

A modern terrestrial phosphorite— an example from Sri Lanka

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Abstract

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At Eppawala in Central Sri Lanka, a thick weathering profile is mined for use as phosphate fertilizer. Recent tropical subaerial weathering processes have produced a phosphate-enriched horizon in the weathering profile which has developed on a Precambrian apatite marble formation. The enriched horizon with P_2O_5 compositions ranging from 10 to 40% is formed essentially of laminar phoscrettes occurring in a network of sinkholes.

Detailed examination of the laminar phoscrettes reveals that primary metamorphic apatite crystals occur in association with phosphatic allochems such as coated grains, ooids, pisoids and intraclasts in a finely layered groundmass. It has been observed that the primary apatite grains released from the parent apatite marble due to tropical weathering processes have been deposited in sinkholes where nutrient-rich percolating meteoric waters were precipitating secondary apatite. Subsequent diagenetic processes active in such sinkhole sedimentary environments have produced the phosphatic allochems characteristic of secondary phosphate mineralization. The allochems together with their mineralized groundmass and the associated primary apatite grains have given rise to the Eppawala phosphorite deposit.

Introduction

Phosphorites are white to dark mainly light coloured shaly/sandy phosphate-carbonate rocks where mineralization is confined to pellets, intraclasts, ooids, oncoids and other allochem grains in fine grained groundmasses. Ancient examples of phosphorites date back to the Precambrian. Some of the better known examples are the late Precambrian phosphorites at Udaipur in India (Banerjee et al., 1980), Middle Cambrian Georgina basin phosphorites in northern Australia (Howard and Hough, 1979), Miocene phosphorites from Florida (Riggs, 1979, 1986), Senonian phosphorites from Israel (Kolodny, 1967; Soudry and Champetier, 1983; Soudry, 1987)

and Eocene phosphorites from Morocco and Tunisia (Champetier et al., 1980; Hamdadou, 1983). Most of the reported ancient and modern occurrences are attributed to or found in marine environments where phosphatic allochems are encountered in fine-grained organic-rich and/or stromatolitic groundmasses (Bremner, 1980; Soudry and Nathan, 1980).

However, phosphorite deposits have been described also from the vadose zone of non-marine terrestrial environments. Such deposits referred to as phoscrettes develop as a result of subaerial weathering processes active on ancient phosphatic rocks (Southgate, 1986a, b). The term phoscrete was initially used by Cook (1972) to describe thick cryptocrystalline phosphate deposits blanketing

older phosphate rocks. In this work, phoscrete or phoscrete profile is comparable to the term caliche or calcrete and the terms used in the description are essentially those used for carbonates by Read (1976). Phoscrete profiles form sequences of laminated to massive rock types that partially or completely infill depressions on some hardground surfaces. The profiles can be divided into an upper crust and a lower altered parent rock (see Southgate, 1986b).

This paper describes a phoscrete profile developed on a Precambrian apatite marble formation in a terrestrial setting at Eppawala, Sri Lanka.

Location, climate and geological setting

The study area is located in the village of Eppawala in North Central Sri Lanka near the city of Anuradhapura (Fig. 1). This village lies in the dry zone of Sri Lanka where the average

annual rainfall is 125 cm and the average daily temperature is around 30°C. The tropical monsoon rains arrive during two two-month periods of the year and intervening period is characterized by high evaporation.

At Eppawala, an apatite marble formation occurs within metasedimentary successions consisting of charnockites, quartzites, marble and migmatitic gneisses characteristic of the Precambrian Highland Series rocks of Sri Lanka (Fig. 1). The apatite marble formation consists of euhedral apatite crystals (ranging from a few microns to several meters in length) in a finer groundmass consisting dominantly of calcite-dolomite and accessory magnetite, spinel, diopside and zircon. Migmatitic bands and scapolite-diopside dikes also containing apatite are found as isolated entities within the apatite marble formation. The apatite marble formation is overlain by isolated ridges with elevations ranging from 100 to

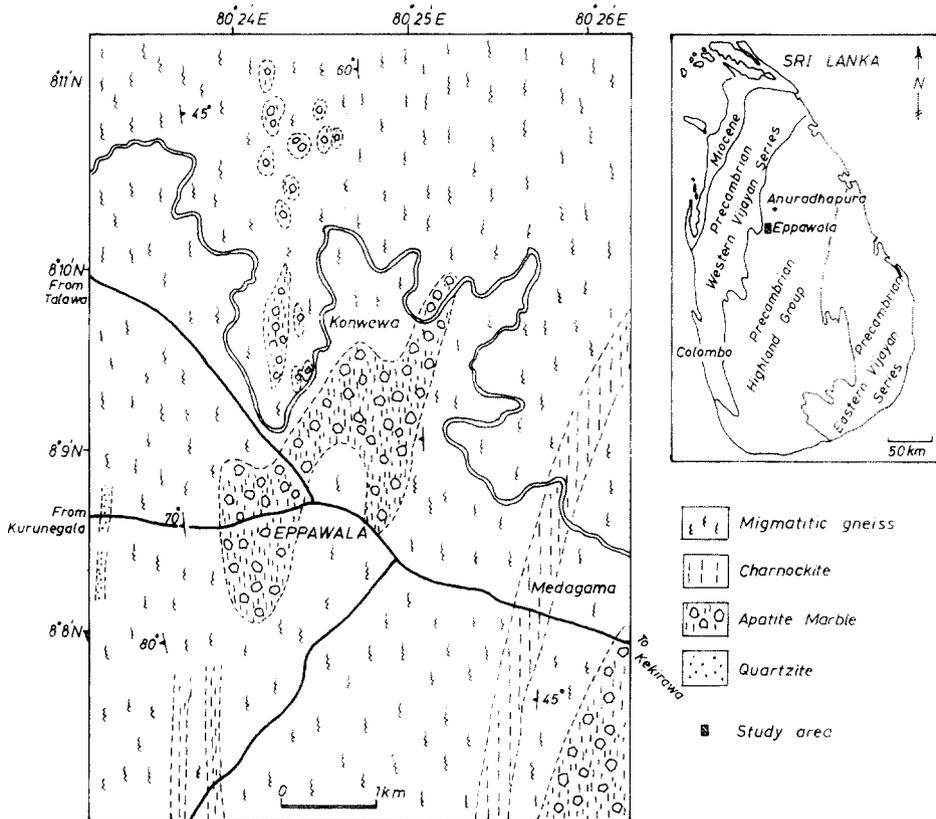


Fig. 1. Geological Map of the Eppawala area showing the location of the phosphorite on the parent apatite marble formation (map modified after Jayawardena (1976—left). Map of Sri Lanka with broad geological divisions showing the location of Eppawala (inset—right).

150 m above mean sea level extending to an area of about 20 km². The ridges are deeply weathered. The weathering profiles show (1) an upper lateritic unconsolidated soil horizon (2–40 m in thickness), and (2) a lower phosphate-enriched indurated horizon (20–50 m in thickness) (Fig. 2).

In the upper lateritic horizon, the average P₂O₅ content lies between 10 and 15% whereas Fe₂O₃ values range from 5 to 15%. In this horizon which is dominantly an unconsolidated yellowish lateritic brown soil, primary apatite crystals of varying size (the maximum length ranging from a few microns to several meters) are found disseminated in an irregular manner. Within the soil, at points, conglomerate-like bodies are observed. These bodies are irregularly distributed in this horizon and can

have maximum diameters varying from a few millimeters to several meters. At other points, rare occurrences of hardened ferruginous lateritic zones and loose siliceous hexagonal “ghost” structures are encountered.

In the lower phosphate-enriched horizon, the average P₂O₅ content varies from 10 to 40% whereas the Fe₂O₃ values are less than 5% (Jayawardena, 1976). In this horizon, the conglomerate-like structure is commonly present as fillings of sink holes which have developed on a yellowish brown substratum resembling the lateritic soils of the upper horizon. The sink hole fillings are stromatolite-like clear and dark layered deposits. In these layered deposits, particulate phosphatic grains are commonly found. These layered sequences are referred to in this study as laminar phoscretes (Fig. 2). The phosphate-enriched horizon lies unconformably on the partially weathered apatite marble formation which shows P₂O₅ values ranging from 5 to 20%.

At Eppawala, in a given weathering profile, the parent apatite marble rock could be located at depths ranging from 1 m to about 125 m below the surface. The two horizons of the weathering profile which can be described as a phoscrete profile (see also Southgate, 1986b) are presently mined for use as a fertilizer for long-term crops such as tea, rubber and coconut. The mined product which is a mixture of the two horizons of the phoscrete profile gives an average P₂O₅ content of 20–30%.

Observations on the phoscrete-type phosphorite

Optical and scanning electron microscopic (SEM) observations were made on the unweathered portions of the laminar phoscrete bodies spread within both horizons. These bodies are more prominent in the enriched horizon where the P₂O₅ content is relatively high thereby suggesting their importance in this phosphate deposit. Based on thin section observations of the aforesaid bodies, several types of constituent particulate grains are recognized in a laminated groundmass. The constituents are primary apatite grains, coated grains, ooids, pisoids, peloids, and intraclasts (Fig. 3a–d).

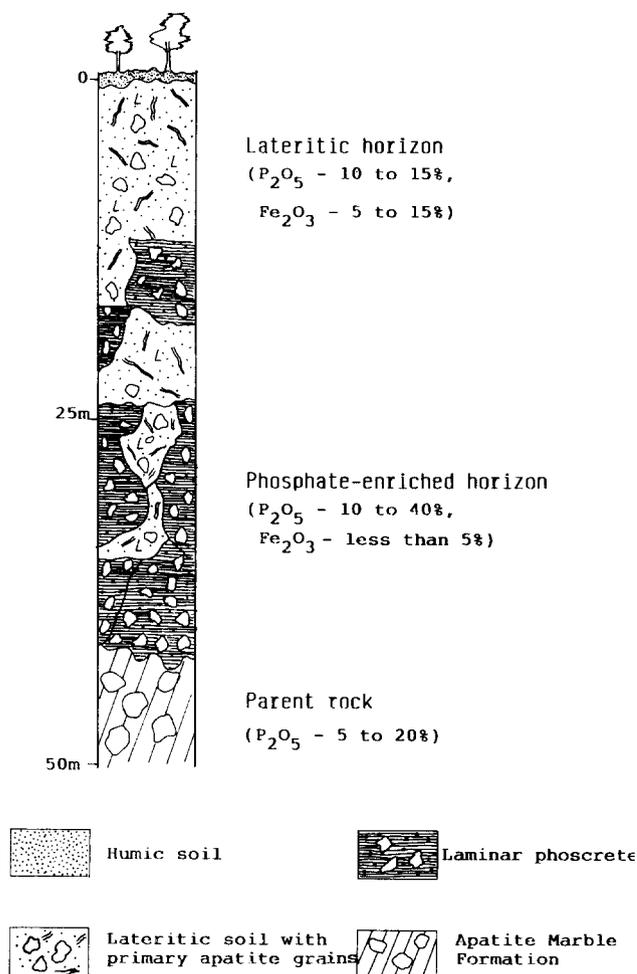


Fig. 2. The development of a terrestrial phoscrete-type phosphorite in a weathering profile at Eppawala.

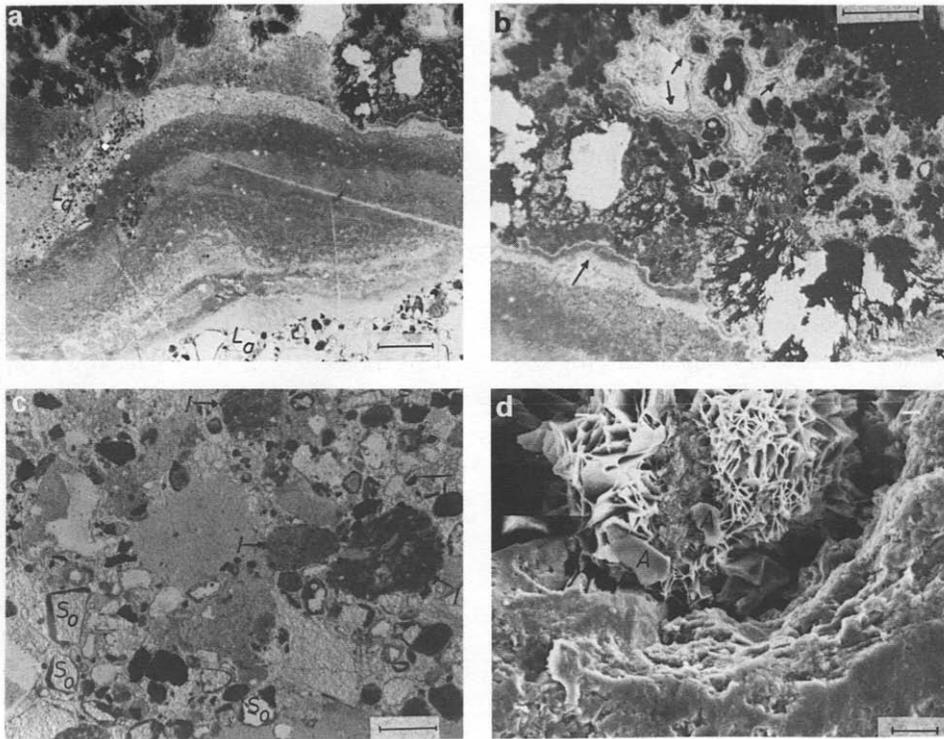


Fig. 3. (a) Photomicrograph of a thin section of the phosphorite showing: (1) clear and dark stromatolitic-type laminations of the groundmass, (2) occurrence of cauliflower-shaped pisoids in the upper layer, and (3) peloids, superficial ooids and intraclasts in allochem layers (L_a). Bar = 250 μm . (b) Detail of a pisoid from (a). Note in the upper middle area the clear and dark laminations (arrows) formed in-situ by secondary phosphate minerals—microcrystalline and cryptocrystalline. The widespread irregular dark patches show cavities where secondary phosphatic mineralization is in progress (see (d)). Bar = 100 μm . (c) Detail of the lower allochem layer in (a) showing (1) superficial ooids (S_0) with primary apatite grains as nuclei, (2) intraclasts (I), (3) peloids (structureless dark grains formed of microcrystalline apatite). Bar = 100 μm . (d) A portion of the laminated groundmass under the scanning electron microscope (SEM). Note the growth of apatite crystals in the upper middle area. Partially formed crystals (A) show protruding branching thread-like structures from their margins (microbial activity? in the secondary mineralization). Bar = 20 μm .

The apatite grains resemble those of the parent apatite marble and they often have retained their hexagonal crystal contours. Their size may vary from a few microns to several meters in maximum length. The coated grains can have a maximum diameter ranging from a few microns to several centimeters. The nucleus of these grains is invariably a primary apatite grain. Around the grain, an envelope of microcrystalline apatite is observed. SEM observations of the coated grains show that there are patches of microcrystalline apatite comparable to those in the envelope within the primary apatite crystals which serve as the nuclei of the coated grains. Ooids and pisoids generally have as their nucleus, a primary apatite grain around which two or more laminations are visible. The thickness of the laminations rarely exceeds the radius of the

nucleus of the ooids and pisoids and they can be regarded as superficial ooids/pisoids (Fig. 3c) (see Dahanayake et al. 1976; Dahanayake, 1977). Some ooid and pisoid structures lack a nucleus suggesting in situ development of laminations within a cavity (Fig. 3b) (see Read, 1976). Peloids have no fixed size, shape or size and they lack internal structure and are formed of micro-crystalline apatite. Some peloids possess a "ghost" hexagonal structure suggesting their development from primary apatite crystals. These bodies are comparable to phosphatic peloids described from marine settings (Soudry and Nathan, 1980; Southgate, 1986a). The laminated groundmass shows alternating dark and clear layers of the order of 250 μm to 1 mm. The dark layers show cryptocrystalline apatite and the clear ones are

formed of microcrystalline apatite (Fig. 3a). X-ray diffractometry and DTA studies have shown the presence of francolite and crandallite within the laminations (Jayawardena, 1976; Tazaki et al., 1987).

Discussion and conclusions

Due to recent tropical weathering processes active on the Precambrian apatite marble formation at Eppawala, the calcite-dolomite matrix has been preferentially dissolved thereby separating the primary apatite crystals from the parent rock. The resulting weathered product appears as a lateritic residual rock. Continuous surficial processes have formed a network of sinkholes within the residual rock mass. Such depressions have in turn served as sites of deposition for the derived apatite crystals and the leached material and as suitable micro-environments for the precipitation of secondary apatite by solar-heated, downward- and upward moving, leached phosphate and nutrient-carrying meteoric waters (see Read, 1976; Southgate, 1986a,b). Repetitive processes of deposition and precipitation would develop sequences of laminar prosecretes in the sinkhole network.

Diagenetic modification and dislocation of primary sediment fabrics could occur in the sinkholes under subaerial weathering conditions through a long span of time. As a result, allochems such as ooids, pisoids, peloids, intraclasts and coated grains will develop. The coated grains with fine-grained apatite envelopes have formed perhaps by a process of grain diminution around the primary metamorphic apatite crystals during diagenesis (see "micritization" in Wolf, 1965). The peloids which are microcrystalline apatite bodies appear to be the end products of such a grain diminution process. The existence of peloids with ghost hexagonal structures characteristic of the primary metamorphic apatite tends to confirm such a process. In the phosphatic peloids from Negev, Soudry and Nathan (1980) noted a process of grain degradation which they referred to as phosphomicritization. Such processes of grain diminution occur with the participation of microorganisms (Wolf, 1965; Soudry and Nathan, 1980).

The occurrence of phosphate-rich allochems such as peloids, ooids, pisoids, intraclasts in laminated groundmasses leads us to compare the Eppawala phosphorete deposit with ancient stromatolitic phosphorites where the microbial influence is well known (Riggs, 1979, 1986; Dahanayake and Krumbein, 1985; Southgate, 1986a, b; Soudry, 1987). Furthermore, SEM studies on the laminated groundmass of the Eppawala phosphorite indicate the association of thread-like structures suggestive of microbial activity in the secondary phosphate mineralization processes.

The present study shows that the terrestrial phosphorite at Eppawala consists of two major components of phosphate enrichment: (1) enrichment due to primary metamorphic apatite, and (2) secondary phosphate mineralization around primary apatite grains and within the laminated groundmasses of the sinkholes. The similarities between the Eppawala phosphorete profile and the calcretes known from carbonates strengthen Southgate's opinion (1986a) that it is the physico-chemical and biological conditions and not the mineralogy that controls the resulting sedimentary textures and structures. As environmental interpretation depends largely on sedimentary textures and structures, we are confident that the present study of a terrestrial phosphorite will shed some light on understanding many problematic phosphorites belonging to different ages particularly in view of the 'phosphoria formula' of McKelvey and Sheldon (McKelvey et al., 1959; Sheldon, 1964; Christie, 1978), which suggests exclusively marine origins for phosphorites.

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