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Secondary phosphate mineralization in a karstic environment in central Sri Lanka

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Abstract. At Eppawala in central Sri Lanka secondary phosphate mineralization is intimately associated with laminated fabrics within depressions (sinkholes and smaller cavities) formed in the thick weathering profiles of a hilly terrain underlain by a Precambrian apatite-bearing formation. The lowermost levels of the profile show extensive zones of leaching where derived apatite crystals occur within fine-grained, laminated stromatolite sequences. The stromatolitic groundmass, which diagenetically formed by percolating oxygenated phosphate and carbonate-rich groundwaters, is impregnated by the phosphate minerals francolite and collophane. Scanning electron microscopy (SEM) reveals that fine filaments, characteristic of microorganisms, are associated with the secondary phosphate mineralization. Continuous degradation and fragmentation of the stromatolitic mat has produced pellets, peloids, and intraclasts all enriched in secondary apatite. Degrading recrystallization around the edges of the primary apatite crystals has developed coated grains. The widespread occurrence of phosphate-enriched allochems in stromatolitic groundmasses is a unique development of a modern phosphorite in a karstic environment.

Sedimentary phosphorite deposits are reported from sediments dating back to the Precambrian (Banerjee et al. 1980; Howard & Hough 1979; Champetier et al. 1980; Horton et al. 1980). Riggs (1979 a, b) recognized phosphatic allochemical particles and orthochemical groundmasses in phosphorites. Coated grains and other allochems occur in microbial mats in phosphate deposits of different ages (Christie 1978; Soudry and Champetier 1983; Dahanayake and Krumbein 1985; Soudry 1987).

In modern sediment systems reported from the continental shelves and slopes of Africa and South America (Baturin 1971, 1982; Burnett 1980; Veeh et al. 1974, Cook 1976) pellets, concretions, and nodules are common in fine-grained groundmasses enriched in organic matter. A widely accepted explanation for the formation of marine phosphorite on continental shelves and slopes is based by Kazakov (1937) on the upwelling of cold phosphate-rich bottom waters. Although oceanic upwellings sometimes coincide with sites of modern phosphorite production, it is doubtful whether such localized phenomena could be responsible for some large phosphorite deposits, e.g. those of North Africa and the Middle East. Furthermore, phosphorites related to upwelling are impoverished in phosphate, e.g., 1.10% P_2O_5 on the Peru-Chile shelves (Manheim et al. 1975) and less than 0.2% on the continental margins of Brazil (Riggs 1979 a; Milliman et al. 1975).

Kolodny (1969) and Kolodny and Kaplan (1970) suggest that phosphate deposits could form by the reworking of ancient phosphorites. Phoscrete-type phosphorites that occur in ancient and modern settings are derived from such reworking resulting from weathering and subsequent diagenetic phenomena in nonmarine environments (Southgate 1986). The main transformations observed during weathering of phosphate deposits are carbonate leaching and neogenic formation of clay and apatite phases. The transformation intensity is dependent on climatic conditions (Flicoteaux and Lucas 1984). The resultant weathering profiles occur within a mixed-mineralogical suite of rocks and are characterized by fabrics and textures identical to those developed in calcretes (Read 1976). Coated grains, peloids, and other allochems dominate such profiles.

One widely accepted factor in the genesis of phosphorite is the relation between biological activity and the phosphate mineralization of all epochs (Christie 1978; Gulbrandsen 1969; Riggs 1979 a, b; Fauconnier and Slansky 1980; Dahanayake and Krumbein 1985; Soudry 1987). A biogenic origin has been suggested for some phosphorites because of associated organic remains. The possibility of activity by bacteria, fungi, or communities of microorganisms has been suggested. Early workers (Kazakov 1937) theorized on the inorganic precipitation of apatite in seawater undisturbed by strong currents. However, (Cook 1976) emphasized the role of biological decay and postdepositional processes in the production of phosphorite.

The literature on sedimentary phosphate deposits is voluminous. It has been the practice to ascribe marine origins to phosphorites even when available evidence (e.g., association with ferruginous sediments) may indicate the contrary. The mechanism of phosphorite formation is much more complicated than simple chemical precipitation of calcium phosphate from a nutrient-rich source.

The massive phosphorite deposits of the world and their associated assemblages of abnormal authigenic sediments are a consequence of complex processes which thus far have not been adequately explained. The absence of a simple comprehensive explanation for the origin of phosphorites caused Riggs (1979 b) to ask the question – are phosphorites being generated anywhere in the world today?

In this paper the author attempts to answer this crucial question at least partially by considering the texture, structure, and mineralogy of a modern phoscrete-type phosphorite, forming presently in a tropical terrestrial setting.

Development of phosphate-rich weathering profiles

A phosphate deposit commonly referred to as the Eppawala phosphate deposit occurs in the township of Eppawala in the Anuradhapura district of Sri Lanka, located about 200 km NNE of Colombo (Fig. 1). The deposit occurs in the form of a series of ridges underlain by apatite marble, dikes, pegmatites, and migmatitic gneisses at elevations of about 175 m above mean sea level. The basement rocks display complex folded structures such as kink folds and are traversed by several cross-cutting scapolite-diopside-apatite and apatite pegmatites. The rocks, which generally trending NS, are interbanded with charnockites, quartzites, gneisses, and marbles characteristic of the Sri Lankan Precambrian metasedimentary formations dated to be between 2 and 3.5 Ga (German-Sri Lanka Consortium 1987).

The study area at Eppawala has daily temperatures ranging 28°–36 °C and is characterized by monsoon rains during the period from October to January with intermonsoon showers spread throughout the rest of the year. The annual average precipitation is 1,200 mm. The area has been subjected to tropical weathering for a considerable length of time as exemplified by the thick weathering profiles (on the order of 50–100 m) characteristic of this area.

A typical profile at Eppawala has an upper zone mostly lateritic and reddish brown in color with primary apatite crystals disseminated in the loose soil. Isolated skeletal apatite grains, which formed due to leaching of their phosphate contents, are observed in finer, loose or hardened lateritic matrices. The lower zone also referred to as the leached zone has larger concentrations of coated apatite grains and peloids within depressions such as sinkholes or smaller cavities developed on the parent rock, which is predominantly an apatite marble. The leached zone is characterized by a multitude of micro-unconformities (Figs. 2, 3).

X-ray diffractometry of samples from both zones of the weathering profile shows the occurrence of primary and secondary phosphate minerals. The lateritic zone is characterized by aluminous, siliceous, and ferruginous apatites, e.g., crandallite $[CaAl_3(PO_4)_2(OH)_5 \cdot H_2O]$, hydroxyl ellastadite $[Ca_{10}(SiO_4)_3(SO_4)_3(OH,F)]$, and jahnsitite $[(Ca \cdot Mg_2)MnFe_2(PO_4)(OH_2)]$. However, the zone of leaching shows a concentration of fluorapatite and hydroxyl apatite, i.e., $Ca_5(PO_4)_3F$, $Ca_5(PO_4)_3OH$ and $Ca_{10}(PO_4)_5CO_3(OH,F)$ (Fig. 3).

The phosphate deposit at Eppawala has P_2O_5 contents varying from 25% to 43%, and its citric acid solubility is low (1%–3%) (Amerasekera et al. 1981; Jayawardena 1976). Eppawala phosphate is currently used as a fertilizer for long-term crops, such as coconut, rubber, and tea, after crushing to a fine size and mixing with other ingredients. Recently, a method has been reported whereby a more soluble fertilizer could be produced from Eppawala phosphate (Tennakone et al. 1988). Considering the present rate of exploitation, the Eppawala deposit with a known reserve of 25 000 000 tonnes of phosphate can be used for more than a century (Tennakone 1988).

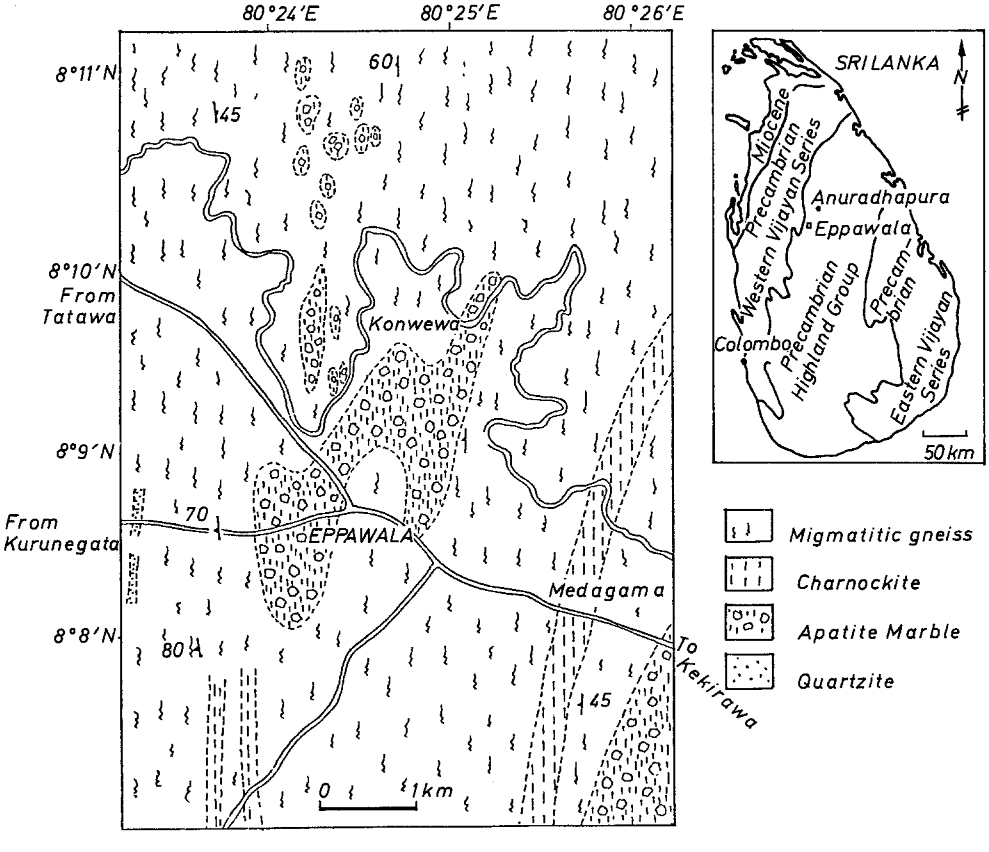

Fig. 1. Location and general geology of the Eppawala phosphate occurrence (modified after Tayawardena, 1976)