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NEW SEDIMENTOLOGIC AND PALEONTOLOGIC DATA FOR THE DOW CHEMICAL #1 B. L. GARRIGAN DRILL HOLE, MISSISSIPPI COUNTY, ARKANSAS

by

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This report is preliminary and has not been reviewed for conformity with U.S. Geological Survey editorial standards and stratigraphic nomenclature.

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INTRODUCTION

The New Madrid region in southeast Missouri was struck by three major earthquakes of estimated magnitudes greater than 8.0 on the Richter scale during the winter of 1811-12 (Johnston and Kanter, 1990). Collectively know as the New Madrid earthquakes, these seismic events affected about one million square miles of the eastern United States (Fuller, 1912). A relatively high level of seismicity continues to extend from northeastern Arkansas through southeastern Missouri and into northwestern Tennessee--an area known as the New Madrid Seismic Zone (Stauder, 1982). Seismic activity in the New Madrid Seismic Zone is associated with structural highs--the Blytheville arch and Pascola arch--in the Reelfoot graben (Hildenbrand and others, 1977; Hildenbrand, 1985; Hamilton and McKeown, 1988). The Reelfoot graben developed by rifting in the late Proterozoic and early Paleozoic (Ervin and McGinnis, 1975; Schwalb, 1982). This report seeks to clarify lower Paleozoic stratigraphic correlations in the Reelfoot rift basin and help facilitate understanding of the geologic framework of the New Madrid Seismic Zone.

This report contains new insoluble residue data from the Dow Chemical #1 B. L. Garrigan (hereafter, Garrigan) drill hole; new trilobite, conodont, and inarticulate brachiopod data from the Garrigan and Dow Chemical Wilson #1 (hereafter, Wilson) drill holes; and a discussion of some implications of these data to the stratigraphic and tectonic history of the Reelfoot basin. Comparison of the Garrigan and Wilson is useful because the Wilson is within the Reelfoot basin but is not affected by the structural influence of the Blytheville arch. The stratigraphy of the Blytheville arch has been poorly understood because the rocks are known only from well cuttings and a minimum amount of core recovered from the Garrigan. This report presents the first biostratigraphic correlations of lower Paleozoic rocks of the Garrigan drill hole.

The Garrigan drill hole is located on the Blytheville arch, within the Reelfoot rift basin, in the NW 1/4, NW 1/4, Sec. 28, T. 15 N., R. 10 E., Mississippi County, Arkansas (Fig. 1). Drilling was completed April 11, 1982, from a ground elevation of 239 ft to a total depth of 12,038 ft.

PREVIOUS STUDIES

According to Houseknecht (1989), the oldest sedimentary rocks filling the Reelfoot basin are Cambrian in age and include the following units: the Reelfoot Arkose (age uncertain; Palmer, 1989), the St. Francis Formation (Middle Cambrian?), Lamotte Sandstone (upper Middle to lower Upper Cambrian), the Bonneterre Formation (lower to middle Upper Cambrian), and the Elvins Group (middle Upper Cambrian).

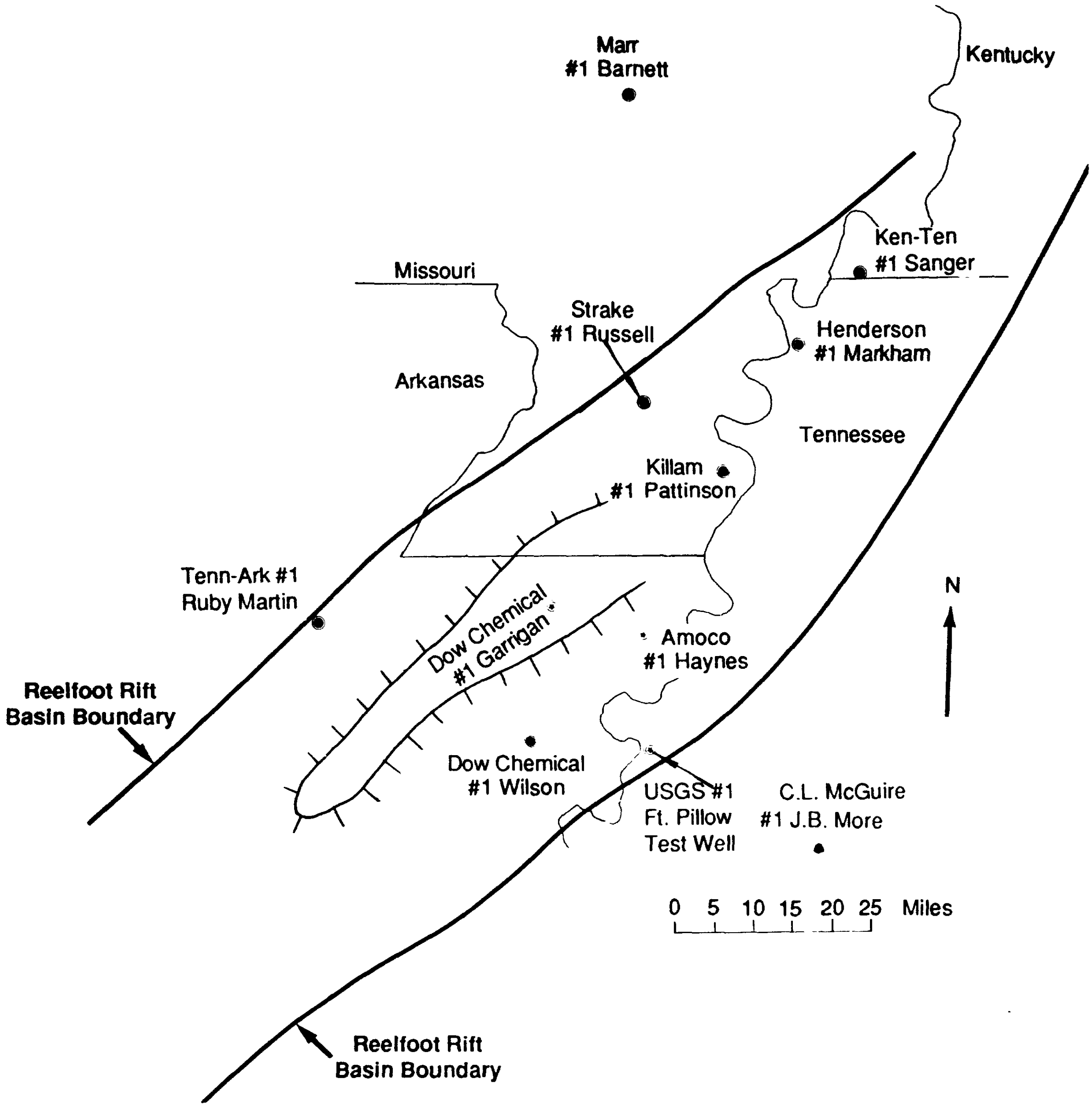

Figure 1. Map of part of the Reelfoot rift basin showing location of drill holes discussed in text. Heavy lines show boundaries of Reelfoot rift basin and single hatch lines outline Blytheville arch. Modified from McKeown and others (1990, fig. 1).

Pre-Bonneterre Rocks

The Reelfoot Arkose of Houseknecht (1989) is only known within the Reelfoot basin. It consists of medium- to coarse-grained, locally conglomeratic, feldspathic sandstone in the north that grades to shale in the south. The St. Francis Formation, which overlies the Reelfoot Arkose, consists of predominantly sandstone in the northern part of the Reelfoot basin and is inferred to grade laterally to carbonates in the southern part of the basin. The Lamotte Sandstone, overlying the St. Francis Formation, is dark-gray quartzose sandstone in the northern part of the basin and grades to shale in the southern part of the basin (Houseknecht, 1989). On the southeastern part of the eastern Missouri platform, the upper contact of the Lamotte Sandstone is gradational with the overlying Bonneterre Formation (Grohskopf, 1955, p. 14).

Bonneterre Formation

On the eastern Missouri platform adjacent to the Reelfoot basin, the Bonneterre Formation is divided from bottom to top into three members: An unnamed lower member, the Sullivan Siltstone Member, and the Whetstone Creek Member (Kurtz, 1989). The unnamed lower member is divided into two informal units: 1) the lower unit is composed of basinal shale, lower-ramp shale, and upper ramp to shoalwater mudstone-wackestone ribbon rock that indicates a shallowing upward sequence; and 2) the overlying unit composed of glauconitic, skeletal to oolitic wackestone-packstone-grainstone of upper-ramp origin (Kurtz, 1989). The Sullivan Siltstone Member consists of laminated calcareous siltstone, local bioturbated intraclast conglomerate, and minor amounts of glauconite. The Whetstone Creek Member overlies the Sullivan Siltstone Member and consists of moderately glauconitic, interbedded mudstone, wackestone, and grainstone (Kurtz, 1989).

In the Reelfoot basin, Houseknecht (1989) identified and described the Bonneterre Formation as a predominantly carbonate unit in the northern part of the basin and marine shale in the southern part of the basin. Grohskopf (1955) observed that near the Missouri Bootheel, the Bonneterre Formation is a calcareous, carbonaceous black shale with oolitic and arenaceous white limestone in the lower part.

Elvins Group

The Upper Cambrian Elvins Group overlies the lower and middle Upper Cambrian Bonneterre Formation and underlies the upper Upper Cambrian Potosi Dolostone (Grohskopf, 1955; Howe and others, 1972; Palmer, 1989). The Elvins is divided into the Davis Formation and Derby-Doerun Formation. On the eastern Missouri platform, the Davis Formation consists of dark-green to dark-gray and locally black shales (Kurtz and others, 1975; Palmer, 1989). Near the town of Lead, in southern Missouri, the shales of the Davis abruptly change laterally to shoal-water ooid-skeletal packstone and grainstone (Kurtz, 1989).

In south-central Missouri, the Derby and Doerun lithic units of Buckley (1909) are widely recognized as a single formation called the Derby-Doerun Formation (for example, Howe and others, 1972). On the southern Missouri part of the eastern Missouri platform, the Derby-Doerun Formation is divided into informal upper and lower units. The lower unit is comprised of finely crystalline, locally bioturbated dolostone with interbedded stromatolites, calcarenite, and brown shale. The upper unit is similar to the lower, but contains planar and digitate stromatolites, calcarenite, thickly bedded oolite, thin shale partings, dickite-filled vugs, and dolomoldic chert (Kurtz and others, 1975).

In southern Missouri, the lower Derby-Doerun Formation is dolostone that contains thin, irregularly bedded, shaley, and fine- to medium-crystalline dolostone, with quartz sand, silt, and glauconite (Howe and others, 1972, p. 33). Rocks in the upper unit are predominantly massive, oolitic dolostone (Howe and others, 1972, p. 33).

The Elvins Group, where recognized within the Reelfoot basin, has been characterized as being composed of limestone and dolostone (Grohskopf, 1955; Kurtz, 1989). However, in eastern Missouri, the lower part of the Elvins Group (Davis Formation) is shale near the Reelfoot basin margin (Kurtz, 1989; Palmer, 1989).

Insoluble residues from the Elvins Group and Bonneterre Formation were used by McQueen (1931), Grohskopf and McCracken (1949), Grohskopf (1955), and Kurtz and others (1975) to differentiate between members of the Elvins Group and Bonneterre Formation. Criteria developed by Grohskopf (1955) and Kurtz and others (1975) for making this differentiation are summarized in Figure 2A.

Stratigraphy of the Garrigan Drill Hole

Grohskopf (1955) described the subsurface stratigraphy and correlated Paleozoic rocks in the northern part of the Reelfoot basin of southeastern Missouri. Kurtz (1989) described and correlated the Upper Cambrian rocks in platform areas of the southern and eastern parts of Missouri. Howe and Thompson (1984), Houseknecht (1989), Palmer (1989), and McKeown and others (1990) described and assigned ages to lower Paleozoic rocks of the Reelfoot basin and vicinity. In the absence of biostratigraphic data, age interpretations have been highly variable and many authors have been inconsistent in applying formation boundary picks. For example, Howe (1984; personal communication to DSC, 1990; also see Howe and Thompson, 1984) originally logged the Garrigan samples and determined that shale, siltstone, and sandstone are the dominant rock types in the Garrigan drill hole (Fig. 3). In contrast, McKeown and others (1990) observed that shale dominates the upper part whereas dolostone is dominant in the lower part of the Garrigan drill hole (Fig. 4A). The dolostone reported in the Garrigan by McKeown and others (1990, fig. 4) was not confirmed by our petrographic studies. Placement of the Elvins Group and Bonneterre Formation contact differs between the published studies. J. R. Howe (personal communication to DSC, 1990; Fig. 3) concluded that the Bonneterre Formation is not present in the Garrigan drill hole because carbonate rocks characteristic of the Bonneterre Formation are absent. However, McKeown and others (1990; Fig. 4A) indicate that carbonate rocks they consider characteristic of the Bonneterre Formation are present in the Garrigan. They interpreted a thin oolitic limestone at 8,830 ft as the top of the Bonneterre Formation (F. A. McKeown, written communication to DSC, 1990). Similarly, some geologists have selected different boundary positions of the Elvins Group/Bonneterre Formation within the Wilson drill hole (Dart, 1990, p. 11).

The predominantly limestone and dolostone of the Elvins Group and the Bonneterre Formation represent shallow-water deposits formed on the eastern Missouri platform adjacent to the Reelfoot basin. The most detailed descriptions of these rocks are from shallow-water platform sites in the mining districts of southeastern Missouri (Bain, 1905; Buckley, 1909; McQueen, 1931; Wood 1938; Snyder and others, 1965).

The confusion in distinguishing between the Bonneterre Formation and Elvins Group in the Reelfoot basin has resulted from attempts to extend the lithostratigraphic nomenclature developed for shallow-water facies of the eastern Missouri platform to rocks of deepwater facies and different lithic characteristics within some parts of the Reelfoot basin, especially in the Blytheville arch (for example Palmer, 1989; McKeown and others, 1990). The problem has been compounded by the scarcity or absence of biostratigraphic data and difficulty in tracing lithic units between drill holes.

METHODS OF STUDY

Insoluble residue analysis was made of cuttings and core samples from the Garrigan drill hole in an attempt to identify the Upper Cambrian Elvins Group and Bonneterre Formation, information that is important for developing an understanding of the stratigraphic and tectonic history of the Reelfoot basin and adjacent areas. In addition, cuttings and core samples were examined for fossils that might aid understanding of age and facies relations in the basin. Results of the insoluble residue analysis are given in Table 1.

Down-hole contamination limits interpretations of the Garrigan rocks. Because the majority of samples are on-site "grab-samples" of well cuttings, contamination at lower (deeper) sample intervals by sloughing from above may be expected. For instance, R. L. Dart (written communication to DSC, 1990) identified 10 borehole breakouts, one major cave-in, and 9 drill-hole washouts between 2,500 ft and 9,630 ft. Also, calcareous foraminifers of Cretaceous or younger age were found in Cambrian-age rock intervals indicating that at least 5,600 ft (from 2,980 to 8,620 ft) of the drill-hole samples were contaminated. However, because less than 6 of these fossils were found below the Mesozoic/Paleozoic unconformity contamination is probably minor.

Beginning at the Cretaceous/Paleozoic unconformity at 2,860 ft depth (F. A. McKeown, written communication to DSC, 1990), 47 consecutive samples of cuttings were collected at about every 200 ft (Table 1). Each well-cutting sample represents a 60-ft interval. Samples were weighed and split. One split of each sample was weighed and examined for the presence of calcareous fossils and magnetic material, and then treated with 10 percent formic acid to dissolve limy fragments and $CaCO_3$ cement. Dolomitic and phosphatic minerals and inarticulate brachiopods are little affected by this treatment. After a maximum of 24 hours in the acid bath, the insoluble residue samples were rinsed in distilled water, weighed, and split again. One split was selected, and a rock-fragment volume percent was visually estimated and classified according to Compton's (1962) classification. Minerals were identified by powder X-ray diffraction, optical microscope, and scanning electron microscope (SEM). The remaining splits, not treated with acid, were retained for future reference.

Three intervals were cored in the Garrigan drill hole: a) 7,973 to 8,002 ft; b) 10,200 to 10,229 ft; and c) 11,402 to 11,426 ft. The core samples fell outside of the 200-ft cuttings-sample intervals and were analyzed separately. The two deeper core intervals 10,200-10,229 and 11,402-11,426, which are predominantly non-calcareous mudstone, were excluded from insoluble residue analysis. Core interval 7,973-8,002, comprised of very fine-grained dolomitic sandstone, was included in the insoluble residue study and sampled for shelly fossils which are discussed below.

SEDIMENTARY COMPONENTS OF THE GARRIGAN SAMPLES

The following rock and mineral descriptions of samples from the Garrigan drill hole are presented in two parts: soluble materials and insoluble residues. Descriptions of the two parts compare those soluble and insoluble materials that were either very distinctive in the overall Garrigan samples or indicative of a specific depth interval. The sample intervals listed in the mineral descriptions below are summarized in Table 1.

	Group/Formation/Member	Component Insoluble residue
	South and Southwestern Missouri (summarized by Kurtz and others, 1975)	
Elvins Group	Derby-Doerun	Upper: Chert, small amounts of white intercrystalline doloclastic chert, and oolites. Lower: Appreciable brown shale, fine and glauconite.
Elvins Group	Davis	Upper: Green shale, fine-grained quartz sand, quartz silt with fine-grained glauconite pellets. Lower: Mostly green shale, and significant amount of glauconite pellets.
Bonneterre Formation	Whetstone Creek Member	Gray or brown shale, sand-sized quartz grains, and glauconite pellets.
Bonneterre Formation	Sullivan Siltstone Member	Dominant quartz silt with small amounts of gray, brown, and occasional green shale.
Bonneterre Formation	Oolite Facies	Porous brown shale and quartz silt with sand-sized quartz grains and some glauconite pellets.
Bonneterre Formation	Micrite and Shale Facies	Silt and fine sand-sized quartz grains.
	Southeastern Missouri (summarized by Grohskopf, 1955)	
	Elvins Group	Silt, fine glauconite, kaolinite and waxy green shale.
	Bonneterre Formation	Brown, gray, and black shale, brown, gray lace-like silica, green dolomitic shale, fine-grained sand, kaolinite (?), a few specks of red hematite, smooth white chert, and gray to greenish gray clay with mica.

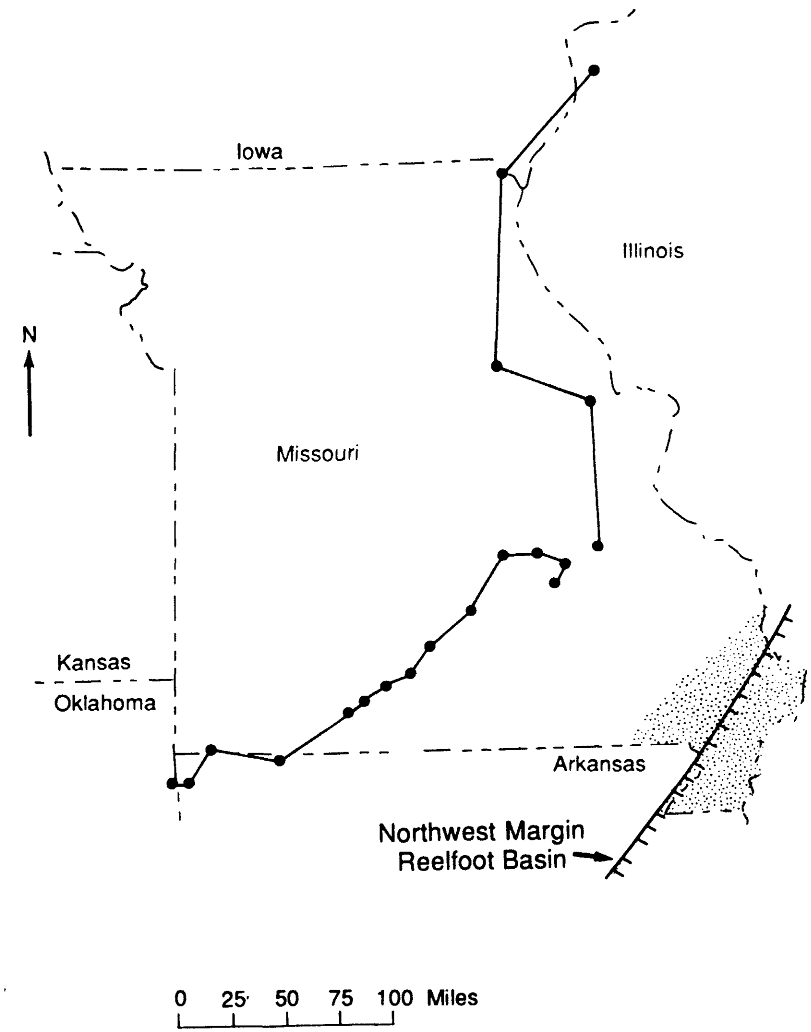

Figure 2. *2A*, Summary of insoluble residue data used for correlation of Upper Cambrian rocks of shallow-water platform origin from within the Reelfoot basin and from the eastern Missouri platform (outside the Reelfoot basin). *2B*, general area of samples used in Fig. 2A: Solid circles, Kurtz and others (1975); stipple pattern, Grohskopf (1955).

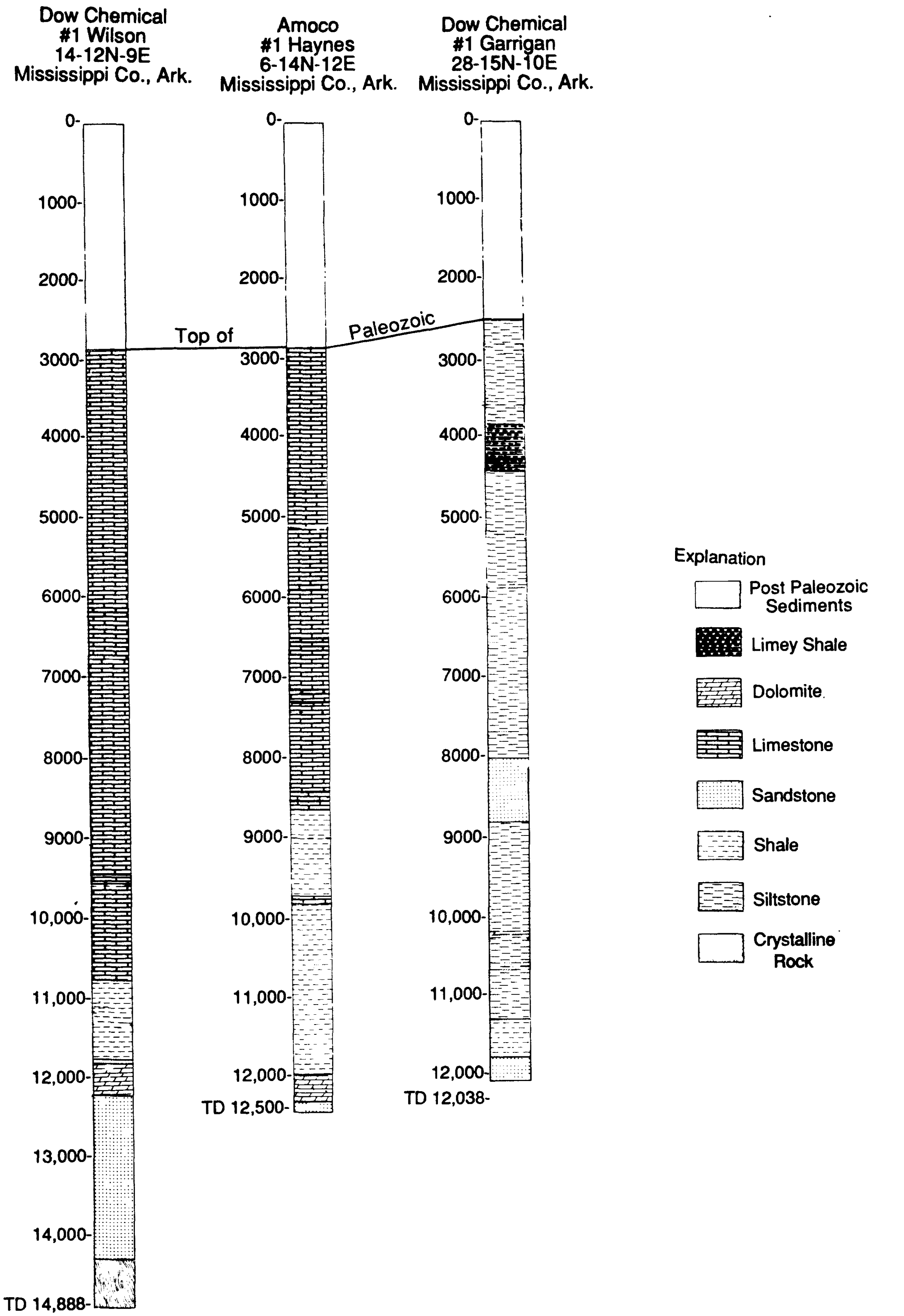

Figure 3. Generalized stratigraphic columns for the Dow Chemical #1 Wilson, Amoco #1 Haynes, and the Dow Chemical #1 B. L. Garrigan drill holes. Depths in feet below land surface. From James R. Howe (previously unpublished data, 1989; used by written permission).

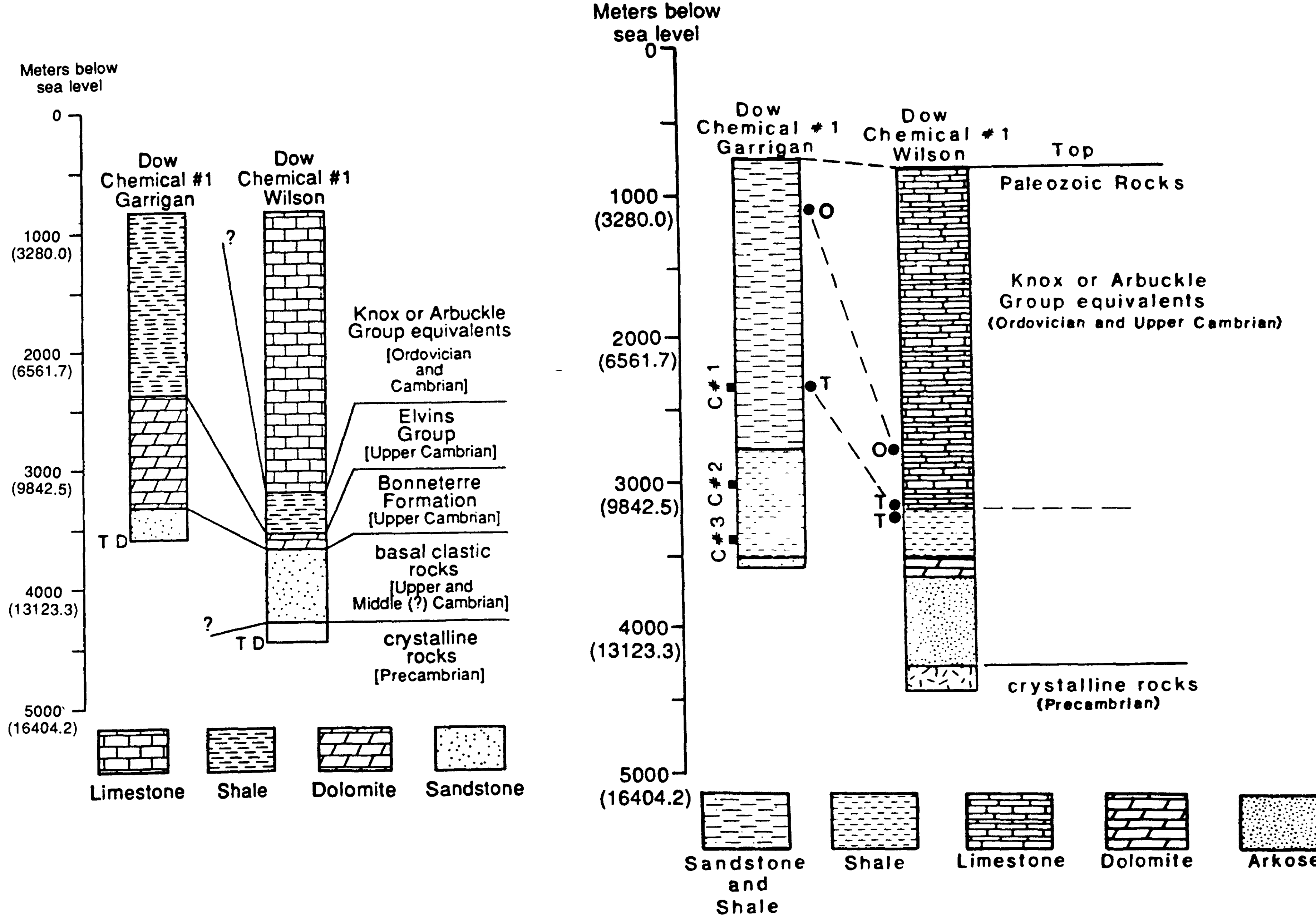

Figure 4. Generalized stratigraphic sections of the Dow Chemical #1 B. L. Garrigan and Dow Chemical #1 Wilson drill holes. *4A*, from McKeown and others (1990, fig. 4). *4B*, modified after Swolfs (1991, fig. 1) and Taylor and others (1991, fig. 2). C, cored intervals in the Garrigan drill hole. T, Upper Cambrian trilobites. O, Lower Ordovician conodonts. Dashed lines, approximate position of boundaries. Feet are given in parenthesis.

TABLE 1.--Residuum from the Dow Garrigan # 1 drill hole

Numbered sample intervals	Footage	Percent weight loss after acid bath	RX Type (%)	Number of quartz grains	Number of glauconite grains	Number of Chert (and color) grains	Number of Iron-stone grains	Number of Fossil (type) frags.	Number of Pyrite grains	Number of "Bumpy" grain (color) grains	Trace minerals	Number of magnetitic grains
1	2740-2860	13.1	Claystone, shaley, 85-90%; sandstone, 10-15%	217	40 dark green	1 yellow-white 5 root-beer 1 orangish-gray	1		1 druse on shale 2 framboidal grains		K-spar Albitic feldspar Kaolinitic clay fragment	none
2	2980-3040	10.5	Mudstone, shaley, 90-95%; sandstone, 5%	108	37 dark green	1 white 1 brownish-gray 2 rootbeer	10	2 spines?	1 cube 17 framboidal grains	2 cream-yellow	Illite Montmorillonite	19
3	3160-3220	7.6	Mudstone, shaley to claystone, shaley, 97-98%; sandstone, 2-3%; trace quartzite	43	2 dark green				1 framboidal grain	2 cream-yellow	Ankeritic-dolomite with quartz	none
4	3400-3460	17.1	Claystone, shaley, 99%; mudstone, shaley, <1%; sandstone, <1%	70	1 dark green		1	brachiopod fragments spine		1 red	Apatite Kaolinite mixture with fine-grained silica and carbonate	none
5	3580-3640	21.5	Claystone, shaley, 70-75%; sandstone, clayey, 25-30%; trace shale to mudstone, shaley	8	1 dark green				3 cubes	2 red-earthy		3
6	3760-3820	20.9	Claystone, silty to mudstone, shale, 90-99.9%; claystone, ~0.5%; sandstone, <0.5%; trace quartzite	83		1 reddish-brown		Trilobite fragment	1 framboidal grain		K-spar fragment	3

TABLE 1.--Residuum from the Dow Garrigan # 1 drill hole--Continued

Numbered sample intervals	Footage	Percent weight loss after acid bath	RX Type (%)	Number of quartz grains	Number of glauconite grains	Number of Chert (and color) grains	Number of Iron-stone grains	Number of Fossil (type) frags.	Number of Pyrite grains	Number of "Bumpy" grain (color) grains	Trace minerals	Number of magnetitic grains
7	4000-4060	23.5	Mudstone, 60-65%; sandstone (graywacke), 10-15%; sandstone, clayey to nonclayey, 5-10%; shale, 5-10%; trace sandstone and quartzite	169		1 grayish-brown	1		1 cube	1 white 1 cream		4
8	4180-4240	18.1	Sandstone, clayey, (graywacke), 60-65%; shale to mudstone, shaley, 35-40%	107	1 dark green	1 rootbeer 2 purplish		1 spines				22
9	4360-4420	20.0	Shale, 75-80%; sandstone, 20-25%	80	1 dark green	1 black			5 cubes			0.039g
10	4600-4660	19.0	Claystone, shaley, 90-95%; shale, <5%; sandstone, <0.5%	10					1 framboidal grain			214
11	4780-4840	24.4	Claystone, 100%	1					1 framboidal grain			4
12	4960-5020	17.3	Claystone, shaley, 99%; trace shale and sandstone	3					11 cubes		Dolomite fragment	6
13	5200-5260	14.7	Claystone, shaley, 100%; trace mudstone, shaley and sandstone	30							Fragment of illitic-smectite with pyrite	31

TABLE 1.--Residuum from the Dow Garrigan # 1 drill hole--Continued

Numbered sample intervals	Footage	Percent weight loss after acid bath	RX Type (%)	Number of quartz grains	Number of glauconite grains	Number of Chert (and color) grains	Number of Iron-stone grains	Number of Fossil (type) frags.	Number of Pyrite grains	Number of "Bumpy" grain (color) grains	Trace minerals	Number of magnetitic grains
14	5380-5440	8.0	Claystone, shaley, 100%; trace quartzite	1 crystal fragment				1 fragment(?)	2 framboidal grains			5
15	5560-5620	8.4	Claystone, shaley, 100%; trace sandstone						1 cube			8
16	5740-5800	10.2	Claystone, shaley, silty, 99.9%; mudstone, shaley, trace; sandstone, trace	1 grain 1 crystal								9
17	5980-6040	13.4	Claystone, shaley, 99.5%; mudstone, shaley, <1%; sandstone, <1%	2								27
18	6220-6280	18.7	Claystone, shaley, 55-60%; sandstone, 25-30%; shale 5-10%	63					1 framboidal 3+ cubes		K-spar fragment	27
19	6340-6400	15.7	Claystone, shaley, 40-45%; sandstone, 30-35%; shale, 20%	30			1		2 cubes			11
20	6580-6640	17.7	Shale, 90-95%; claystone, <5%; sandstone, <5%	57		1 rootbeer		1 brachiopod fragment(?)		1 white		12

TABLE 1.--Residuum from the Dow Garrigan # 1 drill hole--Continued

Numbered sample intervals	Footage	Percent weight loss after acid bath	RX Type (%)	Number of quartz grains	Number of glauconite grains	Number of Chert (and color) grains	Number of Iron-stone grains	Number of Fossil (type) frags.	Number of Pyrite grains	Number of "Bumpy" grain (color) grains	Trace minerals	Number of magnetitic grains
21	6820-6880	17.9	Mudstone, shaley, 75-80%; sandstone, 20-25%	20					1 druse on mudstone			11
22	7000-7060	22.4	Mudstone, shaley, 50-55%; sandstone, 45-50%	11	1 dark green		1					28
23	7180-7240	20.0	Claystone, shaley-shale, 70-80%; sandstone, 15-20%; mudstone-claystone, silty, 5-10%	90					1 cube			85
24	7420-7480	19.4	Sandstone, 40-45%; shale, 30-35%; mudstone, shaley, 15-20%	1		1 gray						40
25	7600-7660	16.3	Sandstone, 60-65%; mudstone, shaley, 35-40%; claystone, shaley, ~5%	4		2 reddish-orange			1 framboidal grain		Kaolinitic clay with fine-grained silica Illite-smectite clay mixture	38
26	7780-7840	13.3	Sandstone (N6), 35-40%; siltstone (N4-N2), 5-10%; claystone, shaley, 30%; shale, 20%	0					1 cube		Illitic clay mixture with pyrite and anatase K-spar fragment Albitic feldspar fragment	15

TABLE 1.--Residuum from the Dow Garrigan # 1 drill hole--Continued

Numbered sample intervals	Footage	Percent weight loss after acid bath	RX Type (%)	Number of quartz grains	Number of glauconite grains	Number of Chert (and color) grains	Number of Iron-stone grains	Number of Fossil (type) frags.	Number of Pyrite grains	Number of "Bumpy" grain (color) grains	Trace minerals	Number of magnetitic grains
27	7960-8020	11.6	Sandstone, 45-50%; shale, 15-20; claystone, 25-30%	21	8 turquoise			5 brachiopod fragments; oolitic(?) Tribolites and Tribolite fragments Sponge spicules			Ankeritic dolomite	58
28	8200-8260	21.1	Sandstone, 35-40%; mudstone, shaley, 35-40%; claystone, shaley, 10-15%	41	1 turquoise			Oolitic	2 fragments 1 framboidal grain 1 cube			115
29	8380-8440	21.6	Sandstone, 75-80%; mudstone, shaley, 5-10%; claystone, shaley to mudstone, shaley, 5-10%	34		1 gray		Oolitic				103
30	8620-8680	27.0	Sandstone, 85-90%; mudstone, shale, ¯10%; claystone, shaley, 5-10%	71				Oolitic	1 framboidal grain			20
31	8800-8860	20.4	Sandstone, 90-95%; mudstone, shaley, 1%; claystone, shaley and silty to nonsilty, 5-10%	44	8 turquoise			Oolitic				77

TABLE 1.--Residuum from the Dow Garrigan # 1 drill hole--Continued

Numbered sample intervals	Footage	Percent weight loss after acid bath	RX Type (%)	Number of quartz grains	Number of glauconite grains	Number of Chert (and color) grains	Number of Iron-stone grains	Number of Fossil (type) frags.	Number of Pyrite grains	Number of "Bumpy" grain (color) grains	Trace minerals	Number of magnetitic grains
32	8980-9040	10.2	Sandstone, 90-95%; mudstone, shaley, ~4%; claystone, shaley, ~1%	76	4 turquoise			Oolitic				47
33	9160-9220	21.2	Sandstone, 65-70%; mudstone, shaley 30-35%; claystone, shaley, ~1%	7				Oolitic	2 framboidal grains			43
34	9400-9460		Mudstone, shaley, 85-90%; sandstone, 10-15%; claystone, shaley, ~3%	7				35 brachiopod fragments; oolitic				10
35	9580-9640	18.0	Mudstone, shaley, 90-95%; sandstone, 3-5%; claytsone, shaley, 1-3%	21								56
36	9760-9820	19.5	Shale, silty, 55-60%; shale to silty shale, 30-35%; sandstone, ~5%	2 grains 1 crystal					1 framboidal grain 1 cube			17
37	10,000-10,060	33.4	Mudstone, shaley, 80-85%; sandstone, 5-10%; claystone, shaley, ~5%	4					1 massive grain 1 cube			22

TABLE 1.--Residuum from the Dow Garrigan # 1 drill hole--Continued

Numbered sample intervals	Footage	Percent weight loss after acid bath	RX Type (%)	Number of quartz grains	Number of glauconite grains	Number of Chert (and color) grains	Number of Iron-stone grains	Number of Fossil (type) frags.	Number of Pyrite grains	Number of "Bumpy" grain (color) grains	Trace minerals	Number of magnetitic grains
38	10,180-10,240	25.7	Mudstone, shaley, 85-90%; claystone, shaley, 5-10%; sandstone, ~5%	3				1 trilobite or brachiopod? fragment; 1 spicule?			1 barite grain	8
39	10,360-10,420	22.1	Mudstone, shaley, 90-95%; claystone, shaley, 5-10%; sandstone, <1%	1							Illitic clay mixture of anatase and pyrite	15
40	10,600-10,660	25.6	Mudstone, shaley, 90-95%; sandstone, 2-3%; claystone, shaley, ~1%	4							Illitic clay	32
41	10,780-10,840	18.6	Mudstone, shaley, 75-80%; claystone, shaley, 15-20%; sandstone, ~2%	7								10
42	10,960-11,020	15.6	Claystone to mudstone, shaley, 0.5%; mudstone, shaley, 99.9%; sandstone, <0.5%	3								14

TABLE 1.--Residuum from the Dow Garrigan # 1 drill hole--Continued

Numbered sample intervals	Footage	Percent weight loss after acid bath	RX Type (%)	Number of quartz grains	Number of glauconite grains	Number of Chert (and color) grains	Number of Iron-stone grains	Number of Fossil (type) frags.	Number of Pyrite grains	Number of "Bumpy" grain (color) grains	Trace minerals	Number of magnetitic grains
43	11,200-11,260	13.9	Mudstone, 80-85%; claystone, shaley, 15-20%; sandstone, 3-5%	23 2 crystal fragments 1 crystal								19
44	11,380-11,440	14.1	Mudstone, shaley, 85-90%; claystone, shaley, 5-10%; sandstone, 3-5%; mudstone, 5%	10							1 diopsidic pyroxene	none
45	11,560-11,620	10.7	Mudstone, shaley, 80-85%; claystone, shaley, 15-20%; sandstone, 3%	14								none
46	11,800-11,860	8.4	Mudstone, shaley, 45-50%; claystone, shaley, 5%; quartzite (N7-N5), 30-35%; sandstone (wacke?) (N8), 5%; sandstone (N2-N1), <0.5%; quartzite (10Y 4/2), <0.5%; sandstone (5YR 4/1), <0.5%	5								64

TABLE 1.--Residuum from the Dow Garrigan # 1 drill hole--Continued

Numbered sample intervals	Footage	Percent weight loss after acid bath	RX Type (%)	Number of quartz grains	Number of glauconite grains	Number of Chert (and color) grains	Number of Iron-stone grains	Number of Fossil (type) frags.	Number of Pyrite grains	Number of "Bumpy" grain (color) grains	Trace minerals	Number of magnetitic grains
47	11,980-12,038	11.8	Claystone, shaley, 55-60%; quartzite, 5-10%; mudstone, 25-30%	6 1 crystal fragment 1 crystal								6

Soluble Materials

Sulfate Minerals

A few gypsum (selenite) crystals were observed on claystone surfaces, but none were found after the acid bath and distilled water rinse. The gypsum crystals probably precipitated from the drilling fluid.

Calcite

Calcite cleavage rhombohedra and fragments (as much as 2 mm in diameter) are present in varying amounts throughout the drill hole. Most fractures in the well cuttings and in the core are filled with calcite.

Rock Fragments

Calcareous sandstone consisting of 50 percent or more fine-grained quartz sand and silt was found in varying amounts throughout the lower portion of the Garrigan drill hole. Some of the calcareous sandstone contains carbonate ooids.

Ooids

Carbonate ooids, occurring in a calcareous sandstone, are present from 7,960-8,020, 8,020-8,080, and 9,160-9,220 ft (Fig. 5).

Fossils

Calcareous foraminifers similar to *Nodosaria* or *Dentalina* (identified by Martin B. Lagoe, University of Texas, written communication to DSC, 1990) were found prior to the acid bath. The foraminifers are present in trace amounts (1-3 fossils) at drill hole intervals 2,980-3,040; 3,100-3,160; 4,360-4,420; and 8,560-8,620 ft. Other soluble fossils found include a calcareous mollusk(?) fragment in sample interval 4,360-4,420 ft and calcitic echinoid spines within sample intervals 3,820-3,880 and 3,400-3,460 ft. These fossils are all contamination from Cretaceous-Tertiary rocks penetrated in the upper part of the drill hole. Fossil trilobite casts and phosphatic inarticulate brachiopods are discussed below.

The formic acid treatment probably destroyed any conodonts present. Conodonts reported below were prepared separately by J. E. Repetski by dissolution of matrix with acetic acid and separation of the apatitic fossils in heavy liquids.

Insoluble Residues

Rock fragments form the bulk of the insoluble residues and constitute 100 percent of the insoluble residue for some samples. Residues include shaley claystone, mudstone, siltstone, and minor amounts of sandstone, graywacke, and quartzite. No igneous or metamorphic rock fragments were observed, although some rare mineral grains may be of igneous or metamorphic origin. Mineral and fossil fragments occur in trace amounts to a maximum of 0.5 volume percent and are described below and listed in Table 1. Relative proportions of siliciclastic rock fragments in Garrigan samples are shown in Figure 5.

Feldspars

Potassium and albitic feldspar grains occur from 2,740-2,860, 3,760-3,820, 6,220-6,280, and 7,780-7,840 ft. Colors for the grains range from light yellow to orange, reddish-brown, and white. No evidence of authigenic feldspar was observed.

Clay Minerals

Clay fragments are generally mixtures of illite, kaolinite, or montmorillonite, with a few clay grains mixed with anatase?, carbonate, pyrite, or fine-grained quartz. A few discrete grains of illite and montmorillonite were found from 5,200-5,260 ft and 7,600-7,660 ft.

Phosphate Minerals

The only phosphate mineral identified was one rounded, reddish-black apatite grain from 3,400-3,460 ft.

Carbonate Minerals

A few rhombohedral cleavage fragments of ankeritic dolomite and dolomite were collected from 3,160-3,220, 4,960-5,020, and 7,960-8,020 ft.

Sulfates

One grain of barite, found in the interval 10,180-10,240 ft, is coated with an iron oxide tentatively identified as limonite.

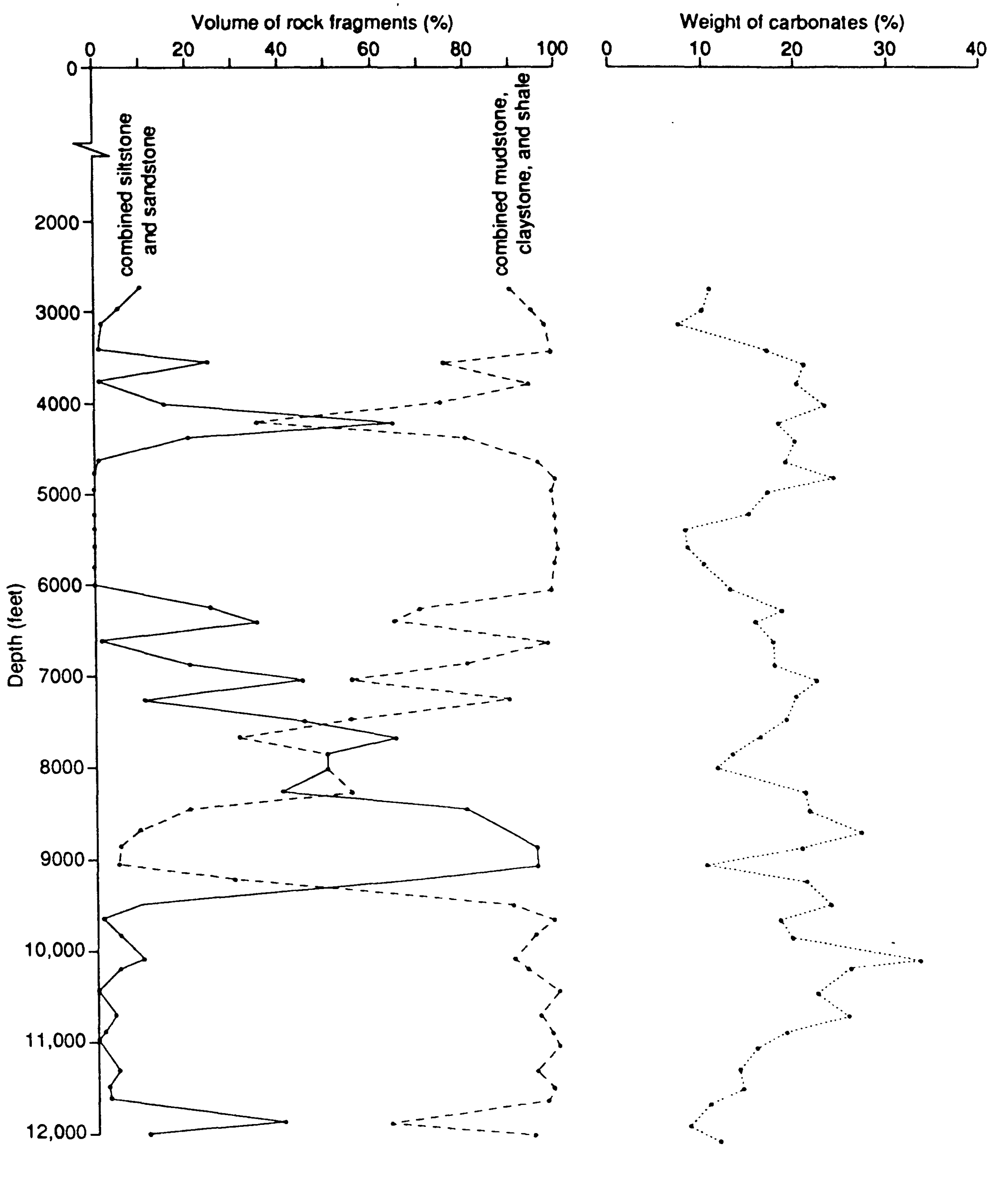

Figure 5. Graph summarizing the relations between volume-percent of insoluble rock fragments and weight-percent of carbonate in drill cuttings from the Dow Chemical #1 B. L. Garrigan. Solid line, sandstone and siltstone. Dashed line, claystone, mudstone, and shale. Dotted line, weight-percent carbonate. Modified from Collins (1991, fig. 2 and table 1).

Pyroxene

One angular, transparent, green diopsidic pyroxene grain was identified from the interval 11,380-11,440 ft.

"Ironstone"

Limonite-coated, rounded, and polished clay nodules ("ironstone", Table 1), appearing to be an illite/montmorillonite mixture are relatively abundant from 2,980-3,040 ft, with only trace amounts found in from 2,740-2,860, 3,400-3,460, 4,000-4,060, 6,340-6,400, and 7,000-7,060 ft.

Sulfides

Pyrite is the only sulfide found in the Garrigan samples. It occurs as either simple cubes, framboidal grains, or as fragments of these forms from 2,740 to 9,640 ft. Pyrite druse on some sedimentary rock fragments is also present.

Magnetic grains

The magnetic grain counts and weights presented in Table 1 were observed in pre-acid splits and assumed to represent the total amount of magnetic material of each pre-acid split.

Magnetic grains are present in varying amounts throughout most of the intervals sampled. Intervals lacking magnetic grains are 2,740-2,860, 3,160-3,460, and 11,560-11,620 ft. Quantity of the magnetic grains range from 3 to 214 grains per sample. Magnetic grains are most abundant from 4,360-4,420 ft, comprising 0.039 g or 0.0018 percent of the pre-acid sample split. Some of the magnetic grains may be fragments of drill stem. Others may be undifferentiated magnetite and/or magnetic ilmenite.

Color of the magnetic grains varies from metallic black to dark gray. The majority of the grains have a platy habit and are angular and oxidized. Grain size ranges from silt-size to coarse grained sand.

Unknown Grains

"Bumpy" grains occur from 2,980-3,640, 4,000-4,060, and 6,580-6,640 ft and resemble elongated, rounded fecal material composed of illitic clay with varying amounts of iron oxide. They range in color from an earthy red to white.

Chert

Angular to subangular grains of chert are found in intervals 2,740-3,040, 3,760-4,420, 7,420-7,660, and 8,380-8,440 ft and are most abundant from 2,740-3,040 ft. Colors include "root beer", black, white, gray, and red.

Quartz

Milky white, white, and a few yellow to pink quartz grains are present in varying amounts throughout the drill hole. The quartz grains range from angular to well-rounded and are transparent to translucent, with some being pitted and/or frosted. Grain size ranges from silt to coarse sand. A few quartz crystals and quartz crystal fragments have also been found.

Glauconite

Glauconite was found in intervals 2,740-3,640, 4,180-4,420, 7,000-7,060, 7,960-9,220 ft. Dark green botryoidal grains characterize intervals 2,740-3,640, 4,180-4,420, 7,000-7,060 ft, whereas blue-green to turquoise, sugary botryoidal masses occur from 7,960-9,220 ft. The interval 7,960-9,220 ft corresponds to the oolitic intervals (Table 1). X-ray diffraction and SEM show that both glauconite types are a mixture of glauconite and illitic clay.

Oil

An oil film was obtained from three core samples at 7,978.2, 7,986.0, and 7,998.3 ft. Whether the oil film is indigenous or was subsequently introduced is uncertain.

Primary Sedimentary Structures

Primary sedimentary structures of turbidite origin are preserved in fossil-bearing, dark-gray dolomitic fine-grained sandstone in core samples from 7,973 to 8,002 ft of the Garrigan drill hole. The core contains Bouma sequence divisions Ta?bce (for turbidite classification see Walker, 1984). The Bouma Ta? divisions are about 1 inch thick, normally graded, and contain fossil fragments and small authigenic pyrite crystals. Bouma Tb divisions are as much as 0.9 inch thick and Tc divisions about 0.4 inch thick. The hemipelagic sediment of Bouma divisions Te are black shale of undetermined thickness because most of it is broken loose from the core chips. Fecal? pellets were recovered from one division Te bed, whereas shelly fossils are sorted but unsegregated in divisions Ta?bc.

PALEONTOLOGY

Garrigan Fossil Identifications

Fossils are rare in samples from the Garrigan drill hole. A few samples contain inarticulate brachiopod fragments, trilobite exuivae, conodonts, sponge spicules, and problematica. Inarticulate brachiopod fragments were found in intervals 3,400-3,460 ft, 4,360-4,420 ft, 6,580-6,640 ft, 7,960-8,020 ft, 9,400-9,460 ft, but are most abundant in intervals 7,960-8,020 ft, and 9,400-9,460 ft. Upper Cambrian inarticulate brachiopod fragments, sponge spicules, and trilobite fragments were found in a core sample at 7,978.2 ft.

Core chips and or cuttings from the Garrigan drill hole were examined by M. E. Taylor for trilobites, inarticulate brachiopods, and other fossils. Conodonts were identified by R. E. Repetski. Taxa recognized are listed below. Also, sedimentary features associated with core chips are given. Samples are identified by depth in feet below the land surface. Trilobite-bearing sample 7,986.0 is assigned USGS catalogue number D3460-CO and is permanently stored in the USGS Cambrian-Ordovician collections at the Denver Federal Center. Other Garrigan samples mentioned here are stored by D. S. Collins, Branch of Geological Risk Assessment, in Denver. Conodont-bearing samples are undergoing additional study by J. E. Repetski in Reston, Virginia.

Garrigan Fossils listed below with an asterisk (*) are down-hole contamination, probably from Cretaceous or Tertiary cover rocks of the Mississippi embayment.

3,400-3,460 ft (cuttings):

inarticulate brachiopod fragments, indeterminate

*echinoid? echinoderm spine

Age: Lower Paleozoic with post-Paleozoic contamination.

3,580-3,640 ft (cuttings):

1 ramiform conodont fragment, genus and species indeterminate

inarticulate brachiopod fragments, indeterminate

*1 ichthyolith, undetermined

Age: Ordovician or younger, based on morphology of the conodont element.

3,820-3,880 ft (cuttings):

*calcareous foraminifers

*echinoid? echinoderm spines

Age: Contaminants are post-Paleozoic.

4,000-4,060 ft (cuttings):

Conodont:

Proconodontus sp.

Other:

*1 pyritized coiled foraminifer

Age: Upper Cambrian (Franconian or Trempealeauan Stage), with post-Paleozoic contaminant.

4,240-4,300 ft (cuttings):

*echinoid? echinoderm spine

Age: Contaminant is post-Paleozoic.

4,360-4,420 ft (cuttings):

*mollusk? fragment

Age: Contaminant is post-Paleozoic.

7,978.2 ft (core chip and insoluble residue):

trilobite fragments, indeterminate

inarticulate brachiopod fragments, indeterminate

sponge spicules

Sedimentary Features: Bouma divisions Tbc

Age: Upper Cambrian by association.

7,986.0 ft (core chips; USGS locality D3460-CO):

Trilobites:

Subfamily Aphelaspidinae, genus and species indeterminate

pseudagnostoid, genus and species indeterminate

Inarticulate brachiopod:

linguloid brachiopod, genus and species indeterminate

Other:

fecal? pellets

Discussion: The two trilobite specimens are preserved as internal molds in acid-etched fine-grained, dolomitic quartz sandstone. The aphelaspidinid is one small cranidium with features similar to *Aphelaspis*, but preservation is too poor for identification more detailed than to subfamily.

Age: Upper Cambrian, upper part of Dresbachian to lower part of Franconian Stages. No older than *Aphelaspis* Zone and no younger than *Elvinia* Zone. Equivalent to rocks ranging from Sullivan Siltstone Member and Whetstone Creek Member of Bonneterre Formation to lower part of Davis Formation of Elvins Group (compare Kurtz and others, 1975, p. 4).

7,998.3 ft (core chip):

inarticulate brachiopod fragment, indeterminate

Sedimentary features: Bouma Ta? and Tb

Age: Upper Cambrian by association.

10,180-10,240 ft (insoluble residue):

siliceous sponge spicule

Age: Cambrian.

Other Reelfoot Basin Fossil Occurrences

Lower Paleozoic shelly fossils and conodonts are known from a few drill holes in the Reelfoot basin. These include the Garrigan (listed above) and additional drill holes, including new data from the Wilson, summarized below (see Fig. 1).

Dow Chemical #1 Wilson

The Wilson drill hole was completed July 8, 1981, from a ground elevation of 225 ft (estimated) to a total depth of 14,868 ft in Sec. 14, T. 12 N., R. 9 E., Mississippi County, Arkansas (Fig. 1). A. R. Palmer (written communication to E. E. Glick, October 1, 1989; and additional data) found Upper Cambrian trilobites and inarticulate brachiopods in twelve samples of cuttings from the Wilson drill hole. Conodonts were identified by J. E. Repetski. Palmer's and Repetski's fossil identifications are as follows:

2,940-3,000 ft:

Conodont:

Drepanodus cf. *D. arcuatus* Pander

Age: Upper Lower Ordovician to lowermost Middle Ordovician. Equivalent to upper part of Powell Dolomite and Smithville Formation.

3,120-3,180 ft:

Conodonts:

"Scandodus" robustus Serpagli or *Juanognathus variabilis* Serpagli

Age: *Oepikodus communis* Zone, highest Lower Ordovician to lowest Middle Ordovician. Equivalent to upper part of Powell Dolomite and Smithville Formation.

3,180-3,240 ft:

Conodonts:

Drepanodus sp.

aff. *"Scandodus" robustus* Serpagli

Glyptoconus quadraplicatus (Branson and Mehl)

Age: *Oepikodus communis* Zone, highest Lower Ordovician. Equivalent to Powell Dolomite and Smithville Formation.

7,920-7,980 ft:

Conodonts:

Cordylodus proavus Müller

Teridontus nakamurai (Nogami)

Age: *Cordylodus proavus* to *Cordylodus intermedius* Zones, uppermost Upper Cambrian or lowermost Lower Ordovician. Equivalent to part of Eminence Dolomite.

8,580-8,640 ft:

Conodonts:

Hirsutodontus hirsutus Miller

cf. *Proconodontus muelleri* Miller

Age: Near *Proconodontus/Cordylodus proavus* Zone boundary, uppermost Upper Cambrian. Equivalent to upper part of Potosi Dolomite or lower part of Eminence Dolomite.

10,140-10,200 ft:

Inarticulate brachiopod:

cf. *Angulotreta* sp. (one pedicle value)

Age: Upper Cambrian, middle Franconian Stage, post-*Elvinia* Zone. Equivalent to upper part of Davis Formation or lower part of Derby-Doerun Formation of Elvins Group.

10,740-10,800 ft:

Trilobite:

Trilobite fragment, genus and species indeterminate

Inarticulate brachiopod:

Linnarssonella sp.

Age: Upper Cambrian, lower Franconian Stage, no younger than *Elvinia* Zone. Equivalent to lower part of Davis Formation of Elvins Group.

10,800-10,860 ft:

Trilobite:

Pseudagnostus sp.

Age: Undifferentiated Upper Cambrian.

10,860-10,920 ft:

Inarticulate brachiopod:

Apsotreta or *Linnarssonella* sp.

Age: Upper Cambrian, upper part of Dresbachian to lower part of Franconian Stages. Equivalent to lower part of Davis Formation or the Whetstone Creek Member of the Bonneterre Formation.

10,920-10,980 ft:

Trilobites:

Pseudagnostus sp.

Homagnostus sp.

Inarticulate brachiopod:

Apsotreta sp.

Age: Upper Cambrian, upper part of Dresbachian Stage, *Apsotreta expansa* Zone of Kurtz (1971, p. 473; Kurtz others, 1975, p. 4). Equivalent to the Whetstone Creek Member of the Bonneterre Formation.

10,980-11,040 ft.

Trilobites:

Homagnostus sp.

Other trilobite fragments, indeterminate

Inarticulate brachiopod:

Apsotreta? sp.

Age: Upper Cambrian, Dresbachian Stage. Probably equivalent to the Whetstone Creek Member of the Bonneterre Formation.

11,040-11,100 ft:

Trilobite:

Homagnostus sp.

Age: Upper Cambrian, Dresbachian Stage, no older than *Aphelaspis* Zone. Sample may correlate with rocks equivalent to the Sullivan Siltstone Member of the Bonneterre Formation or the lower part of the Davis Formation of the Elvins Group.

Henderson #1 Markham, Lake County, Tennessee

Josiah Bridge (*in* Grohskopf, 1955, p. 127-128; also see Palmer, 1962, p. F43) reported several occurrences of *Glyptagnostus reticulatus* (Angelin) from 2,858 to 2,862 ft in the Henderson #1 Markham drill hole located 3.3 mi southeast of Tiptonville, Tennessee (Fig. 1). The species is characteristic of the *Aphelaspis* Zone of the upper part of the Dresbachian Stage, Upper Cambrian (Palmer, 1962, 1965). Below 2,875 ft in the Markham, Bridge (*in* Grohskopf, 1955, p. 128) reported *Kingstonia*? and *Crepicephalus* or *Tricrepicephalus*? which can be assigned to the *Crepicephalus* Zone (lower part of the Dresbachian Stage). In reference to Upper Cambrian stratigraphy of the eastern Missouri platform (Kurtz and others, 1975, p. 4), the *Crepicephalus* Zone correlates with the unnamed lower carbonate member of the Bonneterre Formation and the *Aphelaspis* Zone with the overlying Sullivan Siltstone Member of the Bonneterre Formation.

Marr #1 Barnett, Stoddard County, Missouri

Christina Lochman (*in* Grohskopf, 1955, p. 111-112) identified cf. *Genevievella* or *Avonina*, *Holcacephalus*, and *Cedarina* from 4,215-4,235 ft in the Marr #1 Barnett drill hole in Sec. 3, T. 25 N., R. 11 E., Stoddard County, Missouri (Fig. 1). As recognized by Lochman (*in* Grohskopf, 1955, p. 112), the fossils are equivalent in age to the Bonneterre Formation.

Strake #1 T. P. Russell, Pemiscot County, Missouri

Josiah Bridge (*in* Grohskopf, 1955, p. 83) identified *Acrotreta*, from 3,165 ft and *Coosella* from 3,231 ft in the Strake #1 T. P. Russell drill hole, near the center of Sec. 24, T. 19 N., R. 11 E., Pemiscot County, Missouri (Fig. 1). *Acrotreta* belongs to a group of inarticulate brachiopods that are long-ranging in the Upper Cambrian and Lower Ordovician, whereas *Coosella* correlates with the unnamed lower carbonate member of the Bonneterre Formation.

U.S.G.S. Fort Pillow Test Well, Lauderdale County, Tennessee

Moore and Brown (1969) reported the Lower Ordovician (uppermost Canadian Series) articulate brachiopod *Diparelasma* in a core sample from the U.S.G.S. Fort Pillow Test Well in Lauderdale County, Tennessee (Fig. 1). The shelly fossil was found in a 36-ft-thick core of black, silty lime mudstone at 3,148 ft, just above TD at 3,183 ft. Derby (1982) and Repetski *in* Derby (1982) reevaluated the Fort Pillow core and reported that the interval 3,148-3,183 ft is composed of dark-gray, thinly bedded, shaley limestone that yielded asaphid trilobite fragments and a small articulate brachiopod identified as *Diparelasma*(?). Associated conodonts identified by Repetski are a mixture of both North Atlantic and North American Midcontinent province faunas. These faunas are referable to the Lower Ordovician (Arenigian Series) *Oepikodus smithensis* (or *O. evae*) Zone of the North Atlantic province zonation and the North American Midcontinent province *Oepikodus communis* Zone. This is a fauna that lived in cooler and/or deeper water depths than the faunas from the adjacent carbonate platforms to the west (eastern Missouri) and east (western Tennessee). The Fort Pillow rocks were assigned to the uppermost Knox Group by Moore and Brown (1969).

Other Fossil Occurrences

Ordovician fossils reported by Derby (1982, notes to Column 43) include (1) Lower and Middle Ordovician brachiopods and trilobites in the Tenn-Ark #1 Ruby Martin drill hole, Craighead County, Arkansas; and (2) Lower and Middle Ordovician brachiopods from the Ken-Ten #1 Sanger drill hole in Fulton County, Kentucky (Fig. 1).

Cooper (1956) described a rich articulate brachiopod fauna from the C. L. McGuire #1 J. B. More drill hole near Danceyville in Haywood County, Tennessee (Fig. 1). Genera recognized include *Archaeorthis, Orthambonites, Orthidium, Hesperonomia, Tritoechia, Pomatotrema, Diparelasma, Leptella,* and *Camerella*, which Cooper (1956, p. 20) assigned to the Lower Ordovician, uppermost Canadian Series.

Wood and Stephenson (1989) described Upper Cambrian palynomorphs from the southeastern Missouri platform and Reelfoot rift basin. The fossil microphytoplankton include acritarchs and algal clusters, filaments, and sheets. The acritarchs *Timofeevia phosphoritica* Vanguestaine and *Vulcanisphaera turbata* Martin show affinities with the Late Cambrian high-paleolatitude cool-water North Atlantic province (Wood and Stephenson, 1989). These biofacies relations suggest that marine waters of the Reelfoot basin were deep and/or cool and had free circulation with the open ocean during the Late Cambrian.

Collier Shale, near Jessieville, Arkansas

Hart and others (1987) and Hohensee and Stitt (1989) reported Upper Cambrian (*Elvinia* Zone, lower Franconian Stage) trilobites from carbonate turbidites and other gravity flow deposits in a deepwater section of the Collier Shale, which crops out in the Ouachita Mountains near Jessieville, Arkansas. The Collier Shale occurrence, although not part of the Reelfoot basin deposits, is mentioned here because it suggests commonalty of Upper Cambrian deepwater deposits in the Reelfoot basin and Ouachita structural belt.

Biostratigraphic Correlations

An Upper Cambrian trilobite assemblage from 7,986 ft (2,434 m) in the Garrigan roughly correlates with trilobite assemblages in carbonate shelf deposits from 10,860-11,100 ft (3,310-3,383 m) in the Wilson drill hole. Based on preliminary conodont analysis by J. E. Repetski, the lowest Ordovician samples occur at 3,640 ft (1,109 m) in the Garrigan and at 9,000 ft (2,743 m) in the Wilson (Taylor and others, 1991). Highest Cambrian samples occur at 4,060 ft (1,237 m) in the

Garrigan and 10,140 ft (3,091 m) in the Wilson. Although fossils are rare, these combined trilobite and conodont age assignments suggest that about 4,346 ft (1,325 m) of calcareous siliciclastic rocks in the Garrigan are equivalent in age to about 1,800 ft (549 m) of carbonate rocks in the Wilson. Assuming that faulting has not altered original thickness, these data suggest that the siliciclastic sediment accumulation rate in the Garrigan was about 2.3 times greater than that of the Wilson carbonate rocks. The inferred correlations are shown graphically in Figure 4B.

DEPOSITIONAL ENVIRONMENTS

The source of the siliciclastic sediments in the Garrigan hole was probably granitic basement and eroded pre-existing sedimentary rocks because of the presence of rounded chert grains that probably originated from an eroded sedimentary source and the presence of rounded to subrounded feldspar grains, milky to clear quartz grains, and magnetic material that indicate a probable granitic source. The rounded pyroxene grain found in interval 11,380-11,440 ft also indicates an igneous source area and is commonly believed to be a first-cycle sediment (Boggs, 1987). However, because only one grain was found, it may represent a contaminant. Rounded, frosted, and pitted quartz grains, found throughout the Garrigan drill hole, may indicate an eolian dune source or recycled sediment source. Rare barite crystal fragments found near the base of the drill hole are not derived from the source area and are inferred to result from a post-depositional hydrothermal event. Similarly, the quartz crystal fragments probably originated from vugs and fracture fills that formed after lithification.

The few gypsum grains (less than 20) found on the surface of well cutting fragments probably formed from evaporation of drilling fluids and do not represent a preexisting evaporite deposit.

Examination of the core from 7,973-8,002 ft and a detailed description of the core prepared by D. S. Collins and S. F. Diehl (unpublished data) suggests deposition in a submarine fan by turbidity currents. Evidence for a lower fan environment is suggested by presence of rare and relatively fine-grained Bouma Ta? divisions, dominance of Bouma Tbc divisions, and rare Bouma Te divisions, although the latter may appear rare because the shales tend to break up and could be easily lost from the core samples. Insoluble-residues from a Bouma Ta? bed include turquoise-colored glauconite, shaley fragments, dolomitic trilobite molds, inarticulate brachiopods, and sponge spicules. These materials probably originated in a basin-margin environment and were transported into deeper water by turbidity currents. Interpretation of a turbidite-fan environment for the Upper Cambrian core agrees substantially with an earlier interpretation made by James R. Howe (1984; personal communication to DSC, 1990).

The depositional environment of the core from 7,973-8,003 ft was probably dysoxic to anoxic as suggested by the absence of bioturbation (laminations are not disrupted), presence of authigenic cubic pyrite crystals in Bouma Ta? divisions, and presence of interstitial fine-grained framboidal pyrite (S. F. Diehl, written communication to DSC, 1991). However, presence of a Late Cambrian dysoxic to anoxic environment does not necessarily reflect conditions unique to the Reelfoot rift. The association of pyrite and non-burrowed, thin-bedded distal turbidites is common in Cambrian basinal limestone formed in low-paleolatitude sites in North America, China, and Soviet Central Asia and suggests low-oxygen conditions were probably normal in Late Cambrian oceans (M. E. Taylor and H. E. Cook, unpublished data).

Paleocurrent directions observed in oriented core interval 7,973-8,002 ft indicate a sediment transport direction toward the southwest, parallel to the Reelfoot basin axis (J. R. Howe, written communication to DSC, 1990). Whether this paleodirection reflects the primary architectural fabric of the submarine turbidite fan or merely a subfacies of the fan is not certain.

The interpretation of deepwater origin for the Garrigan core is difficult to quantify, but the absence of interbedded shoal-water sediment, absence of redeposited clasts of shoal-water origin, and rarity or absence of coarse-grained Bouma Ta divisions are all criteria that suggest deposition on a basin plain below maximum storm wavebase some distance from a platform margin (Cook and Mullins, 1983).

In contrast, the Wilson contains predominantly carbonate rocks coeval with the siliciclastic turbidites of the Garrigan. The depositional environments of the Wilson carbonates are difficult to evaluate directly because no core exists. However, the occurrence of parallel seismic reflectors (McKeown and others, 1990, fig. 3), occurrence of mixed warm- and cool-water conodont biofacies in the nearby Fort Pillow drill hole (Fig. 1) suggest that the Wilson rocks may represent the distal, deeper water part of a carbonate ramp.

CONCLUSIONS

New biostratigraphic data show that the formation names and unconstrained age assignments given to the Garrigan rocks by Howe and Thompson (1984, fig. 4), Houseknecht (1989), and McKeown and others (1990, fig. 4; Fig. 4A) result in an inferred stratigraphic stacking of strata that are lateral facies equivalents (compare Figs. 4A and 4B). Apparently, this resulted in part because the thick section of siliciclastic rocks in the Garrigan was assumed to represent an expanded section of Elvins Group, whereas the thick section of carbonate rocks in the Wilson was thought to represent the younger Knox-Arbuckle Groups overlying a condensed section of the Elvins Group. Biostratigraphic data reported here suggest that the thick section of siliciclastic rocks of the Garrigan is the temporal facies equivalent to part of the thick undifferentiated Knox-Arbuckle carbonate section of the Wilson (Figs. 3 and 4B).

Palmer (1989, fig. 1) made an east-west facies reconstruction of Upper Cambrian rocks across southern Missouri and the northwest side of the Reelfoot graben, including the Blytheville arch. His control for the Blytheville arch was the Killam #1 Pattinson drill hole (hereafter Killam) which occurs about 50 km northeast along structural strike from the Garrigan drill hole. Palmer (1989, fig. 1) assigned the thick section of fine grained siliciclastic rocks of the Killam to the Bonneterre and Davis Formations which he interpreted to be unconformably overlain by Cretaceous-Tertiary rocks of the Mississippi embayment. This interpretation implies that Cambrian rocks of the Killam are no younger than the lower part of the Upper Cambrian Franconian Stage. Unfortunately, no fossils are known from the Killam. Whether the lower Paleozoic rocks of the Killam are precisely equivalent to the Garrigan rocks, or whether pre-Cretaceous erosion cut deeper into the Killam rocks than the Garrigan is not known. But, unnamed Upper Cambrian rocks of the Garrigan apparently range through a greater amount of time and are, therefore, equivalent to the Bonneterre Formation, Davis Formation, Derby-Doe Run Formation, Potosi Dolostone, Eminence Dolostone, and lower part of the Canadian Series carbonate rocks of the eastern Missouri platform (compare Palmer, 1989, fig. 1, cross section and inset).

Results of the insoluble residue analyses cannot be used to reliably identify either the Elvins Group or Bonneterre Formation in the Garrigan cuttings. The temptation to use insoluble residue data from the Garrigan to identify formations that have their definition and typical expression on the shallow-water eastern Missouri platform should be avoided. The Upper Cambrian Garrigan rocks examined here are petrographically distinct, apparently stratigraphically discontinuous from coeval platform siliciclastic rocks (see Palmer, 1989, fig. 1), and represent deepwater environments. These differences suggest that the Garrigan rocks should be classified by a different lithostratigraphic nomenclature than platform rocks (also see Derby, 1982). We refrain from proposing a new formation name here because this report is information and of limited distribution.

Limited paleontologic data suggest that the Garrigan includes rocks of Late Cambrian and Early Ordovician age (Fig. 4B). Late Cambrian siliciclastic deposition in the Garrigan area occurred at least partly in a predominantly deepwater, reducing marine environment with sediment supplied from coastal eolian dunes, sedimentary rocks, and minor granitic sources. The depositional environment of at least part of the Garrigan Late Cambrian was a submarine turbiditic fan. Assuming that faulting has not seriously altered Garrigan rock thickness, sediment accumulation rates in the turbidite fan facies are estimated to be over twice that of coeval sediment accumulation rates in the Knox-Arbuckle carbonate platform rocks of the Wilson to the southeast.

The Blytheville arch formed some time after the Ordovician and was accompanied by reversal of both the Reelfoot structural basin (McKeown and others, 1990) and depositional basin, resulting in the elevation of deepwater, Upper Cambrian siliciclastic rocks of the Garrigan in relation to the coeval, relatively shallower water carbonate rocks of the Wilson. Structural relief between the Garrigan and Wilson can be estimated from the observed elevation of both lowest Ordovician samples and highest Upper Cambrian samples from drill hole cuttings samples. Estimates of structural relief are 5,400 ft (1,646 m) between lowest Ordovician samples and 6,100 ft (1,859 m) between highest Upper Cambrian samples. Based on geophysical data, McKeown and others (1990) estimated structural relief on the Blytheville arch as greater than 2 km.

The turbidity current origin of siliciclastic rocks in the Garrigan can be documented only for one short core of Upper Cambrian rocks. Upper Cambrian and Ordovician cuttings are predominantly siliciclastic sand, but sedimentary structures are unknown. While recognizing this shortcoming, we speculate that the northeast-trending, narrow linear-shaped Blytheville arch may record the original shape and position of a turbidite basin that formed in a structural low basinward of a major boundary fault zone which was active during the Late Cambrian (compare Houseknecht, 1989, figs. 6 and 7; Palmer, 1989, fig. 9). Origin of the siliciclastic sediment was probably from the northeast, with transport parallel to carbonate platform margins on each side of the rift basin. Perhaps importantly, the limited biostratigraphic data suggest that about 840 ft of fine grained sandstone from 8,380 to 9,220 ft corresponds, at least in part, to the late Dresbachian and early Franconian sea-level low stand and erosion of the North American craton (Lochman-Balk, 1971; Palmer, 1981).

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REFERENCES CITED

Bain, H. F., 1905, Lead and zinc resources of the United States, p. 251-273, *in* Emmons, S. F., and Hayes, C. W., Contributions to Economic Geology, 1904: U.S. Geological Survey Bulletin 260.

Boggs, Sam, Jr., 1987, Principles of Sedimentology and Stratigraphy: Merrill Publishing Company, Columbus, 748 p.

Buckley, E. R., 1909, Geology of the disseminated lead deposits of St. Francois and Washington Counties: Missouri Bureau of Geology and Mines, v. 9, Part 1, p. 2-46.

Collins, D. S., 1991, Insoluble residue of selected samples from the Dow Chemical B. L. Garrigan #1 drill hole, Blytheville, Arkansas: Program with Abstracts, Louis Unfer, Jr. Conference on the Geology of the Mid-Mississippi Valley. Southeast Missouri State University, Cape Girardeau, Missouri, 6 p. (unnumbered).

Compton, R. R., 1962, Manual of Field Geology: John Wiley and Sons, Inc., New York, 219 p.

Cook, H. E., and Mullins, H. T., 1983, Chapter 11--Basin Margin Environment, p. 540-617. *In*, Scholle, P. A., Bebout, D. G., Moore, C. H., eds., Carbonate Depositional Environments: American Association of Petroleum Geologists, Memoir 33.

Cooper, G. A., 1956, A New Upper Canadian [Lower Ordovician] fauna from a deep well in Tennessee: Journal of Paleontology, v. 30, n. 1, p. 29-34.

Dart, R. L., 1990, Catalog of drill-hole data from wells in the Paleozoic rocks of the upper Mississippi Embayment: U.S. Geological Survey Open-File Report 90-260, 135 p.

Derby, J. R., 1982, Mississippi Embayment, Reelfoot Basin, Column 43, *in* Ross, R. J., Jr., and 27 coauthors, 1982, The Ordovician System in the United States, correlation chart and 36 explanatory notes: International Union of Geological Sciences, Publication Number 12, 73 p., 3 charts.

Ervin, C. P., and McGinnis, L. D., 1975, Reelfoot Rift--Reactivated Precursor to the Mississippi Embayment: Geological Society of America Bulletin, v. 86, no. 9, p. 1287-1295.

Fuller, M. L., 1912, New Madrid Earthquake: U.S. Geological Survey Bulletin 494, 119 p.

Grohskopf, J. G., 1955, Subsurface geology of the Mississippi Embayment of southeast Missouri: Missouri Geological Survey and Water Resources Report 37, Second Series, 133 p.

Grohskopf, J. G., and McCracken, Earl, 1949, Insoluble residues of some Paleozoic formations of Missouri--Their preparation, characteristics and application: Missouri Geological Survey and Water Resources Report of Investigations, no. 10, 39 p.

Hamilton, R. M., and McKeown, F. A., 1988, Structure of the Blytheville arch in the New Madrid seismic zone: Seismological Research Letters, v. 59, no. 4, p. 117-121.

Hart, W. D., Stitt, J. H., Hohensee, S. R., and Ethington, R. L., 1987, Geological implications of Late Cambrian trilobites from the Collier Shale, Jessieville area, Arkansas: Geology, v. 15, (May), p. 447-450.

Hildenbrand, T. G., 1985, Rift structure of the northern Mississippi Embayment from the analysis of gravity and magnetic data: Journal of Geophysical Research, v. 90, no. 12, p. 607-622.

Hildenbrand, T. G., Kane, M. F., and Stauder, William, 1977, Magnetic and gravity anomalies in the northern Mississippi Embayment and their spatial relation to seismicity: U.S. Geological Survey Miscellaneous Field Studies Report MF-914, scale 1:1,000,000.

Hohensee, S. R., and Stitt, J. H., 1989, Redeposited *Elvinia* Zone (Upper Cambrian) trilobites from the Collier Shale, Ouachita Mountains, west-central Arkansas: Journal of Paleontology, v. 63, n. 6, p. 857-879.

Houseknecht, D. W., 1989, Earliest Paleozoic stratigraphy and facies, Reelfoot basin and adjacent craton, p. 25-42. *In* Gregg, J. M., Palmer, J. R., and Kurtz, V. E., eds., Field Guide to the Upper Cambrian of Southeastern Missouri--Stratigraphy, Sedimentology, and Economic Geology: Department of Geology and Geophysics, University of Missouri, Rolla.

Howe, J. R., 1984, Tectonics, sedimentation, and hydrocarbon potential of the Reelfoot aulacogen: Unpublished M.S. thesis, University of Oklahoma, Norman, 75 p.

Howe, J. R., and Thompson, R. L., 1984, Tectonics, sedimentation, and hydrocarbon potential of the Reelfoot rift: Oil and Gas Journal, v. 82, n. 46 (Nov. 12), p. 179-190.

Howe, W. B., Kurtz, V. E., and Anderson, K. H., 1972, Correlation of Cambrian strata of the Ozark and upper Mississippi Valley regions: Missouri Geological Survey and Water Resources Report of Investigations, no. 52, 60 p.

Johnston, A. C., and Kanter, L. R., 1990, Earthquakes in stable continental crust: Scientific American, v. 262, no. 3, p. 68-75.

Kurtz, V. E., 1971, Upper Cambrian Acrotretidae from Missouri: Journal of Paleontology, v. 45, n. 3, p. 470-476.

Kurtz, V. E., 1989, Correlation of Upper Cambrian strata in the subsurface of eastern Missouri, p. 73-83. *In* Gregg, J. M., Palmer, J. R., and Kurtz, V. E., eds., Field Guide to the Upper Cambrian of Southeastern Missouri--Stratigraphy, Sedimentology, and Economic Geology: Department of Geology and Geophysics, University of Missouri, Rolla.

Kurtz, V. E., Thacker, J. L., Anderson, K. H., and Gerdemann, P. E., 1975, Traverse in Late Cambrian strata from the St. Francois Mountains, Missouri to Delaware County, Oklahoma: Missouri Department of Natural Resources, Division of Research and Technical Information, Report of Investigations no. 55, 112 p.

Lochman-Balk, Christina, 1971, The Cambrian of the craton of the United States, p. 79-167, *in* Holland, C. H., Cambrian of the New World: Wiley-Interscience, New York.

McKeown, F. A., Hamilton, R. M., Diehl, S. F., and Glick, E. E., 1990, Diapiric origin of the Blytheville and Pascola arches in the Reelfoot rift, east-central United States: Relation to New Madrid seismicity: Geology, v. 18, (Nov.), p. 1158-1162.

McQueen, H. S., 1931, Insoluble residues as a guide in stratigraphic studies: Missouri Bureau of Geology and Mines, 56th Bienn. Report State Geologist, 1920-1930-1935-1936, p. 102-131.

Moore, G. K. and Brown, D. L., 1969, Stratigraphy of the Ft. Pillow Test Well, Lauderdale County, Tennessee: Tennessee Division of Geology, Report of Investigations No. 26, 2 p.

Palmer, A. R., 1962, *Glyptagnostus* and associated trilobites in the United States: U.S. Geological Survey Professional Paper 374-F, 49 p., 6 pls.

Palmer, A. R., 1965, Trilobites of the Late Cambrian Pterocephaliid Biomere in the Great Basin, United States: U.S. Geological Survey Professional Paper 493, 105 p., 20 pls.

Palmer, A. R., 1981, Subdivision of the Sauk sequence, p. 160-163, *in* Taylor, M. E., editor, Short Papers for the Second International Symposium on the Cambrian System: U.S. Geological Survey Open-File Report 81-743.

Palmer, J. R., 1989, Late Upper Cambrian shelf depositional facies and history, southern Missouri--Stratigraphy, sedimentology, and economic geology, p. 1-24. *In* Gregg, J. M., Palmer, J. R., and Kurtz, V. E., eds., Field Guide to the Upper Cambrian of Southeastern Missouri--Stratigraphy, Sedimentology, and Economic Geology: Department of Geology and Geophysics, University of Missouri, Rolla.

Schwalb, H. R., 1982, Paleozoic geology of the New Madrid area: Report NUREG/CR-2909 RA, Office of Nuclear Regulatory Research, U.S. Nuclear Regulatory Commission, Washington, D.C., 61 p.

Snyder, F. G., Williams, and others, 1965, Cryptoexplosive structures: in Missouri Guidebook, 1965, Annual meeting, Geological Society of America, Report of Investigation No. 30, State of Missouri Geological Survey and Water Resources, 73 p.

Stauder, William, 1982, Present-day seismicity and identification of active faults in the New Madrid seismic zone, p. 21-30. *In* McKeown, F. A., and Pakiser, L. C., eds., Investigations of the New Madrid, Missouri, earthquake region: U.S. Geological Survey Professional Paper 1236-C.

Swolfs, H. S., 1991, Structural characteristics in the Dow Chemical B. L. Garrigan #1, Mississippi County, Arkansas: Program with Abstracts, Louis Unfer, Jr. Conference on the Geology of the Mid-Mississippi Valley. Southeast Missouri State University, Cape Girardeau, Missouri, 5 p. (unnumbered).

Taylor, M. E., Collins, D. S., Palmer, A. R., and Repetski, J. E., 1991, Upper Cambrian biostratigraphic correlations in the Reelfoot basin, northeastern Arkansas: Program with Abstracts, Louis Unfer, Jr. Conference on the Geology of the Mid-Mississippi Valley. Southeast Missouri State University, Cape Girardeau, Missouri, 5 p. (unnumbered).

Walker, R. G., 1984, Turbidites and associated coarse clastic deposits, p. 171-188. *In* Walker, R. G., ed., Facies Models (2nd edition): Geoscience Canada, Reprint Series 1.

Wood, B. W., 1938, Insoluble residues of the Bonneterre Dolomite: University of Missouri, unpublished M.A. thesis, Columbia, Missouri, 50 p.

Wood, G. D., and Stephenson, J. T., 1989, Cambrian palynomorphs from the warm-water provincial realm, Bonneterre and Davis Formations of Missouri and Arkansas (Reelfoot Rift area): Biostratigraphy, paleoecology, and thermal maturity, p. 84-102. *In* Gregg, J. M., Palmer, J. R., and Kurtz, V. E., eds., Field Guide to the Upper Cambrian of Southeastern Missouri--Stratigraphy, Sedimentology, and Economic Geology: Department of Geology and Geophysics, University of Missouri, Rolla.