INSOLUBLE RESIDUES OF SOME PERMIAN AND PENNSYLVANIAN LIMESTONES

by

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INTRODUCTION

Purpose of the Investigation

Interest in the study of insoluble residues was stimulated by knowledge of their use as a means of subsurface correlation by the petroleum industry. In compiling and presenting the data here reported, an effort was made to follow procedures established by oil geologists and to evaluate the results from a practical standpoint as they would be used in subsurface correlation by a petroleum geologist.

In this study, the stratigraphic units are discussed in an order reversed from that used in many geologic reports. The first stratigraphic unit discussed is the youngest, just as though a set of oil-well cuttings was being described. The analyses are restricted to the limestones cropping out in the vicinity of Manhattan, Kansas (Fig. 1). Each limestone is discussed as to sample locations, lithology, insoluble residues, and possible correlation through the use of the insoluble residues of the limestones will be summarized.

This investigation was undertaken with a two-fold purpose in mind. The primary purpose was to determine the feasibility of the correlation of some local limestones by means of their insoluble-residue content. The secondary purpose was to see if there was a marked difference between the

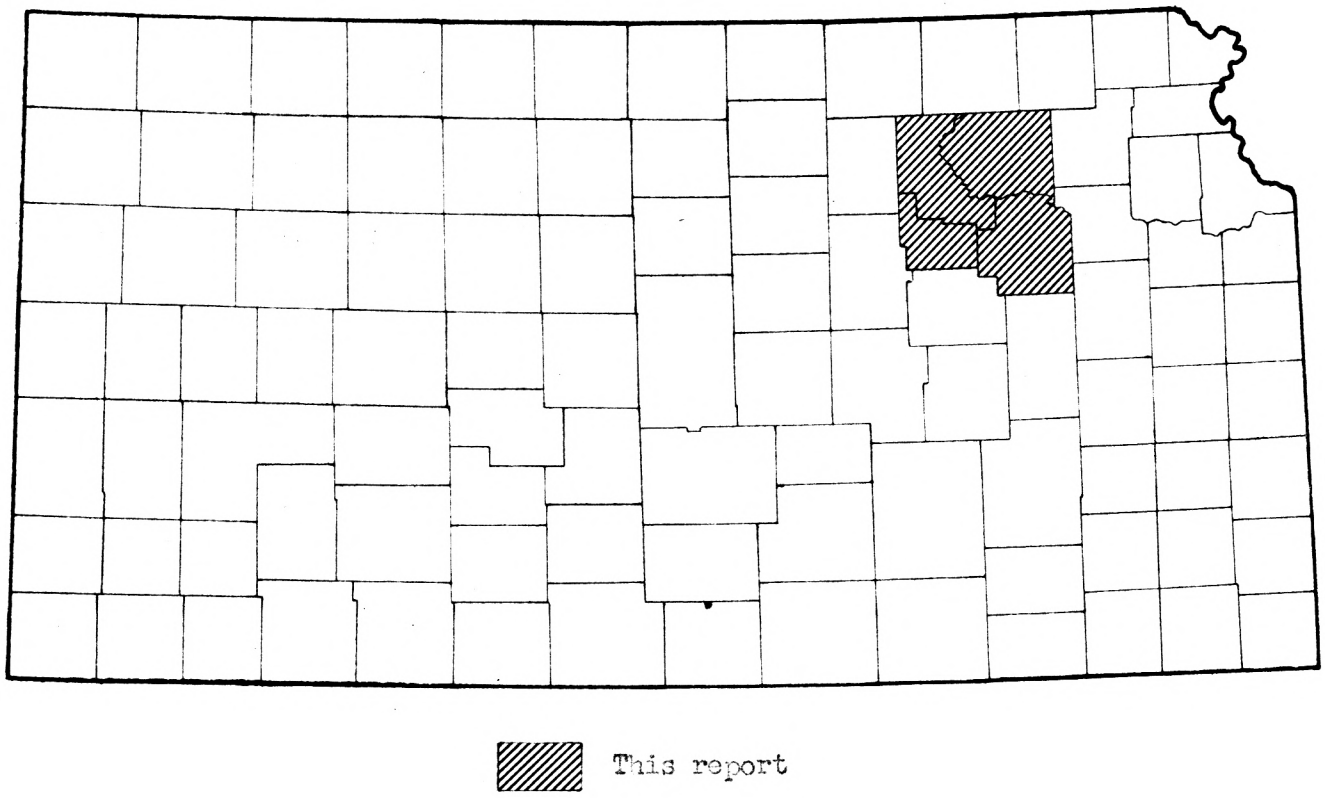


Fig. 1. Index map of Kansas showing area covered by this investigation.

insoluble residues of the Permian limestones and the Pennsylvanian limestones in the area of investigation.

Definition of Insoluble Residues

The term "insoluble residue", as used in this study, will include all of the material remaining after rock fragments have been digested in dilute hydrochloric acid. Therefore, in this study, the use of the term "insoluble residue" is restricted to the calcareous rocks, i.e., limestone, dolomite, and calcareous shale. This definition is the same as that used by Ireland (1950, p. 140) and Grohskopf and McCracken (1949, p. 7).

The term "siliceous residue" used by Crowley and Hendricks (1945, p. 413) is not considered applicable because much of the insoluble residue examined during this investigation consists of pyrite, limonite, celestite, glauconite, silty-clay pellets, muscovite, and fusain.

The total insoluble residue of a calcareous rock may be further classified as fine residue and coarse residue. The fine residue consists of the clay fraction of the total residue and can be separated from the coarse residue by decantation. The coarse residue consists of those particles of the total residue which are larger than clay size and remain in the beaker after the fine residue has been decanted.

In general, most correlative work is done with the coarse-residue fraction. Ireland (1950, p. 143) states, "Little or no work has been done with the fine residues, and their value for correlation and identification is yet to be determined."

Previous Work on Insoluble Residues

Ireland (1936, p. 1087) states that the first paper dealing with insoluble residues was published by E. Wethered in 1388. Since that time insoluble residues have been used by many geologists as a means of correlating calcareous sedimentary rocks. The method used by Trager (1920, p. 170-176) for the examination of well cuttings, consisted of grinding the sample to particles small enough to pass an 80-mesh sieve, measuring out a unit volume, dissolving the carbonates in hydrochloric acid, and centrifuging the residue in water for the separation of sand and shale. The percentages of sand, shale, and soluble carbonates were recorded.

Lamar (1926, p. 578-585), in his analyses of Mississippian limestones, used the total insoluble residue. This residue was separated by size into four fractions - clay, silt, sand, and oversize. Graphs were made showing the constituent percentage of the various fractions, and a heavy mineral study was made of the silt- and sand-size fractions.

Claypool and Howard (1928, p. 1147-1152), in their analyses of well cuttings, classified the various limestones according to the calcite, dolomite, and magnesite content. The sample was ground so as to pass an 80-mesh sieve and the light, medium, and heavy fractions were separated by centrifuging in Thoulet's solutions of various densities. By digesting these fractions in hydrochloric and nitric acid, calcite was dissolved from the light fraction, dolomite dissolved from the medium fraction, and magnesite was dissolved from the heavy fraction. The volume of shale and sand was measured after dissolving the calcite in the light fraction.

Merritt (Ireland, 1936, p. 1087) studied the insoluble residues of the Arbuckle limestone in 1928 and the Simpson formation in 1931, both from outcrops sampled in the Arbuckle Mountains of Oklahoma.

McQueen (Grohskopf and McCracken, 1949, p. 8), in a publication of the Missouri Geological Survey, formulated a system of nomenclature and methods of sample preparation. He dissolved samples of well cuttings in dilute hydrochloric acid, decanted the fine residue, and examined the coarse residue for diagnostic constituents. His methods have become routine practice in the subsurface studies of the Missouri Geological Survey (Grohskopf and McCracken, 1949, p. 8) and are used by most of the workers in other states.

Ockerman (1931, p. 43-46), of the Kansas Geological Survey, used McQueen's methods in his studies of the Hunton and Viola

limestone, sampled from oil wells drilled near Topeka, Kansas. In 1931, Martin (Ireland, 1947, p. 1479) used insoluble residues in the correlation of Mississippian limestones in Indiana and Kentucky. Mitchell (1934, p. 412) used insoluble residues as the basis for his study of the correlation and deposition of certain Pennsylvanian limestones in Ohio. In 1935, Burpee and Wilgus (Ireland, 1936, p. 1087) studied the insoluble residues of Permian beds in New Mexico. Ireland (1936, p. 1086-1121), in his study of the Hunton and Viola limestones in Oklahoma, found insoluble residues a definite aid in the identification of the limestones.

Schoewe, Keroher and Keroher (1937, p. 269-281) made a preliminary study of the insoluble residues of a number of Pennsylvanian limestones in Kansas. Hiestand (1938, p. 1588-1599) zoned the Mississippian limestone in the subsurface of central Kansas on the basis of residue characteristics. Cole (1942, p. 1398-1409) studied residues in his investigation of the Ellenburger limestone in west Texas, and Crowley and Hendricks (1945, p. 413-425) zoned the same limestone in north-central Texas on a similar basis.

In 1946, Ireland (1947, p. 1479-1490) arranged a conference in Midland, Texas for the purpose of standardizing insoluble-residue terminology. All interested workers in the field of insoluble residues were invited. The terminology adopted by this conference follows, for the most part, that used by the Missouri Geological Survey, and proposed by

McQueen in his early reports.

Grohskopf and McCracken (1949, 39 p.) of the Missouri Geological Survey have recently published a supplement to McQueen's report. In it they discuss the insoluble residues of the Mississippian, Ordovician, and Cambrian limestones of Missouri, the preparation of the insoluble residues, and the application of insoluble-residue analyses to various problems.

Area of Investigation and Stratigraphic Units Sampled

In the course of this investigation, 10 limestones cropping out in Riley, Wabaunsee, and Pottawatomie Counties in Kansas were sampled and their insoluble residues studied (Fig. 1). These limestones are located stratigraphically between the Hamlin shale of the Admire Group (Wolfcampian Series of the Permian System) and the Willard shale of the Wabaunsee Group (Virgilian Series of the Pennsylvanian System). The Permian limestones are, from youngest to oldest, the Five Point, Falls City, and Aspinwall. The Pennsylvanian limestones are, from youngest to oldest, the Brownville, Caneyville, Jim Creek, Grandhaven, Dover, Maple Hill, and Tarkio (Fig. 2).

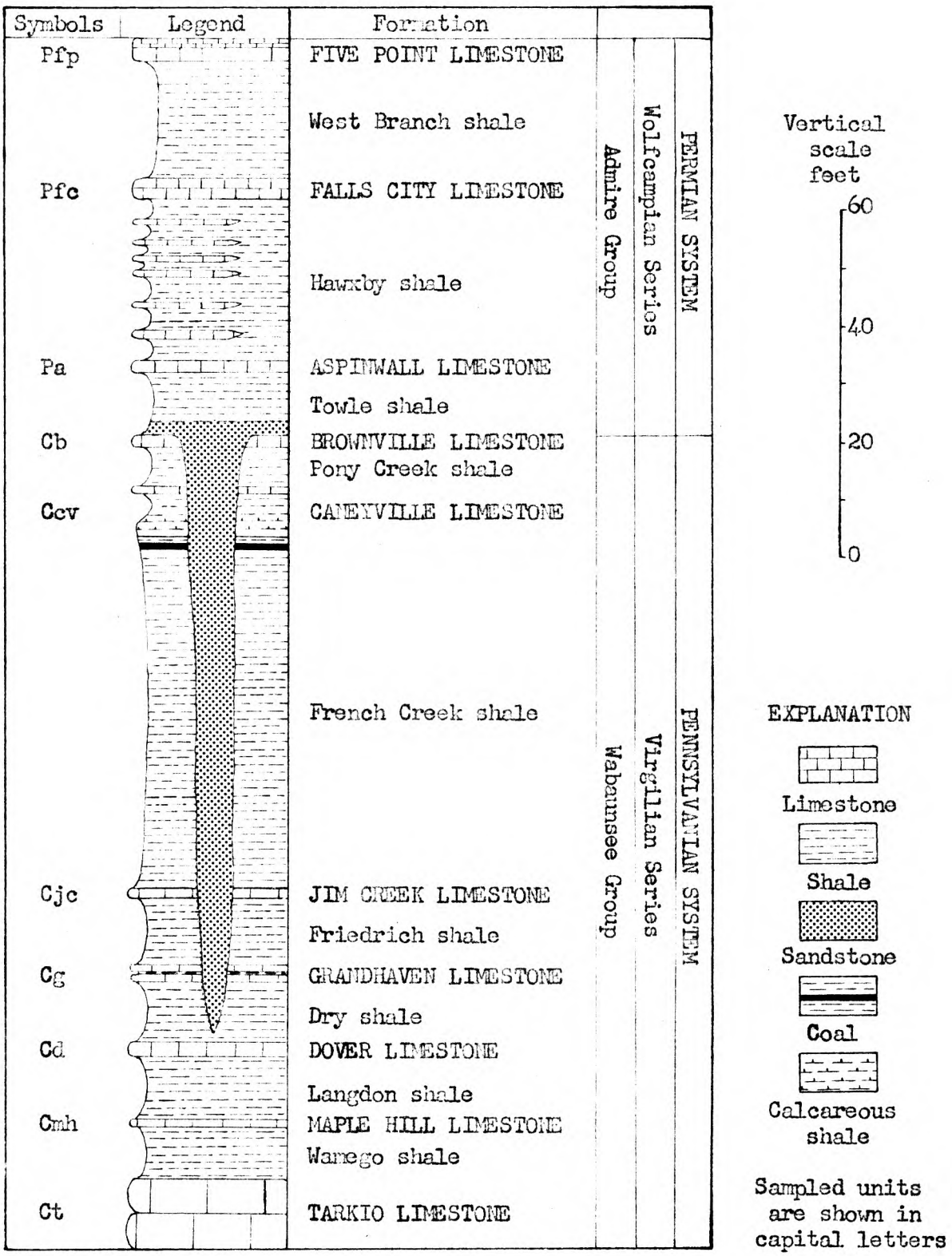


Fig. 2. Generalized stratigraphic section.

Nomenclature and Symbols

Nomenclature. The classification and terminology for insoluble residues proposed by the Residue Conference of 1946 (Ireland, 1947, p. 1479-1490) have been followed, for the most part, in discussing the residues examined during this study. It was found, however, that some constituents, which compose a sizeable fraction of most of the coarse residues examined, are classified by the Residue Conference as "Unclassified Accessory Residues" (Ireland, 1947, p. 1479-1490). In these and other cases in which the terminology proposed by the Residue Conference did not seem appropriate, the terminology of other authorities, considered to be better suited to this study, was adopted or modified as dictated by the residues in question. All terms and definitions for which the authority or a modification is not cited are those proposed by the Residue Conference of 1946.

The definitions of the descriptive terms here used are:

> Abundant dolomolds: Residues with rhombohedral openings with the constituent material comprising from 25 to 75 percent of the volume of the fragment. Openings vary from microscopic to megascopic.
>
> Anhedral: No crystal form developed.
>
> Chalky: Uneven or rough fracture surface; commonly dull or earthy; soft to hard; may be finely porous; essentially uniform composition; resembles chalk or tripolite. (Formerly referred to as 'dead' or 'cotton chert.' This includes dull, unglazed porcelaneous material which grades into glazed porcelaneous material of smooth chert.)

Chert: Cryptocrystalline varieties of quartz, regardless of color; composed mainly of petrographically microscopic fibers of chalcedony and/or quartz particles whose outlines range from easily resolvable to nonresolvable with binocular microscope at magnifications ordinarily used by geologists. Particles rarely exceed 0.5 mm. in diameter.

Clay: Fine material of clay size, under 1/256 mm in diameter. (Modified for this study.)

Dolomold: Rhombohedral cavities in an insoluble residue. (Generally due to the solution of euhedral dolomite or calcite crystals.)

Dolomoldic: Containing dolomolds.

Drusy: Clusters or aggregates of crystals, generally incrustations.

Euhedral: Double terminated crystals; unattached.

Fusain: Fusain, or 'mineral charcoal' is most readily identified because of its resemblance to common charcoal. If not mineralized, it is very friable and highly porous. The pores are in some instances filled with calcite or pyrite (Pettijohn, 1949, p. 367).

Granular: Chert; compact, homogenous; composed of distinguishable relatively uniform-size grains, granules, or druses; uneven or rough fracture surface; dull to glimmering luster; hard to soft; may appear saccharoidal. (This type is frequently referred to as 'crystalline.')

Ordinary: Smooth chert with even fracture surface; all colors, chiefly white, gray, or brown; may be mottled; approaches opaque; generally homogeneous, but may have slight evidence of granularity or crystallinity; grades into chalcedonic or granular chert.

Sand: Quartz grains; very fine, 1/8 to 1/16 mm in diameter. (Modified for this study.)

Silt: Grains of silt size, chiefly quartz; size ranges from 1/16 to 1/256 mm in diameter. (Modified for this study.)

Smooth: Major type of chert with conchoidal to even fracture; surface devoid of roughness; may be botryoidal; homogeneous; no distinctive structure, crystallinity, or granularity.

Subhedral: Crystal forms partly developed; may be loose, drusy, or granulated.

Subrounded: Polygonal grains or fragments but with well-rounded edges and corners.

Tubular silica: Small, highly contorted tubular forms of fragile silica (Schoewe, Keroher, and Keroher, 1937, p. 274). It is believed that this is the residue called "siliceous 'worm casts'" by Grohskopf and McCracken (1949, p. 15, 23). Organic origin is implied in both references. In this study, however, it is considered only as another type of coarse residue. (Modified for this study.)

Sample-number Symbols. The symbols listed below are used to indicate the system, geologic formation, county, and outcrop number within a county for all samples collected during this investigation.

Symbol	Definition
P	Permian System
C	Pennsylvanian System
fp	Five Point limestone
fc	Falls City limestone
a	Aspinwall limestone
b	Brownville limestone
cv	Caneyville limestone
jc	Jim Creek limestone
g	Grandhaven limestone
d	Dover limestone
mh	Maple Hill limestone
t	Tarkio limestone
U	Upper part of the limestone
L	Lower part of the limestone
R	Riley County, Kansas
W	Wabaunsee County, Kansas
P	Pottawatomie County, Kansas

Arabic numbers 1 to 25 were assigned in a chronological sequence to outcrops as they were sampled within a county.

Fine Residue Color Symbols. The color of the fine residues was obtained by comparing them with examples in the Rock-Color Chart. This chart was prepared in 1948 by the Rock-Color Chart Committee of the National Research and is now available through the Geological Society of America, New York, N. Y.

The following color symbols and their equivalent colors are used in this study (as Fig. 3c et seq.):

Symbol	Color
10 YR 7/4	Grayish orange
10 YR 6/6	Dark yellowish orange
10 YR 6/2	Pale yellowish brown
10 YR 5/4	Moderate yellowish brown
5 Y 8/1	Yellowish gray
5 Y 7/2	Yellowish gray
5 Y 6/1	Light olive gray
5 Y 4/1	Olive gray
N 6	Medium light gray

Coarse Residue Color Symbols. The following colors are used in the coarse-residue circlegrams and bar charts to indicate the coarse-residue composition of the samples (as Figs. 3a and 3d et seq.):

Symbol	Definition
	Limonite
	Pyrite
	Sand
	Glauconite
	Tubular silica
	Muscovite flakes
	Celestite
	Fusain
	Clay, silty
	Chert

Preparation of Insoluble Residues from Outcrop Samples

Field Procedure. The lower Permian and upper Pennsylvanian limestones are exposed in road cuts, ditches, stream banks, and on hillsides. The major problem encountered in the field was to find outcrops in which the full thickness of a formation was exposed.

Where a suitable outcrop was found, its geographic location was determined and noted, and the outcrop assigned the next number in the chronological sequence of samples collected in that county. A lithology of the stratigraphic unit was recorded. If the formation consisted entirely of limestone, a channel sample of its full thickness was collected. However, if there was a shale break in the formation, separate channel samples were taken of each bed of limestone; the intervening shales were not sampled. For those formations that included shale breaks, the separate channel samples were either combined to form a composite sample of the limestones in the formation or were treated as separate samples in order to analyze differences in the insoluble residues of the upper and lower limestone layers; portions of them were later combined to form a composite sample.

An attempt was made to collect only fresh rock free from extraneous material. The samples obtained from each

stratigraphic unit are listed under the heading "Sampled Locations" in the descriptions of the insoluble residues of the several limestones.

The amount of each sample obtained varied in direct proportion to the thickness of the sampled formation. In all cases, a sufficiently large sample was collected to permit the repetition of laboratory processing in the event of accident or to check results.

It was hoped that samples of each formation could be collected at evenly spaced intervals over its outcrop area. However, this spacing was found to be impossible because of the limited number of suitable exposures. The sampling of most of the units was restricted to those outcrops in which the full thickness of the formation was exposed. It was thought that this would result in better experimental control and a more representative suite of residues.

Laboratory Procedure. After trying various laboratory techniques and procedures outlined by the workers cited previously, the following laboratory procedure was established and used throughout this investigation.

The already fragmented samples of limestone were crushed to finer sizes and were then sieved. Two sieves, one with a 4-mesh screen and the other with a 10-mesh screen, were used in the sieving operation. Only that part of the sample which passed through the 4-mesh screen and was retained on the 10-mesh screen was saved. These fragments of the sample are

small enough and sufficiently uniform as to be suitable for accurate volumetric measurement; they also probably represent the freshest portion of the total sample. The rock fragments retained on the 4-mesh screen were discarded. They were considered too large and too irregular in shape for accurate volumetric measurement, and their larger size would increase the time required to digest the sample. The fragments which passed through the 10-mesh screen were also discarded. This was done to eliminate the more weathered portion of the rock sample and to prevent contamination by rock powder from other samples. It was routine practice to clean the rock crusher and sieves after each sample had been run to prevent contamination of later samples.

The crushed sample was then poured onto a cloth and thoroughly mixed. The unit sample volume used was 10 drams. For those formations represented by 2 samples, each sample was treated separately and a composite sample of the formation was also made by combining 5 drams of each of the 2 samples. The 10-dram sample was then weighed and placed in a pint fruit jar on which the sample number had been written.

Samples were usually processed in groups of 10. The glass containers were placed in 2 glass trays for convenient handling and to catch any acid which might be spilled during the digestion process. The trays were then placed under a ventilating hood before the acid was applied.

Approximately 50 cc of tap water were first poured over each sample. This was followed by about 5 cc of concentrated technically pure hydrochloric acid. Acid was added to the sample, whenever effervescence ceased, until digestion was complete. Slow application of small quantities of acid was necessary to prevent the froth, caused by the effervescent reaction of limestone and acid, from spilling out of the container. The samples were stirred frequently to prevent the silt and clay, which were released during the digestion of the limestone, from covering the rock fragments and thus retard their digestion.

After digestion of the limestone was complete, the fine residues were allowed to settle and the spent acid was siphoned off. The jars were then filled with tap water under pressure to insure thorough dispersion and washing of the residues. The washing was repeated 7 times. The first 2 washings removed any excess acid and the remaining 5 washings were made to insure the removal of soluble salts and precipitates, such as crystals of gypsum and calcium chloride, which may have been formed by reaction of the acid with the limestone. (See Grohskopf and McCracken, 1949, p. 10 for further information.)

The fine residues were then decanted through numbered filter papers, with care taken to leave the coarse residues in the jars. The coarse residues were transferred to

appropriately labelled 250 cc Pyrex beakers, and both residues were dried in an oven.

After drying, the coarse residues were removed from the beakers, weighed, and placed in 2-dram lip vials. The corks of the vials were labelled with the sample numbers. The fine residues were weighed, removed from the filter papers, powdered, and also placed in 2-dram lip vials with labelled corks.

A small metal pan was used for pouring residues into the vials and later as the tray in which the coarse residues were examined. The pan is 3 inches wide, 5 inches long, and about ¼-inch deep. One end of the pan is tapered and cut off so as to leave an opening about ¼-inch wide (Grohskopf and McCracken, 1949, p. 12). It was painted with black enamel to reduce light glare and to provide a contrasting background for the coarse residues during examination.

The percentage volume of the fine and coarse residues was measured by placing the vials in a specially constructed wooden block. The block was made from 2 by 4 inch lumber and is about 6 inches long. Four holes, each 11/16 inch in diameter, were drilled into the narrow edge of the wooden block so that when the vials were placed in them, only the lips of the vials protruded. The block was planed on one side until the holes were intersected and the contents of the vials could be observed. It was painted with black enamel and 10

equally spaced horizontal lines were marked on the front face and painted with white enamel (Grohskopf and McCracken, 1949, p. 11). Each of the 10 divisions represents 2 percent of the total 10-dram sample. The percentage volumes of the coarse and fine residues were visually determined and later plotted on graphs showing constituent percentage of total sample by volume (as Fig. 3c).

The percentage weights of fine and coarse residues were later computed and noted on the sample data charts (as Fig. 3b).

The colors of the fine residues were obtained by comparison with the Rock Color Chart (See p. 13 and Fig. 3c).

A binocular microscope equipped with 10-power oculars and paired objectives of 2 and 4 powers was used for examination of the coarse residue. After a general examination of the coarse residue, the percentage volumes of the constituents were estimated by visual inspection and were later plotted in colors on graphs showing constituent percentage of coarse residue by volume (See p. 14 and Fig. 3d).

DESCRIPTION OF INSOLUBLE RESIDUES BY STRATIGRAPHIC UNITS

Permian System

Three limestones of the Admire Group (Permian System) were sampled during this investigation. They are, from youngest to oldest, the Five Point, Falls City, and Aspinwall limestones (Fig. 2).

Five Point Limestone. The Five Point limestone underlies the Hamlin shale and overlies the West Branch shale (Fig. 2). It is the uppermost limestone in the Admire Group.

Sampled Locations. Suitable outcrops of the Five Point limestone are relatively scarce in the area covered by this investigation. Five exposures were sampled (Fig. 3a):

Sample number	Type of outcrop	Geographic location
PfpR10	Road ditch	SW¼NW¼SW¼ sec. 8, T. 11 S., R. 9 E., Riley County
PfpUR12) PfpLR12) PfpR12)	Hillside	NW¼SE¼SW¼ sec. 30, T. 10 S., R. 9 E., Riley County
PfpW1	Road cut	SW¼SW¼SW¼ sec. 12, T. 11 S., R. 9 E., Wabaunsee County
PfpW2	Road cut	SW¼SE¼SW¼ sec. 26, T. 11 S., R. 11 E., Wabaunsee County
PfpP13	Road ditch	SE¼SW¼NW¼ sec. 20, T. 9 S., R. 11 E., Pottawatomie County

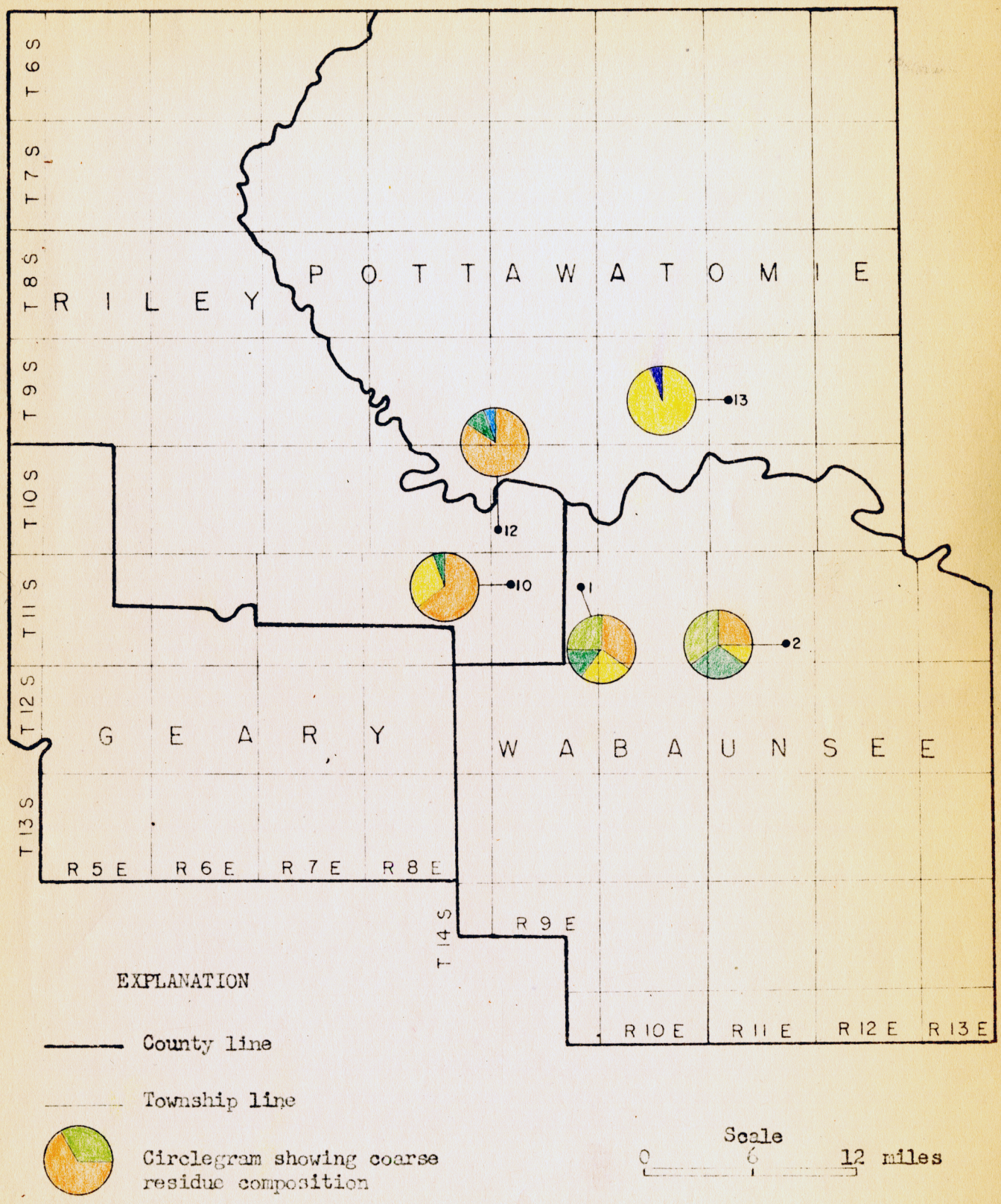


Fig. 3a. Map showing sample locations and coarse residue composition for Five Point limestone.

Lithologic Description. The upper part of the Five Point limestone is platy and argillaceous (Figs. 2 and 3c), and the lower part is hard, massive, and fossiliferous. The limestone is light gray to yellowish gray, and weathers tan gray. The average thickness of this limestone is about 3 feet.

Description of the Insoluble Residue. The total residue of this limestone ranges from 2.8 to 15.0 percent by volume (Figs. 3b and 3c). The volume of the coarse residue varies from 0.2 to 3.0 percent, and the volume of the fine residue comprises from 1.8 to 13.0 percent of the original sample.

The color of the fine residue ranges from dark yellowish orange to light olive gray (Fig. 3c).

The coarse residue consists of varying amounts of limonite, sand, glauconite, and tubular silica. Yellowish-brown limonite is the principal constituent and occurs in the form of small porous grains, cubic and octahedral crystals pseudomorphic after pyrite, and nodules (Fig. 3d). The sand is composed of very fine, anhedral, well-sorted grains of quartz. Sand forms about 95 percent of the coarse residue of sample PfpPl3 (Fig. 3d). The glauconite occurs as rounded grains and as the replacement of sponge spicules(?), bryozoans, foraminifers, and coral fragments. Small muscovite flakes form about 5 percent of the coarse residue of sample PfpPl3 and occur as a trace in the other samples. Pyrite occurs

Sample number	Location	Sample		Residue							
				Coarse				Fine			
		Weight grams	Volume drams	Weight grams	% weight	Volume drams	% volume	Weight grams	% weight	Volume drams	% volume
PfpR10	Road ditch in NW¼SW¼ sec. 8, T. 11 S., R. 9 E., Riley County	49.80	10	0.50	1.00	0.10	1.0	0.40	0.8	0.18	1.8
PfpUR12	Hillside in SW¼ sec. 30, T. 10 S., R. 9 E., Riley County	61.30	10	0.15	0.20	0.02	0.2	6.30	10.3	1.24	12.4
PfpLR12	Hillside in SW¼ sec. 30, T. 10 S., R. 9 E., Riley County	53.20	10	0.05	0.10	0.02	0.2	0.20	0.4	0.10	1.0
PfpR12	Hillside in SW¼ sec. 30, T. 10 S., R. 9 E., Riley County	57.55	10	0.05	0.08	0.02	0.2	2.15	3.7	0.50	5.0
PfpW1	Road cut in SW¼SW¼SW¼ sec. 12, T. 11 S., R. 9 E., Wabaunsee County	61.80	10	0.30	0.40	0.04	0.4	5.90	9.5	1.20	12.0
PfpW2	Road cut in SW¼SE¼SW¼ sec. 26, T. 11 S., R. 11 E., Wabaunsee County	58.00	10	0.10	0.20	0.06	0.6	6.80	11.7	1.30	13.0
PfpP13	Road ditch in SE¼SW¼NW¼ sec. 20, T. 9 S., R. 11 E., Pottawatomie County	57.55	10	1.65	2.80	0.30	3.0	4.05	7.0	1.20	12.0

Fig. 3b. Sample data for Five Point limestone.

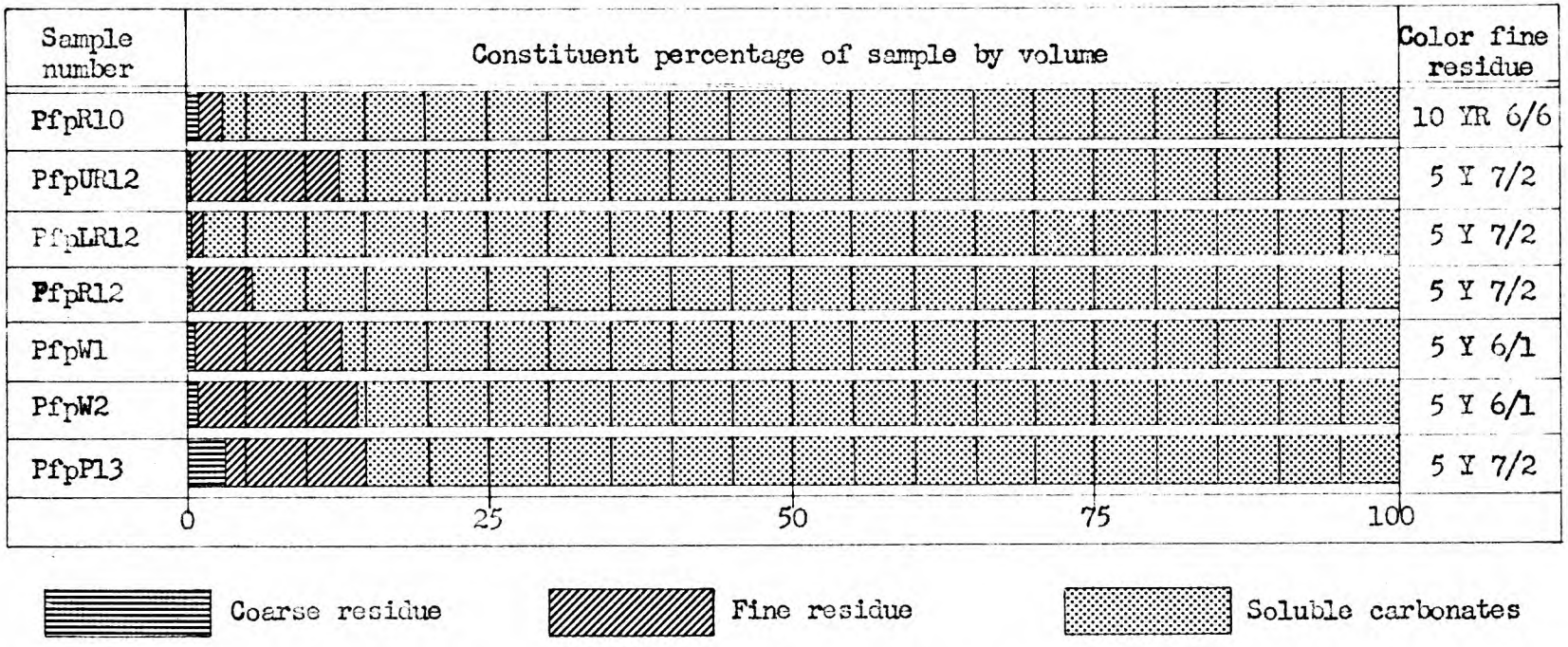


Fig. 3c. Constituent percentage of sample by volume of Five Point limestone.

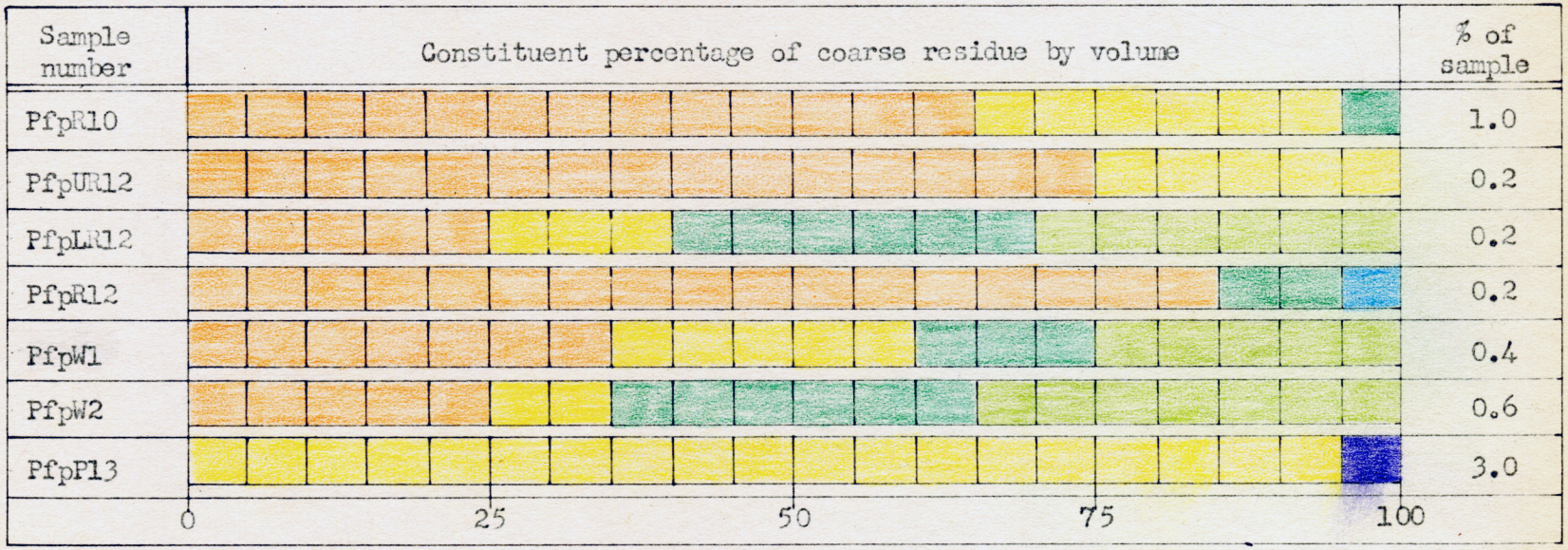


Fig. 3d. Constituent percentage of coarse residue by volume of Five Point limestone.

as a trace in some samples and replaces bryozoan and coral fragments. Aggregates of smooth, ordinary, white chert were found in a few samples and, in sample PfpR12, they form about 5 percent of the coarse residue.

Correlation by Means of Insoluble Residues. Examination of the coarse residue of the Five Point limestone reveals that no constituent which could be considered diagnostic for correlation appears in the residue of this limestone. The absence of silty-clay aggregates was noted but this characteristic can only be considered of negative value in correlation inasmuch as some samples of other limestones also lack this residue constituent.

The percentage volume of the total residue increases toward the east and north from southeastern Riley County from 2.8 percent in Riley County to 13.6 percent in Wabaunsee County and 15.0 percent in Pottawatomie County (Figs. 3b and 3c). The same kind of variation in percentage volume is apparent in both the fine and coarse residues. It is thought that this variation is indication of a facies change in the limestone and might be of some value in correlation when considered along with other data.

The use of weight and percentage weight of coarse and fine residues for correlation of the samples was tried but proved valueless.

The color of the fine residue of the Five Point limestone

is very similar to that of the Falls City limestone and, in general, resembles the fine residues of other limestones (Figs. 3c and 4c). It is not considered significant for correlative purposes.

The similarity in the constituent percentage by volume of the coarse residues of samples PfpW1 and PfpW2 is noticeable and, on the basis of the samples examined, might be considered as the type coarse residue over a small area of northern Wabaunsee County (Fig. 3a). The rapid change in residue characteristics within a few miles of these outcrops would seem to restrict their usefulness on this basis to that area alone.

The percentage volumes of coarse residues of samples PfpR10 and PfpR12 show some similarity and might prove useful for establishing a correlation in southeastern Riley County (Fig. 3a). The considerable difference between them and the samples obtained nearby in Wabaunsee County indicates the need for more data on the coarse residues in that area before they may be used with confidence.

The Five Point limestone in Pottawatomie County is represented by only 1 sample (Fig. 3a). The vast difference in its coarse residue as compared with the residue of other samples of the Five Point limestone makes it useless as a basis for correlation until more samples are obtained from Pottawatomie County.

Falls City Limestone. The Falls City limestone underlies the West Branch shale and overlies the Hawxby shale (Fig. 2).

Sampled Locations. Ten samples of the Falls City limestone were collected during the study (Fig. 4a):

Sample number	Type of outcrop	Geographic location
PfcR9	Stream bank	NE¼NW¼NW¼ sec. 31, T. 10 S., R. 9 E., Riley County
PfcR10	Road ditch	SW¼NW¼SW¼ sec. 8, T. 11 S., R. 9 E., Riley County
PfcR21	Road ditch	SE¼SE¼NE¼ sec. 9, T. 11 S., R. 9 E., Riley County
PfcW10	Road ditch	W½NW¼SE¼ sec. 8, T. 13 S., R. 13 E., Wabaunsee County
PfcP2	Hillside	SE¼SW¼NW¼ sec. 5, T. 10 S., R. 12 E., Pottawatomie County
PfcP10	Stream bank	SW¼NW¼NW¼ sec. 8, T. 9 S., R. 9 E., Pottawatomie County
PfcP12	Road ditch	SE¼NW¼NE¼ sec. 19, T. 9 S., R. 11 E., Pottawatomie County
PfcP20	Road ditch	SW¼SW¼SW¼ sec. 15, T. 7 S., R. 11 E., Pottawatomie County
PfcP24	Road ditch	SE¼SE¼SE¼ sec. 25, T. 6 S., R. 11 E., Pottawatomie County
PfcP25	Road ditch	SW¼SE¼SW¼ sec. 3, T. 8 S., R. 10 E., Pottawatomie County

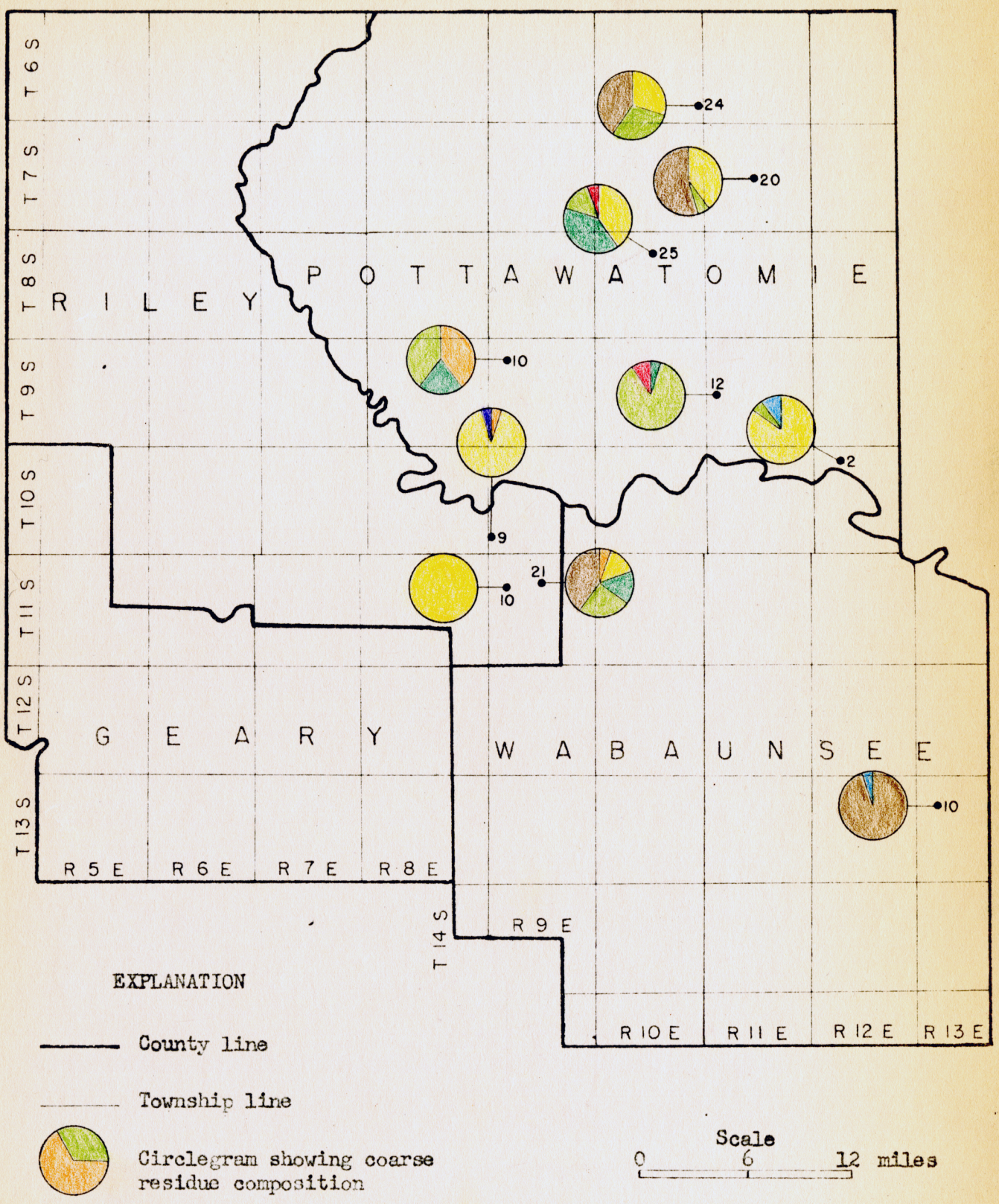


Fig. 4a. Map showing sample locations and coarse residue composition for Falls City limestone.

Lithologic Description. The Falls City limestone is porous and rather soft, has a microcoquina-like texture, and is fossiliferous. It is yellowish-gray, and weathers tan. The average thickness of the Falls City limestone is about 3 feet.

Description of the Insoluble Residue. The total residue of this limestone comprises from 1.4 to 25.6 percent by volume of the original sample (Figs. 4b and 4c). The volume of the coarse residue ranges from 0.2 to 6.0 percent, and the volume of the fine residue varies from 1.0 to 20.8 percent.

The color of the fine residue ranges from dark yellowish-orange to light olive-gray (Fig. 4c).

The major portion of the coarse residue consists of sand, silty clay, tubular silica, glauconite, and limonite. The percentage of these major constituents varies widely between samples (Fig. 4d). Sand, composed of very fine, anhedral, well-sorted quartz grains, is found in all samples and ranges from a trace in three samples to 100 percent of the coarse residue in sample PfcR10. Yellowish-brown, soft, porous, silty-clay aggregates compose 95 percent of sample PfcW10 and constitute significant percentages in samples PfcR21, PfcP20, and PfcP24. Silty-clay casts of ostracods, gastropods, and brachiopods were found in many of the samples.

Sample number	Location	Sample		Residue							
				Coarse				Fine			
		Weight grams	Volume drams	Weight grams	% weight	Volume drams	% volume	Weight grams	% weight	Volume drams	% volume
PfcR9	Stream cut in NW¼NW¼ sec. 31, T. 10 S., R. 9 E., Riley County	60.65	10	2.35	3.90	0.48	4.8	12.20	20.1	2.08	20.8
PfcR10	Road ditch in NW¼SW¼ sec. 8, T.11 S., R. 9 E., Riley County	58.25	10	2.75	4.70	0.60	6.0	7.05	12.1	1.28	12.8
PfcR21	Road ditch in SE¼SE¼NE¼ sec. 9, T. 11 S., R. 9 E., Riley County	60.55	10	0.15	0.20	0.08	0.8	7.65	10.9	1.40	14.0
PfcW10	Road ditch in W½NW¼SE¼ sec. 8, T. 13 S., R. 13 E., Wabaunsee County	59.40	10	0.10	0.16	0.10	1.0	6.95	11.7	1.60	16.0
PfcP2	Hillside in SE¼SW¼NW¼ sec. 5, T. 10 S., R. 12 E., Pottawatomie County	46.50	10	0.10	0.20	0.02	0.2	0.75	1.6	0.20	2.0
PfcP10	Stream cut in SW¼NW¼NW¼ sec. 8, T. 9 S., R. 9 E., Pottawatomie County	51.30	10	0.10	0.20	0.04	0.4	0.38	0.7	0.10	1.0
PfcP12	Road ditch in SE¼NW¼NE¼ sec. 19, T. 9 S., R. 11 E., Pottawatomie County	54.40	10	0.10	0.20	0.04	0.4	0.40	0.7	0.10	1.0
PfcP20	Road ditch in SW¼SW¼SW¼ sec. 15, T. 7 S., R. 11 E., Pottawatomie County	57.70	10	0.30	0.50	0.18	1.8	1.25	2.2	0.22	2.2
PfcP24	Road ditch in SE¼SE¼SE¼ sec. 25, T. 6 S., R. 11 E., Pottawatomie County	52.10	10	0.30	0.60	0.14	1.4	0.75	1.4	0.18	1.8
PfcP25	Road ditch in SW¼SE¼SW¼ sec. 3, T. 8 S., R. 10 E., Pottawatomie County	59.75	10	0.03	0.05	0.02	0.2	2.05	3.4	0.40	4.0

Fig. 4b. Sample data for Falls City limestone.

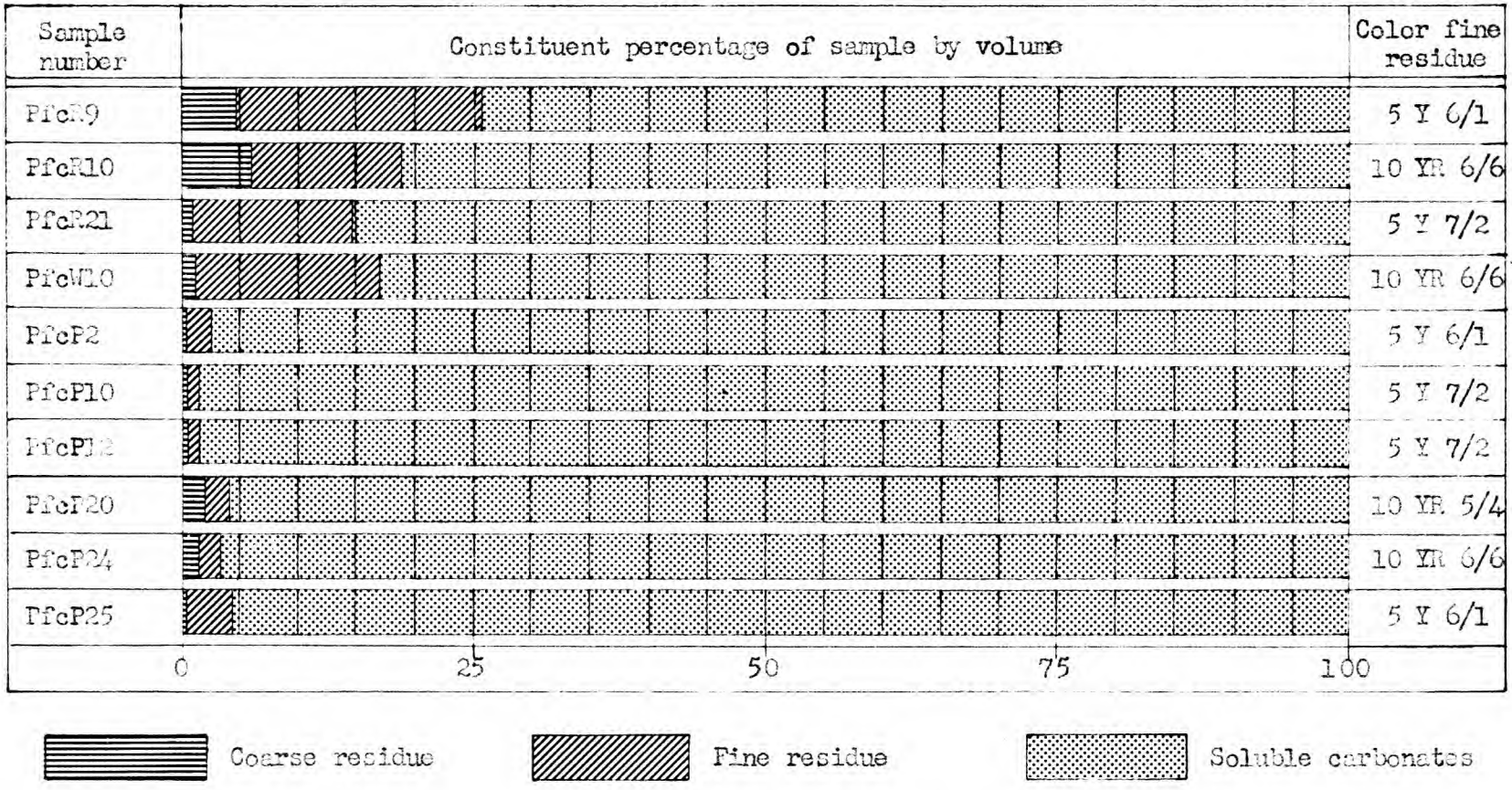


Fig. 4c. Constituent percentage of sample by volume of Falls City limestone.

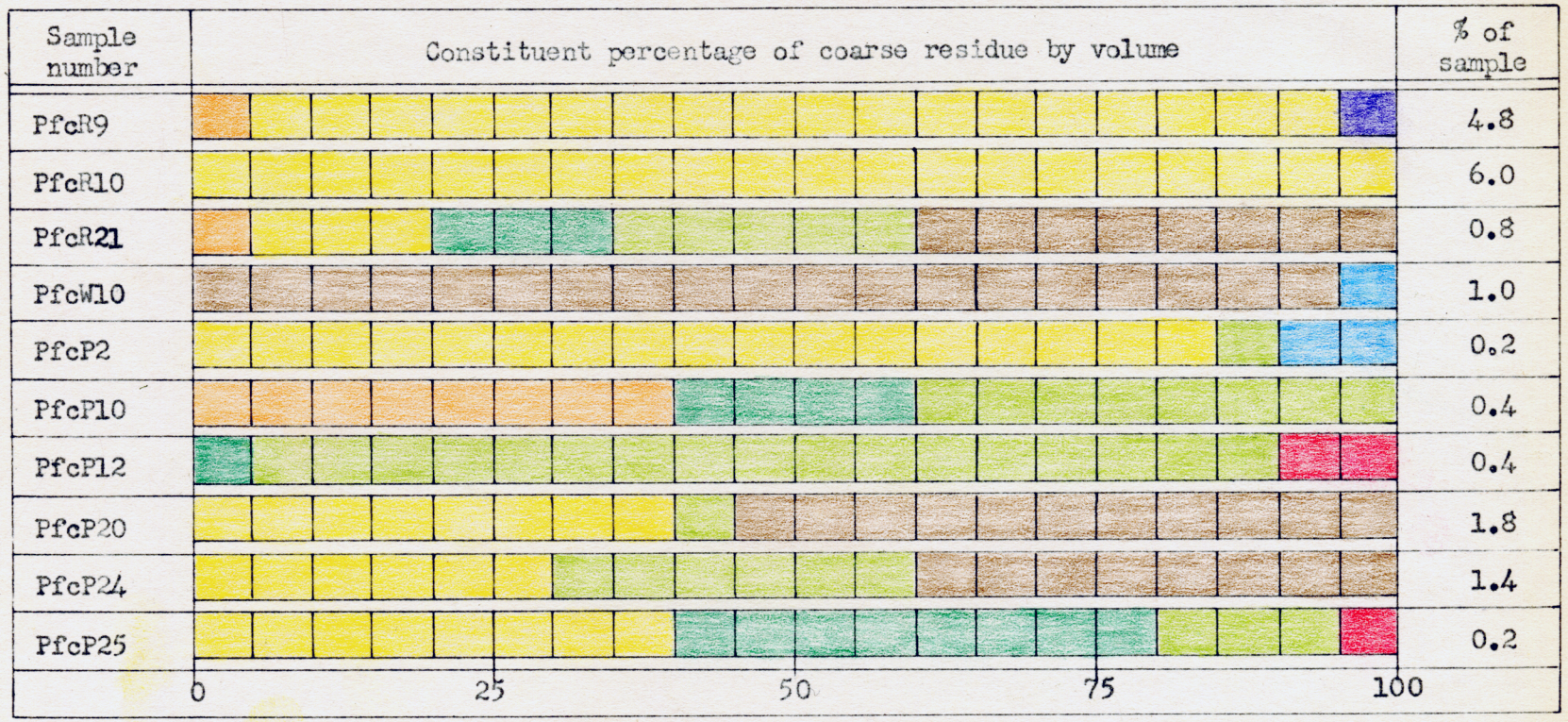


Fig. 4d. Constituent percentage of coarse residue by volume of Falls City limestone.

Tubular silica makes up a large portion of many of the residues. Most of the glauconite is present as a replacement of corals, sponge spicules(?), and foraminifers. A large part of the coarse residue of sample PfcP10 is composed of octahedral limonite crystals pseudomorphic after pyrite. Irregular-shaped masses of limonite occur in minor quantities in a few of the other samples. Fibrous, reddish-orange to colorless celestite was found in samples PfcP12 and PfcP25. There is about 5 percent of soft, white, chalky chert in sample PfcW10, and about 10 percent of hard, smooth, ordinary, white chert, which contains abundant dolomolds, in sample PfcP2. Only traces of pyrite and a minor percentage of small flakes of muscovite occur in the residues of this formation. A distinctive feature of some of the samples is the presence of well-preserved silicified ostracods and coiled foraminifers identified as being of the Family Ammodiscidae.

Correlation by Means of Insoluble Residues. Careful investigation of the coarse residue of the Falls City limestone fails to identify any single residue component that would serve to distinguish this limestone from certain others in the section studied.

It was noted that there is a distinctive difference in the percentage volume of the total and fine residues between the samples from Riley and Pottawatomie Counties. The percentage volume of the total residue of samples from Riley County

ranges from 14.8 to 25.6 percent but for samples from Pottawatomie County it comprises only 1.4 to 4.2 percent of the original samples (Figs. 4b and 4c). The percentage volume of the fine residues of samples from Riley County varies from 14.0 to 20.8 percent whereas those from Pottawatomie County constitute only 1.0 to 4.0 percent of the original sample. This difference does not appear in the percentage volumes of the coarse residues. Differences in percentage volume of the total and fine residues would probably be of value for correlation when combined with other residue data.

Weights and percentage weights of the residues of samples from the two counties show a difference somewhat similar to that apparent in the percentage volume of the residues. Their use would probably be very limited in correlation.

The color of the fine residues of the Falls City limestone is very similar to that of the Five Point limestone (Figs. 3c and 4c). It is not considered of value for purposes of correlation.

The use of the constituent percentage of coarse residue by volume as a means of correlating the Falls City limestone is not indicated. The only samples of the Falls City limestone that show any similarity is constituent percentage of coarse residue by volume are samples PfcP20 and PfcP24 (Fig. 4a). The difference in percentages of the constituents of these two samples is enough to allow them to be confused with Jim Creek limestone residue (Fig. 8a).

Aspinwall Limestone. The Aspinwall limestone underlies the Hawxby shale and overlies the Towle shale (Fig. 2). It is the lowermost limestone in the Admire Group and the Permian System.

Sampled Locations. Eight samples of the Aspinwall limestone were studied in this investigation (Fig. 5a):

Sample number	Type of outcrop	Geographic location
PaR10	Road ditch	SW¼NW¼SW¼ sec. 8, T. 11 S., R. 9 E., Riley County
PaR19	Stream bank	SE¼NW¼NE¼ sec. 31, T. 10 S., R. 9 E., Riley County
PaW3	Road cut	N½NE¼NW¼ sec. 35, T. 11 S., R. 12 E., Wabaunsee County
PaW6	Road ditch	NE¼SE¼SE¼ sec. 12, T. 12 S., R. 12 E., Wabaunsee County
PaP5	Road cut	SW¼SW¼SE¼ sec. 32, T. 8 S., R. 10 E., Pottawatomie County
PaP9	Stream bank	SW¼NE¼SE¼ sec. 4, T. 9 S., R. 9 E., Pottawatomie County
PaP15	Road ditch	SW¼SE¼SE¼ sec. 6, T. 8 S., R. 11 E., Pottawatomie County
PaP19	Stream bank	NW¼SW¼NW¼ sec. 22, T. 7 S., R. 11 E., Pottawatomie County

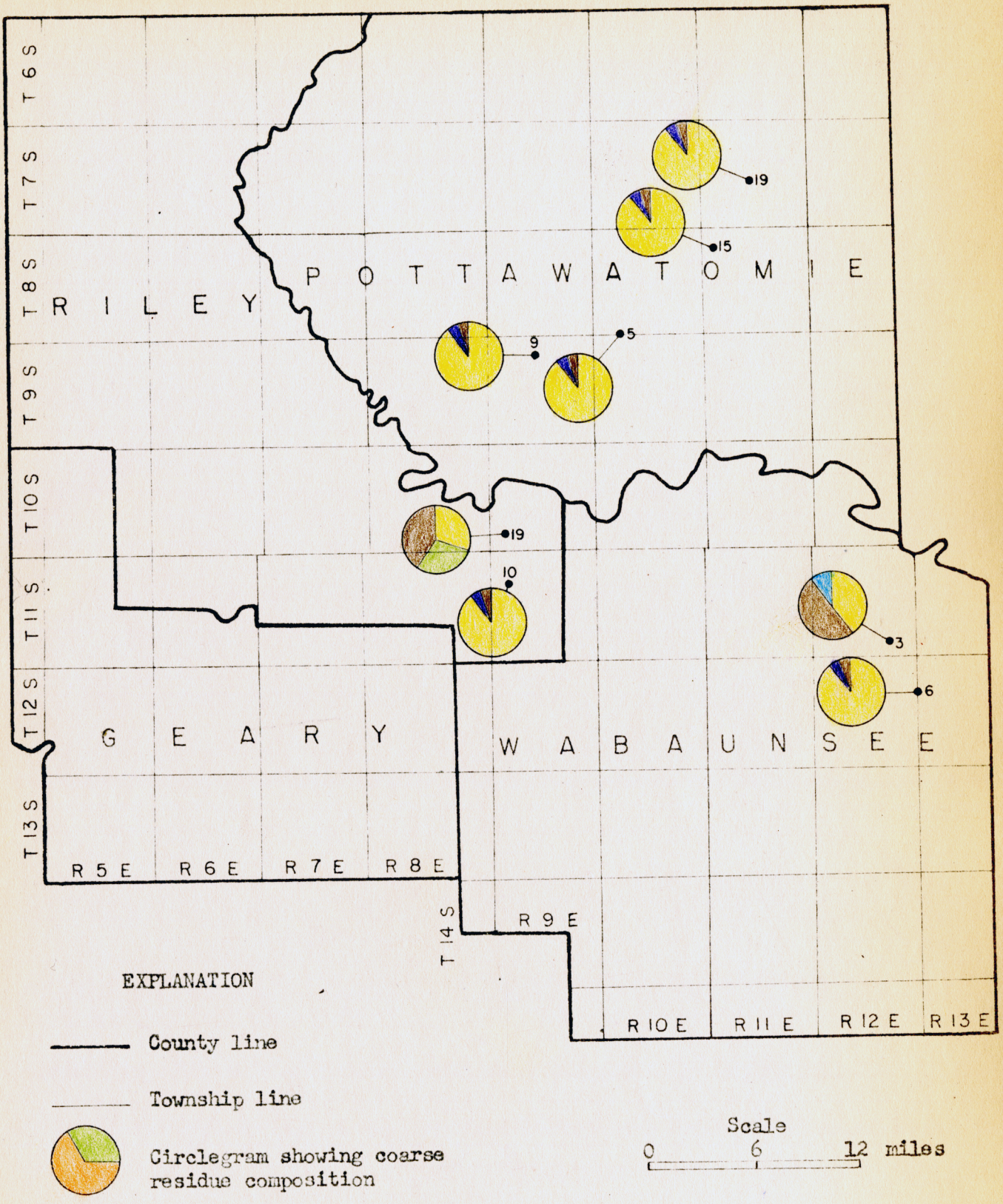


Fig. 5a. Map showing sample locations and coarse residue composition for Aspinwall limestone.

Lithologic Description. The Aspinwall limestone is usually massive, hard, and fossiliferous. It is yellowish brown, and weathers yellowish gray. Locally it resembles the Falls City limestone. Clay balls and limonite stains are scattered throughout this formation, and its average thickness is about 2 feet.

Description of the Insoluble Residue. The total residue of the Aspinwall limestone comprises from 7.8 to 33.4 percent by volume of the original sample (Figs. 5b and 5c). The volume of the coarse residue varies from 0.2 to 18.0 percent, and the volume of the fine residue constitutes from 3.8 to 17.6 percent of the sample.

The color of the fine residue ranges from dark yellowish orange to yellowish gray (Fig. 5c).

The outstanding feature of the coarse residues of this limestone is the consistently high percentage of sand present in most samples (Fig. 5d). The constituent percentages of sand and the minor materials, muscovite and silty clay, are similar in several of the samples (Figs. 5a and 5d). The sand is composed of very fine, anhedral, well-sorted grains of quartz and, in most of the samples, is stained by limonite. Small aggregates of quartz grains cemented with silica or limonite were noted in a few samples. The quantity of sand varies from about 30 to 90 percent by volume of the coarse residues. Small flakes of muscovite with rounded edges compose

Sample number	Location	Sample		Residue							
				Coarse				Fine			
		Weight grams	Volume drams	Weight grams	% weight	Volume drams	% volume	Weight grams	% weight	Volume drams	% volume
PaR10	Road ditch in NW¼SW¼ sec. 8, T. 11 S., R. 9 E., Riley County	59.20	10	10.15	17.10	1.80	18.0	7.30	12.3	1.54	15.4
PaR19	Stream cut in NW¼NE¼ sec. 31, T. 10 S., R. 9 E., Riley County	57.40	10	0.20	0.40	0.40	4.0	1.50	2.6	0.38	3.8
PaW3	Road cut in N½NE¼NW¼ sec. 35, T. 11 S., R. 12 E., Wabaunsee County	51.10	10	0.05	0.10	0.02	0.2	5.00	9.8	1.00	10.0
PaW6	Road ditch in NE¼SE¼SE¼ sec. 12, T. 12 S., R. 12 E., Wabaunsee County	54.70	10	6.25	11.40	1.14	11.4	8.80	16.1	1.60	16.0
PaP5	Road cut in SW¼SW¼SE¼ sec. 32, T. 8 S., R. 10 E., Pottawatomie County	59.05	10	3.15	5.30	0.64	6.4	7.25	12.3	1.46	14.6
PaP9	Stream cut in SW¼NE¼SE¼ sec. 4, T. 9 S., R. 9 E., Pottawatomie County	55.70	10	2.65	4.70	0.52	5.2	8.20	14.7	1.76	17.6
PaP15	Road ditch in SW¼SE¼SE¼ sec. 6, T. 8 S., R. 11 E., Pottawatomie County	56.00	10	5.15	9.20	0.96	9.6	7.60	13.6	1.60	16.0
PaP19	Stream cut in NW¼SW¼NW¼ sec. 22, T. 7 S., R. 11 E., Pottawatomie County	54.45	10	2.00	3.70	0.12	1.2	7.45	13.7	1.40	14.0

Fig. 5b. Sample data for Aspinwall limestone.

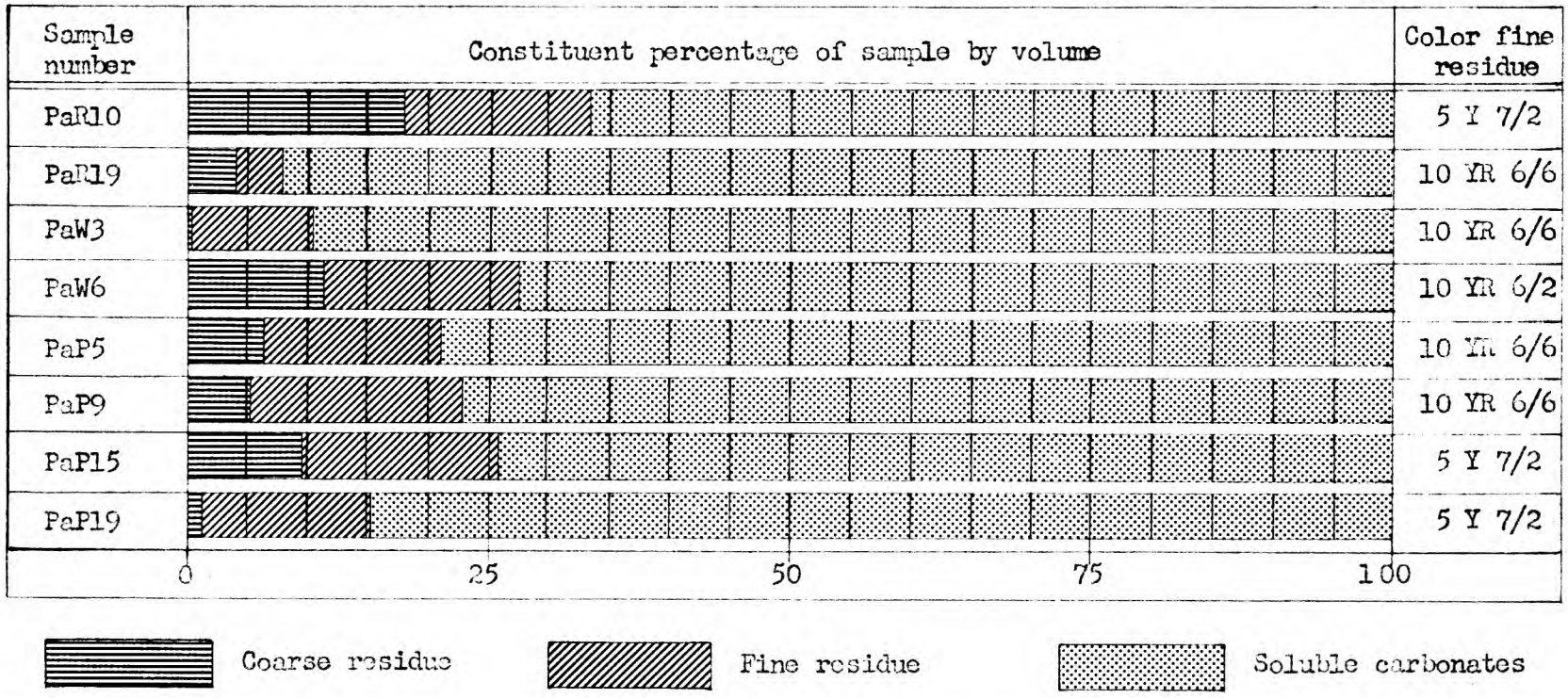


Fig. 5c. Constituent percentage of sample by volume of Aspinwall limestone.

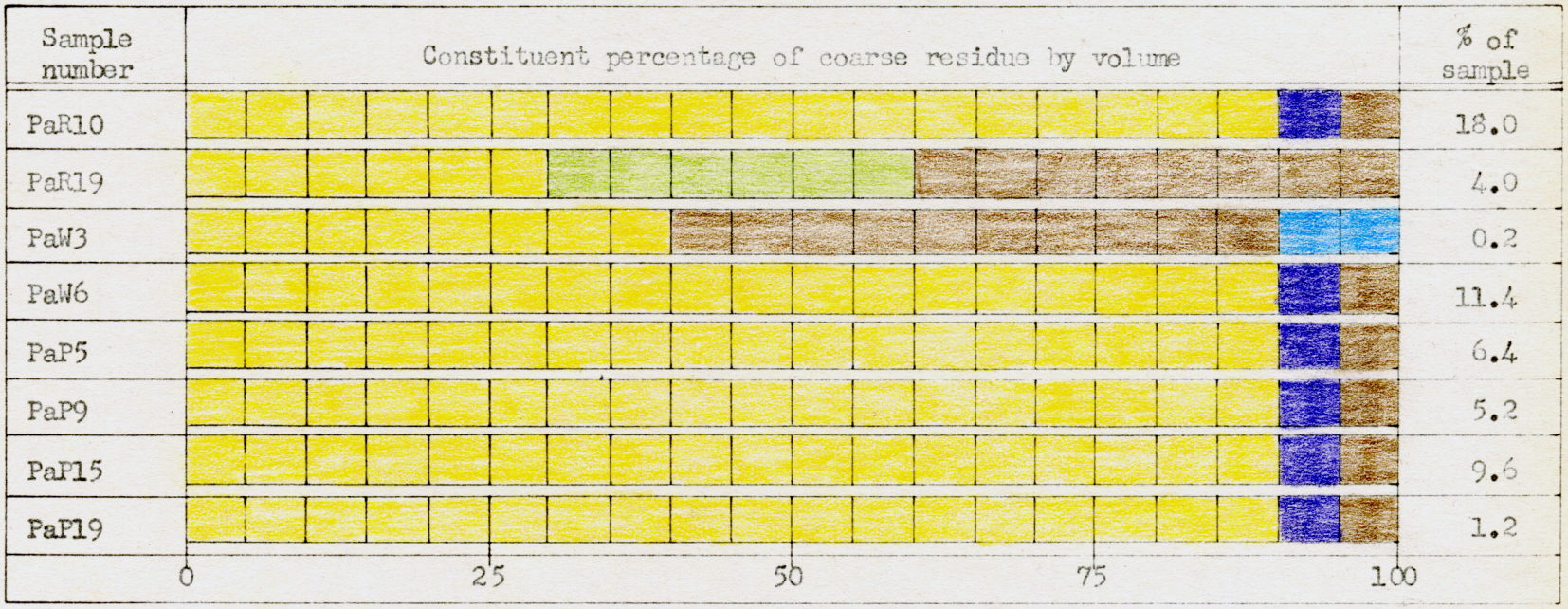


Fig. 5d. Constituent percentage of coarse residue by volume of Aspinwall limestone.

about 5 percent of most of the samples. Although tubular silica was found as a trace in most samples, it constitutes nearly one-third of the coarse residue in sample PaR19. Small, soft, porous, yellowish-brown, silty clay aggregates are found in all samples.

Sample PaW3 is distinctive in its high percentage of fossils, principally siliceous and silty-clay casts of ostracods and gastropods. About 10 percent of the coarse residue of this sample is composed of fine-granular, soft, white chert with abundant dolomolds. A trace of dark-brown limonite, apparently concretionary, was found in one sample. Some of the silty-clay fossil casts in PaW3 appear to be partly limonitic.

Correlation by Means of Insoluble Residues. No single diagnostic residue is present in the coarse residue of the Aspinwall limestone.

The constituent percentage by volume of the total residues and the weights and percentage weights of the total residue show some relationship in a few samples but it is doubtful if this will prove of any real value as a basis for correlation.

The color of the fine residue of the Aspinwall limestone is much like that of the Brownville limestone (Figs. 5c and 6c). It is considered of no value for correlation.

The constituent percentages of the coarse residue by

volume of most samples of this limestone are similar (Fig. 5a). It is also to be noted that glauconite is not present, and that the percentage of limonite is very low in all samples. The variant patterns of two of the samples (PaR19 and PaW3) are due to minor local differences in lithology. On the basis of the samples examined, the Aspinwall limestone can be correlated through the use of the constancy of its constituent percentage of coarse residue by volume.

Pennsylvanian System

Seven limestones of the Wabaunsee Group (Pennsylvanian System) were sampled during this investigation. They are, from youngest to oldest, the Brownville, Caneyville, Jim Creek, Grandhaven, Dover, Maple Hill, and Tarkio limestones (Fig. 2).

Brownville Limestone. The Brownville limestone is the youngest limestone of the Wabaunsee Group. It underlies the Towle shale of Permian age and overlies the Pony Creek shale (Fig. 2).

Sampled Locations. Eighteen samples of the Brownville limestone were collected and analyzed (Fig. 6a):

Sample number	Type of outcrop	Geographic location
CbR10	Road ditch	SW¼NW¼SW¼ sec. 8, T. 11 S., R. 9 E., Riley County
CbR22	Stream bank	NW¼SW¼NW¼ sec. 9, T. 11 S., R. 9 E., Riley County
CbW3	Road cut	N½NE¼NW¼ sec. 35, T. 11 S., R. 12 E., Wabaunsee County
CbW6	Road ditch	NE¼SE¼SE¼ sec. 12, T. 12 S., R. 12 E., Wabaunsee County
CbW7	Roadcut	SW¼SE¼NW¼ sec. 32, T. 12 S., R. 13 E., Wabaunsee County
CbW8	Road cut	NE¼NE¼SE¼ sec. 32, T. 12 S., R. 13 E, Wabaunsee County
CbW10	Road ditch	W½NW¼SE¼ sec. 8, T. 13 S., R. 13 E., Wabaunsee County
CbW13	Stream bank	Center of sec. 29, T. 11 S., R. 13 E., Wabaunsee County
CbUP2	Hillside	SE¼SW¼NW¼ sec. 5, T. 10 S., R. 12 E., Pottawatomie County
CbUP3) CbLP3) CbP3)	Road cut	Center of NW¼SW¼ sec. 4, T. 10 S., R. 12 E., Pottawatomie County
CbP5	Roadcut	SW¼SW¼SE¼ sec. 32, T. 8 S., R. 10 E., Pottawatomie County
CbP9	Stream bank	SW¼NE¼SE¼ sec. 4, T. 9 S., R. 9 E., Pottawatomie County
CbP11	Road ditch	NW¼SW¼NW¼ sec. 24, T. 9 S., R. 10 E., Pottawatomie County
CbP15	Road ditch	SW¼SE¼SE¼ sec. 6, T. 8 S., R. 11 E., Pottawatomie County
CbP19	Stream bank	NW¼SW¼NW¼ sec. 22, T. 7 S., R. 11 E., Pottawatomie County
CbP23	Road ditch	SE¼SE¼NE¼ sec. 13, T. 6 S., R. 11 E., Pottawatomie County

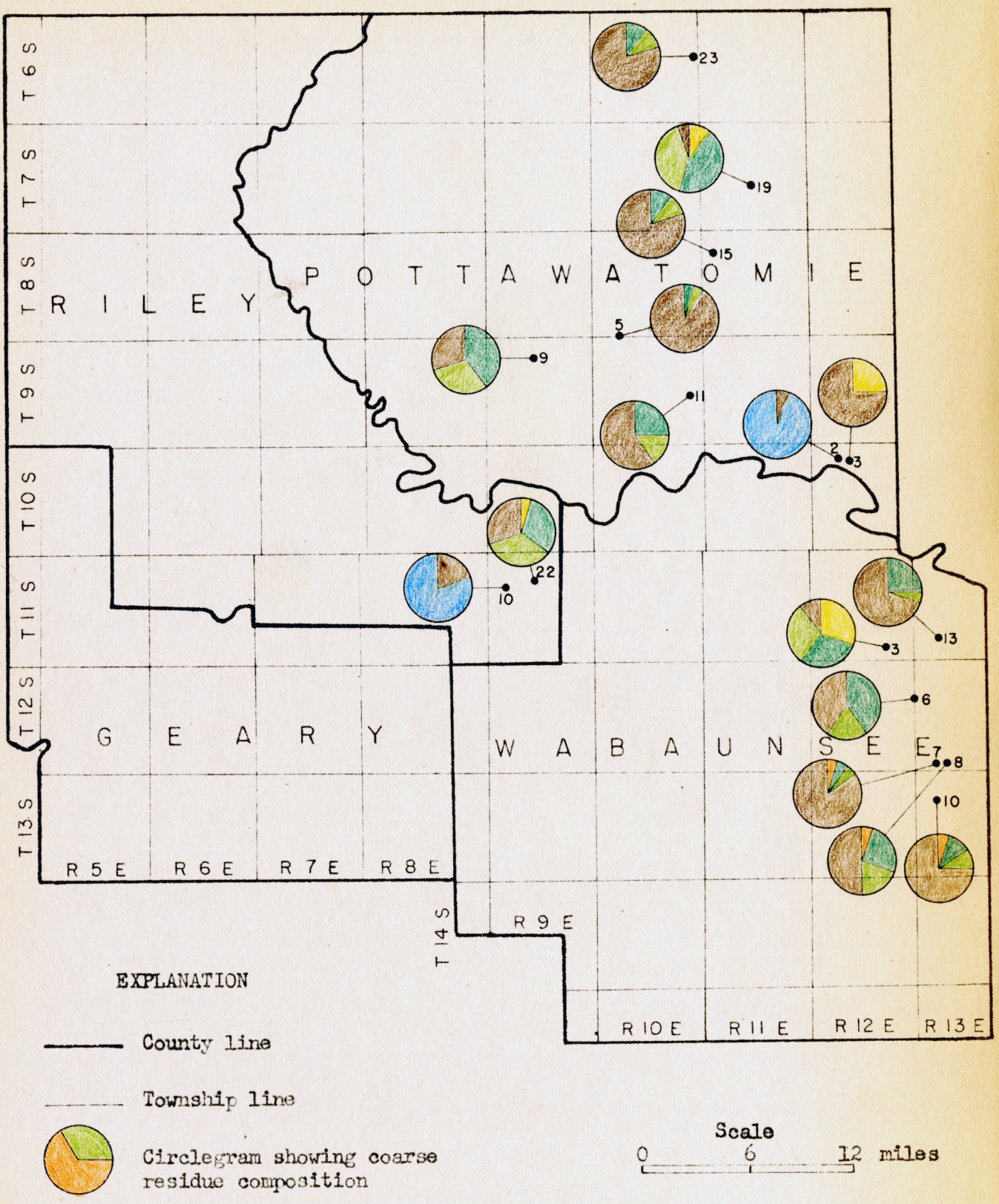


Fig. 6a. Map showing sample locations and coarse residue composition for Brownville limestone.

Lithologic Description. The Brownville limestone is rather hard and has an earthy appearance. It is tan to light brown, and weathers light gray. A prominent zone of Marginifera is usually present. The average thickness of this limestone is about 2 feet.

Description of the Insoluble Residues. The total residue of this limestone ranges from 6.2 to 21.6 percent by volume of the original sample (Figs. 6b and 6c). The volume of the coarse residue constitutes from 0.2 to 3.4 percent, and the volume of the fine residue comprises from 5.8 to 20.0 percent of the original sample.

The color of its fine residue ranges from dark yellowish orange to yellowish gray (Fig. 6c).

The coarse residue of this limestone shows a high percentage of soft, porous, yellowish-brown, silty clay (Fig. 6d). Glauconite and tubular silica are present in considerable amounts in many of the samples, and three of them contain chert. The sand content of the samples, as a whole, is relatively low; however, in a few samples it appears as a principal constituent. The soft, porous, yellowish-brown, silty clay is in the form of aggregates and, in a few samples, as casts of ostracods. Dark-green glauconite occurs in rounded grains and as the replacement of gastropods, corals, brachiopod spines(?), and sponge spicules(?). The white, chalky chert of sample CbR10 is the replacement of plates and spines

Sample number	Location	Sample		Residue							
				Coarse				Fine			
		Weight grams	Volume drams	Weight grams	% weight	Volume drams	% volume	Weight grams	% weight	Volume drams	% volume
CbR10	Road ditch in NW¼SW¼ sec. 8, T. 11 S., R. 9 E., Riley County	51.40	10	0.35	0.68	0.10	1.0	2.50	4.9	0.58	5.8
CbR22	Stream cut in NW¼SW¼NW¼ sec. 9, T. 11 S., R. 9 E., Riley County	60.00	10	0.20	0.33	0.08	0.8	4.65	7.8	1.00	10.0
CbW3	Road cut in N½NE¼NW¼ sec. 35, T. 11 S., R. 12 E., Wabaunsee County	55.10	10	0.10	0.18	0.04	0.4	6.50	11.8	1.58	15.8
CbW6	Road ditch in NE¼SE¼SE¼ sec. 12, T. 12 S., R. 12 E., Wabaunsee County	53.40	10	0.10	0.18	0.04	0.4	7.50	14.0	1.80	18.0
CbW7	Road cut in SW¼SE¼NW¼ sec. 32, T. 12 S., R. 13 E., Wabaunsee County	58.90	10	0.15	0.25	0.14	1.4	8.73	14.8	1.00	10.0
CbW8	Road cut in NE¼NE¼SE¼ sec. 32, T. 12 S., R. 13 E., Wabaunsee County	57.85	10	0.05	0.08	0.02	0.2	6.30	10.9	1.50	15.0
CbW10	Road ditch in W½NW¼SE¼ sec. 8, T. 13 S., R. 13 E., Wabaunsee County	60.95	10	0.40	0.65	0.16	1.6	7.40	12.1	1.60	16.0
CbW13	Stream cut in center sec. 29, T. 11 S., R. 13 E., Wabaunsee County	61.50	10	0.25	0.41	0.16	1.6	8.00	13.0	2.00	20.0
CbUP2	Hillside in SE¼SW¼NW¼ sec. 5, T. 10 S., R. 12 E., Pottawatomie County	56.40	10	0.05	0.09	0.02	0.2	4.70	8.3	0.98	9.8
CbUP3	Road cut in center NW¼SW¼ sec. 4, T. 10 S., R. 12 E., Pottawatomie County	57.10	10	0.05	0.09	0.02	0.2	3.70	6.5	0.80	8.0
CbLP3	Road cut in center NW¼SW¼ sec. 4, T. 10 S., R. 12 E., Pottawatomie County	55.35	10	0.05	0.09	0.02	0.2	1.00	18.1	0.22	2.2
CbP3	Road cut in center NW¼SW¼ sec. 4, T. 10 S., R. 12 E., Pottawatomie County	55.55	10	0.05	0.09	0.02	0.2	2.40	4.3	0.60	6.0
CbP5	Road cut in SW¼SW¼SE¼ sec. 32, T. 8 S., R. 10 E., Pottawatomie County	58.20	10	0.45	0.77	0.12	1.2	6.50	11.2	1.70	17.0
CbP9	Stream cut in SW¼NE¼SE¼ sec. 4, T. 9 S., R. 9 E., Pottawatomie County	54.90	10	0.10	0.18	0.04	0.4	9.00	16.4	1.84	18.4
CbP11	Road ditch in NW¼SW¼NW¼ sec 24, T. 9 S., R. 10 E., Pottawatomie County	56.20	10	0.20	0.35	0.10	1.0	8.35	14.9	1.72	17.2
CbP15	Road ditch in SW¼SE¼SE¼ sec. 6, T. 8 S., R. 11 E., Pottawatomie County	55.45	10	0.65	1.17	0.34	3.4	7.30	13.2	1.60	16.0
CbP19	Stream cut in NW¼SW¼NW¼ sec. 22, T. 7 S., R. 11 E., Pottawatomie County	56.10	10	0.20	3.56	0.06	0.6	5.70	10.2	1.22	12.2
CbP23	Road ditch in SE¼SE¼NE¼ sec. 13, T. 6 S., R. 11 E., Pottawatomie County	59.10	10	0.10	0.17	0.04	0.4	8.90	15.1	1.80	18.0

Fig. 6b. Sample data for Brownville limestone.

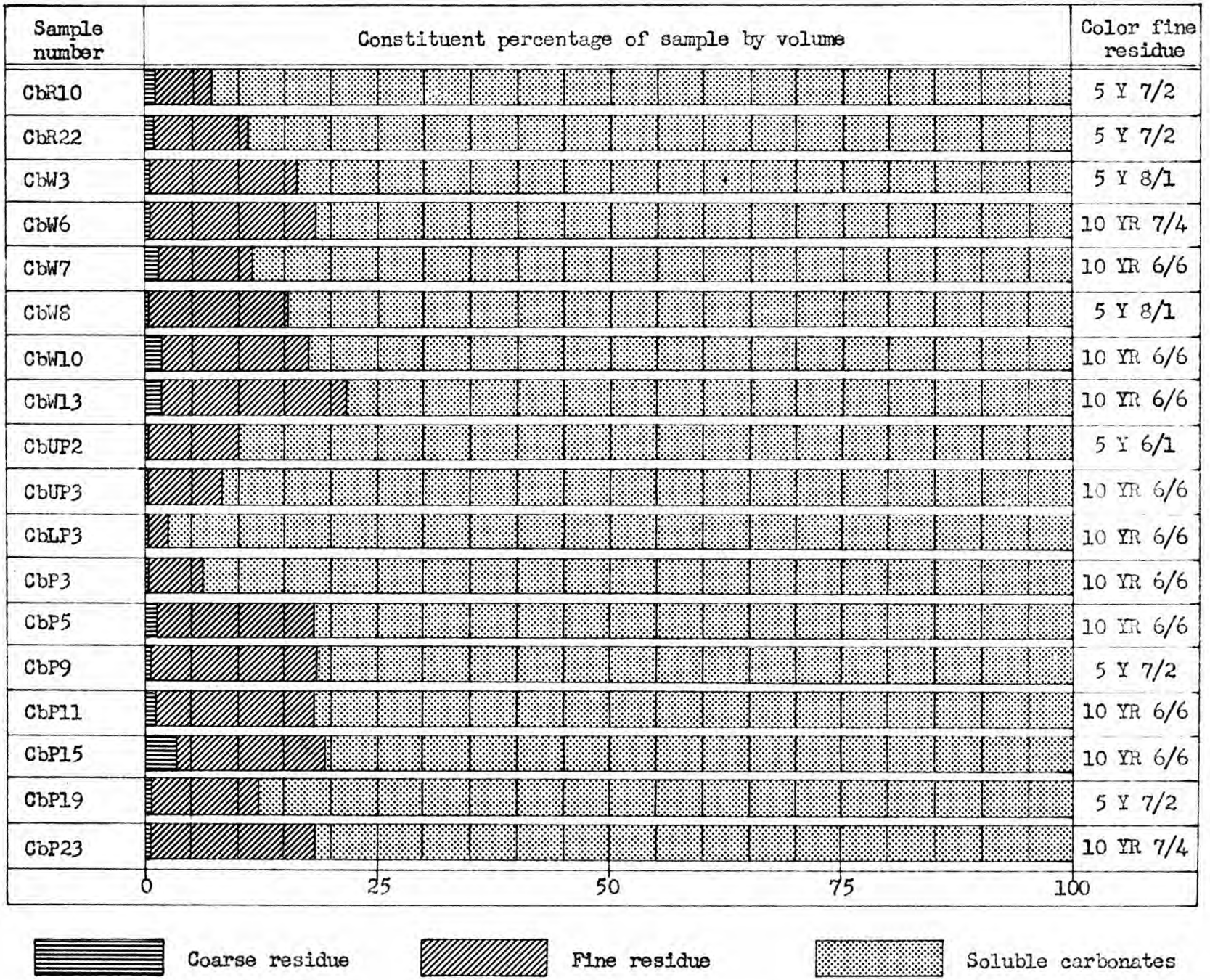


Fig. 6c. Constituent percentage of sample by volume of Brownville limestone.

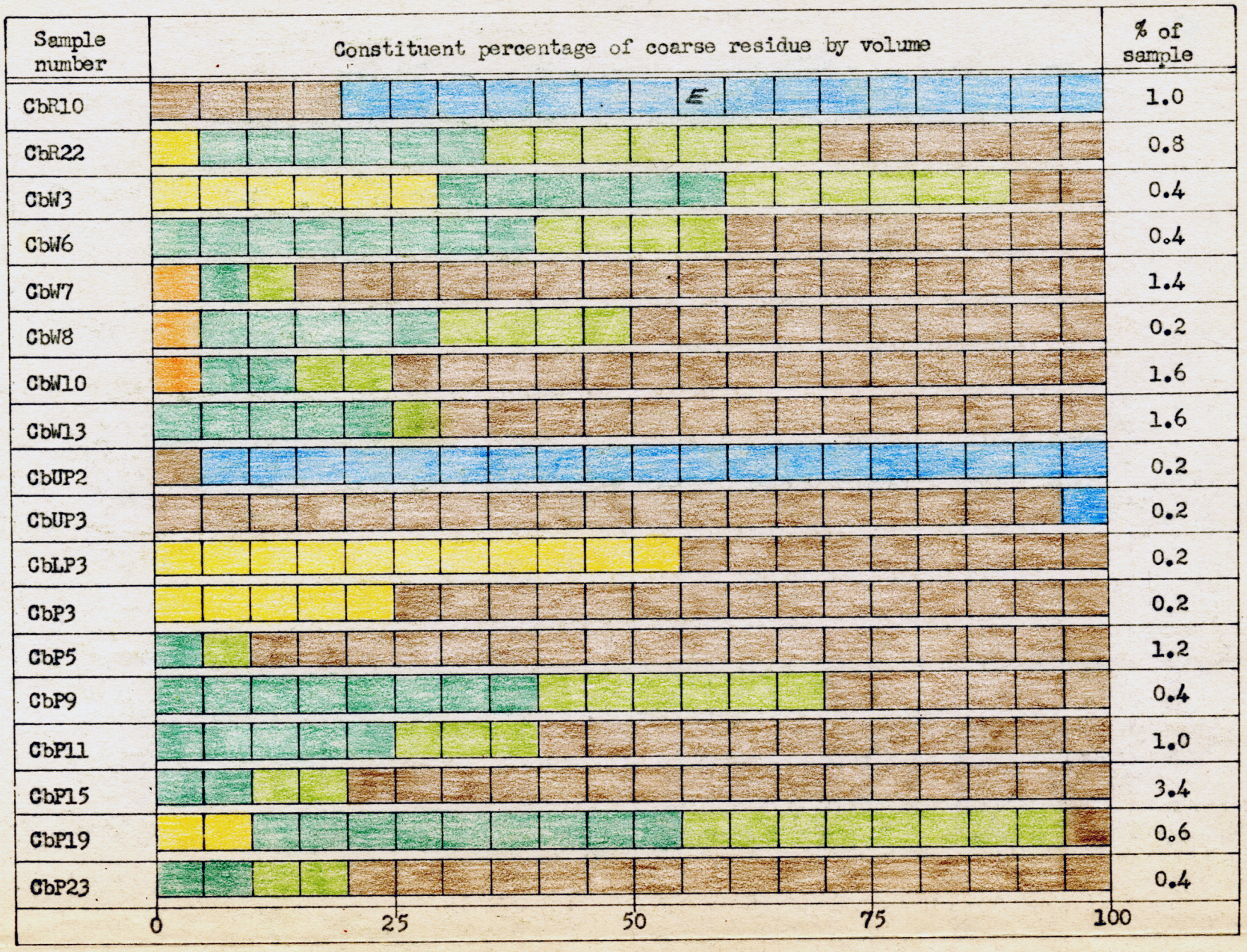


Fig. 6d. Constituent percentage of coarse residue by volume of Brownville limestone.

of Echinocrinus, brachiopod fragments, and foraminifers. The white, granular chert found in samples CbUP2 and CbUP3 is a replacement of ostracods and also occurs in masses characterized by abundant dolomolds. The sand, composed of very fine, anhedral, well-sorted grains of quartz, is mostly confined to those samples in which it appears in measurable amounts. There is a minor amount of limonite in a few samples in which it appears as euhedral cubical and octrahedral crystals, crystal aggregates, and druses pseudomorphic after pyrite. A few concretionary nodules of limonite were also noted.

Correlation by Means of Insoluble Residues. The Brownville limestone lacks a single diagnostic residue which can be used in correlation.

Most of the samples collected in Pottawatomie County contain from 18.2 to 19.4 percent total residue by volume, but the divergence (12.2 percent) exhibited by sample CbP19 limits the usefulness of this characteristic in correlation (Figs. 6b and 6c).

The percentage weights of total residue range widely from 11.97 to 16.58 percent (Fig. 6b).

The color of the fine residue is similar to that of the Aspinwall limestone and is therefore not considered to be a useful characteristic (Figs. 5c and 6c).

Samples CbW7, CbW8, and CbW10, all from Wabaunsee County,

show some similarity in the constituent percentage volumes of coarse residue. However, the difference in coarse residue percentages in samples CbW3, CbW6, and CbW13 from outcrops a few miles north must necessarily limit their application as a type coarse residue for correlation (Fig. 6a).

In Pottawatomie County, another group of samples with similar constituent percentage residues by volume was noted (Fig. 6a). The percentages of samples CbP23, CbP15, CbP5, and CbP11 might be used as a type suite for that part of Pottawatomie County at least. It would probably be advantageous to use the percentage of total residue by volume as a supplemental basis for correlation.

In the examination of the insoluble resudues of the Brownville limestone it was noted that, in general, a high percentage of silty clay aggregates is associated with a virtual absence of muscovite flakes. Correlation of sample CbUP2 with sample CbUP3 can be based on the white, granular chert which appears in both residues.

Caneyville Limestone. The Caneyville limestone underlies the Pony Creek shale and overlies the French Creek shale (Fig. 2).

Sampled Locations. Ten samples were obtained from 6 outcrops of the Caneyville limestone (Fig. 7a):

Sample number	Type of outcrop	Geographic location
CcvUR20) CcvLR20) CcvR20)	Stream bank	$SW\frac{1}{4}SE\frac{1}{4}SW\frac{1}{4}$ sec. 6, T. 11 S., R. 9 E., Riley County
CcvW8	Road cut	$NE\frac{1}{4}NE\frac{1}{4}SE\frac{1}{4}$ sec. 32, T. 12 S., R. 13 E., Wabaunsee County
CcvW10	Road ditch	$W\frac{1}{2}NW\frac{1}{4}SE\frac{1}{4}$ sec. 8, T. 13 S., R. 13 E., Wabaunsee County
CcvUW13) CcvLW13) CcvW13)	Stream bank	Center of sec. 29, T. 11 S., R. 13 E., Wabaunsee County
CcvP9	Stream bank	$SW\frac{1}{4}NE\frac{1}{4}SE\frac{1}{4}$ sec. 4, T. 9 S., R. 9 E., Pottawatomie County
CcvP15	Road ditch	$SW\frac{1}{4}SE\frac{1}{4}SE\frac{1}{4}$ sec. 6, T. 8 S., R. 11 E., Pottawatomie County

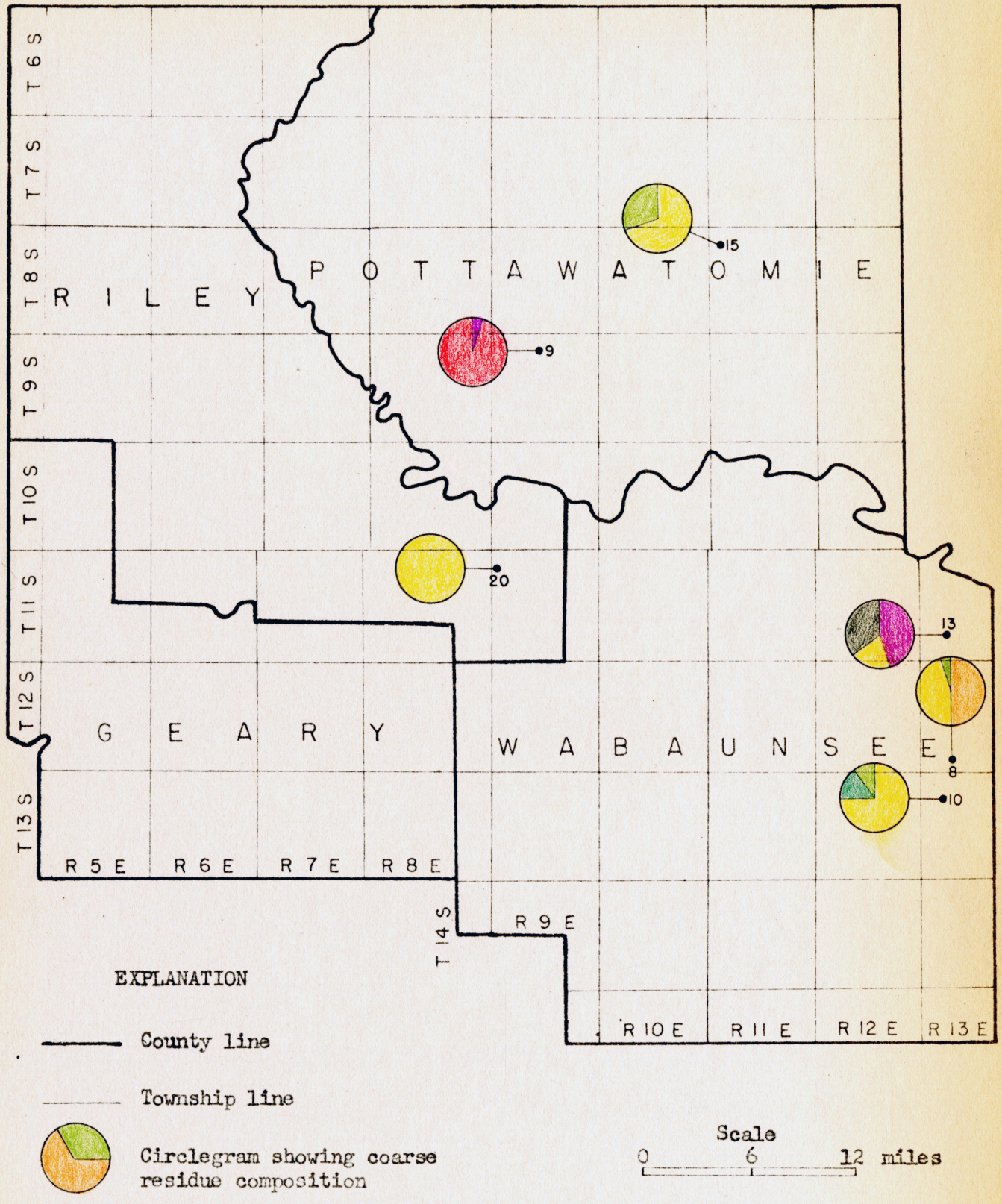


Fig. 7a. Map showing sample locations and coarse residue composition for Caneyville limestone.

Lithologic Description. The Caneyville limestone consists of a limestone at the top and a highly calcareous zone near the base separated by a shale bed. The limestone is relatively hard, tan, and weathers yellowish gray. The lower calcareous zone is hard, platy, and argillaceous. It is dark gray, and weathers tan gray. The intervening shale bed is thin-bedded, c alcareous, and gray. The average thickness of the upper limestone is 2 feet, and the lower calcareous zone averages about a foot thick. The total thickness of the formation is about 9.5 feet.

Description of the Insoluble Residues. The total residue of this limestone ranges from 2.4 to 20.5 percent by volume of the original sample (Figs. 7b and 7c). The volume of the coarse residue varies from 0.4 to 6.2 percent, and the volume of the fine residue constitutes from 1.6 to 15.5 percent of the sample.

The color of the fine residue ranges from grayish orange to olive gray (Fig. 7c).

The coarse residues consist of varying amounts of sand, celestite, pyrite, limonite, fusain, tubular silica, glauconite, silty clay, and muscovite. Sand, composed of very fine, anhedral, well-sorted grains of quartz, is the most abundant constituent of the coarse residues (Fig. 7d). Celestite, in the form of colorless to light-orange bladed crystals, appears in most of the samples and forms 95 percent

Sample number	Location	Sample		Residue							
				Coarse				Fine			
		Weight grams	Volume drams	Weight grams	% weight	Volume drams	% volume	Weight grams	% weight	Volume drams	% volume
CcvUR20	Stream cut in SE¼SW¼ sec. 6, T. 11 S., R. 9 E., Riley County	59.75	10	9.45	15.81	1.48	14.8	6.55	10.9	1.20	12.0
CcvLR20	Stream cut in SE¼SW¼ sec. 6, T. 11 S., R. 9 E., Riley County	56.70	10	0.55	0.97	0.40	4.0	14.55	25.7	3.78	37.8
CcvR20	Stream cut in SE¼SW¼ sec. 6, T. 11 S., R. 9 E., Riley County	57.20	10	2.90	5.06	0.50	5.0	7.65	13.4	1.55	15.5
CcvW8	Road cut in NE¼NE¼SE¼ sec. 32, T. 12 S., R. 13 E., Wabaunsee County	57.60	10	0.25	0.43	0.08	0.8	0.53	0.9	0.16	1.6
CcvW10	Road ditch in W½NW¼SE¼ sec. 8, T. 13 S., R. 13 E., Wabaunsee County	60.45	10	0.20	0.33	0.04	0.4	2.30	3.6	0.42	4.2
CcvUW13	Stream cut in center sec. 29, T. 11 S., R. 13 E., Wabaunsee County	58.20	10	0.55	0.95	0.16	1.6	3.15	5.4	0.60	6.0
CcvLW13	Stream cut in center sec. 29, T. 11 S., R. 13 E., Wabaunsee County	59.60	10	1.40	2.35	0.24	2.4	4.30	7.2	1.16	11.6
CcvW13	Stream cut in center sec. 29, T. 11 S., R. 13 E., Wabaunsee County	58.95	10	0.75	1.27	0.10	1.0	2.45	4.2	0.58	5.8
CcvP9	Stream cut in SW¼NE¼SE¼ sec. 4, T. 9 S., R. 9 E., Pottawatomie County	59.90	10	4.60	7.68	0.62	6.2	3.90	6.5	0.86	8.6
CcvP15	Road ditch in SW¼SE¼SE¼ sec. 6, T. 8 S., R. 11 E., Pottawatomie County	56.70	10	0.10	0.17	0.04	0.4	5.90	10.4	1.42	14.2

Fig. 7b. Sample data for Caneyville limestone.

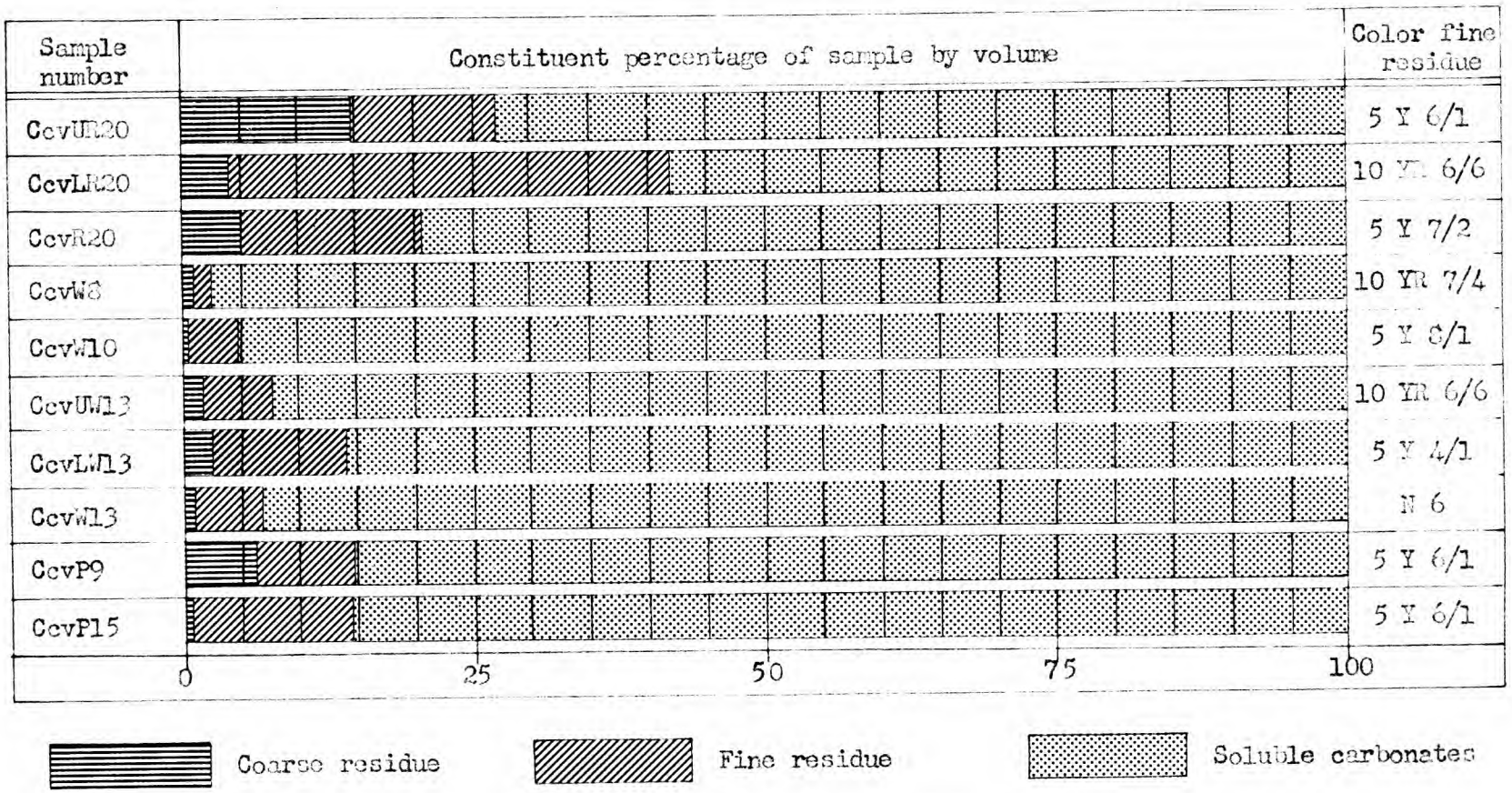


Fig. 7c. Constituent percentage of sample by volume of Caneyville limestone.

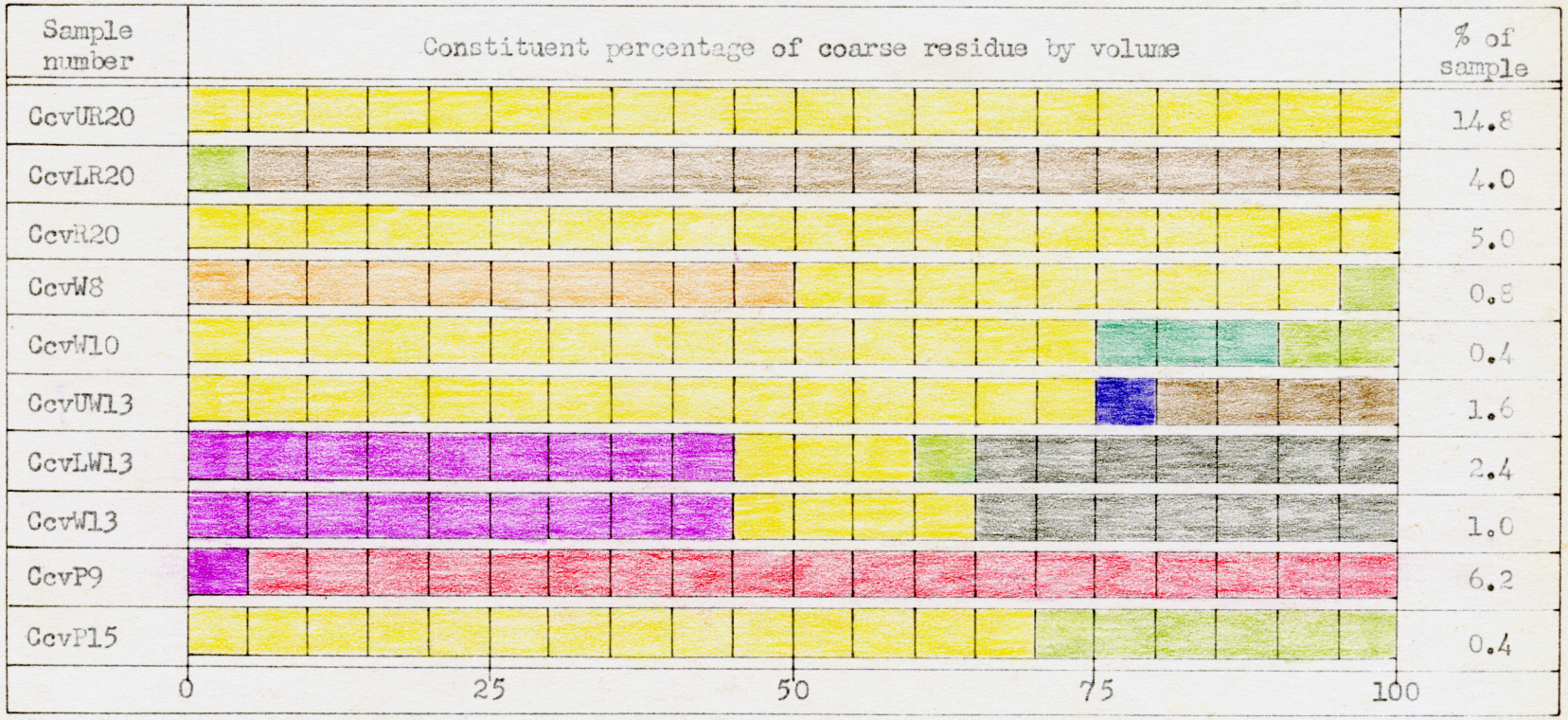


Fig. 7d. Constituent percentage of coarse residue by volume of Caneyville limestone.

of the sample CcvP9. Pyrite constitutes about 45 percent of sample CcvW13. It is also present in other samples as euhedral cubical and octahedral crystals, crystal aggregates, drusy masses, and as the replacement of fusain. Limonite composes 50 percent of sample CcvW8 and is in the form of concretionary nodules. In a few of the other samples, the limonite is in crystals pseudomorphic after pyrite.

Fusain is present in samples CcvLW13 and CcvW13 and is in the form of small, black, shiny, porous fragments. A few microscopic spore cases are found associated with the fusain.

Tubular silica and small muscovite flakes are present in most of the samples. Glauconite is found only in sample CcvW10 in which it appears as a light-green grain and forms 15 percent of the sample. No replacement of fossils by glauconite was noted. Yellowish-brown and pale-yellow, soft, porous, silty-clay aggregates were observed as traces in a few of the samples.

Correlation by Means of Insoluble Residues. The insoluble residues of the Caneyville limestone are typified by their high percentages of celestite, fusain, pyrite, limonite, or sand. No one residue appears consistently enough, however, to be classed as the characteristic residue over a wide area (Fig. 7a).

It was noted that the percentage volume of total residues is 20.5 percent in Riley County, 14.6 to 14.8 percent in

Pottawatomie County, and 2.4 to 6.8 percent in Wabaunsee County (Figs. 7b and 7c). This variation is based on analyses of only 6 samples and should therefore be used with caution.

The weights and percentage weights of the residues are considered to be so variable that they are of no value in correlation.

The color of the fine residue of this limestone is similar to the color of the fine residues of several other limestones and is not a useful basis for correlation (Fig. 7c).

The constituent percentages of coarse residue by volume of this limestone are too variable to be of use.

Jim Creek Limestone. The Jim Creek limestone underlies the French Creek shale and overlies the Friedrich shale (Fig. 2).

Sampled Locations. Only four outcrops of the Jim Creek limestone were found in the area covered by this investigation (Fig. 8a):

Sample number	Type of outcrop	Geographic location
CjcR8	Stream bank	SW¼NW¼NE¼ sec. 9, T. 11 S., R. 9 E., Riley County
CjcR20	Stream bank	SW¼SE¼SW¼ sec. 6, T. 11 S., R. 9 E., Riley County
CjcW15	Stream bank	NE¼NW¼SW¼ sec. 33, T. 12 S., R. 13 E., Wabaunsee County
CjcP16	Road ditch	NW¼NE¼NE¼ sec. 7, T. 8 S., R. 11 E., Pottawatomie County

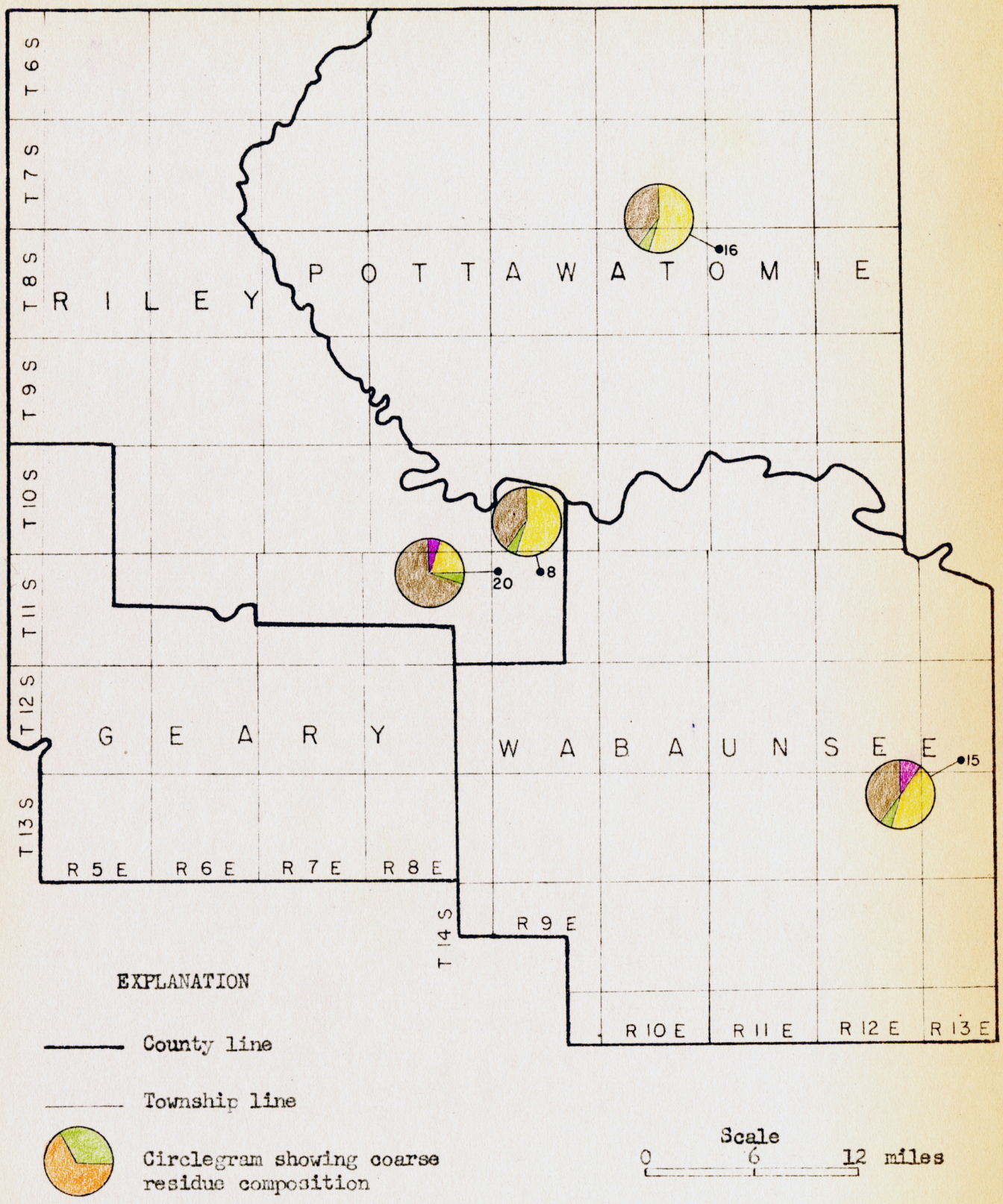


Fig. 8a. Map showing sample locations and coarse residue composition for Jim Creek limestone.

Lithologic Description. The Jim Creek limestone is hard, massive, and appears slightly crystalline. It is bluish gray, and weathers gray. Fossils of brachiopods and crinoid columnals were observed in this limestone, and its average thickness is about 1.5 feet.

Description of the Insoluble Residues. The total residue of this limestone ranges from 7.8 to 14.6 percent by volume (Figs. 8b and 8c). The volume of the coarse residue varies from 0.2 to 1.8 percent, and the volume of the fine residue comprises from 7.6 to 14.0 percent of the original sample.

The color of the fine residue ranges from yellowish gray to light olive gray (Fig. 8c).

The coarse residue consists mainly of sand, soft, porous, yellowish-brown, silty clay aggregates, tubular silica, and pyrite (Fig. 8d). The sand is composed of very fine, anhedral, well-sorted grains of quartz, and forms from 20 to 55 percent by volume of the coarse residue. Silty-clay aggregates are present in amounts ranging from 40 to 70 percent by volume. About 5 percent of the coarse residue consists of tubular silica. There are small crystal aggregates and very small euhedral octahedrons of pyrite in sample CjcR20. In sample CjcW15, the pyrite is present predominantly as a replacement of fossils; corals, sponge spicules(?), bryozoans, and foraminifers are the forms replaced. Small

Sample number	Location	Sample		Residue							
				Coarse				Fine			
		Weight grams	Volume drams	Weight grams	% weight	Volume drams	% volume	Weight grams	% weight	Volume drams	% volume
CjcR8	Stream cut in NW¼NE¼ sec. 9, T. 11 S., R. 9 E., Riley County	57.10	10	0.10	0.17	0.06	0.6	5.80	10.2	1.40	14.0
CjcR20	Stream cut in SE¼SW¼ sec. 6, T. 11 S., R. 9 E., Riley County	58.70	10	0.35	0.59	0.18	1.8	5.35	9.1	1.20	12.0
CjcW15	Stream cut in NE¼NW¼SW¼ sec. 33, T. 12 S., R. 13 E., Wabaunsee County	59.70	10	0.25	0.42	0.10	1.0	4.50	7.5	0.96	9.6
CjcP16	Road ditch in NW¼NE¼NE¼ sec. 7, T. 8 S., R. 11 E., Pottawatomie County	60.05	10	0.15	0.25	0.02	0.2	3.55	5.9	0.76	7.6

Fig. 8b. Sample data for Jim Creek limestone.

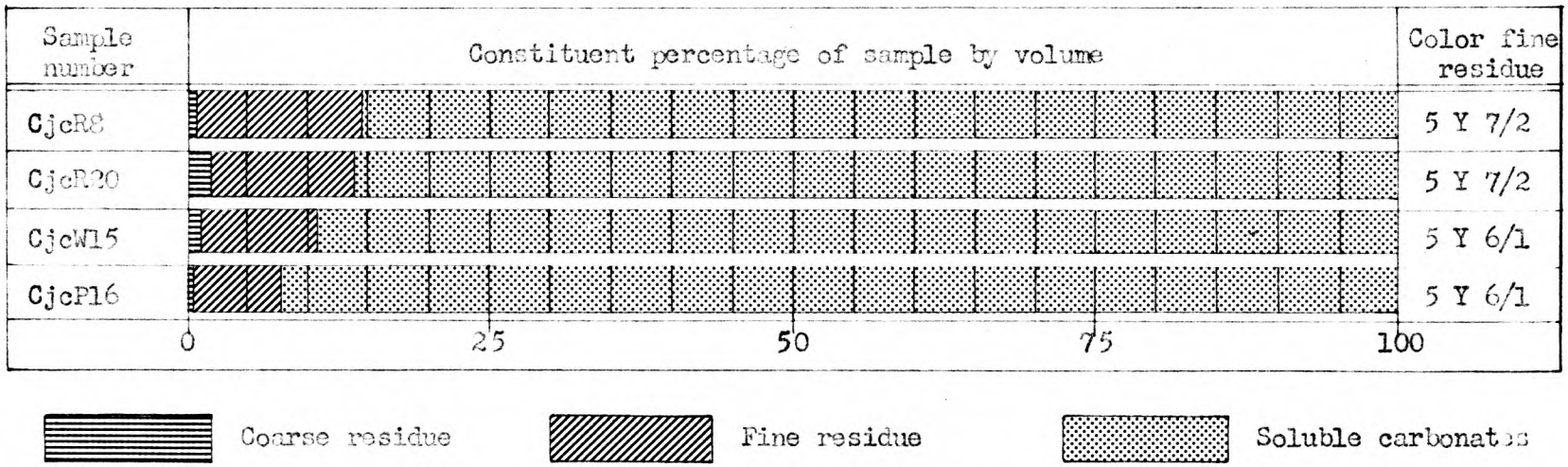


Fig. 8c. Constituent percentage of sample by volume of Jim Creek limestone.

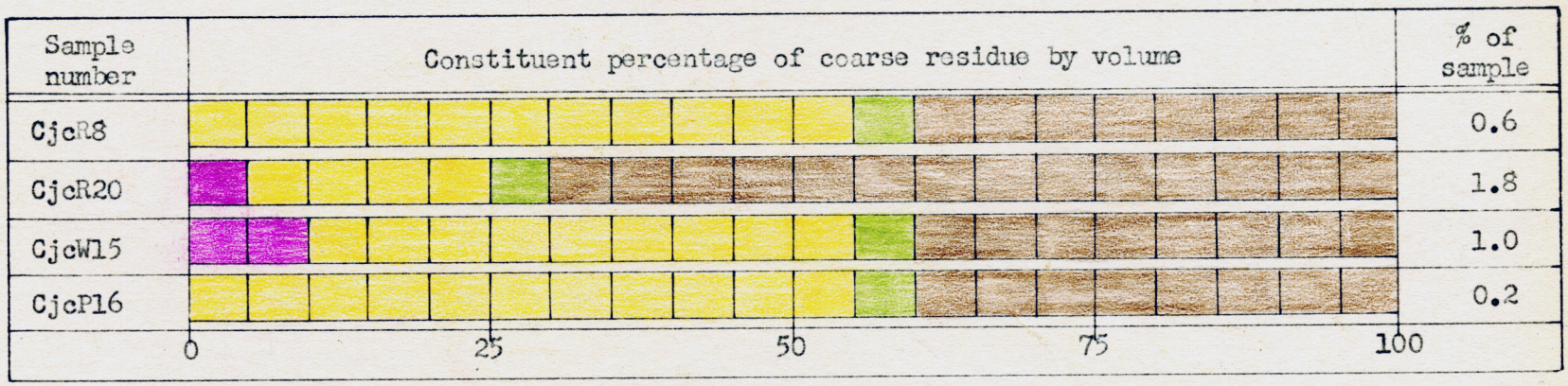


Fig. 8d. Constituent percentage of coarse residue by volume of Jim Creek limestone.

flakes of muscovite with rounded outlines, dark-green glauconite grains, and aggregates of limonite crystals pseudomorphic after pyrite are sparsely distributed throughout the samples.

Correlation by Means of Insoluble Residues. There is no single residue constituent of the Jim Creek limestone that may be considered diagnostic. The percentage of total residue by volume varies from 13.8 to 14.6 percent in Riley County to 10.6 percent in Wabaunsee County to 7.8 percent in Pottawatomie County (Figs. 8b and 8c). A similar variation is apparent in the percentage volumes and the percentage weights of the fine residue. These data are based on the examination of only 4 samples and decision as to the dependability of this variation must be withheld until further information is available.

The color of the fine residue of the Jim Creek limestone resembles the color of the fine residues of several other limestones and is of no value in correlation (Fig. 8c).

The constituent percentage of coarse residue by volume is unusual in that all of the samples show similar coarse-residue percentages (Fig. 8a). The percentages of constituent residues in sample CjcR20 are somewhat different than those of the other samples but the over-all similarity is apparent.

Grandhaven Limestone. The Grandhaven limestone underlies the Friedrich shale and overlies the Dry shale (Fig. 2).

Sampled Locations. Suitable outcrops of the Grandhaven limestone were found in 5 places (Fig. 9a):

Sample number	Type of outcrop	Geographic location
CgUR7) CgLR7) CgR7)	Road cut	NW¼NE¼SW¼ sec. 30, T. 10 S., R. 9 E., Riley County
CgR11	Road ditch	SW¼SE¼NW¼ sec. 9, T. 11 S., R. 9 E., Riley County
CgR18	Road cut	SW¼SE¼SE¼ sec. 6, T. 11 S., R. 9 E., Riley County
CgW9	Road ditch	NE¼NW¼SW¼ sec. 34, T. 12 S., R. 13 E., Wabaunsee County
CgW11	Road ditch	SE¼SW¼SW¼ sec. 30, T. 11 S., R. 13 E., Wabaunsee County

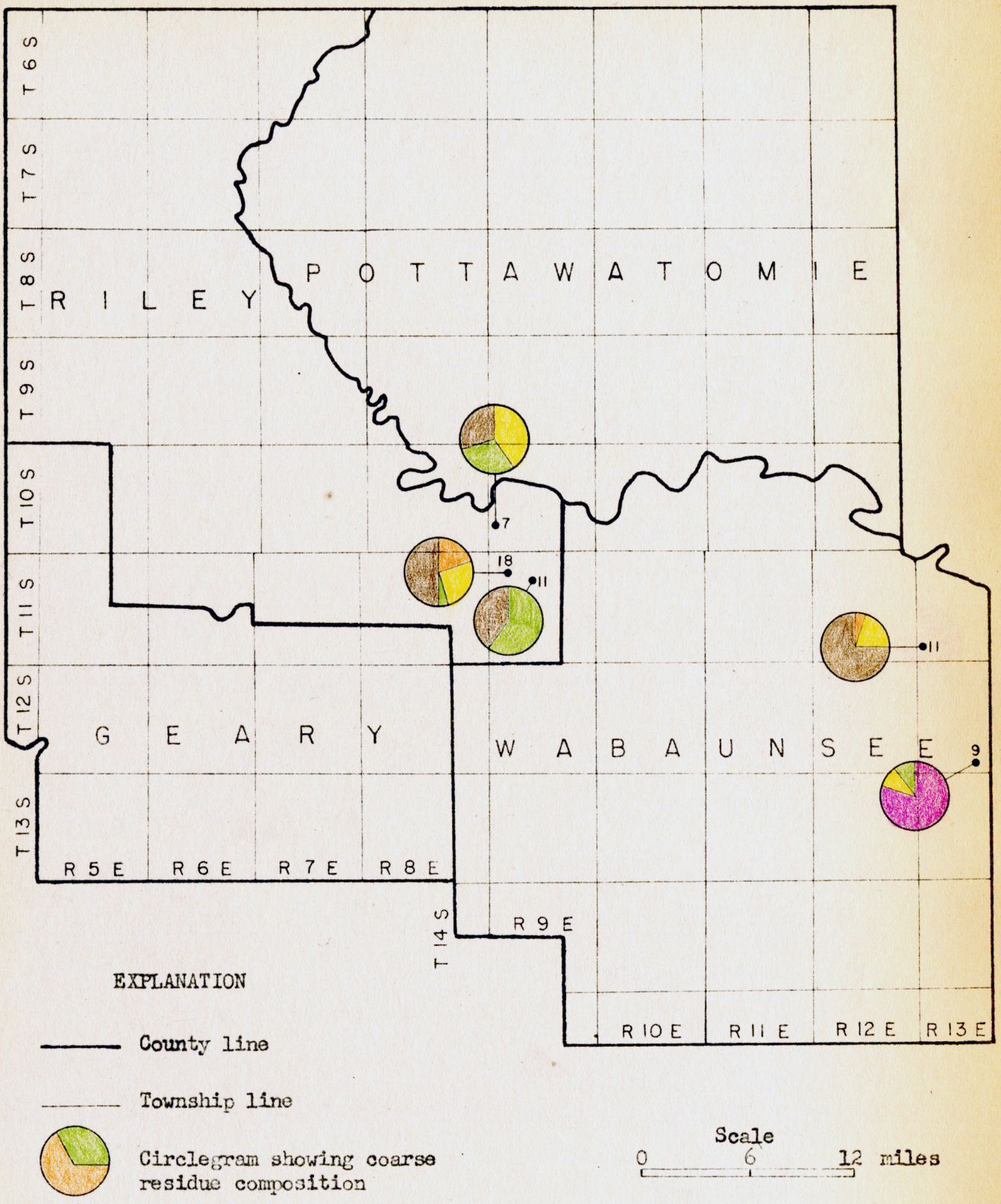


Fig. 9a. Map showing sample locations and coarse residue composition for Grandhaven limestone.

Lithologic Description. The Grandhaven limestone is hard and massive, and is argillaceous in its lower part. There is a thin greenish-gray shale in the middle of this limestone which separates it into two limestones, each about a foot thick. Brachiopods and crinoids were noted in this formation, and its average thickness is about 2 feet.

Description of the Insoluble Residues. The total residue of this limestone is from 10.2 to 19.4 percent by volume of the total sample (Figs. 9b and 9c). The volume of the coarse residue comprises from 0.2 to 6.0 percent of the total sample, and that of the fine residue, from 10.0 to 16.0 percent.

The color of the fine residue ranges from dark yellowish orange to light olive gray (Fig. 9c).

The coarse residue consists of varying amounts of soft, porous, yellowish-brown, silty-clay aggregates, tubular silica, sand, limonite, and pyrite (Fig. 9d). Silty-clay aggregates constitute the major portion of the coarse residues but are noticeably absent from sample CgW9. A large proportion of the silty clay in sample CgW11 is in the form of casts of crinoid columnals, brachiopod fragments, sponge spicules(?), and gastropods. Silty-clay casts of ostracods were noted in sample CgLR7. Tubular silica is present in all samples but only as a trace in samples CgLR7 and CgW11. Sand, composed

Sample number	Location	Sample		Residue							
				Coarse				Fine			
		Weight grams	Volume drams	Weight grams	% weight	Volume drams	% volume	Weight grams	% weight	Volume drams	% volume
CgUR7	Road cut in NE¼SW¼ sec. 30, T. 10 S., R. 9 E., Riley County	60.15	10	0.10	0.16	0.02	0.2	5.20	8.6	1.10	11.0
CgLR7	Road cut in NE¼SW¼ sec. 30, T. 10 S., R. 9 E., Riley County	57.50	10	0.10	0.17	0.06	0.6	13.30	23.1	3.30	33.0
CgR7	Road cut in NE¼SW¼ sec. 30, T. 10 S., R. 9 E., Riley County	57.90	10	0.05	0.08	0.02	0.2	6.75	11.6	1.60	16.0
CgR11	Road ditch in SW¼SE¼NW¼ sec. 9, T. 11 S., R. 9 E., Riley County	58.70	10	0.05	0.09	0.02	0.2	4.50	7.6	1.00	10.0
CgR18	Road cut in SE¼SE¼ sec. 6, T. 11 S., R. 9 E., Riley County	60.00	10	0.90	1.50	0.38	3.8	6.10	10.2	1.56	15.6
CgW9	Road ditch in NE¼NW¼SW¼ sec. 34, T. 12 S., R. 13 E., Wabaunsee County	58.40	10	0.15	0.26	0.02	0.2	6.35	10.8	1.40	14.0
CgW11	Road ditch in SE¼SW¼SW¼ sec. 30, T. 11 S., R. 13 E., Wabaunsee County	58.55	10	1.75	2.99	0.60	6.0	5.10	8.7	1.30	13.0

Fig. 9b. Sample data for Grandhaven limestone.

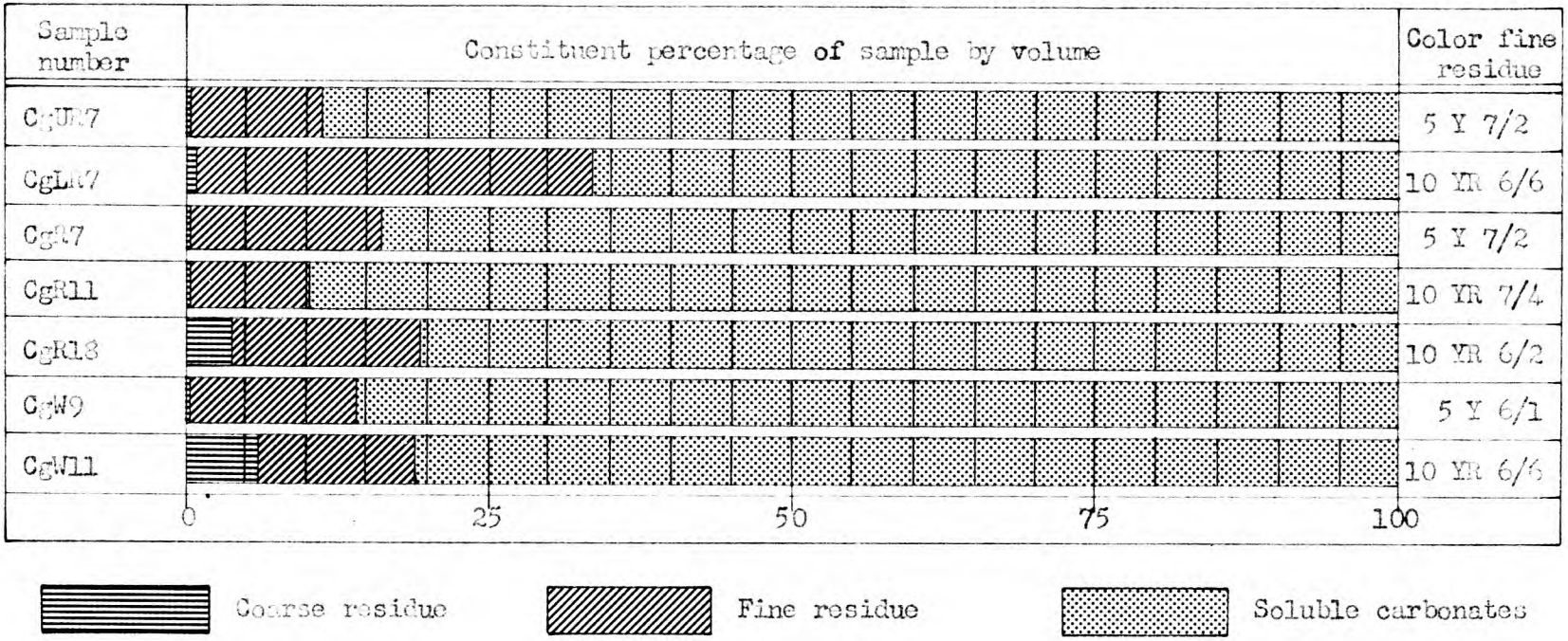


Fig. 9c. Constituent percentage of sample by volume of Grandhaven limestone.

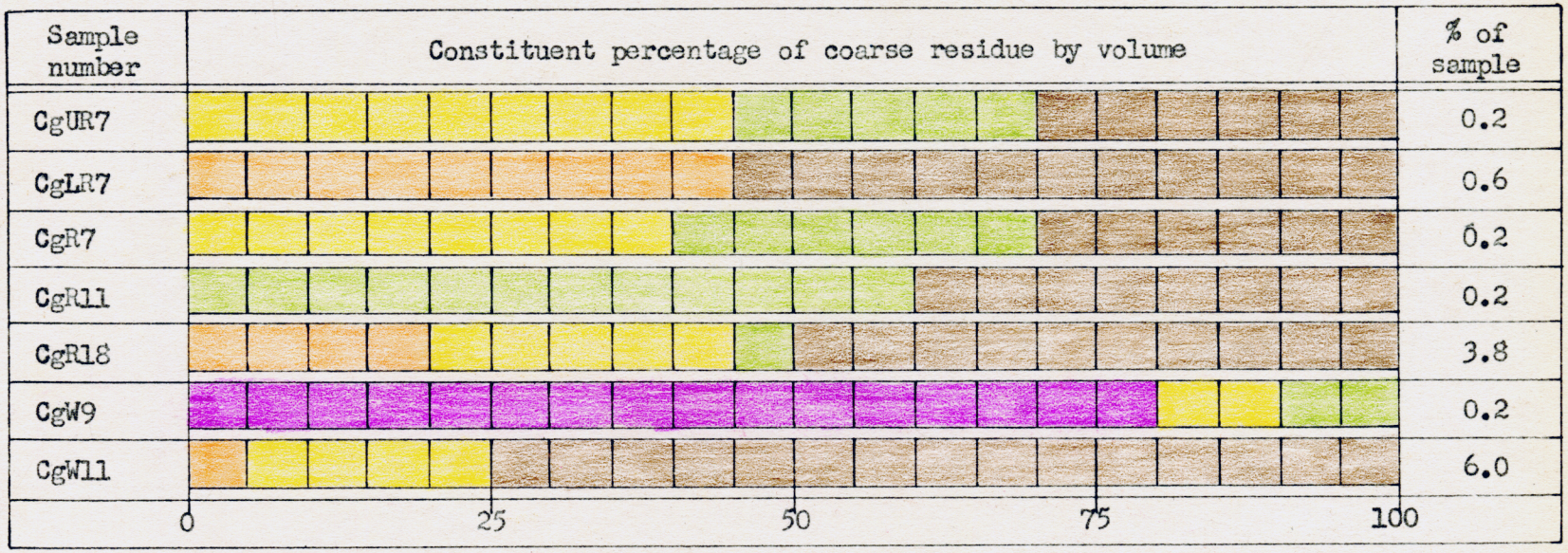


Fig. 9d. Constituent percentage of coarse residue by volume of Grandhaven limestone.

of very fine, anhedral, well-sorted grains of quartz, is present in all samples except CgR11 and is only a trace in sample CgLR7. Limonite in the form of euhedral crystals, crystal aggregates, and drusy incrustations pseudomorphic after pyrite, was noted in all samples. It occurs also as large, dense, irregular masses in sample CgW11. Pyrite is a principal constituent of sample CgW9 and is present as a trace in sample CgR7. It occurs as euhedral crystals, crystal aggregates, and drusy incrustations and, in sample CgW9, as a replacement of many gastropods. Glauconite, in the form of small green grains, occurs as a trace in all samples. There is a trace of light-orange celestite in sample CgW9.

Correlation by Means of Insoluble Residues. There is no individually characteristic residue in the Grandhaven limestone. Attempts to correlate this limestone by use of the percentages of total, fine, and coarse residues by volume and weight proved futile (Figs. 9a, 9b, and 9c), and the color of the fine residue of the Grandhaven limestone is too much like that of other limestones to be used as the basis for correlation (Fig. 9c).

Dover Limestone. The Dover limestone underlies the Dry shale and overlies the Langdon shale (Fig. 2).

Sampled Locations. Ten outcrops of the Dover limestone were sampled as a part of this study (Fig. 10a):

Sample number	Type of outcrop	Geographic location
CdR5	Road ditch	SE¼SE¼SE¼ sec. 5, T. 11 S., R. 9 E., Riley County
CdR6	Stream bank	SE¼SW¼SE¼ sec. 28, T. 10 S., R. 9 E., Riley County
CdR18	Road cut	SW¼SE¼SE¼ sec. 6, T. 11 S., R. 9 E., Riley County
CdW3	Road cut	N½NE¼NW¼ sec. 35, T. 11 S., R. 12 E., Wabaunsee County
CdW5	Road cut	SW¼NW¼NW¼ sec. 6, T. 12 S., R. 13 E., Wabaunsee County
CdW12	Road cut	SW¼SW¼SE¼ sec. 28, T. 11 S., R. 13 E., Wabaunsee County
CdP8	Road ditch	NW¼NE¼NE¼ sec. 28, T. 8 S., R. 10 E., Pottawatomie County
CdP14	Stream bank	NE¼NE¼NW¼ sec. 7, T. 9 S., R. 11 E., Pottawatomie County
CdP18	Road ditch	NW¼NE¼NE¼ sec. 29, T. 7 S., R. 11 E., Pottawatomie County
CdP22	Road ditch	NW¼NW¼NW¼ sec. 5, T. 6 S., R. 11 E., Pottawatomie County

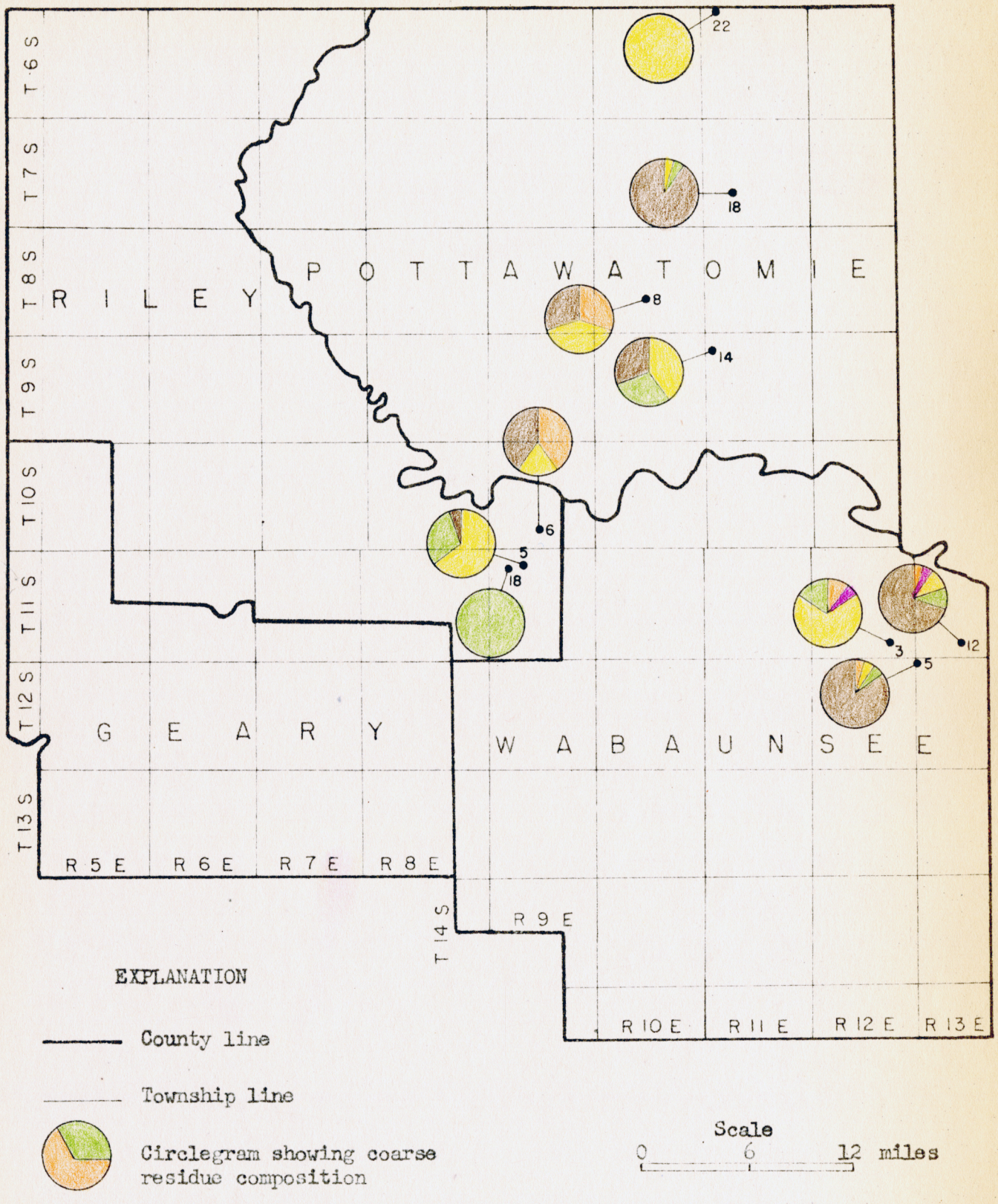


Fig. 10a. Map showing sample locations and coarse residue composition for Dover limestone.

Lithologic Description. The Dover limestone is relatively soft, massive, and is usually argillaceous. It is gray to brown, and weathers light gray. Large fusilinids are scattered throughout the limestone and are especially abundant near the base. Its average thickness is about 3 feet.

Description of the Insoluble Residues. The total residue of this limestone comprises from 4.6 to 27.0 percent by volume of the sample (Figs. 10b and 10c). The volume of the coarse residue varies from 0.2 to 4.2 percent, and that of the fine residue ranges from 4.4 to 26.6 percent of the original sample.

The color of the fine residue is from grayish orange to light olive gray (Fig. 10c).

The coarse residue of this limestone is composed predominantly of yellowish-brown, soft, porous, silty-clay aggregates, sand, and tubular silica (Fig. 10d). The silty-clay aggregates are found in all samples except CdP22 but are present only as traces in CdR18 and CdW3. It was noted that the silty clay in samples CdR6 and CdP8 is in the form of rather large, rounded pellets. The rounding of these aggregates may have occurred during the residue washing process. A few of the silty clay aggregates were found to be slightly impregnated with limonite, thus making them harder than is usual. There are a very few silty-clay casts of

Sample number	Location	Sample		Residue							
				Coarse				Fine			
		Weight grams	Volume drams	Weight grams	% weight	Volume drams	% volume	Weight grams	% weight	Volume drams	% volume
CdR5	Road ditch in SE¼ sec. 5, T. 11 S., R. 9 E., Riley County	63.45	10	0.20	0.32	0.04	0.4	12.20	19.2	2.34	23.4
CdR6	Stream cut in SW¼SE¼ sec. 28, T. 10 S., R. 9 E., Riley County	61.40	10	0.25	0.41	0.04	0.4	12.40	20.2	2.66	26.6
CdR18	Road cut in SE¼SE¼ sec. 6, T. 11 S., R. 9 E., Riley County	63.70	10	0.05	0.08	0.02	0.2	2.35	3.7	0.44	4.4
CdW3	Road cut in N½NE¼NW¼ sec. 35, T. 11 S., R. 12 E., Wabaunsee County	54.85	10	0.10	0.18	0.02	0.2	3.40	6.2	0.78	7.8
CdW5	Road cut in SW¼NW¼NW¼ sec. 6, T. 12 S., R. 13 E., Wabaunsee County	58.70	10	0.15	0.26	0.04	0.4	4.25	7.2	0.90	9.0
CdW12	Road cut in SW¼SW¼SE¼ sec. 28, T. 11 S., R. 13 E., Wabaunsee County	57.90	10	0.40	0.69	0.14	1.4	5.10	8.8	1.34	13.4
CdP8	Road ditch in NW¼NE¼NE¼ sec. 28, T. 8 S., R. 10 E., Pottawatomie County	60.10	10	0.50	0.83	0.10	1.0	8.60	14.3	2.00	20.0
CdP14	Stream cut in NE¼NE¼NW¼ sec. 7, T. 9 S., R. 11 E., Pottawatomie County	56.90	10	0.45	0.79	0.18	1.8	3.05	5.4	0.74	7.4
CdP18	Road ditch in NW¼NE¼NE¼ sec. 29, T. 7 S., R. 11 E., Pottawatomie County	58.30	10	1.00	1.72	0.42	4.2	6.70	11.5	1.76	17.6
CdP22	Road ditch in NW¼NW¼NW¼ sec. 5, T. 6 S., R. 11 E., Pottawatomie County	58.70	10	0.90	1.53	0.22	2.2	7.80	13.3	1.74	17.4

Fig. 10b. Sample data for Dover limestone.

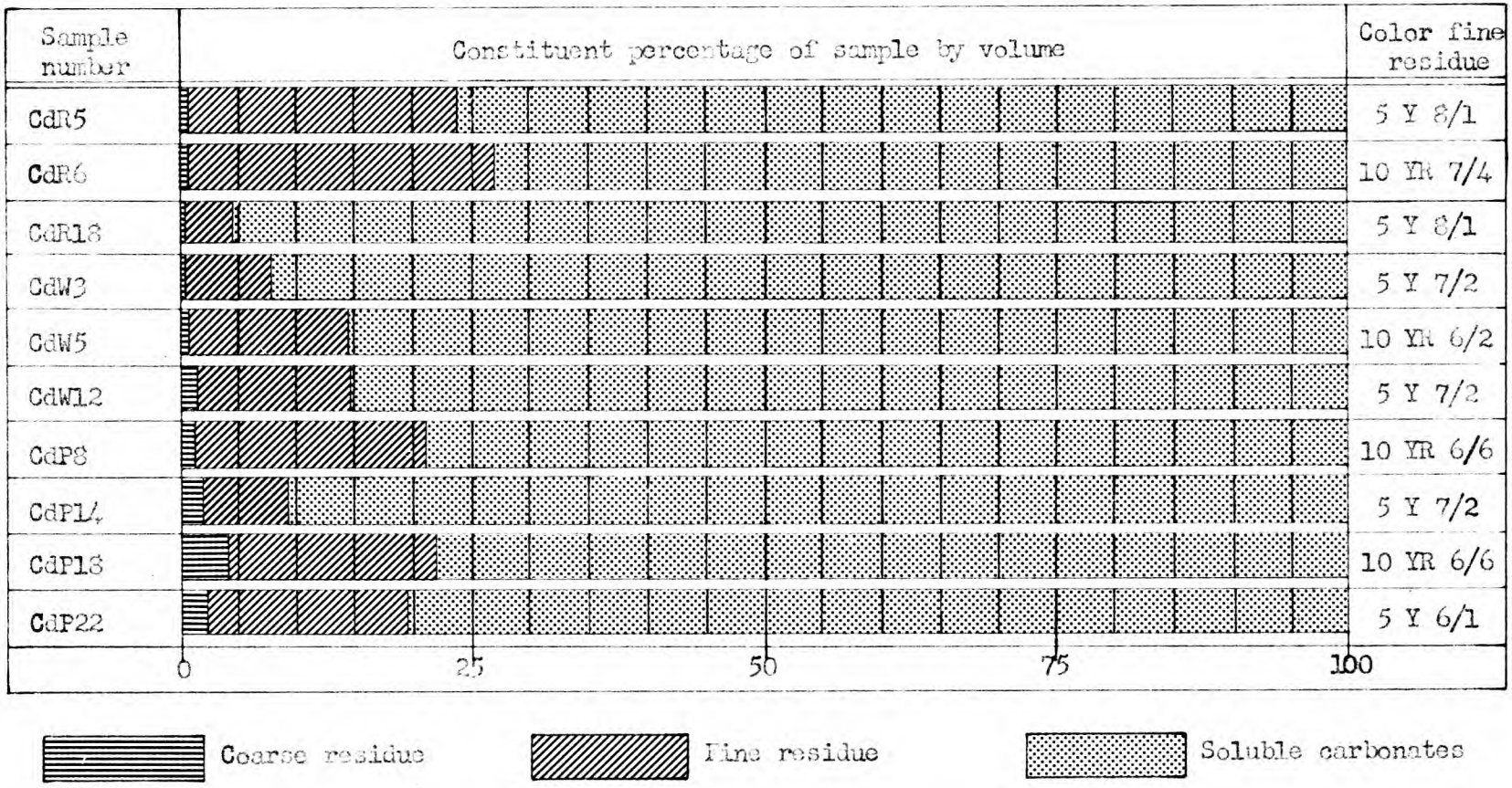


Fig. 10c. Constituent percentage of sample by volume of Dover limestone.

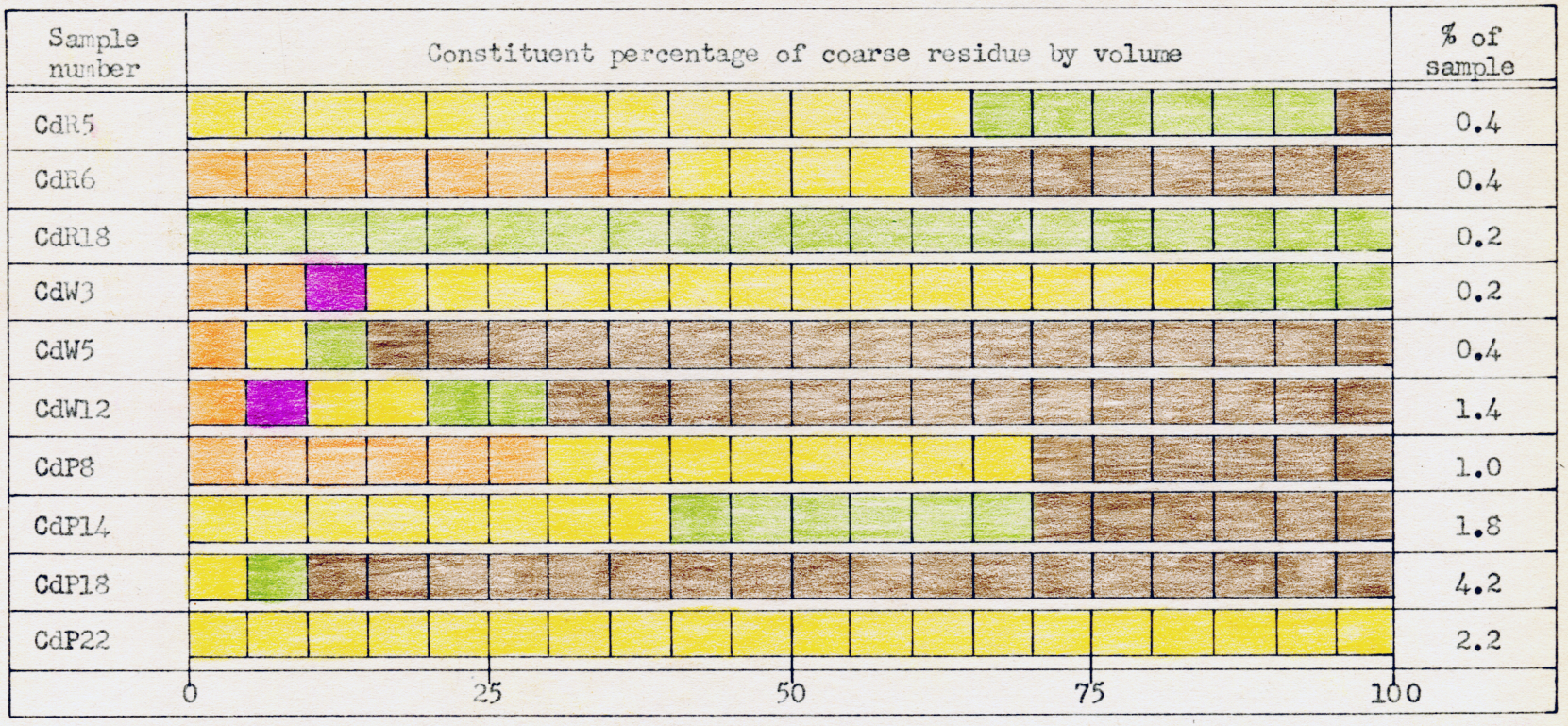


Fig. 10d. Constituent percentage of coarse residue by volume of Dover limestone.

gastropods in sample CdW12.

The sand of this residue is largely composed of very fine, anhedral, well-sorted grains of quartz but there are some notable exceptions. A trace of rather large, subrounded, slightly frosted quartz grains was noted in samples CdR6 and CdP22, but most of the sand occurs as rounded aggregates with minor amounts of muscovite flakes and red orthoclase grains associated with the aggregates. In some samples, a small percentage of the sand grains is stained with limonite. Tubular silica is present in all samples and, in sample CdR18, it forms 100 percent of the coarse residue. Limonite, in the form of crystal aggregates pseudomorphic after pyrite and large concretionary nodules, occurs in measurable amounts in 5 of the samples. Pyrite, in the form of crystals, crystal aggregates, and drusy masses, is present in 3 of the samples. A few small flakes of muscovite and small grains of green glauconite are scattered throughout all samples. The distinctive feature of sample CdP18 is the presence of silicified foraminifers, especially members of the Family Ammodiscidae.

Correlation by Means of Insoluble Residues. There is no residue that may be classed as conclusive evidence of the Dover limestone. The percentage volumes of the fine, coarse, and total residues exhibit a pattern which might be of use in correlation in eastern Wabaunsee County (Figs. 10b, 10c, and 10d). The range in the percentage volume of the total residue

is from 8.0 percent for sample CdW3 to 14.8 percent for sample CdW12. A similar variation was noted for the percentage volumes of the fine and coarse residues and for the percentage weights of the residues.

The color of the fine residue is not diagnostic for this limestone (Fig. 10c). A suggestive correlation of the constituent percentages by volume is shown by samples CdW5, CdW12, CdP8, and CdR6 (Fig. 10a).

Maple Hill Limestone. The Maple Hill limestone underlies the Langdon shale and overlies the Wamego shale (Fig. 2).

Sampled Locations. The Maple Hill limestone was sampled at 8 outcrops in Riley, Wabaunsee, and Pottawatomie Counties (Fig. 11a):

Sample number	Type of outcrop	Geographic location
CmhR3	Road cut	SW¼NW¼NW¼ sec. 27, T. 10 S., R. 9 E., Riley County
CmhR4	Stream bank	Center of the SW¼ sec. 32, T. 10 S., R. 9 E., Riley County
CmhW4	Stream bank	SW¼SW¼NW¼ sec. 25, T. 11 S., R. 12 E., Wabaunsee County
CmhW14	Road cut	SE¼SW¼SE¼ sec. 27, T. 11 S., R. 13 E., Wabaunsee County
CmhP7	Stream bank	SE¼NW¼SE¼ sec. 21, T. 8 S., R. 10 E., Pottawatomie County
CmhP17	Stream bank	NW¼SE¼NE¼ sec. 7, T. 8 S., R. 11 E., Pottawatomie County
CmhP18	Road ditch	NW¼NE¼NE¼ sec. 29, T. 7 S., R. 11 E., Pottawatomie County
CmhP22	Road ditch	NW¼NW¼NW¼ sec. 5, T. 6 S., R. 11 E., Pottawatomie County

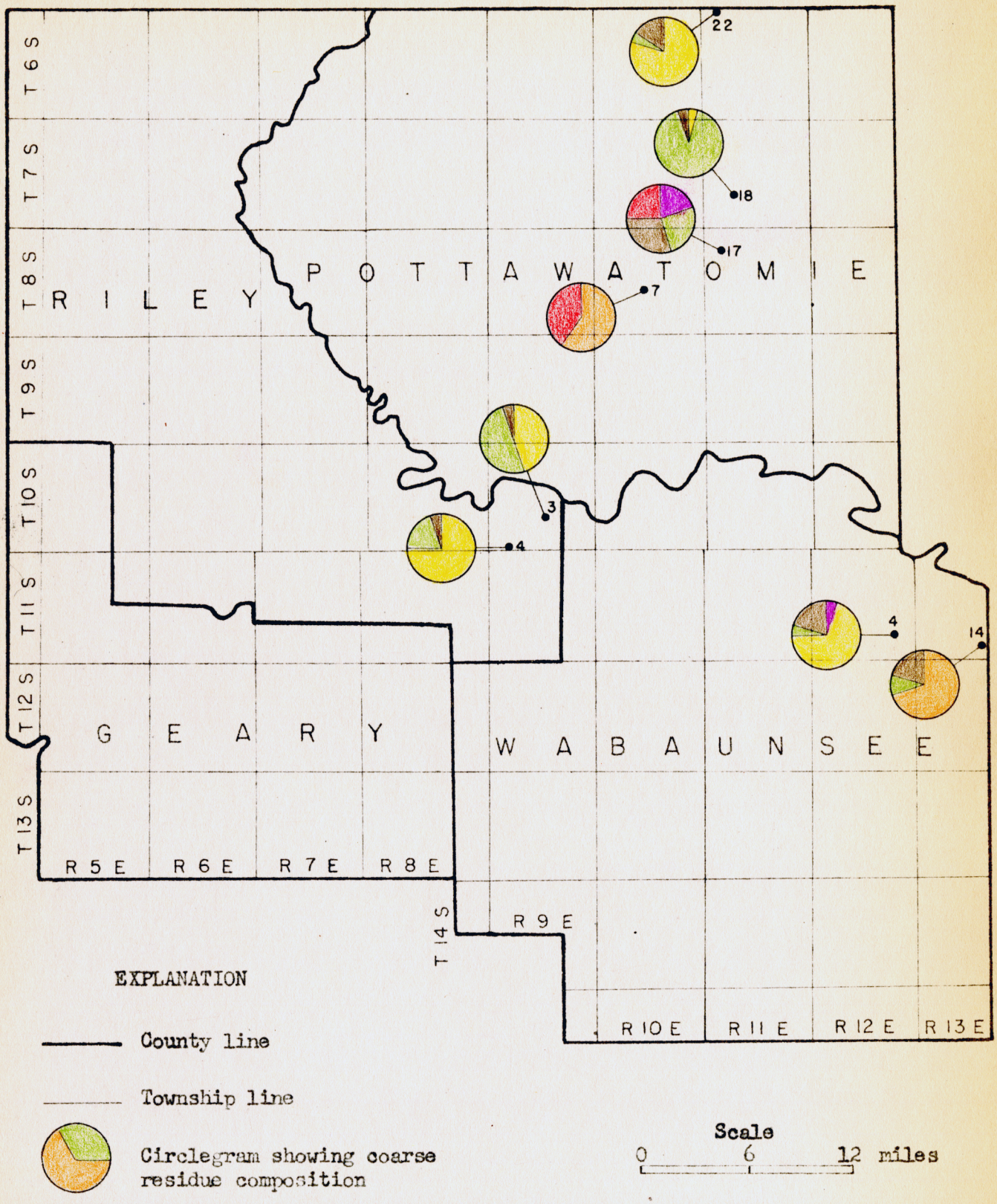


Fig. 11a. Map showing sample locations and coarse residue composition for Maple Hill limestone.

Lithologic Description. The Maple Hill limestone is hard, massive, and crystalline on fresh surfaces. It is bluish gray to yellowish gray, and weathers brown. Fusulinids, crinoid columnals, and brachiopod fragments were noted in this limestone. Its average thickness is about 1.5 feet.

Description of the Insoluble Residues. The total residue of this limestone constitutes from 5.2 to 12.2 percent by volume of the total sample (Figs. 11b and 11c). The volume of the coarse residue varies from 0.2 to 1.8 percent and the volume of the fine residue is from 6.0 to 11.8 percent of the original sample.

The color of the fine residue ranges from pale yellowish brown to light olive gray (Fig. 11c).

The coarse residue consists of sand, tubular silica, limonite, soft, porous, yellowish-brown silty-clay aggregates, pyrite, and celestite (Fig. 11d). The sand is composed of very fine, anhedral, well-sorted grains of quartz. It is absent in samples CmhP7 and CmhP17 and occurs as a trace in sample CmhW14. Tubular silica was found in varying amounts in all samples, and is a major constituent of samples CmhR3 and CmhP18. Limonite is present in all samples, except CmhP22, in the form of crystals, crystal aggregates, and irregular drusy masses pseudomorphic after pyrite. A few ostracods replaced by limonite were found in sample CmhR3. Silty clay aggregates, large and small, are minor constituents of most of

Sample number	Location	Sample		Residue							
				Coarse				Fine			
		Weight grams	Volume drams	Weight grams	% weight	Volume drams	% volume	Weight grams	% weight	Volume drams	% volume
CmhR3	Road cut in SW¼NW¼NW¼ sec. 27, T. 10 S., R. 9 E., Riley County	62.00	10	0.15	0.24	0.04	0.4	3.70	6.0	1.00	10.0
CmhR4	Stream cut in SW¼ sec. 32, T. 10 S., R. 9 E., Riley County	61.10	10	0.20	0.33	0.04	0.4	4.80	7.8	1.18	11.8
CmhW4	Stream cut in SW¼SW¼NW¼ sec. 25, T. 11 S., R. 12 E., Wabaunsee County	57.15	10	0.60	1.05	0.18	1.8	4.70	8.2	0.66	6.6
CmhW14	Road cut in SE¼SW¼SE¼ sec. 27, T. 11 S., R. 13 E., Wabaunsee County	63.00	10	0.50	0.80	0.10	1.0	4.00	6.3	0.90	9.0
CmhP7	Stream cut in SE¼NW¼SE¼ sec. 21, T. 8 S., R. 10 E., Pottawatomie County	59.35	10	0.10	0.16	0.02	0.2	1.90	3.2	0.50	5.0
CmhP17	Stream cut in NW¼SE¼NE¼ sec. 7, T. 8 S., R. 11 E., Pottawatomie County	59.20	10	0.20	0.34	0.04	0.4	4.80	8.1	1.10	11.0
CmhP18	Road ditch in NW¼NE¼NE¼ sec. 29, T. 7 S., R. 11 E., Pottawatomie County	59.45	10	0.05	0.08	0.02	0.2	2.60	4.4	0.60	6.0
CmhP22	Road ditch in NW¼NW¼NW¼ sec. 5, T. 6 S., R. 11 E., Pottawatomie County	61.85	10	0.15	0.24	0.04	0.4	3.50	5.6	0.80	8.0

Fig. 11b. Sample data for Maple Hill limestone.

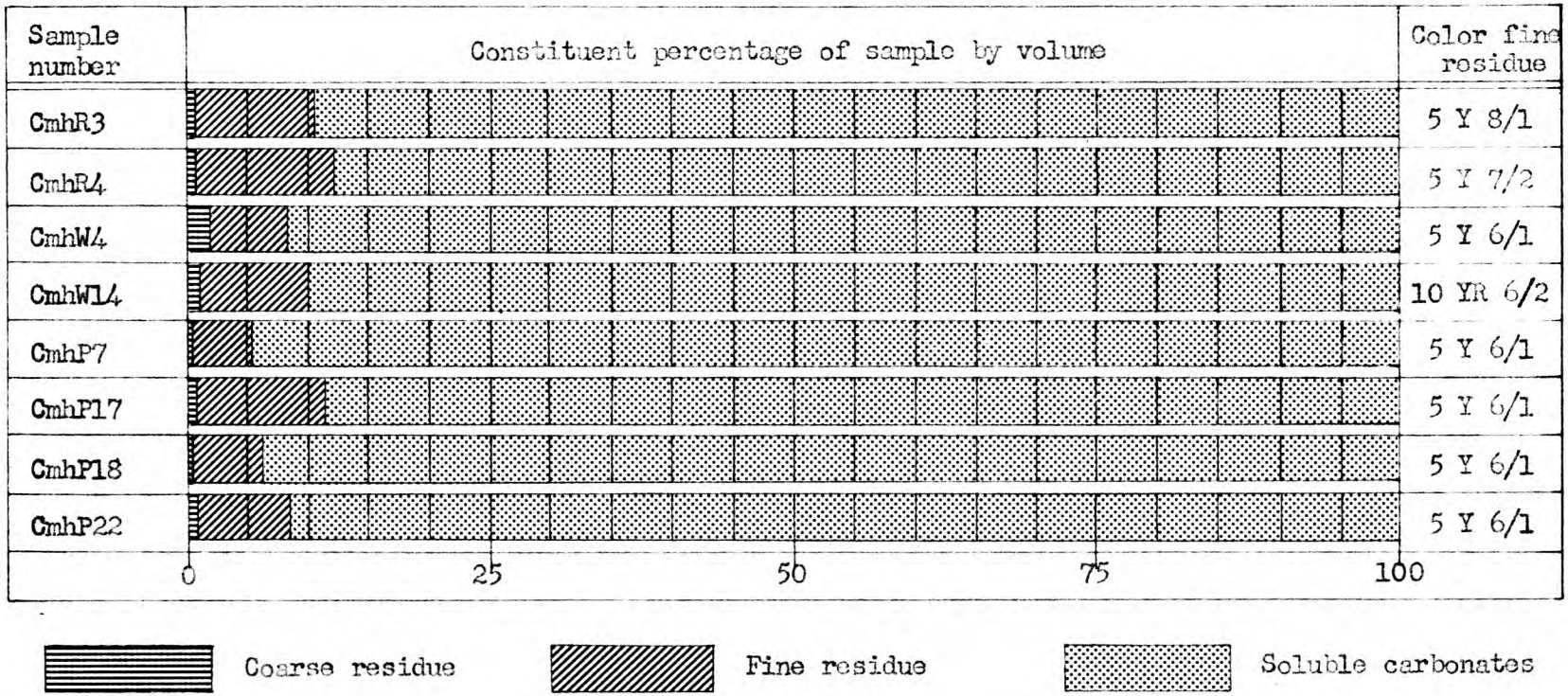


Fig. 11c. Constituent percentage of sample by volume of Maple Hill limestone.

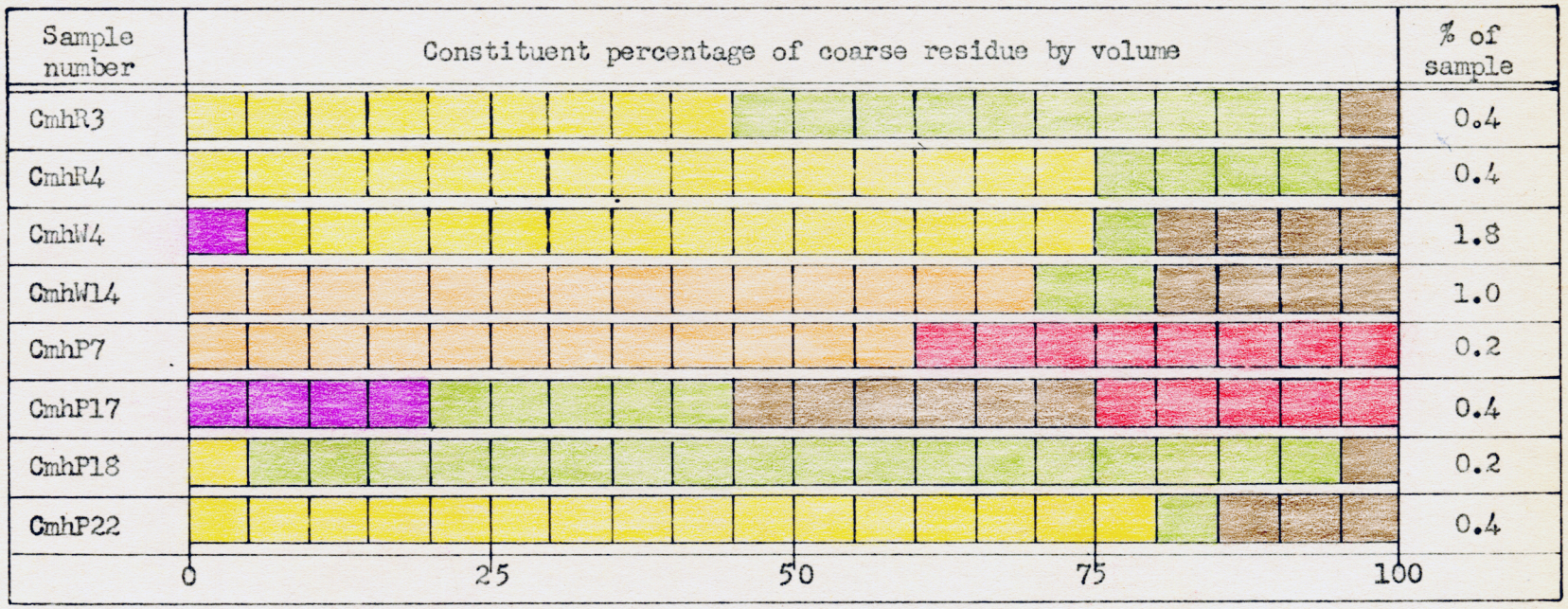


Fig. 11d. Constituent percentage of coarse residue by volume of Maple Hill limestone.

the samples. Euhedral cubical and octahedral pyrite crystals and drusy incrustations are present as traces in many of the samples and occurs in measurable amounts in samples CmhW4 and CmhP17. Pink to orange-red celestite was found as a trace in sample CmhW14 and in larger quantities in samples CmhP7 and CmhP17. Small flakes of muscovite occur in very minor amounts in all samples.

Correlation by Means of Insoluble Residues. No diagnostic single coarse residue was found, for the Maple Hill limestone, nor are the percentage volumes and weights of the total, fine, and coarse residues of value in correlation (Figs. 11b, 11c, and 11d).

The color of the fine residue of this limestone cannot be considered as useful in correlation because of its similarity to the colors of the fine residues of other limestones (Fig. 11c).

A possible aid to correlation might lie in the patterns of the constituent percentage of coarse residues as displayed by samples CmhW4, CmhR3, CmhR4, and CmhP22 (Fig. 11a). However, the differing coarse-residue patterns of the other samples in Pottawatomie County would make this type coarse residue of doubtful utility in that county. The use of this type coarse residue in Riley and northwestern Wabaunsee Counties would seem to be indicative of correlation. A negative characteristic of possible value in correlation is the

absence of glauconite from the residues of the Maple Hill limestone.

Tarkio Limestone. The Tarkio limestone underlies the Wamego shale and overlies the Willard shale (Fig. 2). It is the oldest and the lowermost Pennsylvanian limestone that was sampled during this investigation.

Sampled Locations. Most of the samples of the Tarkio limestone were collected in southeastern Riley County (Fig. 12a):

Sample number	Type of outcrop	Geographic location
CtUR2) CtLR2) CtR2)	Stream bank	NW¼NE¼NW¼ sec. 5, T. 11 S., R. 9 E., Riley County
CtR3	Road cut	SW¼NW¼NW¼ sec. 27, T. 10 S., R. 9 E., Riley County
CtR4	Stream bank	Center of SW¼ sec. 32, T. 10 S., R. 9 E., Riley County
CtR5	Stream bank	Center of SE¼ sec. 5, T. 11 S., R. 9 E., Riley County
CtR6	Stream bank	Center of SW¼SE¼ sec. 28, T. 10 S., R. 9 E., Riley County
CtR14	Road cut	NE¼NW¼SE¼ sec. 29, T. 10 S., R. 9 E., Riley County
CtW4	Stream bank	SW¼SW¼NW¼ sec. 25, T. 11 S., R. 12 E., Wabaunsee County
CtP1	Hillside	SW¼SE¼NW¼ sec. 15, T. 10 S., R. 9 E., Pottawatomie County
CtP4	Roadcut	NE¼SE¼SE¼ sec. 6, T. 9 S., R. 10 E., Pottawatomie County
CtP21	Road ditch	NW¼NW¼SW¼ sec. 11, T. 6 S., R. 11 E., Pottawatomie County
CtP22	Road ditch	NW¼NW¼NW¼ sec. 5, T. 6 S., R. 11 E., Pottawatomie County

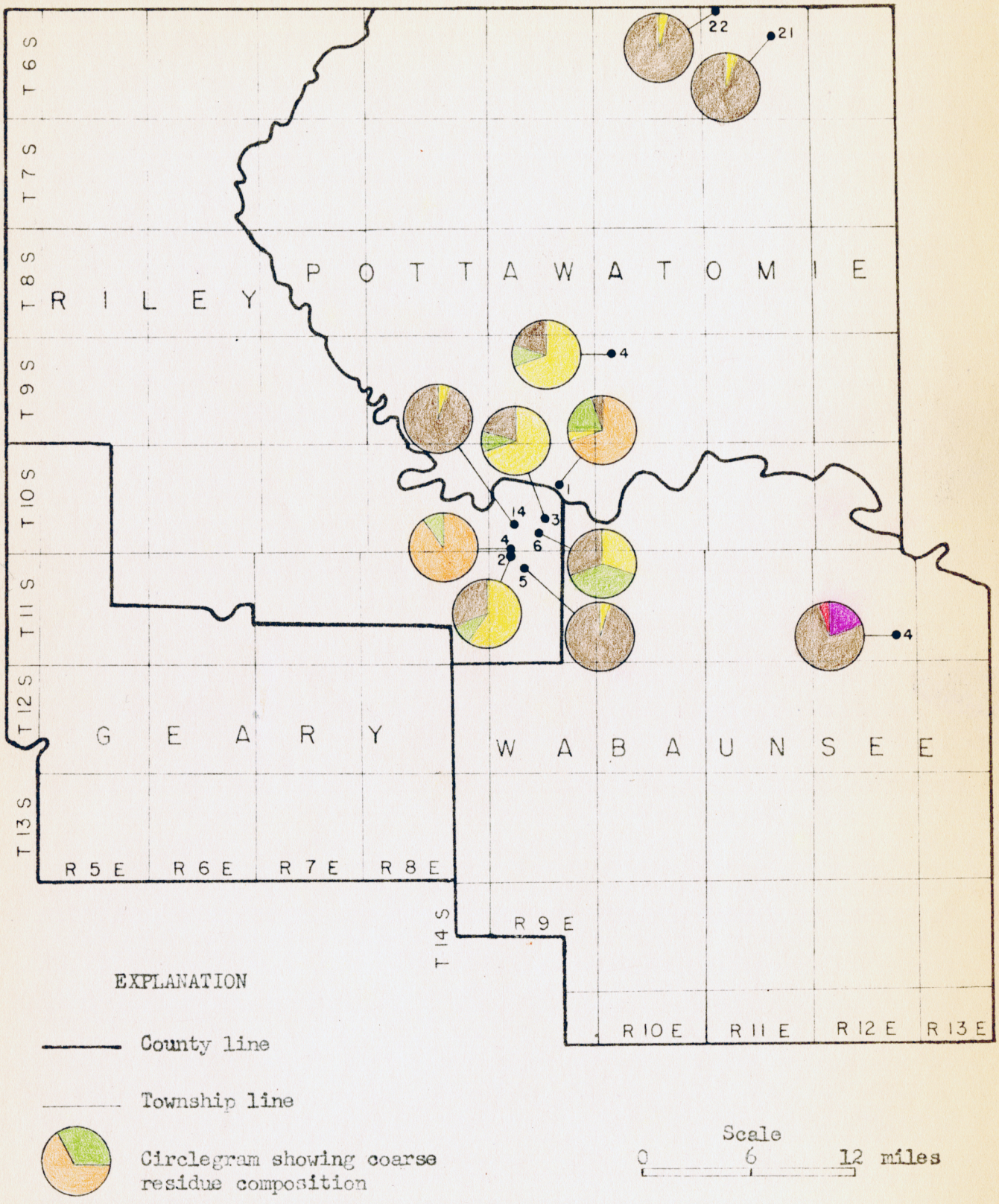


Fig. 12a. Map showing sample locations and coarse residue composition for Tarkio limestone.

Lithologic Description. The Tarkio limestone generally consists of two thick, massive limestones separated by a thin bed of shale. The limestones are hard, grayish orange to yellowish gray, and weather brown. The thin bed of shale is olive gray, and weathers yellowish gray. Large fusulinids are very abundant in the limestones and stand out on the weathered surface. The average thickness of the Tarkio limestone is about 13 feet thick.

Description of the Insoluble Residues. The total residue of this limestone varies from 3.2 to 19.0 percent by volume of the full sample (Figs. 12b and 12c). The volume of the coarse residue constitutes from 0.2 to 4.0 percent, and the volume of the fine residue comprises from 3.0 to 16.0 percent of the original sample.

The color of the fine residue ranges from dark yellowish orange to yellowish gray (Fig. 12c).

The principal constituents of the coarse residue are soft, porous, yellowish-brown, silty-clay aggregates, sand, limonite, and tubular silica (Fig. 12d). Silty-clay aggregates are present in all samples and in several they are the major constituent. The sand is composed of very fine, anhedral, well-sorted grains of quartz and is found in all samples. It usually forms the major constituent of those samples low in silty-clay aggregates. Limonite is present in many of the samples and is the principal type of coarse

Sample number	Location	Sample		Residue							
				Coarse				Fine			
		Weight grams	Volume drams	Weight grams	% weight	Volume drams	% volume	Weight grams	% weight	Volume drams	% volume
CtUR2	Stream cut in NE¼NW¼ sec. 5, T. 11 S., R. 9 E., Riley County	59.20	10	0.80	1.33	0.18	1.8	6.60	11.1	1.40	14.0
CtLR2	Stream cut in NE¼NW¼ sec. 5, T. 11 S., R. 9 E., Riley County	59.50	10	0.05	0.08	0.02	0.2	1.15	1.9	0.24	2.4
CtR2	Stream cut in NE¼NW¼ sec. 5, T. 11 S., R. 9 E., Riley County	61.55	10	0.60	0.97	0.14	1.4	3.50	5.6	0.70	7.0
CtR3	Road cut in SW¼NW¼NW¼ sec. 27, T. 10 S., R. 9 E., Riley County	61.10	10	1.30	2.13	0.30	3.0	2.10	3.4	0.56	5.6
CtR4	Stream cut in SW¼ sec. 32, T. 10 S., R. 9 E., Riley County	63.95	10	0.10	0.15	0.02	0.2	1.20	1.9	0.30	3.0
CtR5	Stream cut in center SE¼ sec. 5, T. 11 S., R. 9 E., Riley County	58.90	10	0.30	0.51	0.16	1.6	2.30	3.9	0.88	8.8
CtR6	Stream cut in center SW¼SE¼ sec. 28, T. 10 S., R. 9 E., Riley County	59.80	10	0.20	0.33	0.08	0.8	2.05	3.4	0.46	4.6
CtR14	Road cut in NE¼NW¼SE¼ sec. 29, T. 10 S., R. 9 E., Riley County	66.50	10	0.25	0.37	0.10	1.0	2.25	3.4	0.50	5.0
CtW4	Stream cut in SW¼SW¼NW¼ sec. 25, T. 11 S., R. 12 E., Wabaunsee County	53.90	10	0.15	0.28	0.02	0.2	1.70	3.1	0.32	3.2
CtP1	Hillside in SW¼SE¼NW¼ sec. 15, T. 10 S., R. 9 E., Pottawatomie County	61.45	10	0.25	0.41	0.04	0.4	1.40	2.3	0.32	3.2
CtP4	Road cut in NE¼SE¼SE¼ sec. 6, T. 9 S., R. 10 E., Pottawatomie County	58.40	10	2.10	3.59	0.40	4.0	6.10	10.5	1.50	15.0
CtP21	Road ditch in NW¼NW¼SW¼ sec. 11, T. 6 S., R. 11 E., Pottawatomie County	56.40	10	0.35	0.62	0.16	1.6	6.25	11.1	1.60	16.0
CtP22	Road ditch in NW¼NW¼NW¼ sec. 5, T. 6 S., R. 11 E., Pottawatomie County	60.50	10	0.45	0.74	0.22	2.2	5.20	8.6	1.40	14.0

Fig. 12b. Sample data for Tarkio limestone.

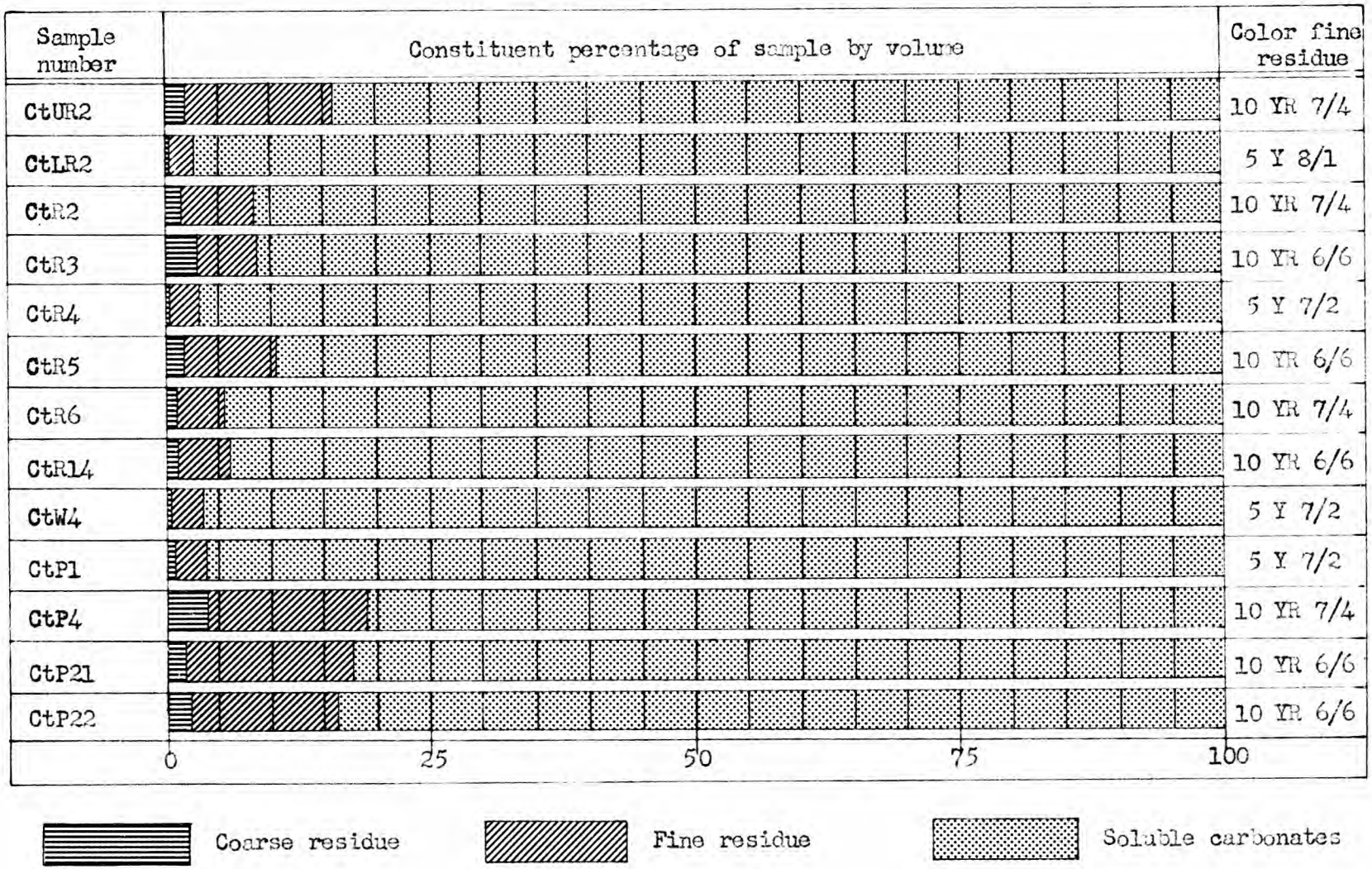


Fig. 12c. Constituent percentage of sample by volume of Tarkio limestone.

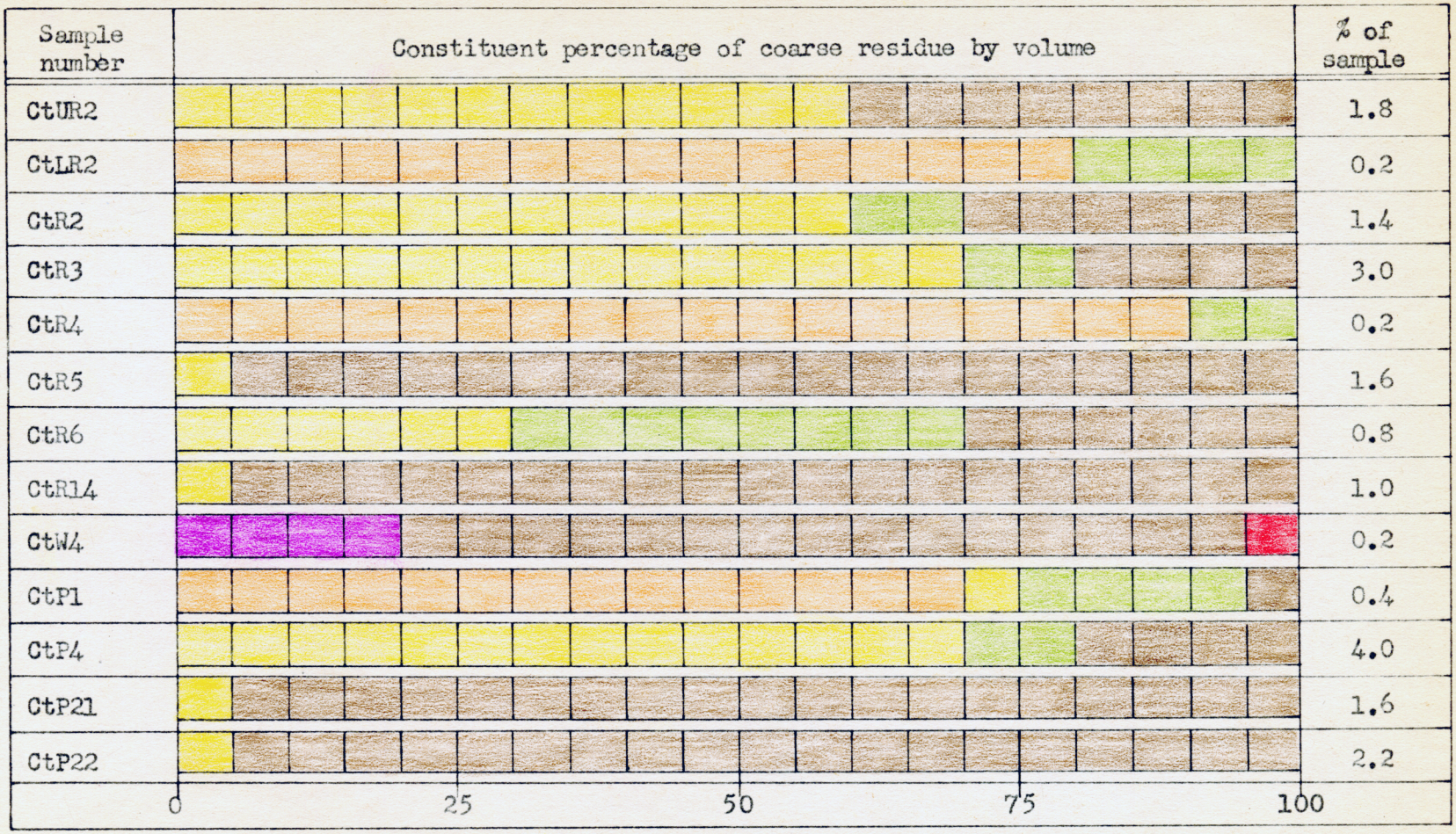


Fig. 12d. Constituent percentage of coarse residue by volume of Tarkio limestone.

residue in 3 of them. It is in the form of small drusy particles pseudomorphic after pyrite and as large, hard irregular-shaped masses. Tubular silica is present in all samples and forms measurable percentages in 7 of the samples (Fig. 12d). Pyrite was found only in sample CtW4 in which it occurs as small, subspherical crystal aggregates. About 5 percent of light-pink bladed crystals of celestite was found in sample CtW4. The only other occurrence of celestite is as a trace in sample CtP22. A very minor amount of small grains of green glauconite and small flakes of muscovite is scattered throughout most of the samples.

Correlation by Means of Insoluble Residues. Study of the insoluble residues of the Tarkio limestone indicates that there is not a single residue characteristic. The percentage volumes and weights of the total, fine, and coarse residues were investigated for correlative gain, but a constant variation or pattern could not be found (Figs. 12b, 12c, and 12d).

The color of the fine residue of this limestone was found to be the same as the color of the fine residues of other limestones and cannot be considered as of value in correlation (Fig. 12c). The coarse residues of the Tarkio limestone are outstanding in that they exhibited two and possibly three type constituent percentages (Fig. 12a). One pattern is displayed by samples CtR5, CtR14, CtP21, and CtP22; the second combination is that of samples CtR2, CtR3,

CtP4, and possibly CtR6; and the third pattern is exhibited by CtR4 and CtP1. Correlation of the Tarkio limestone in Riley and Pottawatomie Counties should be possible by the use of these three type coarse residues.

CONCLUSIONS

Review of the information obtained by analyses of the coarse residues reported in this study bears on several points relative to their use in stratigraphic classification. It may be concluded that there are no single types of residues which are certainly diagnostic for any one of the limestones studied. Practically all of the residues contain silty-clay aggregates; minor variations in color of this residue were observed from one sample to another but, in general, the soft, porous, yellowish brown, silty-clay aggregates are similar in color and size in the residues of all of the limestones. Limonite, pyrite, glauconite, sand, muscovite, and tubular silica are other coarse residues which were commonly found in the different limestones. Their use as characteristic residues is precluded for one or more of the following reasons: (1) the appearance of each of them is not the same in all samples of a limestone, (2) the residue is not consistently present in all samples of a limestone, or (3) the residue remains the same in appearance but was found in nearly

all of the limestones. Celestite and chert were found in relatively few samples. Fusain, when present, was found only in the Caneyville limestone.

The differences and constant variations exhibited by the percentage volumes of some of the fine, coarse, and total residues are believed to be of some value when used in conjunction with other information and methods of correlation.

The differences and constant variations displayed by the weights and percentage weights of some of the fine, coarse, and total residues might be of some use in correlation, but the equipment necessary and the time spent in obtaining them would probably outweigh their usefulness for this purpose.

The color of the fine residue of the samples varies but there are samples of each limestone in which the color of the fine residue shows about the same variation.

The constituent percentage of coarse residue by volume is the only method which could be used successfully by itself with any degree of confidence. It was found that by using a type coarse residue, in which the constituents are in similar proportions, several limestones could be correlated. On the basis of the samples studied, correlation of the Aspinwall, Jim Creek, and Tarkio limestones by this method should be possible in the area covered by this investigation. The Five Point, Brownville, Dover, and Maple Hill limestones can

probably be correlated over small areas by this same method.

A review of the analyses also reveals that there is no marked difference between the insoluble residues of the Permian and Pennsylvanian limestones in this area. No single diagnostic residue is present in either system of rocks. The percentage volumes and weights of the total, fine, and coarse residue of each limestone vary from place to place. The colors of the fine residues of limestones in both systems are similar. The coarse residues of both the Pennsylvanian and Permian limestones have the same constituents and cannot be differentiated as can some of the individual limestones. It is apparent that the use of insoluble residues cannot replace lithologic analysis as the principal basis for stratigraphic correlation but is a supplement to it.

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LITERATURE CITED

Claypool, C. B., and W. V. Howard.
Method of examining calcareous well cuttings. Amer. Assoc. Petrol. Geol. Bul. 12: 1147-1152. 1928.

Cole, Taylor.
Subsurface study of Ellenburger formation in west Texas. Amer. Assoc. Petrol. Geol. Bul. 26: 1398-1409. 1942.

Crowley, A. J., and Leo Hendricks.
Lower Ordovician and Upper Cambrian subsurface subdivisions in north-central Texas. Amer. Assoc. Petrol. Geol. Bul. 29: 413-425. 1945.

Grohskopf, J. G., and Earl McCracken.
Insoluble residues of some Paleozoic formations of Missouri, their preparation, characteristics and application. Missouri Geol. Surv. Rept. of Invest. 10. 39 p. 1949.

Hiestand, T. C.
Studies of insoluble residues from 'Mississippi lime' of central Kansas. Amer. Assoc. Petrol. Geol. Bul. 22: 1588-1599. 1938.

Ireland, H. A.
The use of insoluble residues for correlation in Oklahoma. Amer. Assoc. Petrol. Geol. Bul. 20: 1087-1089. 1936.

_____ and others.
Terminology for insoluble residues. Amer. Assoc. Petrol. Geol. Bul. 31: 1479-1490. 1947.

_____
Correlation and subdivision of subsurface Lower Ordovician and Upper Cambrian rocks in northeastern Oklahoma. U. S. Geol. Surv. Chart 5, Oil and Gas Invest. Ser., with text. 1944.

_____
Maps of northeastern Oklahoma and parts of adjacent states showing the thickness and subsurface distribution of Lower Ordovician and Upper Cambrian rocks below the Simpson group. U. S. Geol. Surv. Prelim. Map 52, Oil and Gas Invest. Ser., with text. 1946.

_____
Insoluble residues. Subsurface Geologic Methods. Golden, Colorado. Colorado School of Mines, p. 140-156. 1950.

Lamar, J. E.
Sedimentary analysis of the limestones of the Chester series. Econ. Geol. 21: 578-585. 1926.

Mitchell, R. H.
Residues from Pennsylvanian limestones. Amer. Assoc. Petrol. Geol. Bul. 19: 412-416. 1935.

Ockerman, J. W.
Insoluble residues of the Hunton and Viola limestones of Kansas. Jour. Sed. Petrol. 1: 43-46. 1931.

Pettijohn, F. J.
Sedimentary rocks. New York: Harper & Brothers, 1949.

Schoewe, W. H., G. C. Keroher, and R. P. Keroher.
Preliminary study of insoluble residues of Kansas Pennsylvanian rocks. Kans. Acad. Sci. Trans. 40: 269-281. 1937.

Trager, E. A.
A laboratory method for the examination of well cuttings. Econ. Geol. 15: 170-176. 1920.

INSOLUBLE RESIDUES OF SOME PERMIAN AND PENNSYLVANIAN LIMESTONES

by

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An investigation was made to determine the practicability of correlating some of the lower Permian and upper Pennsylvanian limestones through the use of insoluble residues. The limestones studied were, from youngest to oldest, the Five Point, Falls City, and Aspinwall of the Admire Group (Wolfcampian Series of the Permian System) and the Brownville, Caneyville, Jim Creek, Grandhaven, Dover, Maple Hill, and Tarkio of the Wabaunsee Group (Virgilian Series of the Pennsylvanian System). Representative samples were collected from outcrops of these limestones in Riley, Wabaunsee, and Pottawatomie Counties, and were treated with hydrochloric acid. In the study of the resultant insoluble resudues, volumetric measurements were made and the constituents described.

It was found that single diagnostic coarse residues are lacking in all of the limestones studied. Other insoluble-residue characteristics apparently vary in usefulness in stratigraphic correlation from one unit to another.

It was also observed that there was no apparent general difference between insoluble residues of the Permian and Pennsylvanian limestones studied.