

Miocene phosphorites from the Murray Ridge, northwestern Arabian Sea

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Received 5 March 2007; received in revised form 4 December 2007; accepted 5 December 2007

Abstract

Phosphorites from the Murray Ridge, NW Arabian Sea comprise nodules, bioclasts, and bone fragments. The nodules are made up of a homogeneous, light-colored phosphate nucleus consisting of *Rivulariacean* filamentous cyanobacteria and a thin dark-grey colored phosphate cortex showing abundant microbial filaments and microborings. The bioclasts comprise of ~14–14.5 Ma old planktonic foraminifers, accepted as the time of deposition. Spherical to ovoid-shaped apatite microparticles resembling fossil bacteria are distinct components in the bioclasts. Bone fragments exhibit apatite fillings. The nodules and bone fragments consist entirely of carbonate fluorapatite (CFA) with low Al, K, and Th concentrations suggesting absence of continental detritus. Shale-normalized REE patterns of the samples support a seawater-derived composition. The highly uniform initial ϵ_{Nd} values of -4.8 to -5.1 are interpreted as the seawater value at the onset of phosphatization ~14 Ma ago. In contrast, $^{87}Sr/^{86}Sr$ ratios show a large range of 0.709055 to 0.709124 corresponding to unusually young stratigraphic ages of ~1 to 3 Ma. The data are interpreted as evidence for post-depositional Sr exchange of the recrystallizing phosphorites with fluids isotopically not much different from modern seawater. It is concluded that the phosphorites formed under oxic, shallow-water conditions where microbial populations assimilated phosphorus primarily from seawater and mediated precipitation of CFA during early diagenesis at the sediment–water interface on different substrates.

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Keywords: Phosphorites; Microbial activity; Murray Ridge; REE and trace elements; Sr and Nd isotopes

1. Introduction

Open-ocean phosphorites occur on isolated seamounts, plateaus, ridges, and other elevated areas of the seafloor (Burnett et al., 1987). Not included in this category are those from continental shelves and slopes. Since the discovery of phosphatized limestones at mid-Pacific seamounts by Hamilton (1956), open-ocean phosphorites were reported from the Pacific, Atlantic, and Indian Oceans (Baturin, 1982). The deposits mostly formed under oxidizing conditions, although some can be linked to the equatorial upwelling and mid-water oxygen-minimum zone (Halbach and Manheim,

1984). Phosphatic argillites associated with volcanic material (Kharin, 1974); Guano-derived (Insular-type; Piper, 1986), and marine sedimentary phosphorites (Glenn et al., 1994) are further varieties. Due to the low organic carbon content in open-ocean phosphorites, the sources of phosphorus, e.g. the water column versus submarine volcanism, have been a topic of debate (Glenn et al., 1994). Despite the fact that phosphorite from mid-ocean ridges can account for up to ~12% of the total annual phosphorus input in the oceans (Feely et al., 1996), there are surprisingly few studies on their composition and origin. The purpose of this paper is to elucidate the genesis of phosphorite samples from the Murray Ridge (MR) located near the highly productive upwelling region of the Oman margin (den Dulk et al., 2000). For this purpose we interpret petrological and mineralogical evidence in combination with geochemical- and Nd–Sr isotopic data.

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2. Geologic setting, age and description of phosphorite samples

The Murray Ridge is a ~420 km long and ~20 to 50 km wide NE-trending asymmetric submarine high in the NW Arabian Sea (Fig. 1). It is a shallow oceanic ridge with a water depth of ~400 m at its NE termination (Minshull et al., 1992). It is a part of the Arabian–Indian plate boundary undergoing uplift since the early Miocene (Clift et al., 2002). The ridge is transected by deep discontinuous troughs with a sediment fill of ~2 km. Due to the fact that the sediment layers on the flanks of the MR are of uniform thickness, it can be concluded that the troughs were formed during recent faulting (Uchipi et al., 2002). The summit of the ridge lies within the oxygen-minimum zone (OMZ: 150 m–1250 m; den Dulk et al., 2000) and the formation of the phosphorites may have influenced by upwelling-induced productivity (den Dulk et al., 2000). During the Tertiary and Quaternary the MR was near sea level and probably influenced by transgressive and regressive episodes. The rise and fall of sea level may have favoured phosphorite accumulation, or aided in reworking and concentrating phosphorite and other authigenic grains (Glenn et al., 1994).

The samples were recovered with a gravity corer from the eastern flank of the MR at 470 m depth (Lat. 21° 24. 4 N, Long. 61° 54.7E; Fig. 1). All samples were collected from a single core at 50 cm depth. We studied three different types of phosphorite samples: samples MRP 1 and 2 comprise phosphorite nodules of 1–3 cm diameter (Fig. 2A–D). Sample MRP 3 is made up of bioclasts (Fig. 2A) consisting of up to 50% of planktonic foraminifers and interspersed basalt and mineral fragments. The planktonic foraminifers (Fig. 2F) are: *Orbulina universa* D’Orbigny’ 1839 (base of zone N9 to Recent), *Orbulina bilobata* (D. Orbnigny, 1846), *Orbulina suturalis* Bronnimann, 1951 (base of zone N9 to Recent), *Praeorbulina sicana* De Stefani, 1950 (base of zone N8 to lower of zone N9), *Globigerinoides trilobus* (Reuss), 1850 (Zone N5 to Recent), *Globigerinoides cf. bisphericus* (lower N7 to lower N9), *Globorotalia archeomenardii* Bolli (Zone N6 to lower N10) and *Globorotalia praemenardii* Cushman and Stainforth (transitional form). According to Postuma (1971) and

Bolli and Saunders (1985), a similar age of ~14–14.5 Ma (Middle Miocene) can be assigned to all of these fossils. Samples MRP 4a and 4b are bone fragments (Fig. 2A, E) showing apatite fillings in the bone structure (grey areas in Fig. 2E). The age of the associated sediments is difficult to constrain as the planktonic foraminifers are highly fractured. From the stratigraphic position of the phosphorites from the core there is no convincing evidence to conclude that these phosphorite samples were reworked at the site. There are several findings of Miocene phosphorites in the vicinity of the MR and the NW Arabian Sea (Baturin, 1982; Rao et al., 1992; Rao and Lamboy, 1995; Grandjean et al., 1987) that support widespread phosphatization during the Miocene.

3. Analytical methods

Thin-section-, mineralogical- and scanning-electron microscope (SEM) studies were carried out at the National Institute of Oceanography, India. Major- and minor element concentrations were determined by microprobe. The REE- and other trace-element concentrations were determined with ICP-MS, following the method described by Govindaraju (1994). $^{143}\text{Nd}/^{144}\text{Nd}$ ratios were determined on a MAT 261 in a dynamic quadruple mass collection mode. The ϵ_{Nd} values were calculated with the parameters of Jacobsen and Wasserburg (1980) and Shaw and Wasserburg (1985). Present-day values for the chondrite uniform reservoir (CHUR) are: $^{147}\text{Sm}/^{144}\text{Nd}=0.1967$, $^{143}\text{Nd}/^{144}\text{Nd}=0.512638$ relative to $^{146}\text{Nd}/^{144}\text{Nd}=0.7219$. $^{87}\text{Sr}/^{86}\text{Sr}$ ratios were measured in a dynamic double mass collection mode. The NIST 987 reference material yielded $^{87}\text{Sr}/^{86}\text{Sr}=0.710221 \pm 11$ ($N=22$) and the $^{87}\text{Sr}/^{86}\text{Sr}$ ratios in Table 3 are reported relative to 0.710240 in NIST 987. Other details are given in the footnote of Table 3.

4. Results

4.1. Petrological- and mineralogical data

The phosphorite samples are depicted in Fig. 2A. In thin-section, the large nodules exhibit homogeneous light-colored

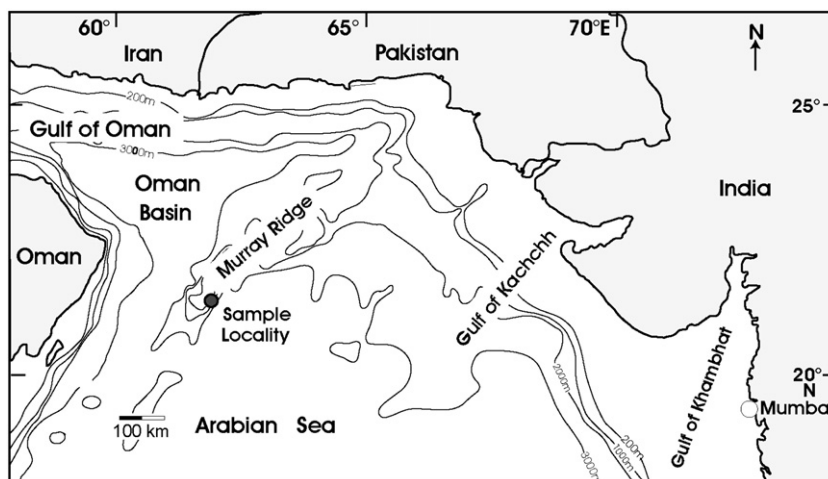


Fig. 1. Map of the Arabian Sea and bordering countries. The Murray Ridge and sample locality are indicated.

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