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Description of insoluble residues from the T.P. Russell No. 1 drill hole and other drill holes in southeastern Missouri

by

D.S. Collins[1] and R.A Bohm[2]

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[1]Denver, Colorado 80225

[2]Missouri Geological Survey
Department of Natural Resources
Rolla, Missouri 65401

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DESCRIPTION OF INSOLUBLE RESIDUES FROM THE T.P. RUSSELL NO. 1 DRILL HOLE AND OTHER DRILL HOLES IN SOUTHEASTERN MISSOURI

By D.S Collins and R.A. Bohm

INTRODUCTION

Three major earthquakes of estimated magnitudes greater than 8.0 on the Richter scale struck the New Madrid region in southeastern Missouri during the winter of 1811-12 (Johnston and Kanter, 1990). These earthquakes, collectively known as the New Madrid earthquakes, are reported to have affected about one million square miles of the Eastern United States (Fuller, 1912). Since those events, a relatively high level of seismicity continues from northeastern Arkansas through southeastern Missouri and into northwestern Tennessee, an area collectively known as the New Madrid seismic zone (Stauder, 1982). In the New Madrid seismic zone, seismic activity appears to be associated with structural highs, such as the Blytheville and Pascola arches, in the Reelfoot rift (Hildenbrand and others, 1977; Hildenbrand, 1985; Hamilton and McKeown, 1988). In this report, the area between the inferred boundaries of the Reelfoot rift will be referred to as the Reelfoot structural basin; the structural basin hosts in part the depositional basin outlined the Blytheville arch (fig. 1). The Reelfoot structural basin formed by rifting during the late Proterozoic and Early Paleozoic (Ervin and McGinnis, 1975; Schwalb, 1982). The resulting Reelfoot depositional basin received sediment during the early Paleozoic and underwent structural reversal sometime after the Ordovician (McKeown and others, 1990). Sediments filling the Reelfoot depositional basin are Cambrian and Ordovician in age. Youngest Paleozoic rocks are separated from the overlying Upper Cretaceous and younger sedimentary rocks by an unconformity.

This report seeks to clarify characteristics of the lower Paleozoic stratigraphic units in the Reelfoot structural basin and to help facilitate an understanding of the geologic framework of the New Madrid seismic zone.

This report contains mineralogic and petrographic descriptions of acid insoluble residue data from the Strake Petroleum--T.P. Russell No. 1 drill hole (hereafter, Strake) and compares these data to insoluble residue data from the Dow Chemical No. 1 Garrigan (hereafter, Garrigan) and O.W. Killam -- K. Pattinson No. 1 (hereafter, Killam) drill holes. This report also compares the stratigraphies of these drill holes to the stratigraphy of the Dow Chemical No. 1 Wilson drill hole (hereafter, Wilson) and relates some of the data to the stratigraphic and tectonic history of the Reelfoot basin.

The Strake drill hole is located on the southeastern edge of the Missouri platform near the northwestern margin of the Reelfoot structural basin in sec. 24, T. 19 N., R. 11 E., Pemiscot County, Missouri (fig. 1). Drilling was completed September 1941 from a ground elevation of 271 ft to a total depth of 4740 ft.

PREVIOUS STUDIES

The following is a reevaluated version of previous stratigraphic investigations which were summarized by Collins and others (1992).

Houseknecht (1989) assigns the oldest rocks in the Reelfoot structural and depositional basins to the Cambrian and includes the following units: the Reelfoot Arkose (Cambrian? age; Palmer, 1989), the St. Francis Formation (Middle Cambrian?), the Lamotte Sandstone (upper Middle to lower Upper Cambrian), the Bonneterre Formation (lower to middle Upper Cambrian), and the Elvins Group (middle Upper Cambrian).

PRE-BONNETERRE ROCKS

The Reelfoot Arkose of Houseknecht (1989) is known only in 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 predominantly of sandstone in the northern part of the Reelfoot structural and depositional basins and is inferred to grade laterally to carbonates in the

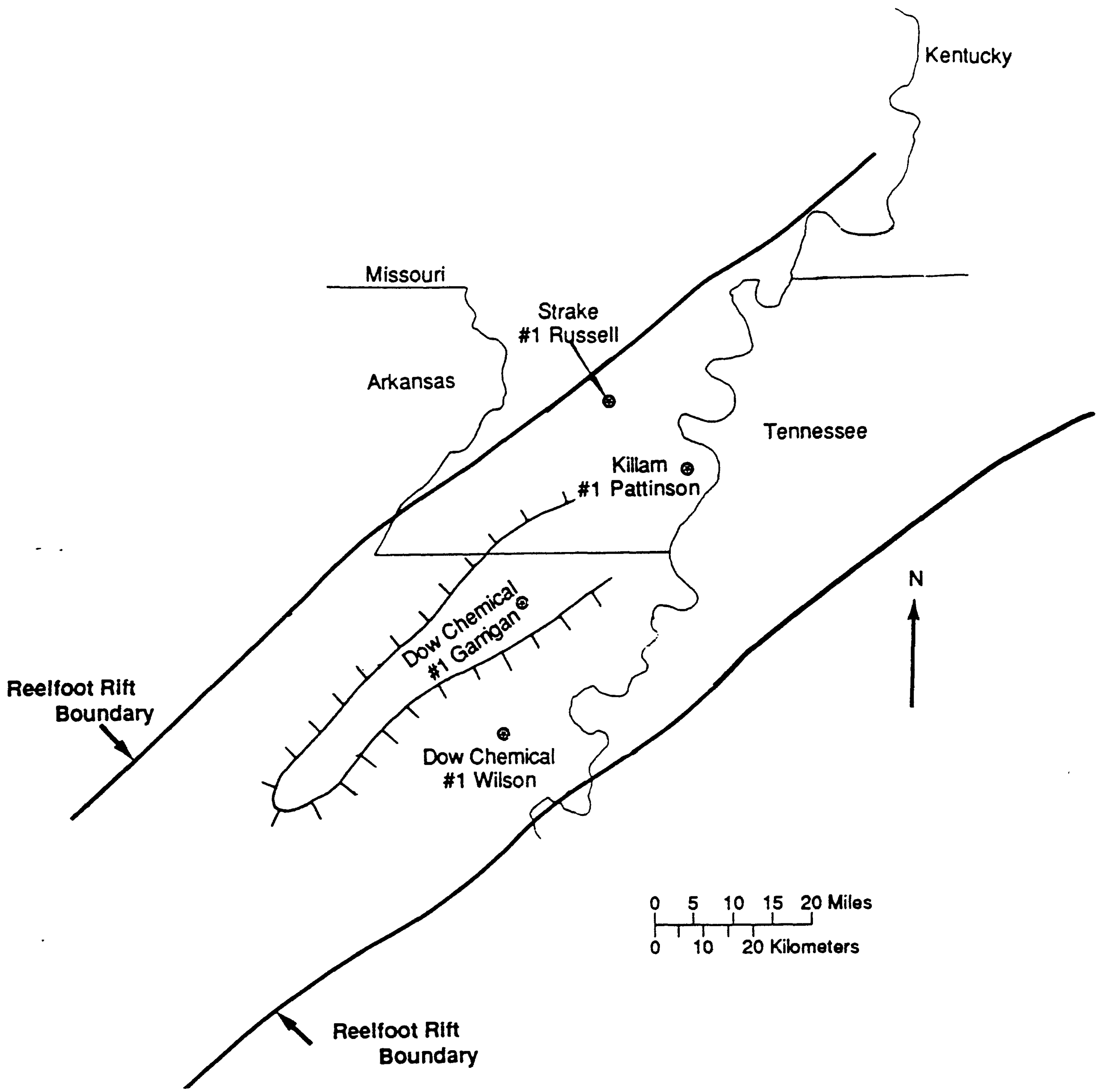


FIGURE 1.--Generalized map of part of the Reelfoot rift showing location of drill holes described in text. Hatch line outlines Blytheville arch. Modified from McKeown and others (1990).

southern part of the structural 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 southern 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 the following three members: an unnamed lower member, the Sullivan Siltstone Member, and the Whetstone Creek Member. According to Kurtz (1989) the unnamed lower member is divided into two informal units: (1) a lower unit composed of basinal shale and mudstone-wackestone ribbon rock that indicates a shallowing upward sequence; and (2) an upper unit composed of mixed glauconitic, skeletal and oolitic wackestone, packstone, grainstone.

The Sullivan Siltstone Member consists of laminated calcareous siltstone, local bioturbated intraclast lime conglomerate with minor amounts of glauconite. Overlying the Sullivan Siltstone Member, the Whetstone Creek Member consists of moderately glauconitic, interbedded lime wackstone and grainstone (Kurtz, 1989).

In the Reelfoot structural 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. South of the Missouri Bootheel and in the Reelfoot structural basin of northeastern Arkansas the Bonneterre Formation is described as sandstone, siltstone, and black shale that grade to platform carbonate rock to the southeast and east (Howe, 1984; Taylor and others, 1991; Collins and others, 1992).

ELVINS GROUP

The Upper Cambrian Elvins Group overlies the lower and middle Upper Cambrian Bonneterre Formation and underlies the upper part of the Potosi Dolostone (Grohskopf, 1955; Howe and other, 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 in the Reelfoot basin, has been characterized as 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 structural 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 used by Grohskopf (1955) and Kurtz and others (1975) for making this distinction are summarized in figure 2*A* and their sample traverses relative to the Reelfoot basin is presented in figure 2*B*. Collins (1991) found that insoluble residues could not be used to correlate between formations on the platform to formations in the Reelfoot depositional basin. Collins (1991) also found that insoluble residues could not differentiate formations in this basin (see Collins and others, 1992). However, these data do provide information on provenance that allows interpretation of sediment source terrane during and after the development of the Reelfoot rift.

STRATIGRAPHY OF THE STRAKE, GARRIGAN, KILLAM, AND WILSON DRILL HOLES

Grohskopf (1955) described the subsurface stratigraphy and correlated Paleozoic rocks in the northern part of the Reelfoot structural 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), Taylor and others (1991), and Collins and others (1992) described and assigned ages to lower Paleozoic rocks of the Reelfoot depositional basin and vicinity. Because of the sparse biostratigraphic data, age interpretation of the Ordovician and Cambrian boundary is based on lithologic changes (Grohskopf, 1955, p. 83). Josiah Bridge (in Grohskopf, 1955, p. 85) tentatively identified trilobites in core from 3229 to 3235 ft in the Strake drill hole as belonging to the *Crepicephalus* biozone of the Middle Dresbachian Stage of Upper Cambrian age. Similar fossils are known in outcrops of lower Bonneterre Formation in Missouri and the Nolichucky Shale of the Appalachian Valley area of eastern Tennessee (Josiah Bridge in Grohskopf, 1955).

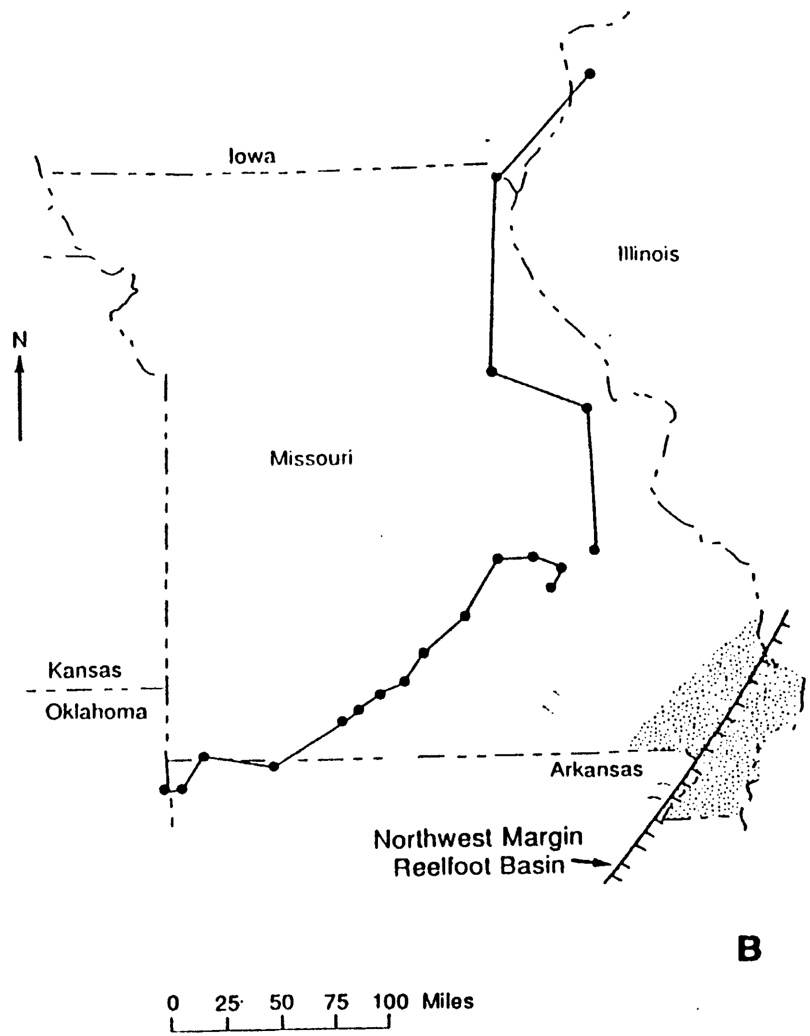
Rocks penetrated in the Strake drill hole include dolostones of the Ordovician Eminence/Potosi Formation (undifferentiated), limestones and dolostones of the Cambrian Elvins Group?, limestones of the Cambrian Bonneterre Formation, and quartzites of the Cambrian Lamotte Sandstone (Grohskopf, 1955, p. 82-83). The sub-Cretaceous unconformity is at 2074 ft and is in contact with the Eminence/Potosi Formation (undifferentiated) of Upper Cambrian age (Grohskopf, 1955).

The Garrigan drill hole is located in the NW¼NW¼ sec.28, T.15 N., R. 10 E., Mississippi County, Arkansas (fig. 1) in the Reelfoot depositional basin. Drilling was completed April 11, 1982, from a ground elevation of 239 ft to a total depth of 12,038 ft. Howe (1984) describes the stratigraphy of the Garrigan drill hole as being predominantly shale, siltstone, and sandstone. Taylor and others (1991) and Collins and others (1992) have demonstrated that most of these rocks are age equivalents of the Knox or Arbuckle Group and some of the rocks are age equivalents of the Bonneterre Formation.

Drilling of the Killam drill hole, located in the SW¼ sec. 33, T.18 N., R. 13 E., Pemiscot County, Missouri, was completed November 17, 1941, from a ground elevation of 263 ft. The Killam is about 50 km northeast of the Garrigan and along strike of the Blytheville arch and is probably in the Reelfoot depositional basin (fig. 1). Grohskopf (1955) describes the Paleozoic rocks in the Killam as hard, black, dolomitic shales that begin at a depth of 2712 ft. This depth marks the sub-Cretaceous unconformity with underlying shale that is interpreted as part of the Bonneterre Formation, the only Paleozoic rocks encountered in the drill hole (Grohskopf, 1955). Grohskopf bases this interpretation only on rock characteristics and insoluble residues. Palmer (1989) made an east-west facies reconstruction of the Upper Cambrian rocks across the southern Missouri and the northwest side of the Reelfoot structural basin using the Killam drill hole as his control for the Blytheville arch, the northeastern part of the depositional basin. Palmer interprets the black shales of the Killam drill hole to be part of the Bonneterre and Davis formations. This implies that these rocks of the Killam drill hole are no younger than the lower part of the Upper Cambrian Franconian Stage (Collins and others, 1992). Like Grohskopf's interpretation, Palmer's interpretation is also based only on lithology.

	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.

A



B

FIGURE 2.--2*A*. 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). 2*B*. General area of samples used in fig. 2*A*: solid circles, Kurtz and others (1975); stipple pattern, Groskopf (1955); hatch line is approximate position of northwest margin Reelfoot basin. (After Collins [illegible])

Completed on July 8, 1981, the Wilson drill hole reached a depth of 14,868 ft from a ground elevation of 225 ft. The Wilson is located in sec. 14, T. 12 N., R. 9 E., in Mississippi County, Missouri. Howe (written commun., 1991) describes the majority of the Paleozoic lithology of the Wilson as being carbonate and the lower part being mainly siliciclastic. Howe (1984) believed that the Wilson lithic section was a part or a continuation of the Garrigan lithic section and combined the two sections. Howe used lithic changes to differentiate between group and formations. Based on fossil evidence, Taylor and others (1991) and Collins and others (1992) concluded that the carbonate section in the Wilson to be age equivalent to the Knox or Arbuckle Group equivalents and the upper part of the underlying siliciclastics to be age equivalent to the Bonneterre Formation.

The predominantly limestones and dolostones 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). At least part of the shales, sandstones, and siltstones of the northeastern portion of the Blytheville arch represent deep water deposits that grade to the adjacent platform carbonate facies (Collins and others, 1992).

METHODS OF STUDY

Insoluble residuum from the Strake was reevaluated in an attempt to correlate the Upper Cambrian Elvins Group and Bonneterre Formation to similar aged rocks in other drill sites, information that is important for developing an understanding of the stratigraphic and tectonic history of the Reelfoot basin and adjacent areas. Results of the insoluble residue analysis are given in table 1.

The insoluble residue samples were originally prepared about 1941 by the State Geological Survey of Missouri following the methods described by McQueen (1931) and Grohskopf and McCracken (1949). In this method, cuttings and core samples were collected every 5 ft for the depth of the drill hole. Six normal HCl was used to digest these samples to acquire the insoluble fraction. Later, M.B. Goldhaber of the U.S. Geological Survey selected 59 of these insoluble residue samples from 2,280 ft (in the Paleozoic lithologies) to 4,740 ft, the bottom of the drill hole. Goldhaber used these samples for a chemical evaluation in an ore genesis study of Mississippi Valley ore deposits. Goldhaber combined some of these samples into as much as 100 foot intervals. After Goldhaber finished his study, we received the unused splits to conduct our investigation. Each of the 59 sample splits were weighed, then bathed in bromoform (spg 2.89) in order to separate each split into a light and heavy fraction. After rinsing the separates in acetone to remove the bromoform, each sample was dried and weighted. After weighing, both the light and heavy fractions were logged.

Identification of mineral and rock fragments was by binocular microscope for the light fractions; whereas, petrographic microscope and scanning electron microscope (SEM) were used to identify minerals and rock fragments in the heavy fractions. The Rock Color Chart distributed by the Geological Society of America (Goddard, 1975) is the reference that was used to define the rock colors. Because identification of mineral grains by color alone was found to be misleading, it was impossible to estimate the percentages for most minerals in each sample interval without identifying each mineral grain. Identification of each mineral grain is beyond the scope of this study; therefore, only the interval limits of most minerals will be provided to indicate their distribution in the rocks of the Strake drill hole.

INSOLUBLE RESIDUES

Strake Drill Hole

Analyses of the heavy fraction of insoluble residue samples from the Strake were made in an attempt to correlate the Upper Cambrian Elvins Group and Bonneterre Formation to those in other drill sites. This information is important for developing an understanding of the stratigraphy and tectonic history of the Reelfoot structural basin and adjacent areas. Results of the insoluble residue analyses are given in table 1.

The following is a list and description of the minerals and rock fragments identified in both the light and heavy fractions of the insoluble residue samples from the Strake drill hole. The sample intervals listed in the mineral and rock descriptions below are summarized in table 1.

Light Fraction

The light fraction forms between 79 and 100 volume percent of the insoluble residue samples. Appendix 1 presents a description of the amounts and types of mineral and rock fragments in each sample interval.

The most common rock fragments found are siltstones, sandstone, mudstone, and shale. Mafic rock fragments in the light fractions roughly correspond to the heavy fraction intervals that also have mafic rock fragments. This may be a result of degree of alteration and/or the time allowed for settling (20 min per-sample with agitation every 5 min) in the heavy liquid. The alteration of the mafic rock fragments would cause a loss in density and/or a short settling time would prevent all of the mafic rock fragments from settling out within 20 min. Among the mineral grains found, only quartz grains are consistently present in varying amounts throughout the intervals. They range in size from silt to very coarse sand size and are well rounded to subangular. In some samples, quartz grains form as much as 95 percent of the light fraction. Trace amounts of dark green glauconite, mica, and chert are also present. Fragments of crinoid stems were the only fossils found. They were present in only interval 2305-2310 ft. Mary Hundhausen (McCracken), H.S. McQueen, and J.G. Grohskopf logged the insoluble residues in 1941 which were later correlated to the platform rocks in southeastern Missouri (Grohskopf, 1955; Kurtz, 1975; R.A. Bohm, unpublished data, 1992). It is possible that some of these loose grains are a contaminate from younger units that occurred during drilling. The light fraction will not be further discussed in this study because Grohskopf (1955) and other works have interpreted its significance for correlation to other platform rocks.

Heavy Fraction

The sample intervals listed in the heavy mineral and rock descriptions below are summarized in table 1. The heavy fraction forms between 0.6 and 19.5 volume percent of the insoluble residue samples. The following is a list of the mineral and rock fragments identified in the heavy fraction of each split.

Mineral Grains

Pyrite. Pyrite is found in almost every interval in trace amounts (less than 1%) to as much as 65% of the heavy residue fraction. It occurs as either framboid (rare), masses, simple cubes, pyritohedrons, octahedrons, diploids, or as fragments of these grains. Pyrite is present in most of the intervals from 2455-2460 ft down to the bottom of the drill hole.

Chalcopyrite. Trace amounts of angular chalcopyrite grains were identified in intervals 3430-3475 ft and 4705-4740 ft.

Galena. Rounded, etched galena grains were found in intervals 2530-2545 ft and 3905-3950 ft. A white, angular grain from interval 3030-3050 ft is a mixture of clay, hornblende(?), pyrite, and galena.

Garnet. The garnets are dominantly angular; subrounded to rounded grains are rare. Colors include pink, pinkish-orange, orange, and red. The pink grains are most abundant (33 percent of the heavy fraction) in the 2405-2410 ft interval and present in variable amounts throughout the majority of the section. The pinkish-orange variety occurs in variable amounts from interval 2315-2320 ft down to about the 3215-3225 ft interval and is present only in trace amounts in intervals 3630-3645 ft and 4510-4550 ft. Orange garnets are present in variable amounts from trace to 5 percent of the heavy fraction above the 3530-3575 ft interval and only in trace amounts in intervals 3655-3700 ft and 3705-3750 ft. Red garnets are only noted in intervals 2325-2330 ft, 2630-2645 ft, 2670-2685 ft, 2900-2925 ft, and 3105-3125 ft. No garnets were found in intervals 3230-3300 ft, 3650 ft, 3755-3800 ft, 3810-3900 ft, 4560-4600 ft, and 4705-4740 ft.

Hornblende. Hornblende grains vary from angular to well rounded and are either yellowish-green, very dark green (black in appearance), or emerald green. These colors are also characteristic of augite, epidote, and tourmaline; thus making visual identification of specific mineral species impossible. Some hornblende grains are elongate and a few are crystal fragments (broken grains with crystal faces) . Hornblende is present in almost every interval in varying amounts from trace levels to as much as 15 percent of the heavy fraction. Intervals that appear to lack hornblende include 2208-2290 ft, 2305-2310 ft, 2360-2370 ft, 2815 ft, 3105-3125 ft, 3755-3800 ft, 4510-4550 ft, 4560-4600 ft, and 4705-4740 ft.

Staurolite. Staurolite is angular to subrounded and is either reddish brown, orangish amber, or orange. Some of these colors are very similar to garnet, rutile, or tourmaline. Staurolite is nowhere abundant (less than 1 percent of the heavy fraction) and is found between intervals 2280-2290 ft and 3380-3470 ft.

Augite. Augite or augitic pyroxene is the only pyroxene identified. It is angular to rounded and is white, smoky-gray, or more commonly greenish-yellow. The smoky-gray and greenish-yellow varieties can be confused with similar colors of hornblende and tourmaline: Several of the augite grains are etched and show individual spear-point crystal laths parallel to the C-axis of the grains. This apparent crystal habit gives rise to a hacksaw termination which is a result of intrastratal solution (fig. 3; Pettijohn, 1975). Augite forms less than 1% of the heavy fraction and was identified in some depths between interval 2315-2320 ft and the bottom of the drill hole.

Mica. Three color varieties of mica were found, but all have limited vertical distribution. These include brownish-amber, reddish brown, white, and a black variety. Semiquantitative-composition by SEM of the brownish-amber mica is that of phlogopite and is about 1% of the heavy fraction in interval 3130-3150 ft. Reddish-brown mica is present in trace amounts in interval 2690 ft, 2870-2895 ft, 2900-2925 ft, 2930-2950 ft, 3180-3200 ft, 3215-3225 ft, 3310-3375 ft (1%), 3380-3475 ft and 4705-4740 ft. The black mica is present in interval 3905-3950 ft. White mica forms about 1% of the heavy fraction in interval 4560-4600 ft and is present in angular, white grains mixed with clay (about 1% of the heavy fraction) in interval 2815 ft.

Epidote. Three species of epidote found include epidote, clinozoisite, and zoisite. These species can be white or light yellow, but more commonly are greenish-yellow and range from angular to well rounded in roundness. Some are pitted and/or have hacksaw terminations similar to that described for augite grains above. The white variety appears to be only characteristic of rounded aggregates composed of individual crystal grains of epidote. These grains collectively create a sugary appearance to the texture of the aggregate grains. Other epidote grains are separate and discrete crystal grains. Epidote is most abundant, about 6% of the fraction, in interval 2325-2330 ft. It also occurs in lesser amounts in most intervals from 2295-2300 ft to 3905-3950 ft.

Clinozoisite. Present in intervals 2710-2755 ft, 3030-3050 ft, and 3155-3175 ft as rounded to subrounded grains.

Zoisite. Only one rounded grain of zoisite from interval, 2690 ft, was identified.

Because both clinozoisite and zoisite are similar in color to epidote and to other mineral species in plane light, it is not known how abundant the members of the epidote group are throughout the Strake sample intervals.

Anatase. Anatase, a trimorph with rutile and brookite, is present in only trace amounts and commonly as angular grains. Identification of one crystal, found at 3655-3700 ft, however, is based only on SEM and crystal habit. Other intervals that have anatase include 2280-2290 ft and 3005-3025 ft.

Rutile. Rutile is present as reddish-orange and deep red angular to rounded grains in intervals 2325-2330 ft, 2390-2400 ft, 2405-2410 ft, 2530-2545 ft and 3005-3025 ft.

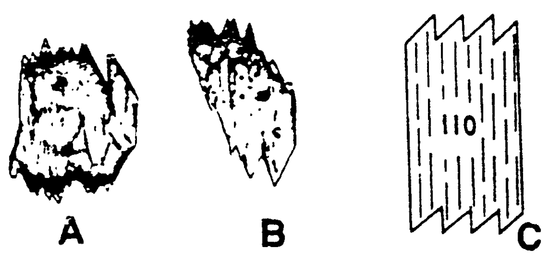


FIGURE 3.--Drawings showing terminations caused by intrastratal solution. A and B: detrital augite; C: drawing of the hacksaw structure parallel to (110) form of a detrital augite. (After Edelman and Doeglas, 1931).

Brookite. A trimorph of rutile and anatase, was specifically identified in intervals 3105-3125 ft, 3655-3700 ft, and 4705-4740 ft. Crystal fragments of brookite (one in a quartz grain) are present in the first two intervals and an angular grain in the last interval.

Anatase, Rutile, and Brookite (Undifferentiated). These minerals were identified only by SEM and due to time allowed for this study were not separated into specific species such as rutile, anatase, or brookite by optical analysis. These grains are generally a red color and are rounded to angular. They occur in some intervals below 2510-2525 ft, 2630-2645 ft, 3180-3200 ft, 4560-4600 ft, and 4705-4740 ft.

Zircon. Three color varieties of zircon are present: pink, red, and white. Most are complete, doubly terminated crystals or fragments of crystals. Some are elongate and rounded grains. Nowhere is this mineral abundant (greater than 3%) and is commonly present in only trace amounts in the heavy fraction. It is found in most intervals from 2315-2320 ft to 3655-3700 ft.

Kyanite/sillimanite. These minerals occur as angular to subangular, white grains. Because these minerals are polymorphs, it is impossible to distinguish them apart by SEM or by color. Only a few were confirmed by optical microscope analysis because of the amount of time required to identify each grain. The intervals that have kyanite and sillimanite are listed, but where these minerals have not been specifically identified, kyanite with a query in table 1 will be used because kyanite appears to be the most common of the two species identified. Kyanite and/or sillimanite are in most intervals from 2315-2320 ft to 3380-3525 ft.

Tourmaline. Tourmaline occurs in angular to rounded grains as well as in crystal fragments or complete crystals. Colors include black, yellowish-brown, dark olive, olive, and "rootbeer". These colors can be confused with similar colors of hornblende. Tourmaline is usually less than 1% of the heavy fraction and is present in some of the intervals between interval 2315-2320 ft and interval 3810-3900 ft.

Chromite. This mineral was found only in intervals 2335-2340 ft and 3155-3175 ft as black metallic, subrounded to rounded grains. One octahedral crystal was identified in interval 3655-3700 ft.

Tungsten minerals. Only identified by SEM. They include compositions that may represent wolframite (interval 2305-2310 ft and 2315-2320 ft), tungstite(?) (intervals 2335-2340 ft-mixed with quartz, 2405-2410 ft, 2510-2525 ft, 2530-2545 ft, 3005-3025 ft), and scheelite(?) (intervals 2420-2430-mixed with clay and quartz, 3030-3050 ft-mixed with pyrite and clay, 3580-3625 ft). The wolframite at interval 2305-2310 ft forms octahedral crystals. Because wolframite occurs as monoclinic crystals, the octahedron habit suggests that it is a pseudomorph after scheelite. The tungstite grains are angular and white and have surface textures that appear as dried, desiccated clay.

Barite. Barite occurs as white, angular-to-rounded grains that are present in intervals 3180-3200 ft to the base of the drill hole. It is most abundant in interval 3655-3700 ft where it forms 15% of the heavy fraction. Barite is also in a few of the intervals above interval 3180-3200 ft.

Dolomite. A few grains of dolomite were identified from intervals 2570-2585 ft, 3310-3375 ft--mixed with quartz, and 3655-3700 ft. These grains are angular and white.

Apatite. One angular fragment of fluorine bearing apatite mixed with clay and pyrite was found in interval 3430-3475 ft.

Unidentified mineral. In a number of the intervals is a well rounded to rounded, greenish-gray, fine-crystalline mineral(?) grain that appears to be serpentine under plane light. However, SEM semi-quantitative analysis indicates that this mineral is an amphibole, perhaps altered to slightly-altered hornblende. Optical analysis is inconclusive because of its fine, fibrous nature upon fracturing. The intervals containing this mineral range from 2295-2300 ft down to and including interval 3905-3950 ft.

Iron oxides. Magnetite, ilmenite or mixtures of these phases are present in almost all the sampled intervals. They occur as black metallic grains that are generally angular, but also range from angular to rounded. One magnetite crystal was found in interval 3180-3200 ft. A few grains of reddish hematite(?) are present in 3 intervals. These mineral species are found in most intervals from 2305-2310 ft to the bottom of the drill hole.

An unidentified iron oxide that forms earthy, limonitic yellow, grooved, curling, cylindrical grains similar to rams horn selenite, and a glassy, reddish-orange to red iron oxide that cements and coats metallic and quartz grains are found in some intervals form the top of the sampled section to the bottom of the drill hole. Both types of iron oxide vary from trace to as much as 62 percent.

Fluorite. Fluorite was searched for during this study but was not found or perhaps could have been over looked. Color was not used during the search because this characteristic is not definitive and could be mistaken for almost any mineral. However, Grohskopf (1955) and R.A. Bohm (unpublished data, 1991) reported fluorite in a sample from 2700 ft. Residuum from this sample at the Missouri Geological Survey contained single, white, transparent cubes of fluorite.

Rock Fragments

Both sedimentary and igneous rock fragments are present in the heavy fraction of the Strake drill hole insoluble residues. The following is a preliminary description of these fragments by interval.

Sedimentary rocks. Sandstone, siltstone, shale, and mudstone comprise the types of sedimentary rocks fragments identified. The sandstone fragments are composed of angular to subrounded, very fine-to-medium sand size grains of quartz. Some sandstones have hematite(?) or magnetite grains and a few have garnet (rare-interval 2360-2370 ft) fragments. Pyrite appears to be a granular cement in some fragments and as separate grains in other fragments. Silt-sized grains of quartz(?), commonly white, are also present in some sandstone fragments. Colors of the sandstones include red (stained by iron oxide) and most commonly, white. Intervals that have sandstone included the following: 2280-2290 ft (about 60%), 2295-2300 ft (8%), 2305-2310 ft (less than 1%), 2325-2330 ft (trace), 2360-2370 ft (25%), 2375-2385 ft (trace), 2390-2400 ft (3%), 2590-2605 ft (1%), 2630-2645 ft (0.5%), 2670-2685 ft (trace), 2690 ft (2%), 2710-2755 ft (about 5%), 2760-2810 ft (trace), 3005-3025 ft (4%), 3030-3050 ft (1%), 3310-3375 ft (19%), 3430-3470 ft (1%), 3905-3950 ft (trace), 4560-4600 ft (1%), 4605-4650 ft (5%), and 4705-4740 ft (trace).

Shale fragments are light to medium gray and are present in intervals 2375-2385 ft (trace), 3310-3375 ft (5%), 3430-3470 ft (38%), 4605-4650 ft (less than 1%), and 4705-4740 ft (15%). Some shale fragments have pyrite (interval 3430-3470 ft) or mica (interval 2325-2330 ft).

Light gray mudstone is present only in interval 2280-2290 ft and is about 0.5% of the heavy fraction. Siltstone is present in the majority of the intervals. Colors of this rock fragment include white and light to medium gray. Pyrite as granular masses or discrete crystals is commonly found in the white variety of siltstone. The following intervals have siltstone fragments: 2280-2290 ft (2%), 2295-2300 ft (40%), 2305-2310 ft, 2315-2320 ft, 2325-2330 ft (31%), 2375-2385 ft (trace), 2570-2685 ft (15%), 2590-2605 ft (1%), 2610-2625 ft (1%), 2650-2665 ft (trace), 2670-2685 ft (44%), 2690 ft (1%), 2710-2755 ft, 2930-2950 ft, 3005-3025 ft (29%), 3030-3050 ft (5%), 3055-3075 ft (35%), 3105-3125 ft (30%), 3155-3175 ft (6%), 3180-3200 ft (46%), 3225-3215 ft (20%), 3310-3375 ft (19%), 3430-3470 ft (26%), 3480-3525 ft (44%), 3130-3150 ft (20%), 3580-3625 ft (29%), 3630 ft (20%), 3650 ft, 3810-3900 ft (20%), 3905-3950 ft (8%), 4510-4550 ft (94%), 4560-4600 ft (20%), 4506-4650 ft (trace), and 4705-4740 ft (trace).

Igneous rocks. Igneous rock fragments are generally white or green with dark mafic minerals. The white color appears to be altered feldspar. The green color is either a result of pyroxene or amphibole. The darker colored (some almost black) mafic minerals are amphiboles, pyroxenes, and reddish-brown mica (phlogopite?). These minerals are derived from mafic rocks from, perhaps, dikes. Intervals that have igneous rock fragments include

2325-2330 ft (7%), 2375-85 ft (trace), 2650-2665 ft (trace), 2690 ft (trace), 2760-2810 ft (trace), 2815 ft (97%), 2845-2865 ft (98%), 2870-2895 ft (33%), 2900-2925 ft (3%), 2930-2950 ft (1%), 3005-3025 ft (15%), 3225-3215 ft (20%), 3230-3300 ft (98%), 3580-3625 ft (79%), 3650 ft (49%), 3655-3700 ft (96%), 3905-3950 (2%), 4605-4650 ft (trace), and 4705-4740 ft (trace). Grohskopf (1955, p. 83) notes basic dike material at 2700 ft, from 2821 ft to 2920 ft, from 3100 ft to 3130 ft, at 3650 ft, and from 4250 ft to 4275 ft. The igneous dike material at 2700 ft contains brown mica, fluorite, serpentine, chlorite, and hornblende. Serpentine is the only mineral identified in the igneous dike material at 3650 ft. Grohskopf (1955) does not describe the minerals found in the other igneous dike occurrences listed above.

Garrigan Drill Hole

The insoluble residue amounts and types were determined for the Garrigan drill hole lithology by Collins (1991) and Collins and others (1992). They report that feldspars, clay minerals, apatite (rare), ankeritic dolomite and dolomite, barite, pyroxene (very rare), "iron stone" (a limonite-coated, rounded, and polished clay "nodules"), pyrite, magnetic grains, chert, quartz, and glauconite were the only mineral grains found. These mineral grains occur in trace amounts to as much as 0.5% of the total insoluble residue fraction. Rock fragments consisting mainly of shaley claystone, mudstone, siltstone, and minor amounts of sandstone, graywacke, and quartzite constitute as much as 100% of the insoluble fraction. No igneous rock fragments were identified in this study.

Killam Drill Hole

The insoluble residues from the Cambrian rocks (the only Paleozoic rocks reported in the Killam (Grohskopf, 1955) are mainly siliciclasts, black dolomitic shales with about 10% black, soluble dolomite. The early descriptions of the insoluble residues by H.S. McQueen, J.G. Grohskopf, and D.R. Stewart (all of the Missouri State Geological Survey) reported the insoluble residuum to be only fragments of siderite and black shale. A cursory inspection of the original cuttings found that some of the shale fragments are micaceous. The micas are white (muscovite?) and are not definitive of a specific rock source. A few reddish-brown mica grains were also found. These grains appear to be biotite, but because they are loose grains, it is not certain of their original position in the Paleozoic section. Dark green glauconite is also present as loose grains and in a silty matrix. Similar dark green glauconite grains are present in intervals 2740-2860 ft, 2980-3040 ft, 3160-3220 ft, 3400-3460 ft, 3580-3640 ft, 4180-4240 ft, and 4360-4420 ft) of the upper Paleozoic section in the Garrigan drill hole (Collins and others, 1992) and in a few sample intervals from the Strake drill hole. It is possible that these glauconite grains are a contaminate derived from the overlying Cretaceous sedimentary units where similar glauconite grains are found (R.A. Bohm, personal commun. to D.S. Collins, 1991). 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.

Wilson Drill Hole

J.E. Repetski conducted an insoluble residue study for conodont fossils in drill cuttings from the Wilson drill hole and summarized his findings in Taylor and others (1991) and in Collins and others (1992). However, the rock and mineral fragments of the residuum were not reported. Drill-hole cuttings from the Wilson were not available for this study; therefore, it is not known what types of insoluble residues were found.

PALEONTOLOGY

No fossils were found during this study of the insoluble residues from the Strake drill hole; however, earlier workers have reported fossils in their studies of the Strake as well as for the Wilson, Garrigan, and Killam drill holes. The following descriptions are of the more important and applicable fossils to this study. With the exception of the Killam, a more detailed summary of fossil occurrence from the following drill holes is provided by Collins and others (1992).

FOSSILS OF THE STRAKE DRILL HOLE

In the Strake, *Coosella* from 3231 ft and *Acrotreta* from 3165 ft were identified by Josiah Bridge (in Grohskopf, 1955). These fossils are known to occur in outcrops of the lower Bonneterre Formation in Missouri and in the Nolichucky Shale of the Appalachian Valley area in eastern Tennessee (Josiah Bridge in Grohskopf, 1955, p. 85). Coosella is assigned to the *Crepicephalus* biozone of the Dresbachian Stage (Moore, 1959, p. 0309; see also Kurtz and others, 1975, p. 4) and is correlated with the unnamed lower carbonate member of the Bonneterre Formation (Kurtz, 1989) and to overlying rocks of the middle Sullivan Siltstone Member of the Bonneterre Formation (see Kurtz and others, 1975, p. 4). *Acrotreta* is a member of a group of inarticulate brachiopods that are long-ranging in the Upper Cambrian and Lower Ordovician (Moore, 1965, p. H276).

FOSSILS OF THE GARRIGAN DRILL HOLE

The few fossils found in the Garrigan drill hole were identified by M.E. Taylor and R.E. Repetski (Taylor and others, 1991; Collins and others, 1992). The important fossils reported include an aphelaspidinid (trilobite) and conodonts. According to M.E. Taylor (in Collins and others, 1992, p. 27), the trilobite has similar features to *Aphelaspis*, but preservation was too poor for identification more detailed than to subfamily. This trilobite group ranges from the upper part of the Dresbachian Stage to the lower part of the Franconian Stage of Upper Cambrian age and is no older than the *Aphelaspis* Zone and no younger than the *Elvinia* Zone. These zones are equivalent to rocks ranging from the Sullivan Siltstone Member and Whetstone Creek Member of the Bonneterre Formation to rocks of the lower part of the Davis Formation of the Elvins Group (Collins and others, 1992). The trilobite fossils are from 7,986 ft in the Garrigan. The highest Cambrian conodont (*Proconodontus* sp.) samples occur at 4060 ft and the lowest Ordovician sample occurs at 3,640 ft (Taylor and others, 1991, and Collins and others, 1992, p. 26, p. 32-33).

FOSSILS OF THE WILSON DRILL HOLE

Trilobite assemblages of the Wilson includes Proconodontus sp. of undifferentiated Upper Cambrian age from about 10,860 ft (Grohskopf, 1955). The lowest Ordovician conodonts occur at 3,640 ft (Taylor and others, 1991, analysis by J.E. Repetski).

FOSSILS OF THE KILLAM DRILL HOLE

The drill hole log for the Killam rocks does not record the occurrence of fossils (see Grohskopf, 1955, p.88-89) nor does the insoluble residue log of H.S. McQueen, J.G. Grohskopf, and D.R. Stewart. However, a cursory investigation by D.S. Collins of the original Killam cuttings found fragments of sponge spicules, pelecypod valves, and crinoid stems of Cretaceous age or younger. Paleozoic fossils were not found in this cursory study.

BIOSTRATIGRAPHIC CORRELATIONS

The Upper Cambrian trilobite assemblage from 7,986 ft in the Garrigan drill hole roughly correlates to the trilobite assemblages in the carbonate shelf deposits at 10,860-11,100 ft in the Wilson drill hole (Collins and others, 1992, p. 32). However, both the Wilson and the Garrigan trilobite assemblages are slightly younger than the trilobite occurrence at about 3231 ft in the carbonate shelf rocks of Strake drill hole (fig. 4).

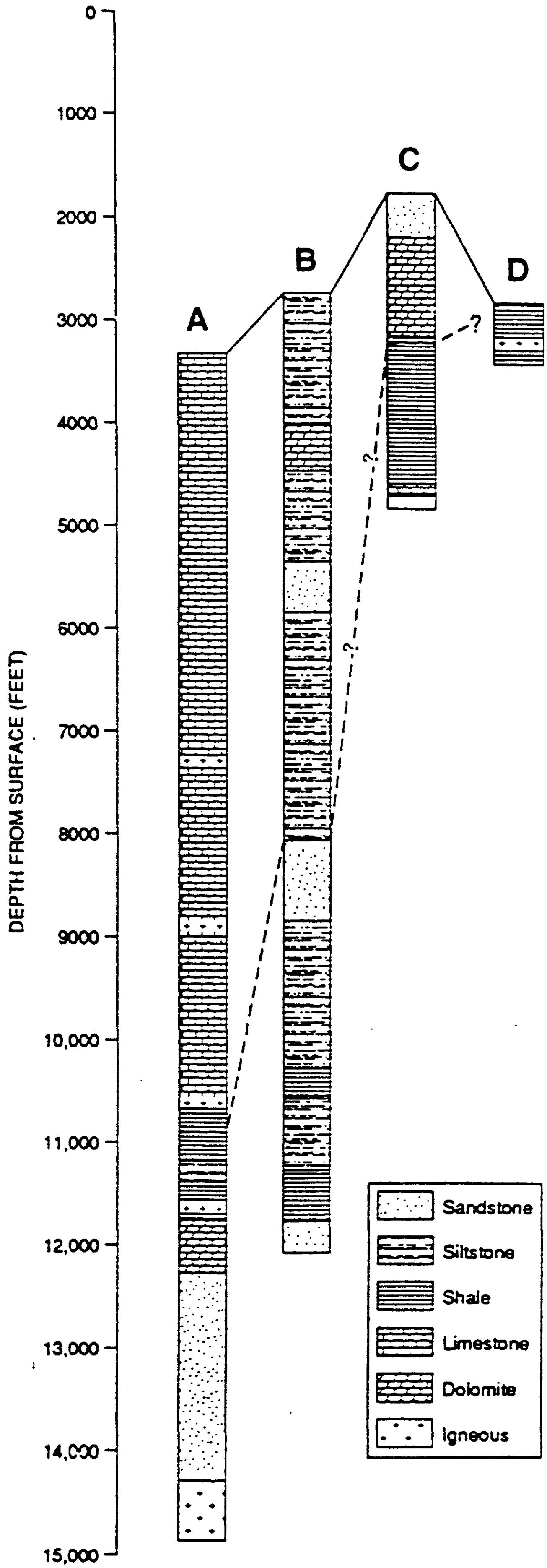


FIGURE 4.--Generalized stratigraphic columns for the Dow Chemical No. 1 Wilson drill hole (A), Dow Chemical No. 1 Garrigan drill hole (B), T.P. Russell No. 1 drill hole (C), and the O.W. Killam--K. Pattinson No. 1 drill hole (D). Depths are below land surface. Solid correlation line is Cretaceous unconformity; dashed line is Bonneterre Formation correlation. Modified from Collins and others (1992) and from Grohskopf (1955).

PROVENANCE AND DEPOSITIONAL ENVIRONMENTS

PROVENANCE

Strake Drill Hole

The heavy mineral fraction of the insoluble residues indicate several rock sources for the detrital sediments of the Strake drill hole. Garnet, staurolite, clinozoisite, zoisite, epidote, kyanite, sillimanite, and perhaps some of the hornblendes and tourmalines represent an amphibolite facies, high rank metamorphic source indicating regional metamorphism (Williams and others, 1982). A basic igneous source is suggested by the minerals anatase, brookite, augite, ilmenite, magnetite, chromite, phlogopite, and rutile. Apatite, hornblende, some of the garnet and tourmaline, and zircon, suggest an acid igneous source (Pettijohn, 1975). Ilmenite can be from either igneous or metamorphic origin (Deer and others, 1978). Barite because of its large size (commonly greater than 3 mm) and its angularity suggests that it is derived from fracture fill that was derived from a mineralization event. The amount of barite present in each of the intervals is probably indicative of the degree of fracturing in or near those lithic intervals of the Strake drill hole.

The earthy, rams-horn shaped, iron oxide fragments as well as the glossy red to reddish-orange iron oxide fragments, cements, and coatings are believed to be an artifact derived from the drilling process. The tungsten minerals, wolframite, tungstite(?), and scheelite are usually associated with granite pegmatites. The powdery or clayey desiccated appearance of the tungstite(?) grains may be the result of the hydrochloric acid used in the insoluble residue process.

Pyrite is a common diagenetic mineral in sedimentary rocks, however the high concentration and crystal habits such as octahedron, diploid, and pyritohedron suggest a mineralization event in some intervals such as 2490-2505 ft (66%), 2510-2525 ft (49%), 2550-2565 ft (36%), 2955-2975 ft (43%), 2980-3000 ft (38%), 3055-3075 (29%), 3130-3150 (85%), 3180-3200 ft (20%), 3655-3700 ft (22%), 3755-3800 ft (40%), and 4560-4600 ft (20%). Other sulfides that suggest mineralization include galena (3030-3050 ft and 3905-3950 ft) and chalcopyrite (intervals 3430-3475 ft and 4705-4740 ft). The fluorite crystals may have been formed in the mafic dike at interval 2700 ft and also suggest in-situ mineralization.

With the exception of the sulfide minerals which may be diagenetic or epigenetic, the angularity and crystal fragments of certain minerals such as kyanite, sillimanite, garnet (rare), augite, hornblende, magnetite, and euhedral zircon argue for a short (perhaps less than 200 miles) transportation distance. The minerals magnetite, augite, hornblende are considered to be characteristic of first cycle sediments that represent the composition of the source area (Boggs, 1987).

The angularity of these minerals also argues for them representing first cycle sediments. This conclusion is based on the abrasion experiments conducted by Friese (1931) and Theil (1940, 1945). Their results are summarized in table 2. Some crystals such as tourmaline (Krynine, 1946) and zircon could have resulted from authigenitic, syntaxial overgrowth form intrastratigraphic solutions (Pettijohn, 1941; Pettijohn and others, 1973). Anatase crystals could also be authigenic in origin (Pettijohn, 1941, p.622-623), perhaps derived from the alteration of other detrital Ti-bearing minerals (Deer and others, 1978). Pettijohn (1941, p. 622) believes that the older the deposit the more probable that anatase is authigenic.

The closest source areas that could have contributed the metamorphic and granitic detrital sediments found in the Strake drill hole are the Central Missouri high, a buried structure located in central Missouri, and the St. Francis Mountains, located in southeastern Missouri. The Central Missouri high is composed of both granitoid and metamorphic Precambrian rocks that include garnet-bearing quartz-microcline gneiss, biotite schist, muscovite-talc schist, quartzite, forsterite marble, sillimanite-bearing quartz-microcline gneiss, kyanite-bearing granite gneiss, metarhyolite, and amphibolite (Kisvarsanyi, 1974; Sims, 1985; Sims and others, 1987, p. 13; Kisvarsanyi, 1991). The principal granite types of the St. Francois terrane include biotite granite, amphibole

TABLE 2. Abrasion resistance of minerals in order of increasing resistance[1] (as summarized by Pettijohn, 1975)

After Friese (1931)	After Thiel (1945)
Hematite (100)[2]	Barite
Monazite (117, av.)	Siderite
Orthoclase (150)	Fluorite
Diopside (160)	Goethite
Andalusite (220)	Enstatite
Kyanite (260)	*Kyanite*
Apatite (175)	Bronzite
Common olivine (290)	*Hematite*
Epidote (320)	*Augite*
Ilmenite (325)	*Apatite*
Garnet (378, av.)	Spodumene
Magnetite (380)	Hypersthene
Topaz (390)	Diallage
Common augite (420)	Rutile
Staurolite (420)	Hornblende
Cordierite (480)	Zircon
Pyrite (500)	*Epidote*
Tourmaline (817, av.)	*Garnet*
	Titanite
	Staurolite
	Microcline
	Tourmaline
	Quartz

[1]Minerals common to two lists are italicized to facilitate comparison.

[2]"Transportwiderstand"; hematite arbitrarily taken as 100.

granite, a two-mica (tin) granite, rhyolitic volcanic rocks, and intermediate and mafic alkaline rocks (trachytes and trachybasalts (Kisvarsanyi, 1974, 1981). The St. Francois terrane is part of the larger eastern granite-rhyolite province in which the Reelfoot structural basin is located (see Bickford and others, 1986). Sims and others (1987) report that tungsten minerals in old mine dumps in the St. Francois Mountains produced 120 short tons of tungsten concentrates between 1916 and 1946. Some of the tungsten minerals found in the Silver Mine district include wolframite and scheelite. Although not conclusive, the granitic rocks of the St. Francois Mountains have both pink and white zircons which are similar to those found in the insoluble residues form the Strake drill hole (Bickford and Mose, 1975; M.E. Bickford, personal commun. to D.S. Collins, 1992). The Eminence Cauldron subsidence structure provides evidence that the St. Francois Mountains provided sediment for the Upper Cambrian sediments. This is indicated by the pinching out of the Lamotte Sandstone; the direct contact of the Bonneterre Formation with the granite and silicic volcanic rocks, and subvolcanic granites; and the direct contact of the Derby-Doerun Eminence-Potosi Dolostones with silicic volcanic rock (fig. 5, Kisvarsanyi, 1981, p. 12). Kisvarsanyi (1974) describes the Precambrian hills and ridges of the St. Francois Mountains as being islands in the transgressing Paleozoic sea. Similarly, Precambrian rocks of the Central Missouri high was a topographic high during Cambrian deposition (E.B. Kisvarsanyi, personal commun. to D.S. Collins, 1992) and the southern part of the high was drowned during the deposition of the Bonneterre Formation (Palmer, 1991).

The altered, mafic rock fragments, containing red-brown mica (phlogopite?) and altered feldspars, are believed to indicate intrusive bodies (dikes) in the Cambrian rocks similar to those found in other drill holes nearby or in the Reelfoot rift area (Grohskopf, 1955).

Garrigan Drill Hole

According to Collins and others (1992), the source of the siliciclastic sediments in the Garrigan was either metamorphic or granitic and eroded preexisting sedimentary rocks. This conclusion is based on the presence of rounded chert grains that probably originated from an eroding sedimentary source and the presence of rounded to subrounded feldspar grains, milky to clear quartz grains, and magnetic material that indicate a probable granitic/metamorphic source. Rounded, pitted, and frosted quartz grains found throughout the Garrigan may indicate an eolian dune source or recycled sediment source. However, because metamorphic detrital minerals are absent from the Garrigan rocks, we believe the source rock to be mainly sedimentary and granitic.

Killam Drill Hole

A cursory inspection of cuttings from the Killam indicate that some of the black shales of the Killam contain white mica. However, white mica (muscovite?) is not indicative of either a metamorphic or an igneous source. However, because the Killam lacks a detrital metamorphic assemblage as found in the Strake, and because the St. Francois Mountains are within 13 miles of the northeastern portion of the Reelfoot depositional basin at the Killam drill site, it is possible that these siliciclastic sediments were originally derived from an igneous source.

DEPOSITIONAL ENVIRONMENTS

The depositional environments of the Strake, Wilson, and Killam drill holes are difficult to evaluate directly in this study because of the scarcity of core and fossils, and because this study deals mainly with insoluble residuum composed of mineral and rock fragments. However, the shales that are age equivalent to the Upper Bonneterre Formation from the Strake drill hole (Grohskopf, 1955) represent a distal portion of a shelf or ramp that were later overlain by carbonate rocks that represent a shallow sea. Both rocks may represent the margin of the Reelfoot depositional basin.

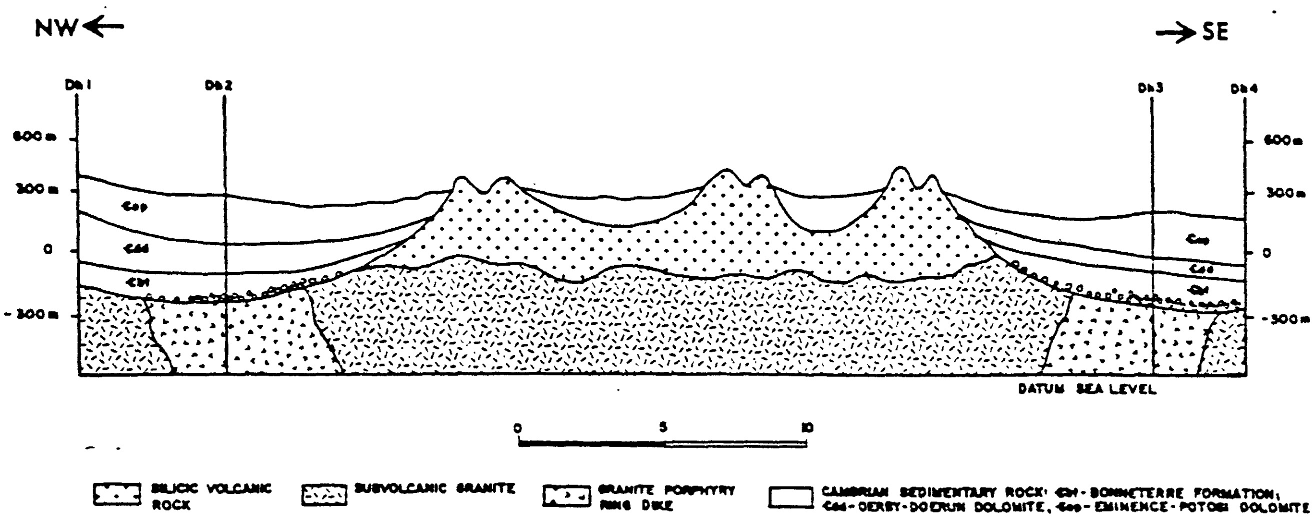


FIGURE 5.--Generalized cross-section of the Eminence Cauldron, southeastern Missouri, showing Cambrian sedimentary rocks in contact with Precambrian igneous rocks (after Kisvarsanyi, 1981). The Eminence Cauldron is located on the southwestern edge of the St. Francois Mountains. Dh1 through Dh4 locate drill sites. Horizontal scale is in kilometers.

Rocks in the Killam drill hole are mainly shales (Grohskopf, 1955, p. 80) that may represent a basinal environment in a portion of the Reelfoot depositional basin. This highly speculative conclusion is based on the location of the Killam drill site positioned along the strike of the Reelfoot depositional basin.

Collins and others (1992) suggest that the rocks of the Wilson drill hole represent the distal, deeper water part of a carbonate ramp. Their conclusion is based on the occurrence of parallel seismic reflectors (McKeown and others, 1990) and the occurrence of mixed warm- and cool-water conodont biofacies in the nearby Fort Pillow drill hole (fig. 1; Derby, 1982; Collins and others, 1992).

From a study of drill core, Collins and others (1992) concluded that at least part of the rocks of the Garrigan drill hole were deposited in a submarine fan by turbidity currents in probably dysoxic to anoxic water. Based on a detailed description of the core from 7,973-8,002 ft, evidence for a lower fan environment is suggested by the presence of rare and relatively fine-grained Bouma Ta(?) divisions, dominance of Bouma Tbc divisions, and rare Bouma Te divisions (Collins and others, 1992). Interpretation of a turbidite fan environment for the same core agrees with an earlier interpretation made by J.R. Howe (1984).

The Bouma Ta and Tbc divisions are part of a turbidite sequence (Bouma sequence) which was first proposed by Bouma (1962). The Bouma sequence is recognized by a typical sequence of sedimentary structures and is characterized by an upward fining grain size. Walker (1984, p. 173) presents a generalized Bouma sequence from Bouma (1962) that grades upward from a relatively course sand-size to mud-size sediment. For instance, the Bouma Ta is either a massive or an upward grading bed. The Bouma Tb consists of parallel laminated sand. Bouma Tc is characterized by rippled and/or convoluted laminae bedding, whereas Bouma Td consists of parallel interlaminated silt and mud. Bouma Te is the final division that consists of either or both a mud introduced by the turbidity current or hemipelagic mud.

The absence of bioturbation, presence of authigenic cubic pyrite crystals in the Bouma Ta(?) divisions, and presence of interstitial fine-grained framboid pyrite are the evidence for a probable dysoxic to anoxic depositional environment (Collins and others, 1992).

Collins and others (1992) also suggested 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 that was active during the Cambrian. The authors further suggested that the origin of the siliciclastics in the Garrigan was probably from the northeast, with transport parallel to the carbonate platforms on either side of the Reelfoot rift boundaries.

SUMMARY AND CONCLUSIONS

PROVENANCE

The heavy fraction of the insoluble residue samples from the Strake drill hole indicate that both a metamorphic and an igneous source existed during Cambrian and Ordovician time. The igneous source was prevalent throughout the sampled Cambrian and Ordovician section, whereas, the metamorphic source was eroding during the Dresbachian Stage of the Upper Cambrian and continued into the Ordovician section. The nearest source areas having these rocks are the Central Missouri high (mainly the source of the metamorphic detritus) northwest of the Strake and the St. Francois Mountains (mainly the source of the igneous detritus) to the northwest and north of the Strake. The barite present in the Strake drill is not detrital and indicates a mineralizing event that filled fractures that occurred sometime after deposition and compaction of the sediments.

Collins and others (1992) suggest a sedimentary and crystalline rock (metamorphic or igneous) source of the siliciclastic sediments of the Garrigan drill hole based on their insoluble residue study. Because they did not find discrete, detrital, metamorphic mineral grains, we speculate that the crystalline source rock was igneous. Similarly, the siliciclastic sedimentary rocks of the Killam drill hole indicate a possible igneous source as implied by the lack of metamorphic minerals and the location of the Killam drill site in the Reelfoot structural basin. The St. Francois Mountains were probably the source for the rocks of both the Garrigan and Killam drill holes.

The carbonate sediment penetrated by the Strake drill hole may have prevented metamorphic sediments (derived from west of the Reelfoot rift) from being deposited in the deeper water of the Reelfoot depositional basin. This is suggested by the apparent lack of metamorphic detrital sediment in the insoluble residues of both the Killam and Garrigan lithologies. Evidence for a structural barrier positioned between carbonate shelf and west side of the Reelfoot depositional basin that may have prevented the metamorphic detrital sediment from being deposited in the Reelfoot depositional basin is lacking at present. The igneous fraction of the insoluble residues from Paleozoic rocks of the Strake drill hole was probably form the southwest and west side of the St. Francois Mountains. The insoluble residues from the Wilson rocks were not available for this study; thus, the provenance for the detrital sediments in the Wilson rocks is not known.

DEPOSITIONAL ENVIRONMENTS

Paleontologic data by earlier workers indicate that the Strake lithology includes Upper Cambrian and Lower Ordovician rocks (Grohskopf, 1955). Siliciclastic deposition in the Cambrian probably occurred in deep water that was later covered by shallower carbonate rocks. In comparison, at least part of the siliciclastic rocks of equivalent age from the Garrigan were deposited in an Upper Cambrian submarine turbiditic fan in a predominately deeper water of a reducing marine environment (Taylor and others, 1990; Collins and others, 1992). The rocks of the Killam drill hole are assigned to age equivalent rocks of the Bonneterre Formation and Elvins Group by Palmer (1989) and are believed to also have been deposited basinward of the shelf carbonates. In contrast, equivalent aged carbonate rocks of the Wilson are believed to represent a distal, deep water part of a carbonate platform (Collins and others, 1992).

INSOLUBLE RESIDUE AND BIOSTRATIGRAPHIC CORRELATIONS

Collins and others (1992) could not correlate the insoluble residuum from the rock cuttings of the Garrigan drill hole to the insoluble residuum from other drill sites on the Missouri platform or to drill sites in the Reelfoot structural basin. Similarly, the insoluble residue of the Killam could not be correlated to insoluble residuum of either the Garrigan or the Strake drill holes because of the lack of distinctive rock and detrital mineral fragments. It is not known if the Wilson residue correlates with the residues from the Garrigan Strake, and/or Killam drill holes because the insoluble residue for the Wilson was unavailable for study.

There is a rough biostratigraphic correlation between the Garrigan and Wilson drill holes. This correlation is based on an Upper Cambrian trilobite assemblage that is present in carbonate rocks at 10,860-11,100 ft in the Wilson drill hole and in siliciclastic rocks at 7986 ft in the Garrigan drill hole. Some of the elevation differences between the Garrigan and Wilson drill holes result from the uplift of the Reelfoot depositional basin which formed the Blytheville arch some time after the Ordovician (McKeown and others, 1990). The uplift resulted in juxtaposition of deep-water Upper Cambrian and Ordovician siliciclastic rocks of the Garrigan in relation to coeval shallow-water carbonate rocks of the Wilson (Collins and others, 1992). The structural relief between the Garrigan and Strake drill holes is about 4700 ft compared to about 7900 ft between the Strake and the Wilson drill holes. These estimates represent maximum structural relief because the *Crepicephalus* trilobite biozone in the Strake is slightly older than the fossil assemblages common to both the Garrigan and Wilson drill holes. This suggests a fault displacement down to the southeast of about 4700 ft between the Garrigan and Strake drill holes and about 7900 ft between the Strake and the Wilson drill holes.

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APPENDIX

APPENDIX.--Description of the light fraction of residuum from the T.P. Russell No. 1 drill hole

Description	Interval (depth in feet)	
	From	To
Quartz, vcU-fL, well rounded to subrounded, white to light gray, 80%. One well rounded quartzite fragment (3.5 mm), light brownish gray (5YR 6/1). Shale, brownish gray (5YR 4/1), 15%. Mudstone, grayish orange (10YR 7/4), <5%. Mudstone or shale?, medium light gray (N4), trace. Siltstone, white (N9), with orange stains, about 0.5%. Siltstone, sandy (fU-cU, angular to subangular), very light gray (N8), about 0.5%.	2280	2290
Quartz grains, same as above, 80-90%. Trace glauconite, dark green, rounded, botryoidal. Round to subrounded granite fragments, K-spar and quartz, trace. Mudstone, shaley (slightly), medium gray (N5), slightly brownish, rounded to subrounded, 5-10%. Mudstone, rounded, pinkish-gray (5YR 8/1), 5-10%. Trace dark gray subrounded (chert?) grains, mL to cU.	2295	2300
Quartz grains, same as above, but vcU-fL, 80-89.5%. One crinoid stem fragment. Mudstone, medium light gray (N6), round to subrounded, 5-10%. Mudstone, pinkish gray (5YR 8/1), 5-10%. Dark gray grains, same as above, as much as vcL in size, <0.5%.	2305	2310
Quartz fine gravel (2.5 mm) to fL, same as above, 90-94.5%. Mudstone, a few shaley, medium gray (N5), some brownish gray, 5-10%. Dark gray grains, same as above, about 0.5%.	2315	2320
Quartz, same as above, 89.5-90%. Mudstone, medium light gray (N6), <5%. Mudstone, pinkish gray (5YR 8/1), 5-10%. Dark gray grains, same as above, <0.5%.	2325	2330
Quartz, same as above, 89%. Mudstone, pinkish gray (5YR 8/1), 10%. Mudstone, brownish gray (5YR 4/1), <1%. Mudstone, medium gray (N5), trace. Black grains, same as above, about 0.5%.	2335	2340
Quartz, same as above, 97.5%. Mudstone, pinkish-gray (5YR 8/1), <1%. Mudstone, medium dark gray (N4) to medium gray (N5). Black grains, same as above, about 1%.	2345	2355
Quartz grains, same as above, 99%. Mudstone, brownish gray (5YR 4/1), trace. Mudstone, medium gray (N5), trace. Black grains, same as above, about 1%.	2360	2370
Quartz grains, same as above, 98.5%. Mudstone, pinkish gray (5YR 8/1), trace. Mudstone about medium light gray (N6), about 0.5%. Black grains, same as above, 1.0%.	2375	2385
Quartz grains, same as above, 98%. Trace glauconite, dark green, botryoidal. Feldspar grains <0.5%. Mudstone, medium light gray (N6) to medium gray (N5) <0.5. Mudstone? yellowish gray 5Y 8/1 Trace. Black grains, about 1%.	2390	2400
Quartz grains, same as above, 98.4%. Trace glauconite, same as above. Mudstone, micaceous, medium dark gray (N4), <0.5%. Silty clay fragments, white, about 0.1%. Mudstone pinkish-gray 5YR 8/1, trace. Black grains, 1%.	2405	2410
Quartz same as above, 89.5-95%. Siltstone, clayey, white (N9), some light greenish gray 5GY 8/1, 5-10%. Black grains, same as above, <0.5%.	2420	2430
Quartz grains, same as above, 94.5%. Trace glauconite, same as above. Siltstone, clayey, white, about 5%. Siltstone, muddy, pinkish-gray (5YR 8/1) with dark mineral grains about 3.2 mm in diameter. Black grains, same as above, <0.5%.	2435	2445
Quartz grains, same as above, 94.5%. Siltsone, clayey, white and white clay fragments, about 5%. Trace glauconite, same as above. Black grains, same as above, <0.5%.	2450	2460
Quartz, same as above, 93%. Siltstone, clayey, white and white clay fragments, about 5%. One amethyst grain. Mudstone, brownish gray (5YR 4/2), trace. Siltstone, trace. Quartzite, very light gray (N8), with fU quartz grains. Black grains, same as above, about 1%.	2465	2485
Quartz grains, same as above, 93%. Glauconite, same as above, trace. Quartzite, rounded, light olive gray (5Y 6/1), with dark grains, <1%. Siltstone, olive gray (5Y 3/2). Siltstone, clayey, white, about 1%. Siltstone, grayish orange (10YR 7/4), about 5%.	2490	2500

APPENDIX.--Description of the light fraction of residuum from the T.P. Russell No. 1 drill hole--Continued

Description	Interval (depth in feet)	
	From	To
Quartz grains, same as above, 97%. Siltstone, clay, grayish orange (10YR 7/4), about 1%. Siltstone, white, about 1%. Siltstone, very clayey, white (N9), trace. Black grains, same as above, 1%.	2510	2525
Quartz grain, same as above, 98.5%. Glauconite, same as above, trace. Siltstone, sandy, clayey brownish gray (5YR 4/1), about 1%. Black grains, same as above, <0.5%.	2530	2545
Quartz grains, same as above, 88-97%. Siltstone, clay, medium gray (N5) to medium dark gray (N4), 3-5%. Siltstone, clayey, light gray (N7), 1%. Siltstone, clayey, white, 5%. Siltstone, shaley, black (N1), 0.5%. Siltstone clayey, grayish orange (10YR 7/4), trace. Black grains, same as above, <0.5%.	2550	2565
Quartz, same as above, 63.5-75%. Siltstone, clayey, grayish orange (10YR 7/4), 5-10%. Siltstone, clayey with dark minerals (looks like salt and pepper), light gray (N7), 20-25%. Shale, silty, black (N1), <0.5%. Siltstone, white, about 1%.	2570	2580
Quartz, same as above, 97%. Mudstone, slightly shaley, a little silty, olive gray (5Y 4/1), 1%. Siltstone, clayey with dark minerals about light gray (N7), <0.5%. Siltstone, clayey, grayish orange (10YR 7/4), trace. Siltstone, clayey, white (N9) to very light gray (N8), 1%. Black grains, same as above, <0.5%.	2590	2605
Quartz, same as above, 97.5%. Mudstone, olive gray (5Y 4/1), <0.5%. Siltstone, light olive gray (5Y6/1), trace. Siltstone, clayey, white, about 1%. Black grains, same as above, about 1%.	2610	2625
Quartz, same as above, 98.5%. Trace glauconite, same as above. Siltstone, clayey, white, <0.5%. Mudstone, medium gray (N5), <0.5%. Black grains, same as above, about 0.5%.	2630	2645
Quartz, same as above, 54%. Siltstone with dark mineral grains, yellowish gray (5Y 8/1) to white (N9), 25%. Siltstone, clayey, grayish orange (10YR 7/4), about 5%. Mafic rock fragments?, dominantly greenish gray (5GY 6/1), 15%. Mudstone, medium gray (N5) to medium dark gray (N4), <0.5%. Black grains, same as above, <0.5%.	2650	2665
Quartz grains, same as above, 99%. Mafic rock fragments?, same as above, trace. Mudstone, medium gray (N5), trace. Black grains, same as above, <0./5%.	2670	2685
Quartz grains, same as above, 97.5%. Trace glauconite, same as above. Siltstone, white, about 1%. Mudstone, some with pyrite druse, medium gray (N5), <0.5%. Black grains, same as above, <1%.	2690	2705
Quartz, same as above, 98.5%. Mudstone, medium dark gray (N4), <0.5%. Sandstone, white, trace. Siltstone, white (N9) to light gray (N8), <0.5%. Mudstone or shale?, black (N1), trace. Black grains, same as above, <0.5%.	2710	2755
Quartz, same as above, 69-75%. Trace glauconite, same as above. Siltstone, clayey, very light gray (N8) to white (N9), 25-30%. Mudstone, some with mica, olive gray (5Y 4/1), 0.5%. Mudstone or shale?, black (N1), trace. Black grains, same as above, <0.5%.	2766	2810
Quartz, same as above, 69-75%. Siltstone, clayey, white (N9) +o very light gray (N8), 25-30%. metamorphic or igneous rock frags. with a white (N9) "ground mass" and black (N1). Mudstone, olive gray (5Y 4/1), <0.5%. Black grains, same as above and biotite, <0.5%.	2815	2840
Quartz, same as above, 45-55%. Siltstone, clayey, white (N9) to very light gray (N8) 15-20%. Large rock fragments? with biotite? and other dark mineral present, 30-35%. Color varies from white to medium gray (N5); also some grayish blue (5PB 5/2).	2845	2865
Quartz, same as above, 64.5-95%. Siltstone, clayey, white, 5-10%. Igneous rock fragments, same as above, 3%. Mudstone, olive gray (5Y 4/1), 20%. Chert, dark yellowish-orange (10YR 6/6), <2%. Black grains, same as above, <0.5%.	2870	2895
Quartz, same as above, 95%. Mudstone, with some mica, olive gray (5Y 4/1), 5%. Trace igneous rock, same as above. Black rock fragments and fine grained dolomite? (N1), <1%.	2900	2925

APPENDIX.--Description of the light fraction of residuum from the T.P. Russell No. 1 drill hole--Continued

Description	Interval (depth in feet) From	To
Quartz grain, same as above, 74.5-80%. Siltstone?, or igneous rock fragments with pyrite and fibrous clasts of clear, white crystals filling pore space or cementing fragments, light gray (N7) with grayish yellow (5Y 8/4) patches, 20-25%. Fragments with pyrite are common. A few have pyrite and quartz crystals. Mudstone, medium dark gray (N4), <0.5%. Black (N1) rock fragment and fine grained dolomite, trace.	2930	2950
Quartz grains, same as above, but coarser grains sizes not as common, 65-75%. Siltstone, olive gray (5Y 4/1), 25-30%. Some have silica filled fracture less than 0.5 mm wide. Some are slicked on a black shale? laminae surface. Mudstone or siltstone, muddy, light gray (N7) to medium gray (N6), about 5%. Siltstone, dark mineral, greenish gray (5GY 6/1), trace.	2955	2975
Quartz grains same as above, but an increase in coarser grain sizes, 35%. Siltstone, olive gray (5Y 4/1) to brownish gray (5YR 4/1); some have black shale laminae and a few are slicked, 65%. Siltstone, muddy with dark minerals, greenish-gray (5GY 6/1), trace.	2980	3000
Quartz grains, same as above, 54-99%. Siltstone to mudstone, brownish gray (5YR 4/1) to grayish black (N3), 40%. Mudstone or kaolinite fragments, very light gray (N8), about 1-5%. Black (N1) rock fragments and fine grained dolomite, trace. Igneous rock fragments with dark minerals, <1%.	3005	3025
Quartz grains, same as above, 73-80%. Siltstone, muddy, light olive gray (5Y 6/1) and black (N1), 20-25%; some have thin laminae. Some have pyrite. Siltstone, muddy with dark minerals, white (N9) to very light gray (N8), <1%. Black grains, same as above, <1%.	3030	3050
Quartz grains, same as above, 30%. Siltstone, muddy or shaley, some with pyrite, some with silica filled fractures less than 0.5 mm wide, light olive gray (5Y 6/1) (some yellow) to olive gray (5Y 4/1), 70%. Some have black silica fracture fills about 1 mm wide.	3055	3075
Quartz grains, same as above, but cL to fl, <1%. Mica, reddish brown, about 5%. Igneous rock, altered to serpentine(?) with reddish brown mica, about 5%. Mudstone, medium gray (N5), micaceous with silica fractures less than 0.5 mm wide, about 20%. Siltstone, light olive gray (5Y 6/1) with dark gray (N3) discontinuous laminae or wisps, 10%. Mudstone, light gray (N7) , about 5-10%. Siltstone, muddy, olive gray (5Y 4/1), 30% mica. Mudstone, dark (N3), about 15%.	3105	3125
Quartz grains, same as above, 5%. Siltstone, muddy, brownish gray (5YR 4/1), micaceous, about 92%. Igneous, same as above, about 1%.	3130	3150
Quartz grains, same as above at beginning of log, 35%. Siltstone, muddy, brownish gray (5YR 4/1), 30%. Siltstone, muddy, brownish black (5YR 2/1), 35%.	3155	3175
Quartz grains, same as above, <0.5%. Siltstone, muddy, olive gray (5Y 4/1), some with mica, 90%. Shale, black (N1), 5%.	3180	3200
Quartz grains, same as above, 1%. Siltstone, shaley, medium dark gray (N5), about 98.5%. Shale, black (N1), <0.5%.	3205	3225
Siltstone, shaley, medium dark gray (N4), about 82%. Shale, medium dark gray (N4), 17%. Quartz grains (same as above), mica, and rust grains, about 1%.	3230	3300
Quartz, same as above, about 1%. Siltstone, olive gray (5Y 4/1), 99%.	3310	3375
Quartz, same as above, 5%. Siltstone, shaley to muddy, micaceous, olive gray (5Y 4/1) to siltstone, black (N1), 95%.	3380	3475
Quartz grains, same as above, 1%. Siltstone, shaley, olive gray (5Y 4/1), micaceous to siltstone, black (N1), 97%. Kaolinite fragments(?) and white siltstone fragments with dark to very light gray grains, <0.5%.	3430	3475
Siltstone, shaley, olive gray (5Y 4/1) to dark gray (N3), about 99%. Trace amounts of quartz grains, white (N9) or very light gray (N7) kaolinite, claystone, and siltstone fragments.	3480	3525

APPENDIX.--Description of the light fraction of residuum from the T.P. Russell No. 1 drill hole--Continued

Description	Interval (depth in feet)	
	From	To
Shale, silty, very light gray (N6) to medium dark gray (N4), 95%. Siltstone, black (N1), <5%. Quartz grains, same as above, <1%.	3530	3575
Quartz grains, trace. Shale, medium gray (N4), 99%. Shale, black (N1), about 1%.	3580	3625
Quartz grains, same as above, about 1%. Siltstone, shaley, medium gray (N5), 95%, some with mica, some with silica fractures <5.0 mm wide. Siltstone, clayey, very light gray (N8) to white (N9), about 5%. Siltstone, micaceous, light olive gray (5Y 4/4), <0.5%.	3630	3645
Quartz grains, trace. Siltstone, clayey, medium gray (N5) to medium dark gray (N5), 45%. Siltstone, clayey, white (N9) to very light gray (N8), 55%. Igneous rock fragments, grayish yellow green (5GY 7/2)?, trace.	3650	
Quartz grains, trace. Siltstone, shaley, medium gray (N5), 99%. Igneous rock fragments, grayish yellow green (5GY 7/2)? with reddish brown mica, trace. Siltstone, clayey, very light gray (N8), <0.5%.	3655	3700 A
Quartz grains, about 1%. Sandstone, white (N9) to very light gray (N8), with vfU to ufL, rounded to subrounded quartz grains, about 45%. Siltstone, shaley, olive gray (5Y 4/1), some fragments are micaceous, about 42%. Siltstone, clayey, black (N1), about 10%. Siltstone, clayey or kaolinite fragments, white (N9) to very light gray (N8), about 1%.	3655	3700 B
Quartz grains, trace. Siltstone, shaley, muddy, some with silica fractures less than 0.5 mm wide, medium gray (N5), 99%.	3705	3750
Quartz grains, trace. Siltstone, same as above, medium gray (N5), 99%. Siltstone, clayey, white (N9) to very light gray (N8), 1%.	3755	3800
Quartz grains, trace. Siltstone, black (N1), 10-15%. Siltstone, shaley, muddy, medium gray (N5), 85%. Siltstone, clayey, very light gray (N8) to white (N9), trace. Trace pyrite fragments (No discrete crystals) that look like castings or replacement or fracture fill?	3810	3900
Quartz grains, about 1%. Siltstone, shaley, medium dark gray (N3) with dark gray (N4), 96-99%; some are coated with pyrite druse. Siltstone grayish black (N2), 1-3%.	3905	3950
Quartz grains, about 1%. Sandstone, light brownish gray (5YR 6/1) with vfL, rounded quartz grains and with about 0.3% dark grains, about 1% glauconite, and about 1% white (N9) silica cement. Siltstone,shaley, olive gray (5Y 4/1); some with silica-filled fractures less than 0.5 mm wide, about 94%. Siltstone, clayey, grayish black (N2), about 1%. Siltstone, olive gray (5Y 4/1) to white (N9), about 1%. Rare quartz crystals, white (milky), euhedral.	4510	4550
Quartz grains, trace. Shale, dark gray (N3), about 55%. Siltstone, shaley, clayey, olive gray (5Y 4/1), 25-30%. Sandstone, medium light gray (N6) with vfU to fL size quartz grains and white (N9) cement(?). Some have rounded pyrite, about 10%. Some have glauconite. Siltstone, grayish black (N2), 1%; some have fractures less than 0.5 mm wide. Siltstone, light gray (about N7), <1%.	4560	4600
Quartz grains, 1%. Sandstone, same as above, 5-10%. Siltstone?, shaley, clayey, dusky yellowish brown (10YR 2/2), about 20%. Siltstone, clayey, shaley, dark gray (N3), <1%. Siltstone, clayey, black (N1), <1%. Siltstone, shaley, medium to dark gray (N4-N3), about 70%.	4605	4650
Sandstone, same as above, 25%. Siltstone, grayish black (N2), <1%. Siltstone, shaley, dusky yellowish brown (10YR 2/2), about 10%. Siltstone, dark gray (N3), about 65%.	4705	4740

TABLE 1.--Residuum from the T.P. Russell No. 1 drill hole

[Chaclopyrite (ch), galena (g), clinozoisite (cl), zoisite (z), anatase (A), rutile (R), brookite (B), TiO2 (Ti), sillimanite (S), chromite (Cr), tungstite (T), wolframite (W), scheelite (Sc), apatite (Ap), dolomite (D), fluorite (F), trace (tr). x, indicates minerals present, ? where questionable. Numerical values are estimated percentages of mineral. Color codes are in parentheses (p=pink, o=orange, r=red, w=white, b=brown, bk=black]

Interval (feet)	Rock frag. (%)	Pyrite (%)	Garnet[1]	Hornblende	Magne-tite (%)	Iron ore (%)	Zircon	Augite	Mica	Epidote	Staurolite	Kyanite	Tourma-line	Barite	Amphibole (%)	Other minerals
2280-2290						1										A
2295-2300				x						x	x				2	
2305-2310					ˉ6	62					x				1	W?
2315-2320			x	x		18	x	x		x	x	x?				R,W?
2325-2330	7		x(r)	x	x		x(r)			6			x			S
2335-2340			x	x	x		x(p)			x		x?	x		1	S,Cr,T?
2345-2355			x	x	1	58	x(w)			x?		x?				
2360-2370			x(r)	x	41					x?	x?	x?			1	
2375-2385	tr		x	x	33		x(p)				x	x?			T	
2390-2400			x(p)	x	10		x(p)						x		2	R,S
2405-2410			x	x	33		x			x		x?			7	
2420-2430			x	x	10						x	x?	x		0.5	Sc?
2435-2445			x	x	11		x(p)			x	x	x?	x			
2455-2460		10	x	x	2		x	x				x	x			

TABLE 1.--Residuum from the T.P. Russell No. 1 drill hole--Continued

Interval (feet)	Rock frag. (%)	Pyrite (%)	Garnet[1]	Hornblende	Magnetite (%)	Iron ore (%)	Zircon	Augite	Mica	Epidote	Staurolite	Kyanite	Tourmaline	Barite	Amphibole (%)	Other minerals
2465-2485		88	x	x	5	5	x(p)						x	x		
2490-2505		66	x	x	2			x					x		tr	
2510-2525		49	x	x	<5		x(p,w)			x	x	x?			tr	R,Ti,T?
2530-2545		5	x	x	<10	34				x		x	x		3	g(tr),T?
2550-2565		37	x	x	4					x		x			tr	
2570-2585		10	x	x	7		x(w)			x		x?			1	D
2590-2605		6	x	x	11		x(p)			x		x				
2610-2625		8	x	x	<15		x(p)	x		x	x				5	
2630-2645		16	x(r)	x	16		x(p,w)	x		x		x?	x			Ti
2650-2665	tr		x	x	44							x				
2670-2685			x(o-r)	x						x		x				
2690	tr		x	x	11	32	x(p)		tr			x	x			z
2710-2755			x	x			x(p)					x		x		cl,F
2760-2810	tr		x	x			x(p)			x?		x			15	
2815	97		x						1						tr	
2845-2865	98		x	x				x?								
2870-2895	33		x	x	tr			x	x			x?			tr	
2900-2925	3	10	x	x	7		x(o)	x	x			x			1	

TABLE 1.--Residuum from the T.P. Russell No. 1 drill hole--Continued

Interval (feet)	Rock frag. (%)	Pyrite (%)	Garnet[1]	Hornblende	Magne-tite (%)	Iron ore (%)	Zircon	Augite	Mica	Epidote	Staurolite	Kyanite	Tourma-line	Barite	Amphibole (%)	Other minerals
2930-2950	1		x	x	2	18			x							
2955-2975		43	x	x	10					x	x					
2980-3000		38	x	x	14		x(w)			x					3	R
3005-3025	15	9	x	x	<4		x(w)			x		x		x	4	T?,A
3030-3050		16	x	x	4		x(w)	x				x	x	x	2	g(tr), cl
3055-3075		29	x	x			x(p)			x						g
3105-3125			x(o)							x			x		tr	B
3130-3150			x	x	<0.5	9	x(w)		1(r-b)	x					tr	
3155-3175		9	x	x	<15	5	x(r-p)				x	x				cl, Cr
3180-3200		20	x	x	3		x(p)		tr(r-b)	x	x?	x		x		Ti
3215-3225	20		x	x			x(p)	x	1(r-b)	x				x	2	
3230-3300	98			x	<1	1										
3310-3375				x	11		x	x		x	x			x	1	D
3380-3475				x	tr				tr(r-b)			x	x	x	x	
3430-3475		8		x	2									x		Ap,Ch
3480-3525			x(o)	x	<1											
3530-3575				x										x		Sc
3580-3625	79		x	x		3								x		

TABLE 1.--Residuum from the T.P. Russell No. 1 drill hole--Continued

Interval (feet)	Rock frag. (%)	Pyrite (%)	Garnet[1]	Hornblende	Magne-tite (%)	Iron ore (%)	Zircon	Augite	Mica	Epidote	Staurolite	Kyanite	Tourma-line	Barite	Amphibole (%)	Other minerals
3630-3645			x	x	0.5									x	0.5	
3650	49	9		x	1											
3655-3700	96	22	x(o)	x	tr	36	x(p,r)	x					x	15		A,B,Cr, D
3705-3750		8	x(o)	x										x		
3755-3800		40			tr	tr							x			
3810-3900				x	3	2				x				x		
3905-3950	2			x	<6	43		x	x(bk)					x	tr	g
4510-4550		5	x(o)		tr									x		
4560-4600		20			tr	tr			1(w)					x		
4605-4650	52			x	1	17								x		Ti
4705-4740	tr	6			2			x	tr(r-b)					x		B,Ti,Ch

[1]Pinkish-orange plus color indicated by code.