The Geology of the Florida Land-Pebble Phosphate Deposits

Trace Elements Investigations Report 265

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THE GEOLOGY OF THE FLORIDA LAND-PEBBLE PHOSPHATE DEPOSITS*

By

J. B. Cathcart, L. V. Blade,

D. F. Davidson, and K. B. Ketner

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THE GEOLOGY OF THE FLORIDA LAND-PEBBLE PHOSPHATE DEPOSITS

by

J. B. Cathcart, L. V. Blade, D. F. Davidson, and K. B. Ketner

ABSTRACT

The land-pebble phosphate district is on the Gulf Coastal Plain of Florida. The phosphate deposits are in the Bone Valley formation, dated Pliocene by most writers. These strata overlie the Miocene Hawthorn formation and are overlain by unconsolidated sands 3 to 20 feet thick.

The minable phosphate deposits, called "matrix" in the district, range from a featheredge to about 50 feet in thickness and consist of phosphatic pellets and nodules, quartz sand, and montmorillonitic clay in about equal proportions. Locally the matrix displays cross-bedding and horizontal laminations, but elsewhere it is structureless. The phosphorite particles, composed largely of carbonate-fluorapatite, range in diameter from less than 0.1 mm to about 60 cm and in P_2O_5 content from 30 to 36 percent. Coarse-pebble deposits, containing 30 to 34 percent P_2O_5 are found mainly on basement highs; and fine-pebble deposits, containing 32 to 36 percent P_2O_5, are found in basement lows. Deposits in the northern part of the field contain more phosphate particles and their P_2O_5 content is higher than those in the southern part.

The upper part of the phosphatic strata is leached to an advanced degree and consists of quartz sand and clay-sized particles of pseudowavellite and wavellite. The leached zone ranges in thickness from a featheredge to 60 feet.

The origin of the land-pebble deposits is incompletely known. Possible modes of origin are a residuum of Miocene age, or a reworked residuum of Pliocene or Quaternary age.

INTRODUCTION

The land-pebble phosphate district of Florida is an irregular-shaped area between 27°15' and 28°15' North latitude and 81°30' and 82°30' West longitude (fig. 1). Mining of the deposits started in 1888, and production has increased steadily; in 1951 more than 7 million long tons of phosphate rock was produced. Because about two-thirds of the 185 million tons of phosphate rock produced in the United States has been from the Florida land-pebble district, it has been one of the most productive in the world.

Since 1947 the U. S. Geological Survey has maintained a field party in the district to study the geology in detail--to study the distribution, composition, and origin of the phosphate deposits, to determine the relations of the deposits to the geologic formations of the district, and to revise and bring up to date the estimates of tonnage and grade. This paper summarizes available information on the origin and distribution of the deposits.

Such a project in an active mining district can not succeed without the wholehearted cooperation of the mine owners and operators of the district. The writers are happy to acknowledge such cooperation by the active mining companies in the land-pebble district: American Agricultural Chemical Co., American Cyanamid Co., Coronet Phosphate Co., Davison Chemical Corp., International Minerals & Chemical Corp., Swift & Co., and Virginia-Carolina Chemical Corp., U. S. Phosphoric Products Co., and the Royster Guano Co., who are principally processors of phosphate rock, have furnished information,

as has Mr. Wayne Thomas, an independent consultant on Florida phosphate land.

Since 1947, 21 geologists have helped in the investigations of the Florida phosphate deposits, and each of these men contributed to the present knowledge of the deposits. Most of the ideas expressed in this paper have been expressed in frequent discussions among the party members; thus the writers can be credited only with presenting them here. This work was done on behalf of the Division of Raw Materials of the U. S. Atomic Energy Commission.

GENERAL GEOLOGY

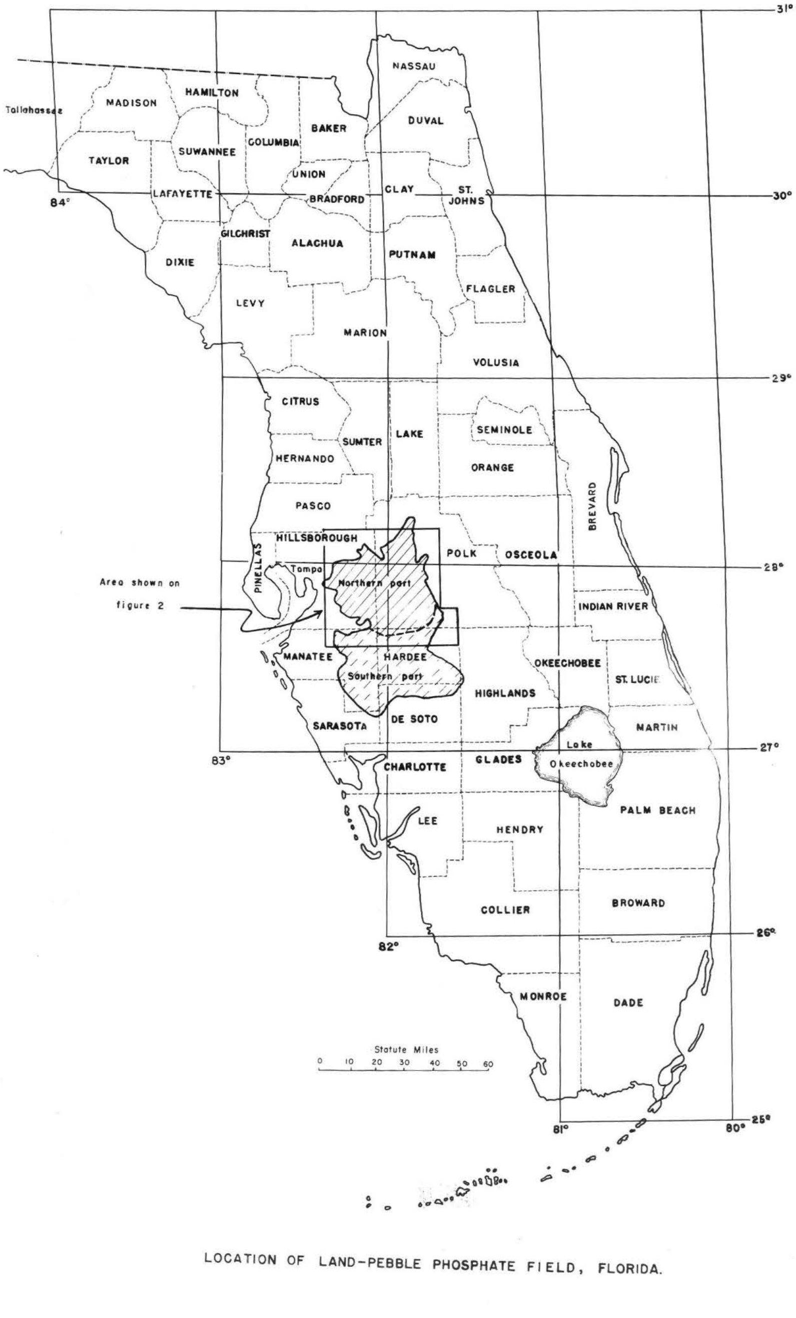
Geologic setting

The land-pebble phosphate district (fig.1) is on the east Gulf Coastal Plain. King (1951) points out, however, that the geology of peninsular Florida differs considerably from that of the remainder of the eastern Coastal Plain, for peninsular Florida was a positive, relatively stable area during a large part of Mesozoic and Genozoic time. Because of its distance from the main part of the North American Continent, it received relatively small amounts of land-derived sediments; and because of the Ocala uplift, the usual gentle seaward dip of the coastal plain formations is not maintained.

The rocks in the land-pebble phosphate district are divided into four formations by most writers. They are the middle Miocene Hawthorn formation, which underlies most of the district, the Pliocene Bone Valley formation, Pleistocene terrace sands, and Recent deposits (Cooke, 1945; MacNeil, 1950).

Structure

According to published data (Jordan, 1950; Vernon, 1951), formations



LOCATION OF LAND-PEBBLE PHOSPHATE FIELD, FLORIDA.

older than the Hawthorn formation in the land-pebble district dip gently to the south. The Hawthorn formation in the land-pebble phosphate district is wedge-shaped, thinning from several hundred feet in the southern part of the district to a featheredge in the northern part.

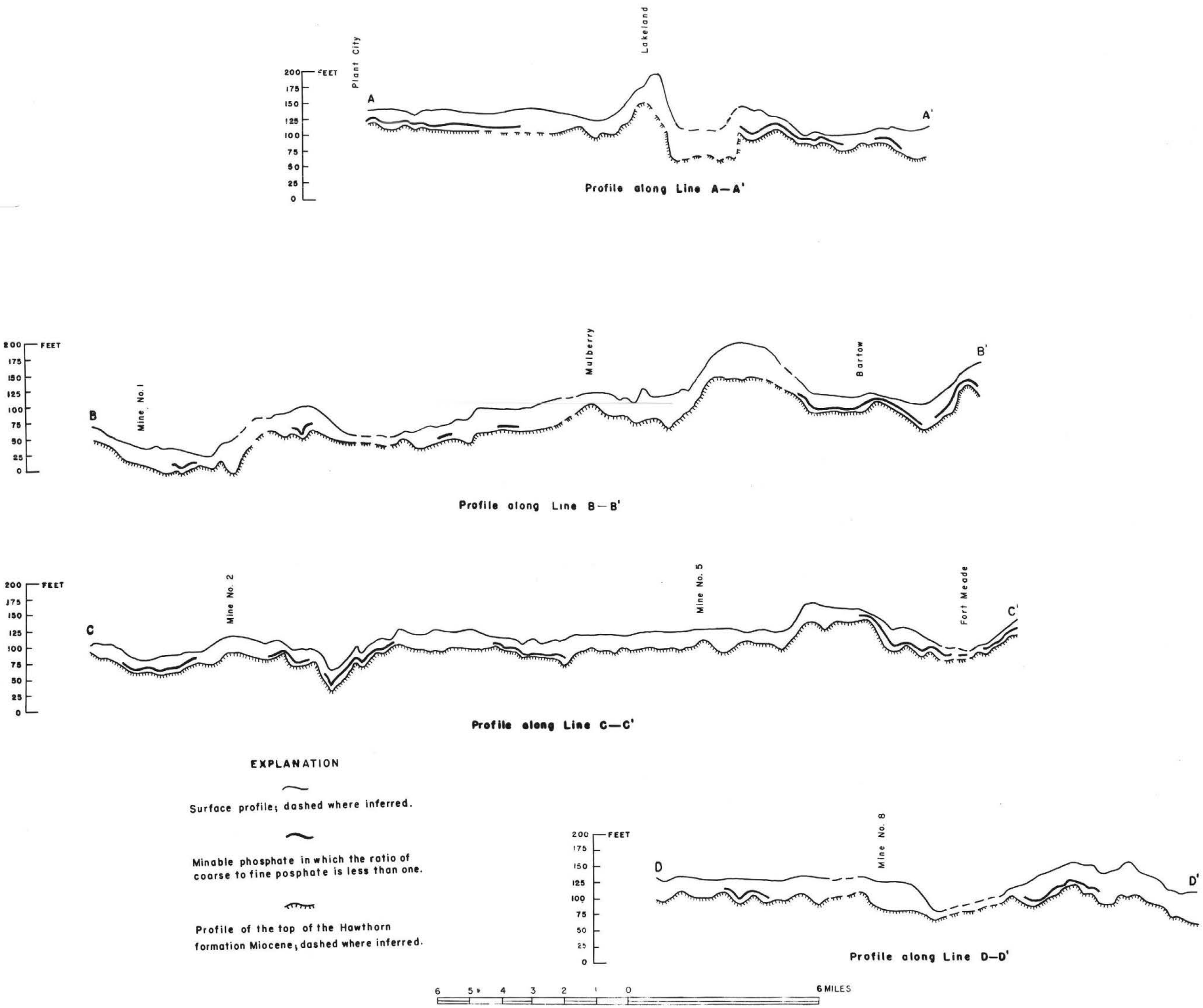
The Bone Valley formation blankets the Hawthorn throughout the district except along the Alafia and Peace Rivers, where the Hawthorn is exposed in the channels. Recent work by Blade and Ketner in one area near the Peace River and another area farther west indicates that the Bone Valley formation thickens as the elevation of the present land surface increases. Whether or not this relationship is general for the district had not yet been determined.

Quartz sands overlie the Bone Valley formation in most of the district, but their age and origin are in dispute. In general the structure of these sands and the nature of their contact with the Bone Valley are obscure.

A structural relationship that may have a bearing on the origin of the Bone Valley formation is that topographic highs and lows of the present surface coincide in general with highs and lows on the limestone surface of the Hawthorn formation (fig. 2).

GEOLOGIC HISTORY

The writers' interpretation of the complete geologic history of the land-pebble phosphate district must await resolution of problems of the origin of the deposits. It may be said, however, that after the marine deposition of the middle Miocene Hawthorn formation there followed a period of erosion that may or may not have continued without interruption into the Pleistocene. During part of the Pleistocene the district was covered by the sea as



PROFILES ACROSS THE NORTHERN PART OF THE LAND-PEBBLE PHOSPHATE FIELD, FLORIDA.

recorded by marine terraces (Cooke, 1945; MacNeil 1950). In Recent time the district has remained above the sea and has undergone only modifications produced by weathering and erosion.

STRATIGRAPHY

Stratigraphic relations, local terminology, and mineralogy are summarized in figure 3.

Hawthorn formation

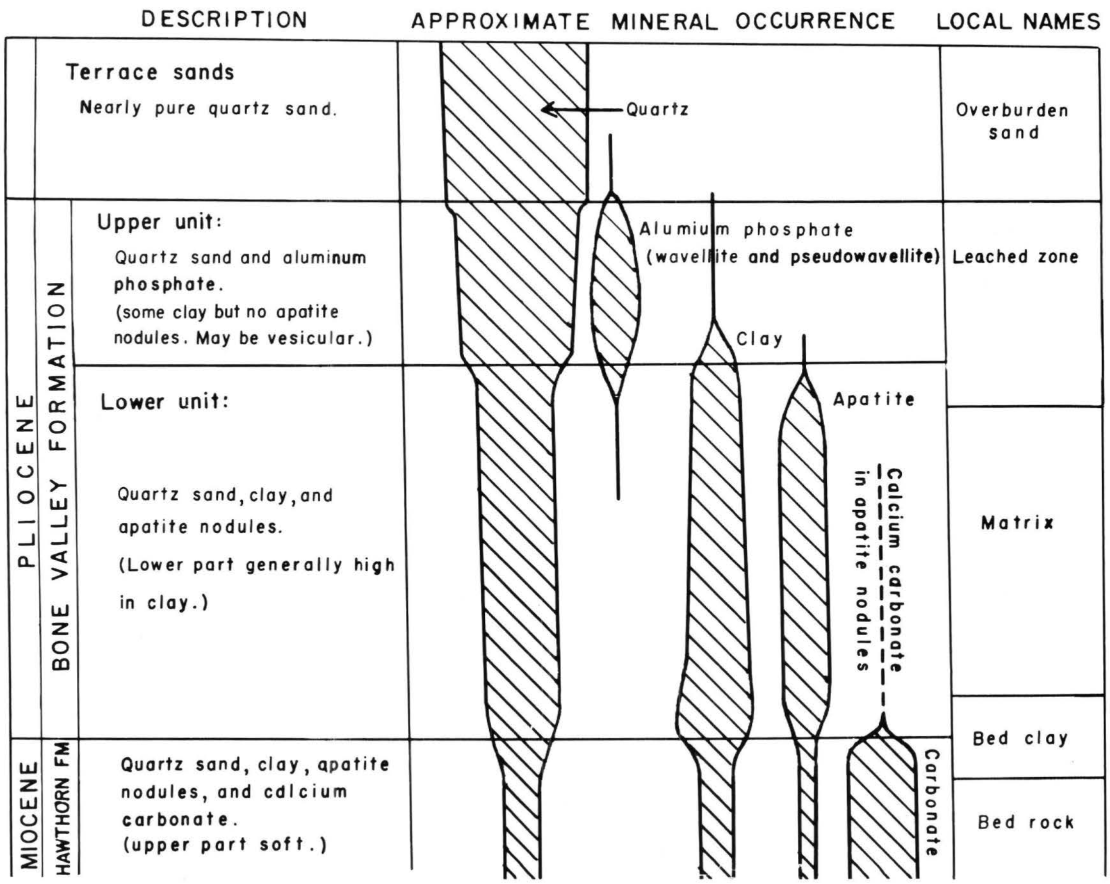
The Hawthorn formation is middle Miocene in age (MacNeil, 1947). Work by the Geological Survey field party suggests that in the land-pebble district the Hawthorn may be roughly divided into three lithologic units: (1) lowermost phosphatic marls and hard limestone containing clay and quarts sands; (2) next a series of clastic beds composed of phosphatic sands, clays, and sandy clays; and (3) uppermost, dolomites and dolomitic limestones. Because of pre-Bone Valley tilting and erosion, the two middle and upper units occur only in the southern part of the district.

Phosphorite particles ranging from less than 0.1 mm to 10 cm in diameter occur within the formation.

Bone Valley formation

The Bone Valley formation generally is said to be of Pliocene age although evidence is not conclusive.

In Polk and Hillsborough Counties--the northern part of the land-pebble district--the Bone Valley formation is divided into a lower and an upper



CORRELATION OF STRATIGRAPHY, MINERALOGY, AND LOCAL TERMINOLOGY, LAND-PEBBLE PHOSPHATE DISTRICT, FLORIDA unit. The lower unit, which locally is cross-bedded and horizontally laminated but elsewhere is structureless is composed of poorly sorted clay, silt, sand, and gravel. Almost all the gravel, which includes pebbles as much as 60 cm in diameter, and a large part of the sand and clay-sized material in this unit are composed mainly of phosphate, which has recently been identified as carbonate-fluorapatite by Z. S. Altschuler and E. A. Cisney. The remainder of the sand is mainly quartz, with minor amounts of feldspar and trace amounts of ilmenite, zircon, tourmaline, staurolite, and other minerals. Altschuler and C. E. Boudreau have identified the remainder of the clay-sized material as chiefly montmorillonite, although minor amounts of kaolin are present. They have identified the minerals in the upper unit of the Bone Valley formation as chiefly quartz sand, the aluminum phosphate minerals wavellite and pseudowavellite, and kaolinite.

The lower unit, which ranges in thickness from less than a foot to more than 50 feet, is commonly about 20 feet thick; and the upper unit, which ranges from a featheredge to about 60 feet in thickness, is commonly about 6 feet thick. The two units tend to complement one another in thickness in some areas.

In the southern part of the district the Bone Valley formation cannot be divided into an upper and a lower unit on the basis of present information. The entire formation is thought to be homogeneous, consisting of fairly well sorted quartz and phosphate sand and sandy clay.

Terrace sands

Loose massive sand, in terraces commonly considered to be of Pleistocene age, overlies the Bone Valley formation. This sand ranges from 2 feet to

30 feet or more in thickness. Although Cooke (1945) described seven terraces in peninsular Florida, MacNeil (1950) recognized only three in the land-pebble district--one at 30 feet, one at 100 feet, and one at 150 feet above sea level.

Recent deposits

Thin, discontinuous sands, silt, and muck at the surface are considered Recent.

THE PHOSPHATE DEPOSITS

Matrix

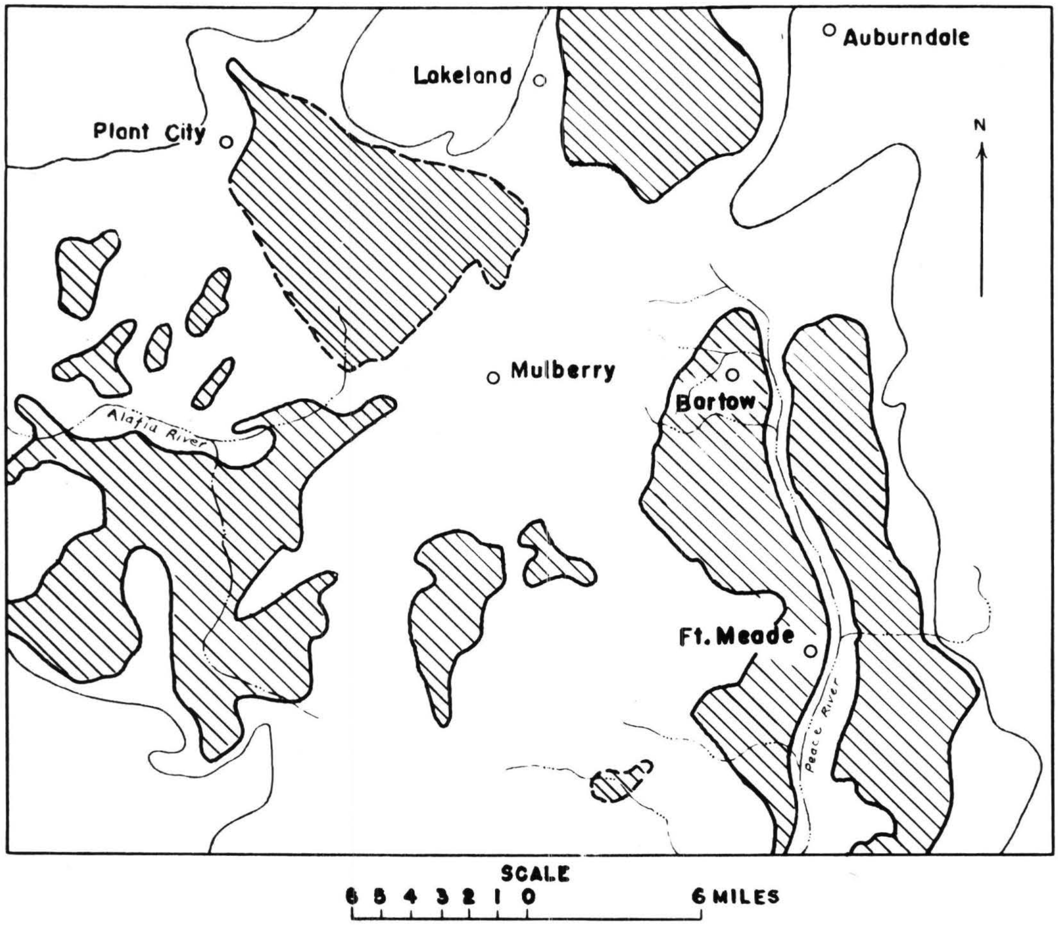
Phosphate is being mined only in the northern part of the district from parts of the lower zone of the Bone Valley formation, locally termed "matrix". The main factors in determining the minable parts of the lower Bone Valley are: (1) tonnage of recoverable phosphate per acre, which is determined both by thickness of the lower zone and by the proportion of phosphorite nodules within it; (2) P_2O_5 content of the phosphorite nodules; and (3) thickness of overburden. Material now being mined generally consists of about equal parts of quartz sand, clay, and phosphorite nodules.

The tonnage of recoverable phosphate ranges from about 500 to 35,000 tons per acre and is typically about 5,000 tons per acre. The P_2O_5 content of the phosphorite nodules ranges from 30 to 36 percent. In general this content varies inversely with nodule size, probably because the larger nodules have a greater proportion of calcium carbonate. The content also generally increases upward within the lower unit of the Bone Valley formation, probably as a result of removal or replacement of contained carbonate in the nodules in the upper part of the zone.

Coarse phosphorite nodules containing 30 to 34 percent P_2O_5 predominate in the north-central part of the district, whereas finer-grained phosphorite containing 32 to 36 percent P_2O_5 predominates in peripheral areas (fig. 4). The grain size of nonphosphatic constituents is more uniform over the district. In general fine phosphorite particles are found on Hawthorn formation lows and coarser phosphorite is found on Hawthorn formation highs. Although the lower zone of the Bone Valley formation conforms to irregularities on the surface of the limestone of the Hawthorn formation, as does the entire sequence of unconsolidated beds, it generally tends to thicken somewhat over the major hills on the limestone (fig.2).

The leached zone

The upper part of the Bone Valley formation probably represents leached and weathered material originally somewhat similar to the lower zone immediately below. This clayey sand (locally indurated) has been found in all but the southern part of the district. As has been stated, its thickness varies, as does its composition. About 5 to 40 percent of the material occurs in particles smaller than 0.1 mm. The material greater than 0.1 mm includes coarse to fine quartz sand, small amounts of "heavy" minerals—including variable amounts of nodular apatite—and variable amounts of aggregated wavellite and pseudowavellite. Kaolinite, wavellite, pseudowavellite, apatite, and quartz make up the bulk of the material smaller than 0.1 mm.



EXPLANATION

AREAS WHERE COARSE (+1.2 mm) / FINE (-1.2 TO 0.1 mm) = <1

LIMITS OF MINABLE PHOSPHATE DEPOITS

VARIATION IN RATIO OF COARSE TO FINE PHOSPHATIC PARTICLES IN THE FLORIDA LAND-PEBBLE FIELD

An indication of the variations in proportions of the above minerals is given by the Al_2O_3 and P_2O_5 contents. The Al_2O_3 ranges from less than 9.0 to more than 39 percent of the minus 0.1 mm fraction. The P_2O_5 for the same fraction ranges from less than 2 to more than 28 percent.

The minerals in the lower unit of the Bone Valley formation contain all the elements necessary to produce the minerals found in the upper unit. This permits the interpretation that the upper unit of the Bone Valley was probably formed in place by percolating ground waters from material similar to that in the lower unit.

ORIGIN

The origin of the land-pebble deposits is incompletely known. Possible modes of origin are: (1) a residuum of Miocene age (hereinafter referred to as the residual hypothesis) and (2) a reworked residuum of Pliocene and/or Quaternary age (hereinafter referred to as the depositional hypothesis).

The residual hypothesis

The residual hypothesis of origin of the phosphate deposits in its extreme form attempts to account for the entire sequence of unconsolidated material overlying the limestone of the Hawthorn formation in the land-pebble district as the relatively insoluble residue of the Hawthorn that has been concentrated in place by weathering. This hypothesis is suggested by the following facts: (1) With some exceptions--the bed-clay, for example,--minerals present in the limestone persist upward in overlying strata in accordance with their insolubilities (fig. 3). The calcium carbonate content of the phosphorite nodules in much of the lower unit of the Bone Valley formation decreases upward, whereas they increase upward in the less soluble apatite and iron and aluminum oxide contents. The bed-clay might be analogous to a clay hardpan, formed by downward migration of clay-sized particles freed during decomposition of enclosing materials. (2) There are relics of lower zones in higher zones; i.e., the terrace sands contain fragile, irregular fragments of material similar to that composing the upper unit of the Bone Valley formation, the upper unit contains vesicles resembling the molds of phosphate nodules similar to phosphate nodules present in the lower unit of the Bone Valley, and the lower unit of the Bone Valley formation contains nodules having cores of fossiliferous carbonate similar to that of the limestone of the Hawthorn formation. (3) Contacts between the various zones are gradational--not patently unconformable. (4) District-wide cross sections show the unconsolidated material above the limestone conforming in general to the irregularities of the limestone surface rather than tending to fill depressions. Actually, the highest hills on the limestone surface are generally overlain by zones that are somewhat thicker than usual, as is common in residual deposits. (5) Paleontologic evidence indicating different ages for the different zones is open to more than one interpretation. The residual hypothesis requires that the entire sequence of zones be Miocene in age. Paleontologist express uncertainty about the identification and correlation of many of the fossils because of their fragmentary nature or non-diagnostic character. Simpson (1930), reviewing the evidence afforded by land mammals in the Bone Valley formation says: "It indicates approximate equivalence with the Upper Snake Creek or the Republican River. With this relative age established, it is of little consequence whether it be called late Miocene or early Pliocene. At present the consensus seems to be that the Republican River and equivalents are referable to the Lower Pliocene."

Kellogg (1924), on the other hand, says that certain marine mammals found in the Bone Valley formation are clearly earlier than Pliocene. Most fossils used in dating the Bone Valley formation were collected by laymen in the process of mining. The few found in place by geologists have not settled the question of age.

The depositional hypothesis

The depositional hypothesis was set forth in detail by Sellards (1915) and has been generally accepted. It postulates erosion of the limestone of the Hawthorn formation at the end of Miocene time, deposition in Pliocene time of the lower unit of the Bone Valley formation in a shallow marine near-shore environment, the upper unit of the Bone Valley in a marine offshore environment, subsequent erosion, and finally, deposition in Pleistocene time of surficial terrace sands. The following facts support this hypothesis: (1) Vertebrate fossils indicate different ages for different formations. The Hawthorn formation has been dated middle Miocene on the basis of abundant invertebrate remains. Vertebrate remains support this age. The following fossils have all been collected from the lower unit of the Bone Valley formation (matrix) and have been identified by Jean Hough and C. L. Gazin, of the U. S. National Museum. The fossils dated Pliocene and Quaternary have, with one exception, been found in the central area of the northern part of the land-pebble district, whereas the Miocene fossils were found in the peripheral areas.

	Age	Mine No.
Teleoceras proterus	Pliocene	2
Nannippus ingenuus	lower Pliocene	3
Nannippus minor	lower Pliocene	4, 5
Neohipparion phosphorum	lower Pliocene	4, 5
Tayassuid of Desmathyus Matthew	lower to middle Pliocene(?) possibly Miocene	6
? Aphelops	middle Miocene	7 and 6
Merychippus westoni	middle Miocene	6
Bison	Quaternary	West of 3
Antilocaprid, generically undet.	Upper Tertiary	6

(2) Conglomerates and irregular contacts immediately above and below the Bone Valley formation are evidence of unconformities. (3) There is a rather distinct bedding, including graded and cross-bedded forms, in places in the lower and upper units of the Bone Valley formation. Such bedding is not likely to have been preserved as relics of bedding of the Hawthorn formation in a residual deposit because of slumping.

Conclusion

A combination of the two working hypotheses might best explain the origin of the Bone Valley formation. In the north-central part of the district the depositional hypothesis is applicable, whereas in the periphery the residual hypothesis is more suitable. However, excellent bedding is found in a few places in the periphery. The lower part of the lower unit of the Bone Valley formation may be residual in places, whereas the upper part and all overlying strata may be transported. Although the fact that the general sequence of strata illustrated in figure 3 is nearly universal in the district, militates against the idea of diverse modes of origin, it is possible that the whole district was more or less uniformly zoned by subsequent intense weathering. (See fig. 3.)

Evidence is lacking on which to establish either hypothesis as a fact at any specific place because many field relations are subject to two or more interpretations.

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