

Sedimentary Phosphate Deposits Mineral Deposit Profile F07

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IDENTIFICATION

SYNONYMS

Upwelling phosphate deposits, phosphorite or stratiform phosphate deposits

COMMODITIES (BYPRODUCTS)

Phosphate \pm F, \pm rare earth elements (REE including Y), \pm V, \pm U, \pm gypsum (phosphogypsum)

EXAMPLES

(British Columbia (MINFILE #) – *Canada/International*): Crow (082GNE025), Cabin Creek (CS) (082GSE055), Bighorn (082GSE060), Ram 1 (082GSE056), Wapiti (093I 008) and Wapiti East (093I 022); *Athabaska Basin (Saskatchewan, Canada), Bone Valley and Hawthorn Formations (Florida, U.S.A.), Phosphoria Formation (Idaho, Montana and Wyoming, U.S.A.); Ganntour deposit (Morocco).*

GEOLOGICAL CHARACTERISTICS

CAPSULE DESCRIPTION

Sedimentary phosphate deposits are stratiform or lens-shaped, measuring from less than 1 metre to tens of metres in thickness. They extend for tens to hundreds of kilometres in their longest dimension. Mineralized zones consist of phosphorites ($\geq 18\%$ P₂O₅) or phosphate rocks ($< 18\%$ P₂O₅). These rocks are bedded. They may be primary or reworked (secondary). The main ore mineral is microcrystalline francolite, commonly in form of laminae, pellets, oolites, nodules and fragments of bones or shells (Figure 1). This mineral may be also present within the rock matrix.



Figure 1. Typical appearance of phosphate rock containing a fragment of a crinoid (Fernie Formation, southeastern British Columbia).

TECTONIC SETTING(S)

The most favourable tectonic settings for larger deposits are passive continental shelves and adjacent sag basins; some sedimentary phosphate deposits formed at active continental margins, intracontinental basins and even lacustrine environments.

DEPOSITIONAL ENVIRONMENT / GEOLOGICAL SETTING

Deposition usually occurred in areas of warm paleoclimate, mostly between the 40th parallels. The most common depositional environment for sedimentary phosphate deposits is a marine sedimentary basin with a good connection to the open sea (commonly west-facing at the time of phosphate deposition), and upwelling areas with high plankton productivity.

AGE OF MINERALIZATION

Deposits range in age from Proterozoic to Holocene. Phosphate deposits are particularly abundant in Cambrian, Permian, Jurassic, Cretaceous, Eocene and Miocene times (Cook and McElhinny, 1979). In terms of inferred resources (tonnage), the Eocene, Miocene and Permian are the most important time intervals. In British Columbia, the majority of phosphate occurrences are located in rocks of Jurassic and Triassic age.

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HOST / ASSOCIATED ROCK TYPES

Hostrocks are phosphorites ($\geq 18\%$ P_2O_5) and phosphate rocks ($< 18\%$ P_2O_5). Associated rock types are typically sedimentary rocks including marl, black shale, chert, limestone, dolostone, and in some cases lava flows, tuffs and diatomite-bearing rocks. Figure 2 shows conceptual vertical section of the platform perpendicular to the shoreline.

DEPOSIT FORM

Phosphate-bearing rocks are generally stratiform; bed thicknesses range from less than 1 metre to tens of metres and may extend for distances up to several hundreds of kilometres in their longest dimension. The thickest deposits are amalgamated/condensed beds (tabular units) reflecting variations in upwelling intensity and storm frequency through time. Individual phosphorite deposits delimited by drilling may measure from a few hundreds of metres to tens of kilometres in their longest dimension. Phosphorite deposits commonly occur in belts.

TEXTURE / STRUCTURE

Phosphorite deposits commonly contain phosphate pellets and nodules as well as phosphatized shells and bones; ooids (Figure 3), intraformational rip-up breccias, clasts, concretions, phosphatic stromatolite mounds (or their fragments), crossbeds, hardgrounds and burrows. Phosphatic minerals may also form the matrix. Gangue mineralogy and textures in phosphorites are determined partially by the depositional environment at the time of phosphogenesis and partially by the environment that prevailed during reworking and winnowing (natural P_2O_5 upgrading) of the original phosphate rocks and during diagenesis. Phosphorites formed by replacement (during diagenesis) may be paler buff, tan and/or macroscopically featureless.

“Pristine” phosphate accumulations (one cycle of phosphogenesis) are characterized by phosphatised laminae and lenses, coated grains, coprolites, peloids and fossils. Allochthonous phosphate accumulations show sharp and erosive lower boundary, assemblages of phosphatic and non-phosphatic particles and internal grading, accreted grains, minor unconformities, scour marks and bed truncations, and heterogeneous phosphate particles. Condensed phosphates represent an intermediate stage between pristine and allochthonous phosphate deposits (Föllmi, 1996).

ORE MINERALOGY (Principal and subordinate)

Francolite (carbonate-rich fluorapatite), *secondary minerals derived by the weathering of francolite: millisite, Fe-pallite, crandalite, wavellite and other Al-phosphates*. Secondary minerals are not desirable from the metallurgical point of view.

GANGUE MINERALOGY (Principal and subordinate)

Dolomite, calcite, quartz, montmorillonite or illite \pm chert, \pm halite, \pm gypsum, \pm iron oxides, \pm siderite, \pm pyrite, \pm carnotite*, \pm glauconite, \pm sphalerite, \pm zeolites.

*Carnotite is a potassium uranium vanadate radioactive mineral with chemical formula: $K_2(UO_2)_2(VO_4)_2 \cdot 3H_2O$. It is commonly considered as a gangue mineral; however, if present in high concentrations it becomes an ore mineral.

ALTERATION MINERALOGY

Dahlite is believed to form during late diagenesis (Trappe, 1998).

WEATHERING

Lateritic alteration of francolite results in the formation of millisite, Fe-pallite, crandalite, wavellite and other aluminum-phosphates. Turquoise may form if copper is present. Weathering decreases concentrations of pyrite and sphalerite and may result in the release of selenium.

ORE CONTROLS

Phosphorites are stratigraphically and spatially linked to paleodepositional environments favourable for phosphogenesis (high bio-productivity and phosphorus flux, stratification within water/unconsolidated sediment column, and a moderate to low supply of allogenic sediment). Phosphorite deposits are spatially related to multiple cycles of regression-transgression. Phosphate facies commonly rest on, or are associated with, erosional surfaces (unconformities) and/or start with phosphatic lag concentrates. Entrapment basins (zones) characterized by a low influx of continent-derived sediments are required for the deposition of phosphorites.

GENETIC MODEL

Seawater averages 0.071 ppm phosphorous (Redfield, 1958) and may contain as much as 0.372 ppm phosphorus (Gulbradsen and Robertson, 1973). Warm surface waters typically contain less than 0.0033 ppm phosphorus (McKelvey, 1973). Phosphate rocks and primary phosphorites form in or laterally adjacent to organic-rich sediments beneath regions where upwelling, nutrient-rich, cold waters interact with a warm sunlit surface seawater layer, creating favourable conditions for intense algal bloom. Algae die, or are eaten by other life forms, then accumulate on the seafloor as fecal pellets and/or organic debris beneath sites of active coastal upwelling. Decomposition of organic debris in an oxygen-deprived environment by bacteria and dissolution of fish bones and scales are linked to precipitation of phosphate minerals (phosphogenesis) near the sediment-water interface. Precipitation of apatite within intergranular spaces during diagenesis and through non-biological chemical processes may also contribute to formation of phosphate rocks.

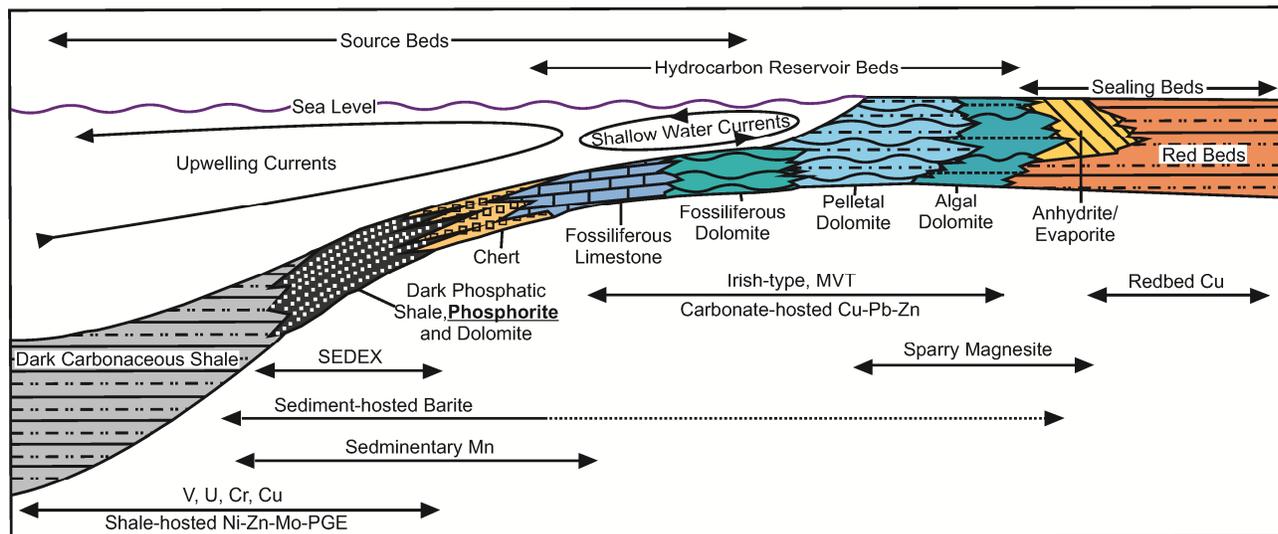


Figure 2. Schematic vertical section across continental platform, showing key lithologies and spatial relationship between phosphorites and other deposit types and hydrocarbons (modified from Sheldon, 1963; Hein *et al.*, 2004).

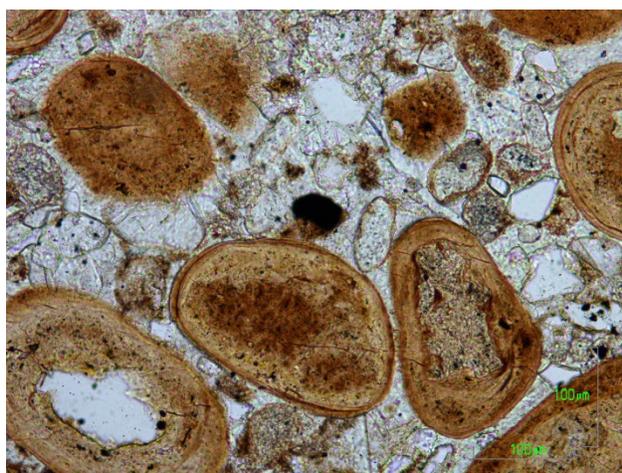


Figure 3. Phosphorite of Sulphur Mountain Formation, northeast British Columbia. Phosphate ooids in carbonate matrix (plane-polarized light; shorter margin of the photograph equals 500 microns). This phosphorite contains 23.6% P_2O_5 , 1167.4 ppm of rare earth elements (including 227 ppm La, 122.5 ppm Ce, 45.4 ppm Pr, 186 ppm Nd, 35.7 ppm Sm, 8.75 ppm Eu, 43.5 ppm Gd, 8.4 ppm Ho, 23.7 ppm Er, 3.0 ppm Tm, 15.2 ppm Yb, 2.1 Lu and 399 ppm Y).

Most phosphorites were enriched by the reworking, winnowing (concentration) and accumulation of the above described phosphorus-bearing sediments.

ASSOCIATED DEPOSIT TYPES

Sedimentary manganese deposits (F01), evaporites (gypsum-anhydrite, F02), SEDEX deposits (E14), coal deposits (A03 and A04), hydrocarbon reservoirs, Mississippi Valley-type Pb-Zn deposits (E12), sparry magnesite deposits (E09) and red bed Cu deposits (E04) are spatially associated with the phosphate deposits. See Figure 2.

COMMENTS

The high trace element content of some phosphorites may limit their suitability for agricultural applications. Repetitive fertilizing of agricultural fields over several decades may result in unacceptable concentrations of potentially harmful elements in soils. For example, elevated concentrations of uranium, thorium, lead, cadmium, selenium and chromium in fertilizer are not desirable.

Phosphorite deposits can supply several by-products, such as fluorine (Simandl, 2009). Uranium and vanadium were extracted from phosphate deposits in United States. Phosphate deposits also have the potential to produce yttrium (Pell, 1991) and other rare earth elements as byproducts (Simandl *et al.*, 2011a, b). Synthetic gypsum (phosphogypsum) can also be a byproduct of phosphoric acid production; however, its use is typically limited because it incorporates unwanted trace elements.

EXPLORATION GUIDES

GEOCHEMICAL SIGNATURE

Phosphorous and in some cases rare earth elements, fluorine, and uranium can be used as pathfinders. Since phosphogenesis is commonly associated with organic-rich sediments, nitrogen and carbon may be considered as part of the signature; however, in practice these elements are not part of standard analytical packages used in exploration. Rapid ammonium molybdate – nitric acid field method can be used for field identification of phosphate (Swanson, 1981); however, this method is generally considered as over sensitive. A portable, hand-held XRF is an effective tool in determining the concentrations of phosphorus, light rare earth elements,

yttrium, and a number of other trace elements commonly contained in phosphate rocks (Fajber and Simandl, 2012).

GEOPHYSICAL SIGNATURE

Radiometric surveys could be an effective exploration tool if the deposit contains above background concentrations of radioactive elements.

OTHER EXPLORATION GUIDES

Phosphate deposits are expected to occur mostly in favourable paleolatitudes (between the 40th parallels). Remote sensing (spectral analysis) is also showing some promise. Conceptual vertical section showing spatial distribution of the associated deposit types (Figure 2) may be used as a guide in early stages of exploration.

Phosphatic and glauconitic facies are commonly spatially related (Odin and Letolle, 1980). In those settings, glauconite, characterized by its green colour (easily recognizable by prospector), may be used as an indirect guide to mineralization.

ECONOMIC FACTORS

TYPICAL GRADE AND TONNAGE

According to the United States Geological Survey grade and tonnage model, 90% of the sedimentary phosphate deposits contain more than 26 million tonnes, 50% of them contain 330 million tonnes or more, and less than 10% of these deposits contain more than 4200 million tonnes (Mosier, 1992). According to the same model, 90% of these deposits grade more than 15% P₂O₅, 50% of them grade more than 25% P₂O₅ and less than 10% grade more than 32% P₂O₅ (Mosier, 1992).

Historically only deposits with grades exceeding 25% P₂O₅ were considered of economic interest. As these deposits are being depleted, lower ore grades are becoming acceptable and upgrading has become common practice. For example, in Idaho companies use high-grade ore (or acid grade >31% P₂O₅) directly in fertilizer plants, while medium grade (or furnace grade) rock (24 to 31% P₂O₅) can be used as feed for elemental phosphorus plants. Lower grade rocks (15 to 24% P₂O₅) are also mined but they have to be beneficiated to meet the above requirements.

Under favourable conditions (*i.e.* near existing flotation plants, as in Florida), even phosphate rocks grading as low as 3% P₂O₅ may be of economic interest (Zhang *et al.*, 2006). Furthermore, a small proportion of mined phosphate rock is simply ground and sold to growers of organic products as “natural rock phosphate”. Such products work reasonably well in acidic soils; however, most of the phosphorus contained in these products is not readily available for plant use in neutral or alkaline soils (pH ≥7).

ECONOMIC LIMITATIONS

Most of the deposits are being mined using open-pit methods or drag lines; however, under exceptional circumstances, high-grade deposits may be mined by underground methods.

Phosphatic rocks may be enriched in REE, V, U, F, Ag, Cd, Cr, Mo, As, Se, Sr, Te, Zn and other elements. Elements such as U, Th and their decay products, Cd, Tl, Se and Hg are closely monitored. If found in excessive concentrations these elements are recovered to mitigate environmental risks linked to fertilizer use or phosphate tailings disposal (Laznicka, 1985; Northolt, 1994; Trappe, 1998).

High concentrations of certain elements other than P can cause problems during processing. High CaO/P₂O₅ ratios result in an increase in sulfuric acid consumption during phosphoric acid production; high concentrations of Mg and SiO₂ cause filtration problems; high concentrations of Na and K results in scaling; organic matter causes foaming during production of phosphoric acid; high Cl concentrations cause premature corrosion. High levels of relatively toxic elements (*e.g.* Cd, Se and As) may make a phosphorite unsuitable for fertilizer production.

IMPORTANCE

World phosphate production for 2011 is estimated at 176 million tonnes. Sedimentary phosphate deposits account for 80% of the world phosphate production. Morocco and the Western Sahara (administered by Morocco) accounted for 50 million tonnes. Other North African countries, China, U.S.A. and Russia are also major producers (Jasinski, 2011). Other sources of phosphorus include apatite concentrate produced from some carbonatite deposits (N01) and peralkaline intrusions (Brazil, Canada, Russia and South Africa), guano deposits (small and only of local importance) and also apatite produced as a by-product of iron extraction from some of iron oxide copper gold (IOCG) deposits (D07).

Phosphorus is an essential element for plant and animal life. There are no substitutes for phosphorus in agricultural applications. Elemental phosphorus is used in production of variety of intermediate products that are consumed in the manufacturing of detergents, matches, fireworks, pesticides, toothpastes and explosives. Phosphorus compounds may also be used as gasoline additives, in some plastics, fire retardants, *etc.*

The recovery of phosphate from waste waters is technically possible; however, the economics of the process remain challenging at current prices of phosphate fertilisers (Parson and Smith, 2008).

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