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Heavy minerals in the Roubidoux and other sandstones of the Ozark Region (MO.)

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HEAVY MINERALS IN THE ROUBIDOUX AND OTHER SANDSTONES OF THE OZARK REGION (MO.)

by

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A

THESIS

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INTRODUCTION.

The discovery and development of new oil fields has created a demand for increased detail and exactness in the study of sedimentary formations. Every effort is being made to gather information concerning strata that may be of value in correlating them more definitely. Since drilling depths, and therefore costs, are gradually increasing, it becomes of prime importance to know the horizon at which one is drilling at all times. The exactness with which this can be done is determined by the precision with which the various formations can be correlated.

At the present time more detailed petrographic studies are being made of the sedimentary formations than ever before. These have been directed along two lines: (1) The study of micro-faunas; and (2) the investigation of detrital or heavy minerals. The micro-fossils are undoubtedly the more valuable, but often they either do not exist or are so poorly preserved that they cannot be identified. It is in such formations that the detrital minerals may be of most value for correlation purposes. The fact that they are less likely to be destroyed by drilling, than micro-fossils, often renders them more available for study. For the above reasons it becomes important to consider the bearing that conditions of derivation may have upon the problem, and also to make exhaustive studies of their reliability in formations already correlated.

Since the heavy minerals are derived from the same source as the sedimentary beds themselves, they will be likely to vary from one locality to another. The presence of a suite of heavy minerals, in one formation is no indication that the same suite may be contained in another formation of like geologic age in a different locality. Unlike the fossil content of a formation, which is rather uniform throughout widespread areas of the same geologic age, the heavy mineral content may or may not be constant, depending upon the character of the source from which it was derived. Whether the heavy minerals in one formation will be different from those in an overlying formation depends upon whether the sediments of the two formations were derived from a single source or from different sources. If from different sources, the two formations will probably contain different suites of heavy minerals, and thus afford a basis for discrimination. Since in any limited area a formation was probably derived from a single source, it is likely within that area to contain a single suite of heavy minerals. At more remote points material from other sources was probably introduced, and for this reason long range correlation, by means of heavy minerals is impracticable. The problem is related to paleogeographic conditions at the time the various sediments were being deposited. Therefore, their use for correlation purposes is a problem that will have to be worked out for each individual area under consideration.

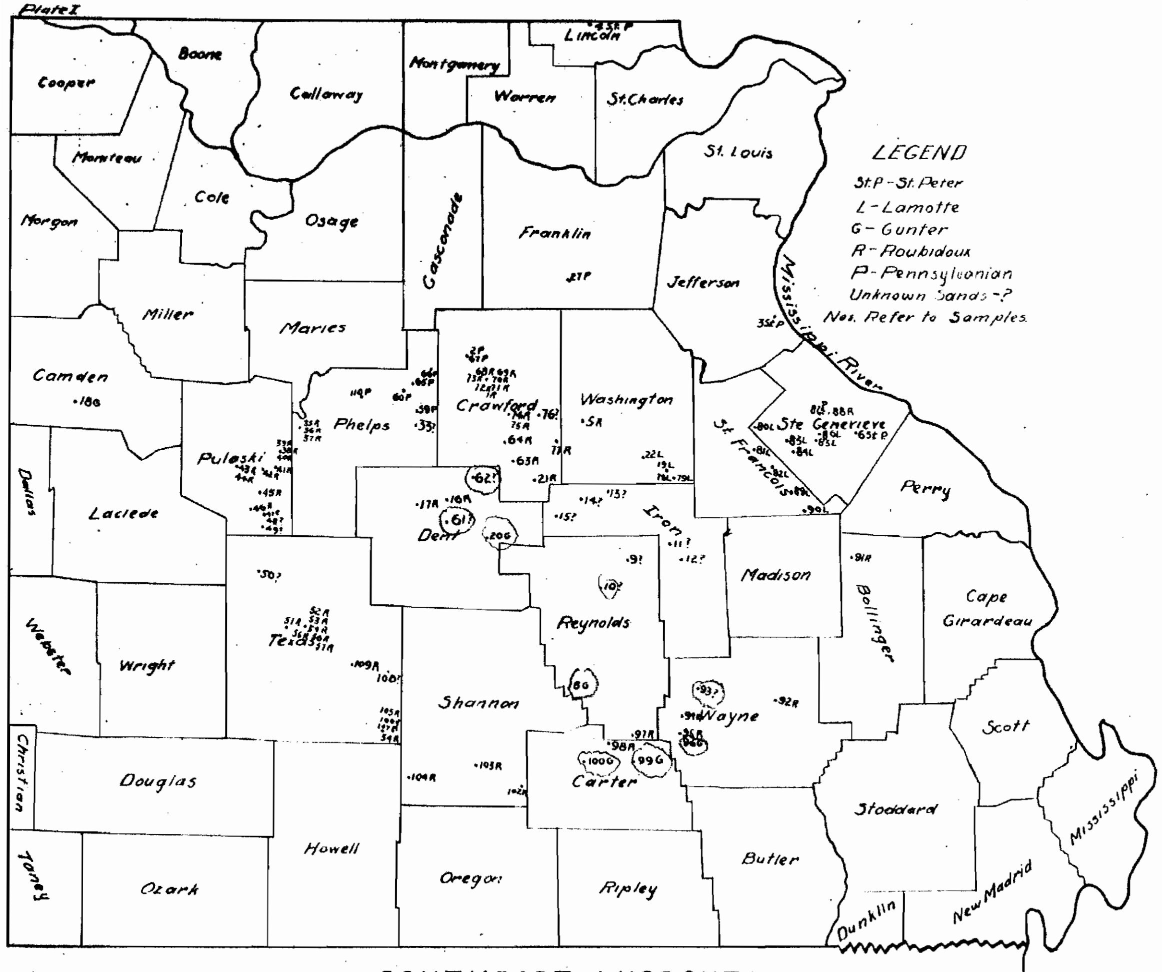
In this study an attempt has been made to determine the usefullness of heavy minerals for correlation of formations over a limited area, in the heart of the Ozark uplift in southeast Missouri. The Roubidoux formation, already definitely correlated by other means, has been rather systematically sampled throughout the area, and the heavy minerals determined to ascertain their dependability for correlation purposes. Several samples from other horizons have been studied for comparison with the Roubidoux.

Also, within the area studied there are numerous isolated patches of sandstone, the horizons of which have not been definitely determined. Samples from a few such patches have been included in the study in order to determine whether it was possible to correlate them definitely by such means. No effort has been made to systematically sample and study these since the chief object was to obtain data upon known formations.

It is not to be assumed that the results of this limited study will definitely approve or condemn the method, but a body of data will have been assembled which may throw light not only on the correlation of these specific formations, but also on general problems of heavy mineral correlation.

Throughout the entire study the faculty members of the Geology Department have offered valuable suggestions from time to time. Dr. C. L. Dake collected most of the samples and critically read the manuscript. Dr. G. A. Muilenburg and Mr. L.W.Currier

Plate I



SOUTHEAST MISSOURI

Scale Of Miles

have given assistance and suggestions in the petrographic identifications. Dr. Schrenk of the Chemistry Department has very kindly offered his services from time to time. The Missouri Bureau of Geology and Mines very kindly furnished the necessary equipment for the investigation. Several advanced students in geology have aided in the preparation of samples for study, and also in the determination of the relative percentages of grains present.

PREPARATION OF SAMPLES FOR PETROGRAPHIC STUDY.

Only those methods used in this investigation will be discussed, as this subject has been adequately treated in numerous other places (see Bibliography).

SAMPLING.

As already stated, the samples were taken from sandstone formations which are present in the Ozark region of southeast Missouri. This area includes roughly the southeast quarter of the state (Plate I), being bounded on the north by the Missouri River, on the east by the Mississippi River, on the south by the Arkansas-Missouri boundary line, and on the west by the 93rd meridian.

Most of the samples used were taken from outcrops, but in a few instances, where there could be little doubt as to its source, sandstone float was utilized.

In some instances suites of samples were taken at irregular intervals from bottom to top of the formation, but for the most part specimens were chosen at random, and no effort was made to get composite or channel samples.

The five most important sandstone formations include the Lamotte, Gunter, St. Peter, Roubidoux, and Pennsylvanian, the Lamotte being the oldest. All of the sandstones do not outcrop over the entire area, but are more or less localized in certain portions.

In order to better grasp the relationships that exist among the various formations in this region a brief discussion of the stratigraphy and structural conditions follows. For geologic column see Plate II.

STRATIGRAPHY OF THE AREA.

Pre-Cambrian.

Pre-Cambrian rocks, composed chiefly of granite and rhyolite porphyry, constitute what are known as the St. Francois Mountains. They are exposed in St. Francois, Washington, Iron, Ste. Genevieve, Wayne, Shannon, Carter, Crawford, and Madison counties. These Pre-Cambrian rocks represent the core of the Ozark uplift, and are simply the tops of the Pre-Cambrian mountains which have been exposed by the removal of overlying sedimentary beds.

The sediments rest unconformably upon these older crystallines and dip away from them in all directions, so that in going out from the center of the uplift one encounters successively younger and younger formations. The dip on the east side of the uplift is much greater than that on the west, the width of the outcropping formation is less there than on the west. The outcrops of sedimentary strata form more or less regular bands surrounding the crystalline core.

Cambrian system.

Lamotte sandstone.--The following description represents an abstract of Buckley's[1] report and Dake's[2] unpublished manuscript.

1. Buckley, E.R., Geology of the disseminated lead district of St. Francois and Washington counties; Missouri Bureau of Geology and Mines, Vol. IX, Part 1.
2. Dake, C. L., Report on the Potosi-Edgehill Quadrangle; Missouri Bureau of Geology and Mines, in preparation.

The Lamotte formation is the basal sandstone of the Cambrian in this region. Since it rests unconformably upon the Pre-Cambrian crystalline rocks its distribution is confined to approximately the same area as the St. Francois Mountains, where it is found outcropping around the borders of the porphyry knobs. It is composed largely of quartz sandstone, varying in color from light gray to reddish brown, red, and shades of yellow brown, depending upon the amount of iron.

Since it is a basal sandstone resting on a very uneven surface its thickness varies considerably. In fact it may vary from a few feet to possibly more than 250 feet in the Pre-Cambrian valleys.

Samples taken from outcrops of this formation come from a small area immediately surrounding the St. Francois Mountains in Washington, St. Francois, and Ste. Genevieve counties. The area sampled was more or less circular with a radius of 12 to 15 miles. As stated before, this sandstone is basal, resting on igneous rocks, and to avoid local irregularities in mineral content, the samples, so far as possible, were taken from the upper part of the formation.

The transition zone lying between the Lamotte and the Bonneterre dolomite is represented by dolomite and sandstone, extending in places through forty or fifty feet.

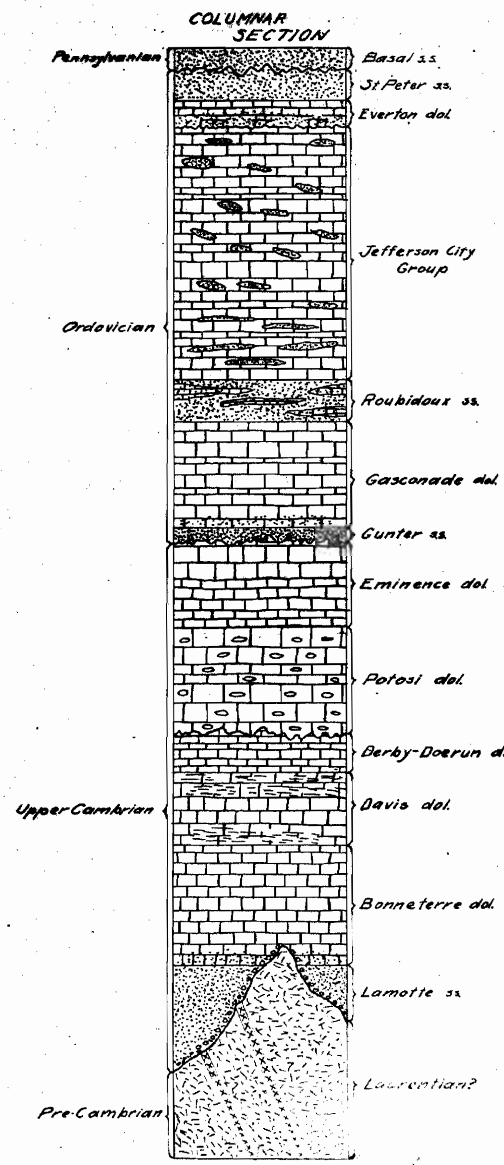
Bonneterre dolomite.--The Bonneterre formation is a massive, gray to buff, noncherty dolomite, with an average thickness of about 265 feet, but varying greatly since it overlaps the Lamotte sandstone onto the porphyry knobs.

Davis formation.--The Bonneterre dolomite grades conformably into the Davis formation, which is composed of thin bedded dolomitic limestone, and shales, with limestone predominating. Its average thickness is about 170 feet.

Derby-Doerun formations.--The Davis formation grades conformably into the Derby, a massive dolomite formation about 40 feet thick. Above this is the Doerun, an argillaceous dolomite about 50 feet in thickness. Outcrops are confined to areas within the vicinity of the St. Francois Mountains.

Potosi dolomite.--This formation outcrops widely in Washington, Iron, Crawford, Reynolds, Shannon, and Madison counties, where it is found resting unconformably on the Derby-Doerun, Davis, and Bonneterre. It consists of dark brown, massive

Plate II


COLUMNAR SECTION
Pennsylvanian
Ordovician
Upper Cambrian
Pre-Cambrian
Basal s.s.
St Peter ss.
Everton dol.
Jefferson City Group
Roubidoux ss.
Gasconade dol.
Gunter ss.
Eminence dol.
Potosi dol.
Derby-Doerun dol.
Davis dol.
Bonneterre dol.
Lamotte ss.
Laurentian?

dolomite with abundant quartz druses. The dolomite usually possesses a foetid odor on freshly broken surfaces. Its thickness is extremely variable, but may average 250 feet.

Eminence dolomite.--This formation is best known in Shannon County, where it has a thickness of more than 200 feet. It consists of light gray, massively bedded, cherty dolomite.

Ordovician system.

Gasconade formation.--Gunter sandstone.--The Gunter sandstone is the basal member of the Gasconade. It consists of a very pure, light gray to brown, well cemented, often quartzitic sandstone. Its thickness ranges from a few feet up to 35 or more feet. Its type locality is Hahatonka Spring, Camden Co., and it is known in Morgan and Miller counties, but it also has a wide distribution in Shannon, Reynolds, Carter, Wayne and Ste. Genevieve counties. It is sparingly developed in the central St. Francois Mountain area, but its horizon laps across all the older formations, due to the pre-Gunter erosion interval. A few samples were taken from outcrops in each area.

Above the Gunter member there is 250 feet or more of very cherty dolomite. This thick dolomitic member is much more widely known than the basal sand. Due to its thickness its upper beds are often found outcropping in deep valleys, where the Gunter is not exposed.

Roubidoux sandstone.--This is the most conspicuous and widespread sandstone in the Ozark region. In reality it is made up of sandstone and dolomitic limestone lenses. The lenses are not widely persistent, but rapidly change from one locality to another, so that it is impossible to trace them throughout the entire area. The sandstone is medium to coarse grained, and generally ferruginous. Its thickness varies from 75 to 150 feet.

It outcrops entirely around the St. Francois Mountains, but is found in wider areas on the south, west and northwest sides, because of the gentler dips in these directions. It caps a great many of the uplands in Dent, Crawford, Phelps, Pulaski, Texas, Reynolds, Shannon, Carter, Ripley, and Butler counties. It is also widely known in Camden, Morgan, and Miller counties. No samples were obtained from these last three counties, and only a very few from the east flank of the St. Francois Mountains, thus leaving the great majority from Phelps, Crawford, Pulaski, Texas, Shannon, and Dent counties. The entire area from which samples were taken is more or less circular with a radius of 30 to 40 miles.

Whenever it was possible the horizon within the formation was noted, and at a few places (Plate I), where good sections of the formation were exposed, samples were taken at irregular intervals from the base to the top.

Jefferson City group.--This group includes what are now known as the Jefferson City, Cotter, and Powell formations. They are essentially argillaceous dolomites averaging probably more than 600 feet in thickness, with occasional sandstone lenses.

Everton formation.--The Everton consists of two members, the lower one being a sandy phase with interbedded limestone, and the upper a sandy limestone, with a total thickness of approximately 60 feet.

St. Peter sandstone.--This description was abstracted from Dake's[1] bulletin. The sandstone outcrops in this area as a narrow border, on the north and east slopes of the uplift. In south Missouri it rests upon the Everton, but to the north the Everton apparently becomes more and more sandy and finally grades into the St. Peter. Where the Everton is present in Ste. Genevieve and southern Jefferson counties, the St. Peter probably averages 60 feet in thickness, but farther to the north the two combined reach 115 feet or more. The St. Peter sandstone is noted for its high percentage of silica. Numerous analyses show a silica content varying from 96 to 99½ per cent. Only a few samples were selected from this horizon.

Above the St. Peter several other formations are present on the borders of the uplift, but in the central Ozark region the Pennsylvanian sandstone is the next overlying formation, except for one small patch of Devonian, and numerous areas of residual Mississippian chert.

Carboniferous system.

Pennsylvanian sandstone.--This sandstone is found as remnants over a large part of the Ozark region, but it is most

1. Dake, C.L., Problem of the St. Peter sandstone; Missouri School of Mines and Metallurgy, Bull. Vol. VI, No.1, Aug.,1921.

conspicuous in Phelps, Crawford, Maries, and Gasconade counties, where it is associated with clay deposits. Since there is a great unconformity at its base, it is found in contact with all formations down to the Potosi, and it often-times fills sinks which existed in the older formations. A few samples were collected in Phelps and Crawford counties.

A list showing the locations from which samples were taken is given below.

1. Roubidoux--one mile north of Meremac River on Highway No. 19, Crawford County.
2. Pennsylvanian--one mile south of Cuba, on Highway No. 19, Crawford County.
3. St. Peter--Crystal City, Jefferson County.
4. St. Peter--ten miles northwest of Winfield, Lincoln County.
5. Roubidoux--NW.¼ sec. 19, T. 37 N., R. 1 E., Washington County.
6. St. Peter--River aux Vases, Ste. Genevieve County.
8. Gunter--SE.¼ sec. 7, T. 29 N., R. 1 W., Reynolds County.
9. Sandstone float--where road crosses hill in NE. ¼ SE.¼ sec. 18, T. 33 N., R. 2 E. Occurs over 100 feet above the base of the Gasconade float. Probably a remnant of the Roubidoux.
10. Sandstone float--on hillside along Highway No. 21, between Lesterville and Centerville, where road crosses the saddle in N.½ sec. 15, T. 32 N., R. 1 E., Reynolds County. May be Gunter, Roubidoux, or Pennsylvanian.
11. Sandstone float--top of hill along Highway No. 21, between Glover and Lesterville, near the center of sec. 5, T. 33 N., R. 3 E. Occurs about 100 feet above the lower margin of

Gasconade float. Probably Roubidoux.

12. Sandstone float--near the crest of Tip Top Mountain, along Highway No. 21, between Hogan and Arcadia. Abundant blocks far above lower margin of Gasconade float.

13. Sandstone float--saddle along Highway No. 32, just west of Shepherd, Iron County, in NW. ¼ SW.¼ sec. 36, T. 35 N., R. 1 E. Is resting on Potosi float. Possibly Gunter, more probably Roubidoux.

14. Sandstone float--along Highway No. 32, in Iron County, in SW. ¼ SW.¼ sec. 31, T. 35 N., R. 1 E. Heavy float above a considerable thickness of Gasconade float. Probably Roubidoux.

15. Sandstone float--Highway No. 32 in west edge of Bixby, Iron County. About 100 feet above Eminence-Gasconade contact. Probably Roubidoux.

16. Roubidoux--3½ miles east of Salem, Dent County, on temporary Highway No. 32, just east of a double right angled offset.

17. Roubidoux--seven miles northwest of Salem, Dent County, at the Deep Ford school on Rolla-Salem road.

18. Gunter--Hahatonka Spring, Camden County. Type locality.

19. Lamotte--N.½ sec. 7, T. 35 N., R. 3 E., Washington County.

20. Gunter--two miles west of Stone Hill, on Highway No. 32 (temporary), elevation 1130 feet, Dent County.

21. Roubidoux--SW. ¼ sec. 12, T. 29 N., R. 2 W.

22. Lamotte--center W.½ sec. 36, T. 36 N., R. 2 E., Washington Co.

27. Pennsylvanian--coal mine at Anaconda, Franklin County.

33. Sandstone float--one mile west of Meremac Spring on St. James road. Taken from top of hill and is probably Roubidoux.

34. Roubidoux--Highway No. 17, on the north bank of Jack's Fork Creek at the Jack Fork Bridge, Texas County.

35. Roubidoux--Highway No. 66, 1½ miles southwest of the Arlington bridge on the big hill. Basal two feet of the formation.

36. Roubidoux--same as No. 35, except 35 feet above the base of the formation.

37. Roubidoux--same as No. 35, except 60 feet above the base of the formation.

38. Roubidoux--Highway No. 66, on the hill one mile northeast of Hooker.--Basal conglomerate.

39. Roubidoux--same as No. 38, except about two feet above the base.

40. Roubidoux--same as No. 38, except about 45 feet above the base.

41. Roubidoux--Highway No. 66, west of the Devil's Elbow, about 20 feet above the big stone railing. Close to the base of the formation.

42. Roubidoux--at the junction of Highway No. 66 and temporary Highway No. 28. One mile west of Devil's Elbow. Estimated to be 50 or 60 feet above the base of the formation.

43. Roubidoux--top of the hill on Highway No. 66, one mile east of Waynesville. About 50 or 55 feet above the base of the formation.

44. Roubidoux--same as No. 43, except within 10 feet of the base of the formation.

45. Roubidoux--Highway No. 17, about 3 miles south of its junction with Highway No. 66. Taken from shallow road ditch on the

ridge top, between 50 and 75 feet above the base of the formation.

46. Roubidoux--road ditch along the ridge top one half mile south of Bloodland on Highway No. 17.

47. Roubidoux--at the school house where Highway No. 17, (temporary) crosses the first creek south of Bloodland. Conglomerate taken to be the base of the formation.

48. Sandstone--just above sample No. 47. Roubidoux or Jefferson City.

49. Sandstone--one mile south of samples No. 47 and 48, on the top of the ridge. Probably very high in the Roubidoux or it may be Jefferson City.

50. Sandstone--top of the ridge along Highway No. 17, one-half mile east of Roby. Either Roubidoux or Jefferson City.

51. Roubidoux--top of the hill on Highway No. 17, three-fourths of a mile southeast of Bucyrus, on road to Houston. Near the top of the formation.

52. Roubidoux--where Highway No. 17 crosses the Piney River, west of Houston. Twenty feet above the level of the river, and near the base of the formation.

53. Roubidoux--same as No. 52, except 45 feet above the base.

54. Roubidoux--same as No. 52, except 65 feet above the base.

55. Roubidoux--same as No. 52, except 85 feet above the base.

56. Roubidoux--same as No. 52, except 105 feet above the base.

57. Roubidoux--same as No. 52, except 130 feet above the base.

59. Pennsylvanian--NE.¼ NW.¼ sec. 35, T. 38 N., R. 6 W., about

two miles northwest of Meremac Spring. Massive sandstone thought to be Pennsylvanian resting on thin bedded basal Roubidoux.

60. Pennsylvanian--N.½ NE.¼ NE.¼ sec. 29, T. 38 N., R. 6 E., along the road about one mile east of St. James.

61. Sandstone--temporary Highway No. 19, about 2 miles northeast of Howe Station, Dent County. Probably Roubidoux very low in the formation.

62. Sandstone--temporary Highway No. 19, in Dent County, about midway between Meremac River and Crooked Creek. Probably extreme base of the Roubidoux.

63. Roubidoux--Highway No. 19, where it crosses the Palmer fault, about two miles southwest of Cherryville, Crawford County. About 40 to 50 feet above the base of the formation.

64. Roubidoux--Highway No. 19, about midway between Cherryville and Steeleville, on top of the hill at Ernest A. Smith Memorial Chapel. Probably about middle Roubidoux.

65. Pennsylvanian--road-cut on Highway No. 66 (temporary), at the right angle turn 1--1~~½~~¼ miles northeast of St. James.

66. Pennsylvanian--from Highway No. 66 (temporary), one-fourth mile east of Phelps County-Crawford County line.

67. Pennsylvanian--road cut on Highway No. 19, one mile south of Cuba.

68. Roubidoux--Highway No. 19, between Cuba and Steeleville, on the hill north of the Meremac River bridge, about 10 to 15 feet below the top of the hill.

69. Roubidoux--same as No. 68, except 20 feet below it.

70. Roubidoux--same as No. 68, except 40 feet below it.

71. Roubidoux--same as No. 68, except 60 feet below it.

72. Roubidoux--same as No. 68, except 80 feet below it.

73. Roubidoux--same as No. 68, except 110 feet below it, and within 10 or 15 feet of the base of the formation.

74. Roubidoux--Highway No. 8, about one mile east of Steeleville, near the center of section 35, T. 38 N., R. 4 W. Base of the formation.

75. Roubidoux--same as No. 74, except about 50 feet above the base.

76. Sandstone--hill west of Huzzah Creek, on Highway No. 8 (temporary), NW. ¼ NE.¼ sec. 35, T. 38 N., R. 3 W. Either basal Roubidoux or Pennsylvanian in sink structure.

77. Roubidoux--Highway No. 8 (temporary), one mile west of Berryman, and just west of the Berryman fault in the SW.¼ sec. 14, T. 37 N., R. 2 W.

78. Lamotte--W.½ SW.¼ NW.¼ sec. 8, T. 35 N., R. 3 E., on Caledonia-Bismark road. Horizon within formation unknown.

79. Lamotte--W.½ SW.¼ sec. 11, T. 35 N., R. 3 E., on the Caledonia-Bismark road. Horizon with the formation unknown.

80. Sandstone--transition zone between the Lamotte and Bonneterre, where the 25 minute meridian (Ste. Genevieve Co. map) crosses Salem Creek, on the old Farmington-St. Louis road, in what would be, if the area were sectionized, the E.½, sec. 25, T. 37 N., R. 5 E.

81. Sandstone--transition zone between the Lamotte and the Bonneterre. About one mile south of Farmington Junction (Ste.Genevieve Co. map).

82. Lamotte--where the Farmington-Ste. Genevieve road crosses Camp Creek near the center of sec. 33, T. 36 N., R. 6 E. Forty feet below the Bonneterre contact.

83. Lamotte--Highway 32 (temporary), one mile southwest of Jonca, in SE.¼ sec. 13, T. 36 N., R. 6 E. About 125 feet above the granite contact.

84. Lamotte--where the Ste. Genevieve-Farmington road crosses the south fork of Jonca Creek in SW.¼ NW.¼ sec. 18, T. 36 N., R. 7 E. About 100 feet below sample No. 83.

85. Lamotte--where the Ste. Genevieve-Farmington road crosses the railroad in NW.¼ NW.¼ sec. 4, T. 36 N., R. 7 E., about 140 feet above the granite contact.

86. Lamotte--W.½ NW.¼ sec. 35, T. 37 N., R. 7 E. Very close to the top of the formation.

87. Sandstone--within the fault zone in the railroad cut about one mile west of Weingarten in SW.¼ sec. 26, T. 37 N., R. 7 E. Probably Roubidoux, or possibly Gunter.

88. Roubidoux--in the railroad cut in Weingarten in NW.¼ sec. 25, T. 37 N., R. 7 E. Within 20 feet of the base of the formation.

89. Lamotte--Highway No. 61 in W.½, sec. 14, T. 35 N., R.6 E.Within 30 feet of the top of the formation.

90. Lamotte--Highway No. 61 (temporary), in what would be, if the area were sectionized, the NW. corner sec. 20, T. 35 N., R. 7 E. About 50 feet below the top of the formation.

91. Roubidoux--Highway No. 61 (temporary), at center of SW.¼ sec. 29, T. 33 N., R. 9 E. Horizon within the formation not known.

92. Roubidoux--top of hill on Highway No. 54, about 3 miles east of its junction with Highway No. 67, Wayne County. Near the base of the formation.

93. Sandstone float--Highway No. 34, at top of hill about 3 miles east of Piedmont, Wayne County. Either Gunter or Roubidoux in sink structure.

94. Roubidoux--temporary Highway No. 34 at the highest point of the divide, about half way between Piedmont and Leeper, Wayne County. Low in the formation.

95. Roubidoux--top of high hill along county road about/½--2 miles east of Mill Springs, Wayne County. Base of the formation.

96. Gunter--same as 95, except about 160 feet lower on the hill.

97. Roubidoux--hill top at Garwood, Reynolds County, along Highway No. 34. Very base of the formation.

98. Roubidoux--junction of Highways No. 21 and 60, Carter County. Basal beds.

99. Gunter--about 5 miles east of Van Buren, on Highway No. 60, near base of the big hill.

100. Gunter--about two miles west of Van Buren, Carter County, on Highway No. 60 (temporary). About 10 feet above the saddle.

102. Roubidoux--Highway No. 60, about 5 miles west of Fremont at the top of the ridge. Probably basal bed.

103. Roubidoux--one mile west of Winona, Shannon County, on Highway No. 60. Horizon within the formation not known.

104. Roubidoux--about one mile east of Teresita, in shallow valley on Highway No. 60. Horizon within the formation not known.

105. Roubidoux--Highway No. 17, just north of Jack's Fork bridge. Extreme base.

106. Roubidoux--same as No. 105, except 60 feet above the base.

107. Roubidoux--same as No. 105, except 100 feet above the base.

108. Sandstone--two miles NW. of Summersville on Highway No. 17 (temporary). Either top of Roubidoux or base of Jefferson City.

109. Roubidoux--Highway No. 17 (temporary), between Eunice and Raymondsville, in NE.¼ NE.¼ sec. 33, T. 30 N., R.8 W. Within 30 feet of the top of the formation.

110. Pennsylvanian--Highway No. 63, 2 miles north of Rolla, Phelps County.

SEPARATION.

The samples were crushed in an iron mortar with an iron pestle, care being taken to prevent any undue breaking of the individual grains. After a little practice this was accomplished with excellent results. In most cases the samples were sufficiently friable so that no trouble in crushing was encountered, but a few highly quartzitic ones presented a problem that was not easily overcome. In such cases it is practically impossible to prevent breakage of grains. Whenever it was possible quartzitic bands in the sample were discarded, and the more loosely cemented material used.

After some preliminary experimenting with a few of the samples it was found that the total quantity of detrital minerals was very small, therefore some means of preliminary concentration was necessary before attempting the final separation by means of acetylene tetrabromide. Panning 300 to 500 cc. of the crushed material was tried, but found inconvenient and time-consuming. Several samples, however, were concentrated by this method. Continued agitation and washing was carried on until the original material had been reduced in volume to 10 or 15 cc. Good crops of "heavies" were secured from the samples so treated, but as stated above this method required painstaking care and more time than was available. Screening[1] was then resorted to and found

1. Suggested by Mrs. Fanny C. Edson of the Roxana Petroleum Corp., Tulsa, Oklahoma.

to be much more satisfactory.

The concentration by screening is based upon the assumption that the heavy minerals in a sandstone are smaller in size than the average quartz grains themselves. When the difference in specific gravity of quartz and that of the detrital grains is considered along with the mechanics of sedimentation, it appears that the assumption is based on principles which are fundamentally true. A quartz grain of given size will be moved by the force of flowing water, whereas a mineral with greater specific gravity and equal size would be left undisturbed. Thus when the final resting place was reached the quartz grains would have associated with them smaller grains of the heavier detritals.

After studying screen tests made by Dake[2] on various sandstones, and after making some preliminary tests, a 60 mesh Tyler screen was selected as being suitable for most samples.

2. Dake, C. L., Problem of St. Peter sandstone; Missouri School of Mines and Metallurgy, Bull. Technical Series, Vol. VI, no.1, August, 1921.

This screen in the great majority of cases allowed from 10 to 30 per cent of the sand to pass. All material which passed the screen was further separated with acetylene tetrabromide.

In order to get some idea of whether concentration by screening resulted in any appreciable loss of the heavy mineral content, measurements were made of grains from those samples which had been panned, rather than screened. A comparison of these sizes with the size of the openings in a 60 mesh screen, suggests that only a very few of the largest grains could have been lost by this process. Only a few of the largest grains in each slide were measured, and the results are presented in the accompanying table.

SIZE OF LARGEST GRAINS IN PANNED SAMPLES (mm).

Sample #16	Sample #17	Sample #18	Sample # 23
0.14 x 0.11	0.25 x 0.16	0.27 x 0.11	0.20 x 0.14
0.10 x 0.08	0.27 x 0.20	0.30 x 0.30	0.22 x 0.18
0.19 x 0.12	0.31 x 0.24	0.26 x 0.21	0.15 x 0.20
	0.26 x 0.16	0.24 x 0.08	0.22 x 0.14
	0.18 x 0.08	0.27 x 0.11	
	0.31 x 0.09		

Size of openings in screen 0.22 mm to 0.24 mm.

The measurements show the long and short dimensions of the grains. In sample No. 16 all grains would have passed the screen. In sample No. 17 one grain would possibly have been retained on the screen, and undoubtedly one would have been retained in sample No.18, while all grains in sample No. 33 would have passed. From the comparison it is seen that only two grains would have possibly been retained on the screen. A glance at the measurements will show that in most cases the long dimension of the grain exceeded the size of the opening in the screen. The question as to whether this fact might affect passage through the screen may be raised. Measurements of grains in many samples which actually passed the 60 mesh screen show grains with long dimensions equally as great. Therefore it seems that the above fact does not materially affect passage through the screen.

Another matter of importance to be considered in the above comparison of grain sizes, is the question of whether or not the largest grains might have been lost, even in the panning process. Tourmaline and zircon make up the greater percentage of the heavy minerals. The tourmaline grains are from two to ten times as large as those of zircon. Since the specific gravity of tourmaline (2.98-3.2) is much nearer that of quartz (2.65) than is zircon (4.68-4.70), and since the size of the tourmaline grains also approaches that of the quartz grains, it appears likely that the larger grains of tourmaline will tend to remain associated with the quartz and be lost. But even if such was the case, it does not appear logical that all of the large grains of tourmaline would be lost in panning. Certainly the percentage of the large grains present is very small, or more than two such grains would have been encountered in the four slides which were panned and later measured. That concentration of these sandstones by screening through a 60 mesh screen is sufficiently accurate for most scientific purposes there remains little doubt. It is believed that concentration by screening will result in fewer grains being lost than when the panning process is used.

As has been noted above, all of the material which passed the 60 mesh screen was then separated by means of acetylene tetrabromide; the material retained on the screen being discarded.

With most of the samples 250 cc of the original crushed sandstone was screened, although as was later found 100 cc would have been sufficient for the great majority of cases, and difficulties which later developed would have been avoided.

The screened material was in practically all cases to a greater or less extent coated with iron oxide. To remove this coating the sample was boiled in a 50 per cent solution of hydrochloric acid for a period of time varying from twenty to forty minutes depending upon the amount of iron oxide present.

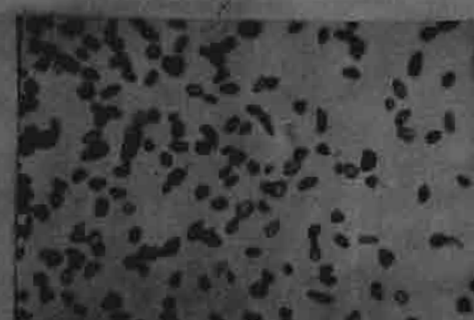
When the destructive forces to which the minerals in these sandstones have already been subjected in nature is considered, it is seen that there is little likelihood that they will be destroyed by this treatment in acid. Of course pyrite would be dissolved, but since it is a secondary mineral, and is known to exist in all of the sandstones of this region, its retention would be of little diagnostic value. Magnetite, also, if present, would have been lost. This ubiquitous mineral also probably has little value for discriminatory purposes. Other minerals which may be expected would suffer little or no change in this acid treatment.

After the removal of the oxide was complete the samples were thoroughly washed by decantation to remove all traces of acid, after which they were set upon the hot plate or sandbath to dry. When the sand was dry it was pure white, and was then ready for the final separation of the quartz from the detrital heavy minerals.

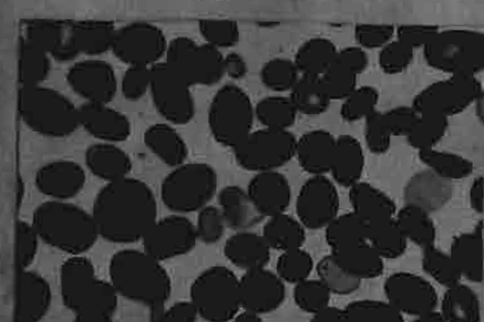
For this, acetylene tetrabromide with specific gravity of 2.94 was used. In separating the first samples six inch evaporating dishes were used. They were partially filled with acetylene tetrabromide and the sand poured on top. The mixture was then stirred every few minutes for a period of an hour or more. This stirring was carried on in such a way that once the grains had settled to the bottom they were not again brought back up into the mixture. After stirring was completed, from two to three hours, often longer, was allowed for complete separation to take place. Then the lighter material was simply decanted, leaving the heavy grains on the bottom of the dish. These were subsequently collected and washed onto filter paper with benzene. They were then washed three to five times with benzene, and after drying, were placed in envelopes and filed for future petrographic study.

While the above method gave excellent crops of heavy minerals, more time and painstaking care were necessary than when the separation was done with simple separatory funnels. These were of the type with very steep conical sides, in order to prevent undue retardation of the slowly settling grains. They were arranged in a battery of ten, although more would have been better. After they were filled about two-thirds full of liquid, the sand was introduced and thoroughly stirred every fifteen or twenty minutes for a period of about three hours. They were then allowed to stand, without stirring, for a period of several hours, usually over night.

Plate III



A. Angular Grains
Chiefly ZIRCON
x 80



B. Rounded Grains
Chiefly TOURMALINE
x 80

When the heavy minerals had collected at the stop cock of the funnel they were drawn off onto a filter paper and treated in the same manner as those which had been separated in evaporating dishes. It is doubtful if a complete separation can ever be affected, due to the fact that the very small heavy grains will tend to adhere to larger quartz grains and will thus be prevented from sinking. The completeness of the separation is directly related to the number of times the mixture is stirred.

In all of the above processes the time element must be considered. The time taken depends largely upon the standardization of the processes, after preliminary experiments have shown what treatment gives best results.

PETROGRAPHIC STUDY

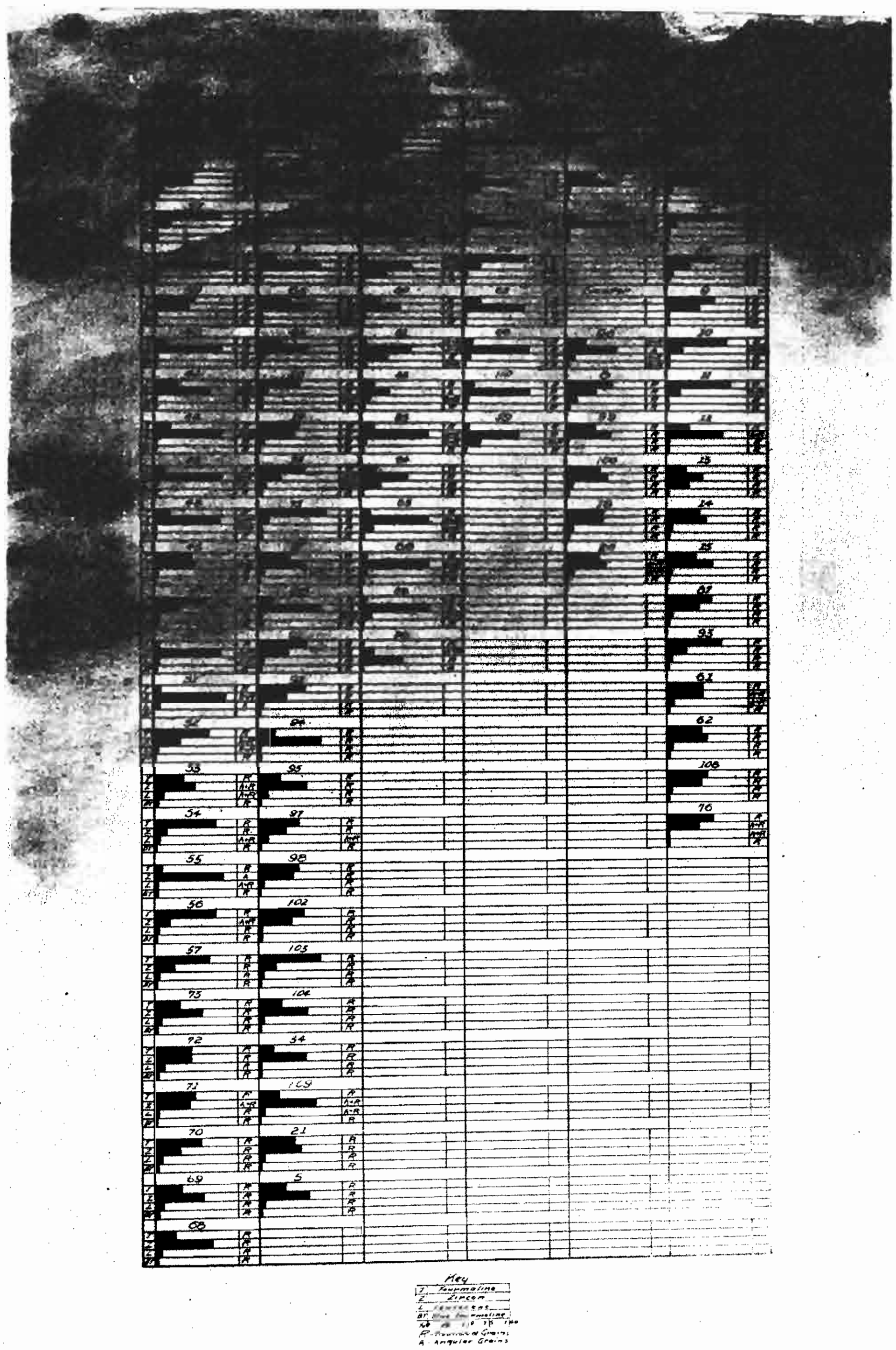
There are two methods of mounting the grains for petrographic study: (1) Temporary mounts in index of refraction liquids or (2) permanent mounts in Canada balsam. Both methods have advantages and both were used in this study. Permanent mounts can be filed and referred to any future time, although it is practically impossible to positively identify some unknown grains which may be discovered in such a mount. Therefore temporary mounts in liquids of known index of refraction are practically indispensable. A method used to good advantage, consisted of first studying the material under a low power binocular microscope, and isolating those grains that appeared to be alike. Then four or five of these grains were transferred to a liquid of known index of refraction and studied under the polarizing microscope. When it was necessary to transfer them to another liquid the cover glass was removed and the slide again placed under the low power binocular microscope, and with a fine needle the grains were isolated from the liquid and collected on one end of the slide, where they were washed with a drop or two of xylol. When the xylol had evaporated they were transferred to another slide with a fine camel's hair brush. This process was repeated as many times as was necessary. The above procedure may seem slow and laborious, but it is only necessary to perform it once, in most cases, and after that when the mineral grain is encountered it can be recognized almost at sight.

In most cases there was a sufficient number of grains to make more than one slide. It had been planned to mount one slide of the mineral grains in Canada balsam and retain the remainder for further study in liquids of known index of refraction, in case this became necessary after studying those in the permanent mount. Such a procedure was carried out except in about ten cases, where the total was mounted permanently. The minerals in the permanent slides were determined, counted and the percentages of each calculated. A graphical chart was made showing the comparison of percentages in the various samples. Some very interesting information was revealed by a study of this chart.

In most cases where the total material (Samples No. 40 to 50) was mounted, the percentage of zircon exceeded that of tourmaline, while in the great majority of other cases (those in which only a part of the material was mounted) the ratio between zircon and tourmaline was reversed. An investigation into the cause of this discrepancy revealed additional information.

A study of the two minerals showed that the tourmaline grains were not only much larger, but were also better rounded than those of zircon. The cause of the variation in ratio was very apparent. When the minerals were filed after separation, they, as already indicated, were preserved on filter paper. At the time of mounting, the grains were allowed to roll from the center of the paper to the outer margin, where a part was shaken onto the slide and the remainder again filed. It will be readily seen that since the tourmaline grains were larger and better rounded than the zircon grains, they, along with a few of the better rounded zircons reached the outer margin first, and were thus, more or less segregated from the smaller and more angular minerals, and as such appeared in the first slide mounted. Upon mounting a few slides of the remaining material, and studying them under the microscope, their content, in most instances, proved to be made up largely of small zircon and leucoxene grains with only a few of tourmaline.

A few samples have been selected more or less at random to show the above effect, and the results are tabulated in the following table:



Key
T Tourmaline
Z Zircon
A - Angular Grains

Comparison of first and second mounts.

	Sample #27		Sample #109		Sample #53		Sample #66	
	Part mtd.	All mtd.	Part mtd.	All mtd.	Part mtd.	All mtd.	Part mtd.	All mtd.
Tourmaline	40%	25%	70%	25%	90%	32%	10%	8%
Zircon	50%	70%	25%	70%	5%	50%	65%	80%
Leucoxene	10%	5%	5%	5%	5%	18%,	25%	12%
Blue Tour.	Pres.	Pres.	Pres.	Pres.	Pres.	Pres.	Pres.	Pres.

The first column represents slides in which only a part of the material from each sample was mounted, the second column the total "crop". In every case the percentage of tourmaline was reduced while that of zircon was increased, in most cases the change being very great. The percentage of leucoxene was not greatly affected, since these grains vary more in size and angularity than do those of tourmaline and zircon. The above incident in technique reveals an important caution that must be exercised in such studies, and it is hoped that the above discussion will be of value to future workers.

After this error was discovered it became necessary to mount all of the remaining material and recalculate the ratios of one mineral to another.

Difficulty in obtaining the relative percentages of the minerals present was now encountered, since the first slide mounted contained most of the tourmaline and larger zircon grains, while the second slide contained chiefly the small, more angular zircon and leucoxene grains. This could have been easily overcome by counting all of the grains had the number been small, but in many cases the total number was well over 5,000 and the time available would not permit such large counts to be made. Even though it had, such a procedure would have been a stupendous task. The only choice left was to estimate as closely as possible the relative number of grains present. This was accomplished in the following manner.

Since there was no way of knowing exactly what part of the total was in each slide, both were taken, and actual counts made in various parts of each. Estimates were then made on the number of grains present in each slide and the counts weighted accordingly. Checks on the accuracy of the estimates were made by counting the total number of grains in two samples. These were selected, because the total number of grains was comparitively small, but even so sample No. 5 contained 4285 grains and No. 50 contained 1816. The relative percentages were first estimated in the manner indicated above, and then actual counts were made. A glance at the chart below shows that in no case does the estimate differ more than ten per cent from the actual count, and and the average error was five per cent. An error this small would have little effect in a problem of this nature, although it is possible that it may be somewhat greater in cases where the total number of grains was unusually large.

Comparison of counts and estimates of grains in slides.

	Sample #5			Sample #50		
	Estimate	Count	Error	Estimate	Count	Error
Tourmaline	25%	23%	2%	63%	58%	5%
Zircon	60%	70%	10%	30%	36%	6%
Leucoxene	15%	7%	8%	7%	6%	1%
Blue Tour.	Pres.	Pres.	~~Pres.~~	Pres.	Pres.	

RESULTS.

Zircon was the most conspicuous mineral grain in most cases. The most common species was colorless, although a few yellow-brown grains were encountered in practically every sample. Inclusions within the grains are common, in many cases producing a dusky appearance. The grains vary considerably in form, from very well rounded to almost perfect euhedral crystals. The larger the size, the more perfect the rounding. Some of the very largest grains were almost spherical, while the very smallest ones showed well developed prismatic and pyramidal forms. Of course the great majority of the grains lie between these two extremes, but sharply angular fragments are very rarely encountered. As already stated the size of the grains varies greatly, but rarely are they as large as those of tourmaline. Some of the largest are .15 to .18 mm in diameter, while the smallest are .02 mm or less in size, with the average probably about .08 to .12 mm. A characteristic grain of zircon is often well rounded, with one dimension two to three times the other.

In general the next most frequent mineral grain was tourmaline. The most important feature exhibited by this mineral was the high degree of rounding. No grains were observed that showed the least resemblance to a crystal face. Many show a strong elongation parallel to the c-axis, as shown by absorption, but the rounding is always good. Spherical grains, although not very common, do occur, and from them the best interference figures are obtained. Several colored varieties are present, among which are brown, brownish yellow, black, green, blue, and possibly a few colorless grains. Inclusions are very common. No attempt was made to separate the varieties, except in the case of the blue grains. Because they were conspicuous and relatively few in number, it was a simple matter to note their occurrence. In general the tourmaline grains are much larger than the zircon grains, in many cases the long dimension of the grain being .2 mm or more.

A third mineral present is leucoxene. This occurs in rounded or irregular grains, white to brownish white in reflected light. A rough, pitted, porous surface is also characteristic. Many of the grains show a rudely triangular shape with slightly rounded edges. Some difficulty was experienced in positively identifying the mineral under the microscope, and finally a sample (No.84) which showed a large percentage of the opaque mineral was tested chemically for titanium. The test was decidedly positive, and upon the basis of this test, coupled with the microscopic characteristics, the mineral was called leucoxene. The size of these grains is very variable, some being as large as those of tourmaline while the great majority are smaller, probably averaging smaller than the zircon grains.

Another mineral which is found in some samples in great abundance is anatase. It is transparent to opaque, often showing a yellowish tinge, with euhedral form. Most of the crystals are square tablets, lying on the basal pinacoid. It is presumably a secondary mineral derived in situ since the well developed euhedral forms are found associated with well rounded tourmaline and zircon grains. This mineral was noted in five samples, although it is possible that it may be present in others. (See table below).

Percentage of Anatase.

	Sample #16 Roubidoux	Sample #34 Roubidoux	Sample #80 Lamotte	Sample #82 Lamotte	Sp.#90 Lamotte
Anatase	25%	10-15%	33%	50%	45%

In making the relative percentage chart anatase is not shown because of the relatively few samples in which it was observed.

At the same time the mineral identification was made the rounding of the grains was also noted. Two photomicrographs (Plate III) were taken to show the degree of rounding. Grains are designated as being rounded (R) and angular (A).

This method of notation has been used to give only a rough approximation of the degree of rounding. Grains which are designated as rounded really show rounding to a high degree, while those grains which have been called angular include a rather wide range, from a few truly angular, to subangular, and euhedral grains. Most of those grains which have been designated as angular are possibly subangular. The idea was to show that some grains are not as well rounded as others. No attempt was made to obtain a quanitative estimate on round and angular grains.

TABLE SHOWING RESULTS

PLATE 5

ROUBIDOUX	PENNSYLVANIAN	GUNTER	ST. PETER	LAMOTTE
[illegible]NE AND [illegible] DOMINANT	TOURMALINE AND ZIRCON DOMINANT	TOURMALINE AND ZIRCON DOMINANT	TOURMALINE AND ZIRCON DOMINANT	TOURMALINE AND ZIRCON DOMINANT
30 Cases Zircon > Tourmaline [illegible] Cases Tourmaline > Zircon [illegible] Tourmaline = Zircon	7 Cases Zircon > Tourmaline 1 Case Tourmaline > Zircon	4 Cases Zircon > Tourmaline 1 Case Tourmaline > Zircon 1 Case Tourmaline = Zircon	2 Cases Zircon > Tourmaline 1 Case Tourmaline > Zircon	13 Cases Zircon > Tourmaline
LEUCOXENE [illegible] In All [illegible] 20%	LEUCOXENE Present In All Trace To 25%	LEUCOXENE Present In All Trace To 15%	LEUCOXENE Present In All Small Percentages	LEUCOXENE Present In All Trace To 50%
[illegible] TOURMALINE Present In All Cases Very Small Percentages	BLUE TOURMALINE Present In All Cases Very Small Percentages	BLUE TOURMALINE Present In All Cases Very Small Percentages	BLUE TOURMALINE Present In All Cases Very Small Percentages	BLUE TOURMALINE Present In All Cases Very Small Percentages
All Tourmaline Well Rounded Zircon and Leucoxene Rounded and Angular	All Tourmaline Well Rounded Most Zircon and Leucoxene Well Rounded Few Zircon and Leucoxene Rounded and Angular	All Tourmaline Well Rounded Zircon and Leucoxene Rounded and Angular	All Tourmaline Well Rounded All Others Nearly As Well Rounded	All Tourmaline Well Rounded Many Zircon and Leucoxene Rounded and Angular
No Constancy Of Percentages Geographically or Stratigraphically	No Constancy Of Percentages Geographically Not Determined Stratigraphically	No Constancy Of Percentages Geographically Not Determined Stratigraphically	No Constancy Of Percentages Geographically Not Determined Stratigraphically	No Constancy Of Percentages Geographically Not Determined Stratigraphically

Since there were only three chief minerals present in the sands examined and since they were present in all of the samples, the method of graphical representation was simple. It gives at a glance the comparison of any one sample with another, either in one of the sandstones or in all of them.

The relative percentage chart (Plate IV) indicates only the percentage of the mineral grains present, as no attempt was made to plot the percentages of the minor varieties of mineral species in the different sands.

A careful study of this percentage chart shows the data which is indicated in Plate V.

SUMMARY OF RESULTS.

Summarizing the results, the following are outstanding:

1. The presence of the same mineral suite--tourmaline, zircon, leucoxene--in each of the five sandstone formations.
2. The high degree of rounding exhibited by the minerals, especially tourmaline, in practically every sample from all of the formations.
3. A lack of constancy in the relative percentages of the various minerals, either in one formation or in the group as a whole.

CONCLUSIONS.

From the aforementioned results it is seen that it is not possible to discriminate between any of the five sandstones, on the basis of the heavy mineral content alone, since the same minerals are present in each of them, and since the relative percentages are as variable within any single formation as they are throughout the entire group of formations.

To say that any one of the unknown samples is Lamotte, Gunter, Roubidoux, St. Peter, or Pennsylvanian, from the data so far discovered concerning the heavy mineral content would be merely a guess.

The minerals present in these particular sandstones represent exceptionally stable varieties. This may have some bearing on the determination of the source from which the sediments were derived. As suggested by Milner[1], the presence of

1. Milner, H. B., Introduction to the Study of Sedimentary Petrography, p. 106, 1922.

this particular suite of heavy minerals, to the exclusion of all others, implies a derivation of the formations from pre-existing sediments, from which less stable varieties had largely been eliminated by weathering and abrasion. Also the very remarkably perfect rounding of minerals as resistant as these is suggestive of more than one cycle of erosion and deposition. Of course transportation from a very distant source would also tend to produce a high degree of rounding.

The similarity in heavy mineral suites, and the corresponding variation in ratios between the species, suggests that the sandstones studied were probably derived from a common ultimate source. The Pennsylvanian, which in this region is the very basal sand, was probably derived from the re-worked material of all these older sandstones.

Further intensive petrographic studies might reveal differences in the mineral species, which would in turn afford a basis for discrimination. Varieties may be present in one formation and not in another. A careful study of the inclusions within the mineral grain might be helpful. Careful screening might show the size of the heavy minerals in one formation to be different from those in another.

If the heavy minerals of these five formations could be discriminated with any certainty, the method would be very helpful in correlating the isolated patches of sandstone in the Ozarks. It appears rather doubtful, however, whether further studies would reveal differences great enough to enable discrimination between the sands, if the sediments were derived from a common source, and from pre-existing sediments as suggested above.

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