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STEWART L. UDALL, *Secretary*

GEOLOGICAL SURVEY

Thomas B. Nolan, *Director*

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Petrography of Some Sandstones and Shales of Paleozoic Age From Borings in Florida

By DOROTHY CARROLL

SHORTER CONTRIBUTIONS TO GENERAL GEOLOGY

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A description of thin sections of the rocks and of their heavy minerals

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PETROGRAPHY OF SOME SANDSTONES AND SHALES OF PALEOZOIC AGE FROM BORINGS IN FLORIDA

By Dorothy Carroll

ABSTRACT

Sandstones, orthoquartzites, and other arenaceous sediments and black and red shales occur in the basement rocks of Florida and adjacent parts of Georgia and Alabama. Most of the sandstones are Early Ordovician in age. The shales range in age from Middle Ordovician to Middle Devonian.

The quartzites range in mineralogic complexity from submature to mature. Feldspars are scarce. Micaceous and clayey sandstones can be classed as subgraywackes. Many of the quartzites grade into siltstones that are intercalated with shaly and micaceous layers. Such beds show disturbed bedding and penetration by worm borings. Many beds contain calcite and siderite. All the arenaceous sediments contain small amounts of heavy minerals. Three characteristic heavy-mineral assemblages were recognized. The kinds of minerals present indicate that these rocks are of granitic and metamorphic provenance, although rounding of the grains suggests that most of the rocks were derived finally from second- or third-cycle sediments.

The black shales contain abundant organic matter, pyrite, and, commonly, interlaminations of siderite and calcite. The color of the red shales is due to minute blebs of hematite in the micaceous matrix.

INTRODUCTION

Core samples and thin sections of sandstones and other arenaceous rocks in the Paleozoic strata in Florida and adjacent parts of Georgia and Alabama and of overlying red and black shales were made available for examination by Jean M. Berdan, U.S. Geological Survey. These rocks were penetrated by test wells for oil. The cores are largely from the pre-Mesozoic sedimentary rocks that are sparsely fossiliferous or nonfossiliferous. The fossils found indicate that the beds range in age from Early Ordovician to Middle Devonian.

The lithology of the sediments penetrated by the wells was described by Applin (1951), and a brief description of the mineralogy of a few samples was given by Carroll (1959a).

Applin (1951) summarized the records of 78 wells drilled into the pre-Mesozoic rocks. Since then additional wells have been drilled. Some of the earlier wells penetrated igneous rocks such as rhyolite and tuff. The dominant subsurface structural feature of north-central Florida and southeastern Georgia is a large anticlinal fold, or arch, about 275 miles long. Applin (1951) named this feature the Peninsular arch. Paleozoic rocks occupy an area of about 25,000 square miles in the Peninsular arch (Applin, 1951, p. 13). The distribution of these rocks is shown in figure 1.

Preliminary correlations of the sandstones and shales penetrated by the wells listed in table 1 were made by Bridge and Berdan (1952).

The purpose of this paper is to give petrographic descriptions and information on the heavy minerals in sandstones and shales penetrated by the wells. The work was started in 1954 at the request of Jean M. Berdan, U.S. Geological Survey. No correlations of beds have been made as a result of this work, although the heavy minerals present suggest that correlation may be possible if extensive examinations of the rocks are undertaken. The wells, however, do not penetrate very far into rocks of Paleozoic age. The wells from which samples were examined are shown on figure 2.

Table 1.—*List of wells in Florida and adjacent States from which rocks were examined*

[Core sample: × indicates cores examined. Thin sections: An asterisk indicates slides described in table 3. The numbers following the initials of the wells are the core numbers used by the companies drilling the wells, except for well 70, where the depth is given in feet below the land surface]

Well	Name and location	Core sample	Thin sections
23	Sun Oil Co. Henry N. Camp 1, sec. 16, T. 16 S., R. 23 E., Marion County, Fla.	×	*Cp-21, *Cp-22, Cp-23
30	Union Producing Co. E. P. Kirkland 1, sec. 20, T. 7 N., R. 11 W., Houston County, Ala.	×	*K-38, *K-39, *K-41, *K-46
36	Tidewater-Associated Oil Co. R. H. Cato 1, sec. 23, T. 8 S., R. 18 E., Alachua County, Fla.	×	*Ca-14
37	Tidewater-Associated Oil Co. Josie Parker 1, sec. 33, T. 7 S., R. 19 E., Alachua County, Fla.	×	*JP-31, *JP-37, *JP-38
38	Tidewater-Associated Oil Co. J. A. Phifer 1, sec. 24, T. 9 S., R. 21 E., Alachua County, Fla.	×	*P-29
39	Hunt Oil Co. H. L. Hunt 1, sec. 21, T. 1 N., R. 20 E., Baker County, Fla.	--------	*Hu-15
40	Tidewater-Associated Oil Co. M. F. Wiggins 1, sec. 15, T. 6 S., R. 20 E., Bradford County, Fla.	--------	*Wg-2
41	Humble Oil & Refining Co. Foremost Properties Corp. 1, sec. 4, T. 6 S., R. 25 E., Clay County, Fla.	×	*?F-43, FM-71, FM-78, *FM-169

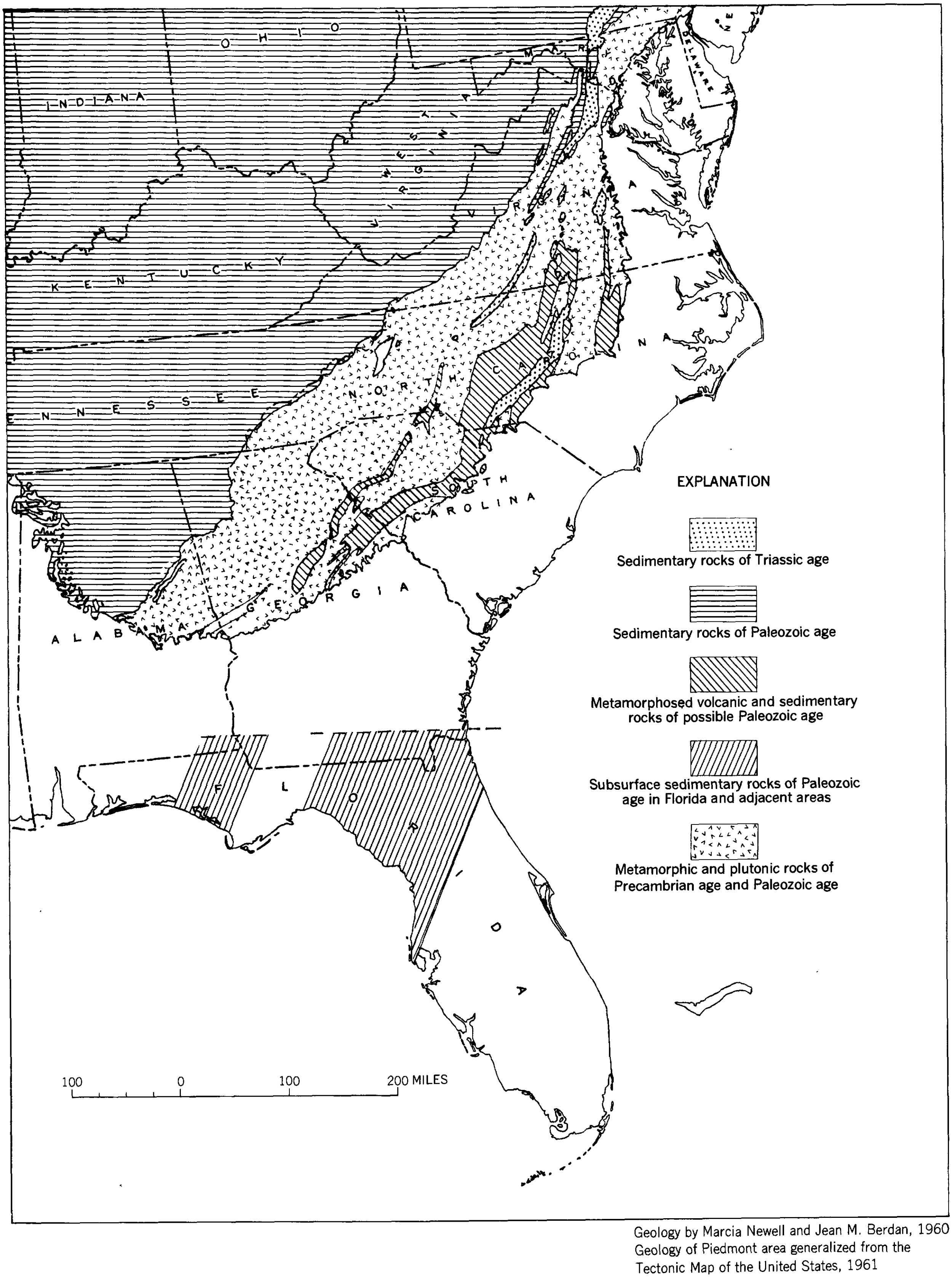

FIGURE 1.—Map of Southeastern United States showing known areal distribution of subsurface rocks of Paleozoic age in Florida and adjacent areas.

TABLE 1.—*List of wells in Florida and adjacent States from which rocks were examined*—Continued

Well	Name and location	Core sample	Thin sections
42	Humble Oil & Refining Co. J. P. Cone 1, sec. 22, T. 1 N., R. 17 E., Columbia County, Fla.	×	C–122, C–132, C–141, C–150, C–153, C–160
43	Sun Oil Co. Ruth M. Bishop 1, sec. 10, T. 4 S., R. 17 E., Columbia County, Fla.	×	*Bi–1
44	Sun Oil Co. W. F. Johnson 1, sec. 27, T. 4 S., R. 16 E., Columbia County, Fla.	--------	*J–29
45	Sun Oil Co. Clarence Loyd 1, sec. 11, T. 5 S., R. 17 E., Columbia County, Fla.	--------	*Lo–23
46	Sun Oil Co. M. W. Sapp 1A, sec. 24, T. 2 S., R. 16 E., Columbia County, Fla.	×	
47	Stanolind Oil & Gas Co. and Sun Oil Co. Perpetual Forest, Inc. 1, sec. 5, T. 11 S., R. 11 E., Dixie County, Fla.	×	*PF–69, *PF–75
49	Sun Oil Co. Hazel Langston 1, sec. 8, T. 8 S., R. 14 E., Dixie County, Fla.	×	*L–14
52	Ohio Oil Co. Hernasco Corp. 1, sec. 19, T. 23 S., R. 18 E., Hernando County, Fla.	×	*H–166, *H–167
57	Humble Oil & Refining Co. R. L. Henerson 1, sec. 20, T. 4. S., R. 11 E., Lafayette County, Fla.	--------	*He–152, *He–157, *He–162, *He–185
58	Sun Oil Co. P. C. Crapps 1, sec. 25, T. 6 S., R. 12 E., Lafayette County, Fla.	×	Cr–155 (Lower Cretaceous), *Cr–164–169, *Cr–180
59	Coastal Petroleum Co. J. B. and J. P. Ragland 1, sec. 16, T. 15 S., R. 13 E., Levy County, Fla.	×	
60	Humble Oil & Refining Co. C. E. Robinson 1, sec. 19, T. 16 S., R. 17 E., Levy County, Fla.	×	*R–61, R–74, R–76
62	Hunt Oil Co. J. W. Gibson 2, sec. 6, T. 1 S., R. 10 E., Madison County, Fla.	×	G2–2
63	Hunt Oil Co. J. W. Gibson 4, sec. 5, T. 2 S., R. 11, E., Madison County, Fla.	--------	*G4–7
66	Sun Oil Co. H. T. Parker 1, sec. 24, T. 14 S., R. 22 E., Marion County, Fla.	--------	*HP–17
68	Sun Oil Co. and Seaboard Oil Co. Q. I. Roberts 1A, sec. 19, T. 9 S., R. 25 E. Putnam County, Fla.	--------	*Ro–1
69	Sun Oil Co. Earl Odom 1, sec. 31, T. 5 S., R. 15 E., Suwannee County, Fla.	×	O–8, O–9
70	Sun Oil Co. A. B. Russell 1, sec. 8, T. 5 S., R. 15 E., Suwannee County, Fla.	--------	*Ru–3139
71	Sun Oil Co. J. H. Tillis 1, sec. 28, T. 2 S., R. 15 E., Suwannee County, Fla.	×	T–44
73	Mont Warren et al. A. C. Chandler 1, Lot 406, Land District 26, Early County, Ga.	×	Ch–5
74	Humble Oil & Refining Co. Bennett and Langsdale 1, Lot 146, Land District 12, Echols County, Ga.	--------	*BL–44
75	Hunt Oil Co. Superior Pine Products Co. 1, Lot 364, Land District 13, Echols County, Ga.	×	
76	Hunt Oil Co. Superior Pine Products Co. 2, Lot 317, Land District 13, Echols County, Ga.	×	*SPP2–5
101	Gulf Oil Co. Brooks-Scanlon, Inc., Block 37 1A sec. 18, T. 6 S., R. 9 E., Taylor County, Fla.	--------	*BS37
102	Gulf Oil Corp. Kie Vining 1, sec. 2, T. 4 S., R. 15 E., Columbia County, Fla.	×	
103	National Turpentine & Pulpwood Corp. Fee 1, sec. 7, T. 4 S., R. 19 E., Baker County, Fla.	×	NT–24, *NT–25

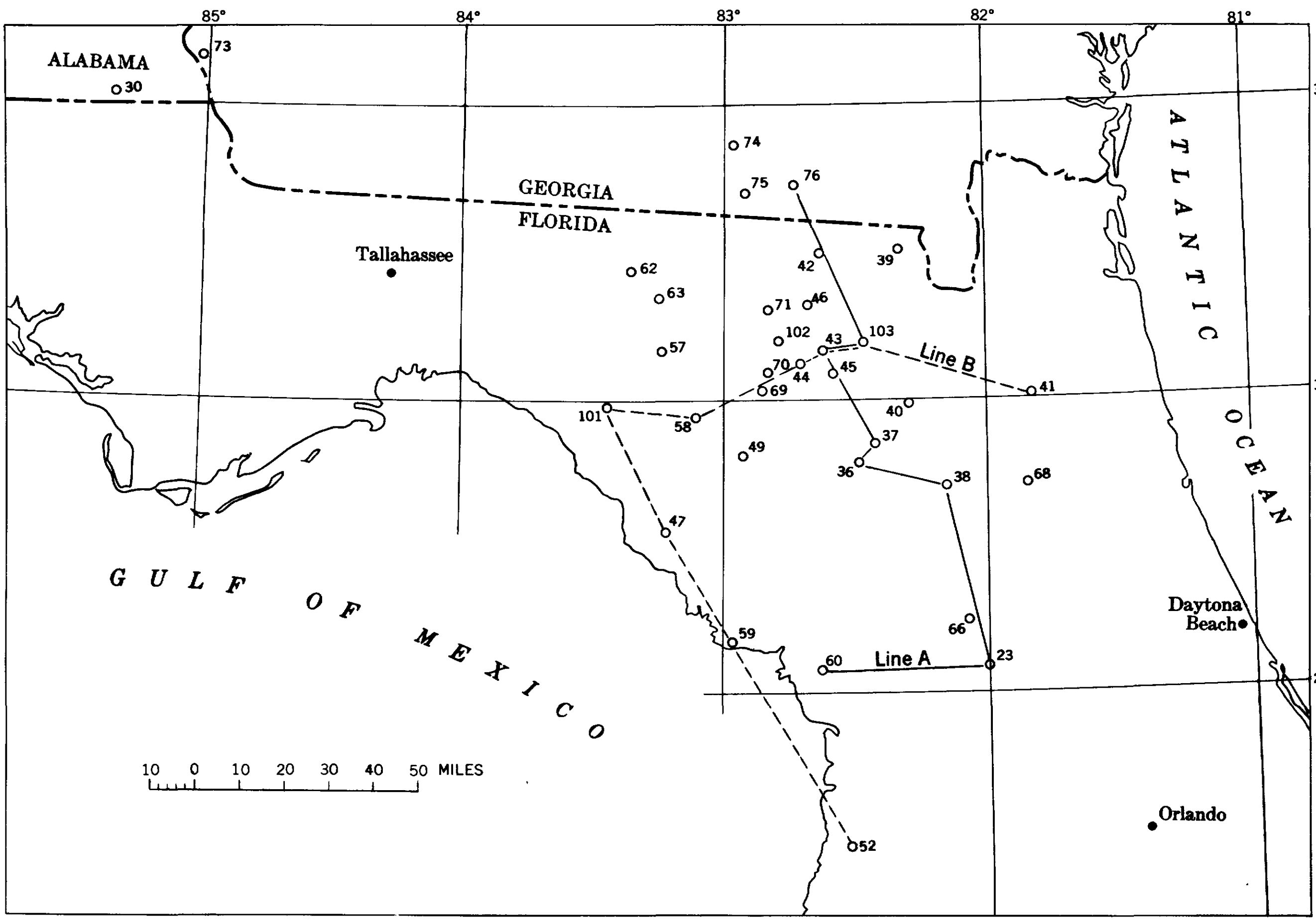

FIGURE 2.—Index map showing locations of wells in Florida, Georgia, and Alabama from which rocks were examined.

ACKNOWLEDGMENT

I am indebted to Jean M. Berdan, U.S. Geological Survey, for supplying the core samples used in this investigation, for many helpful discussions as the work progressed, and for many checks of the well data.

STRATIGRAPHY OF THE PALEOZOIC ROCKS

By Jean M. Berdan

The Paleozoic rocks underlying Florida and adjacent parts of Georgia and Alabama range in age from Early Ordovician to Middle Devonian. As none of the wells have penetrated strata with a succession of faunas, dating by means of direct superposition is not possible; nevertheless, an approximate sequence of beds can be inferred from the fossils. On this basis, the oldest unit is a series of quartzite and quartzitic sandstone interbedded with micaceous shales which commonly contain *Scolithus* burrows. This unit is about 1,800 feet thick and is dated as Early Ordovician on the basis of the graptolites present in one of the wells (No. 30). It is overlain by about 300 feet of white, tan, and pale-pinkish-red unfossiliferous quartzitic sandstone, which is also assumed to be Early Ordovician in age because of its stratigraphic position. About 1,200 feet of dark-gray to black shales, with minor thin sandstone beds, of Middle Ordovician to Late Silurian age presumably overlies the quartzite, although none of these shales have yet been found in contact with the quartzite. In one well (No. 74) about 65 feet of fine-grained sandstone and interbedded dark shale dated as Late Silurian by James M. Schopf (written communication, 1959) suggest a return to arenaceous sedimentation in Late Silurian times.

The unit of sandstone and interbedded shale represents the youngest Paleozoic rock yet found on the Peninsular arch. In western Florida and Georgia, however, near the junction of the boundaries of Georgia, Florida, and Alabama, two wells penetrated strata which are as young as Middle Devonian. One of these (well 53) penetrated 805 feet of gray and pale pinkish-red siltstones and fine-grained sandstones containing plant fragments, the other (well 73) penetrated 720 feet of dark-gray and brownish-red shale and gray fine-grained sandstone with a fauna of ostracodes and small pelecypods. Whether these two wells represent contemporaneous facies or whether one is slightly older than the other has not yet been determined.

All samples of arenaceous rocks described in this report are from Lower Ordovician units, except one sample (well 74) that is from an Upper Silurian unit. The shales, on the other hand, range in age from Middle Ordovician to Middle Devonian. Four wells penetrated red or brownish-red shales below which black shales were cored. Except at the site of one well (No. 3), where Middle Devonian strata were cored, the red shales of differing ages lie just below the pre-Mesozoic unconformity and are not interbedded with the underlying black shales. This has led some geologists to consider that the red color might be the result of weathering of the top of the Paleozoic rocks.

METHODS OF EXAMINATION

Many of the sandstones and shales were examined in thin section only, but sufficient sedimentary material was available from some samples to concentrate the heavy minerals.

Thin sections were used to identify the minerals, to compute the modal compositions of some sandstones and shales, and to measure grain sizes.

For heavy-mineral analysis the core samples were crushed to minus 60 mesh (0.25-mm grain diameter), weighed, and heated in 1 + 1 HCl to remove soluble material. The loss on acid treatment was recorded as soluble minerals, mostly calcareous. The insoluble residues were dried and weighed and then sieved through standard sieves to obtain a fraction, 0.12–0.06-mm grain diameter, that is suitable for microscopic examination. The heavy minerals in this fraction were separated by bromoform (sp gr 2.8). The heavy residue was weighed and expressed a percentage of the fraction separated. The minerals were identified optically, and the percentage of each mineral in a residue was estimated by partial grain count. Tourmaline grains, which are very resistant to weathering and abrasion, were examined more closely than other detrital grains, because they are present in nearly all the residues and therefore can yield information about history and possible sources of supply of sedimentary materials better than most other minerals. All the sandstones yielded small quantities of detrital minerals, but the shales yielded only negligible amounts. The clay minerals in the shales, but not in the sandstones, were identified by John C. Hathaway, U.S. Geological Survey, using the X-ray diffraction method.

SANDSTONES

Macroscopically the arenaceous rocks consist of fine silty sandstone interbedded with thin dark shale layers and laminations and of clean white orthoquartzites. Most of the sandstones are orthoquartzites that are nonfeldspathic or contain only a very small (about 1 percent) amount of feldspar. Some of the sandstone is more properly described as subgraywacke with angular quartz grains in a matrix of micaceous clay. Mica is commonly present on bedding planes; it has probably been reconstituted into larger grains by pressure of overlying sediments.

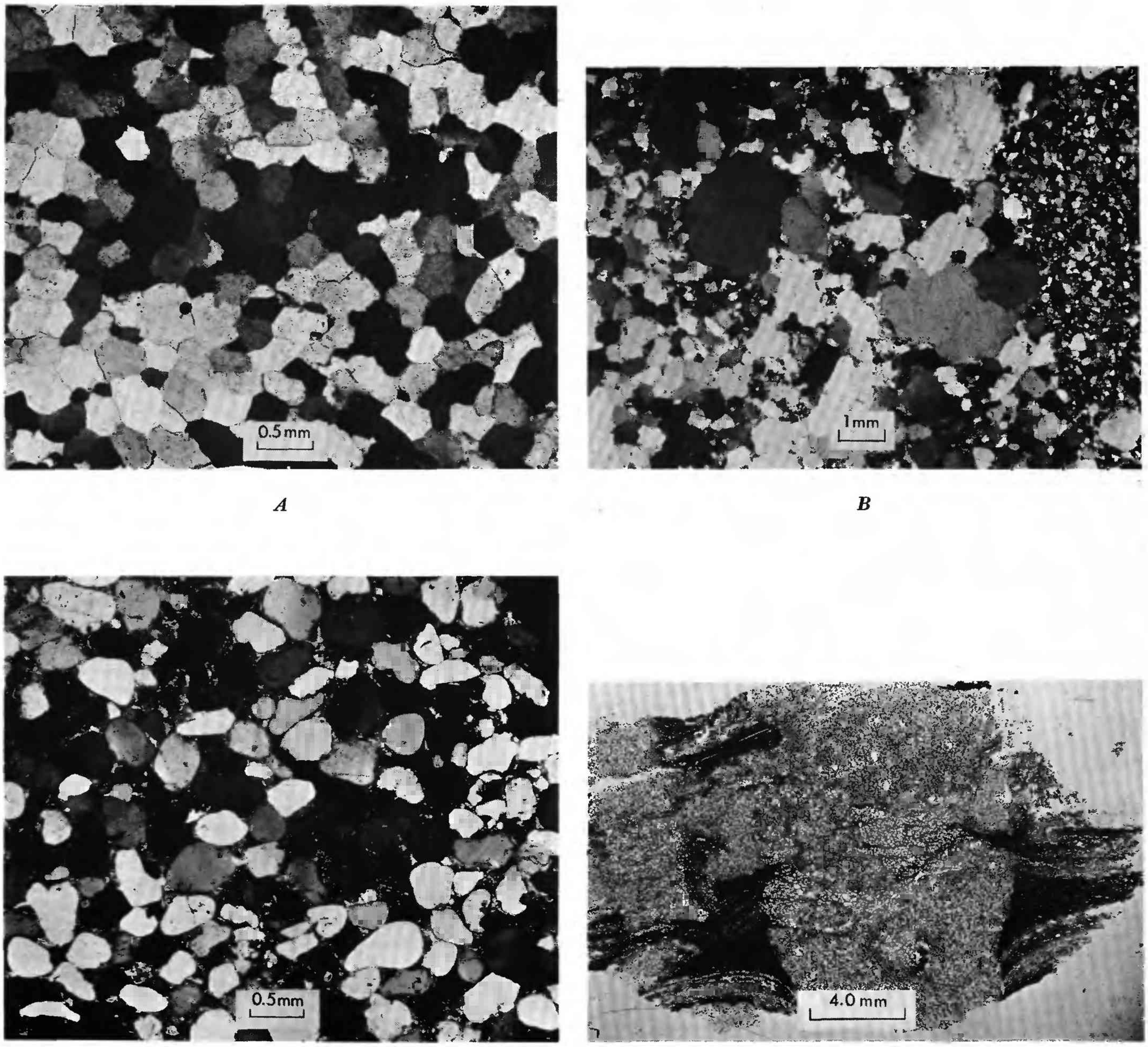

FIGURE 3.—Orthoquartzites and worm boring in silty sandstone.

A. Orthoquartzite, well 57 (Henderson 1). Depth below sea level, 4,180.5–4,181 feet. Compact quartzite with some overgrowths and no matrix. Average grain size, 210μ. Crossed nicols.

B. Orthoquartzite, well 52 (Hernasco Corp. 1). Depth below sea level, 8,183–8,185 feet. Modal composition: quartz grains 95 percent; siliceous matrix, 4 percent; and microcline, 1 percent. Uneven grained with some rounded grains of quartzite and some large strained quartz grains. The smaller grains are angular, and there are many sutured contacts. Average diameter of quartz, 360μ; average size of matrix, 80μ. Crossed nicols.

C. Orthoquartzite, well 37 (Josie Parker 1). Depth below sea level, 3,143–3,150 feet. Well-rounded quartz grains set in a cement of chalcedony. Modal composition: quartz, 73 percent; chalcedony, 27 percent. Average grain size of quartz is 210μ. Crossed nicols.

D. Cross section of worm boring, well 39 (Hunt 1). Depth below sea level, 3,342–3,343 feet. The tube filling consists of fine quartz and clay. The rock penetrated is fine sandstone with interbedded silty layers. Boring is about 10 mm in diameter. Plane polarized light.

677-291 O–63—2

The relation between the component mineral grains of the sandstones, as shown in thin section, is given in table 2. The rocks range from compact angular orthoquartzites to argillaceous sandstones. Quartz is the most abundant constitutent. The appearance in thin section of the different types of quartzite and micaceous sandstones or siltstones is shown in figures 3*A–D* and 4*A*, *B*. The grain size and modal composition are given in the explanations of the figures.

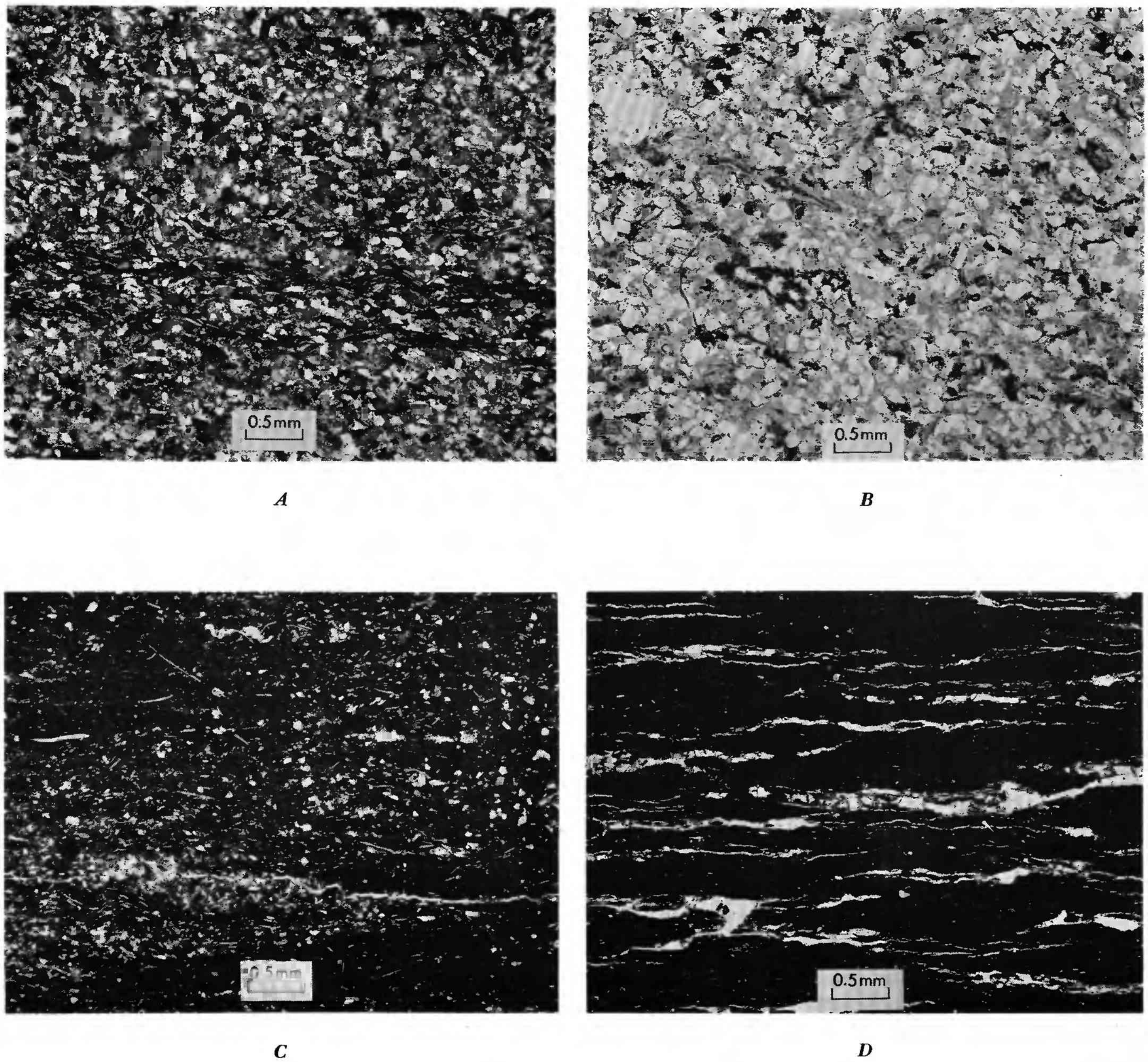

FIGURE 4.—Fine-grained micaceous and clayey sandstones; red and black shale.

TABLE 2.—*Descriptions of thin sections of arenaceous rocks*

[Criteria for describing sandstones and quartzites after Siever (1959)]

Clay: I, irregular filling; C, reconstituted.
Mica: D, detrital; C, reconstituted.
Carbonate: F, indefinite filling; X, well crystallized.
Pebbles: M, metaquartzite; V, vein quartz; Ch, chert.
Detrital outline of quartz grains: O, none; R, rounded and free; +, <10 percent; ++, >10 percent.
Detrital contact of quartz grains; O, no interpenetration; +, slight interpenetration; +++, sutured.
Secondary quartz, O, none; +, 10 percent pores filled; ++, 10–75 percent pores filled; +++, >75 percent; Cy, chalcedony.
Authigenic contacts of quartz grains: O, no interpenetration; +, sutured interpenetration.

Well	Depth of sample below sea level (feet)	Components of rock									Rock description
							Quartz grains				
		Slide	Clay	Mica	Carbonate	Pebbles	Detrital outline	Detrital contact quartz	Secondary	Authigenic contact	
30	7,772	K-38	I	C	---	---	+	++	+	+	Compact angular quartzite with very little cement.
30	7,891	K-39	I	C	---	---	O	+++	O	+	Compact angular quartzite with sutured contacts.
30	7,897–7,907	K-41	---	C	F	---	++	+	+	---	Fine-grained calcareous, micaceous quartzite (fig. 4A).
30	8,078	K-46	I	C	F	---	++	+	O	O	Fine-grained calcareous silty quartzite.
23	4,500–4,510	Cp-22	---	C	F	V	+	++	+, Cy	+	Coarse-grained quartzite.
23	4,371–4,378	Cp-21	---	C	F	V	+	+++	+, Cy	+	Feldspathic quartzite with microcline and other feldspars.
36	3,140–3,150	Ca-14	---	D, C	---	---	++	O	O	O	Micaceous quartzite with recrystallized mica.
37	2,972–2,982	JP-31	---	---	F	---	R	O	++, Cy	O	Quartzite with well-rounded grains cemented with chalcedony and carbonate (fig. 3C).
37	3,032–3,035	JP-37	---	C	---	---	++	+	Cy	+	Uneven grained closely packed quartzite, slightly feldspathic.
37	3,035–3,042	JP-38	I	D	---	---	++	O	O	O	Fine-grained graywacke.
38	3,093–3,095	P-29	---	C	---	---	+	++	++	+	Quartzite with well-rounded closely packed grains.
39	3,212–3,213	Hu-15	---	D,C	F	---	R	O	O	O	Fine-grained calcareous shaly sandstone with worm boring (fig. 3D).
40	3,152–3,154	Wg-2	I	C	F, X	---	++	+	O	+	Clayey to micaceous, calcareous quartzite.
41	4,928–4,931	FM-43	---	---	---	---	---	---	---	---	Shale with chert inclusions.
	4,938–4,941	FM-169	I	C	---	---	++	+	O	O	Quartzite with schistose shaly inclusions.
43	2,649–2,654	Bi-1	I	---	---	---	++	+	O	O	Fine-grained quartzite with well-rounded to subangular grains.
44	2,947–2,948.5	J-29	---	---	---	M	+	+++	+	+	Fine-grained quartzite of second cycle material.
45	2,923.5–2,928	Lo-23	---	C	---	---	++	+	O	O	Quartzite with rounded to subangular small grains.
47	5,310–5,317	PF-69	---	C	---	---	+	+++	O	O	Fine-grained feldspathic quartzite; broken quartz at some grain boundaries.
47	6,242–6,244	PF-75(1)	---	[1] C	---	---	++	++	O	O	Micaceous, feldspathic quartzite; patchy composition.
47	6,242–6,244	PF-75(2)	I	---	---	M	++	++	O	O	Clayey feldspathic quartzite.
49	3,668–3,671	L-14	---	C	---	---	++	++	+	+	Uneven grained quartzite, closely packed, with a matrix of chalcedony and mica.
52	8,121–8,125	H-167	I	C	---	---	+	++	+,Cy	O	Coarse-grained quartzite with clayey micaceous matrix.
52	8,136–8,138	H-166	I	C	---	M	O	+++	+,Cy	O	Coarse, uneven-grained feldspathic quartzite; strained quartz (fig. 3B).
57	4,180.5–4,181	He-152	---	---	---	---	+	+	++	O	Quartzite, closely packed; rounded grains with regrowths (fig. 3A).
57	4,187–4,189	He-157	---	C	---	---	+	+	+	O	Fine-grained closely packed quartzite.
57	4,198–4,203	He-162	---	C	---	---	++	O	O	O	Fine silty sandstone.
57	4,213–4,213.5	He-185	---	---	---	M	+	++	++	---	Closely packed quartzite with secondary silica.
58	4,129–[2] 4,133	Cr-180	---	C	F	---	++	O	O	O	Fine-grained silty quartzite interbedded with shale.
58	3,926–3,955	Cr	I	C	---	---	++	O	O	+	Angular to subangular quartzite with shale inclusions.

See footnotes at end of table.

EXPLANATION OF FIGURE 4

A. Fine-grained micaceous, calcareous quartzite, well 30, (Kirkland 1). Depth below sea level, 7,897–7,907 feet. Modal composition: quartz, 50 percent; matrix, 32 percent; and mica, 18 percent. The quartz is angular and subangular and is surrounded by a micaceous matrix. Quartz grains average 44μ, and the matrix patches average 48μ across. The micaceous bands are 115μ wide. A little calcite is present as a packing around the quartz grains. Crossed nicols.

B. Clayey micaceous quartzite, well 66 (H. T. Parker 1). Depth below sea level, 3,836–3,845 feet. Modal composition: quartz, 69 percent; matrix, 27 percent; and mica, 4 percent. The matrix is poorly crystallized mica that has apparently formed authigenically from original clay. Laths of mica have formed under pressure and in some parts of the section laminae of mica occur. Average grain size, quartz, 87μ, matrix, 76μ. Plane polarized light.

C. Red shale, well 75 (Superior Pine Products 1). Depth below sea level, 3,828–3,833 feet. A somewhat schistose shale with rather coarse, angular quartz and recrystallized mica. The red coloring is due to finely divided iron oxide, probably hematite. Some of this oxide is submicroscopic in size, but larger distinct rounded blebs may be oxidizing pyrite. Crossed nichols.

D. Black shale, well 42 (Cone 1). Depth below sea level, 3,562–3,587 feet. Shale consists of very fine grained angular quartz and carbonaceous matter interlaminated with well-crystallized siderite and minor calcite. The siderite is slightly oxidized in places so that reddish-brown rims occur at the edges of the laminae. The clay material occurs as very fine micaceous laths and as indefinite aggregates that exhibit aggregate polarization. A little carbonate also occurs as minute irregular patches in the clay matrix. Plane polarized light.

TABLE 2.—*Descriptions of thin sections of arenaceous rocks*—Continued

Well	Depth of sample below sea level (feet)	Components of rock									Rock description
		Slide	Clay	Mica	Carbonate	Pebbles	Quartz grains				
							Detrital outline	Detrital contact quartz	Secondary	Authigenic contact	
60	4,439–4,456	R-74	I	C			++	O	+	O	Quartzite with clayey matrix; grades into shale.
63	3,994–3,996	G-47		C			++	+	+	O	Quartzite with well-rounded closely packed grains.
66	3,757–3,766	HP-17	I	C			++	++	O	+	Micaceous quartzite (fig. 4*B*).
66	3,757–3,766	do.[3]	I	C			++	O	O	O	Micaceous, feldspathic quartzite.
68	3,118–3,120	Ro-1		C		M	+	++	+,Cy	+	Coarse-grained quartzite, partly recrystallized.
70	3,043	Ru					++	++	+		Closely packed uneven grained quartzite with iron oxide films.
74	4,178–4,179	BL-44		D			++	O	O	O	Quartzite with shale inclusions; quartz grains in a micaceous matrix.
76	3,845–3,850	SPP2-5	I	C			++	O	O	O	Argillaceous quartzite.
101	4,780	BS-37					+	+++	O	O	Tightly packed even-grained quartzite.
103	2,885–2,890	NT-1					+	+++	Cy	O	Quartzite with subangular to rounded grains.

[1] Probably chlorite.
[2] Bottom.
[3] 6th 20 feet.

The coarser quartzite has quartz grains 200μ to 360μ in diameter. In the finer grained or silty sandstones, the quartz grains range in diameter from 45μ to 85μ. Feldspar, where present, is microcline but is very scarce.

Most of the coarser grained quartzites are compact, with the grains packed together tightly. Many typical quartzites contain grains of metaquartzite, as well as those of vein quartz, and quartz of unknown origin. Some quartzites have no matrix (fig. 3*A*), whereas others contain chalcedony and scattered carbonate as cement. Figure 3*C* shows chalcedony as a cement in orthoquartzite, in which the chalcedony amounts to nearly 30 percent of the rock by volume. Some quartzites have well-rounded grains, but others, such as that shown in figure 3*A*, have grains with sutured contacts that indicate considerable pressure from overlying beds. Well-rounded quartz grains occur in some of the quartzites (fig. 3*C*).

The finer grained clayey micaceous sandstones are shown in figure 4*A*, *B*. In the sandstone in figure 4*A*, the clayey matrix has been somewhat reconstituted to mica, and some degree of orientation is apparent from the alinement of mica flakes into thin layers. A sandstone with angular to subangular quartz grains in a clayey matrix is shown in figure 4*B*. The matrix has not been reconstituted, although in a few places some rather well crystallized mica laths can be seen.

A thin section through a typical worm boring is shown in figure 4*D*. The material in the tube consists of clay and fine-grained quartz that differ in grain size and appearance from the interlaminated shale and silt beds that were penetrated.

The carbonate, where present, occurs as very fine grains in rims around some quartz grains and in a filling between the grains. The percentage of carbonate present in these rocks is indicated by the figures for loss-on-acid treatment given in table 3. The amount ranges from 0 to more than 40 percent. Most of the sandstones examined contain about 20 percent of calcareous material, probably largely siderite. The oxidation of the siderite accounts for the light-tan to pinkish-brown color of many of the sandstones.

SHALES

The samples of red and black shales examined are given in table 3, and a thin section of each type is shown in figure 4*C*, *D*.

The loss-on-acid treatment in the black shales ranges from less than 1 to 13 percent. Some of this loss is due to the presence of siderite and calcite, and some to the solution of iron compounds. In the red shales the loss ranges from 3 to 17 percent and is largely due to the removal of iron oxides. Data are given in table 3.

The red shales are seen in thin section (fig. 4*C*) to consist of a fine micaceous clayey paste in which are embedded silt-sized angular quartz grains. Much of the mica is recrystallized into small laths. The red color is due to finely divided iron oxide, probably hematite. Some of this iron oxide is extremely fine, but elsewhere in the section distinctly rounded blebs may be oxidizing pyrite.

The black shale in thin section (fig. 4*D*) ranges in lithologic character from rather dense black shale with abundant organic matter to black micaceous shale. In many thin sections siderite and calcite occur as well-crystallized layers. The siderite may be oxidized in places at the outside edges of the layers. The organic matter is black and opaque. Clay is present as extremely fine micaceous laths and as indefinite aggregates exhibiting aggregate polarization. X-ray examination by John C. Hathaway, U.S. Geological Survey, of material less than 2μ in grain diameter from 15 samples of black shale and from 3 samples of red shale showed that both kaolinite and hydrous mica (illite) are present in almost equal proportions.

TABLE 3.—*Petrographic and mineralogic data on samples from wells penetrating Paleozoic sedimentary rocks in Florida and adjacent States*

[Well data from Applin, 1951]

Well	Surface elevation (feet)	Depth to top of Paleozoic rocks (feet)	Depth of samples (feet)	Rock	Loss-on-acid treatment (percent)	Heavy residue[1] (percent)	Heavy minerals in 0.12–0.06 mm grade (approximate percent)																
							Opaques	Pyrite	Tourmaline	Zircon	Rutile	Epidote	Chloritoid	Garnet	Sphene	Glaucophane	Anatase	Barite	Corundum	Hypersthene	Amphibole	Mica [2]	Others
42	141	3,482	4,196–4,206	Black shale	5.3	Tr.	----	+	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----
			4,281–4,300	do	8.2	Tr.	----	+	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----
			4,320–4,330	do	4.3	Tr.	----	+	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----
			4,337–4,347	do	5.8	Tr.	----	+	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----
			4,347–4,354	do	5.8	Tr.	+	+	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----
			3,485–3,487.5	Red shale	3.0	0.26	+	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----
46	138	3,303	3,306–3,311	Black shale [3]	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----
59	14	5,810	5,791.5–5,796.5	Red shale	17	2.8	+	----	----	----	----	----	----	----	----	----	----	----	----	----	----	+	----
			5,840–5,850	Black shale	15	Tr.	----	+	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----
62	107	4,626	5,154–5,162	do	11.2	Tr.	----	+	----	+	----	+	+	----	----	----	----	----	----	----	----	+	+
69	73	3,040	3,060–3,080	do	9.3	1.9	+	+	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----
			3,152–3,157	do	10.2	1.5	+	+	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----
71	162	3,500	3,494–3,502	Red shale	8.1	.1	+	+	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----
			3,552–3,568	do	8.6	.6	----	+	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----
73	187	6,950	6,636–6,643	do	7.0	Tr.	+	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----
			7,001–7,042	Black shale	11.2	Tr.	+	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----
75	148	3,782	3,828–3,833	do	.3	.4	----	+	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----
102	117	3,338	3,450–3,470	do.[4]	133.0	Tr.	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----
23	74	4,240	4,445–4,452	Quartzite	nil	.2	35	----	4	55	----	1	----	----	+	----	----	----	----	----	----	----	----
30	140	7,556	7,856–7,897	Sandstone, shale	16	.2	15	65	10	7	3	----	----	----	----	----	----	----	----	----	----	----	----
			7,948–7,949	Quartzite	25	Tr.	20	----	40	5	7	----	4	20	1	3	----	----	----	----	----	----	----
			7,983–7,995	Black shale	55	Tr.	+	90	3	3	2	----	----	2	----	----	----	----	----	----	----	----	----
			8,024–8,046	Sandstone	33	Tr.	10	80	3	4	----	----	----	3	----	----	----	----	----	----	----	----	----
			8,069–8,100	Sandy shale	34	Tr.	45	----	5	5	2	3	----	40	----	----	----	----	----	----	----	----	----
36	112	3,135	3,130–3,137	Silty sandstone	30	.1	+	40	5	40	5	----	+	5	----	----	+	----	----	----	----	----	----
37	168	3,170	3,203–3,210	Sandstone	27	Tr.	10	2	3	----	----	----	----	85	----	----	----	----	----	----	----	----	----
38	132	3,127	3,223–3,225	Quartzite	4	.2	5	45	20	20	3	----	----	----	----	----	2	----	----	----	----	----	----
41	115	3,725	3,753–3,754	Sandstone	41	.1	10	----	25	50	10	3	2	----	----	----	----	----	----	----	----	----	----
			3,760–3,761	do	21	.2	10	----	25	50	10	----	----	----	----	----	5	----	----	----	----	----	----
			4,076–4,077	do	14	.1	15	----	20	50	5	----	----	5	----	----	5	----	----	----	----	----	----
			4,528–4,530	do	26	.1	5	----	20	35	10	----	----	5	----	----	----	25	----	----	----	----	----
			4,746–4,751	Shale	22	.5	20	----	15	10	5	----	+	50	----	----	----	----	+	----	----	----	----
			4,938–4,941	do	29	.1	10	----	20	15	10	----	+	40	----	----	5	----	----	----	----	----	----
			5,051–5,061	do	28	.3	5	+	15	15	5	----	+	50	----	----	----	----	----	----	----	----	----
			5,242–5,252	Sandstone	23	.6	5	----	15	15	5	----	+	60	----	----	----	----	----	----	----	----	----
			5,653–5,663	do	26	.9	10	----	5	5	5	20	----	50	----	----	----	----	----	----	----	----	----
			5,720–5,725	Shale	32	1.1	10	----	5	2	3	50	----	50	----	----	----	----	----	----	----	----	----
			5,778–5,783	Shaly sandstone	28	.9	10	----	5	2	5	50	----	30	----	----	----	----	----	----	----	----	----
			5,859–5,862	do	37	.7	10	----	----	5	5	25	----	50	----	----	----	----	----	----	----	----	----
43	174	2,813	2,824	Shale	9	.2	20	----	55	23	2	----	----	----	----	----	----	----	----	----	----	----	----
47	33	5,228	5,415–5,420	Sandstone, shale	51	1.0	10	----	----	2	----	40	----	48	----	----	----	----	----	----	----	----	----
			6,275–6,282	Sandstone	18	2.0	10	----	----	2	----	40	----	48	----	----	----	----	----	----	----	----	----
			6,275–6,382	do	18	2.9	20	----	----	2	----	35	----	42	----	----	----	----	----	----	----	----	----
58	70	3,923	3,996–4,025	Silty sandstone	25	.2	42	8	20	2	2	----	2	22	----	----	----	----	----	----	----	----	----
			4,127–4,133	do	23	.1	30	----	20	4	1	----	----	45	----	----	----	----	----	----	----	----	----
52	47	7,220	8,468–8,472	Sandstone	8	.4	18	2	15	50	----	----	----	----	----	----	14	----	----	1	----	----	----
60	58	4,377	4,384–4,391	Quartzite	30	Tr.	10	----	3	2	10	----	----	75	----	----	----	----	----	----	----	----	----
			4,393–4,401	Quartzite and shale	22	1.0	10	80	3	4	3	----	----	----	----	----	----	----	----	----	----	----	----
			4,482–4.505	Quartzite	33	.2	40	50	4	3	----	----	----	3	----	----	----	----	----	----	----	----	----
			4,506–4,530	Silty sandstone	16	Tr.	10	----	35	53	2	----	----	----	----	----	----	----	----	----	----	----	----
			4,564–4,575	Sandstone	15	.1	10	----	40	48	2	----	----	----	----	----	----	+	----	----	----	----	----
76	142	3,770	3,845–3,850	Fine sandstone	19	.6	10	----	3	3	3	18	2	60	----	----	----	----	----	----	----	----	----
101	67	4,809	4,874–4,876	Quartzite	13	Tr.	10	----	40	45	5	----	----	----	----	----	----	----	----	----	----	----	----
103	155	2,884	3,039–3,040	Fine sandstone	Nil	Tr.	20	----	35	35	10	----	----	+	----	----	----	----	----	----	+	----	----
			3,040–3,043	do	Nil	Tr.	15	----	35	40	10	----	----	----	----	----	+	----	----	----	----	----	----

[1] Heavy residue separated in bromoform; Tr., <0.1 percent; +, one or two grains only in the residue;
[2] Mica in heavy residue only, most mica is in light fraction.
[3] Loss on acid treatment, heavy residue, and heavy minerals not determined.
[4] Heavy minerals not determined.

HEAVY MINERALS

The amount of heavy residues from sandstones and shales and the minerals identified in them are given in table 3. Most of the shales contain only pyrite and iron oxides in their heavy residues, but the black shale from well 62 (J. W. Gibson 2) contains detrital minerals similar to those in the sandstones.

The amounts of heavy residues in the 0.12- to 0.06-mm grade ranged from less than 0.1 to 2.9 percent in the sandstones and quartzites. The minerals identified are: the opaque minerals ilmenite, leucoxene, and pyrite; tourmaline; zircon; rutile; epidote; zoisite; garnet; glaucophane; hypersthene; amphibole; mica; sphene; corundum; chloritoid; anatase; and barite. Mica is very abundant in many of the fine silty sandstones and on bedding planes, but because of its flaky nature most of it remains in the light fraction.

The three following assemblages, or suites, of heavy minerals could be recognized in the residues: (A) Ilmenite, zircon, tourmaline, rutile; (B) garnet, epidote, ilmenite; and (C) ilmenite, garnet, tourmaline, glaucophane, chloritoid.

Fine- to coarse-grained quartzites and quartzites with little mica or clay contain minerals of assemblage A. Fine silty sandstones and sandy shales contain minerals of assemblage B or C. The mineral grains of assemblage A are well rounded, but those of B and C are subangular.

The heavy minerals in these quartzites and other arenaceous rocks do not in themselves have any very striking characteristics. The most abundant minerals (table 3) are ilmenite, zircon, tourmaline, garnet, and epidote. The remaining minerals are present in very small amounts only. Ilmenite, zircon, and tourmaline grains are well rounded in most of the residues. Both ilmenite and leucoxene grains have a polished appearance in reflected light. Figure 5 shows the appearance of typical heavy residues.

INDIVIDUAL MINERALS

Zircon grains have varietal features that may be of use in tracing their provenance when more is known of the detrital grains in the Paleozoic rocks of the Appalachian region. The zircon in most of the residues is colorless, contains few inclusions, and is well rounded. In some residues, however, the colorless zircon is accompanied by a few grains of purple zircon, in the proportion of about 50 to 1. This proportion is similar to that described for the sandy beds of the Conococheague Limestone (Upper Cambrian) in Virginia (Carroll, 1959b, p. 133).

Several different types of tourmaline grains can be distinguished by their shapes and colors. Brown rounded grains are the most common. Brown tourmaline is the granitic type described by Krynine (1946, p. 68). Some blue pegmatitic tourmaline is present in many of the residues. Typical tourmaline grains are shown in figure 5*A*, *B*. Two of these grains have overgrowths such as are formed authigenically on

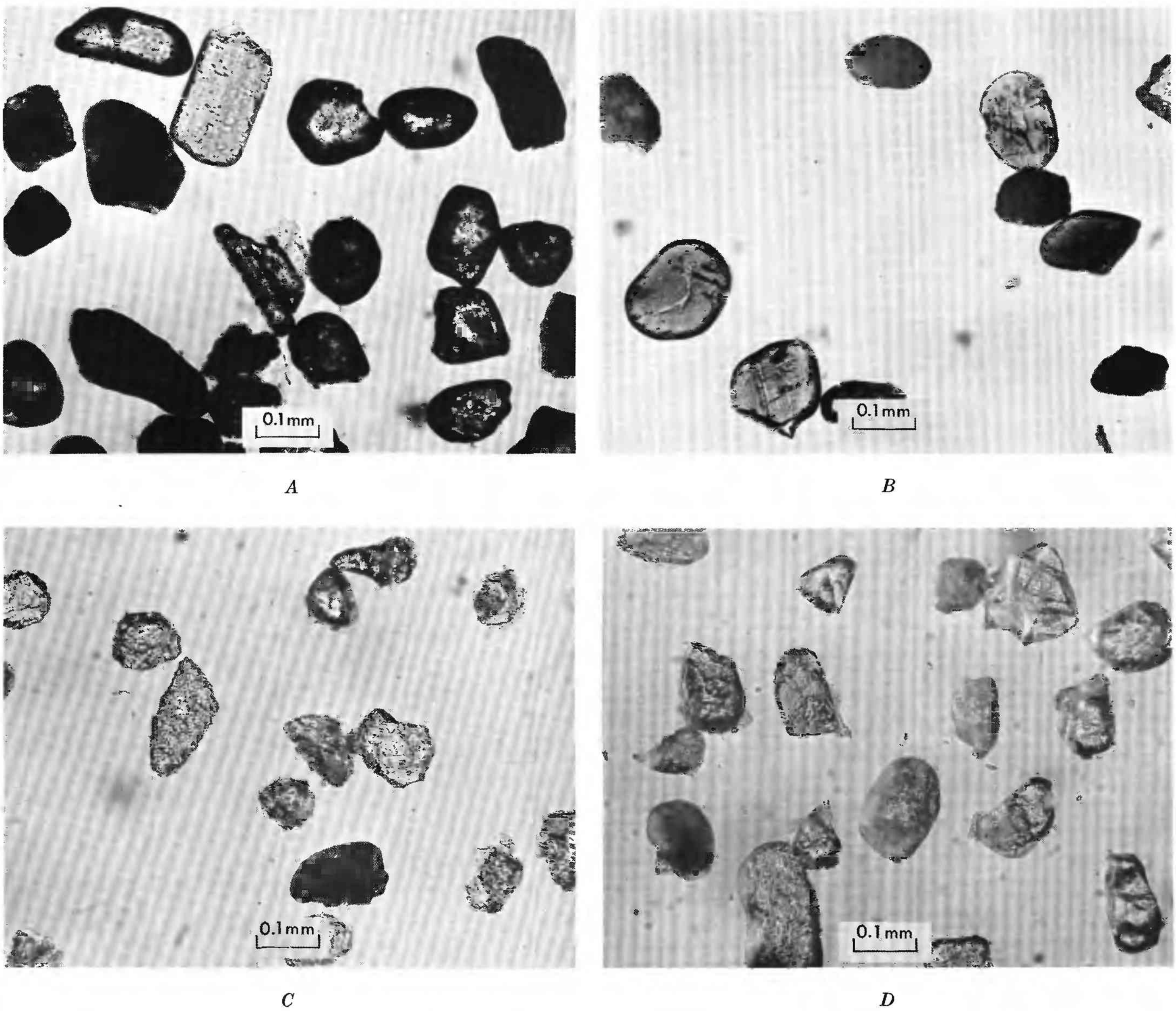

FIGURE 5.—Heavy minerals separated from sandstones and shale.

tourmaline in arenaceous rocks of the Appalachian geosyncline and elsewhere. Such overgrowths are apparently an epigenetic feature caused by leaching and alteration within the rock in which the grains occur (Nicholas, 1956; Carroll, 1959b).

The shapes of the tourmaline grains were classified as angular, subangular, and well rounded. The percentages of each type of grain in each residue were obtained from counts and are given in table 4. Table 4 indicates that the percentage of well-rounded tourmaline ranges from 0 to 60 percent. There does not seem to be any readily recognizable relation between the type of mineral assemblage and the percentage of well-rounded tourmaline that it contains. Table 3 shows that the amount of tourmaline in these residues varies considerably, however, and this is one basis for the distinction of assemblage A.

Rutile generally occurs as well-worn dark-reddish-brown grains. It apparently belongs in the same category as the rounded zircon and tourmaline and was contributed by a source rock or rocks containing all three minerals.

Epidote and zoisite (fig. 5*D*) are found with garnet of assemblage B. Both epidote and zoisite grains show the effects of abrasion. Their presence indicates a contribution from crystalline rocks.

Garnet (fig. 5*C*) occurs as sharp angular grains that have etched surfaces. These surfaces were probably produced by solution within the sediments in which the garnet occurs. Most of the garnet is colorless, but pale-pink grains are present in some residues. The amount of garnet ranges from 20 to 85 percent in assemblage B and is commonly about 40 percent (table 3).

Chloritoid, glaucophane, hypersthene, and amphibole are minor constituents of assemblage C. Their scarceness suggests that much of these minerals were removed during transportation or that their source area is far off.

Anatase occurs sparsely as authigenic crystals that have probably formed from the titanium released during the decomposition of ilmenite within the sediments.

Sphene and corundum were identified in a few of the heavy residues but do not amount to more than a grain or two in any one of them.

TABLE 4.—*Distribution of tourmaline shapes in heavy-mineral assemblages from sandstones in the Paleozoic rocks of Florida*

Well	Depth of sample below sea level (feet)	Rock type	Mineralogic assemblage [1]	Tourmaline in heavy residue (percent)	Percent of total tourmaline		
					Angular	Subangular	Well rounded
Samples from north-south subsurface traverse [Line A, fig. 2]							
75	3,657–3,662	Fine sandstone.	B	3	58	27	17
103	2,884–2,885	do	A	35	20	30	50
	2,885–2,888	do	A	35	20	25	55
43	2,650	Shale	A	55	5	35	60
37	3,035–3,042	Sandstone	C	2	----	75	25
36	3,018–3,025	Silty sandstone.	C	5	21	53	25
38	3,091–3,093	Quartzite	A	20	28	42	30
23	4,376–4,383	do	A	4	100	----	----
60	4,326–4,331	do	C	2	52	34	14
	4,355–4,343	Quartzite and shale.	A	3	34	42	24
	4,424–4,447	Quartzite	C	4	32	55	13
	4,448–4,472	Silty snadstone.	A	35	44	28	28
	4,506–4,517	Sandstone	A	40	40	37	23
Samples from west-east subsurface traverse [Line B, fig. 2]							
101	4,807–4,809	Quartzite	A	40	8	42	50
58	3,955–3,984	Silty sandstone.	C	20	62	30	8
	4,086–4,092	do	C	20	52	26	22
43	2,650	Shale	A	55	5	35	60
103	2,884–2,885	Fine sandstone.	A	35	20	30	50
	2,885–2,888	do	A	35	20	24	56
41	3,638–3,639	Sandstone	A	25	42	28	30
	3,645–3,646	do	A	25	25	47	27
	3,961–3,962	do	C	20	32	33	35
	4,413–4,415	do	C	20	62	30	8
	4,631–4,643	Shale	C	15	59	34	7
	4,823–4,826	do	C	20	39	31	30
	4,936–4,946	do	C	15	43	35	22
	5,127–5,137	Sandstone	C	15	56	38	6
	5,538–5,548	do	B	5	46	47	7
	5,605–5,610	Shale	B	5	32	43	25
	5,663–5,668	Shaly sandstone.	B	5	52	24	24
	5,744–5,747	do	B	5	54	31	15
47	5,352–5,387	Sandstone, shale.	B	1	P	----	----
	6,242–6,249	Sandstone, calcareous	B	1	P	----	----
	6,242–6,249	Sandstone, noncalcareous.	B	1	P	----	----
52	8,421–8,425	Sandstone	A	15	85	13	2

[1] Assemblage A: Ilmenite, zircon, tourmaline, and rutile. Assemblage B: Garnet, epidote, and ilmenite. Assemblage C: Ilmenite, garnet, tourmaline, glaucophane and chloritoid.

Barite was found in the residue of a sandstone from a depth of 4,528 to 4,530 feet in well 41 (Foremost Properties Corp. 1). It apparently was present as a cement in this sandstone.

EXPLANATION OF FIGURE 5

A. Silty sandstone, well 60 (Robinson 1). Depth below sea level, 4,448–4,472 feet. Well-rounded zircon, subangular tourmaline, and rounded rutile. Ordinary light.

B. Noncalcareous black silty shale, well 43 (Ruth M. Bishop 1). Depth below sea level, 2,650 feet. Well-rounded tourmaline, zircon, and leucoxene. Ordinary light.

C. Fine-grained quartzite, well 60 (Robinson 1). Depth below sea level, 4,326–4,331 feet. Etched garnet and well-rounded zircon and rutile. Ordinary light.

D. Shaly, micaceous sandstone with worm borings, well 41 (Foremost Properties 1). Depth below sea level, 5,663–5,668 feet. Worn epidote, angular garnet, rounded zircon, tourmaline, and rutile. Ordinary light.

Mica is present in many of the rocks examined. It occurs as minute flakes in the shales and as a fine-grained matrix in micaceous and clayey sandstones. Apparently some of the mica has formed authigenically from micaceous clay minerals originally present. The mica occurs in flakes larger than those in most of the matrices and seems to be in the first stage of low-grade metamorphism produced by pressure of overlying rocks. In the oldest unit, which consists of a series of quarzites and sandstones interbedded with micaceous shales, mica commonly occurs as large colorless rather soft and brittle flakes on the bedding planes of the silty and immature sandstones. X-ray examination (Carroll, 1961) shows that these flakes consist of a mechanical mixture of muscovite, hydrous mica, chlorite, and possibly some dioctahedral vermiculite. For the most crystalline mica the index of refraction for γ is 1.59–1.60, and for various flakes 2V=23°–37°. Probably the mica was originally derived from a granitic or pegmatitic source area and was floated gently in shallow water and then deposited on top of the sandy beds at times when no other detritus was being moved. The large composite flakes have been produced from originally much smaller flakes by compression of overlying rocks.

MINERAL ASSEMBLAGES

The three types of mineral assemblages—A, B, and C—present in these sediments suggest that it may be possible to use them for the correlation of one bed with another in this rather uniform series of arenaceous rocks. The stratigraphic position and distribution of A, B, and C in the various wells were found and related to the known top of the Paleozoic strata. In figure 6 the wells with the heavy-mineral assemblages are arranged in an approximately north-south distribution across the Peninsular arch (line A, fig. 2), and in figure 7 they are arranged in an approximately east-west distribution (line B, fig. 2). The position of the surface of the Paleozoic strata is shown as a dashed line in figures 6 and 7. The samples that have been described nearly all come from within a few feet of this surface. It can be seen that assemblage A is almost always just below the top of the Paleozoic strata.

Well 41 (Foremost Properties Corp. 1) in Clay County, Fla., probably penetrated almost all the Lower Ordovician section. The composition of the individual heavy residues of the fraction 0.12 to 0.06 mm and the distribution of assemblages A, B, and C in this well are shown in figure 8.

DISCUSSION

Potter and Glass (1958) pointed out that siltstone-shale laminations in the Pennsylvanian sedimentary rocks of southern Illinois are very similar to those found on modern tidal flats, such as the Wadden Sea in the Netherlands and the Texas gulf coast. Many of the fine-grained interlaminated micaceous siltstone and shale beds with borings in the Paleozoic rocks of Florida

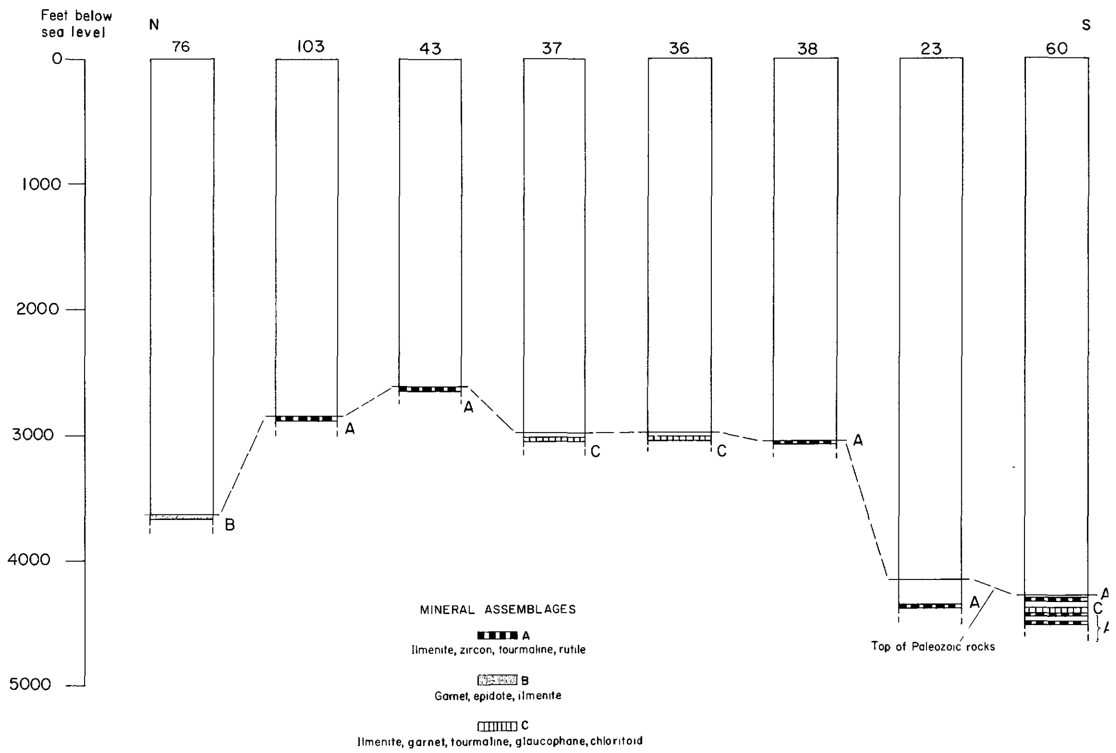

FIGURE 6.—Heavy-mineral assemblages in sandstones from wells in an approximate north-south traverse of the Peninsular arch (line A, fig.2).

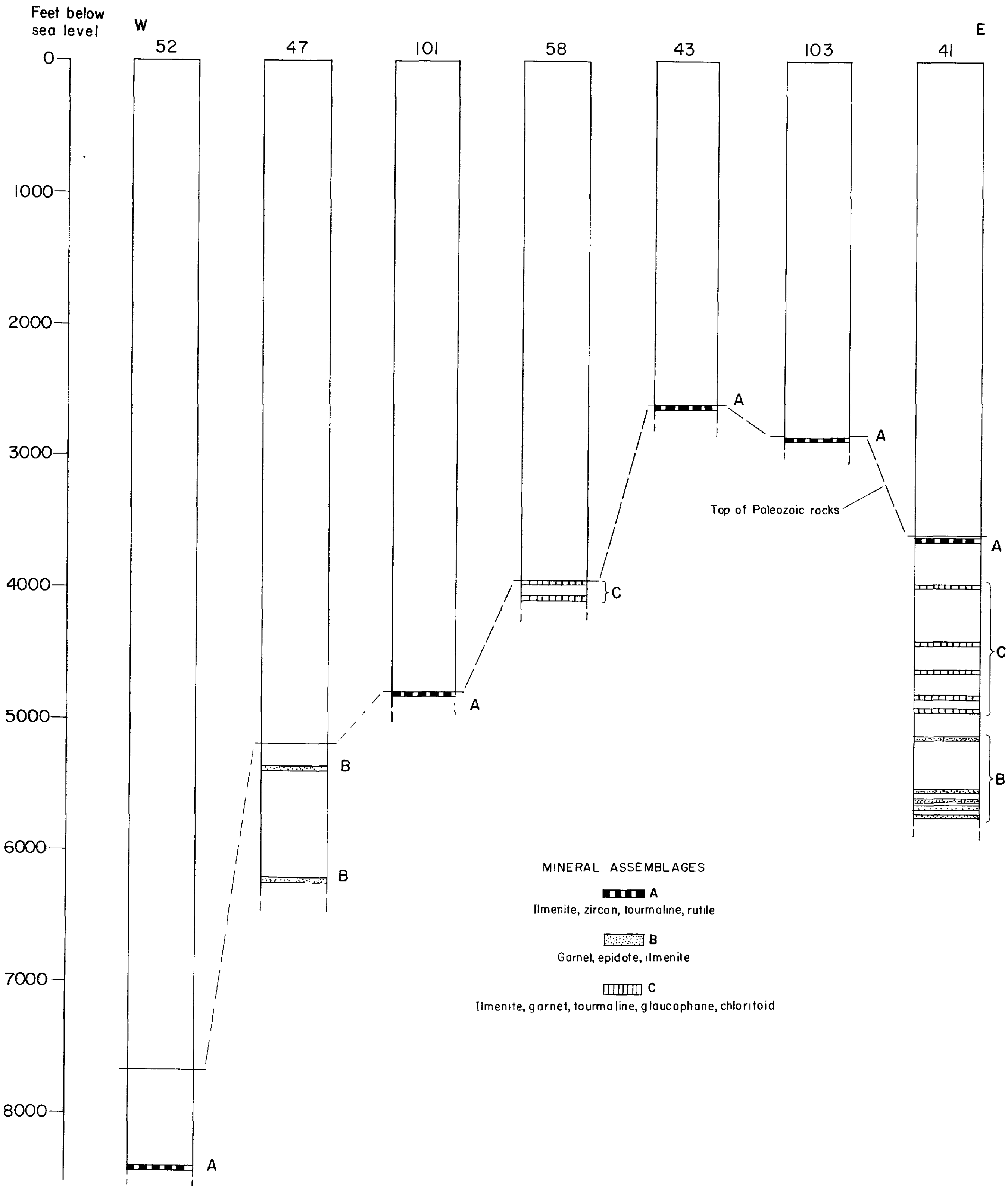

FIGURE 7.—Heavy-mineral assemblages in sandstones from wells in an approximate west-east traverse of the Peninsular arch (line B, fig. 2).

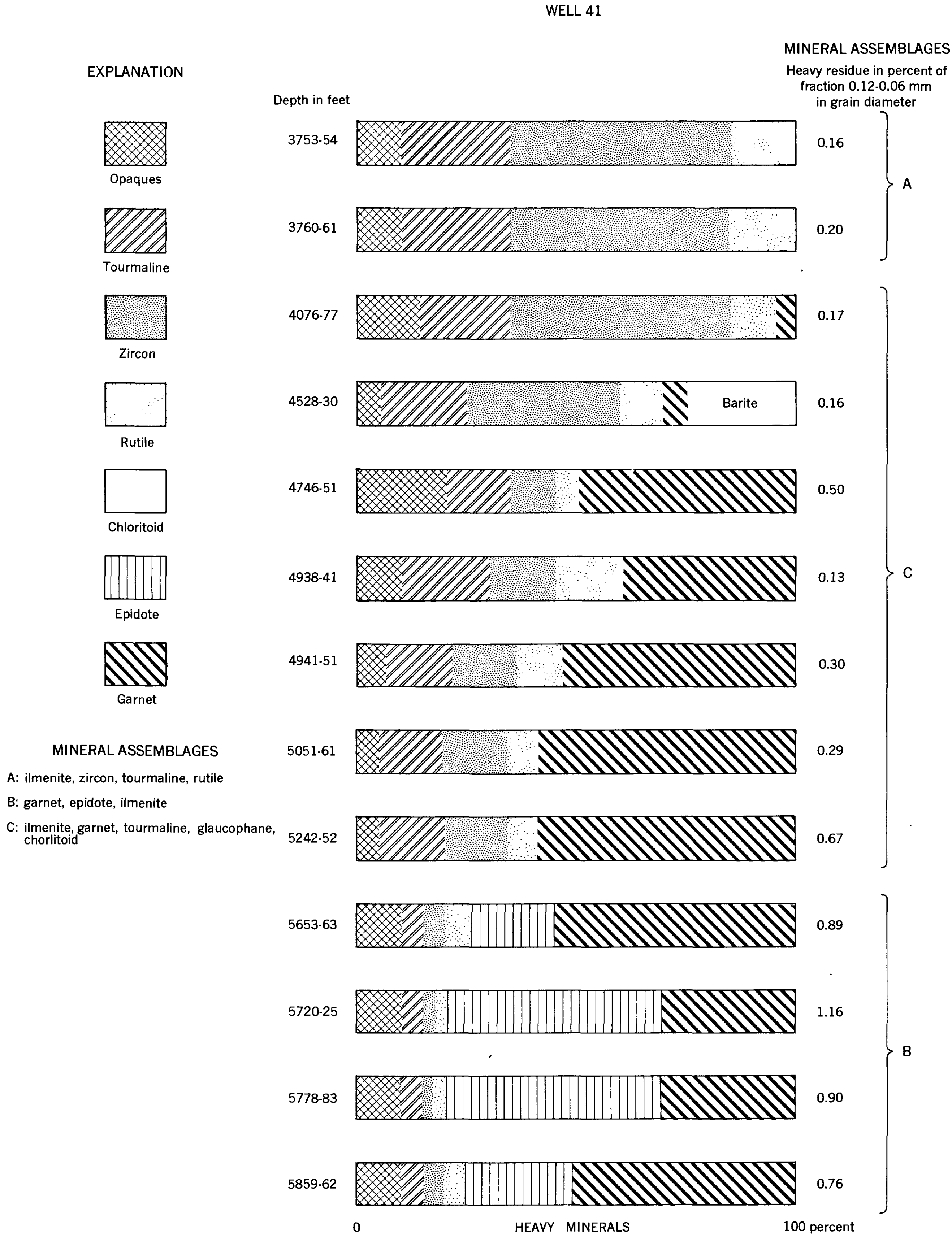

FIGURE 8.—Details of the heavy-mineral assemblages in the sandstones in well 41 (Foremost Properties Corp. 1).

probably had a similar origin; that is, they are of shallow-water marine origin.

The heavy-mineral assemblages in the quartzites and other rocks are very simple, but they are present over rather wide areas. This fact indicates similarity of distributive province (Milner, 1952, p. 432), transportation, and deposition. Such features are not uncommon in arenaceous sediments in the United States. Krynine (1946) drew attention to the persistence over large areas of the suites of heavy minerals that are characteristic of certain formations, notably the suites of the Gatesburg Formation (Upper Cambrian), the Bellefonte Dolomite (Lower Ordovician), and the Tuscarora Quartzite (Lower Silurian). Nicholas (1956) showed that the heavy minerals in the sandy beds of the Conococheague Limestone (Upper Cambrian) are similar over a wide area. The Ocoee Series (Precambrian) in Tennessee maintains its mineralogical identity for many miles (Carroll and others, 1957). Such heavy-mineral assemblages, or suites, could perhaps be used to correlate certain beds and to determine provenance of the minerals. For example, erosion of the Conococheague Limestone could have provided the rounded zircon and tourmaline in the rocks of Early Ordovician age in Florida, but it is unlikely that the Ocoee Series was a contributor.

The question of the similarity or difference of the red shales to the underlying black shales has not been completely resolved. The red shales seem to contain a greater quantity of fine mineral detritus than the black shales which have abundant organic matter and pyrite. Oxidation by weathering of pyrite and siderite in the black shales, however, could produce a reddish brown color. The clay minerals in both types of shale are similar. Grim (1951, p. 231) pointed out that red coloration indicates the absence of appreciable organic matter, and hence, an oxidizing environment. Such sediments retain their original color and mineralogy. It is possible that the red shales in this sequence were deposited in a reducing environment that was gradually changing to an oxidizing environment. The presence of siderite in the black shales indicates that the Eh was 0 to -0.2 v at the pH of sea water (7.6–8.3) (Krumbein and Garrels, 1952, p. 15). Pyrite is also present, and for it to remain stable the Eh would have to be -0.2 to -0.4 v. The presence of abundant organic matter maintains this Eh range. Pyrite is not stable in the same environment as hematite (Eh, 0 to $+0.2$ v). Hence, the depositional environment of the red shales was different from that of the black shales. The red shales probably represent rapid accumulation of sediment in an oxidizing environment with little or no organic matter.

SUMMARY

Petrographic descriptions are given for 17 black and 3 red shales and for 40 quartzites from the upper part of the Paleozoic strata penetrated by wells in Florida and adjacent parts of Georgia and Alabama. The rocks were selected from the very large number of available core samples and are probably representative of the principal types present. Many of the rocks are calcareous orthoquartzites, but some could be classed as subgraywackes. They were probably deposited in shallow water. The heavy minerals, separated from the quartzites and other rocks, have been identified. Three distinct mineral assemblages were found that could be used to correlate different beds in the sequence. The minerals indicate sources in sedimentary and metamorphic rocks.

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