Pre-Cambrian Rocks Encountered in Test Holes in Indiana

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Introduction

The pre-Cambrian basement rock complex in Indiana has been reached in six test holes drilled for oil and gas in Wayne, Henry, Jay, Howard, and Allen Counties, on the north and northwest flanks of the Cincinnati Arch (Fig. 1). The purpose of this study is to provide petrologic information on the basement complex in Indiana. Samples obtained from six holes that are only a few inches in diameter and that are scattered through an area of about 2,300 square miles obviously cannot be representative of the pre-Cambrian rocks. In addition, although one hole penetrated 468 feet of granite, the other holes extended 100 feet or less into the basement complex. Despite this scarcity of samples, the material from these test holes provides our only specific knowledge of the pre-Cambrian rocks beneath Indiana, and must be the point of departure for any additional study.

Recent geophysical investigations in Indiana have increased the need for information on the basement complex. An aeromagnetic survey of Indiana has been completed as a joint project of the United States Geological Survey and the Indiana Geological Survey. Maps on a scale of 1 inch to the mile have been published for all counties. Because the sedimentary rocks in the state are essentially non-magnetic, variations in the magnetic character of the basement complex must be the major causes of anomalies shown on these aeromagnetic maps. The topography of the upper surface of the basement complex also affects the magnetic intensities at the surface, but this effect is insignificant in comparison with the effect of changes in magnetic susceptibility in the pre-Cambrian rocks. Because the sample representation is so sparse, the general aspect of the pre-Cambrian rock types is more important at this time in the interpretation of the aeromagnetic maps than the details of whether or not any particular sample contains magnetite.

The Indiana Geological Survey has completed a regional gravity survey of the entire state. The nature of the basement complex affects the strength of the gravitational field. Here again the genetic types into which the pre-Cambrian rocks fall are more meaningful than the density of any single sample.

The total thickness of the Paleozoic strata and glacial drift above the pre-Cambrian ranges from 3,333 to 3,895 feet in the test wells. The shallowest pre-Cambrian rocks encountered to date are in Jay County. Pre-Cambrian rocks identified in the drill cuttings are hornblende micrographic granite, dolomitic marble, siliceous argillite, augite andesite microporphyry, quartzite, and slate.

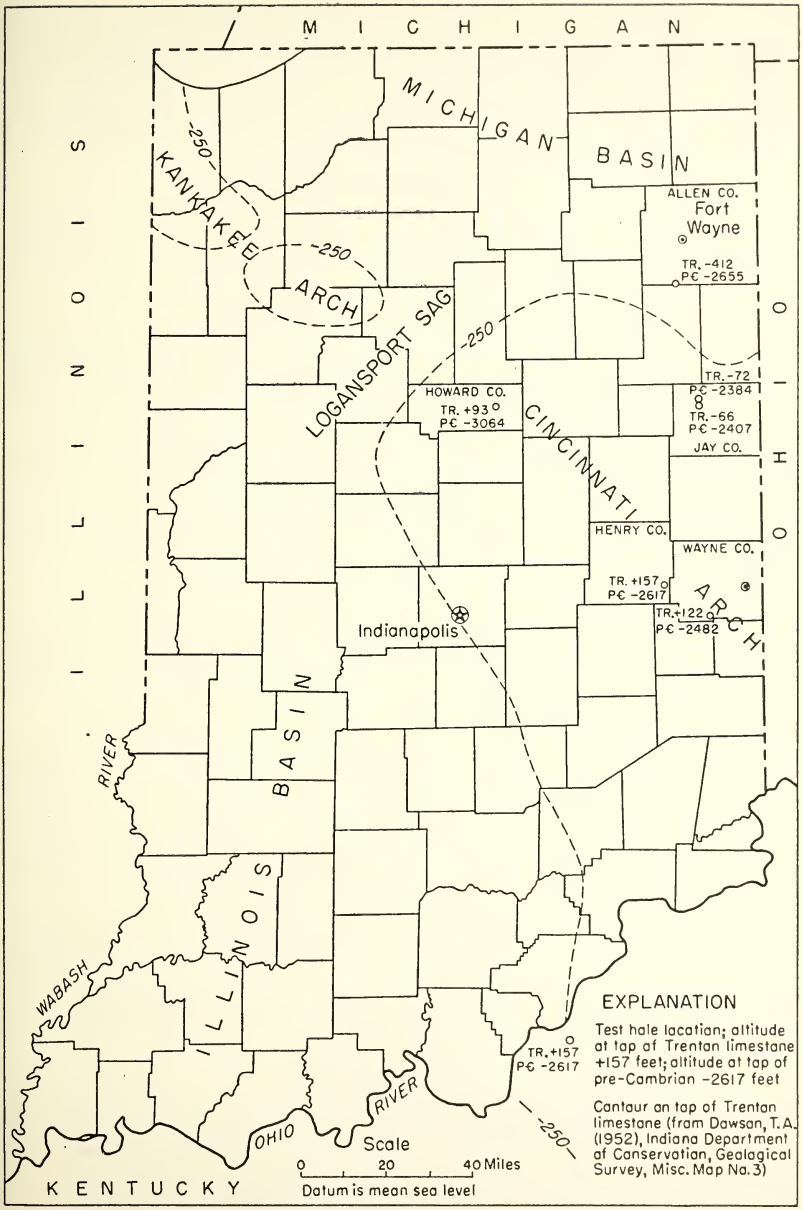


Fig. 1. Map showing pre-Cambrian test holes in Indiana.

Methods of Study

Small rock chips, ranging from 1 to 7 mm in diameter, were obtained from drill cuttings made available by the Petroleum Section of the Geological Survey, Indiana Department of Conservation. Mr. Edwin Hickam prepared sections about 0.03 mm thick from the rock chips. These thin sections, along with crushed fragments, were studied with the petrographic microscope and by X-ray diffraction and microchemical methods.

Pre-Cambrian Test Holes

Wayne County.—The Porter Gorden *et al.* No. 1 Doddridge was drilled in the NW¼NW¼NW¼ sec. 23, T. 15 N., R. 13 E. Chloritic hornblende micrographic granite was encountered from the depth of 3,439 feet to the total depth of 3,907 feet. Surface elevation was 957 feet.

Henry County.—The Ohio Oil Company No. 1 May was drilled in the SW¼SW¼SE¼ sec. 12, T. 16 N., R. 11 E. The same hornblende micrographic granite appeared at a depth of 3,649 feet and extended to the total depth of 3,670 feet. The reported surface elevation was 1,031 feet.

Jay County.—The Petroleum Development Company No. 1 Binegar was drilled in the NE¼NE¼NW¼ sec. 29, T. 24 N., R. 13 E. It encountered dolomitic marble at a depth of 3,351 feet and siliceous argillite from 3,374 feet to the total depth of 3,404 feet. More than one surface elevation was reported for this location. The elevation used for this report is 944 feet.

The Farm Bureau Oil Company No. 1 Binegar was drilled only one location north of the first deep well on the Binegar tract. The Farm Bureau well did not encounter marble at the top of the pre-Cambrian section but reached the siliceous argillite at 3,333 feet and continued in it to the total depth of 3,395 feet. Derrick floor elevation was 949 feet.

Howard County.—The Kokomo Gas and Fuel Company No. 1 Greentown was drilled in the SE¼SW¼NW¼ sec. 32, T. 24 N., R. 5 E. to a total depth of 3,996 feet. Alternating beds of yellow-brown to reddish-brown, iron-impregnated quartzite; blue-gray marble; pinkish-brown, siliceous argillite; and gray-green slate were encountered between depths of 3,895 and 3,996 feet. The surface elevation was 831 feet.

Allen County.—The Tecumseh Oil and Gas Company No. 1 Gibson was drilled in the NE¼SW¼SW¼ sec. 33, T. 29 N., R. 12 E. Dark, purplish-gray augite andesite microporphyry was encountered from 3,476 feet to the total depth of 3,517 feet. Surface elevation was 821 feet.

Paleozoic Strata

General statement.—The two wells drilled in Henry and Wayne Counties encountered the fossiliferous interbedded limestones and shales of the upper part of the Cincinnatian series (upper Ordovician) directly beneath the glacial drift. The other four wells encountered dolomite, dolomitic limestone or silty calcareous shale within the Niagaran series (middle Silurian). Westward from the Cincinnati Arch increasing thicknesses of Paleozoic strata lie above the pre-Cambrian rocks. The increase in thickness is caused mostly by the fact that Devonian, Mississippian and

Pennsylvanian rocks successively make their appearance toward the center of the Illinois Basin and partly to the fact that the Silurian and Devonian rocks thicken appreciably toward the center of the basin. Parts of the Mississippian section also thicken basinward.

Much the same situation prevails northward from the Cincinnati Arch into the Michigan Basin, although considerably less is known from subsurface data than in the case of the Illinois Basin. Northward from the Cincinnati Arch, Devonian and Mississippian rocks make their appearance beneath the glacial drift, as revealed by rather meager well data in the northern counties of the state. Northwestward from the Cincinnati Arch another structurally positive crest that has been called the Kankakee Arch causes Niagaran rocks to lie immediately beneath the drift in a belt that passes out of Indiana in the northwest corner of the state. Thus, except in the Logansport Sag, a narrow, structurally negative area centered in Carroll and Cass Counties (Fig. 1), Niagaran rocks underlie the glacial drift fairly continuously from Henry County and northern Wayne County northwestward to Lake Michigan. The best state-wide horizon for structural control has generally been considered to be the top of the Trenton limestone (middle Ordovician). Structural maps contoured on this horizon have been published within recent years by Harris and Esarey (6, fig. 4) and by Dawson (1).

The distribution of Upper Ordovician, Silurian, Devonian, Mississippian, and Pennsylvanian bedrock appears on the Geological Map of Indiana (9), and these strata will not be discussed in this paper. The Cambrian rocks and most of the Ordovician section are not exposed in Indiana and a resumé of their lithology and thickness as known from drilling will be given here. The Paleozoic succession in two of the pre-Cambrian test wells has been described by Esarey and Bieberman (2, p. 4-6).

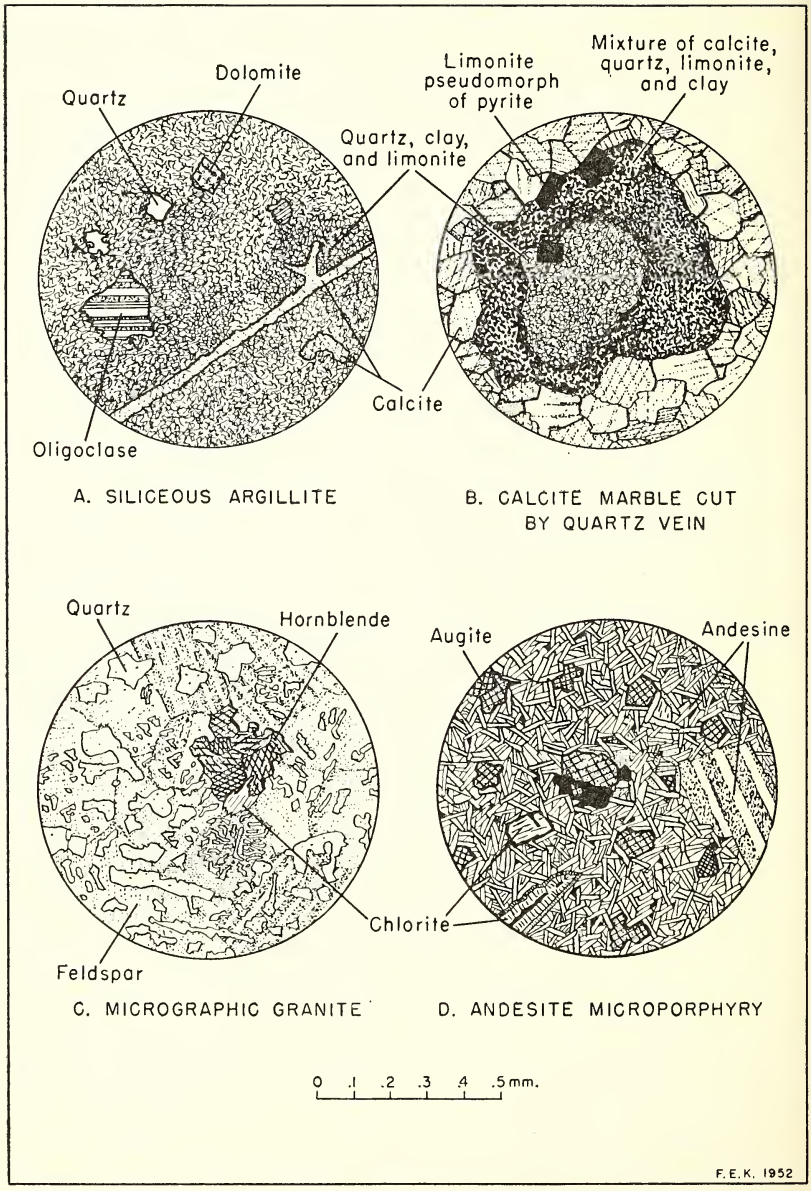
Cambrian rocks.—In all six of the test wells considered here, the pre-Cambrian rocks have been overlain by a thick, fairly pure, soft sandstone that has been correlated with the Mt. Simon sandstone, the basal formation of the Croixian Series (Upper Cambrian). The Mt. Simon has ranged in thickness from 237 to 406 feet in these wells. The sandstone is a mixture of white, amber, and pink grains that range from fine to coarse in texture, are angular to rounded, and poorly sorted. Cementation is generally poor and the sandstone is soft or only moderately firm in drilling.

The Mt. Simon is overlain by 530 to 735 feet of Upper Cambrian sediments that may contain equivalents of the Eau Claire and Dresbach sandstones. The lower part of this section consists of white and gray, fine- to coarse-grained, dolomitic, glauconitic sandstone. The large grains are rounded and frosted. The middle and upper parts consist of gray and pink, glauconitic, locally micaceous dolomite, mixed with minor amounts of gray-green and red shale.

In general the materials above this point are much more pure carbonate rock (mostly dolomite) than those below. This strong change in lithology appears to be the best place in the section to place the Cambrian-Ordovician contact.

PLATE 1

Kottlowski and Patton



Sketches of Thin Sections

Ordovician rocks.—A thick succession of rather pure dolomite occupies the Lower Ordovician interval. It is not readily divisible into formations, but it is roughly equivalent to the Prairie du Chien group (Lower Ordovician). In eastern Indiana the group is composed principally of white, tan, and light gray, crystalline dolomite that contains irregular thin beds of oolitic, chalky-white or blue chert. Fine quartz grains, glauconite, and disseminated pyrite are present but not abundant. The thickness of the group ranges between 724 and 1,261 feet in the wells reported here. The section thickens from north to south and from west to east.

The Chazy group (Lower Ordovician) is represented in the Wayne County well by an 8 foot zone that consists of round, frosted sand grains loosely cemented with dolomite. This zone is probably the St. Peter sandstone, although the St. Peter is not present as true sandstone in most of east-central Indiana. Round, frosted sand grains occur in beds of granular dolomite at about this horizon in many wells in the area.

Above the Chazy group lie the beds of the Mohawkian series (Middle Ordovician). The base of the series generally contains a 5 to 35 foot thickness of green, dolomitic shale in which round, frosted sand grains are locally plentiful. This green shale zone has been correlated with the Glenwood shale, the lowermost formation of the Black River group. The entire group ranges from 250 to 350 feet in thickness in the counties near the Ohio line. The portion above the Glenwood shale consists mostly of tan and brown, slightly dolomitic limestone that is dense to medium-grained and contains green, bentonitic shale in the upper part.

Above the Black River group lies the Trenton limestone, which is 150 to 200 feet thick in east-central Indiana. The formation consists mainly of tan to creamy-white, dense to crystalline, cherty limestone.

The Trenton limestone is directly overlain by dark, bluish, soft shales of the Eden group, succeeded by the fossiliferous, interbedded shale and limestone of the Maysville and Richmond groups. These three groups constitute the Cincinnatian series (Upper Ordovician).

Pre-Cambrian Rocks

Determination of the relative ages of the pre-Cambrian rocks studied from the six scattered drill holes can be only tentative. The rocks have undergone only mild metamorphism as is typical of the later pre-Cambrian rocks in the Great Lakes region. The quartzite in the Greentown well contains detrital fragments of hornblende micrographic granite similar to the granite in the May and Doddridge wells. Fragments of marble and siliceous argillite occur with quartzite in the upper section of the pre-Cambrian in the Greentown well, and greenish-gray slate is interbedded with the quartzite in the lower part of the hole. A chip of quartzite, composed of a simple mosaic of quartz (5, p. 67), occurs within the augite andesite in the Gibson well but is petrographically dissimilar to the quartzite in the Greentown well. The relative age of the augite andesite cannot be determined from the available data.

Marble.—The upper 20 feet of the pre-Cambrian in the Petroleum Development Corporation's Binegar well consists of medium-gray, recrystallized limestone or marble interbedded with and partly replaced by

pinkish-brown dolomite. The carbonate grains are anhedral to subhedral and are arranged in decussate texture. The crystals average 0.16 mm in diameter, cleavages are indistinctly shown, and twinning lamellae are partly masked by numerous inclusions. A few lenses of extremely fine-grained calcite are composed of anhedral crystals that average 0.02 mm in diameter. Cement between the carbonate crystals and impurities within the crystals consist of limonite, siderite, illite (?), and cryptocrystalline silica. A few tiny, rounded, detrital grains of quartz are present. Limonite is pseudomorphic after cubes of pyrite.

Superimposed over the decussate texture of the carbonate grains are indefinite, discontinuous, parallel streaks in which limonite, illite (?), quartz, and minor chlorite are abundant. These bands may be relic lamination. Veins of cryptocrystalline silica cut the marble and are surrounded by irregular rings of silicified marble composed of tiny crystals of dark calcite, quartz, clay, and limonite. The larger limonite cubes of pyrite pseudomorphs are concentrated near these veins. Plate 1B shows a cross-section of a silica vein in marble.

Chips of similar dolomitic marble were obtained from the Greentown well. Laminae of quartzite occur in this marble.

Siliceous argillite.—The lower 30 feet of the pre-Cambrian in the Petroleum Development Corporation well and the entire 62 feet of pre-Cambrian in the Farm Bureau No. 1 Binegar are siliceous argillite that ranges in color through tan, pink, and light gray to nearly black. This rock may also be termed siliceous shale, siliceous siltstone, or sandy chert. Except for relatively large angular grains of quartz and feldspar, clastic texture is not present; the rock is a mesh of tiny quartz grains clouded by inclusions, cryptocrystalline silica, chlorite, illite (?), sericite, hematite, and carbonaceous matter. Calcite occurs as veinlets, as euhedral authigenic crystals, as angular detrital grains, and as a minor constituent of the cement. A few rhombs of dolomite are present. Angular grains of clear quartz and oligoclase, Ab_{84}, range from 0.1 to 0.2 mm in diameter. A few of these grains have hacksaw terminations which Pettijohn (10, p. 491) believed due to intrastratal solution. Several quartz grains show secondary enlargement. Relic hornblende crystals are laths composed of chlorite, limonite, calcite, and magnetite. Zircon occurs as rounded detrital grains.

Most of the crystals are 0.01 mm or less in diameter, as shown in Plate 1A. This is in the lower range of silt size. The larger detrital grains indicate a clastic origin for the rock. The bulk of the rock probably formed either by chert replacement of an argillaceous sandy limestone, or by deposition of fine clastic material which was cemented by silica plus impurities and was partly recrystallized during diagenesis.

In the Farm Bureau Oil Company's Binegar well, the middle layer of several chips from the upper part of the pre-Cambrian is a mixture of tiny calcite and quartz grains. One side of the chips is siliceous argillite, and the other side is fine-grained marble. Either the two types of rock are interlaminated or interbedded, or the marble is only partly replaced by silica and the metasomatism has proceeded along bedding planes.

The lower 13 feet of argillite in the Farm Bureau No. 1 Binegar is sufficiently calcareous to effervesce vigorously in dilute hydrochloric acid. However, the effervescence is brief, and appreciable loss in volume does not result. The residue consists of angular light blue-gray fragments that resemble chert.

A few chips of similar siliceous argillite which occur in the cuttings from the Greentown well may be from a pebble in the quartzite, or may be from strata interbedded with the quartzite. These chips contain silicified relics of fossils (algae?), and much carbonaceous matter.

Quartzite.—Reddish-brown to yellow-brown quartzite occurs throughout the 100 feet (?) of pre-Cambrian cut by the Greentown drill hole. The coloration is due to stain by limonite and hematite. The rock resembles granite if seen as small chips under a binocular microscope. In thin sections relatively large grains of quartz and feldspar are seen to be separated and cemented by small, rounded quartz grains. Secondary enlargement of the large crystals has, in places, engulfed the smaller grains. Two grain sizes predominate; the smaller consists of rounded to subangular quartz grains 0.01 to 0.03 mm in diameter, and the larger consists of oval to elliptical grains of granite, quartz, alkaline feldspars, chert, and hornblende partly altered to chlorite and limonite, averaging 0.4 mm by 0.25 mm in size. Skeleton crystals of iron oxides and chlorite occur as irregular prisms about 0.3 mm in diameter. The cement is chiefly crypto-crystalline silica and iron oxides, but also includes minor amounts of sericite and chlorite. Laminae and a partial cement of calcite occur.

Parts of the quartzite are entirely fine-grained. The grains average 0.05 mm in diameter and are heavily stained by limonite. Several chips, 2 mm in diameter, are entirely massive quartz crystals, cloudy with inclusions, stained by limonite, and fractured. The inclusions are in subparallel lines not parallel to bedding planes. Feldspars are cloudy, and many grains are almost completely altered to sericite and clay. Most of the quartzite chips are 90 per cent or more quartz, but several contain about 30 per cent orthoclase and albite (?). The grains of cryptocrystalline silica (chert?) contain much disseminated magnetite and limonite and resemble some varieties of flint. A 20 foot section near the base of the Greentown well has been described (8, p. 353) as "Igneous intrusion, diabase." The samples now available do not contain diabase. A speckled appearance that might be mistaken for microdiabasic texture is produced by a mixture (average grain diameter 0.02 mm) of clean quartz and quartz stained by fibrous iron oxides.

Near the bottom of the Greentown well the quartzite contains rounded grains, 1 to 2 mm in diameter, of the hornblende micrographic granite, and of perthite, resembling thin sections illustrated by Pettijohn (10, Pl. 24C and 24D). One quartz crystal clearly shows secondary growth. An inner rounded core, 0.4 mm in diameter, is cloudy quartz, outlined by a band, 0.05 mm thick, of small, rounded and angular quartz mixed with sericite and limonite. The core and band are surrounded by an irregular rim, 0.1 mm thick, of clear quartz.

Slate.—A few small chips of greenish-gray slate were identified from the lower part of the Greentown well. The rock is hard but splits easily

along slaty cleavage into paper-thin flakes. In thin sections the slate is a felty mesh of chlorite, limonite, hematite, sericite, quartz, and clay minerals. Crystals are less than 0.01 mm in diameter except for irregular masses of hematite that are as much as 0.03 mm in diameter. Only a vague alignment of crystals was seen in the felty mesh.

Hornblende micrographic granite.—The granite is medium-grained, highly altered, hypidiomorphic-granular, and pink to the naked eye. Diameters average 1 to 5 mm. Most of the rock is a beautiful micrographic intergrowth of relatively clear quartz and highly altered feldspars (Pl. 1C); the feldspars are 75 per cent altered to kaolinite and sericite. Percentages from the Doddridge well are: quartz 33.3 per cent, orthoclase 43.3 per cent, microcline 10.4 per cent, albite 9.8 per cent, chlorite 1.5 per cent, and magnetite 1.7 per cent. This disregards the kaolinitization and sericitization. In this rock only skeleton crystals of the amphibole remain, altered to chlorite, chalcedony, and hematite. The deep weathering of the granite in the Doddridge well, which is altered for a depth of at least 400 feet, suggests that the alteration is due to hydrothermal solutions of the ore-bearing type or from a younger intrusion. Abundance of chlorite and sericite and lack of carbonates suggest hydrothermal solutions. Some of the chlorite even occurs as fibrous crystals along feldspar cleavages.

The granite from the May well is less altered, although the feldspars are mostly a felty mass of kaolinite and sericite. The quartz grains contain many tiny inclusions. Hornblende is pleochroic from aqua to greenish yellow-brown, with extinction at 22 degrees. The hornblende is altered to chlorite, iron oxides, magnetite, and chalcedony. Alteration begins along cleavages. Fibrous halos of chlorite form around pseudomorphs from hornblende. A few small crystals of fluorite, sphene, and zircon are present.

Augite andesite microporphyry.—The andesite occurs in the Tecumseh Oil and Gas No. 1 Gibson in Allen County. The rock is a felty mesh with ophitic texture of equigranular, colorless to pale green soda augite, laths of andesine, and scattered crystals of chlorite and iron oxides (Pl. 1D). The augite crystals average 1 mm x 1.5 mm in size and are partly altered to chlorite, iron oxides, and serpentine. Extinction from c to Z is as much as 70 degrees, which indicates aegirine-augite; the pale color of the crystals, however, is typical of augite rather than aegirine.

Andesine feldspar occurs in the groundmass as laths which average 0.16 mm to 0.04 mm in size. Phenocrysts of andesine average 0.3 mm by 0.7 mm in size and are mostly altered to clay minerals and some sericite. The small laths of andesine lose their form when altered. The andesine is Ab_{49}, which is very close to labradorite. Chlorite and antigorite (?) serpentine occur in flamboyant radial aggregates associated with cubes of magnetite and coatings of limonite and hematite. A few crystals of secondary quartz and calcite occur in the interstices. The andesite is cut by veinlets of calcite, cryptocrystalline silica, antigorite, and chlorite, bordered by rims of iron oxides.

The upper part of the andesite is greatly altered, probably due to weathering prior to deposition of the Cambrian strata. The weathered rock is heavily stained by iron oxides. Only a few relic cores of augite

remain surrounded by chlorite, hematite, and chalcedony. Banded fibrous veinlets and pods of chlorite occur with cores of red hematite. The ophitic texture is lost in a structureless mesh of secondary minerals.

Correlations

The nearest outcrops of pre-Cambrian rocks are in northern Michigan, Wisconsin, and Missouri. The pre-Cambrian rocks examined from six deep test wells in northern and western Illinois were described by Grogan (3). Granophyre (7) from the Eastern-Mumford drill hole in Pike County, Illinois, vaguely resembles the hornblende micrographic granite but lacks hornblende or any other primary mafic minerals. Several chips of the quartzite from the Greentown test well partly resemble the rhyolite porphyry from the Campbell test well in Pike County, Illinois, except that the clastic origin of the Greentown quartzite appears to be fairly certain. Secondary enlargement of quartz and feldspar crystals are common in the rhyolite porphyry in Missouri (11) but the groundmass of this rock has a felty texture in contrast to the clastic texture of the quartzite. That only igneous rocks were encountered in the six Illinois drill holes is surprising in view of the thick sections of metasedimentary rocks that crop out in Wisconsin, Minnesota, and Michigan (12, 4).

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