*, 1995, **32**, 191–209.
19. Sikka, D. R., *Curr. Sci*., 1997, **72**, 35–46.
20. Kar, A., *J. Arid Environ*., 1993, **25**, 83–96.
21. Gupta, J. P., Agarwal, R. K. and Raikhy, N. P., *J. Arid Environ*., 1981, **4**, 15–20.
22. Reddy, M. S. and Venkataraman, C., *Atmos. Environ.*, 2002, **36**, 677–697.
23. Tsoar, H. and Pye, K., *Sedimentology*, 1987, **34**, 139–153.
24. Elias, R. W., Hirao, Y. and Patterson, C. C., *Geochim. Cosmochim. Acta*, 1982, **46**, 2561–2580.
25. Blum, J. D. *et al.*, *Nature*, 2002, **417**, 729–731.
26. Herut, B., Starinsky, A. and Katz, A., *Earth Planet. Sci. Lett*., 1999, **120**, 77–84.
27. Jacobson, A. D. and Blum, J. D., *Geology*, 2000, **28**, 463–466.
28. Chesley, J. T., Quade, J., Ruiz, J., *Earth Planet Sci. Lett*., 2000, **179**, 115–124.
29. Bhatt, N., *Proc. Indian Natl. Sci. Acad*., 2003, **69**, 137–150.
30. Wasson, R. J. *et al.*, *Z. Geomorphol. N. F. Suppl.*, 1983, **45**, 117–151.
31. Gaudie, A. S. and Sperling, C. H. B., *J. Sediment. Petrol*., 1977, **47**, 630–633.
32. Péwé, T. L., Péwé, E. A., Péwé, R. H., Journaux, A. and Slatt, R. M., *Geol. Soc. Am. Spec. Pap*., 1987, **186**, 169–190.
33. Whipkey, C. E., Capo, R. C., Chadwick, O. A. and Stewart, B. W., *Chem. Geol*., 2000, **168**, 37–48.
34. Galy, A., France-Lanord, C. and Derry, L. A., *Geochim. Cosmochim. Acta*, 1999, **63**, 1905–1925.
35. Mukhopadhyay, B., Datar, S. V. and Srivastava, H. N., *Mausam*, 1992, **43**, 249–258.
36. Wake, C. P., Mayewski, P. A., Xie, Z., Wang, P. and Li, Z., *Geophys. Res. Lett*., 1993, **20**, 1411–1414.
37. Tiwari, S., *Vayu Mandal*, 1999, 376–380.
38. Kar, A., *Mem. Geol. Soc. India*, 1995, **32**, 168–190.
39. Veizer, J., *Annu. Rev. Earth Planet. Sci*., 1989, **17**, 141–167.
40. Pant, R. K., *Curr. Sci.*, 1993, **11 and 12**, 841–847.

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Occurrence of xenotime in the Narasapur beach placers, West Godavari District, AP

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Xenotime has been identified in the beach placers of India from Narasapur, West Godavari District, Andhra Pradesh. It occurs in 63 and 73 μm size mode, strewn in rear and inter dunes and distributed vertically down to investigated depth of 10–12 m. The average heavy mineral content in this coast is 14.7% within which the xenotime grade varies from 0.09 to 1.32% (average 0.61%). Though many possible source rocks exist within the Eastern Ghat Mobile Belt (EGMB), the bipyramidal shape and fine size of xenotime indicates high temperature of formation leading to the surmise that granite and granite pegmatites in the EGMB are the source.

XENOTIME, an yttrium (Y) and heavy rare earth (HREE) phosphate mineral has specific high-tech applications in Nuclear and Space industry as in the making of superconductors and rare earth magnets. The Atomic Minerals Directorate of Exploration and Research (AMD), Hyderabad has the responsibility of exploration and exploitation of xenotime. In the last three decades AMD has proved sizeable deposits in the continental environs, especially in fluvial placers (Siri River in Chhattisgarh and Deo River in Jharkhand)[1], and soils (Kanyaluka in Jharkhand)[2]. Xenotime is also being exploited in these areas on a minor scale for a long time. Many xenotime occurrences have been brought to light in the fluvial placers of Raigarh and Surguja Districts, Madhya Pradesh, Gumla and Singbhum Districts, Jharkhand, South Arcot District, Tamil Nadu[3], Baroda and Panchmal Districts,

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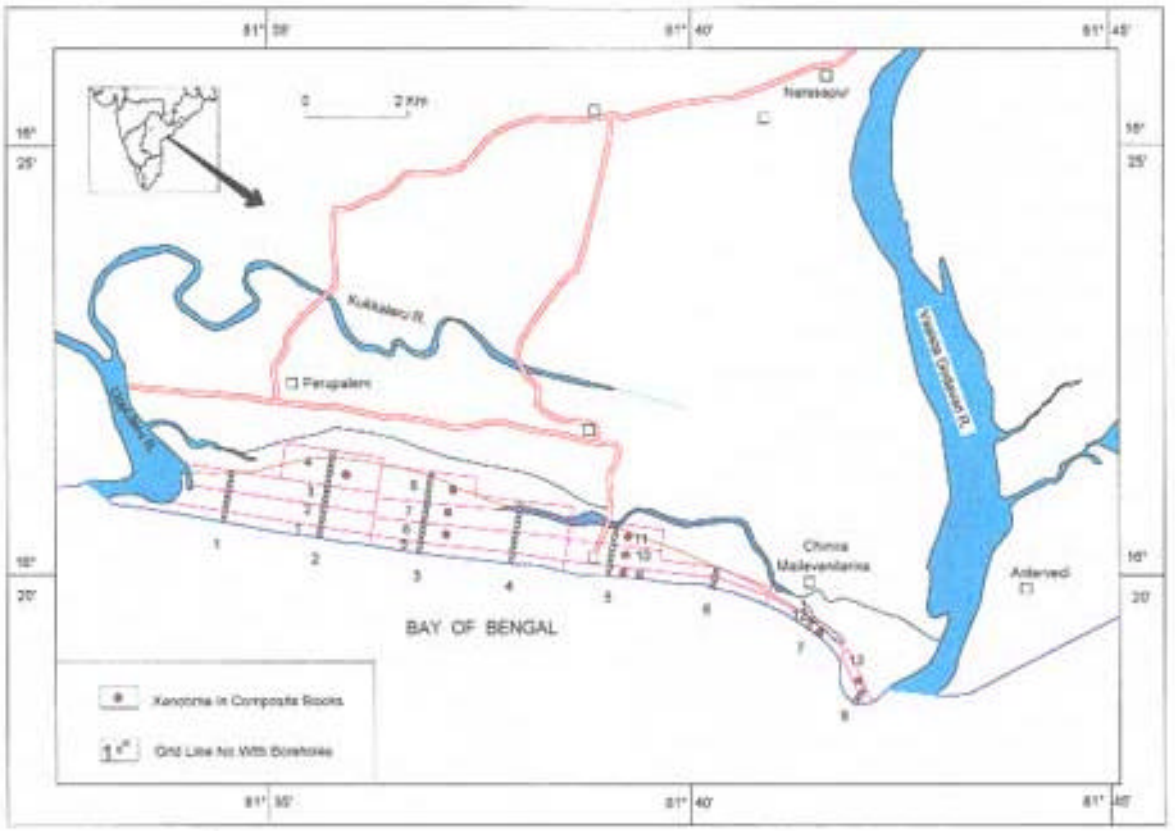

Figure 1. Map showing xenotime occurrence along the Narasapur coast.

Gujarat[4], Koraput District, Orissa[5], Mehboobnagar District, Andhra Pradesh[6] and Raichur District, Karnataka[7]. In North East India, xenotime is recorded in placers in Kameng District, Arunachal Pradesh[8], West Khasi Hills[9,10] and Garo Hills District, Meghalaya[11].

Beach placers are the source of xenotime all over the world in general (Florida, USA)[12], and Asia in particular (Indonesia, Malaysia, and China)[13]. This communication describes the mode of occurrence of xenotime in the beach placers of Narasapur, in the east coast, Andhra Pradesh, India. Figure 1 presents the location of samples from composite blocks in which xenotime has been identified.

The Narasapur coast has been surveyed systematically for heavy minerals on a grid interval of 2000×100 m laid across the E–W trend of the coast. The dormer drill that operates manually has been used and samples were collected at each 1.5 m up to a depth of 10 to 12 m. These individual samples were grouped into composite samples based on the morphology (frontal, inter and rear dunes) and water table depth. The samples were studied at AMD, Beach Sand and Offshore Investigations Laboratory, Hyderabad. A representative portion was analysed for shell, slime, size and total heavy mineral content. Each size fraction was subjected to bromoform separation and magnetite was separated by hand magnet. The magnetite free heavies were further separated into magnetic and nonmagnetic fractions using electromagnetic separator at 0.2 amperage. Both the fractions were studied under the microscope for estimating individual heavy mineral percentages by grain-counting method. Generally, clove oil (refractive index, RI 1.53) is used as the medium in grain mounting, however, methylene iodide (RI 1.72) is used to distinguish xenotime and monazite. Xenotime and monazite are cogenetic phosphate minerals. The distinct property of xenotime is that it has two refractive indices of 1.7 (*çþ*) and 1.8 (*çð*) with an appreciable difference, while monazite has all three (*çá*, *çâ*, *çã*) RI about 1.8. This property has been used in differentiating these two minerals. When the heavy liquid, methylene iodide is used as an immersing medium, the relief of xenotime changes with direction (Figure 2). The mineral does not stand out along *çþ* direction, but it stands out along (*çð*) direction. The positive relief of monazite grains in all directions is clearly visible. This is the confirmatory test under microscope. Though xenotime and monazite are cogenetic, monazite crystallizes in the monoclinic system and xenotime in tetragonal system. It is observed that grain size is fine and xenotime resembles (in shape) zircon that is isostructural to a greater extent; hence caution is exercised in distinguishing between these two minerals while grain-counting. Some hand-picked grains have been subjected to XRD confirmation.

Under microscope, xenotime is translucent (Figure 3 *a*) and shows bipyramidal shape (Figure 3 *b*). However, some

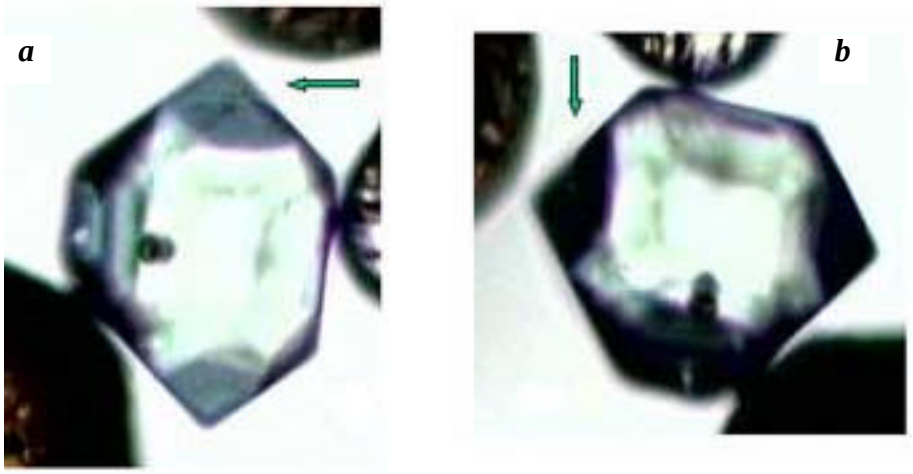

Figure 2. Xenotime in methylene iodide. Arrow shows two reliefs in different orientations, under plane polarized light, magnification 1 cm = 0.05 mm.

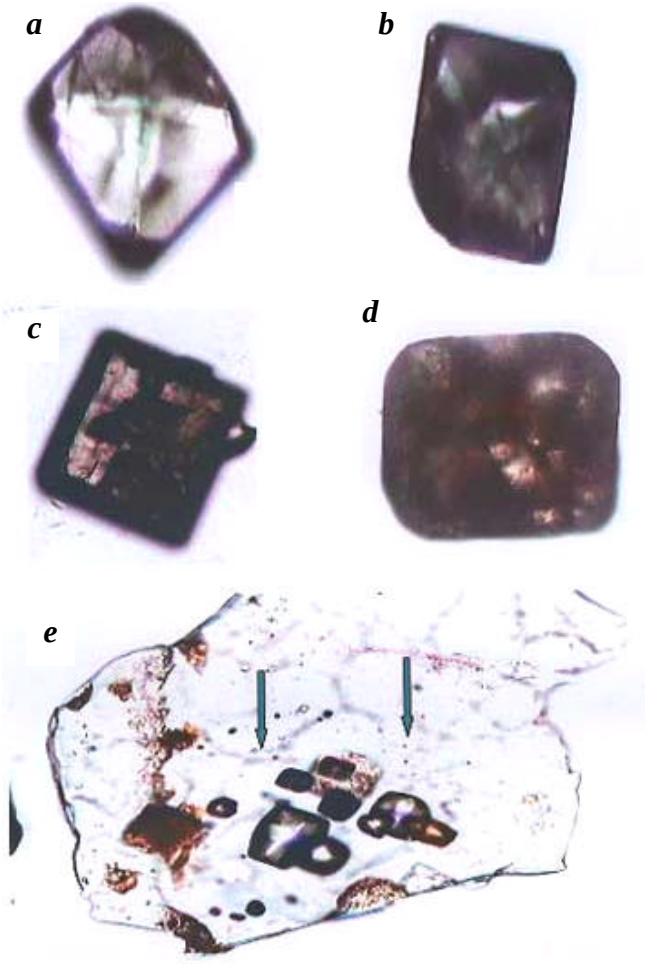

Figure 3 *a*–*d*. Different forms of xenotime. ***e***, Xenotime inclusions within garnet grain under plane polarized light; magnification 1 cm = 0.05 mm.

grains show perfect square shape (Figure 3 *c*) with rounded corners (3D). Lustre is vitreous; relief and birefringence are very high. It is weakly pleochroic, optically uniaxial positive and shows straight extinction. Some grains are coated with iron oxide (Figure 3 *d*). Colour of the grains varies between orange, pale yellow and brownish-red. Some grains show opaque inclusions and their shapes are distorted, often broken pieces of this type also occurring. Xenotime was confirmed by the XRD studies also.

Xenotime is distributed vertically down to a drilled depth of 10–12 m and it may extend in the sands deeper down. It is traced laterally into inter and rear dunes of the area, where monazite and zircon concentrations are also high. It occurs in 63 and 73 μm sizes. The heavy mineral crops with which xenotime is associated in the area are sillimanite, garnet, ilmenite, zircon and monazite. Other heavy minerals in the area are staurolite, tourmaline, apatite and epidote. The grade of xenotime in the raw sand ranges from 0.02 to 0.35%, with an average of 0.06 (n = 14) for those blocks wherein this mineral is identified (Figure 1). The average total heavy mineral content in the area is 14.7%. Within this, the xenotime grade varies from 0.09 to 1.32%. The identification of xenotime in Narasapur beach placers is reported in the beach environment in India.

In India, poly mineralic riverine placers are the source of xenotime and AMD has so far estimated 3500 tonnes of poly mineralic concentrate containing 3 to 8% grade in the pre concentrate[14]. The low grade and fine grain size of xenotime in the beach placers, unlike coarse-grained riverine placers, may hinder its extraction at present. However, it can be economically exploited either as a by-product or with advanced extraction technique.

The Narasapur coast lies in the central part of Krishna–Godavari basin and this part of the coast is bounded between Vasista Godavari River in the northeast and Upputeru in the southwest. Generally, it is an accepted theory that beach placers reflect hinterland rocks mineralogy. However, in the absence of reported xenotime occurrences in the hinterland geology, this discovery is significant. To understand the source of derivation of xenotime, the following are considered.

The source rocks for the xenotime all over the world and in India are granites, alkali granites, pegmatites and alkaline rocks, nephelene syenites. These rocks are located in the hinterland Eastern Ghat Mobile Belt (EGMB). Xenotime together with monazite has been reported in sillimanite biotite gneisses and other metamorphic rocks from Idaho Springs, Colorado[15] and the same rock types are dominant in the EGMB also. The bipyramidal shape of xenotime indicates formation at a high temperature, which ultimately points towards granites and granitic pegmatites as source rocks in the EGMB.

The garnets that are co-occurring in the placers of this coast, are in 120 μm size dominantly, showing various mineral inclusions. Some inclusions are akin to xenotime in shape, size and optical properties, especially relief and extinction (high compared to host garnets, Figure 3 *e*). These garnets (with mineral inclusions) are fresh and appear to be derived from magmatic rocks. Hence, these inclusions are interesting and further studies on the garnet placers and garnets in different rock types in the hinterland EGMB may also throw some light on the source rocks.

This work reports on the occurrence of xenotime in the beach placers of Narasapur. Continued efforts as part of heavy mineral exploration in the vast coastal stretches may enhance the xenotime reserve base. Further, this study has opened new vistas for rare minerals search in the beach placers of India.

1. Sinha, R. P., Unpublished Annual Report of RMRE Group, AMD, Hyderabad, 2001.
2. Ramachandran, S., Parthasarathy, T. N. and Saraswat, A. C., Xenotime from Kanyaluka, Singhbhum dist., Bihar, India. *J. EARFAM*, 1989, **2**, 177–182.
3. Rai, S. D., Shivananda, S. R., Tiwary, K. N., Banerjee, D. C. and Ravi Kaul, Xenotime bearing inland placers of India. *J. EARFAM*, 1991, **4**, 77–92.
4. Maithani, P. B., Rathaiah, Y. V. and Varughese, S. K., A note on the occurrence of xenotime bearing placers of Vasvanali, Zoz area, Baroda dist., Gujarat, India. *J. Indian Assoc. Sediment.*, 1993, **12**, 41–48.
5. Desapati, T., Unpublished Annual Report on Koraput Dist, Orissa, AMD, Hyderabad, 1991.
6. Yamuna Singh, Rai, S. D., LakshmiNarayana, Y. and Sankaran, A. V., A note on the yttrium mineral potential of granitic soils in the parts of A.P., India. *J. Geol. Soc. India*, 1991, **38**, 207–210.
7. Desapati, T., Unpublished Annual Report on Mehoboobnagar and Raichur dists A.P. and Karnataka, AMD, Hyderabad, 1994.
8. Hansoti, S. K., Unpublished Annual Report on Radiometric Survey in Kameng dist., Arunachal Pradesh, AMD, Hyderabad, 1986.
9. Subrahmanyam, A. V., Unpublished Petrology Report on Lower Mahadek Sandstone Samples, North Eastern Region, AMD, 1997.
10. Subrahmanyam, A. V., Unpublished Petrological Report on Samples from Granites of Mawlait, West Khasi Hills district, Meghalaya, North Eastern Region, AMD, 1998.
11. Sastry, I. V., Rawat, T. P. S. and Basu, A. N., A note on the occurrence of xenotime in the residual granitic soils of Mandalagiri area, Garo hills dist., Meghalaya India. *J. Atom. Miner. Sci.*, 1995, **3**, 61–65.
12. Milner, H. B., *Sedimentary Petrography*, Thomas and Murrey & Co, London, 1952, p. 353.
13. Baxter, J. L., *Miner. Resour. Bull. 10*, Geological Survey of Western Australia, 1989.
14. Banerjee, D. C., Sinha, R. P. and Dwivedi, K. K., Xenotime resource in India – An overview. Proceedings of the Seminar on Recent Developments in Science and Technology of REE, Cochin, 1995, pp. 1–9.
15. Vlasov, K. A., Geology and chemistry of rare elements. Israel Project for Scientific Translations, Jerusalem, 1966, p. 204.

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