THE MINERALOGY OF SOME SHALES OF THE LOWER PERMIAN SYSTEM OF RILEY COUNTY, KANSAS

by

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INTRODUCTION

A study of some shales of the lower Permian system of Riley County, Kansas was undertaken in an attempt to determine some of the authigenic and allogenic minerals present in the shales.

The purposes of this work are: (1) to determine the authigenic and allogenic minerals present in some of the shales; their physical properties such as degree of rounding, presence of euhedral crystals, degree of weathering; relative concentration in the shales, and optical properties; (2) usefulness for correlation work by noting the relative abundance of a particular mineral, presence or absence of a particular mineral, certain physical properties such as color, structure, degree of rounding, etc.; and (3) some facts about the disintegration of the shales that are being prepared for mineral analysis. The material obtained from this research may be helpful in correlation of stratigraphic units and may have some practical value in deep well cuttings.

Field survey procedure

The field work was accomplished by automobile and consisted primarily of reconnaissance, the collection of samples, and the taking of field notes.

Variations in the lithologic characteristics existing between the various rock units required the maintaining of a perfect stratigraphic orientation at all times.

Roadcuts and stream banks offered excellent sampling sites, and care was exercised in sampling the various units. In general, the "Channel" method of sampling was employed, but the "Spot" sampling method was also used. The "Channel" method would indicate what heavy minerals might be present in a particular rock unite, while the "Spot" method would give some idea what minerals might be present at a particular spot in the rock unit; and this information might prove useful for correlation purposes. Where the rock units were very thick, the quartering method of sampling was employed (1).

Each sample was given a number and located by the section, township, and range method. The sample was recorded also as being either a "Channel" or a "Spot" sample.

Laboratory procedure

The samples upon reaching the laboratory were air dried. After they were thoroughly dry, the shale samples were run through a rock disaggregating machine in order to break down the shales into smaller particles. The sample was split by hand in the following manner: The sample was caught in a low, wide pan. The material was thoroughly mixed by hand, flattened and then divided into quarters. Since the material used was more than sufficient, 100 grams was taken from each quarter. The material was mixed again and divided into quarters and the procedure repeated until the desired amount was obtained.

It was necessary to use from 500 to 800 grams of material depending upon the lithologic characteristics of the particular sediment. A shale that is silty requires 500 grams while a clayey shale would require at least 800 grams to give a reasonable analysis.

After the desired amount of shale had been carefully weighed on a balance type scale, the shale was put into 16-ounce bottles. To each portion in the bottle, 0.5 grams of sodium silicate was added per 50 grams of shale. The purpose of the sodium silicate is to assist in the dispersion of the shale. The rest of the bottle was partially filled with de-ionized water to provide a liquid medium for further disaggregation and dispersion of the shale particles.

When the bottles had been thoroughly stoppered, they were put into a Hornor shaking machine and run for a period of two hours or more to further disperse the shale particles. The bottles containing the samples were then removed and allowed to stand for a period of 30 minutes in order that the heavy particles might settle to the bottom of the bottle, and the clay and silt-size particles were then decanted off and tested by thermal analysis. After the decantation of the clay and silt-size particles, the material was washed repeatedly to remove most of the clay and thus facilitate sieving later on. The heavy minerals were permitted to settle out according to the time factor of Stoke's law (2) which deals with the rate of settling of particles in a liquid medium.

The heavy fraction was then transferred from the 16-ounce bottles to a beaker, and care was exercised to make sure that all of the particles were washed from the bottles into the beaker. Hydrochloric acid was added to this portion of the heavy fraction to digest the carbonate cements and such particles as calcite, aragonite, dolomite, and siderite. It is a further possibility that some other cements and particles are digested in whole or in part.

When all the carbonate cements and particles had been digested, the material was boiled in hydrochloric acid for a period of ten minutes to remove the iron oxide coatings and stains and perhaps some dolomite particles which were not affected by the cold hydrochloric acid.

After a thorough washing of the material to remove the hydrochloric acid, the heavy fraction plus the clay particles was boiled in a 40 percent solution of sodium hydroxide for a period of ten minutes to remove any colloidal silica and opal that might be present. The alkalinity produced by the sodium hydroxide also serves to further disperse the shale particles. The material was thoroughly washed and prepared for sieving.

Sieving was accomplished by the wet sieve method. The entire suspension was poured first through a sieve #120 (U. S. sieve series) to remove all coarse particles and other particles larger than 1/8 mm in diameter. To make sure that all particles smaller than 1/8 mm were saved, the sieve was agitated in a large pyrex bowl while taking care that none of the material was washed over the edge of the sieve. After all the particles were washed through the #120 sieve, the suspension was poured into a #230 sieve (U. S. series). Again the sieve was agitated in the water to wash all the clay and silt size particles smaller than 1/16 mm in diameter through the sieve. The clay fraction was saved for further thermal analysis after being treated with hydrochloric acid and sodium hydroxide.

The particles retained on the #230 sieve were washed several times to insure removal of the clay. In those samples which contained organic matter, the sieved sample was boiled in a 15 percent hydrogen peroxide solution to remove the organic matter. This treatment is not harmful to the grains and leaves no by-products other than carbon dioxide and water. The particles were then transferred to a small dish and dried before making the separation of the minerals based upon the specific gravity of bromoform.

The heavy fraction of minerals was separated from the light fraction by suspending the sieved sample in bromoform and drawing off the heavy minerals that descended to the bottom of the separation funnel. The bromoform that was used had a specific gravity of about 2.75; and, upon this basis, the minerals that floated on top were designated the light fraction, and those that settled were designated the heavy fraction.

The light fraction was found to consist chiefly of chalcedony, quartz, and the various feldspars. The heavy fraction was found to consist of such minerals as zircon, muscovite, topaz, magnetite, sillimanite, garnet, etc.

Upon completion of the mineral separation, the light and the heavy fractions were washed in alcohol to remove the bromoform and dried in a controlled temperature oven.

Mineral mounts of the heavy and light fractions were made. Canada balsam, which has a refractive index of 1.537 was used as the mounting medium.

After the mineral mounts were made, a petrographic analysis was made of both the light and the heavy fractions to determine what minerals were present, grain counts of the minerals, and a calculation of their relative abundance on a percentage basis. This was done for each shale sampled. Notes were taken for the physical characteristics of the mineral grains regarding structure, degree of rounding, shape of crystals, weathering characteristics, and, in some cases, optical properties were used. In several cases the oil immersion method was used to determine the refractive indices along with the other optical properties as determined by the petrographic microscope.

In respect to the determination of the clay mineral present in the shale, the most expedient method of analysis of the methods considered proved to be analysis by differential thermal apparatus.

The particular differential thermal apparatus used has been described in detail in other papers and is very similar to those used in other laboratories. Briefly, the method consists of heating a small sample of the substance to be analyzed to approximately 1,000 degrees C. at a rapid (33 degrees C. per minute) and constant rate, and recording by suitable means the endothermic and exothermic effects. A differential thermocouple is used to detect these effects. One of the junctions is placed in the sample being studied and the other is set in a thermally inert substance that is under-going the same heat treatment on the sample. The temperature at which these endothermic and exothermic effects take place and the intensities of the effects are characteristic for most minerals tested.

Recording such characteristics may be of diagnostic aid in future work, and the presence or absence of authigenic and allogenic minerals could be made on this basis.

REVIEW OF LITERATURE

The sedimentary rocks consist basically of two kinds of material: (1) clastic materials and (2) chemically precipitated materials. These mixed together in various proportions form the sedimentary rocks as we find them today. Both kinds of material, however, are derived ultimately from the breakdown of an igneous rock. Igneous rocks are unstable to a mechanical and chemical environment and as a result of the complex weathering process yield three kinds of materials which eventually form the sedimentary rocks. Pettijohn's (3) arrangement of these materials are as follows: (1) stable primary minerals of the parent rock which survive the weathering processes and which are released upon the breakdown of the source rock; (2) stable secondary minerals formed by chemical decay of the unstable primary minerals in the source rock; and (3) solutions from which are precipitated the chemical end members of the sedimentary rocks. Some examples of the stable minerals are as follows: quartz, chalcedony, garnet, magnetite, muscovite, topaz, rutile, titanite, tourmaline, and zircon. Examples of the stable secondary minerals formed by decay of the unstable primary minerals are: kaolin, limonite, some calcite, some epidote, and some gypsum. Some examples of minerals derived from solutions are as follows: the carbonates such as calcite, dolomite, siderite, and halite, collophane, silica in the form of opal, chalcedony, or quartz.

The minerals of sedimentary rocks are marked by simple composition such as the simple oxides, hydroxides, carbonates, etc.; and these usually are rich in water, carbon dioxide and oxygen. Water, carbon dioxide and oxygen are the active chemical components of the atmosphere. These minerals are stable under low-pressure, low temperature and a hydrous environment at the surface of the Earth. They are more or less comparable to the minerals that crystallize out of a magma during the late stages in the presence of a large amount of water.

The stable primary minerals are usually of sand and silt size particles. The stable secondary minerals are of clay size because they are the result of the products of decomposition of the unstable primary components of igneous rocks. For the most part these minerals are crystalline but of very fine grain, and some are even amorphous. The various precipitates formed from solutions show variation in grain size dependent upon the conditions existing during the time of deposition.

In sedimentary petrology two terms are commonly used, "allogenic" and "authenic" to describe, in a general way, two main classes of minerals. "Allogenic" minerals are those minerals that originated outside of the sediment and are transported to the place of deposition. From a listing by Krumbein and Pettijohn (2) some of the common allogenic minerals are as follows: zircon, muscovite, rutile, garnet, staurolite, hornblende, etc. "Authenic" minerals originate in the place they are found - that is, they grow in place. Some "Authigenic" minerals that are common are as follows: celestite, calcite, collophane, limonite, hematite, pyrite, clay minerals, etc.

For the purpose of correlation, the most useful minerals of the parent rock surviving destruction by weathering, abrasion, or solution are the so-called "heavy minerals". They are marked by a specific gravity which is higher than average, and they rarely exceed one percent of the rock.

When these heavy minerals which have been newly derived from crystalline rocks are incorporated into a new sediment, they are comparatively little worn. Such features as cleavage fragments, more or less euhedral crystals, characterize the assemblage. However, if the heavy minerals are derived from earlier sediments, the less stable species tend to be absent and the more stable varieties tend to show rounding. By making use of such features, the heavy mineral residue has proved useful for correlation purposes.

According to Milner (4), the basic principles underlying the techniques of correlating strata include the use of the stable minerals present. Such principles are embodied in the geographical cycle which consists of terrestrial uplift of a base-levelled or peneplaned region, consequent workings of the forces of denudation, slow wearing down of the newly-formed land surface, and the persistence of such forces until a new base-level is once more attained. Such a complete cycle is thus a geological episode and modern stratigraphy owes much to the recognition of these periodic recurrences. Such a cycle may be referred to as a cycle of sedimentation.

The basis for petrographic correlation is the presence of a distinct heavy mineral assemblage, both above and below a certain strata. Such correlation depends for its success not only on the recognition of a distinctive association of minerals but also upon peculiar varieties, changing proportions of minerals, the various physical properties of minerals such as degree of rounding, weathering characteristics, presence of inclusions, and etc. On the other hand, correlation is complicated by the reworking of earlier sediments and the incorporation of such reworked minerals in younger strata.

EXPLANATION OF PLATE I

Map of Riley County, showing sample locations of the various shale units.

1. Salem Point shale (upper shale zone)
2. Salem Point shale (lower shale zone)
3. Speiser shale
4. Havensville shale
5. Blue Springs shale
6. Easly Creek shale
7. Hooser shale
8. Salem Point shale (upper zone)
9. Salem Point shale (lower zone)
10. Easly Creek shale
11. Speiser shale
12. Blue Rapids shale
13. Blue Springs shale
14. Oketo shale
15. Florena shale
16. Florena shale
17. Wymore shale
18. O Dell shale
19. Paddock shale
20. O Dell shale
21. Grant shale
22. Holmesville shale
23. Grant shale
24. Gage shale
25. Florena shale
26. Hughes Creek shale
27. Johnson shale (upper shale zone)
28. Johnson shale (middle shale zone)
29. Johnson shale (lower shale zone)
30. Florena shale
31.(A) Eskridge shale
31.(B) Eskridge shale
32. Salem Point shale (upper shale zone)
33. Salem Point shale (lower shale zone)
34. Roca shale (lower shale zone)
35. Roca shale (middle shale zone)
36. Roca shale (upper shale zone)
37. Eskridge shale
38. Roca shale (upper shale zone)
39. Oaks shale
40. Hughes Creek shale
41. Roca shale (middle shale zone)
42. Roca shale (lower shale zone)
43. Roca shale (middle shale zone)
44. Roca shale (lower shale zone)
45. Stearns shale
46. Towle shale (Indian Cave Sandstone)
47. Salem Point shale (lower shale zone)
48. Salem Point shale (middle shale zone)
49. Blue Rapids shale
50. Bennett shale (upper shale zone)
51. Bennett shale (lower shale zone)

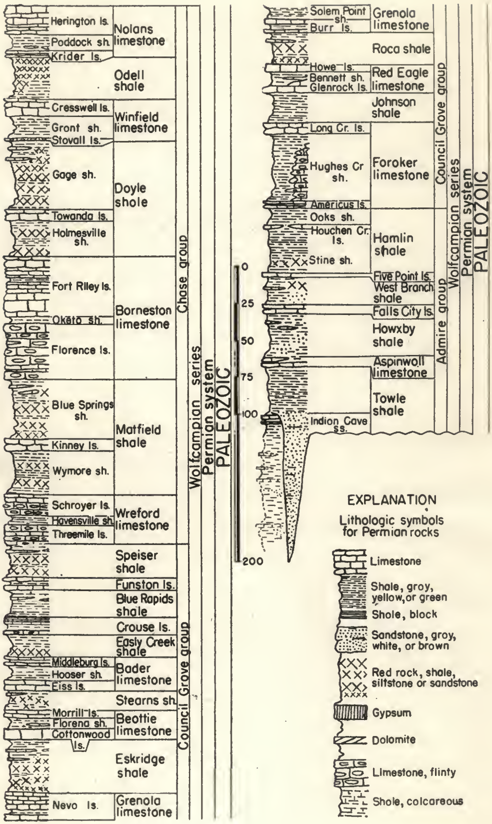
PLATE I


R4E
R5E
R6E
R7E
T 6 S
Cleburne
Winkler
Randolph
T 7 S
Walsburg
Leonardville
T 8 S
Bala
Riley
Stockdale
R7E
T 9 S
Keats
R8E
Fort Riley Military Reservation
T 10 S
Manhattan
R9E
Zeandale
Ogden
T 11 S
SCALE
1 0 1 2 3 4 5 MILES

EXPLANATION OF PLATE II

Generalized stratigraphic section of the lower Permian System in Riley County, Kansas as adapted from J. M. Jewett.

PLATE II


Herington ls.
Nolans limestone
Paddock sh.
Krider ls.
Odell shale
Cresswell ls.
Winfield limestone
Grant sh.
Stovall ls.
Gage sh.
Doyle shale
Towanda ls.
Holmesville sh.
Fort Riley ls.
Oketo sh.
Barneston limestone
Florence ls.
Blue Springs sh.
Matfield shale
Kinney ls.
Wymore sh.
Schroyer ls.
Havensville sh.
Wreford limestone
Threemile ls.
Speiser shale
Funston ls.
Blue Rapids shale
Crouse ls.
Easly Creek shale
Middleburg ls.
Hooser sh.
Bader limestone
Eiss ls.
Stearns sh.
Morrill ls.
Florena sh.
Beattie limestone
Cottonwood ls.
Eskridge shale
Neva ls.
Grenola limestone
Chase group
Council Grove group
Wolfcampian series
Permian system
PALEOZOIC
0
25
50
75
100
200
Salem Point sh.
Grenola limestone
Burr ls.
Roca shale
Howe ls.
Bennett sh.
Red Eagle limestone
Glenrock ls.
Johnson shale
Long Cr. ls.
Hughes Cr sh.
Foraker limestone
Americus ls.
Ooks sh.
Houchen Cr. ls.
Hamlin shale
Stine sh.
Five Point ls.
West Branch shale
Falls City ls.
Howxby shale
Aspinwall limestone
Towle shale
Indian Cave ss.
Council Grove group
Admire group
Wolfcampian series
Permian system
PALEOZOIC
EXPLANATION
Lithologic symbols for Permian rocks
Limestone
Shale, gray, yellow, or green
Shale, black
Sandstone, gray, white, or brown
Red rock, shale, siltstone or sandstone
Gypsum
Dolomite
Limestone, flinty
Shale, calcareous

MINERALOGY OF SOME SHALES OF THE LOWER PERMIAN SYSTEM OF RILEY COUNTY, KANSAS.

General

An effort was made to obtain representative samples of nearly all lower Permian shales outcropping in Riley County, Kansas. However, a few shales occurring near the base of the lower Permian make very poor outcrop exposures and for this reason no samples were taken. The shales that were not sampled were as follows: Stine shale member of the Hamlin shale; West Branch shale, Hawxby shale and the unnamed member of the Towle shale.

On each of the shales sampled a brief lithologic description if given as adapted from J. M. Jewett, Geologist, State of Kansas (5). A resume of the minerals found to be present, including physical and optical properties, was thought to be important, as was the ease of disaggregation of the shale in some cases, and finally the clay mineral as determined by thermal analysis. The primary basic for classifying the clay mineral in this thesis is based on the notation of the middle major peak. The clays whose middle major peak is above 645° C. being assigned to the illite - montmorillonite series (7); while the clays whose middle major peak is below 645° C. are assigned the illite group. No effort was made to include the thermal analysis curves where several samples were run of the same unit as the curves appeared to be similar. In such a case a notation will be made to see the figure representative of the shale unit.

Each of the shales is taken up in sequence - the youngest at the top of the stratigraphic column appears in the discussion first.

Paddock shale member lithology. Shale; gray, with stringer and veins of calcite. Pelecypods locally abundant. Average thickness is 11 feet.

Mineralogy. The heavy fraction consisted chiefly of muscovite, which was fairly abundant, and pyrite, celestite, and magnetite. Other accessory heavy minerals present were corundum, zircon, topaz, and garnet. The garnet appeared colorless and showed irregular fractures and was somewhat jagged. Many grains were coated, and this coating appeared to be limonite. Originally they may have been pyrite. Some of the muscovite contained small inclusions of zircon and magnetite and the grains showed rounding indicating that they are of detrital origin.

The light fraction consisted chiefly of chalcedony. Some quartz was found to be present with a limited amount of orthoclase and microcline. The plagioclase present appeared to be oligocase. The grains for the most part appeared large and rectangular, thus indicating excellent cleavage. Inclusions were fairly abundant and these consisted primarily of chalcedony and quartz. A few grains showed small inclusions of zircon. Grains of the plagioclase were examined using the oil immersion method and the following optical properties were obtained: High 2-v, biaxial positive; alpha index-1.544, beta index-1.546, gamma index-1.550; low birefringence; colorless; somewhat blotchy appearance under crossed nicols; and a poor interference figure. Twinning was hard to distinguish if present. Due to the good rectangular outline, the feldspar appears to be an authigenic mineral. The abundance of calcium carbonate in the shale may account in part for the presence of a calcium member of the feldspar group.

The clay mineral as determined by thermal analysis belongs to the illite-montmorillonite series (?). See Fig. 1 for the thermal analysis curve.

Odell shale lithology. Shale; red in the upper and middle parts, gray or yellow in lower part. Average thickness is 30 feet.

Mineralogy. Two spot samples were taken of the Odell shale member - samples number 18 and 20.

Among the heavy minerals present were muscovite, which showed some variations in abundance between the two samples, tourmaline, pyrite, magnetite, zircon, topaz, and celestite. A trace of chlorite was found which may have been due to the alteration of the biotite. The tourmaline showed well-developed crystals which were terminated. Some tourmaline was present as inclusions in the muscovite. Sample number 20 contained a large amount of coated mineral grains as compared with the other sample. The coated grains appeared to be limonite. The celestite was identified by the low birefringence, good cleavage, and the obtaining of an interference figure that showed the 2-v to be greater than 37 degrees. This optical property helped to distinguish the mineral from barite. The garnet of the shale was colorless and showed the etchings which are quite common for detrital garnet. The zircon and topaz were rounded, and this would indicate detrital origin. The celestite and pyrite appeared to be the principal authigenic minerals in the heavy fraction.

The light fraction consisted principally of chalcedony. Also quartz and some feldspars were present in the shale samples.

The clay mineral present as determined by thermal analysis was an illite. See Fig. 2 for the thermal analysis curve.

Grant shale member lithology. Shale; chiefly gray, calcareous, and fossiliferous. Average thickness is 10 feet.

Mineralogy. Two samples were taken; sample number 21 was a spot sample and number 23 was a channel sample.

In the heavy fraction, muscovite and celestite were fairly abundant. Inclusions were present in the muscovite, and these (because of their absorption) appeared to be small crystals of tourmaline. Other heavies present in small quantities were zircon, topaz, rutile, sillimanite, magnetite, hornblende, and lamprobolite. The lamprobolite was yellowish green, possessed parallel extinction, was pleochroic, had a high birefringence, and showed good cleavage. The sillimanite appeared fibrous, the fibers being length slow, showed good cleavage, and had a high birefringence. Rutile in the sample possessed a very high relief, was slightly pleochroic, was reddish-brown in color and irregular in outline.

Celestite and pyrite were the chief authigenic minerals while the other heavy minerals present appeared allogenic because of their irregular and rounded forms.

The light fraction contained an abundance of chalcedony. Quartz was the next most abundant light mineral, followed by the feldspars which consisted of orthoclase, microcline and plagioclase. A small part of the plagioclase appeared to be authigenic oligoclase.

The clay mineral as determined by thermal analysis belongs to the illite-montmorillonite group. See Fig. 3 for the thermal analysis curve.

Gage shale member lithology. Clay shale; upper parts calcareous and with thin limestones; middle and lower parts varicolored and non-calcareous. Average thickness is 48 feet.

Mineralogy. One spot sample of this shale was taken. Many of the grains were coated with limonite suggesting that the original mineral may have been some other iron-bearing mineral. Also small quantities of topaz, hornblende, muscovite, garnet, rutile, celestite, hematite, and magnetite were observed. The garnet was colorless and showed fractures. Again the rutile was reddish-brown in color, with a high relief, and showed the same color under crossed nicols as in plane light.

The light fraction consisted chiefly of chalcedony, followed in percentage present by orthoclase. A minor amount of quartz was found to be present. A trace of microcline was also present.

The clay mineral as determined by thermal analysis was an illite. See Fig. 4 for the thermal analysis curve.

Holmesville shale lithology. Varicolored shale; thin seams of limestone. Average thickness is 25 feet.

Mineralogy. Channel sample number 22 contained the following heavy minerals: zircon, topaz, muscovite, garnet, pyrite, celestite, and hematite. The abundant mineral was pyrite which was easily recognized by its brassy yellow color in reflected light and its aggregate structure resembling a bunch of grapes. Some of the pyrite may have been due to the replacement of fossils. The hematite present may have been due to psuedomorphs after pyrite. The garnet appeared colorless and was irregular, while the zircon was well rounded and was distinguished by its extreme birefringence under crossed nicols.

The light fraction consisted chiefly of chalcedony with quartz and the feldspars being about equal in abundance. Some of the grains in the light fraction appeared to be coated.

The clay mineral as determined by thermal analysis belongs to the illite-montmorillonite series (?). See Fig. 5 for the thermal analysis curve.

Oketo shale member lithology. Shale; gray, calcareous, locally absent; fossiliferous. Average thickness is 5 feet.

Mineralogy. One channel sample was taken and the heavy fraction contained zircon, topaz, hornblende, abundant muscovite, titanite, magnetite, corundum, pyrite, and ilmenite. The hornblende had a dark green color, was pleochroic, and its rounded form indicated it to be of detrital origin. One grain showed typical cleavage of what appeared to be the cross-section for an amphibole. The zircon was rounded and showed some staining. The ilmenite appeared white in reflected light. The corundum showed a high relief, was colorless, and when checked for an interference figure yielded a uniaxial cross with the sign being negative.

The light fraction was predominatly chalcedony with the quartz and the feldspar appearing in about equal proportions.

The clay mineral as determined by thermal analysis was an illite (?). See Fig. 6 for the thermal analysis curve.

Blue Springs shale member lithology. Chiefly red and gray shale. Average thickness is 40 feet.

Mineralogy. Two samples, numbers 5 and 13, and one spot sample, number 12, were taken of the unit. Quite a variation in the abundance of muscovite was noted between the two channel samples. This variation may have been due to the difficulty of disaggregating sample number 5 and failing to free all the muscovite. The spot sample, number 12, shows about the same amount of muscovite as channel sample number 13. Other heavy minerals noted in the samples were zircon, topaz, hornblende, biotite, garnet, pyrite, celestite, tourmaline, magnetite, and hematite. The garnet was colorless and possessed an irregular outline. The hornblende showed an extinction angle of about 15^{o}, was green and pleochroic. The tourmaline noted in the spot sample showed strong absorption, good crystal outline with terminations and no additional growth. Some of the muscovite appeared to have inclusions of small crystals of rutile which were star-like in form. The enstatite appeared nearly colorless, showed good prismatic cleavage, parallel extinction, and a low birefringence.

In the two channel samples, the light fraction consisted of chalcedony followed in percentage present, by quartz and the feldspars. In the spot sample quartz was fairly abundant as well as orthoclase. Chalcedony was not too abundant. Among the feldspars, orthoclase, microcline, and plagioclase were noted. Most of the grains showed some rounding, a refractive index lower than balsam, and weathering products on the surface of the grains which was probably kaolin.

The clay mineral as determined by thermal analysis belongs to the illite-montmorillonite series (?). See Fig. 7 for the thermal analysis curve.

Wymore shale member lithology. Shale; chiefly gray and yellow but with varicolored bands. Average thickness is 30 feet.

Mineralogy. The heavy fraction of the channel sample number 17 revealed an abundance of muscovite and other minerals in smaller amounts such as zircon, topaz, garnet, titanite, sillimanite, magnetite, pyrite, lamprobolite, celestite, enstatite, chlorite, and ilmenite. The garnet tended to possess a gray color and showed irregular fractures. The titanite had a very high refractive index, brownish color, and showed no position of extinction. The shale was hard to totally disaggregate and this may be one reason for the lack of some of the other minor heavy constituents appearing in the heavy fraction.

Chalcedony was the principal mineral in the light fraction with its characteristic "salt and pepper shaker" appearance under crossed nicols. Quartz was fairly common and some orthoclase, microcline, and plagioclase were noted in small amounts. Some of the plagioclase appeared to be authigenic oligoclase and showed the same characteristics as that found in the Paddock shale member.

The clay mineral as determined by thermal analysis belongs to the illite-montmorillonite series (?). See Fig. 8 for the thermal analysis curve.

Havensville shale member lithology. Shale; gray, calcareous; thin limestones. Average thickness is 7 feet.

Mineralogy. Channel sample number 4 revealed the heavy fraction to contain an abundance of muscovite and also a good portion of pyrite. Zircon, topaz, biotite, and magnetite were present in small amounts. Some of the pyrite showed fantastic shapes and aggregate structure along with the typical brassy yellow color in reflected light.

The light fraction contained an abundance of chalcedony. Some of the chalcedony has replaced fossils, probably small forams. The quartz is found in small grains and in certain instances appeared to be intergrown with the chalcedony. A small amount of the feldspars were observed. These feldspars consisted of orthoclase, microcline, and plagioclase. A few grains were coated thus making it hard to determine the original mineral.

The clay mineral as determined by thermal analysis was an illite. See Fig. 9 for the thermal analysis curve.

Speiser shale lithology. Upper part gray fossiliferous shale underlain by persistent foot-thick limestone; middle and lower parts, varicolored shale. Average thickness is 25 feet.

Mineralogy. Two channel samples, 3 and 11, revealed the following heavy minerals: zircon, topaz, muscovite, titanite, magnetite, enstatite, pyrite, corundum, celestite, hematite, and ilmenite. Sample number 3 did not totally disaggregate, and as a result not too many heavy minerals appeared in the mineral count. The residue that was left consisted of green particles of shale. This sample contained an abundance of hematite and other minerals that were coated. The enstatite present was grey, had good prismatic cleavage; showed an optic axis figure with a high 2-v, and was non-pleochroic.

The light fraction consisted principally of chalcedony with very little quartz being noted. Many of the grains in the light fraction were coated, making it difficult to tell the original mineral.

The clay mineral as determined by thermal analysis belongs to the illite-montmorillonite series (?). See Fig. 10 for the thermal analysis curve.

Blue Rapids shale member lithology. Shale; gray with local limestones. Average thickness is 20 feet.

Mineralogy. Channel sample number 49 contained the following heavy minerals: zircon, topaz, muscovite, biotite, augite, titanite, sillimanite, pyrite, magnetite, enstatite, celestite, and corundum. Pyrite was very abundant, thus reducing the percentage of the other heavies. The augite-diopside was green in color, slightly pleochroic, and had an extinction angle of 33 degrees. The sillimanite present showed a good biaxial interference figure with a 2-v near 40 degrees, colorless, and had positive elongation. The muscovite contains a few inclusions of tourmaline, zircon, and magnetite.

The light fraction consisted of practically equal amounts of quartz and chalcedony along with a moderate amount of feldspars. A few of the grains were coated.

The clay mineral as determined by thermal analysis was an illite. See Fig. 11 for the thermal analysis curve.

Easly Creek shale lithology. Shale; upper part light colored and calcareous, lower part red. Average thickness is 15 feet.

Mineralogy. One channel sample, number 10, and one spot sample, number 6, were taken. The heavy fraction of the channel sample of the upper shale contained the following heavy minerals: topaz, muscovite in abundance, garnet, pyrite, chlorite, and ilmenite. The spot sample contained zircon, topaz, muscovite, pyrite, magnetite, and hematite. Also a large proportion of the grains showed a coating. The zircon present was a perfect euhedral crystal showing extreme birefringence. Due to the extreme quantity of clay present, a larger sample should be taken to insure a larger amount of heavy minerals.

The light fraction consisted principally of chalcedony with a moderate amount of quartz and feldspars present.

The clay mineral as determined by thermal analysis was an illite. See Fig. 12 for the thermal analysis curve.

Hooser shale member lithology. Shale; gray, and impure limestones. Fossiliferous with pelecypods predominating. Average thickness is 10 feet.

Mineralogy. Spot sample number 7 revealed the following minerals in the heavy fraction: zircon, topaz, muscovite, biotite, pyrite, magnetite, and chlorite. The muscovite constituted the major portion of all the heavy minerals noted. It also appeared that some of the muscovite showed additional growth as evidenced by a difference in the interference color which appeared to be wavy.

The light fraction was found to contain an abundance of orthoclase, as the refractive index was slightly lower than that of balsam, and most of the grains showed a cloudy appearance which was probably due to the feldspar altering to kaolin on the surface. The chalcedony and quartz were found to be present in nearly equal quantities. A few grains observed appeared to be coated.

The clay mineral as determined by thermal analysis belongs to the illite-montmorillonite series (?). See Fig. 13 for the thermal analysis curve.

Stearns shale lithology. Shale with impure limestones; gray to olive but red in middle or lower parts. Average thickness is 14 feet.

Mineralogy. One spot sample, number 45, contained the following heavy minerals: zircon, topaz, muscovite, hematite, celestite, magnetite, corundum, garnet, and pyrite. The corundum was distinguished by its high relief, low birefrigence and its uniaxial negative sign. The topaz observed was a euhedral crystal showing a high relief and a high birefringence. The garnet appeared as an elongate grain and was gray in color. Some contamination of the light fraction was observed in the heavy fraction. Much of the contamination consisted of chalcedony containing grains of some small heavy mineral. This was a common observation many times. An abundance of hematite was found, and part of the hematite may be psuedomorphs after pyrite.

The light fraction consisted principally of chalcedony with a minor amount of quartz and feldspars. Some of the grains were stained, and this made it impossible to determine the original mineral.

The clay mineral as determined by thermal analysis belongs to the illite-montmorillonite series (?). See Fig. 14 for the thermal analysis curve.

Florena shale member lithology. Shale; gray to yellow-gray; fossils abundant, especially chonetes. Average thickness is 7 feet.

Mineralogy. One channel sample, number 25, and three spot samples, numbers 15, 16, and 30, were taken of the unit. In the heavy fraction of the channel sample these heavy minerals were noted: zircon, topaz, muscovite, garnet, titanite, tourmaline, rutile, hematite, celestite, corundum, enstatite, magetite, chlorite, and lamprobolite. A particular spot sample did not reveal all of the heavy minerals present in the channel sample; however, most of the minerals of the channel sample were found to be present in the combined analyses of the spot samples. Also sillimanite was found in two of the spot samples but not in the channel sample. A perfect crystal of tourmaline showed good terminations, was colorless, lacked pleochroism, and had straight extinction. Since tourmaline was noted to appear in such small crystals, this may be a reason for its lack of abundance in some of the samples. The garnet varied from gray to colorless and usually showed a jagged or irregular outline.

The light fraction showed an abundance of chalcedony in all the samples, with quartz occurring in a minor amount. The feldspars were found in a minor amount, too; and some authigenic oligoclase was present which resembled the same plagioclase as found in the Paddock shale member and the Wymore shale member.

The clay mineral as determined by thermal analysis belongs to the illite-montmorillonite series (?). See Fig. 15 for the thermal analysis curve.

<u>Eskridge shale</u> lithology. Shale; and thin impure limestones; upper part yellow-gray to greenish, calcareous, fossiliferous, lower part varicolored. Average thickness is 37 feet.

Mineralogy. Two channel samples were taken of the unit. One channel sample, number 37, was of the entire unit; in another locality the unit was divided in half and a separate channel sample was taken for each half, samples number 31A and 31B.

The heavy fraction of the two channel samples varied some. In sample number 37 such heavies as garnet, enstatite, zircon, topaz, muscovite, biotite, titanite, tourmaline, pyrite, corundum, celestite, chlorite, magnetite, and hematite were found. In the other channel samples no zircon or tourmaline was noted. This result was reversed in sample number 37, since no hornblende or rutile were noted in this sample. The garnet showed etchings on the surface, was slightly irregular, and was colorless. Muscovite was fairly common. The pyrite was present in a very small quantity.

The shale was not totally disaggregated and the residue consisted of green particles of shale.

The light fraction showed chalcedony to be the predominant mineral with quartz not very abundant. The feldspars were present in a slightly larger quantity than the quartz, and authigenic oligoclase was found to be present. Again the oligoclase appeared as large grains showing inclusions, good cleavage and a rectangular shape suggesting the mineral to be authigenic.

The clay mineral as determined by thermal analysis was an illite. See Fig. 16 for the thermal analysis curve.

<u>Salem Point shale member</u> lithology. Shale; gray, calcareous, limestone separating the two shales. Average thickness is 8 feet.

Mineralogy. Three channel samples, 1, 8, and 32, were taken of the upper shale break, and three channel samples of the lower shale break, 2, 9, and 33 were taken. In addition a spot sample, number 48, was taken of the upper shale zone and a spot sample, number 47, of the lower shale zone was also taken.

The heavy minerals found in the upper shale zone consisted of zircon, topaz, muscovite, garnet, corundum, augite-diopside, celestite, hematite, magnetite, pyrite, and hornblende. Again not all the minerals were picked up in each of the samples, but were observed in at least one other sample.

Fluorite was observed in sample 48 and was distinguished by being colorless, having a refractive index considerably lower than balsam, showing an isotropic character, and containing small inclusions. The garnet varied from colorless to gray; etchings were observed and the grains were angular and irregular. The augite-diopside showed a pale color, good prismatic cleavage, and an extinction angle of about 25 degrees.

The heavy fraction of the lower shale zone consisted of zircon, topaz, muscovite, garnet, augite-diopside, pyrite, ilmenite, chlorite, biotite, hornblende, titanite, celestite, magnetite, hematite, and corundum. The muscovite was very abundant and from the mineral counts seems to be rather consistent in abundance in the lower shale as compared to the upper shale zone. One grain of corundum was observed to possess a good euhedral outline. Some collophane, which appears nearly isotropic, was found in the lower shale break. The collophane had a refractive index of 1.614 as determined by the oil immersion method, was yellowish-brown in color, contained iron oxide stains, and was massive and angular, and, in some cases irregular. The garnet varies in color from pink to colorless to gray. Etchings are common and one grain showed a slight pitting of the surface.

The light fractions of both shale zones were very similar, with chalcedony being the predominant mineral. Quartz and the feldspar group were not too abundant. Some of the chalcedony grains were noted to contain very small inclusions of zircon and tourmaline in a few cases.

The clay mineral as determined by thermal analysis for the upper shale zone is an illite and for the lower shale zone belongs to the illite-montmorillonite series (?). See Figs. 17 and 18 for the thermal analysis curves.

Roca shale lithology. Shale; chiefly gray and olive; clay shale but with some green and red shale and thin limestone near the top. Average thickness is 20 feet.

Mineralogy. Two channel samples, numbers 36 and 38, were taken of the upper shale zone; two were taken of the middle shale zone, numbers 35 and 41; and two, numbers 34 and 42, were taken of the lower shale zone. Also a spot sample, number 43, was taken of the middle shale zone, and spot sample, number 44, was taken of the lower shale zone.

The heavy minerals found in the upper shale zone were zircon, topaz, hornblende, muscovite, garnet, kyanite, titanite, magnetite, andalusite, celestite, corundum, hematite, pyrite, enstatite, augite-diopside, chlorite, ilmenite, and rutile. The garnet ranged in color from pink to gray to colorless. Some of the grains were elongate, some were angular, and some were slightly pitted and jagged. The andalusite was pleochroic, pink in color, showed wavy striae, had a low birefringence, and showed negative elongation as compared to sillimanite which shows positive elongation. The kyanite grain was long, colorless, had an extinction angle of 34 degrees and a moderate birefringence.

The light fraction of the upper shale zone consisted of chalcedony which was abundant. Quartz was fairly abundant and the feldspars, including microcline, orthoclase and plagioclase, were noted. A very small portion of authigenic oligoclase was again observed. A few coated grains and some organic material was also noted. The shale was not totally disaggregated.

The clay mineral as determined by thermal analysis belongs to the illite-montmorillonite series (?). See Fig. 19 for the thermal analysis curve.

The heavy minerals present in the middle shale zone were as follows: zircon, topaz, hornblende, muscovite, garnet, titanite, tourmaline, celestite, hematite, magnetite, pyrite, and chlorite. Muscovite and hematite appeared to be the predominant minerals. The garnet showed striations and etchings and again the color was variable.

The light fraction consisted principally of chalcedony with a very minor amount of quartz and feldspar being present.

The shale was not totally disaggregated and green shale particles were present in the residue.

The clay mineral of the middle shale zone as determined by thermal analysis belongs to the illite-montmorillonite series (?). See Fig. 20 for the thermal analysis curve.

The lower shale zone contained the following heavy minerals: zircon, topaz, muscovite, garnet, tourmaline, celestite, hematite, chlorite, magnetite, pyrite, enstatite, lamprobolite, rutile, and biotite. The abundant mineral was muscovite which represented over half of the total percentage of all heavy minerals present. The muscovite contained inclusions of zircon, tourmaline, and magnetite. Also star-like inclusions were noted in the muscovite which may be needle-like crystals of rutile. Some of the muscovite grains were pitted with limonite stains. Included in the heavy fraction were rounded grains which appeared to be chalcedony which contained abundant inclusions of needle-like material. These needle-like inclusions appeared dark, and were of such small size that it was impossible to determine the mineral. The grains showed a low birefringence, and some appeared cloudy in plane light.

The light fraction consisted chiefly of chalcedony with quartz next in order of abundance followed by the feldspars.

The clay mineral as determined by thermal analysis was an illite. See Fig. 21 for the thermal analysis curve.

Bennett shale member lithology. Shale; usually dark colored, local coquinas; local impure limestones. Average thickness is 7 feet.

Mineralogy. Two spot samples were taken; one of the upper Bennett shale zone, sample number 50, and one of the lower zone, sample number 51.

The heavy fraction of the upper shale zone contained such minerals as zircon, topaz, muscovite, garnet, hematite, corundum, magnetite, celestite, enstatite, fluorite. The opaque minerals were rather abundant, but no fair mineral analysis could be acurately made because of the difficulty encountered in totally disaggregating the shale. Black shale particles were present in the residue. The garnet was colorless, elongated, and showed fractures.

The light fraction was abundant in chalcedony, with quartz and the feldspars being present in very small quantities.

The clay mineral as determined by thermal analysis was an illite. See Fig. 22 for the thermal analysis curve.

The heavy fraction of the lower Bennett shale zone is not too representative as the shale again was hard to totally disaggregate. According to the analysis, hematite was abundant and many of the grains were coated. These grains may have been magnetite, pyrite, or hematite. Garnet, rutile, magnetite, pyrite, and corundum were also noted.

The light fraction again consisted principally of chalcedony with quartz and the feldspars being present in very small quantities.

The clay mineral as determined by thermal analysis was an illite. See Fig. 23 for the thermal analysis curve.

Johnson Shale lithology. Shale; gray, locally thin beds of argillaceous limestone; carbonaceous in upper part; middle and lower parts often somewhat sandy. Average thickness is 20 feet.

Mineralogy. Three channel samples were taken: one of the upper shale zone, number 27; one of the middle shale zone, number 28; and one of the lower shale zone, number 29. The samples were not totally disaggregated and the residue contained black particles of carbonaceous shale.

The heavy fraction of the upper shale zone contained zircon, topaz, muscovite, garnet, tourmaline, rutile, celestite, hematite, magnetite, collophane, and lamprobolite. Celestite and collophane were very abundant. The collophane was distinguished by its nearly isotropic character, its refractive index of 1.614 as determined by using the oil immersion method, its yellowish-brown color, the presence of iron oxide stains, and the massive and angular structure of the grains in some cases. The garnet grains appeared gray or dark, were irregular and showed a slight amount of pitting on the surface. The collophane appears to have been formed by the replacement of fossil shells as this particular zone was very fossiliferous as noted in the field.

The light fraction consisted principally of chalcedony with quartz and the feldspars making up a small percentage of the minerals present.

The clay mineral as determined by thermal analysis was an illite (?). See Fig. 24 for the thermal analysis curve.

The heavy fraction of the middle shale zone contained such minerals as zircon, topaz, hornblende, muscovite, garnet, pyrite, celestite, magnetite, chlorite, hematite, and collophane. Pyrite was very abundant, as well as celestite and muscovite. Collophane was practically absent from this zone.

The light fraction was abundant in chalcedony with quartz and the feldspars present in small quantities.

The clay mineral as determined by thermal analysis was an illite. See Fig. 25 for the thermal analysis curve.

The heavy mineral fraction of the lower shale zone was abundant in celestite. Other minerals present were zircon, topaz, hornblende, muscovite, titanite, pyrite, ilmenite, hematite, augite-diopside, and corundum.

The light fraction was abundant in chalcedony with the feldspars and quartz next in abundance. Some authigenic oligoclase possessing good rectangular outline was noted.

The clay mineral as determined by thermal analysis was an illite (?). See Fig. 26 for the thermal analysis curve.

Hughes Creek shale member lithology. Shale; light gray to black, and interbedded thin limestones. Abundant fusilinids and, in lower part abundant brachiopods. Average thickness is 40 feet.

Mineralogy. One channel sample, number 40, of the lower portion of the unit, and one spot sample, number 26, below the base of the Long Creek limestone member were taken. The samples were not totally disaggregated.

The heavy mineral fraction of both samples were much alike with the exception of the abundance of pyrite in sample number 26. Other minerals present were zircon, topaz, hornblende, muscovite, which was abundant in both samples, tourmaline, rutile, celestite, corundum, chlorite, and magnetite. The garnet was colorless and showed an irregular outline. The muscovite contained inclusions of zircon and magnetite.

The light fraction consisted chiefly of chalcedony. Quartz and orthoclase were present in about the same quantity.

The clay mineral as determined by thermal analysis was an illite. See Fig. 27 for the thermal analysis curve.

Oaks shale member lithology. Shale; mostly gray. Average thickness is 12 feet.

Mineralogy. The heavy fraction of this unit consisted of zircon, topaz, hornblende, epidote, garnet, titanite, tourmaline, rutile, magnetite, hematite, celestite, ilmenite, and corundum. Many of the grains were coated; thus making identification of the original mineral difficult. Hematite and celestite were abundant, and these were authigenic minerals. The tourmaline showed good crystal outlines, but the crystals were not terminated.

The garnets are colorless, possess a rough surface, and are irregular.

The light fraction contains an abundance of quartz followed by chalcedony and the feldspars in smaller amounts.

The clay mineral as determined by thermal analysis belongs to the illite-montmorillonite series (?). See Fig. 28 for the thermal analysis curve.

Towle shale (Indian Cave sandstone member) lithology. Sandstone or siltstone with local conglomerate in lower part; channel fillings; grades into overlying shale. Thickness ranges from a featheredge to about 120 feet.

Mineralogy. The heavy fraction of the sample is composed primarily of muscovite. Other minerals present are: zircon, topaz, epidote, biotite, titanite, tourmaline, rutile, sillimanite, chlorite, celestite, hematite, and pyrite. Many of the grains show a coating; thus making it difficult to determine the original mineral. The zircon grains, as well as the other grains present, were well rounded; and this rounding suggests they are allogenic. Rounded grains of chalcedony were noted that contained inclusions of dark material. These grains show an aggregate structure which is rather poorly defined under crossed nicols.

The light fraction consists primarily of quartz with a moderate amount of feldspar. Chalcedony is present in a very small amount.

The clay mineral as determined by thermal analysis appears to be intermediate between a typical illite and kaolin. See Fig. 29 for the thermal analysis curve.

Table 1. Location of sampled units and their characteristics.

Sample number	Kind of sample	Date collected	Location	Unit sampled	Remarks
19	Channel	June 4, 1949	NE, NE, 12, 6, 4 (Quarry)	Paddock shale member	Top of Krider limestone member to base of Herrington limestone member.
20	Spot	June 4, 1949	NE, NE, 12, 6, 4 (Quarry)	Odell shale	1.0' below base of Krider limestone member.
18	Spot	June 4, 1949	SW, SE, 5, 6, 5 (Road cut)	Odell shale	1.5' below base of Krider limestone member.
21	Spot	June 4, 1949	SW, NE, 22, 7, 5 (Road cut)	Grant shale member	1.5' below base of Cresswell limestone member.
23	Channel	June 6, 1949	NE, NE, 1, 9, 4 (Railroad cut)	Grant shale member	Top of Stovall limestone member to base of Cresswell limestone member.
24	Spot	June 6, 1949	SW, NE, 31, 9, 5 (Road cut)	Gage shale member	1.5' below base of Stovall limestone member.
22	Channel	June 4, 1949	SE, SW, 18, 7, 6 (Road cut)	Holmesville shale member	Top of Fort Riley limestone member to base of Towanda limestone member.
14	Channel	June 4, 1949	NE, NE, 12, 9, 6 (Road cut)	Oketo shale member	Top of Florence limestone member to base of Fort Riley limestone member. Very fossiliferous.

Table 1. (Cont.).

Sample number	Kind of sample	Late collected	Location	Unit sampled	Remarks
5	Channel	June 3, 1949	SW, SW, 21, 11, 8 (Road cut)	Blue Springs shale member	Top of Kinney limestone member to base of Florence limestone member.
13	Channel	June 4, 1949	SE, NW, 24, 9, 6 (Road cut)	Blue Springs shale member	Top of Kinney limestone member not in evidence.
12	Spot	June 4, 1949	NW, SW, 26, 9, 6 (Stream cut bank)	Blue Springs shale member	2.0' below base of Florence limestone member.
17	Channel	June 4, 1949	SW, SE, 7, 6, 6 (Stream cut bank)	Wymore shale member	Top of Schroyer limestone member to base of Kinney limestone member.
4	Channel	June 3, 1949	SE, NE, 32, 10, 8 (Road cut)	Havensville shale member	Top of Threemile limestone member to base of Schroyer limestone member.
3	Channel	June 3, 1949	SW, NW, 33, 10, 8 (Road cut)	Speiser shale member	Top of Funston limestone member to base of Threemile limestone member.
11	Channel	June 4, 1949	SW, SE, 36, 9, 6 (Stream cut bank) Keats.	do	do

Table 1. (Cont.).

Sample number	Kind of sample	Date collected	Location	Unit sampled	Remarks
49	Channel	July 5, 1949	SW, SE, 36, 9, 6 (Stream cut bank on Military Reservation).	Blue Rapids shale member	Top of Crouse limestone member to base of Funston limestone member.
10	Channel	June 3, 1949	NW, NW, 33, 8, 7 (Road cut)	Easly Creek shale member	Top of limestone about 1.0' thick near middle of unit to base of crouse limestone member.
6	Spot	June 3, 1949	SE, SW, 28, 10, 8 (Road cut)	Easly Creek shale member	1.0' below limestone present near middle of unit.
7	Spot	June 3, 1949	SE, SW, 28, 10, 8 (Road cut)	Hooser shale member	4.0' below base of Middleburg limestone member.
45	Spot	July 5, 1949	SE, NW, 33, 8, 7 (Road cut)	Stearns shale member	2.0' above top of Morrill limestone member.
25	Channel	Oct. 11, 1948	NW, SE, 34, 10, 8 (Road cut)	Florena shale member	Top of Cottonwood limestone member to base of Morrill limestone member.
30	Spot	June 6, 1949	SE, SW, 23, 10, 7 (Old road cut)	do	Top of Cottonwood limestone member up about 4.0 inches.

Table 1. (Cont.).

Sample number	Kind of sample	Date collected	Location	Unit sampled	Remarks
15	Spot	Oct. 11,1948	NW, SE, 34, 10, 8 (Road cut)	Florena shale member	1.0' below base of Morrill limestone member.
16	Spot	Oct. 11,1948	NW, SE, 34, 10, 8 (Road cut)	do	Top of Cottonwood limestone member up to about 6.0 inches.
37	Channel	Oct. 11,1948	NE, SW, 10, 10, 7 (Road cut)	Eskridge shale	Top of Neva limestone member to base of Cottonwood limestone member.
31(A)	Channel	June 6, 1949	SE, SE, 23, 10, 7 (Old road cut)	Eskridge shale	Base of Cottonwood limestone member to middle of unit which consists of a red zone about 1' thick.
31(B)	Channel	June 6, 1949	do	do	From red zone to top of Neva limestone member.
1	Channel	June 3, 1949	SW, NW, 28, 10, 8 (Road cut)	Salem Point shale member	Base of Neva limestone member to top of limestone break near middle of unit.
2	Channel	June 3, 1949	do	do	Base of limestone break near middle of unit to top of Burr limestone member.

Table 1. (Cont.).

Sample number	Kind of sample	Date collected	Location	Unit sampled	Remarks
8	Channel	June 3, 1949	NW, SE, 25, 9, 7	do	Same as sample number 1.
9	Channel	June 3, 1949	do	do	Same as sample number 2.
32	Channel	June 6, 1949	SE, SE, 23, 10, 7	do	Same as sample numbers 1 and 8.
33	Channel	June 6, 1949	do	do	Same as sample numbers 2 and 9.
48	Spot	July 5, 1949	SE, SE, 25, 9, 7 (Road cut)	do	4.0 inches above limestone break near middle of unit.
47	Spot	do	do	do	1.0' below limestone break near middle of unit.
36	Channel	June 6, 1949	SE, SE, 23, 10, 7 (Road cut)	Roca shale	Top of limestone break to base of Burr limestone member. (Upper shale break).
35	Channel	June 6, 1949	do	do	Top of 1st limestone to base of limestone at top. (Middle shale break).
34	Channel	June 6, 1949	do	do	Top of Howe limestone member to base of 1st limestone break. (Lower shale break).

Table 1. (Cont.).

Sample number	Kind of sample	Date collected	Location	Unit sampled	Remarks
38	Channel	June 7, 1949	NW, NW, 28, 10,8 (Road cut)	do	Same as sample number 36.
41	Channel	do	do	do	Same as sample number 35.
42	Channel	do	do	do	Same as sample number 34.
43	Spot	July 5, 1949	SE, NE, 7, 10,8 (Road cut)	do	1.0' above second limestone break. (Middle shale break).
44	Spot	do	do	do	1.0' below second limestone break. (Lower shale break).
50	Spot	Oct. 15, 1948	NW, NE, 7, 10, 8 (Bluemont Hill road cut)	Bennett shale member	2.0' below base of Lowe limestone member.
51	Spot	do	do	do	2.0' above top of Glenrock limestone member.
27	Channel	June 6, 1949	SE, NW, 13, 10, 7 (Wildcat Creek)	Johnson shale	Top of limestone break to base of Glenrock limestone member. (Upper shale break).
28	Channel	do	do	do	Top of 2nd limestone break to base of 1st limestone break. (Middle shale break).

Table 1. (Cont.).

Sample number	Kind of sample	Date collected	Location	Unit sampled	Remarks
29	do	do	do	do	Top of Long Creek limestone member to base of 1st limestone break. (Lower shale break).
40	Channel	June 7, 1949	NW, NE, 7, 10, 8 (Bluemont Hill railroad cut)	Hughes Creek shale member	Top of Americus limestone member to base of 1st limestone break. Chiefly black shale.
26	Spot	June 6, 1949	SE, NW, 13, 10, 7 (Wildcat Creek)	do	1.0' below base of Long Creek limestone member.
39	Spot	June 7, 1949	NW, NE, 7, 10, 8 (Bluemont Hill railroad cut)	Oaks shale member	At very base of Americus limestone member. Sample of the silty phase.
46	Spot	July 5, 1949	SW, NE, 30, 10, 9 (Road cut)	Towle shale (Indian Cave sandstone member)	8.0' below top of cut in road ditch.

Table 2. Mineral analysis of some shales of the lower permian system of Riley County, Kansas.

Minerals	Paddock shale #19	Odell shale #20	Odell shale #18	Grant shale #23	Grant shale #21	Gage shale #24	Holmesville shale #22
			Heavy Fraction				
Zircon	.5		1.1		.5		.2
Hornblende					1.0	.6	
Augite & Diopside							
Garnet	.2		.6			.6	.2
Muscovite	54.8	17.8	89.4	27.5	31.4	3.0	1.7
Biotite		.3	1.6				
Epidote							
Topaz	.5	.3	.8	.1	2.1	1.2	.2
Lamprobolite				.1			
Enstatite							
Sillimanite					.5		
Rutile					.5	.6	
Tourmaline			.8				
Kyanite							
Celestite	7.0	6.1	1.6	70.7	11.0	8.4	3.2
Corundum	.5						
Fluorite							
Chlorite	.2	1.1	1.6	.3			
Titanite							
Collophane							
Andalusite							
Pyrite	6.4	7.6	.3		3.6	4.8	91.3
Magnetite	2.0	2.6	.8	.5	5.2	3.5	
Hematite	6.0	11.0			10.5	10.8	1.4
Ilmenite				.1		.6	
Coated	21.7	52.8	1.1	.6	33.5	65.8	1.4
			Light Fraction				
Quartz	16.0	5.1	23.9	30.5	6.1	4.5	11.2
Chalcedony	64.0	86.5	55.6	60.3	80.0	61.5	77.8
Orthoclase	4.5	1.2	17.9	6.8	5.4	33.0	7.2
Microcline	.5	.5	1.0	.3	.7	.3	
Plagioclase	12.0		1.6	.7	2.6		1.8
Coated	3.0	6.6		1.4	5.1	.6	1.8

Table 2. (Cont.).

Minerals	Oketo shale #14	Blue Springs #5	Blue Springs shale #13	Blue Springs shale #12	Blue Rapids shale #49	Wymore shale #17
			Heavy Fraction			
Zircon	1.4	.7	.3	.3	.2	.8
Hornblende	1.1		.3			.1
Augite & Diopside					.2	
Garnet		.7		.1		.8
Muscovite	83.0	6.6	81.4	89.7	20.2	87.2
Biotite		2.2	.4	1.9	.2	.9
Epidote						
Topaz	1.8	.7	.3	.6	.4	1.3
Lamprobolite						.1
Enstatite			.3		.7	.1
Sillimanite			.1		.4	.1
Rutile						
Tourmaline			1.2	1.2	.2	
Kyanite						
Celestite		42.9			2.3	.6
Corundum	1.4		.1		.2	
Fluorite						
Chlorite				.6		.1
Titanite	.3		.3	.3	.2	.3
Collophane						
Andalusite						
Pyrite	1.8	1.2	.7	1.2	73.5	2.7
Magnetite	3.1		9.1	1.9	.9	1.1
Hematite		33.6	3.4			
Ilmenite	.7		.1			.1
Coated	2.9	11.1	3.1	2.2	.4	3.1
			Light Fraction			
Quartz	8.4	6.1	15.7	46.4	40.9	16.2
Chalcedony	81.5	76.3	73.2	19.2	47.8	60.0
Orthoclase	8.8	13.0	3.8	27.1	7.2	7.0
Microcline			.9	2.4	.6	
Plagioclase	.4	1.5	1.1	3.0	1.6	14.7
Coated	.8	3.0	5.2	1.6	1.6	1.1

Table 2. (Cont.).

Minerals	Havensville shale #4	Speiser shale #3	Speiser shale #11	Easly Creek shale #6	Easly Creek shale #10
			Heavy Fraction		
Zircon	.3		2.2	1.3	
Hornblende					
Augite & Diopside		.8			
Garnet					.9
Muscovite	63.9	2.3	36.9	15.0	94.3
Biotite	.5				.9
Epidote					
Topaz	.3		5.6	2.7	.5
Lamprobolite					
Enstatite			1.1		
Sillimanite					
Rutile					
Tourmaline		.8			
Kyanite					
Celestite		1.5			
Corundum		3.8	4.5		
Fluorite					
Chlorite					.5
Titanite			1.1		
Collophane					
Andalusite					
Pyrite	34.0		6.7	4.1	2.3
Magnetite	.3	5.4	28.1	12.3	
Hematite		55.8	1.1	31.4	
Ilmenite			2.2		.5
Coated		29.4	11.2	32.8	
			Light Fraction		
Quartz	22.1	1.2	16.3	1.9	18.0
Chalcedony	71.9	76.5	60.5	93.5	44.8
Orthoclase	.9		6.8	.9	32.2
Microcline	.9		.5		1.9
Plagioclase	.9		.1		1.9
Coated	2.7	22.3	15.6	3.5	1.4

Table 2. (Cont.).

Minerals	Hooser shale #7	Stearns shale #45	Florena shale #25	Florena shale #15	Florena shale #16	Florena shale #30
			Heavy Fraction			
Zircon	.3	1.6	2.0			11.5
Hornblende						11.5
Augite & Diopside					1.9	
Garnet		1.6	1.0	5.6		4.0
Muscovite	94.5	11.3	41.7	2.8		6.0
Biotite	.6			2.8		
Epidote						
Topaz	.3	1.6	1.0			13.4
Lamprobolite			1.0	2.8		6.0
Enstatite			1.0			6.0
Sillimanite				8.3		2.0
Rutile			1.0			
Tourmaline			2.0		1.9	
Kyanite						
Celestite		8.0	5.2	13.9		
Corundum		1.6	7.3	2.8		7.7
Fluorite						
Chlorite	.3		1.0			4.0
Titanite			1.0		1.9	4.0
Collophane						
Andalusite						
Pyrite	.9	1.6				4.0
Magnetite	.9	3.2	4.2	11.1	24.5	6.0
Hematite		59.3	26.0	44.4	60.3	
Ilmenite						9.6
Coated	1.9	9.7	4.2	5.6	9.4	6.0
			Light Fraction			
Quartz	22.0	3.3	1.0	1.4	1.8	4.4
Chalcedony	21.8	84.6	88.0	97.1	93.2	90.0
Orthoclase	43.2	1.2	1.0	.5	1.3	3.1
Microcline	3.9		.5		.4	
Plagioclase	3.9	.8	9.4	1.0	3.1	.6
Coated	6.3	9.9				1.8

Table 2. (Cont.).

Minerals	Eskridge shale #37	Eskridge shale #31(A)	Eskridge shale #31(B)	Salem Point shale #1	Salem Point shale #2
			Heavy Fraction		
Zircon	1.5			1.2	.7
Hornblende		.4		.1	
Augite & Diopside				1.1	.4
Garnet	.8		.9	6.8	.4
Muscovite	62.2	57.7	52.3	2.2	90.5
Biotite	.8		.9		
Epidote					
Topaz	2.3	1.3	2.7	10.2	1.1
Lamprobolite	.4				
Enstatite	.8				
Sillimanite					
Rutile		.4			
Tourmaline	4.0				
Kyanite					
Celestite	4.0	9.6	16.4	3.2	
Corundum	4.8		1.8	4.5	
Fluorite					
Chlorite	.8				
Titanite	.8				
Collophane					
Andalusite					
Pyrite	.8	.8		2.2	3.7
Magnetite	3.1	6.2	1.8	11.3	
Hematite	11.0	5.3	14.6	27.2	
Ilmenite		1.7		1.1	.7
Coated	2.3	16.0	8.2	28.4	2.2
			Light Fraction		
Quartz	2.7	5.6	5.7	4.5	3.0
Chalcedony	88.2	64.1	86.3	90.9	94.0
Orthoclase	1.7	11.8	4.8	3.3	2.5
Microcline			.4		
Plagioclase	5.7	1.5	.8		.5
Coated	2.2	16.9	1.7	1.1	

Table 2. (Cont.).

Minorals	Salem Point shale #8	Salem Point shale #9	Salem Point shale #32	Snlem Point shale #33
		Heavy Fraction		
Zircon		1.2	6.0	.7
Hornblende		.6	9.0	.5
Augite & Diopside		.6		
Garnet	1.0	1.2	3.0	.2
Muscovite	2.1	81.3	38.0	12.7
Biotite				.5
Epidote				
Topaz		.6	7.6	.9
Lamprobolite				
Enstatite		.6	3.0	
Sillimanite				
Rutile	1.0	.6	3.0	
Tourmaline				
Kyanite				
Celestite		1.8	6.0	22.3
Corundum	1.0	6.2	4.5	
Fluorite				
Chlorite				
Titanite			3.0	.2
Collophane		2.4		
Andalusite				
Pyrite	7.3		9.0	54.3
Magnetite	30.5	1.2	6.0	.2
Hematite	46.3			3.6
Ilmenite				
Coated	10.5	1.2	1.5	3.3
		Light Fraction		
Quartz	.9	1.4	4.1	18.5
Chalcedony	98.5	80.7	85.4	73.4
Orthoclase	.5	1.9	5.8	3.8
Microcline			1.2	1.0
Plagioclase			.8	1.4
Coated		16.0	2.5	1.8

Table 2. (Cont.).

Minerals	Salem Point shale #48	Salem Point shale #47	Roca shale #36	Roca shale #35	Roca shale #34
		Heavy Fraction			
Zircon		.4	2.6	1.7	.2
Hornblende				1.7	
Augite & Diopside			.5		
Garnet			2.1	1.7	.2
Muscovite	59.2	95.4	28.7	1.7	74.0
Biotite		1.4			5.5
Epidote			.5		
Topaz			6.9		.2
Lamprobolite					.2
Enstatite			2.1		.2
Sillimanite			1.0		
Rutile			.5		
Tourmaline		.4		1.7	.2
Kyanite			.5		
Celestite	3.7		7.4	6.8	1.6
Corundum	7.0		8.0		
Fluorite	7.0				
Chlorite		.4	.5		2.5
Titanite			2.1		
Collophane			.5		
Andalusite			.5		
Pyrite		.4	1.0	1.7	.5
Magnetite	14.8	1.4	10.1	25.8	2.5
Hematite	3.7		12.2	50.0	3.6
Ilmenite			.5		.5
Coated	3.7		11.1	3.4	7.2
		Light Fraction			
Quartz	2.4	7.3	33.5	1.3	4.8
Chalcedony	95.6	87.3	54.3	95.9	65.0
Orthoclase	1.4	3.4	8.1	2.7	2.0
Microcline		.8	2.2		.6
Plagioclase	.4	.8	.8		.6
Coated			1.1		26.6

Table 2. (Cont.).

Minerals	Roca shale #38	Roca shale #41	Roca shale #42	Roca shale #43	Roca shale #44
			Heavy Fraction		
Zircon	5.7	1.4		.8	1.0
Hornblende	2.8				
Augite & Diopside					
Garnet	5.7	1.4			
Muscovite	5.7	60.2	66.5	91.4	82.5
Biotite		1.0	2.8	.8	2.0
Epidote					
Topaz	4.2	1.4	.3		
Lamprobolite					
Enstatite	1.4			.4	
Sillimanite					
Rutile			.3		
Tourmaline		.7			
Kyanite					
Celestite	7.1	1.4	1.0	1.2	7.0
Corundum	1.4			.4	
Florite					
Chlorite		1.0	1.0		1.0
Titanite	1.4	.4	.3		
Collophane					
Andalusite					
Pyrite	4.2				1.0
Magnetite	20.0	5.7	11.1	1.6	.5
Hematite	15.7	20.5	14.6	2.4	3.5
Ilmenite	1.4	.4	.3	.8	
Coated	22.8	5.3	1.4		1.5
			Light Fraction		
Quartz	4.1	1.3	5.1	8.9	5.9
Chalcedony	73.6	90.0	86.8	82.6	90.9
Orthoclase	2.4	2.6	1.4	2.9	1.8
Microcline	1.4	.4		.8	
Plagioclase	.7			.4	1.3
Coated	18.0	5.7	6.5	4.2	

Table 2. (Cont.).

Minerals	Bennett shale #50	Bennett shale #51	Johnson shale #27	Johnson shale #28	Johnson shale #29
			Heavy Fraction		
Zircon	6.7		.2	.8	.5
Hornblende				.4	.5
Augite & Diopside					.2
Garnet	2.7	1.0	1.1	.4	
Muscovite	5.4		.2	17.2	7.2
Biotite					
Epidote					
Topaz	5.4		.5	.4	1.1
Lamprobolite			.2		
Enstatite	2.7				
Sillimanite					
Rutile		1.0	.2		
Tourmaline			.2		
Kyanite					
Celestite	2.7		53.0	28.1	75.6
Corundum	12.1	1.0			.8
Fluorite	2.7				
Chlorite				.8	
Titanite					1.1
Collophane			30.4	.4	
Andalusite					
Pyrite		2.1		49.0	6.1
Magnetite	14.8	26.0	2.0	.4	2.5
Hematite	37.8	34.7	8.0	.8	2.5
Ilmenite					.2
Coated	6.7	33.7	3.0	.8	1.1
			Light Fraction		
Quartz	3.7	1.4	2.1	2.1	10.8
Chalcedony	93.4	96.7	93.2	91.5	69.2
Orthoclase	1.8	.4	3.4	2.8	10.8
Microcline		.4		1.4	2.8
Plagioclase			.4	.7	2.8
Coated	.9	.9	1.7	1.4	4.4

Table 2. (Cont.).

Minerals	Hughes Creek shale #26	Hughes Creek shale #40	Oaks shale #39	Towle shale (Indian Cave) #46
		Heavy Fraction		
Zircon	.3	.4	2.5	3.7
Hornblende	.2		.2	
Augite & Diopside				
Garnet	.2	.4	1.2	
Muscovite	51.0	78.9		71.7
Biotite	.2			.3
Epidote			.2	.3
Topaz	.9	.4	2.7	.3
Lamprobolite				
Enstatite				
Sillimenite		.8		.7
Rutile	.3		.5	.3
Tourmaline		.4	2.5	3.4
Kyanite				
Celestite	4.6	4.2	35.6	1.4
Corundum	.5	.4	2.5	
Fluorite				
Chlorite		1.2		2.2
Titanite			1.5	.3
Collophane				
Andalusite				
Pyrite	40.9	6.6		.3
Magnetite		4.6	.8	
Hematite			14.2	1.1
Ilmenite			.5	
Coated	.5	1.2	34.9	13.2
		Light Fraction		
Quartz	1.9	24.2	85.9	70.8
Chalcedony	92.3	68.1	5.7	8.5
Orthoclase	.7	6.8	2.1	16.7
Microcline		1.0	.8	2.5
Plagioclase				1.3
Coated	3.0		5.2	

Table 3. Average percent of minerals present in Riley County shale as compared to Riley County tills (6).

Minerals	Average percent in Riley County shales.[1]	Average percent in Riley County tills.
	Heavy fraction	
Apatite	0.000	0.500
Zircon	1.700	4.487
Hornblende	0.832	14.200
Augite & Diopside	0.048	0.450
Garnet	1.032	7.625
Muscovite	63.590	7.700
Biotite	0.890	0.250
Epidote	0.025	17.312
Topaz	2.022	1.550
Lamprobolite	0.338	0.912
Enstatite	0.635	0.000
Sillimanite	0.254	0.412
Rutile	0.119	0.125
Tourmaline	0.396	4.225
Kyanite	0.041	0.075
Celestite	3.574	0.000
Corundum	2.287	0.000
Fluorite	0.312	0.000
Chlorite	0.609	4.587
Titanite	0.483	0.125
Collophane	0.093	0.000
Andalusite	0.016	0.000
Magnetite	5.838	18.800
Pyrite	2.990	- -
Hematite	5.693	- -
Ilmenite	0.664	- -
Coated	5.519	- -
Other Opaques	- -	12.850
	99.919	96.785
	Light fraction	
Quartz	13.106	70.412
Chalcedony	71.690	17.600
Orthoclase	7.661	3.150
Microcline	0.616	0.000
Plagioclase	2.135	2.037
Coated	4.793	- -
Clay mineral	- -	6.587
Heavy mineral	- -	1.575
	99.585	101.361

[1]The average percent of the minerals present in Riley County shales was determined by eliminating the shales that showed a total of 50 percent or more of the combined authigenic minerals: celestite, pyrite, hematite, and coated minerals.

EXPLANATION OF PLATE III

Fig. 1. Thermal analysis curve of Paddock shale member, sample number 19.

Fig. 2. Thermal analysis curve of Odell shale member, sample number 18.

Fig. 3. Thermal analysis curve of Grant shale member, sample number 23.

Fig. 4. Thermal analysis curve of Gage shale member, sample number 24.

Fig. 5. Thermal analysis curve of Holmesville shale member, sample number 22.

PLATE III

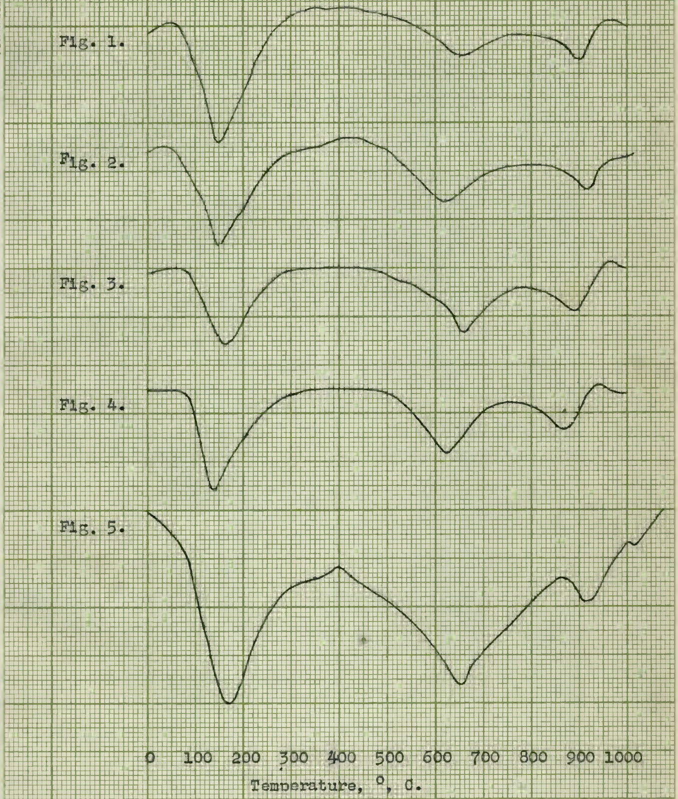


Fig. 1.
Fig. 2.
Fig. 3.
Fig. 4.
Fig. 5.
0 100 200 300 400 500 600 700 800 900 1000
Temperature, °, C.

EXPLANATION OF PLATE IV

Fig. 6. Thermal analysis curve of Oketo shale member, sample number 14.

Fig. 7. Thermal analysis curve of Blue Springs shale member, sample number 12.

Fig. 8. Thermal analysis curve of Wymore shale member, sample number 17.

Fig. 9. Thermal analysis curve of Havensville shale member, sample number 4.

Fig. 10. Thermal analysis curve of Speiser shale, sample number 11.

PLATE IV

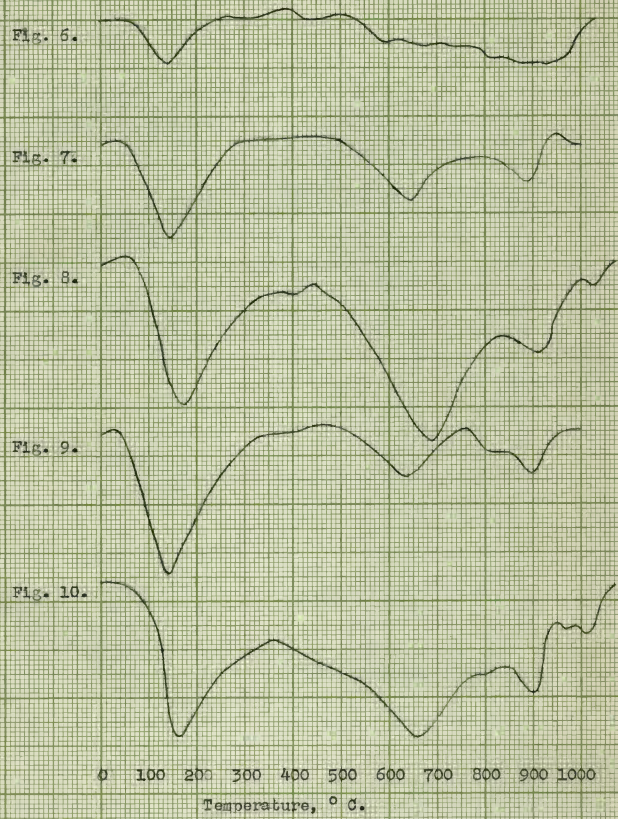


Fig. 6.
Fig. 7.
Fig. 8.
Fig. 9.
Fig. 10.
0 100 200 300 400 500 600 700 800 900 1000
Temperature, ° C.

EXPLANATION OF PLATE V

Fig. 11. Thermal analysis curve of Blue Rapids shale member, sample number 49.

Fig. 12. Thermal analysis curve of Easly Creek shale, sample number 10.

Fig. 13. Thermal analysis curve of Hooser shale member, sample number 7.

Fig. 14. Thermal analysis curve of Stearns shale, sample number 45.

PLATE V

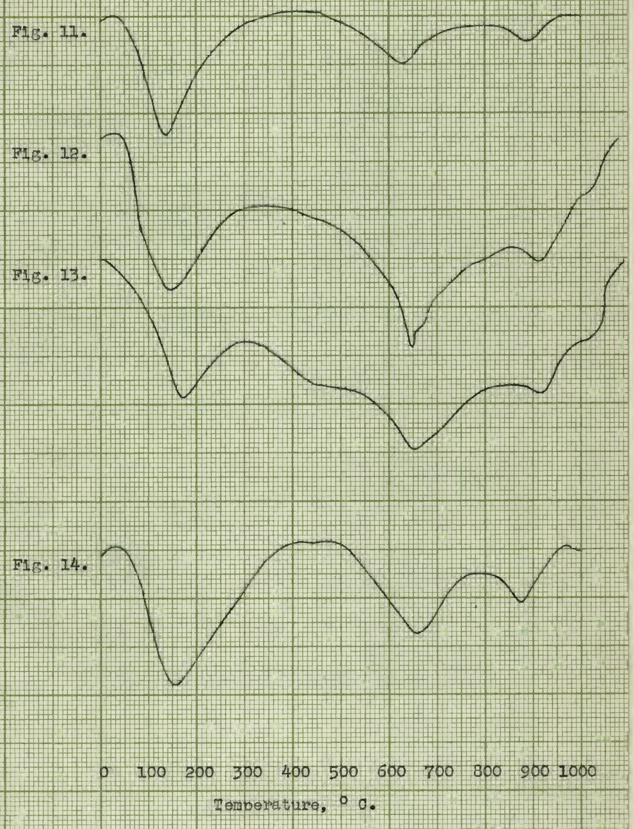


Fig. 11.
Fig. 12.
Fig. 13.
Fig. 14.
0
100
200
300
400
500
600
700
800
900
1000
Temperature, ° C.

EXPLANATION OF PLATE VI

Fig. 15. Thermal analysis curve of Florena shale member, sample number 30.

Fig. 16. Thermal analysis curve of Eskridge shale, sample number 31 (B).

Fig. 17. Thermal analysis curve of the upper shale zone of Salem Point shale member, sample number 48.

Fig. 18. Thermal analysis curve of the lower shale zone of Salem Point shale member, sample number 9.

PLATE VI

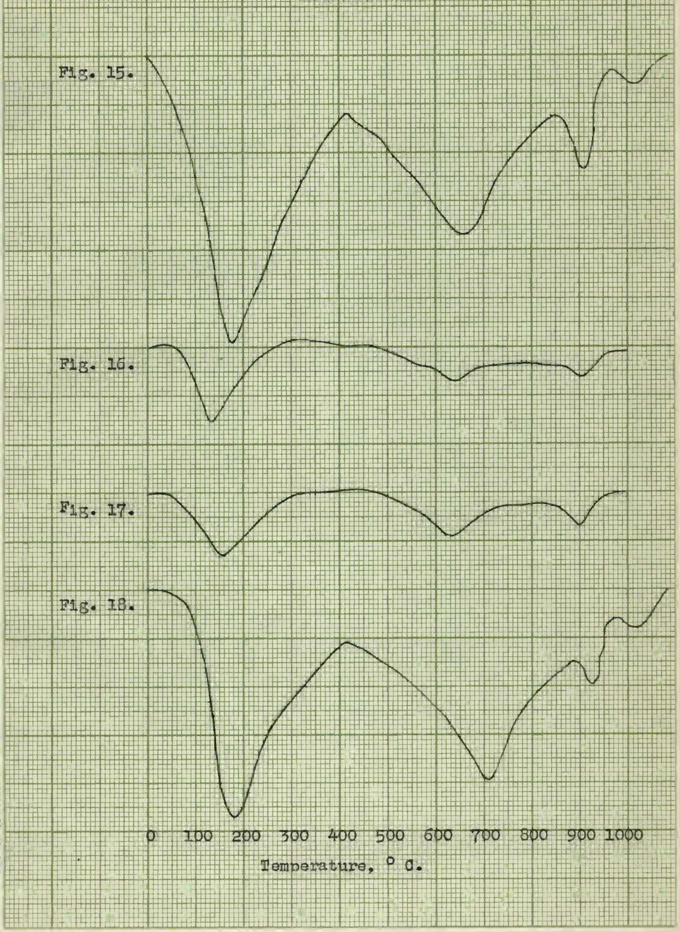


Fig. 15.
Fig. 16.
Fig. 17.
Fig. 18.
0 100 200 300 400 500 600 700 800 900 1000
Temperature, ° C.

EXPLANATION OF PLATE VII

Fig. 19. Thermal analysis curve of upper shale zone of Roca shale, sample number 36.

Fig. 20. Thermal analysis curve of middle shale zone of Roca shale, sample number 35.

Fig. 21. Thermal analysis curve of lower shale zone of Roca shale, sample number 34.

Fig. 22. Thermal analysis curve of upper shale zone of Bennett shale member, sample number 50.

Fig. 23. Thermal analysis curve of lower shale zone of Bennett shale member, sample number 51.

Fig. 24. Thermal analysis curve of upper shale zone of Johnson shale, sample number 27.

PLATE VII

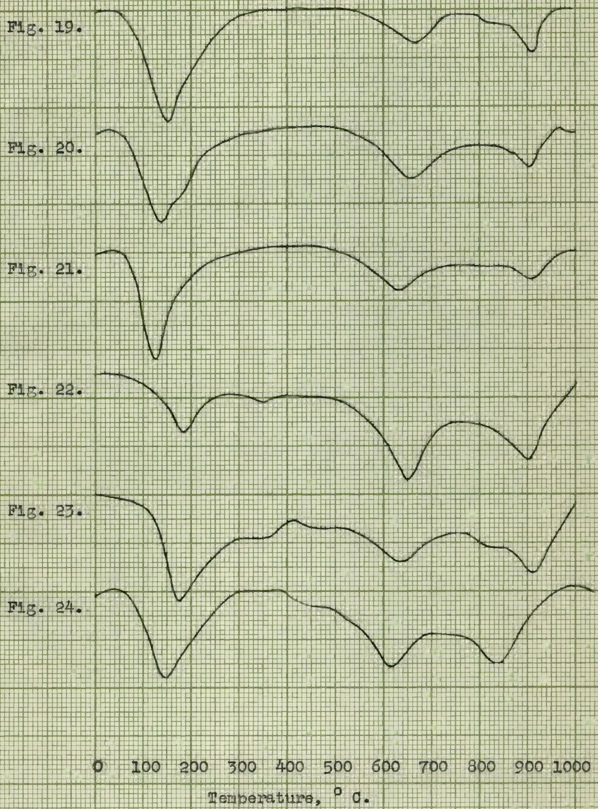


Fig. 19.
Fig. 20.
Fig. 21.
Fig. 22.
Fig. 23.
Fig. 24.
0 100 200 300 400 500 600 700 800 900 1000
Temperature, ° C.

EXPLANATION OF PLATE VIII

Fig. 25. Thermal analysis curve of middle shale zone of Johnson shale, sample number 28.

Fig. 26. Thermal analysis curve of lower shale zone of Johnson shale, sample number 29.

Fig. 27. Thermal analysis curve of Hughes Creek shale member, sample number 26.

Fig. 28. Thermal analysis curve of Oaks shale member, sample number 39.

Fig. 29. Thermal analysis curve of Indian Cave sandstone member, sample number 46.

PLATE VIII

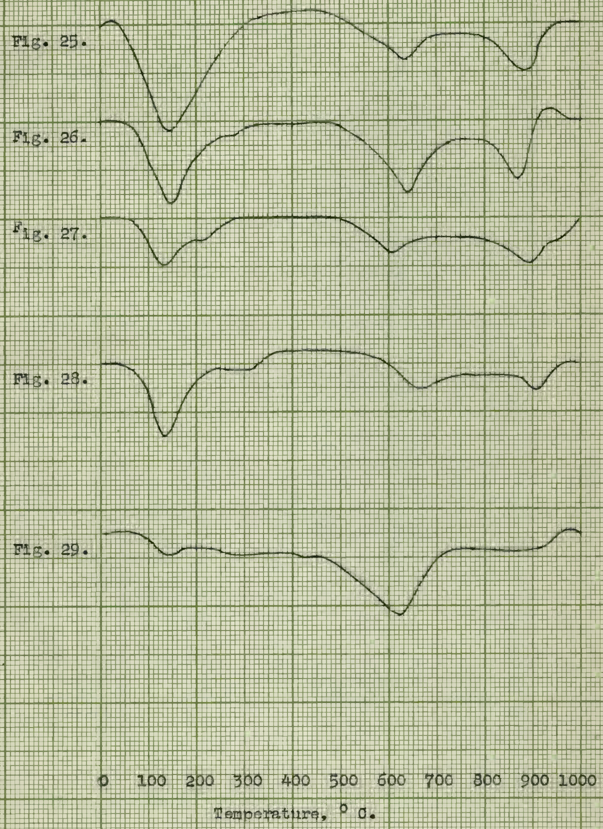


Fig. 25.
Fig. 26.
Fig. 27.
Fig. 28.
Fig. 29.
0 100 200 300 400 500 600 700 800 900 1000
Temperature, ° C.

SUMMARY AND CONCLUSIONS

In general, one sample is not sufficient to determine accurately the minerals present in a particular rock unit. A reasonable idea of the minerals present may be obtained, but some minor accessory minerals may not appear in the sample when only one sample is run of the unit.

Another factor that may enter into the results and the determination of the various minerals present is the ease of disaggregation of the shale. In general, the black carbonaceous shales are the hardest to disaggregate. Some of the green shales are also hard to totally disaggregate, and this may be due to iron being present in a very complex state. Following the green shales are the red shales which are difficult to disaggregate at times. The highly calcareous shales consumed a lot of time in digesting the calcium carbonate but usually are very easy to disaggregate.

Celestite was found as an authigenic mineral in many of the shales. In some of the shales it was present only as a trace while in other shales it was very abundant. The shales in which celestite was found to make up five percent or more of the total percentage of the heavy minerals present were as follows: Paddock shale member, Odell shale, Grant shale member, Gage shale member, Blue Springs shale member, Stearns shale, Florena shale member, Eskridge shale, upper shale zone of the Roca shale, all three shale zones of the Johnson shale, Hughes Creek shale member, and the Oaks shale member. One sample of the lower shale zone of the Salem Point shale member also showed celestite in excess of the above limits. Out of twenty-four shale units sampled, only four units did not show any trace of celestite in the heavy minerals analyses. These were the Oketo shale member, Havensville shale member, Easly Creek shale, and the Hooser shale member.

Authigenic plagioclase, which was determined as being oligoclase, was found to be present in the following shale units: Paddock shale member, Grant shale member, Wymore shale member, Florena shale member, Eskridge shale, a portion in the upper shale zone of the Roca shale, and a small portion in the lower shale zone of the Johnson shale. In each shale where the plagioclase was found, muscovite was fairly common with the exception of the lower shale zone of the Johnson shale. The muscovite may be an indication of a silty phase of the shale in which there may have been pore space to carry the sulphate solution and precipitate the celestite. In each shale unit listed above, pyrite was also present with the muscovite with the exception of the Florena shale member where part of the hematite may originally have been pyrite. In each case, celestite was present in a moderate amount with the exception of the lower shale zone of the Johnson shale where the celestite was exceedingly abundant.

Where pyrite was found to be rather common in the shale unit, investigation of the shale in the field revealed the color as being gray, dark gray, or black. These colors are typical of the presence of organic matter and afford a good place for the pyrite to form. Abundant pyrite was found in the green shale of the Blue Rapids, also; and this shale has a tendency to be dark gray near the top of the unit. If pyrite is found in red shales it appears to be of sporadic occurrence.

Collophane was found in the upper shale zone of the Johnson shale. The collophane appears to be an authigenic mineral and investigation in the field showed no evidence of phosphate nodules. From this investigation it appears that the collophane was formed by the replacement of the invertebrate shells which are very abundant in this particular zone. A trace of collophane was found in one of the lower shale zones of the Salem Point shale member and in one sample of the upper shale zones of the Roca shale. A trace of collophane was also found in the middle shale zone of the Johnson shale.

Feldspars including orthoclase, microcline, and plagioclase (other than authigenic oligoclase) were found to be rather common in the Cage shale member and the Hooser shale member. In the other shale units, the feldspars were present in minor quantities.

From Table 3, showing a comparison between the Riley County tills, and Riley County shales, certain conclusions may be drawn. It is noticed that hornblende, epidote, and garnet are rather abundant in the tills and only present in very small quantities in the Riley County shales. Another significant difference is the shape of the hornblende found in the two kinds of material. The hornblende present in the tills tends to be elongated and somewhat jagged while that present in the shales is smooth and rounded. Epidote is a common mineral in the tills suggesting that its origin may be from a metamorphic source. The epidote is found only as a trace in the shales. Corundum appears to be rather common in the Riley County shales and is absent in the tills. Regarding the light fraction, quartz is abundant in the tills and not very abundant in the shales. In the shales, chalcedony is very abundant and is present in the tills in only moderate quantity.

The common authigenic minerals found in the Riley County shales are celestite, pyrite, some collophane, and, in some cases, hematite. Some authigenic plagioclase, which was determined as being oligoclase, was found in some of the shales. The common allogenic mineral is muscovite, which may be very abundant. Magnetite, corundum, topaz, and zircon may be abundant at times. All of these minerals are of detrital origin in the shales as indicated by their rounded appearance.

In making use of heavy minerals for correlation purposes, the concentration of a particular heavy mineral may be helpful. It was observed in most of the Salem Point shale member samples where muscovite was present in both shale zones, but was much more concentrated in the lower shale zones. At times, the muscovite would make up about 90 percent of the total percentage of all the heavy minerals found in the lower shale zone, while in the upper shale zone the muscovite never exceeded about 60 percent.

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