STATE GEOLOGICAL SURVEY OF KANSAS

Franklin D. Murphy, M.D.
Chancellor of the University, and ex officio Director of the Survey

Frank C. Foley, Ph.D.
State Geologist and Director

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1955 REPORTS OF STUDIES

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EVALUATION OF ACID ETCHING OF LIMESTONE

By

William Ives, Jr.

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ABSTRACT

Acid etching of surface and subsurface samples of limestones from the Lansing and Kansas City groups of the Missourian Series, Pennsylvanian, in Kansas was studied and the procedure and terminology systematized. The effect of the etching on the constituents of the limestone is described, and the results of this method are compared with those obtained by other common techniques of study. Etching with acid is an excellent means of determining the gross lithology of a limestone. Chemical composition can be estimated accurately by converting the estimated volume percentage of each constituent to weight percentage by a formula developed for that purpose. The opportunity for quickly and cheaply estimating chemical composition that is thus offered suggests possible economic applications of the method. Etching revealed no distinctive features in these limestone strata that could be used for correlation.

INTRODUCTION

The purpose of this study was to ascertain the usefulness of an acid-etch test in the economic investigation of limestones. Specifically, work has been directed toward determining whether acid etching can (1) reveal sufficient information for description of the gross lithology of a limestone, (2) expose features of the limestone which are useful for correlation purposes, and (3) permit prediction of economic possibilities of a particular limestone. The limestones chosen for etching are from the Lansing and Kansas City groups, which represent a major part of the Missourian Series of the Pennsylvanian System of Kansas. The samples represent both surface and subsurface occurrences of the two groups.

Published information.—Although acid etching is not a new technique, an investigation of available geologic literature indicates an almost total absence of published information on the subject. The only publication which deals specifically with acid etching is "Acid Etching in the Study of Limestones and Dolomites" by J. E. Lamar (1950), which is excellent general introduction to acid etching.

Acknowledgments.—Russell T. Runnels of the State Geological Survey suggested this project. Holly C. Wagner, of the U.S. Geological Survey, aided the author with helpful hints and friendly criticism on procedure and terminology. For assistance with photographic problems, Robert O. Fay is thanked sincerely.

SOURCE OF SAMPLES

Core samples.—The core samples used in this study were se-
lected from the core of a well drilled in the Max oil pool, located in
northeastern Stafford County, Kansas. The core, donated to the
State Geological Survey of Kansas by the Stanolind Oil and Gas
Company for study, penetrates all strata of the Lansing and Kan-
sas City groups present at this location and is particularly valuable
because there was complete recovery of all the strata penetrated.

Outcrop samples.—The outcrop samples were selected from a
group of specimens of Pennsylvanian limestones collected by the
author in Kansas during the summers of 1952 and 1953. The field
sampling was done to obtain specimens of limestones for chemical
analysis in order to determine the possibility of economic utiliza-
tion. Because only limestone beds of considerable thickness can be
developed profitably by private industry, the thinner limestone
strata in the geologic succession were not sampled. This accounts
for omission of descriptions of some Lansing and Kansas City lime-
stones.

PROCEDURE

SAMPLE PREPARATION

Derivation of samples.—A sample was taken from the 4⅞-inch
diameter core at each change in lithology. The determination of a
change was made on the basis of megascopic examination of the
core and lithologic descriptions of the coring record provided by the
Stanolind Oil and Gas Company. The size of the sample was limited
by the diameter of the core and dimensions of the diamond saw and
polishing laps.

It was deemed best to cut the samples in the form of slabs, each
representing a 6-inch section of the core. After the location of a
sample had been selected, the piece of core was cut parallel to its
longitudinal axis and along one side so that the surface produced
generally was perpendicular to the bedding (Fig. 1A, B). The slab
was then trimmed along both sides to produce a rectangular speci-
men about 6 inches by 1⅝ inches which was easy to handle, polish,
and store (Fig. 1C, D, E). All samples were marked to indicate the
top of the bed, and the interval represented was noted.

The outcrop samples were prepared by cutting the selected piece
of rock with a diamond saw to produce a flat surface perpendicu-
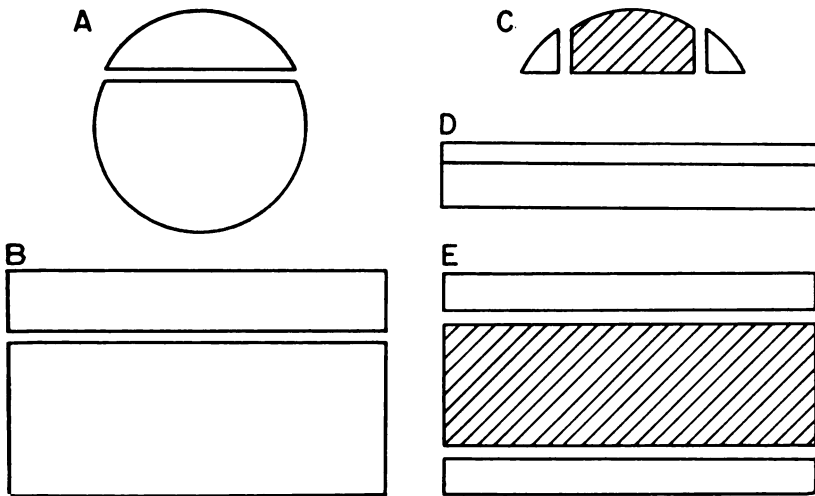
Fɪɢ. 1.—Procedure for cutting core to produce specimen for etching. Initial cutting of specimen from core: **A**, end view; **B**, side view. Trimming to produce final specimen (shown by shaded area): **C**, end view; **D**, side view; **E**, top view.

lar to bedding planes. Direction toward the top of the formation was marked on the sample. The name of the limestone represented and the location from which the sample was collected (section, township, range, and county) were recorded. When feasible, a second surface was cut parallel to the first, producing samples which range from half an inch to an inch in thickness. The second flat surface greatly facilitates storage and leveling of the sample in the etching process.

Polishing of samples.—The specimen was polished on one of the freshly cut faces to facilitate leveling and to avoid undesirable differential etching due to surface irregularities. Initial grinding with 150-grade carborundum removed irregular features such as saw marks and minor projections. A uniformly smooth surface was then produced by polishing with 500-grade carborundum. The polished face was scrubbed with a soft brush and soap and water to remove clinging pieces of abrasive, rock fragments, oil stains, and any other material that might interfere with the action of the etching solution. The specimens were then stored in containers to await etching.

Etching technique.—Both the hydrochloric and acetic acid solutions used for etching the samples were prepared in accordance

with the directions given by Lamar (1950, p. 2), i.e., 8 cc of C.P. concentrated hydrochloric acid in 100 cc of water or 23 cc of C.P. glacial acetic acid in 100 cc of water. Each sample was placed in a glass dish with the polished face upward, and was raised above the bottom of the dish on small pieces of modeling clay. Horizontality of the surface of the sample was checked with a bubble level and adjustments made by means of the modeling clay. Levelling is necessary in order to prevent unwanted differential etching because (Lamar, 1950, p. 2) "... inclined surfaces of specimens, especially limestone specimens, are apt to become mildly corrugated by localized rising streams of carbon dioxide bubbles which cause more rapid circulation of acid along their paths and thus produce greater local solution." After all specimens in a dish had been leveled, the dish was filled with the acid solution until the specimens were covered by about half an inch of solution. The specimens were allowed to etch for 8 minutes if hydrochloric acid solution was used, whereas, if acetic acid solution was used, the etching time was 20 minutes. After being etched the specimens were removed gently from the solution and (Lamar, 1950, p. 2) "... cautiously washed by immersing them gently several times in water so as to disturb as little as possible the insoluble material adhering to the plane surface of the specimen." Then the specimens were thoroughly dried and stored, the etched plane surface up, pending examination.

TERMINOLOGY

Clear and concise description of the etched surfaces is an inherent problem in this study. Limestones are particularly difficult to describe, because they (Pettijohn, 1948, p. 115) "... are in part exogenetic or clastic, in part endogenetic ('chemical' or 'organic') and in the main 'metamorphic' derivatives of these basic types." Acid etching chiefly reveals physical characteristics of the limestone constituents so terminology adopted for description of the specimens must focus attention on significant physical features.

General.—In a study of physical properties of limestones, it is necessary to classify the constituents in broad categories, which in turn can be subdivided. Such terms as "granular" and "crystalline" have been applied to these broad categories. Granular means "consisting of grains or granules," whereas crystalline signifies "consisting of crystals." It is understood that a grain is a solid par-

ticle of generally irregular external form and that a crystal exhibits the regular external form assumed naturally by a mineral (Winchell, 1942). Matrix refers collectively to the relatively small constituents that fill the interstices between larger particles, and its application is restricted to rocks consisting of both small and large particles (Krynine, 1948).

Size.—One of the outstanding and readily observed features disclosed by etching is the size of the grains and crystals in the limestone. The scale used to record this feature was devised by DeFord (1946). It is based on logarithms to the base 10 and grain diameters measured in millimeters (Table 1). Such a scale, although arbitrary, is useful for description of gross lithology and is particularly adaptable to the study of etched samples because it allows accurate description of grain size. A second-order term, such as "very fine paurograined," denotes a restricted size category, whereas a first-order term, such as "micrograined," used alone, signifies a range of grain size between appropriate limits.

Color.—The color of a particular constituent is noted if it seems to have diagnostic value. Munsell Soil Color Charts (Munsell Color Company, Inc., 1948) are recognized as a standard for color refer-

TABLE 1.—*Scale of grain size* (adapted from DeFord, 1946)

Class	Order	Type	Grain diameter, mm
		Coarse	5.6–10.0
	Megagrained	Medium	3.2–5.6
		Fine	1.8–3.2
		Very fine	1.0–1.8
Phaneric (grains can be distinguished by unaided eye)	Mesograined	Coarse	0.56–1.0
		Medium	0.32–0.56
		Fine	0.18–0.32
		Very fine	0.1–0.18
	Paurograined	Coarse	0.056–1.0
		Medium	0.032–0.056
		Fine	· 0.018–0.032
		Very fine	0.01–0.018
Aphanitic (grains not distinct to unaided eye)	Micrograined	Coarse	0.0056–0.01
		Medium	0.0032–0.0056
		Fine	0.0018–0.0032
		Very fine	0.001–0.0018
	Cryptograined	Grains less than 0.001 mm in diameter	
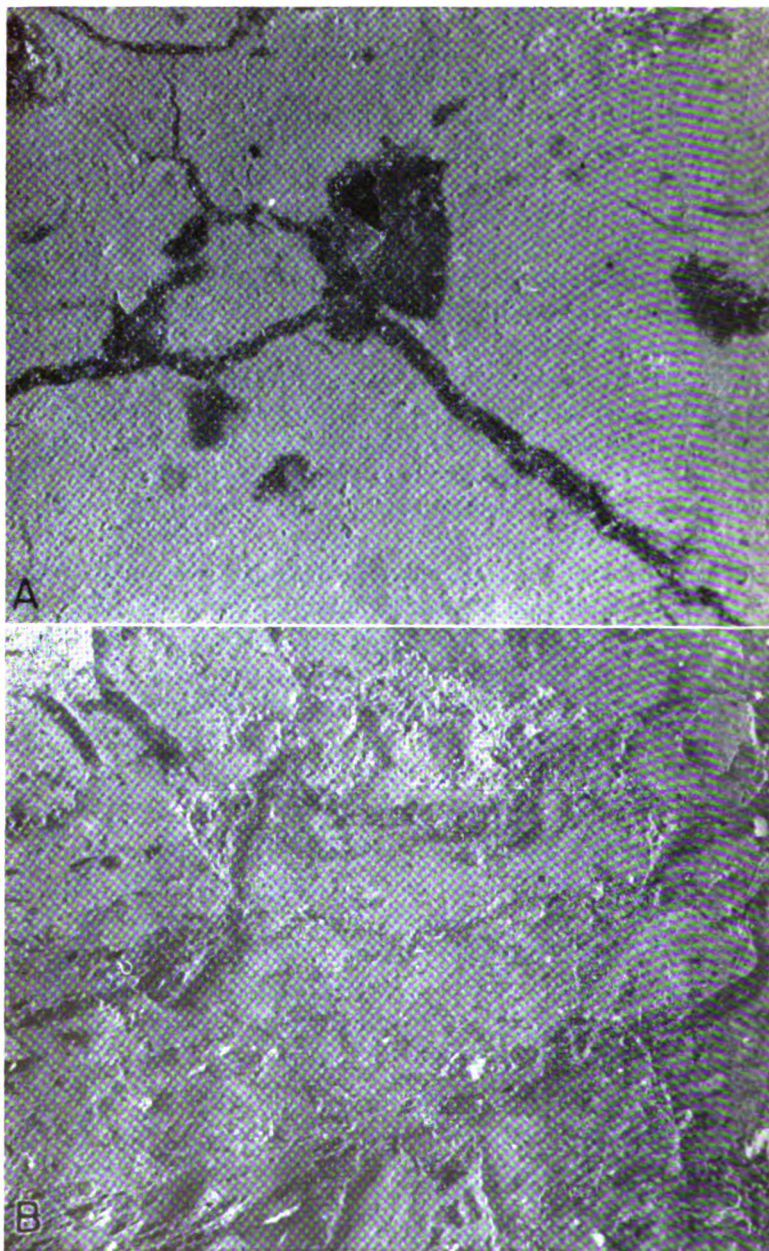
PLATE 1. Examples of surface features. **A,** Vein of crystalline calcite (5X); **B,** partings (5X).

ence. Each color in a Munsell chart is represented by a symbol, which is used for recording color in the descriptions.

Characteristic features.—Certain distinctive features of the lithology exhibited by the etched surfaces need to be defined so that their limits may be recognized. Thus, "vein" is defined as an irregular, narrow, elongate filament of crystalline mineral matter surrounded by material of different form but not necessarily of different composition (Pl. 1A). This term is used almost exclusively in describing areas of crystalline calcite. A "parting" is a thin tabular layer of material, essentially linear in cross-section, bounded by material of different composition (Pl. 1B). A "stylolite" (Pl. 2A) or stylolitic seam "is a surface of contact marked by interlocking or mutual interpenetration of the two sides" (Pettijohn, 1949, p. 156). "Glassy" means that the grain or crystal borders in a matrix cannot be distinguished, even under high magnification of a binocular microscope. This term may or may not infringe upon application of the size term cryptograined, because distinctness of the borders of very minute grains is largely a matter of visual perception.

DETERMINATION OF LITHOLOGY

EFFECTS OF ETCHING

The action of acid on limestone is primarily solution of calcium carbonate. Other constituents are affected in various ways by etching and the selectivity of dilute acid solutions in differentiating many of them is noteworthy.

Effect on carbonates.—Naturally, the carbonates present in a sample are affected most by the acid solution. Of the two carbonates, calcite and dolomite, commonly found in limestones, calcite is greatly preponderant.

When exposed to acid, calcite is decomposed so that carbon dioxide is driven off, leaving water-soluble calcium chloride. In the acid-etching technique, the length of time the sample is immersed in acid solution controls the amount of calcite dissolved. Thus characteristics of the remaining calcite are revealed and accentuated. The reaction of calcite and hydrochloric acid is vigorous, being marked generally by strong effervescence; the reaction of calcite and acetic acid, however, is slower, being accompanied by only moderate effervescence.
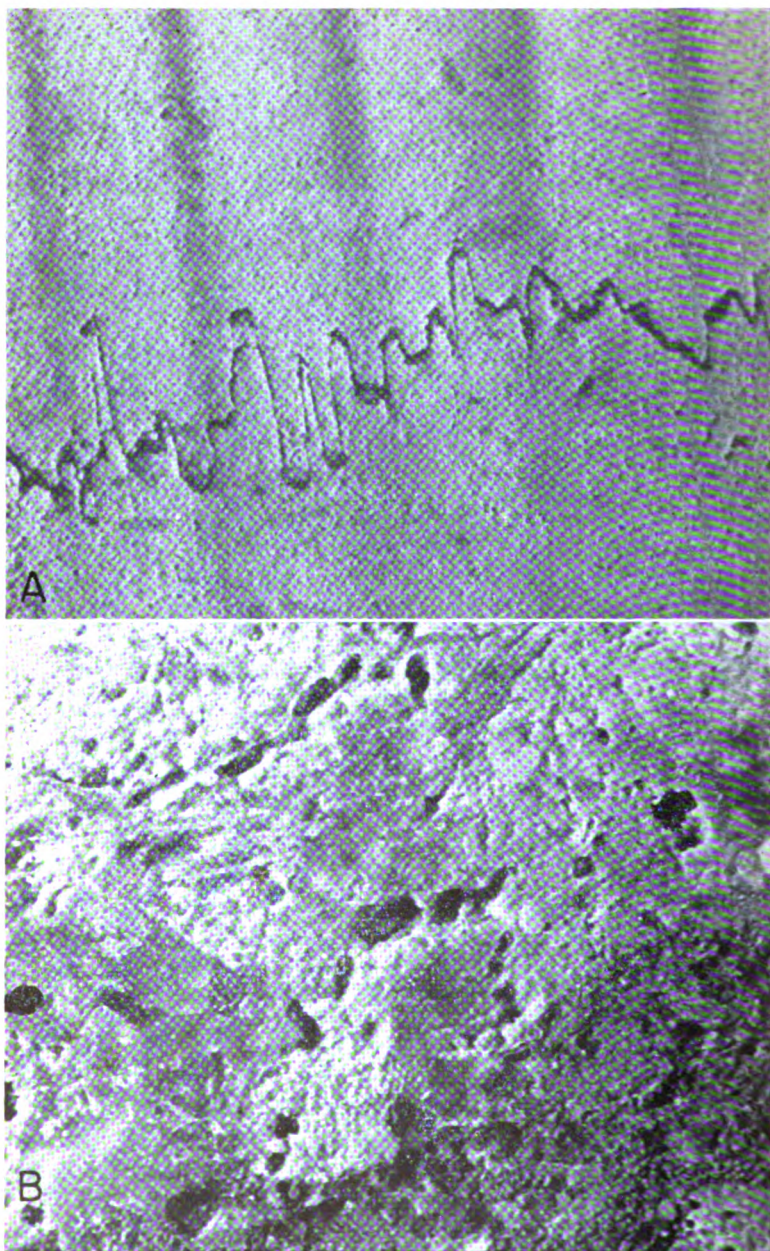
PLATE 2. Forms delineated by etching. **A,** Stylolite on an etched surface
(7X); **B,** vugs accentuated by etching (5X).

Because hydrochloric acid tends to react with calcite at a nearly uniform rate, most differentiation is due to the presence of impurities that slow the reaction. The reaction of hydrochloric acid and crystalline calcite is selective, however, depending on grain size and crystallinity, so that crystalline areas after etching are usually lower than the surrounding surface. Because of the greater reacting power of hydrochloric acid, this etching medium tends to emphasize such features as vugs, porosity, fossils, fractures, and cleavage. The manner in which vugs are exposed is shown in Plate 2B. An excellent example of porosity due to the removal of oölites and the effect produced by etching is seen in Plate 3A. In Plate 3B the selective action of the etch along a fracture is shown.

The action of acetic acid is not only slower but somewhat different from that of hydrochloric acid. Etching with acetic acid does not remove as much material as etching with hydrochloric, but it often reveals more clearly the character of the calcite in a particular sample. The action of acetic acid seems to be inversely proportional to the size of the grains or crystals making up the sample, small grains dissolving somewhat faster than large ones, perhaps because more surface area is available in a given volume of sample. Details of the grain sizes of calcite that are not ordinarily visible by examination in a hand specimen are thus disclosed.

Dolomite reacts differently to the acids used for etching, for it is relatively unaffected by dilute cold acid unless the mineral has been reduced to a fine powder. Therefore, the use of either hydrochloric or acetic acid brings dolomite grains into relief (Pl. 4A). This fact and the tendency of the mineral to exhibit excellent rhombohedral cleavage make dolomite easy to identify on the etched surface.

If dolomite remains in contact with acid for a sufficient length of time, it will dissolve. By greatly increasing the etching time and concentration of acid in the etching solution, a differential surface can be produced on a dolomite. The consideration of dolomites is outside the scope of this study, however. For information on this subject one should refer to Lamar (1950).

Effect on silicates.—Silicates are negligibly soluble in hydrochloric or acetic acid; therefore, these constituents remain elevated above the rock surface after solution of the surrounding calcite. The presence of both quartz and chert should be and usually is made apparent by this action. The sharp outlines of chert are
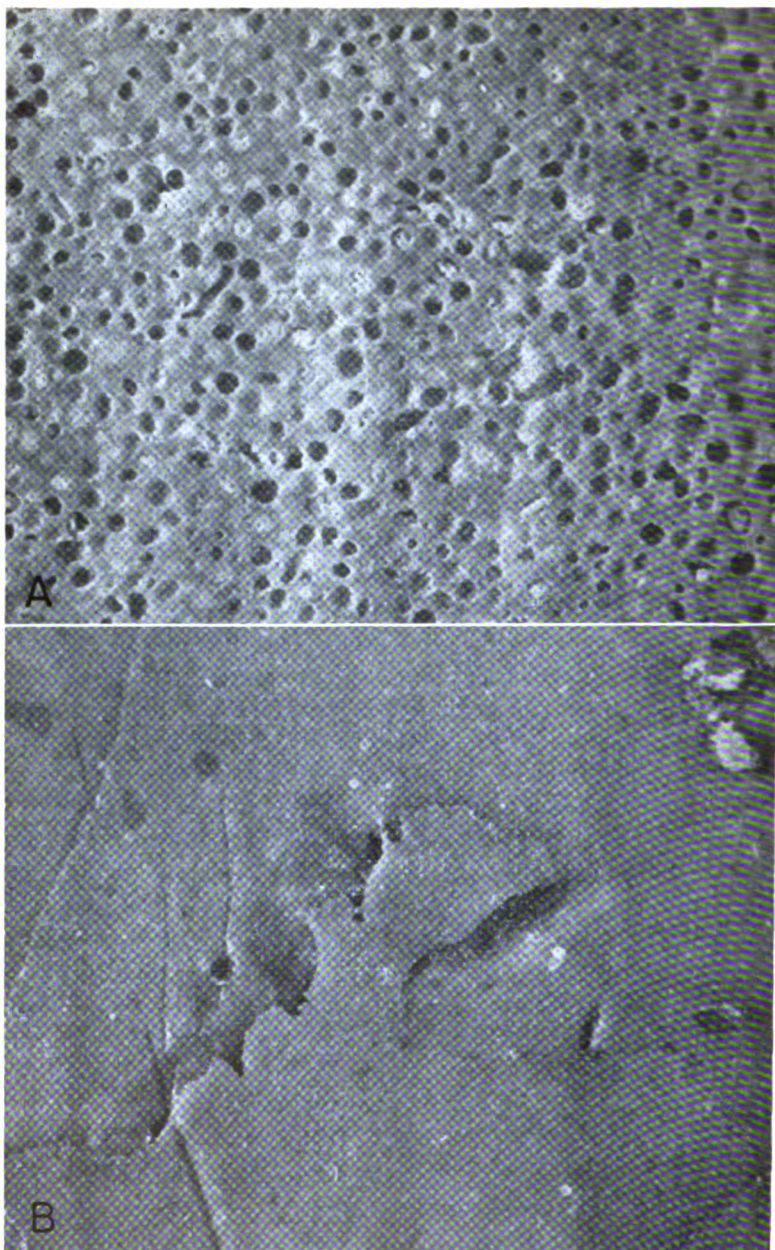
PLATE 3. Effects of etching. **A,** Porosity of an oölitic limestone revealed by etching (7X); **B,** differential etching along a fracture (7X).

emphasized by etching, because obscuring matter is removed (Pl. 4B). Areas of quartz grains likewise become more evident. However, if quartz grains are disseminated among calcite grains of the same general size, etching merely loosens the quartz grains so that they are free and thus not recognized. This is rare in limestones but the possibility must always be taken into consideration.

Effect on other components.—Other components of limestones consist of clay and heavy minerals and the acid has little chemical effect on them. The clay minerals usually are very fine and either thoroughly scattered throughout the limestone, or concentrated in partings and stylolites. Most of the clay minerals associated with the dissolved calcite are removed either by the flotation effect of bubbles of carbon dioxide during etching or by the subsequent washing. This loss and the obscurity due to fine dissemination make the recognition and evaluation of clay extremely difficult, so much so that usually it is ignored in descriptions of gross lithology.

Heavy minerals found in the limestones studied include pyrite, limonite, hematite, magnetite, and a copper compound. Other heavy minerals which could occur in limestones are those listed for insoluble-residue analysis by Ireland and others (1947). These are marcasite, sphalerite, feldspar, mica, chlorite, glauconite, barite, celestite, and a few less common minerals. The percentage of these constituents in most limestones is very small, but one or several of the heavy minerals may form an appreciable amount of some rock.

Etching tends to bring all the heavy minerals into relief. The ease with which they can be recognized is dependent on (1) size of the individual particle, (2) extent to which mineralogical characteristics are revealed, (3) quantity, and (4) distribution of the mineral throughout the sample. As is true of clays, etching also loosens some of the very fine thoroughly disseminated minerals so that they are lost by flotation action of the gas bubbles or removed by washing. The exposure and recognition of these minerals conceivably could be of great importance for they might provide a means of correlation.

APPLICABILITY OF ETCHING TO DESCRIPTION OF GROSS LITHOLOGY

One of the purposes of this study was to determine the value of using an acid-etch test as an aid in describing the gross lithology

of limestones. This process makes the overall relationship of the mineral ingredients more evident by differing reactions between the separate constituents of the limestone and the acid solution. Because the specimen is not powdered or altered in any way, the etched surface presents each part of the limestone in its original lithologic relationships, the original color and shape of the noncarbonates is preserved, and it is very probable that the carbonates are not changed. Inasmuch as the original structural pattern, color, and form of the constituents of limestones are preserved and emphasized, this method is valuable for studies of gross lithology. If more detailed information is desired, the acid-etch method must be accompanied by other techniques, such as some which are discussed in the following section.

COMPARISON WITH OTHER STUDY METHODS

Acid etching is only one of several methods useful for the study of limestones. Attributes of various other methods are compared, without expression of judgment as to their relative value, as this comparison may suggest supplementary applications of these methods of study.

In order to achieve a standard for comparison, each method under discussion was applied to a sample of the same limestone. Although this procedure is not entirely reliable, because a limestone cannot be expected to retain exactly the same lithologic characteristics throughout, the slight divergences probably have very little if any effect on the outcome of such comparison. The individual samples were taken from a specimen of Stoner limestone obtained from sec. 33, T. 18 S., R. 21 E., Franklin County, Kansas.

Insoluble residues.—One of the methods used in studying limestones is the determination of insoluble residues. For detailed information on this subject, reference is made to the discussion by Ireland (1951) who defines an insoluble residue (p. 140) as "the material remaining after rock fragments have been digested in acid," either hydrochloric or acetic acid being used. In limestones, this material normally constitutes a small percentage of the total rock volume, and determination of the constituent substances of the residue provides an accurate picture of the noncarbonate impurities of the rock.

The initial weight (113.35 grams) of the limestone sample used for making an insoluble residue was much larger than an average
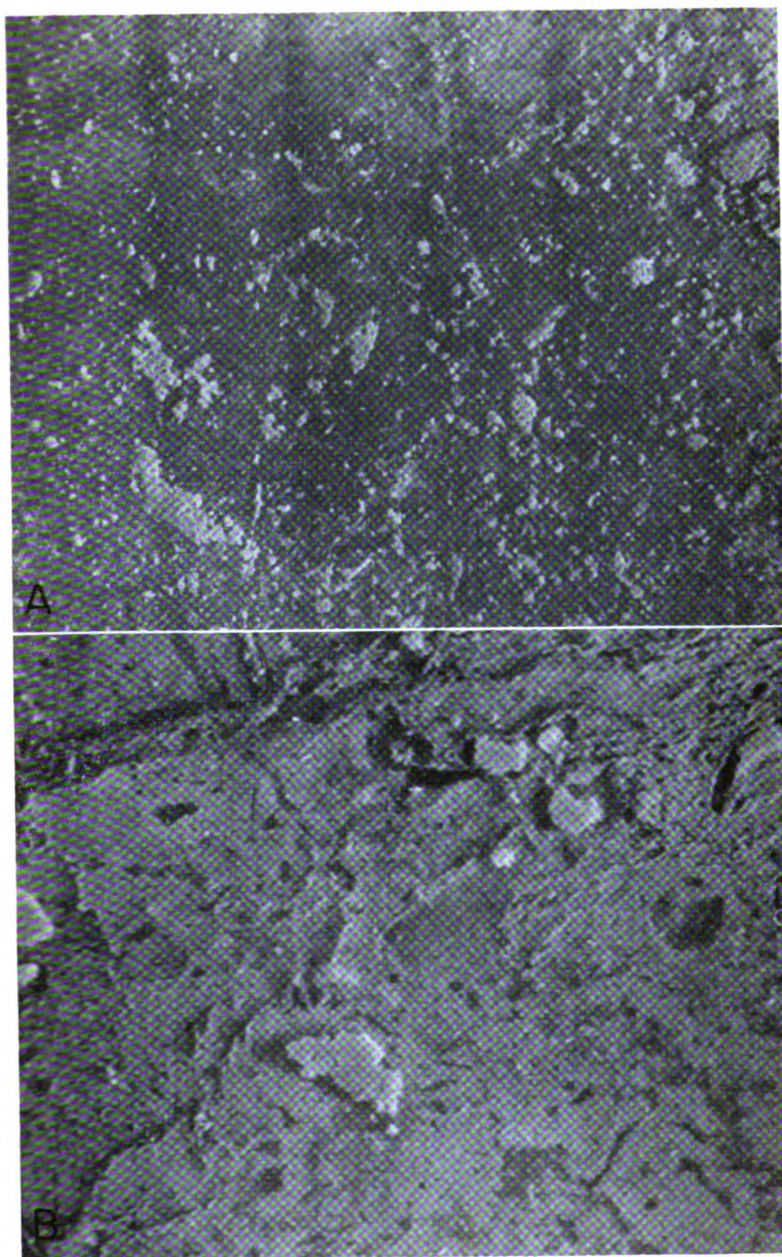
PLATE 4. Exposed lithologic constituents. **A,** Dolomite exposed by etching (5X); **B,** chert made prominent by etching (7X).

sample, but it was selected because of its approximate equivalence in volume to the other samples. The insoluble residues were obtained by following the procedure described by Ireland (1951). After solution of the soluble matter, washing, decanting, and drying, the residue was found to weigh 0.2696 grams. This quantity does not represent all the insoluble material in the limestone, however, because some very fine matter was lost during decanting. Even if the weight of the residue is doubled so as to compensate for‧ the fines lost, the insoluble material in the limestone amounts to only 0.4 percent of the total weight. This denotes a limestone of extreme purity. The insolubles present, using the terminology of Ireland and others (1947) are: limonite, 1 percent; beekite, 2 percent; unmodified loose anhedral quartz, 2 percent; and very fine flaky clay, 95 percent.

Essentially, the determination of insoluble residues constitutes an etching process carried to completion. The insoluble-residue technique completely destroys the original lithologic relationships and presents only an accurate determination of the noncarbonate constituents. Etching of polished surfaces of limestone with acid reveals the nature of noncarbonate constituents of the rock but provides only an approximation of their volume. The two methods used in conjunction provide more information about insoluble constituents than either can do alone.

Thin sections.—The use of thin sections for examination of rocks has a long history in geology. This technique has been rated very highly because of the amount and range of knowledge acquired by its use. The preparation of thin sections requires a diamond saw, polishing equipment, and materials for mounting, such as glass slides, canada balsam, and cover glasses. But because a diamond saw and polishing wheels are the essential equipment used in preparing samples for etching with acid, their availability permits adoption of either or both of these methods.

A thin section permits detailed determination of grain relationships and mineral identities. It does not reveal gross lithologic characters of the rock, however, because the area represented by the thin section is only a relatively small part of a hand specimen. The etched sample provides a much better concept of gross lithologic characters, but, conversely, treats coarsely the relationship of grains and precise delineation of minerals. Obviously, the choice of method of study is wholly dependent on the type of information de-

sired and the aim of the investigator. More information can be obtained by use of both procedures.

Dry peels.—A recent development that is widely used for studying rock characteristics is the dry-peel technique. As described by Sternberg and Belding (1942), dry peels offer a simple means of obtaining an impression of a slightly etched flat surface cut on a limestone sample. The sample is prepared for etching in the manner described previously. The time of etching is much shorter, however, and much less differentiation of the surface is produced. The etched surface, moistened with acetone, is pressed firmly against a piece of cellulose acetate. The solvent action of the acetone on the acetate provides an extremely accurate reproduction of the features of the rock surface. When dry, the acetate is peeled (hence the name) from the etched surface.

It is remarkable how much information can be gained by the use of peels. They are particularly suited for study of the structures of limestones. The microstructure of fossils, nature of crystal boundaries, grain size variations, and other characters are reproduced in extremely fine detail. Identification of the minerals in a sample is hampered by the general absence of color, a defect not shared by the acid-etch method. It is possible to distinguish some minerals by such characteristics as form (pyrite crystals), cleavage lines (calcite), and depth of impression (chert).

If the peels are made on acetate sheets of sufficient thinness, it is possible to cut out and mount 2-inch squares of the peels in the same manner as Kodachrome slides. Prepared in this fashion, they can be projected to high magnifications, and are studied advantageously in this way. Because peels can be projected, a photograph can be made directly from the peel itself, instead of from a negative. This is done frequently in research and provides an excellent means of illustration. Drafting acetate retains ink or crayon marks, so each peel can be numbered, and the thinness of the acetate permits filing of the peels in much the same manner as thin sections. Depending on the importance attached to determination of specific minerals, one may find the peel technique admirably suited to research. It possesses enough good characteristics to merit consideration in any sort of research on limestones. Plate 5A and 5B show the features revealed by acid etching and peels, respectively; these illustrations were made from the same sample of Spring Hill limestone (O21).
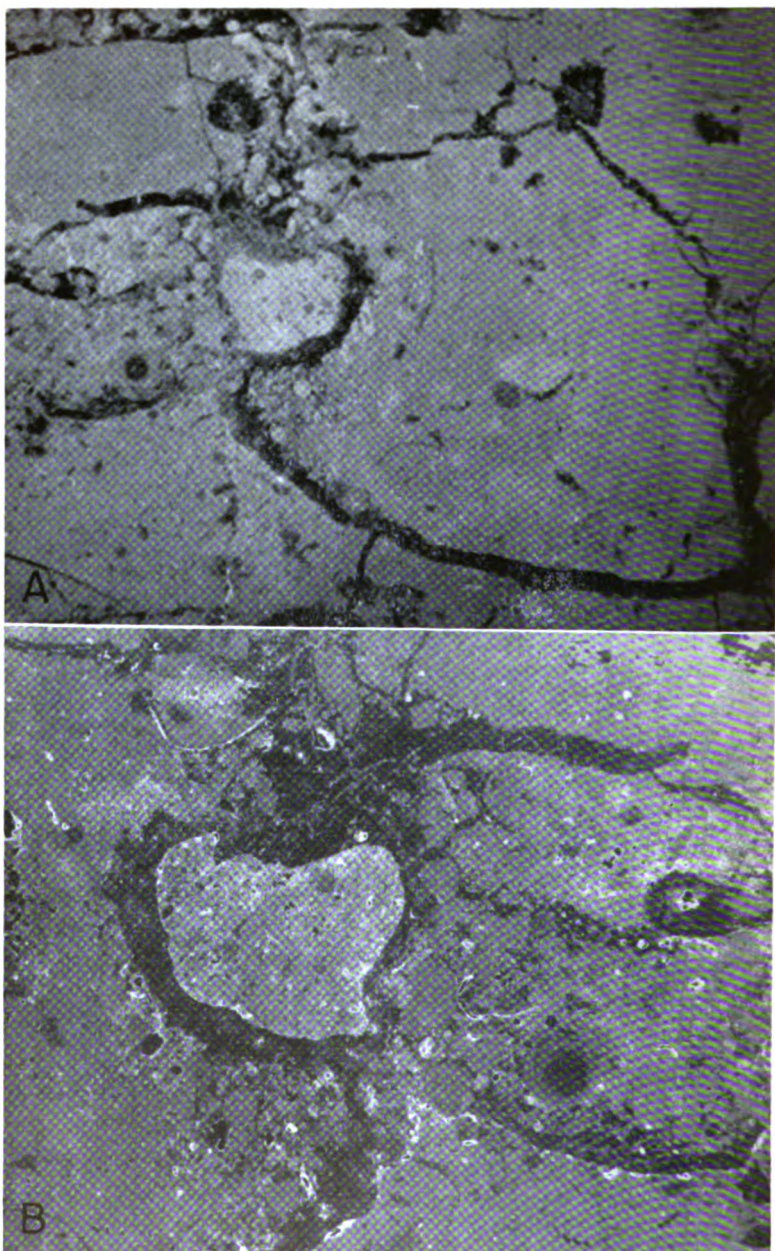
PLATE 5. Comparison of acid etching and dry peel techniques on a sample of Spring Hill limestone (sample O21). **A,** Etched sample (2X); **B,** dry peel of sample (4X).

Chemical analysis.—Chemical analysis requires trained personnel, much specialized equipment, and more time than other methods; hence it is not used extensively. Analyses are usually made and used by large agencies rather than individuals.

The preparation of a sample for chemical analysis requires its reduction to powder. This destroys all evidence of lithology so that after the ingredients are identified, their relationship to one another cannot be shown. As previously noted, etching provides a fair picture of the arrangement of various minerals but identification of them is possible only in part. For most geologic studies, acid etching is probably more useful because of its simplicity, speed, and inexpensiveness.

CORRELATION OF LIMESTONES

The second purpose of the study is to determine the usefulness of acid etching as an aid to stratigraphic correlation of limestones. It was hoped that if physical characteristics having value for correlation exist in the limestones, acid etching would reveal them. To test this matter, samples of the same stratigraphic unit obtained from different places were etched and studied in order to determine whether correlation on the basis of observed similar characters was possible. The examination of observed features excluded identification of any recognizable fossils.

OUTCROP-TO-OUTCROP CORRELATION

It was thought advisable to determine first whether any relationships exist between etched samples of the same stratigraphic unit selected from outcrops only a short distance apart, for any similarities should be most evident in such samples. Samples from the Argentine member of the Wyandotte limestone, the Spring Hill member of the Plattsburg limestone, and the Captain Creek member of the Stanton limestone were selected for attempted correlation. For some correlations it was not deemed necessary to use all three.

Lithology.—The first feature tested for correlation was lithology of the limestone. As the dominant mineral is calcite, its nature of occurrence is important and the character of grains probably best reflects conditions of deposition of the rock. The large calcite crys-

tals, usually found replacing fossils or as large veins, are believed to be secondary features.

Certain minor similarities are noticeable in the samples of the Argentine limestone. In sample O3* limonitic material occurs in a cryptograined matrix. Sample O4 also has areas of cryptograined calcite but contains no limonite. Both cryptograined calcite and limonite occur in sample O2, but in sample O1 neither limonite nor calcite of cryptograined size appears.

The three samples of Spring Hill limestone exhibit little lithologic similarity. Sample O18 has quartz grains and a trace of pyrite in a matrix of very fine to coarse paurograined calcite grains. However, in sample O20, which is from the same location as O18, dolomite (instead of pyrite) occurs in a similar matrix. Medium- to coarse-micrograined calcite and dolomite characterize sample O19, whereas sample O21 is unique in that it seems to consist entirely of calcite.

Correlation on the basis of lithology alone is always hazardous; the possibility was tested on the chance that some significant relationships could be found. None were discovered. The limonite in the samples cannot be used for correlation, because it is introduced as a result of near-surface weathering (Pettijohn, 1949, p. 106), as is corroborated by lack of limonite in any of the core samples studied. Dolomite provides a poor basis for correlation, as it may be the result of local replacement (Pettijohn, 1949, p. 315) and would be restricted to only a part of the lithologic unit. The most encouraging observation is the rather close similarity between calcite grain sizes of the samples. This grain-size similarity is insufficient for correlation but it deserves notice.

Percentage of constituents.—A second possible basis for correlation is constancy in percentage of individual constituents of the limestone. If these percentages prove to be constant or nearly so throughout an area sampled, this should be significant. The estimated percentage of constituents in the Argentine and Spring Hill samples is shown in Table 2. These data show that the minerals of the limestones maintain a fairly constant relationship.

Correlation on this basis seems to be of little value, however, because samples from limestones above and below the Argentine and Spring Hill members also contain comparable percentages of the

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*Gross lithology descriptions of samples are given at the end of the report.

TABLE 2.—*Estimated percent of constituents in selected samples*

Sample no.	Constituents, in percent					
	Calcite	Silica	Dolomite	Clay	Limonite	Pyrite
O1	97	0.5	1	0.5	..	trace
O2	99	0.5	..	..	0.5	..
O3	99.9	..	..	..	trace	..
O4	99.8	0.2	..	..	..	..
O18**	95	5	..	..	..	trace
O19	98	..	2	..	..	..
O20**	97	2	1	..	..	..
O21	100	..	..	..	..	..

* Samples O1-O4 are of the Argentine member; samples O18-O21 are of the Spring Hill member.
** These samples were taken at the same outcrop.

same ingredients. The Farley limestone member, which is the next limestone above the Argentine, as studied in sample O13, had an estimated content of 98 percent calcite, 0.5 percent silica, 0.5 percent dolomite, and 1 percent limonite, so it would be impossible to distinguish the Farley from the Argentine by the percentage of these constituents. The same situation arises in regard to the Spring Hill member. The Captain Creek member, which is stratigraphically above the Spring Hill, exhibits percentage characteristics shown in Table 3. Some variations are evident, but some samples of the Captain Creek resemble samples of the Spring Hill. Based on an examination of sample O14, the Merriam limestone member, which underlies the Spring Hill, shows the most diversity in content with an estimated content of 75 percent calcite, 20 percent quartz, and 5 percent limonite. The use of percentage of constituents for correlation of limestones is both unwise and unwarranted. It seems likely that conditions of deposition were very similar when all the limestones used in the study were deposited. Perhaps in another area, it would be possible to obtain better results.

Distinctive minerals.— A feature of the limestones that could be used for correlation purposes would be the presence of distinctive minerals exposed by etching. Minerals ideally suited for this purpose should be those deposited during formation of the limestone, which have maintained their identity and are restricted in their occurrence in the stratigraphic column. Minerals that fit this description are not common in the calcareous rocks, but favorable conditions of deposition could produce them.

TABLE 3.—*Estimated percentage of constituents in selected samples of Captain Creek limestone member*

Sample no.	Constituents, in percent			
	Calcite	Dolomite	Quartz	Iron minerals
O8	96	..	1	3
O9	99	..	..	trace
O10	95	5	..	..

Unfortunately, no minerals of a distinctive nature were found in any of the outcrop samples studied. Quartz and pyrite are the only minerals in the limestones whose emplacement probably was contemporaneous with formation of the rock and whose identity has not been altered, but they are much too common to serve as distinguishing characteristics of a certain stratum. Their presence is indicative of repetition of depositional conditions that must have prevailed during the time of formation of many limestones.

Percentage of fossils.—A feature brought out by etching and considered as a possible correlation tool is the percentage of fossil matter in the limestone. The estimated percentage of such material in several limestones studied is shown in Table 4. From this table it seems that the fossil content of the limestone is reasonably constant.

Whether this apparent constancy of fossil material is due to the supposed wide-spread uniformity of depositional conditions in the Pennsylvanian (Moore, 1929) is unknown. It is common paleontological knowledge that marine animals are selective in their environment. Thus, complete lack of animal life in an area of lime-

TABLE 4.—*Percentage of fossil matter in selected samples*

Sample no.	Limestone sampled	Fossil matter, percent
O1	Argentine	3
O2	do	4
O3	do	1
O4	do	3
O8	Captain Creek	2
O9	do	2
O10	do	15
O18	Spring Hill	3
O19	do	1
O20	do	1
O21	do	4

stone deposition is possible and this makes correlation on the basis of percentage of fossil matter unreliable.

OUTCROP-TO-CORE CORRELATION

Another part of the problem was to determine whether features revealed by etching could be used to correlate rock units from outcrops to cores. The features under consideration are those of the preceding section: lithology, percentage of constituents, distinctive minerals, and percentage of fossil matter.

The decisions reached in the previous discussion concerning the correlation value of the different features have equal validity with respect to outcrop-to-core correlation. Inasmuch as it is hazardous to correlate for a distance of 8 or 10 miles on the basis of lithology, certainly such correlation for a distance of about 180 miles is unwarranted. The same conclusion is reached regarding the other features considered in this report; as they have not proved of value for correlation of units between localities close to one another, they seem to have no use in long-distance correlation.

The effectiveness of etching in discovering distinctive features depends on the presence of distinctive features. The uniform nature of the limestones may preclude the use of factors under consideration for correlation purposes. Although it seems that etching does not disclose features that can be used for correlation of Pennsylvanian limestones of Kansas, the technique may prove of value in other places.

PREDICTION OF ECONOMIC USE

The primary purpose of the study of native limestones by the Kansas Geological Survey is to determine whether they are of economic value. This determination is made on the basis of chemical analyses, as utilization of a limestone depends to a large degree on its chemical composition.

As part of the research on acid etching, application of etch tests and their relative value to the economic program was studied. Because acid etching accentuates the impurities in limestones, the prediction of the chemical composition of a limestone by etching seemed a likely possibility. Physical properties also may determine the use of a limestone. Determination of these properties might be aided by acid-etching studies through exposure of significant phy-

sical features. Data were available for definite comparison, as each of the outcrop samples used was analyzed by the Kansas Geological Survey Geochemistry Laboratory.

ESTIMATION OF CHEMICAL COMPOSITION

The percentage of constituents present in the etched samples is determined by visual estimation. Each percentage represents the estimated volume of the sample occupied by the particular mineral constituent. Percentages determined by chemical analysis are reported on a weight basis, however, so direct comparison of estimated percentages and chemical analyses is not feasible. Therefore, it is necessary to convert the volume percentages to weight percentages. This is done by establishing simple relationships between the volume percentages and weight percentages so that lengthy calculations are avoided.

Specific gravity relationships.—The weight of a mineral is equal to its volume times its density. Each of the mineral constituents of a limestone has a specific gravity* different from that of the other minerals. To convert the volumetric estimates to weight values with maximum accuracy, one should multiply the estimated percentage of mineral by the density of that mineral and divide by the total sample weight. This process involves extensive computation and adds appreciably to the time required for acid etching analysis. It was therefore expedient to derive a simpler and faster method that would maintain the same relative accuracy.

Table 5 shows that close numerical relationship exists between the specific gravities of calcite, dolomite, quartz, kaolin, and illite. By adding these specific gravities together and dividing by five, an average specific gravity of 2.68 is obtained. The assumption that this number is representative of all five minerals introduces an error which is equivalent to the average deviation from the mean divided by the mean. The average deviation from the mean is derived by adding the differences between 2.68 and each of the actual specific gravities and dividing the result by five. Thus, it is found that the average deviation from the mean is 0.08. The error introduced by use of this method is 0.08 divided by 2.68 or 2.98 percent. It will be shown later that this error does not affect final results.

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* The specific gravity is the ratio of the density of a body to that of water. Density and specific gravity are numerically equivalent in the metric system, but in the English system density is 62.4 times the specific gravity.

TABLE 5.—*Derivation of factors for chemical-content estimates*

Mineral	Specific gravity	Average specific gravity	Quotient	Factor
Calcite	2.72	2.68	1.01	1
Dolomite	2.85	2.68	1.06	1
Quartz	2.65	2.68	0.99	1
Kaolin	2.61	2.68	0.97	1
Illite	2.60	2.68	0.97	1
Limonite	3.80	2.68	1.42	1.5
Pyrite	5.02	2.68	1.87	2

The average specific gravity may be used to determine a factor that eliminates detailed calculations. If the actual specific gravity of a mineral is divided by the average specific gravity, the resulting number, when rounded off, becomes a simple factor that can be used in calculating chemical compositions. These factors and their derivation are shown in Table 5.

In using 2.68 as an average specific gravity, one assumes that this value represents the specific gravity of the entire sample. In order to test the validity of this assumption, specific-gravity tests were run, by means of a Jolly balance (Hurlbut, 1952), on several of the limestone samples. Four determinations were made for each sample. The results are given in Table 6. The variations of specific gravity in a given sample probably are due to the inherent lack of uniformity in the limestone fragments used in the determination.

The average specific gravity of the selected limestones is 2.51. If this number is substituted in Table 5 for 2.68 and divided into the mineral specific gravities, no appreciable change is effected in the factors. Therefore, no additional error is introduced if the average mineral specific gravity is used instead of the average rock specific gravity.

TABLE 6.—*Specific-gravity determinations of selected limestone samples*

Sample no.	Determination				Average
	1	2	3	4	
O1	2.46	2.48	2.63	2.49	2.53
O4	2.67	2.41	2.50	2.58	2.54
O8	2.46	2.47	2.47	2.35	2.44
O11	2.46	2.69	2.37	2.65	2.54
O16	2.45	2.43	2.87	2.58	2.58
O22	2.54	2.40	2.34	2.49	2.44

Chemical equivalents of minerals.—In a chemical analysis, the constituents of a limestone are reported as oxides, except sulfur, which often is reported as an element. Because the minerals in a limestone are not all oxides, it is necessary to have factors for converting the estimated mineral values into the various oxide values. Table 7 gives the conversion factors for each mineral in deriving the chemical compositions.

Formulation of chemical composition.—It is now possible to set up a formula for the calculation of the chemical constituents from the estimated mineral volumes. The estimated volume of mineral times the weight factor (Table 5) gives the estimated weight of mineral present; this number multiplied by the chemical-constituent conversion factor (Table 7) gives the estimated weight percentage of chemical constituent. V x F x C equals the percent of chemical constituent where V is the estimated volume of the mineral, F is the weight factor, and C is the chemical-constituent conversion factor. In order to show the application of this formula, a sample computation is presented. If the estimated volume of pyrite in a sample is 1 percent, then the estimated amount of ferric oxide in the sample is computed: 1 (percent of pyrite) x 2 (weight factor) x 0.67 (conversion factor) $=1.34$ (percent Fe_2O_3 estimated present). This procedure was used to estimate the chemical compositions of the etched samples.

Limitations.—Because the initial estimation of mineral constituents is visual, limitations are imposed on the accuracy of the determinations. Any constituent that is too small to detect visually probably will be included in the estimated value for calcite,

TABLE 7.—*Conversion factors for minerals of limestones for derivation of chemical equivalents**

Mineral	Conversion factor	Chemical equivalent
Calcite	0.56	CaO
do	0.44	CO_2
Dolomite	0.30	CaO
do	0.22	MgO
do	0.48	CO_2
Clay	0.70	SiO_2
do	0.30	Al_2O_3
Quartz	1.00	SiO_2
Limonite	0.90	Fe_2O_3
Pyrite	0.67	Fe_2O_3
do	0.57	S

* Compiled from Hurlbut (1952) and Hodgman (1935).

as most of this hidden material will be disseminated through the most abundant mineral. For this reason, it is expected that the estimated percentage of calcite generally will be slightly greater than the actual calcite content. Silica is present in the samples in the form of quartz, chert, and various silicates. The sulfur in limestone may occur as calcium sulfate or various sulfides, chiefly pyrite. Pyrite is relatively easy to detect, except when the particles are extremely minute. Magnesium carbonate, which is present in limestone chiefly as the mineral dolomite, usually can be recognized in an etched sample.

Determination of the phosphate content of the limestones is a unique problem. According to Rankama and Sahama (1950), phosphates probably are deposited in marine sediments both as inorganic and organic calcium phosphates. They list the average phosphate content of limestones as 0.04 percent. Certain animals show more of a tendency to concentrate phosphate than others; these are annelids, mollusks, and vertebrates (Twenhofel, 1939, p. 181).

TABLE 8.—*Comparison of estimated fossil content and phosphate present*

Sample no.	Percentage of fossil matter	Phosphate
O1	3	0.06
O2	4	trace
O3	1	0.04
O4	3	0.02
O5	..	0.01
O6	1	trace
O7	..	0.06
O8	2	trace
O9	2	0.03
O10	15	0.01
O11	80	trace
O12	5	trace
O13	2	trace
O14	75	0.08
O15	30	0.07
O16	3	trace
O17	1	0.07
O18	3	0.03
O19	1	0.05
O20	1	0.03
O21	4	trace
O22	1	0.04
O23	6	0.04

Normally it would be impossible to detect any inorganic calcium phosphate in a limestone because of its close affinity with calcium carbonate. However, a test was made to determine whether any relationship exists between the percentage of fossil matter and the phosphate content. These results are given in Table 8.

It is readily apparent that little, if any, relationship exists between the amount of phosphate and the percentage of fossil material present in a limestone. Phosphate values, therefore, could not be determined in this study.

Evaluation of results.— The estimated chemical composition of each of the outcrop samples was determined by utilizing the previously derived formula. These estimates are tabulated in Table 9. The chemical analyses of the samples are listed in Table 10. A comparison of these two tables affords an evaluation of the accuracy of the acid-etch method in predicting chemical composition.

TABLE 9.—*Estimated chemical composition of samples*

Sample no.	Constituents, in percent							Calcu- lated $CaCO_3$	Calcu- lated $MgCO_3$
	SiO_2	Al_2O_3	Fe_2O_3	S	CaO	MgO	CO_2		
O1	0.85	0.15	0.67	0.57	54.62	0.22	43.16	97.48	0.46
O2	0.85	..	0.68	..	55.44	..	43.56	98.95	..
O3	..	..	0.9	..	55.94	..	43.96	99.84	–
O4	0.10	..	..	..	55.94	..	43.96	99.84	..
O5	0.35	0.15	..	..	55.18	0.22	43.60	98.48	0.46
O6	7.20	..	..	..	51.52	..	40.48	91.95	..
O7	99.00	..	0.45	..	..	..	..	..	..
O8	1.00	..	2.70	..	53.76	..	42.24	95.95	..
O9	..	..	0.09	..	55.94	..	43.96	99.84	..
O10	..	..	..	..	54.70	1.10	44.20	97.63	2.30
O11	7.00	..	7.20	..	47.60	..	37.40	84.95	..
O12	..	..	..	..	54.18	1.54	44.28	96.70	3.22
O13	0.50	..	0.90	..	55.03	0.11	43.36	98.21	0.23
O14	20.00	..	4.50	..	42.00	..	33.00	74.96	..
O15	1.00	..	..	.	54.10	0.66	43.24	96.55	1.38
O16	7.02	0.01	..	..	46.77	4.40	41.63	83.47	9.20
O17	2.00	..	9.00	..	49.28	..	38.72	87.95	..
O19	..	..	..	..	55.48	0.44	44.08	99.02	0.92
O20	2.00	..	..	..	54.62	0.22	43.16	97.48	0.46
O21	..	..	..	..	56.00	..	44.00	99.95	..
O22	..	..	4.50	..	53.20	..	41.80	94.95	..
O23	1.00	..	0.45	..	54.88	..	43.12	97.95	..

The silica present in the specimens, except in the one sample of a sandstone, is generally more than the estimated amount. This is to be expected, because it is impossible to discern the submicroscopic grains of silica, which, if abundant, cause the content to exceed the estimated figure.

The clay, which provides the alumina estimate, may be partly or wholly hidden because of its extremely small particle size. Therefore, the actual alumina content is likewise usually greater than the estimated amount.

The greatest divergences between chemical content and estimated content are found in the data for iron oxide. It seems that estimates of the amount of limonite are not very reliable as a basis for predicting iron oxide. It may be that the iron was present originally as iron carbonate and only part of it has weathered to limonite. The distribution of the limonite in a limestone is usually erratic and the random selection of a sample for etching could lead to an estimated limonite content in excess of the actual percentage, which is based on analysis of a composite sample.

The greatest accuracy was achieved in the estimation of the calcium carbonate content. A comparison of Tables 9 and 10 shows that in general the estimated CaO is greater than the actual CaO. If the actual CaO content is subtracted from the estimated CaO present, the resulting figure is the error of estimation. This error was determined for each sample and an average error calculated. The average error of estimation was only 2.39 percent. Thus, it is clear that acid etching enables one to predict the calcium carbonate content of a limestone with considerable accuracy. This method of determining approximate calcium carbonate percentage is of value to industries that use limestone for its calcium carbonate.

The determination of magnesium content also was relatively successful. The sample estimated to have the highest MgO content was proved by chemical analysis to contain the most MgO. It was possible to pick out certain samples as having higher MgO percentages than the average. The inability to pick others may be due to inclusion of magnesium in the molecular structure of calcium carbonate.

In several samples, the percentage of a certain constituent was considerably misjudged. In an attempt to determine the reason for the error, samples O1, O6, O8, O14, O15, O16, and O22 that showed

TABLE 10.—Chemical analyses of outcrop samples

Sample no.							Constituents							
	SiO$_2$	Al$_2$O$_3$	Fe$_2$O$_3$	TiO$_2$	CaO	MgO	P$_2$O$_5$	SO$_3$	K$_2$O	Na$_2$O	Sulfide sulfur as S	Loss on ignition [*]	Calculated CaCO$_3$	Calculated MgCO$_3$
O1	7.05	1.02	0.99	..	48.58	1.71	0.06	0.06	..	..	0.04	39.89	86.47	3.58
O2	2.34	0.64	0.35	..	53.40	0.57	trace	trace	0.07	0.04	..	42.33	95.22	1.19
O3	0.63	0.16	0.97	..	54.01	0.54	0.04	nil	..	..	nil	43.17	96.26	1.13
O4	1.27	0.42	2.06	..	52.50	1.40	0.02	trace	..	..	..	42.39	93.61	2.93
O5	2.99	1.22	0.69	..	52.15	0.76	0.01	nil	..	..	0.05	41.96	93.08	1.59
O6	9.41	0.94	1.65	..	47.37	1.88	trace	nil	..	..	0.11	38.52	84.47	3.93
O7	79.32	9.95	2.35	0.99	0.93	0.31	0.06	nil	1.43	1.81	..	2.70	..	..
O8	1.06	0.30	1.37	..	52.98	0.51	trace	nil	..	..	nil	42.89	94.47	1.07
O9	2.17	0.40	0.80	..	53.37	0.51	0.03	trace	..	..	..	42.40	95.16	1.07
O10	2.08	0.56	1.17	..	52.02	1.58	0.01	trace	..	..	0.07	42.32	92.74	3.31
O11	6.65	1.96	2.40	..	48.84	0.76	trace	nil	..	..	nil	39.20	87.09	1.59
O12	1.12	0.33	1.34	..	52.90	1.75	trace	trace	..	..	trace	42.69	94.33	3.66
O13	0.79	0.30	0.49	..	54.61	0.61	trace	nil	..	..	trace	43.14	97.47	1.28
O14	11.57	3.90	2.66	..	43.01	1.63	0.08	0.16	0.62	0.17	0.13	36.31	76.55	3.41
O15	7.06	2.35	2.51	..	47.40	0.89	0.07	nil	0.37	0.10	nil	38.29	84.42	1.86
O16	8.65	2.03	1.81	..	45.55	2.92	trace	trace	0.35	0.13	0.31	38.42	81.22	6.12
O17	7.84	2.76	2.39	..	47.04	0.83	0.07	0.10	0.03	0.07	nil	38.47	83.70	1.74
O19	0.59	0.27	0.88	..	54.03	0.83	0.05	nil	..	..	0.06	42.91	96.38	1.74
O20	6.70	2.08	1.27	..	47.73	1.95	0.03	trace	..	..	0.11	39.45	85.15	4.08
O21	2.12	0.72	1.16	..	52.05	1.28	trace	nil	..	..	0.07	42.16	92.81	2.68
O22	5.22	0.17	0.71	..	52.70	trace	0.04	trace	..	..	nil	41.30	93.97	trace
O23	5.03	0.28	0.51	..	52.16	0.34	0.04	trace	..	..	..	41.20	92.96	0.71

* Loss on ignition at 1000° C. Sample dried at 105° C.

a large discrepancy between the estimated and actual value were restudied.

The reason for the error in estimation could not be found in re-examination of samples O1, O6, O15, and O22. The constituents were hidden either because of extremely small size or because of their existence as chemical impurities in other minerals. However, several important facts were discovered in regard to the other three samples. Samples O8 and O14 were restudied because the estimated amount of ferric oxide greatly exceeded the actual amount present. In sample O8, the limonite was found to be very porous and in some places resembled boxwork. Pore space comprised about 50 percent of the volume occupied by limonite. Some of the limonite projections were removed, crushed, and scattered to determine whether minerals other than iron were present. These projections contained as much as 50 percent other minerals, chiefly calcite. Allowance for the combination of pore space and other minerals lowered the limonite estimate to about one-fourth the original amount. The re-examination of sample O14 showed that about 80 percent of the material originally estimated to be limonite was iron-stained quartz. It is, therefore, highly advisable that one examine very closely any limonite in an etched sample in order to obtain maximum accuracy in estimation. Sample O15, when restudied, revealed that part of the estimated dolomite was actually quartz. The fact that the dolomite, quartz, and calcite in the sample have about the same grain size and are intimately mixed probably led to the original error.

Application.—The industrial use of a limestone invariably hinges on the presence of limiting values of certain constituents; therefore, prediction of chemical composition by the etch test has many possible applications. This test might replace or augment other commercial tests of limestones.

Each industry has specifications as to type and amount of impurities allowable in limestone for various uses. These specifications are so extensive and varied that it is impossible to list them. Runnels (1951) sets the following figures as representative of the average impurity specifications of high-calcium limestones: silica 3 percent, sulfur 0.1 percent, phosphate 0.1 percent, and magnesium carbonate (dolomite) 5 percent. Also the Production and Marketing Administration of the United States Department of Agriculture specifies 80 percent total carbonates in addition to certain size requirements in any limestones used for subsidized fertilizer.

Usually, only certain substances are regarded as deleterious by any given industry; therefore, the general specifications of the various industries are fairly simple. The lime and acetylene producers require high CaO content and low overall impurity content. Chert and clay are harmful in the manufacture of concrete aggregate. The presence of appreciable amounts of iron in a limestone prohibits its use by the glass and metallurgical industries. A large percentage of magnesium is not permissible in a limestone to be used for cement production.

Acid-etching tests would be of definite value in the detection of many of the undesirable impurities. It has been shown that the tests permit the prediction of the chemical composition with considerable accuracy. At present, it is necessary to analyze a limestone chemically, a process requiring several days and considerable expense, to determine its commercial use. In many cases, an acid-etch test would supply adequate information in a matter of hours at minimum expense. Thus decision as to rejection or continued study of a particular sample could be made quickly. If study of an etched sample reveals the presence of a deleterious substance in excess of the specified amounts, the sample can be discarded immediately. It is not suggested that all the unsuitable samples will be discovered by acid etching; this study indicates that most unsuitable samples could be detected, however, representing a definite saving of time and money.

Several factors that improve the accuracy of the acid-etch test should be pointed out. First of all, it is of utmost importance to obtain samples that are relatively large, fresh, and representative of the lithology. In the training of persons in the use of the acid-etch technique, it is advisable to emphasize that first studies of etched samples should be guided by chemical analyses. The analyses serve as a guide in the search for the various minerals and give an idea of the percentages to expect. After the observer has become familiar with the technique, active use of the method can begin.

DETERMINATION OF PHYSICAL PROPERTIES

The prediction of physical properties of a limestone by acid etching is untried. The testing of possible relationships is not included in this study. Machinery was not available for Los Angeles abrasion tests, freeze-and-thaw tests, and strength tests (American

Society for Testing Materials, 1952). Data from such tests is necessary for comparison before any conclusions can be reached.

Acid etching conceivably could reveal features having an effect on physical characteristics. Etching would disclose fractures, which would affect the strength of a rock or, perhaps, its reaction to freezing and thawing. The size, shape, and distribution of the minerals in a given limestone affect its crushing properties. Acid etching possibly could allow the prediction of the size classification that would be produced by crushing with standard commercial equipment. Many physical characteristics might be detectable after acid etching, but extensive and detailed study is needed before concrete conclusions can be reached.

SUMMARY

Etching with acid is effective in distinguishing the different minerals in limestones. Through the removal of calcite, the presence of other minerals is accentuated. It is possible to distinguish all but the finest size fraction. Acid etching is, therefore, an excellent method of determining gross lithology of limestones.

Acid etching exposes certain features of limestones that are not exposed by other studies. On the other hand, acid etching lacks certain attributes possessed by other methods and often is best used in conjunction with other methods.

Attempts to correlate limestone strata by using features exposed by etching were not successful. The uniformity of the limestones and the lack of unusual constituents are thought to be the main reasons for this failure. Correlation by this method may succeed in an area having limestones of more variable lithology.

The most practical application of acid etching is in prediction of gross chemical composition, which can be done with a fair degree of accuracy. This fact has possible application in reducing the amount of time and expense involved in detailed chemical analyses.

DESCRIPTION OF GROSS LITHOLOGY

The following are descriptions of the gross lithology of each of the limestone samples etched in this study. The location of each sample and the acid used in the etching process are noted. The terms used are discussed under terminology. Photographs of cer-

tain selected samples are used in the text. Reference is made at the end of the description if the sample is illustrated.

<center>OUTCROP SAMPLES</center>

The name of the limestone member, the location of the outcrop sampled, and the acid used for etching are noted at the beginning of each description.

O1. Argentine limestone, SW¼ SW¼ NW¼ sec. 29, T. 11 S., R. 25 E., Wyandotte County, Kansas; hydrochloric acid. Areas of clear crystalline calcite, mostly replacing fossils, in a matrix of coarse micrograined to medium paurograined calcite grains. Minor constituents of the matrix are pyrite crystals, elongate areas of dolomite, scattered chert particles, and micaceous particle? Estimated percentage: calcite, 97; dolomite, 1; chert, 0.5; and micaceous matter, 0.5; 3 percent of the sample is fossil matter.

O2. Argentine limestone, NW¼ NW¼ NW¼ sec. 14, T. 16 S., R. 24 E., Miami County, Kansas; hydrochloric acid. An intimate and random mixture of crystalline calcite, calcareous fossil fragments, silicified fossil fragments, and scattered limonite in a cryptograined calcite matrix. Estimated percentage: calcite, 99; limonite, 0.5; and silica, 0.5. Fossil matter comprises 4 percent of the sample.

O3. Argentine limestone, SE¼NW¼NW¼ sec. 12, T. 17 S., R. 22 E., Miami County, Kansas; hydrochloric acid. Sparse ostracods, fossil fragments, and limonite in a very uniform cryptograined matrix; 1 percent of the sample is fossil matter.

O4. Argentine limestone, NW¼ NW¼ NW¼ sec. 20, T. 14 S., R. 25 E., Johnson County, Kansas; hydrochloric acid. Large veins and areas of crystalline calcite separate areas of calcite grains. The crystalline calcite contains many fossil fragments and in several places is bordered by thin dense rims of clay minerals. Calcite grains are mostly cryptograined, but a few are as large as fine paurograined. The granular calcite contains a few minute chert particles. Fossil matter, 3 percent.

O5. Bethany Falls limestone, NW¼ NW¼ SW¼ sec. 23, T. 11 S., R. 24 E., Wyandotte County, Kansas; acetic acid. Extremely uniform, very fine to medium paurograined calcite grains comprise most of the sample. Several thin micaceous stylolites and scattered

dolomite interrupt the continuity of the calcite. Estimated percentage: calcite, 98; dolomite, 1; and clay, 0.5.

O6. Block limestone, SW¼ SW¼ SE¼ sec. 28, T. 18 S., R. 25 E., Miami County, Kansas; acetic acid. Medium to coarse micrograined grains of calcite, containing several partings consisting of fine paurograined quartz and minute crystalline calcite. Quartz comprises 8 percent of the sample; fossil matter 1 percent.

O7. Canville limestone, NE¼ NE¼ NE¼ sec. 29, T. 27 S., R. 19 E., Neosho County, Kansas; acetic acid. Specimen is composed of medium to coarse paurograined quartz grains. Quartz has prominent bands of iron stains. (Lithologically, sample is a sandstone.)

O8. Captain Creek limestone, NW¼ NW¼ NW¼ sec. 20, T. 24 S., R. 18 E., Allen County, Kansas; acetic acid. Calcite as large areas of crystals and grains of fine to coarse paurograined size. Limonite, quartz, and a minute quantity of hematite interspersed among the calcite grains. Numerous vugs. Estimated percentage: calcite, 96; iron minerals, 3; and quartz, 1. The sample contains 2 percent fossil matter.

O9. Captain Creek limestone, NW¼ SE¼ NE¼ sec. 7, T. 12 S., R. 24 E., Johnson County, Kansas; acetic acid. Veins and individual mesograined crystals of calcite in a matrix of coarse micrograined to fine paurograined calcite grains. Traces of limonite. Fossil matter 2 percent.

O10. Captain Creek limestone, SW¼ NW¼ SW¼ sec. 2, T. 24 S., R. 20 E., Allen County, Kansas; hydrochloric acid. Numerous fossil fragments, mostly crystallized, make up 15 percent of the sample. The fragments, many areas of clear crystalline calcite, and scattered dolomite are contained in a matrix of very fine to medium paurograined granular calcite. Estimated percentage: calcite 95, dolomite 5.

O11. Critzer limestone, NE¼ NE¼ SE¼ sec. 24, T. 21 S., R. 23 E., Linn County, Kansas; hydrochloric acid. Profuse minute fragments of fossils in a glassy calcite matrix. Quartz grains and groups of grains and masses of limonite scattered through the matrix. Estimated percentage: calcite, 85; quartz, 7; and limonite, 8; 80 percent of the sample is fossil matter.

O12. Dewey limestone, NE¼ NE¼ NE¼ sec. 18, T. 26 S., R. 19 E., Allen County, Kansas; acetic acid. Intimate mixture of crystals and grains of calcite and iron-stained dolomite crystals. Calcite

grains are coarse micrograined to fine mesograined; crystalline calcite areas are large. Dolomite crystals as large is 0.3 mm. Fossils have been recrystallized and comprise 5 percent of the sample. Iron staining only on the dolomite. Estimated percentage: calcite, 93; dolomite, 7 (Pl. 2B).

O13. Farley limestone, SW¼ SE¼ SE¼ sec. 31, T. 14 S., R. 25 E., Johnson County, Kansas; hydrochloric acid. Clear crystalline calcite veins, fossil fragments, and minute particles of dolomite, chert, and limonite interspersed through a matrix of micrograined calcite partly obscured by glassy calcite. Estimated percentage: calcite, 98; limonite, 1; chert, 0.5; and dolomite, 0.5. Fossils constitute 2 percent.

O14. Merriam limestone, NW¼ SW¼ SW¼ sec. 18, T. 29 S., R. 16 E., Wilson County, Kansas; acetic acid. Crinoid columnals, bryozoan and other fossil fragments scattered profusely through an intimate mixture of calcite and limonite. Grain size of calcite obscured by limonite. Traces of siliceous material around some fossils. Estimated percentage: calcite, 75; quartz, 20; and limonite, 5. Fossil matter is 75 percent of the sample.

O15. Unnamed limestone in Lane shale, SE¼ SE¼ NE¼ sec. 7, T. 17 S., R. 22 E., Miami County, Kansas; hydrochloric acid. Areas of brownish clear crystalline calcite comprising about 40 percent of the sample are surrounded by areas of coarse micrograined calcite grains, interrupted by several partings of fine to coarse paurograined rhombohedral dolomite. Fossils mostly replaced by calcite, but a few silicified. Estimated percentage: calcite, 95; dolomite, 3; and silica, 1. Fossils make up 30 percent of the sample.

O16. Raytown limestone, NE¼ SE¼ SE¼ sec. 7, T. 17 S., R. 22 E., Miami County, Kansas; hydrochloric acid. Mixture of micrograined calcite and fine to coarse paurograined dolomite crystals. Scattered bryozoan fragments, crinoid columnals, and intergrowths of pyrite crystals. Dolomite most abundant at top and bottom of sample. Estimated percentage: calcite, 72.8; dolomite, 20; quartz, 7; and clay, 0.2. Fossil content is 3 percent of the sample.

O17. South Bend limestone, NW¼ NE¼ NE¼ sec. 32, T. 25 S., R. 17 E., Woodson County, Kansas; hydrochloric acid. Intimate mixture of limonite and medium micrograined to fine paurograined calcite grains and minor silica. Prominent banding in which either

limonite or calcite may predominate. Estimated percentage: calcite, 58; limonite, 40; silica, 2; and fossil matter, 1.

O18. Spring Hill limestone, SE¼ SE¼ NW¼ sec. 12, T. 17 S., R. 19 E., Franklin County, Kansas; hydrochloric acid. In a matrix of very fine to coarse paurograined calcite grains are chert particles, quartzose partings, traces of pyrite, and fossil fragments replaced by calcite. Estimated percentage: Calcite, 95, and quartz, 5; fossil matter 3 percent.

O19. Spring Hill limestone, SE¼ SW¼ SW¼ sec. 8, T. 15 S., R. 23 E., Johnson County, Kansas; hydrochloric acid. Numerous veins of clear crystalline calcite and areas of dolomite crystals in matrix of medium to coarse micrograined grains of calcite. Estimated percentage: calcite, 98, and dolomite, 2. Fossils make up 1 percent of the sample.

O20. Spring Hill limestone, SE¼ SE¼ NW¼ sec. 12, T. 17 S., R. 19 E., Franklin County, Kansas; hydrochloric acid. Almost entirely very fine to medium paurograined calcite grains and scattered areas of crystalline calcite. Sparse grains of quartz and dolomite. Estimated percentage: calcite, 97; quartz, 2; and dolomite, 1. Fossils 1 percent.

O21. Spring Hill limestone, SE¼ SE¼ NW¼ sec. 23, T. 19 S., R. 21 E., Linn County, Kansas; acetic acid. Large veins and areas of brownish clear crystalline calcite in matrix of very fine to fine paurograined calcite grains. Some crystalline areas show thin rims of cryptograined calcite. Fossils 4 percent of sample, but all recrystallized (Pls. 1A, 5A).

O22. Stoner limestone, NE¼ NW¼ NW¼ sec. 33, T. 18 S., R. 21 E., Franklin County, Kansas; hydrochloric acid. Prominent veins of crystalline calcite cut a cryptograined calcite matrix. Many vugs, most of which contain limonite. Estimated percentage: calcite, 95; limonite, 5; fossil matter, 1 percent.

O23. Winterset limestone, SE¼ SE¼ SE¼ sec. 21, T. 23 S., R. 21 E., Allen County, Kansas; hydrochloric acid. Areas of clear crystalline calcite, calcitized fossil fragments, particles of chert, siliceous spines, and masses of limonite in a matrix of fine to medium paurograined calcite grains, much of which is obscured by glassy calcite. Estimated percentage: calcite, 98; silica, 1; and limonite, 0.5; 6 percent of the sample is fossil matter.

CORE SAMPLES

Preceding each description, the interval of the core represented and the acid used for etching is noted.

C1. 3,299.3 to 3,299.8 feet; hydrochloric acid. Large areas of chert, ranging from white to very light gray (n8), and long veins of crystalline calcite in fine micrograined matrix of calcite grains. Chert particles contain a few calcareous fusulinids and, in one, a calcite crystal. Calcite also fills thin fractures in chert. Calcitized spines or spicules and several thin clay partings dispersed through the sample.

C2. 3,304.4 to 3,304.9 feet; hydrochloric acid. Chert partings and particles, clay partings, and clear crystalline areas of calcite, seemingly replacements of fossil fragments, scattered through a paurograined calcite matrix.

C3. 3,307.3 to 3,307.8 feet; hydrochloric acid. Brachiopods, many replaced by crystalline calcite, dispersed among fossil fragments, algal deposits, and areas of clear crystalline calcite; all included in a matrix of fine to coarse paurograined calcite grains. Disseminated particles of a silica-clay complex compound (Runnels, personal communication; material was tested with hydrofluoric acid).

C4. 3,312.4 to 3,312.9 feet; hydrochloric acid. Many fusulinids, brachiopods, and fragments, most of which are replaced by crystalline calcite, interspersed in a matrix of medium to coarse micrograined grains of calcite. Few random particles of silica-clay complex. Several small pieces of an iron compound, which cannot be identified.

C5. 3,320 to 3,320.5 feet; hydrochloric acid. Uniform, cryptograined calcite grades into uniform medium micrograined quartz grains. Upper part of sample calcite with quartz laminae, but quartz increases downward until calcite occurs as laminae in quartz in lower part.

C6. 3,325 to 3,325.5 feet; hydrochloric acid. Prominent areas of paurograined crystalline calcite in matrix of cryptograined calcite. Several stylolites of clean medium micrograined quartz grains. Several scattered particles of chert, one of which contains a prominent piece of sulfur. Scattered fossil fragments.

C7. 3,330.1 to 3,330.6 feet; hydrochloric acid. Cryptograined calcite matrix containing partings of quartz, calcite, and clay intimately mixed is the outstanding feature. Several fossils show replacement both by calcite and silica. Few minute flakes of some unknown compounds, probably containing iron. Many small areas of crystalline calcite, seemingly replacing fossil fragments, dispersed throughout.

C8. 3,334 to 3,334.5 feet; hydrochloric acid. Coquina of fusulinids, algae, and minute fragments of fossils cemented by clear micrograined crystalline calcite. Particles of chert scattered throughout.

C9. 3,339 to 3,339.5 feet; hydrochloric acid. Many irregular areas of crystalline calcite, some as fossil replacements, in uniform cryptograined calcite matrix. Few small areas of micrograined quartz grains and several scattered pyrite crystals.

C10. 3,340.5 to 3,341 feet; hydrochloric acid. In a matrix of uniform cryptograined grains of calcite are many crystalline calcite areas, minute fossil fragments, a few small chert particles, and several stylolites of micrograined quartz grains seemingly bonded by clay minerals. Large mass of pyrite prominent.

C11. 3,342 to 3,342.5 feet; acetic acid. Micrograined matrix of calcite grains containing random quartz grains, magnetite, pyrite, and a few minute fragments of sulfur. The only crystalline calcite is around the sparse fossil fragments. Several partings composed of quartz grains and minor amounts of clay. Pyrite is coarse micrograined and widely disseminated, as is the much finer magnetite.

C12. 3,344.3 to 3,344.8 feet; hydrochloric acid. Large areas of calcite crystal, from 1 to 15 mm, in uniform cryptograined matrix. Many fossil fragments, mostly recrystallized calcite but a few replaced by silica.

C13. 3,349.5 to 3,350 feet; acetic acid. Cryptograined calcite interrupted only by a few dark partings composed of fine micrograined quartz; color probably due to carbonaceous matter or finely disseminated dark minerals. Abundantly fossiliferous.

C14. 3,358.9 to 3,359.4 feet; hydrochloric acid. Densely fossiliferous with small crinoid columnals, algae, and assorted fossil fragments, many of which show partial replacement by silica. Matrix

cryptograined calcite, dark to megascopic examination, but disseminated material causing dark tint is too fine to be identified. A few micrograined quartz grains, showing iron stains.

C15. 3,360.2 to 3,360.7 feet; acetic acid. Calcite grains, fine paurograined to coarse mesograined, no readily apparent sorting. Some grains dark, but the cause cannot be detected.

C16. 3,365.3 to 3,365.8 feet; hydrochloric acid. Sample is composed almost entirely of very broken fossil fragments, bound by clear crystalline calcite filling voids. Slight silicification of fossil parts. Minute quantities of finely disseminated opaque material, probably pyrite.

C17. 3,367 to 3,367.5 feet; hydrochloric acid. Micrograined clay minerals and coarse micrograined silica particles dispersed throughout matrix of minute fossil fragments and paurograined calcite grains. Some silica replaces fossil fragments. Pyrite as fine micrograined crystals or as intergrowths reaching paurograined size. Magnetic opaque material, thought to be magnetite with the pyrite. Estimated percentage: calcite, 83; silica, 7; clay, 7; and opaques, 3.

C18. 3,368.3 to 3,368.8 feet; hydrochloric acid. Intimate mixture of fine paurograined to mesograined crystalline calcite and micrograined chert particles. Medium to coarse micrograined pyrite grains sparsely disseminated. Few siliceous partings. Estimated percentage: calcite, 75; chert, 24; and pyrite 1.

C19. 3,371.3 to 3,371.8 feet; hydrochloric acid. Crystalline calcite veins and fossil replacements in matrix of cryptograined to micrograined calcite grains. Only other constituent is chert as sparsely scattered particles; only 3 percent of the sample.

C20. 3,374.2 to 3,374.7 feet; acetic acid. Fine micrograined to fine paurograined calcite grains and few small crystalline calcite areas; few chert particles interspersed in interstices. Estimated percentage: calcite, 96, and chert, 4.

C21. 3,377 to 3,377.5 feet; hydrochloric acid. Small irregular pieces of chert and areas and veins of crystalline calcite in a matrix of fine to coarse micrograined calcite grains. Most fossils have been replaced by crystalline calcite or silica. Few crystals of pyrite. Estimated percentage: calcite, 93, and chert, 7.

C22. 3,378.8 to 3,379.3 feet; acetic acid. Intimate mixture of fine to coarse paurograined grains of calcite and quartz. Calcite grains

predominate at top and bottom, a higher percentage of quartz grains in the center section. Partings composed of medium to coarse paurograined quartz grains and few crystals of pyrite. A few fossils replaced by calcite and one large vein of crystalline calcite in the calcareous section.

C23. 3,381.7 to 3,382.2 feet; hydrochloric acid. Matrix composed of medium micrograined grains of calcite. Included in matrix are areas of calcite crystals, ranging from fine to medium mesograined, and scattered particles of chert. Stylolites of quartz grains, clay particles, and scattered pieces of pyrite and magnetite. Sample features a few inclusions of reddish-yellow (5YR7/6) flaky material believed to be an iron-clay compound. Estimated percentage: calcite, 96; silica, 4; and iron minerals, 2.

C24. 3,386.7 to 3,387.2 feet; hydrochloric acid. Large quantity of dolomite crystals and numerous pyrite crystals widely scattered throughout cryptograined, glassy calcite matrix. Dolomite crystals range from megagrained to micrograined; pyrite crystals generally micrograined, except for occasional larger intergrowth. Estimated percentage: calcite, 75; dolomite, 15; and pyrite, 10 (Pl. 4A).

C25. 3,388.8 to 3,389.3 feet; hydrochloric acid. Many areas of clear crystalline calcite and several crystalline masses of dolomite in glassy matrix of calcite. Pyrite finely disseminated and also concentrated along fractures. Calcite contains numerous minute fossil fragments.

C26. 3,392 to 3,392.5 feet; hydrochloric acid. Many dolomite crystals and coarse micrograined grains of pyrite in glassy calcite matrix. Two prominent stylolites of clay minerals. Estimated percentage: calcite, 86; dolomite, 12; clay, 1; and pyrite, 1.

C27. 3,394 to 3,394.5 feet; acetic acid. Fragments of dolomite crystals and few random particles of chert in matrix of medium to coarse.micrograined calcite grains. Three stylolites of dark, extremely fine granular material, possibly a mixture of quartz and clay minerals. Estimated percentage: calcite, 96; dolomite, 2; and chert, 4 (Pl. 2A).

C28. 3,397 to 3,397.5 feet; hydrochloric acid. Fragments of dolomite crystals and fine paurograined pyrite crystals in matrix of part glassy calcite, part clear crystalline calcite. Pyrite finely and widely disseminated. Estimated percentage: calcite, 96; dolomite, 3.5; and pyrite, 0.5.

C29. 3,401 to 3,401.5 feet; hydrochloric acid. Crystalline fragments of dolomite scattered through the sample, some surrounded by cryptograined calcite. Large crystalline calcite masses make up most of the sample; a few random pyrite intergrowths. One clay parting. Estimated percentage: calcite, 98, and dolomite, 1.

C30. 3,406.2 to 3,406.7 feet; acetic acid. Veins and areas of crystalline calcite, crystalline dolomite masses, and traces of pyrite in uniform, medium to coarse micrograined matrix of calcite grains. Estimated percentage: calcite, 99, and dolomite, 1.

C31. 3,410.5 to 3,411 feet; hydrochloric acid. Crystalline masses of dolomite and crystalline calcite, in form of veins, irregular areas, and fossil replacements, in matrix chiefly of medium to coarse micrograined calcite grains, but glassy in places. Estimated percentage: calcite, 93, and dolomite, 7.

C32. 3,419.5 to 3,420 feet; acetic acid. Fine to medium micrograined grains of calcite and quartz intimately mixed. Some areas of crystalline calcite. Fossil fragments replaced by both calcite and silica. Few partings of quartz grains bonded by clay minerals.

C33. 3,429.7 to 3,430.2 feet; hydrochloric acid. Entire specimen is oölitic, oölites ranging from about 0.3 to 1 mm. Some oölites replaced by crystalline calcite and some by dolomite. Material between oölites is coarse micrograined to fine paurograined calcite grains and veins of crystalline calcite. Estimated percentage: calcite, 98, and dolomite, 2.

C34. 3,431.3 to 3,431.8 feet; acetic acid. Sample is totally oölitic, the oölites ranging from 0.25 to 1 mm. Oölites bound by a partly micrograined, partly glassy matrix of calcite grains. Openings left by removal of oölites have formed small geodes. Prominent stylolite cuts across oölites. Distinct bedding (Pl. 3A).

C35. 3,436.8 to 3,437.3 feet; hydrochloric acid. Sample features many wavy and anastomosing partings of medium to coarse micrograined quartz grains. Partings and crystalline calcite areas and fossil replacements in matrix of fine to medium paurograined grains of calcite. Few fragments of chert and an occasional pyrite crystal. Estimated percentage: calcite, 94, and quartz, 6 (Pl. 1B, 4B).

C36. 3,441 to 3,441.5 feet; hydrochloric acid. Scattered fossils and fragments, replaced by crystalline calcite, and clear crystalline calcite veins in matrix of medium to coarse micrograined cal-

cite grains. In lower part of sample, very fine paurograined quartz grains and few minute pieces of pyrite disseminated through the matrix. Estimated percentage: calcite, 88, and quartz, 12.

C37. 3,445.7 to 3,446.2 feet; hydrochloric acid. Coquina of whole and fragmental fusulinids, ostracods, gastropods, corals, pelecypods, algae, and oölites bonded by glassy clear calcite.

C38. 3,447.5 to 3,448 feet; acetic acid. Coquina of fossil fragments and whole corals, fusulinids, and brachiopods, all cemented with fine to medium paurograined calcite crystals. Rock is extremely porous.

C39. 3,449.5 to 3,450 feet; hydrochloric acid. Numerous fusulinids and some crinoid fragments in a partly glassy, partly micrograined matrix of calcite grains. Partings of quartz grains and minute particles of a copper compound (proved by reaction with NH_4OH). Fusulinids generally oriented with longitudinal axis parallel to bedding. Estimated percentage: calcite, 95, and quartz, 5.

C40. 3,452 to 3,452.5 feet; hydrochloric acid. Extremely fossiliferous (algae, fusulinids, and fragments); many fossils have been replaced by crystalline calcite. Scattered among the fossils are minute chert particles, few pyrite crystals, and trace of copper; all in matrix of medium micrograined to coarse paurograined calcite grains. Estimated percentage: calcite, 98, and quartz, 1.

C41. 3,456.5 to 3,457 feet; hydrochloric acid. Coquina of algae, ostracods, and fragments of other fossils, cemented with cryptograined calcite. One fragment of dolomite, several pyrite crystals. Several partings, composed of platy clay minerals.

C42. 3,460.6 to 3,461.1 feet; hydrochloric and acetic acids. Several partings of medium paurograined quartz grains and scattered chert particles and a few areas of crystalline calcite in matrix of medium micrograined to fine paurograined calcite grains. Estimated percentage: calcite, 99, and quartz, 1.

C43. 3,464 to 3,464.5 feet; hydrochloric acid. Large areas of what is apparently a mixture of calcite and an iron compound, and large crystal fragments of dolomite in uniform, cryptograined matrix of grains of calcite. Estimated percentage: calcite, 97; iron mineral, 2; and dolomite, 1 (Pl. 3B).

C44. 3,468.1 to 3,468.6 feet; acetic acid. Oölitic, interstices filled with very fine to fine paurograined calcite. Several pronounced stylolitic zones, and numerous vugs.

C45. 3,470.3 to 3,470.8 feet; acetic acid. Numerous rounded masses of crystalline calcite, traces of chert and dolomite in paurograined calcite matrix. Numerous vugs, many of which are geodiferous.

C46. 3,475.2 to 3,475.7 feet; hydrochloric acid. Intimate mixture of oölites, fusulinids, algae, other fossil fragments, and scattered particles of chert and dolomite in a cryptograined calcite matrix. Several stylolites in the upper part, and traces of copper. Estimated percentage: calcite, 98; dolomite, 0.5; and chert, 1.

C47. 3,478.8 to 3,479.3 feet; hydrochloric acid. Areas of clear calcite crystals, chert particles, pyrite intergrowths, dolomite crystals, and quartzose partings scattered through matrix of very fine to medium paurograined calcite grains. Some of the crystalline calcite replaces fossil fragments. Estimated percentage: calcite, 97; dolomite, 1; chert, 1, and pyrite, 0.5.

C48. 3,482 to 3,482.5 feet; hydrochloric acid. Intimate mixture of cryptograined calcite and coarse micrograined to medium paurograined quartz grains. A few particles of chert, traces of copper compound, and scattered nodules of what seems to be weathered or altered pyrite. Estimated percentage: calcite, 63; quartz, 35; and pyrite, 2.

C49. 3,487.6 to 3,488.1 feet; acetic acid. Many fusulinids and some crinoid fragments, nearly all recrystallized, and traces of pyrite in fine to coarse paurograined matrix of calcite grains. Numerous vugs, 1.5 to 0.05 mm in diameter, many geodiferous.

C50. 3,492 to 3,492.5 feet; hydrochloric acid. Areas of crystalline calcite and stylolites of quartz grains and clay in uniform micrograined calcite grain matrix. Dark areas seemingly caused by finely disseminated carbonaceous or mineral matter, but no definite particles detected. Estimated percentage: calcite, 89; opaques, 10; and quartz, 0.5.

C51. 3,497.6 to 3,498.1 feet; hydrochloric acid. Very few chert particles and pyrite crystals in matrix of very fine to medium paurograined calcite grains. Estimated percentage: calcite, 99; chert, 0.5; and pyrite, 0.5.

C52. 3,508.7 to 3,509.2 feet; acetic acid. Small particles of chert and fossil fragments replaced by crystalline calcite in matrix of mixed very fine to medium paurograined quartz grains and medium to coarse micrograined calcite grains. Several bits of copper com-

pound. Quartz shows fair bedding. Estimated percentage: quartz, 60, and calcite, 40.

C53. 3,515.2 to 3,515.7 feet; hydrochloric acid. Laminae of fine to medium paurograined quartz grains alternating with layers of coarse micrograined to fine paurograined calcite grains, which also contain areas of crystalline calcite.

C54. 3,525.8 to 3,526.3 feet; hydrochloric acid. Several stylolites of silica and clay and many scattered areas of crystalline calcite in matrix of very fine to medium paurograined calcite grains.

C55. 3, 537.6 to 3,538.1 feet; acetic acid. Intimate mixture of re-crystallized oölites and fossil fragments cemented by paurograined calcite grains and minor amounts of iron carbonate. Few particles of chert and trace of copper compound. Estimated percentage: calcite, 96, and iron carbonate, 3.

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