PETROGRAPHY OF DEVONIAN PHOSPHATES OF INDIANA

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ABSTRACT.—In the Devonian rocks of Indiana phosphate occurs in thin bands either as an in situ replacement of limestones, or as a detrital constituent. Although some phosphate is nearly opaque and without recognizable texture, much is oolitic, with the ooliths having textures similar to their carbonate counterparts. Mineral associations include glauconite, pyrite, dolomite, calcite, and some fluorite. The phosphates are underlain by well sorted limestones and overlain, firstly by beds rich in crinoids to be followed by beds with bryozoa. It is concluded that these phosphate bands result from phosphate enrichment of the waters during regressions of the Devonian seas.

The occurrence of calcium phosphate in rocks of Devonian age aroused some interest with the discoveries of commercial phosphate in Tennessee, made known by the work of Hayes (1896). Since then other occurrences have been reported from the Devonian of the midcontinent including Ohio (Westgate and Fisher, 1933) and Indiana (Campbell, 1946 and Murray, 1955).

In Indiana the phosphate beds are developed most extensively in the Sellersburg limestone of central Scott County. Their presence in strata of Jeffersonville age usually is in the form of thin impersistent bands of granular, sand-sized, detrital phosphate. In the Sellersburg beds, they occur as layers about 10 cm. thick, some of which are persistent for hundreds of yards; and such accumulations are noteworthy for their variety of textures. The most persistent occurrences of phosphate are directly below the New Albany Shale extending from the Meshberger quarries in the north to the Ohio River in the south.

PETROGRAPHY

The petrography of these Devonian phosphates is discussed under two headings: in situ occurrences and detrital occurrences.

In situ occurrences. — Phosphatic crusts on limestones have been recorded by Andersson (1896), Lamplugh (1889), Bristow (1889), and Hayes (1896), but the Devonian rocks studied here have only one good example exposed at a locality in Scott County (near Kent, about 10 miles west of Madison, Indiana). Here phosphate crusts, about 15 cm. thick display a hummocky upper surface and pass laterally and vertically into detrital phosphates described below. Transition between the phosphate and the underlying limestones is gradual, and is observed at the limestone end of the series as an initial development of phosphate along grain boundaries accompanied by the development of secondary dolomite. Large syntaxial grains, granular rims, and fossil debris remain unaffected in this early stage, but with increasing phosphatization the cement or matrix is replaced gradually until only the organic debris remains. Although not seen in this occurrence a study of pebble phosphate (see below) suggests that the final product of the phosphatization is a rock composed wholly of light or dark brown phosphate studded with only the most resistant organic elements (e.g. crinoids), and detrital quartz grains.

Detrital occurrences. — Detrital phosphate probably is the most common occurrence in the geological record and is certainly most frequently observed in the Devonian of Indiana. Much is in the form of pebbles ranging in size from 5-50 mm., usually well rounded; and, although some have a nodular appearance, are interpreted as of detrital origin as indicated by their sharply defined margins and distinctive textures.

Oolitic textures characterize many of the pebbles. Such ooliths, range in size from 0.2-0.5 mm.; are either ovaloid or spherical, and distinguished from the surrounding phosphate by their bright reddish colour. Inclusions of quartz, glauconite, calcite, and pyrite are common.

Pebbles composed of almost opaque phosphatic material seldom show any distinctive textures; in these varieties, however, pyrite is relatively common. Pebbles also occur with abundant relic organic remains of bryozoans, brachiopods, and crinoids. Generally the original calcite matrix has been replaced completely by phosphate, but from a study of a number of pebbles it is possible to describe the manner in which a fossil test is phosphatized and also record the relative susceptibility of each organism to this form of replacement. Bryozoans are amongst the earliest to show signs of replacement, and generally it is manifested by the infilling of the pores with phosphate; the wall structure, however, remains fairly resistant. Brachiopods also amongst the earliest to be replaced usually show uniformly phosphatized shells; whereas, crinoids (among the most resistant) have the wall structure replaced first, leaving the original pores filled with calcite.

Some of the pebbles are transected by thin veins of calcite which may enclose the phosphatic ooliths within the pebble so as to appear to release them from the main phosphate mass of the pebble.

Ooliths also occur commonly as discrete grains, usually 0.2-0.7 mm.; oval or spherical in cross section and consist of several concentric layers. When ovaloid they lie with their long axes parallel to the bedding, but both shapes are found as components of laminated or cross laminated limestones. Some ooliths have cores composed of rounded quartz grains, rounded or euhedral glauconite (cf. Dietz et al. 1943), microgranulose and single crystals of calcite, dolomite euhedra, francolite, and pyrite (either as a single grain or a cluster of several).

Concentric layering in many of the ooliths may be composed of alternations of light and dark collophane (cf. Carozzi 1960), or alternations of clear, brown collophane with layers of collophane crowded with minute specks (of indeterminate nature); but, alternations of collophane and francolite, collophane and calcite, and collophane and pyrite are common. The configuration of such layering besides being concentric is sometimes eccentric (Fig. 1). Moreover, the initial shape of the core usually controls the final form of the oolith (as with calcareous ones). There are also examples of broken and re-coated ooliths similar to those described by Carozzi (1961, fig. 6) from limestones.

The dark layers of the ooliths are often areas of pyrite growth and replacement: in some examples the whole or one complete part of an oolith has been replaced by pyrite—the original banding being identifiable only in reflected light.

As with many phosphates broken and distorted ooliths are common in these examples (Fig. 1). There are two general types present: those which are broken by some force of impact, and those broken by forces related to diagenesis and compaction. Impact breakage of the ooliths is frequently of the type—group 1 of Carozzi (1961, p. 271-273) where the small circle of the oolith has collapsed, and is thought to have originated by the striking together of the oolith and other bodies. Compaction breakage occurs when other constituents of the rock penetrate the skins of the oolith with the result that there is an in situ collapse of the latter. When the outer dark skin is rigid (as is often the case) the oolith fractures into small fragments but the brown collophane behaves as a plastic medium with the result that it folds during deformation. In a few examples, destruction of the oolith is accompanied by a replacement of the collophane by calcite. The oolith may be at or near the center of a large calcite grain and its disintegration resembles the "exploding bomb" structure seen in geodes and described by Bassler (1908).

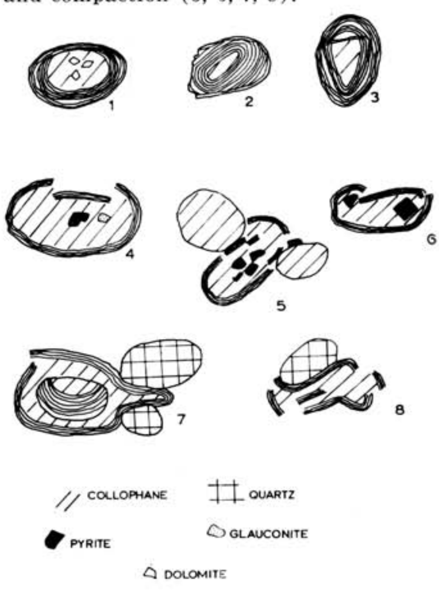
Other detrital phosphatic components include ovulites, fish remains and other organic debris.

Associations

The common associations of phosphate have been listed by Kazakov (1937) and Carozzi (1960).

Mineral associations. — Accessory minerals in the phosphates herein reported are numerous and intricate in their interrelations. Glauconite is fairly common, and is found replacing crinoids (cf. Carozzi 1960, p.

Figure 1.—Diagrams showing the disconformable layering in the ooliths (1, 2, 3) and the breakage by impact (4) and compaction (5, 6, 7, 8).



375), as isolated rounded grains, or as cores to collophane ooliths (where in some instances the glauconite replaces the surrounding collophane).

In common with most phosphates pyrite is abundant and occurs as a primary constituent of the limestone, as a nucleus for oolith development, and as a secondary mineral replacing individual ooliths (see p. 45) or the whole rock fabric (which may include the already pyritized ooliths).

Dolomite occurs either as euhedral grains zoned with brown iron-oxide inclusions or as a somewhat finer grained granoblastic variety. Dolomitization is believed to precede the 'front' of phosphatization in many of the examples where the latter process is or has been in operation.

Calcite is particularly abundant both as pre- and post-phosphate mineral. It occurs replacing some of the phosphate ooliths as described by Lowell (1952, p. 24). Fluorite is present in small amounts, but little is known about its age and origin.

Stratigraphic associations. — The association of phosphate with non-sequences is well known, and their occurrence at the bases of transgressions has been recorded by Kirkaldy (1939, p. 409) and Oakley (1941, p. 2). In the Indiana occurrences, the following succession is considered to prevail from the base upward (Fig. 2):

1. Beds of well sorted fragmental limestone (below the phosphate).
2. Phosphates, size graded upward and with comparatively large quartz grains.
3. Badly sorted fragmental limestone, relatively rich in crinoids.
4. Limestones which are comparatively rich in bryozoans.

This order of occurrence is interpreted to be the result of a marine regression during which 1 and 2 (above) were deposited, followed by a marine transgression during which 2 (above) was eroded, and 3 and 4 deposited. If the occurrences of phosphate bands indicate such cycles of events, then the maximum number of cycles observed in the Jeffersonville and Sellerburg is five (excluding the phosphate below the New Albany shale transgression).

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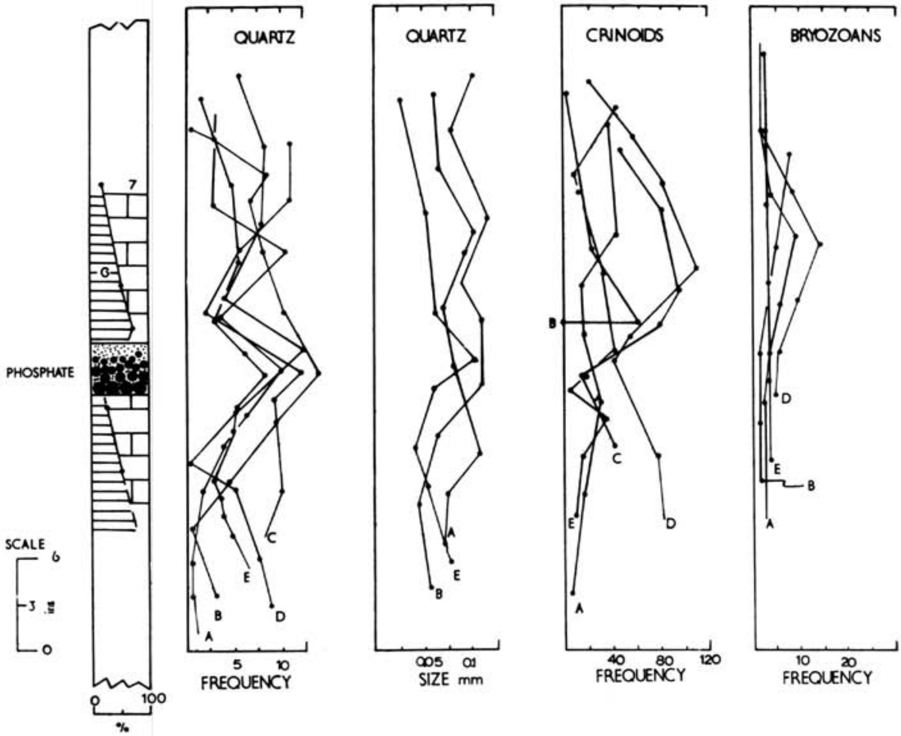

Figure 2.—Variations in composition and lithology across the phosphate bands. The distribution of lithological types, given in the column on the left, is an average for all the phosphate beds studied; and 6 is a poorly sorted limestone, 7 is a well sorted limestone. A refers to a section in Meshberger Quarry; B, C, and D to Paul Frank Quarry, E to Scott County Quarry.

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