

PETROGRAPHIC ANALYSES OF THE INSOLUBLE RESIDUE
OF THE PERMIAN CHASE AND COUNCIL GROVE LIMESTONES
WITH REGARD TO THE ORIGIN OF CHERT

by

ROBERT OLDS WILBUR

B. S., Kansas State College
of Agriculture and Applied Science, 1954

A THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Geology and Geography

KANSAS STATE COLLEGE
OF AGRICULTURE AND APPLIED SCIENCE

1956



LD
2668
T4
1956
W56
C.2

Document

11

TABLE OF CONTENTS

	Page
INTRODUCTION	1
Purpose of Investigation	1
Area of Investigation	2
Stratigraphic Units Investigated	2
Methods of Investigation	3
REVIEW OF LITERATURE	3
Chert and Flint	4
Organic	15
Inorganic Precipitation	16
Magmatic Origin	17
Penecontemporaneous	17
Cavity Fillings	20
Replacement Below Water Table	20
Replacement Above Water Table	21
Chalcedony	23
Opal	25
Volcanic Ash	26
Bentonites	28
Tuffs	29
Unaltered Ash Deposits	30
Sediments Containing Individual Shards	30
Heavy Minerals	31
PROCEDURE OF INVESTIGATION	36
Determining Units and Areas to be Sampled	36

Securing Samples From the Field	37
Sample Preparation in Laboratory	39
Rock Preparation	39
Acid Treatment	41
Heavy Mineral Separation	43
Preparation of Detrital Slides	45
Sample Analysis	46
RESULTS OF ANALYSES	48
Types of Cherts Sampled	48
Presence of Ash and Amorphous Silica	55
Volcanic Ash	55
Amorphous Silica	59
Light and Heavy Mineral Analysis	60
Light Minerals	60
Heavy Minerals	65
Coarse Residue Analysis	67
CONCLUSIONS	71
Origin of the Cherts	71
Long Creek Limestone	74
Bennett Shale Bioherm	74
Neva Limestone	75
Cottonwood Limestone	75
Morrill Limestone	76
Eiss Limestone	77
Crouse Limestone	77

Funston Limestone	78
Stovall Limestone	78
Cresswell Limestone	79
Herington Limestone	79
Hollenberg Limestone	80
Ash in the Non-Cherty Limestones	81
General Conclusions	81
ACKNOWLEDGMENTS	83
BIBLIOGRAPHY	84

INTRODUCTION

Purpose of Investigation

This investigation consisted of the collection, preparation, examination and analyses of the insoluble mineral constituents of some of the lower middle Permian limestones in the Flint Hills physiographic region of East Central Kansas. Particular attention was given to those parts of limestones immediately adjacent to cherty nodules. It was hoped that by determining and comparing the insoluble mineral suites of both the limestones containing chert and the chert free limestones of the same or different horizons, characteristic differences between them might provide valuable information concerning the origin of the chert. Previous investigators at Kansas State College believed that volcanic ash was essential in chert genesis, since they found that only cherty limestones contained volcanic ash as an accessory constituent.

It was also hoped that studies of the mineral suites would help in correlating the limestone units in subsurface studies. The insoluble residue from any rock unit whose mineral suite is notably different from those rocks of the same lithologic character above and below, and which maintains that same mineral suite over a large horizontal area, can be used for correlation purposes.

After a thorough review of the literature, it became apparent that little scientific data existed concerning the finer grained sedimentary rocks, shale, limestone, and chert. Petrographic studies, such as this, provide information about properties and genesis of these all-important sediments.

Area of Investigation

The rocks that were sampled in this study were confined to the East Central portions of Kansas known as the Flint Hills physiographic province, and included the counties of Riley, Clay, Pottawatomie, Geary, Lyon, Chase, and Marion.

Stratigraphic Units Investigated

With one exception, all of the rocks sampled were from the Chase and Council Grove groups of the Wolfcampian Series. The exception was the Hollenberg limestone, which is the basal limestone of the Wellington shale of the Sumner group, Leonardian Series. The Wellington shale lies immediately above the Herington limestone, the upper member of the Wolfcampian Series. The Florence, Schroyer, and Threemile limestones of the Chase group, all of which are very cherty, were not covered in this investigation, since Hartig (1954) had already conducted a similar study of them. Also the Krider limestone of the Chase group and the Glenrock limestone of the Council Grove group were excluded, since good outcrops were not available in the area.

Methods of Investigation

The procedure for this study was conducted in the following sequence: (1) A thorough review of the literature was made to determine the localities of outcrops of various Permian limestones known to contain chert. (2) Samples, as free as possible from contaminants, were collected from carefully selected localities and brought to the laboratory. (3) The carbonates were removed by hydrochloric acid and the remaining insoluble residue separated into light and heavy fractions and mounted on glass slides. (4) The slides were then examined with the petrographic microscope to determine their mineral properties and identification. (5) The above procedures were supplemented, where needed, with the oil immersion method, and binocular microscope examinations.

REVIEW OF LITERATURE

The literature dealing with the definitions and origins of the many different forms of naturally occurring silica has revealed a continuous controversy. A uniform usage of such terms as flint, chert, and chalcedony has seldom been agreed upon, partly because little is known about the physical and mineralogical composition of these and other forms of silica, and partly because the origin of these important materials is so difficult to determine. After intensive study of the literature concerning these materials it appeared that no one theory

adequately answered all of the questions that have arisen from field and laboratory studies. Therefore, the following discussion will present the more plausible theories of chert origin and the criteria responsible for the formation of these theories.

Chert and Flint

On the subject of chert and flint, there is little agreement among previous workers as to their exact definition; their differences, if any; and, most important of all, their origin (Glock, 1920).

In discussing the definitions of chert and flint that were most widely accepted, Glock (1920) summarized them as follows:

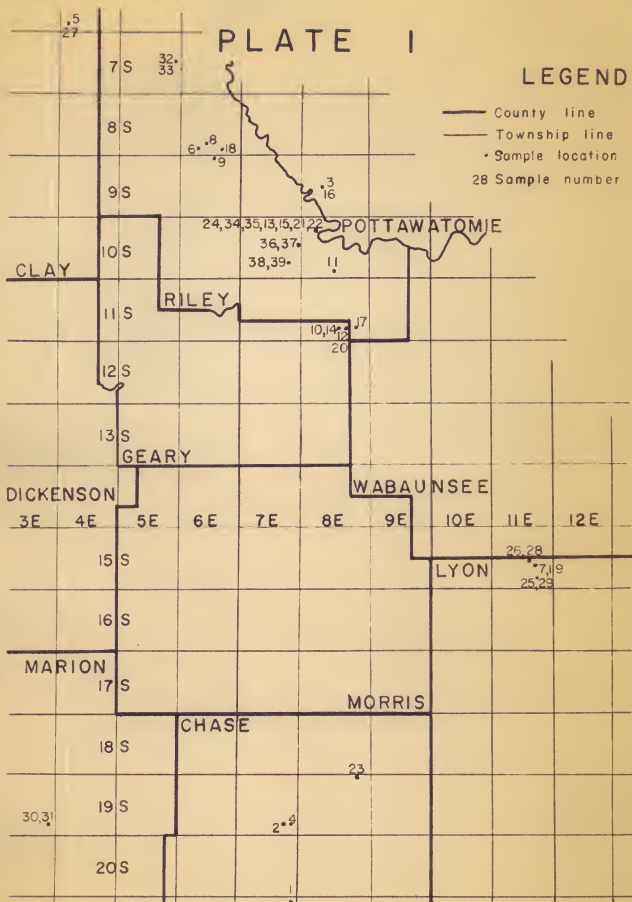
Chert. 'impure flints, usually light colored'; 'a more or less general term applied to hornstone, impure flint and jaspers'; 'siliceous concretions in limestone'; 'an amorphous and hydrous variety of quartz'; 'hornstone and chert are names given to compact flinty varieties of chalcedony, the latter is generally of organic origin'.

Flint. 'a very compact, dark grey siliceous rock', occurs in limestone; 'a compact dark chalcedonic or lithoid form of quartz'; found in chalk deposits; 'gray, smoky, brown, . . . nodular variety (of quartz) closely related to chalcedony. It is usually found in chalk beds and limestone'; 'siliceous concretions found in chalk; 'flint contains sponge spicules and is of organic origin'; 'jasper variety of quartz; diagenetic origin; caused by meteoric water; 'a subvitreous variety of quartz resembling chalcedony somewhat . . . and occurs chiefly in the chalk of England and France'.

Chert and Flint. Silica, deposited as shells, is later gathered into nodules or concretions of chert or flint; no difference; chert and flint are compact or crypto-crystalline and not glassy; 'flint and chert are gray to black, translucent to opaque quartz masses which occur in chalk and limestone'.

Explanation of Plate I

Map of area showing locations of outcrops sampled.



Explanation of Plate II

Plate II shows a stratigraphic column of the rocks sampled. This column shows the approximate thickness of the limestones in the Manhattan area. Important divergences from this lithology are indicated along the side of the main column with the name of the locality printed above. The shales, in each case, were broken to the same size since only their stratigraphic position was of importance in this thesis.

PLATE II

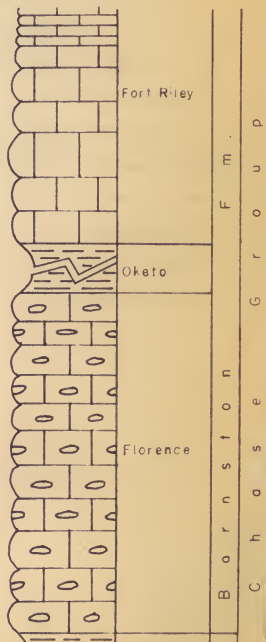
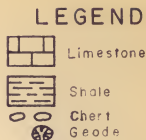
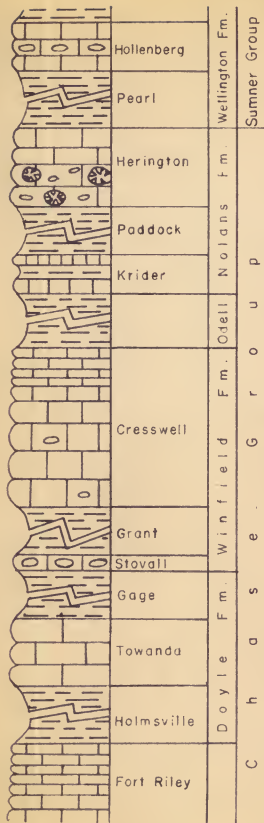


PLATE II (Cont.)

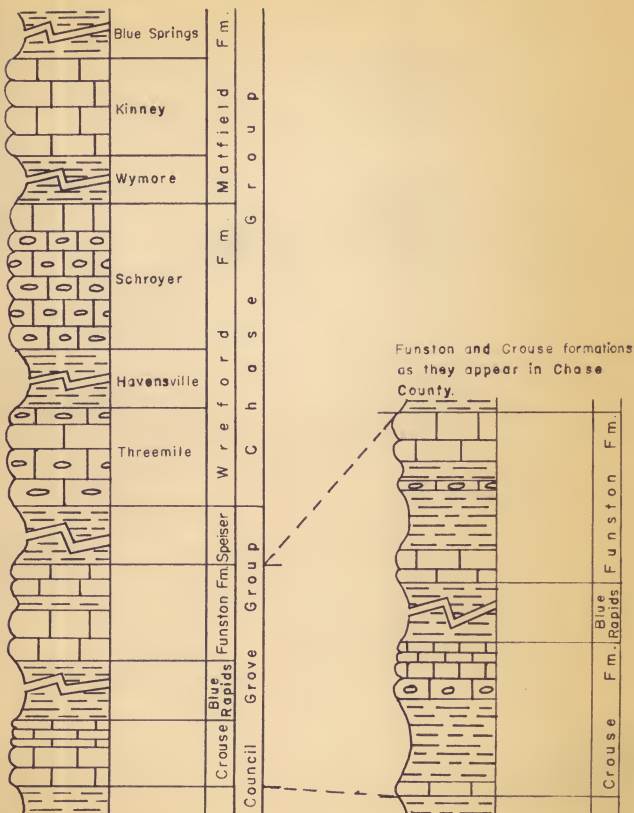


PLATE II (Cont.)

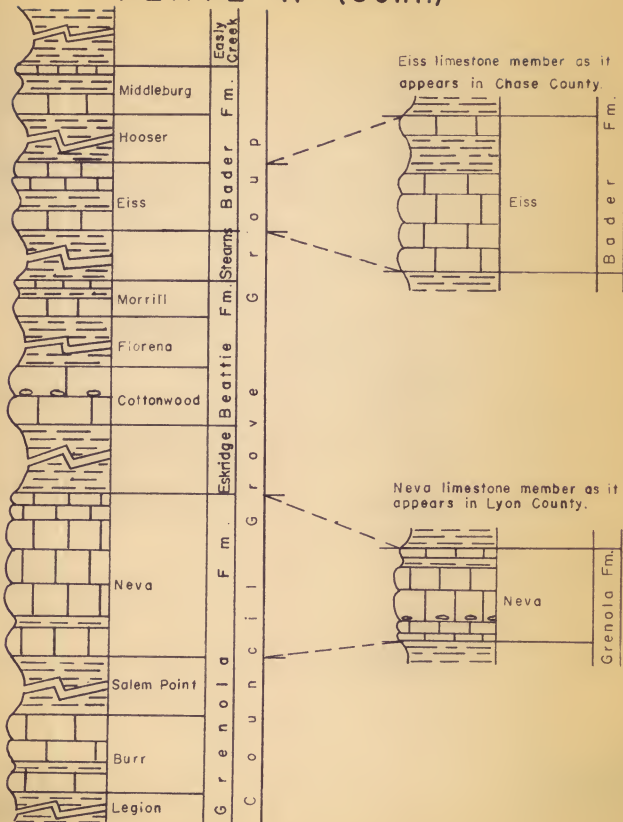
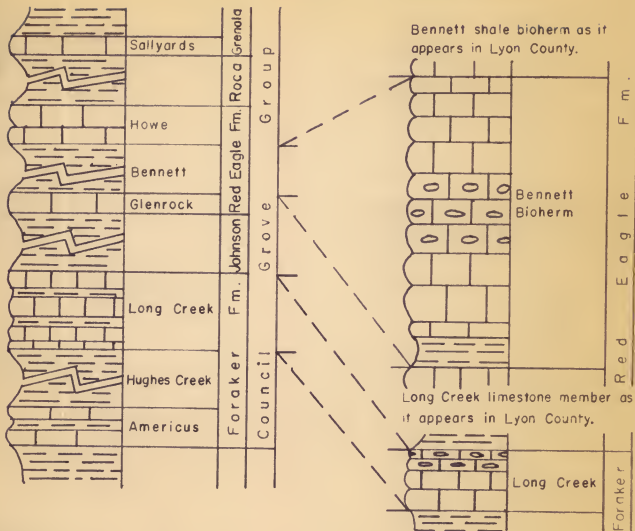


PLATE II (Concl.)



Pettijohn (1949), p. 320, defined chert as "... a dense cryptocrystalline rock, composed mineralogically of chalcedony (microcrystalline fibrous silica and microfibrinous amorphous silica or opal) and cryptocrystalline quartz." Flint, he stated, had been used as both a synonym for and a variety of chert, and, quoting Tarr, said that the term should be dropped or reserved for artifacts.

Other varieties of chert include jasperoid, a dense, dark gray to black chert that is a common gangue material for the lead-zinc ores of the Tri-State region (Bastin, 1951); jasper, "... a red or brown chert, made up of cryptocrystalline quartz colored by ferric oxides" (Williams, et al., 1954, p. 359); porcelainite, a siliceous material (opal and chalcedony) with a texture and appearance of unglazed porcelain (Taliaferro, 1934); and many other materials with a slightly different appearance or origin but essentially the same composition, such as novaculite, hornstone, agate, distonite, radiolarite, silicite, phthanite, tripoli, siliceous sinter, and geyserite (Pettijohn, 1949, p. 320).

The mineralogical constitution of chert is also disputed. Tarr (1926) said that chert is made up of cryptocrystalline varieties of quartz. Frye and Swineford (1946) described the chert of the Ogallala formation in Kansas as composed of opal, chalcedony, fine-grained calcite, and minor quartz. Pure cherts, according to Taliaferro (1935) are hardened, greatly dehydrated silica gels, whereas Twenhofel (1919) found no

amorphous silica in the Wreford and Foreker cherts of southern Kansas. Although Spock (1953) p. 179, called chert chalcedonic, Keller (1941), in discussing the Permian Rex chert, said that its chief component was microcrystalline quartz, and not chalcedony. Williams, et al. (1954), p. 359, summarized the problem by stating, "Chert is a general name for very compact sediments composed of opal, chalcedony, and cryptocrystalline or microcrystalline quartz, or a mixture of these constituents. It may have any color and undoubtedly originates in a number of ways."

Twenhofel (1950), pp. 410-414, discussed the more prominent theories of the time and mode of origin of chert and flint, and divided them into the following categories:

- Syngenetic (contemporaneous)
 - Organic precipitation
 - Inorganic precipitation
 - Magmatic origin
- Diagenetic (penecontemporaneous)
- Epigenetic (subsequent)
 - Filling of cavities
 - Replacement
 - Zone of cementation below water table
 - Zone of weathering above water table

All of these theories have their strong proponents, and the evidence is such that most or all of these theories explain the origin of the different chert deposits throughout the world. It should be kept in mind, however, that any author who hypothesizes the origin of chert is, in reality, hypothesizing only the particular chert studied and not cherts as a whole. In the following discussion, each of the theories outlined by Twenhofel

will be presented.

Organic. One of the older theories on the genesis of chert was proposed after it was noted that chert nodules frequently were found to contain numerous, well preserved fossils. Grabau (1924), p. 764, and Chamberlain and Salisbury, as summarized by Glock, (1920) concluded that siliceous fossils, such as sponge spicules and siliceous shells, aggregated about organic nuclei and were cemented together by silica precipitated from the sea water. This silica originally came from partially and wholly dissolved siliceous organisms.

A modified and more recent version of this theory was proposed by Bramlette (1946) in his study of the diatomaceous Monterey formation of California. He believed that the only possible source of silica for such a tremendous number of diatoms was from dissolved volcanic ash deposited contemporaneously with the diatomite. There was ample evidence of ash in the form of scattered shards, volcanic ash beds, and bentonite beds throughout the Monterey formation. A possible source of the silica cement in the diatomite deposits came from the volcanic ash as it altered to bentonite, since it takes 1.5 parts of silica in volcanic ash to form 1 part of silica in a bentonite (Weaver, 1953), the excess silica going into solution or redepositing in another form. Shrock (1948), p. 91, supported this idea by saying, "Unusual numbers of radiolarians, diatoms, sponges, and other silica-precipitating organisms might well indicate a strong influx of silica."

Rubey (1929) attributed the origin of the siliceous material of the Mowry shale in the Rocky Mountain area to the precipitation of silica from sea water by decaying organic material.

Twenhofel (1919) wondered if the banding in the Wreford and Foraker limestones of Kansas might be due to a siliceous replacement of fossil cryptozoa. This possibility has received little study.

Inorganic Precipitation. The main proponent of the direct precipitation theory was Tarr (1917, 1926, 1933). He proposed the idea that silica, having been chemically weathered on land, was carried to the sea in colloid form and precipitated by alkali salts in the sea water. This precipitate appeared as an amorphous colloid gel on the sea floor and later hardened to form irregularly elliptical chert nodules. Later, he substantiated these findings in a general theory on chert origin (Tarr, 1926), and still later in a study of the Miami-Picher lead-zinc area (Tarr, 1933). As evidence for this theory, he stated that silica was the second most common material carried to the ocean by fresh water streams, yet was found in less than one part per million in sea water. This indicated chemical precipitation of the silica upon reaching the ocean, since this quantity is much too great for the siliceous organisms to remove. The ellipsoidal shape of the colloidal gel was due to a partial flowing of the gel under its own weight, and the presence of many chert nodules along the same bedding plane indicated rapid

deposition of the gel with a rapid cover of sediments being deposited on top. Tarr's studies of the paleogeographic distribution of chert indicated an accumulation of these deposits in the shallow epi-continental seas where the fresh and salt waters would have had a chance to mingle (Twenhofel, 1950, p. 409). Lack of the expected clastics in these spots to mask any gel precipitate was explained by the fact that highly weathered, low-lying land masses would furnish few clastics but an overabundance of silica.

Magmatic Origin. Magmas may have played a part in the origin of some cherts, both as a direct source of the chert, itself, as seen intimately interstratified with pillow lavas, (Williams, et al., 1954, p. 360), or as an indirect source of the silica, only, such as the Pre-Cambrian cherts of Canada (Twenhofel, 1950, p. 411). Formerly magmas were thought to be the source of the Tri-State jasperoid deposits, but Tarr (1933) later questioned this.

Penecontemporaneous. This genetic theory of chert genesis is somewhat similar to Tarr's direct precipitation theory, except that the silica that was precipitated with the other sediments was not formed into chert nodules until later during diagenesis.

It has been frequently recorded in the literature that cherts or other silicified sediments often underlie bentonite beds. As was previously mentioned, excess silica is often the result of volcanic ash beds altering to bentonites. Whether

this silica was redeposited in the form of chert during diagenesis or later when the beds were lithified, is not always known for certain, but Grim (1953), p. 363, has stated,

The evidence strongly indicated that the alteration of the ash to montmorillonite takes place soon after accumulation or possibly almost contemporaneously with accumulation. It does not seem, at least in most cases, to be a later process and certainly is not a weathering process.

If this were true, then the discussion of cherts related to ash beds should come under diagenesis rather than epigenesis.

Kerr and Kulp (1949), in collecting bentonites for reference clay minerals, noted that most of the bentonites samples were underlain by siliceous deposits. Flowers (1952) and Pettke (1952) noted the same feature in studying some Paleozoic "metabentonites". Probably one of the best examples of this feature is the Mowry shale of the Rocky Mountain region, as studied by Rubey (1929). He hypothesized that when volcanic ash fell into the ocean and was partly dissolved by the numerous bases present, the silica became precipitated by decaying organisms to form a gel on the ocean bottom. This gel became thoroughly mixed with clastics, since the silica was deposited concurrently with the other sediments. Also the supersiliceous solutions that were formed as the ash altered to bentonite leached through the underlying shale and redeposited their silica. This was evidenced by the fact that the shales became increasingly harder progressively towards the bentonite beds. Twenhofel (1919) believed that the silica responsible for the cherts in the Wreford and Foraker limestones of southern Kansas was deposited with the

sediments. This silica then went into solution and diffused through the unconsolidified sediments, finally forming chert nodules around organic nuclei. He believed the original source of the silica was either dissolved finely-divided silica silt, dissolved siliceous organisms, silica present in the sea water, or silicates deposited with the sediments.

Folk (1949) called the chert of the lower Ordovician Beekmantown group a syngenetic or early replacement of the calcium carbonate. The presence of V-shaped shrinkage cracks in the chert pointed to an early gel origin.

Keller (1941) used the same evidence for labeling the Permian Rex chert penecontemporaneous, although he did not know whether the source of the silica was volcanic or weathered rocks.

In studying the cherts of the Florence, Schroyer, and Threemile limestones of the Manhattan area, Markley (1953) found shards of ash in the chert nodules. Hartig (1954), in studying the limestones of the same units, discovered ash shards in the limestones containing chert nodules. However, in the limestones and shales above and below the cherty limestones, no ash was found. Together they concluded that the cherts were formed by the penecontemporaneous deposition of volcanic ash with the normal marine sediments. This ash, together with partially dissolved ash formed a mushy gel on the sea floor. Subsequent lime deposition covered the gel mass and lithified while the silica was still soft. As a result, the

limestone adjacent to the gel mass was replaced by the silica in the gel, this process lasting until the excess silica was exhausted.

Hartig (1954) also found montmorillonite in the shales adjacent to the cherty limestones. He concluded from this that ash that fell onto a limey bottom was either converted into chert or preserved as a shard, and the ash that fell onto a muddy bottom was converted into montmorillonite.

Cavity Fillings. Van Tuyl (1918) mentioned that he had seen some cavities and fissures containing chert, but Twenhofel (1950), p. 412, believed that this mode of origin was of little consequence in considering the overall chert deposits of the world.

Replacement Below Water Table. One of the more popular theories of chert origin, at least for nodular cherts, is that of replacement of the original sediment, usually limestone, by silica deposited from cold circulating ground waters. Van Tuyl (1918) gave the following evidence for this replacement theory:

- (1) the occurrence of chert along fissures in limestone
- (2) the very irregular shape of some chert nodules
- (3) the presence of irregular patches of limestone in some chert masses
- (4) the association of silicified fossils and chert in some limestones
- (5) the presence of replaced fossils in some cherts
- (6) the preservation of structures and textures in some cherts
- (7) the failure of some cherts to follow definite zones in limestone formations
- (8) the occurrence of silicified colites formed by the replacement of calcareous ones

Howell, et al. (1953), p. 164, found evidence of chert in the Permian reefs of Texas showing traces of the original stratification of the adjacent limestone. Bestin (1933) found similar features in the Mississippian Boone formation of Missouri. He also found cherts bordered by stylolites, indicating that the cherts were both older and younger than the stylolites. Trefethen (1947), in describing this same feature, called attention to the V-shaped shrinkage cracks as evidence that the replacing silica was in the form of a colloid gel. White's (1947) study of some Mexican cherts showed that the replacing chert nodules retained the same color as the adjacent replaced limestone.

Replacement Above Water Table. This type of replacement usually implies the downward leaching of highly siliceous waters from the weathering of rocks on the surface. Before much was known about subsurface geology, cherts were believed to be a surface phenomenon, a view held by Bain and Ulrich (1905) in their study of the Potosi chert of Missouri. This idea was also supported by Pirsson and Schuchert, as reported by Glock (1920).

Recently Frye and Swineford (1946) applied this replacement theory to the origin of the silicified rock in the Ogallala formation (Pliocene) of the Great Plains area. In determining the source for the silica in the Ogallala, both opalized chert and quartzite, they excluded the possibility of circulating ground water, since the concentration of silica

was too low and was present in solution, whereas the opalized chert was colloidal in origin and came from a highly siliceous solution. Since volcanic ash beds occurred above the silicified zones, it was believed that this was the source for the highly charged waters. If solutions of silica are acid, as believed in this case, then precipitation was produced when the solutions came in contact with the calcium carbonate zones in the Ogallala. Therefore, silica was formed as a replacement of the earlier calcium carbonate cement.

At this point it should be mentioned that even though most geologists agree that silica is transported as a colloid, there is by no means unanimity on this subject. Reiche (1950), p. 19, defined a solution as "... a system in which the dispersed-phase material is in units of molecular and ionic dimension". A colloid, he defined as "... a dispersed substance whose particle diameters range between 5 millionths and 200 millionths of a millimeter". Tarr (1917, 1926) believed that the silica brought down to the oceans by streams was colloidal in form and was the result of chemical weathering on land. Jenny, as quoted by Hauser (1952) went farther by describing how silica tetrahedra were peeled off of primary minerals, such as orthoclase, during weathering, by a combination of hydration and hydrolysis, and transported by streams as a colloid. Twenhofel (1950), p. 405, stated that transported silica appeared mostly in the form of a hydrophyllic colloid that was not very sensitive to electrolytes, although in his study of the Wreford formation (1919), he thought

that the source of some of the silica may have been from dissolved siliceous organisms or dissolved silica silt. Roy (1945) analyzed the problem of silica transportation and concluded that most geologists considered silica as a true colloid, while chemists were almost unanimous in believing that silica appeared in solution as the SiO_3^- ion or in crystalloid form.

Chalcedony

Chalcedony, unlike chert, is a mineral rather than a rock, but like chert, its exact composition is not agreed upon in the literature. Many have considered chalcedony as a variety of quartz. Palto (1956) defined chalcedony as a microcrystalline quartz with submicroscopic pores. Williams, et al. (1954), p. 358, concluded that amorphous silica and other impurities may also be present. Sosman (1927), p. 154, on the other hand, said chalcedony was neither quartz nor a variety of quartz. Instead he called it an end member of a series of natural silica minerals with a chemical composition of $\text{SiO}_2 + \text{H}_2\text{O}$, the other end member being opal. Sosman's definition of chalcedony was a "waxy, translucent, natural, micro-crystalline-fibrous silica".

After studying the textures of various chalcedonies and cherts with an electron microscope, Folk and Weaver (1952) found numerous cavities in the chalcedony that they interpreted as being filled with water. If this were true, then chalcedony does not contain opal, as such, as an impurity, but is only a type of quartz with numerous inclusions of free water. They also noted

an absence of any fibers, as would be expected from a microscopic study of chalcedony, but found instead alternating zones of few and many cavities. In their conclusions they stated that chert and chalcedony contained two types of quartz; microcrystalline quartz of interlocking equant grains in random or polyhedral orientation, and chalcedonic quartz, a massive and homogeneous quartz with few or many water inclusions. They also stated that the chalcedonic quartz differed from the "regular" quartz, with reference to the specific gravity and index of refraction, in direct relation to the number of cavities that the chalcedonic quartz contained.

Pelto (1956), in a recent study of chalcedony, arrived at approximately the same conclusions as Folk and Weaver. He noticed that often chalcedony grades imperceptibly into quartz, a feature noticed by others (Sosman, 1927, p. 789). The brown color of chalcedony, according to Pelto, was due to the scattering of light from submicroscopic pores. It was not definitely known, however, whether the water in these pores was bonded chemically or not, since the evidence was contradictory. Chalcedony behaved like opal, in that it was attacked by alkalis, whereas quartz was not. The heating curve of chalcedony started at a lower temperature and extended over a wider range than quartz, and there was no heating break in the curve at 375° Centigrade, the inversion point of quartz. Also, even small particles of chalcedony did not lose large amounts of water below 350° Centigrade. On the other hand, X-ray has

shown chalcedony to have the same atomic arrangement as quartz (Sosman, 1927, p. 154, and Pettijohn, 1949, p. 111).

Opal

Taliaferro (1935), who did extensive research on opal, defined it as a "... hardened, greatly dehydrated silica gel". The amount of water that it contains may be as high as 12 percent (Sosman, 1927, p. 794) with cristobalite or quartz becoming impurities when the water content is below 10 percent (Winchell and Winchell, 1951, p. 251).

Taliaferro (1935) showed how the density and index of refraction of opal were inversely proportional to the water content. In the same investigation he found that the index of refraction-density-water content curves of various opals appeared midway between the calculated curves of anhydrous-silica-water and cristobalite-water, thus indicating that the atoms of opal were not entirely random. Proof of this came from X-rays of opal that showed a faint beta-cristobalite (high temperature silica) pattern, even though the opal appeared isotropic under the microscope.

The index of refraction of opal varies from 1.41 to 1.46 (Pettijohn, 1949, p. 112), but if it is true that opal eventually crystallizes to chalcedony and then to quartz (Tarr, 1926), then various stages of transitional opal-chalcedony (birefringent opal) should be found in nature. References to such a transitional opal were not discovered in the literature, but vague

references to "opal or glass" were used by Rubey (1929), "opal or amorphous silica" by Twenhofel (1950), p. 403, "... amorphous form of silica, ... harder and denser, and has a much higher refractive index (1.53±) than opal, and is said to contain much less water than opal" by Williams, et al. (1954), p. 358, and "an unknown mineral similar to opal (index approximately 1.42) but with a birefringence higher than chalcedony.." by Bramlette (1946).

Frye and Swineford (1946) described the opaline nodules and cement of the Ogallala formation of the Great Plains area as having come from the silica of volcanic ash, and mentioned that the presence of opal as a cement was seldom found in literature. Goldman (1915) found the sand grains of the Catahoula sandstone of Texas cemented with opal, and Newell, et al. (1953), p. 163, believed that some chalcedony sponge spicules found in the Permian reef of Texas were formerly opal. Taliaferro (1934) determined the banded spheroids of the Monterey formation, California, to be opal, with the banding due to the dehydration and contraction of the colloid gel, and Pettijohn (1949), p. 499, stated that probably most chalcedony was originally opal. Milner (1952) p. 511, emphasized the fact that opal was invariably of secondary origin.

Volcanic Ash

Although the complex mechanics of volcanic eruptions are not exactly known, it is believed that all of the molten magma

in the vent of the volcano changes almost simultaneously from the molten liquid state to the gaseous state, accompanied by a tremendous change in volume (Pirsson, 1915). Volcanic ash formation is dependent upon the kinetics of gas evolution, the crucial factor being the number of bubbles per unit volume which may be present at a certain time (Verhoogen, 1951).

Twenhofel (1950), p. 144, defined volcanic ash as the broken glass of lava froth. The lava bubbles cooled so rapidly, while in the air, that the liquid did not have time to crystallize, and the resulting ash became an amorphous glass with the approximate chemical constitution of the original magmas.

When the volcano exploded, the ash was ejected with such force that it was blown into the upper stratosphere where the wind may have carried it around the world many times before coming to rest (Kuenen, 1950, p. 212). In fact Spock (1953), p. 60, stated that the finest dust may remain in the atmosphere indefinitely.

The individual ash particle, termed shard, usually has a characteristic shape, determined by where along the bubble boundary the shard came from, and the size of the vesicles present (Swineford and Frye, 1956). Ross (1928) divided shards into three shapes: (1) Y-shaped shards from the junction of three bubbles, (2) flat, angular plates from the area between two bubbles, and (3) fibrous shards.

Twenhofel (1950), p. 145, said that "ash has fallen everywhere and has been incorporated in all kinds of sediments".

Kuenen (1950), p. 212, concluded from studies of recent marine sediments that ash comprises the important part of ocean sediments as far as 500 kilometers away from the source, and that volcanic muds (where ash is the dominant sediment) constitute 0.5 percent of the total present day marine sediments.

Volcanic ash, both from ancient and recent sediments, may be divided into four convenient categories; ash beds that have altered to bentonite, tuffs, unaltered ash deposits, and sediments containing individual shards.

Bentonites. Pettijohn (1949), p. 265, defined bentonite as "...a rock composed of clay-like material -- usually montmorillonite, less commonly beidellite -- which has been formed by the devitrification and attendant chemical alteration of glassy igneous material". According to Grim (1953), p. 361,

.....it has the unique characteristic of swelling to several times its original volume when placed in water, and it forms thixotropic gels with water even when the amount of bentonite in such gels is relatively small.

Metabentonites are also formed by the same process, but do not have the properties of intense swelling and thixotropy due to the almost complete collapse of the montmorillonite structure (Grim, 1953, p. 362). Twenhofel (1950), p. 137, concluded that bentonites were formed rapidly and represent a single fall or a rapid succession of falls. For this reason, ash and bentonites cut across differences in facies and are therefore excellent tools of correlation (Wood, 1949).

Not all ash alters to bentonite, however. Rubey (1929) thought that ash high in silica did not change to bentonite, and Grim (1953), p. 363, found that ash with no magnesia and ash that fell on land did not alter to bentonite. Whether ash that fell in fresh water becomes bentonite or not is not known.

Ross (1928) gave the following criteria for recognition of bentonites: reaction to water, texture, optical properties, chemical composition, waxy luster, absence of non-volcanic minerals, and relic glass structures. Also euhedral biotite, feldspar, pyroxenes, or hornblende are evidence of a volcanic origin.

The relationships of bentonite to chert has already been discussed.

Tuffs. Although numerous tuffs are known (Heinrich, 1956, p. 96), only the silicified tuffs are important in chert formation. The word tuff may have different meanings, but Lahee's (1952, p. 133) definition, a consolidated volcanic dust or ash, will be used in this thesis. When tuffs weather, silica is released which easily passes through the porous material and is redeposited as an opaline or chalcedonic cement, thus giving the tuff a hard, flinty appearance (Bramlette, 1946). These sediments may be difficult to recognize from the true cherts (Pettijohn, 1949, p. 267). The rate at which tuffs change to cherts is determined by the composition of the ash (basaltic ash decomposes faster than silicic ash), texture, thickness of the tuff, and availability of free solutions (Bramlette, 1946).

Unaltered Ash Deposits. Many deposits of relatively pure volcanic ash are known, but most of these deposits are of Mesozoic or Cenozoic age, since glass is in a state of chemical unstable equilibrium and will change to the stable form on the slightest pretext (Pirsson, 1915). Swineford and Frye (1956) made extensive studies of the Pliocene and Pleistocene volcanic ashes of western Kansas and found all stages of ash alteration. Apparently devitrification starts around the edges of the shard and works inward until the entire grain is birefringent. They found that the ashes of the two epochs could be distinguished by the color of the particles, the characteristic shard shape, specific gravity, and ferric oxide content.

George (1924) in his study of natural glasses, including ashes, found that most glasses in nature have a composition similar to a rhyolite. He also found that the index of refraction for the glasses was directly proportional to the specific gravity and inversely proportional to the silica content.

Sediments Containing Individual Shards. There is little mention of the presence of glass shards in the literature of many mineral analyses, probably because of the extreme difficulty in recognizing ash (Pirsson, 1915), especially the ash that has lost its shard shape or has become partly devitrified. Krynine (1950) found abundant ash in the Triassic sediments of Connecticut but very few shards. Ross (1928) mentioned that ash that falls on land may become reworked and redeposited, thus destroying the characteristic shard shape.

As previously mentioned, Markley (1953) found ash shards in the cherts of the Manhattan area, and Hartig (1954) found shards in the limestones of the same units. Also Twiss (1955) working in the same general area, found minor amounts of ash in the non-cherty rocks of the lower Permian and upper Pennsylvanian Systems.

Individual shards found in a sediment would most likely be small, since the source of the shards was apt to be a great distance away (Swineford and Frye, 1956). Also the shape would probably be a curved triangular film, the most common shape according to Pirsson (1915). George (1924) found that glasses may have a different index of refraction, even on the same particle. This might also be true of ash shards, so the index should not be too diagnostic.

Heavy Minerals

Reed (1924), p. 326, defined a heavy mineral as "... one that sinks in bromoform". The particular heavy liquid used, however, need not necessarily be bromoform. Twenhofel and Tyler (1941), p. 75, listed 46 different liquids and combinations that have been used for heavy mineral separations. Only those with a specific gravity around 2.90 were used to separate the heavy minerals from the lights, however, the rest being used for separation of a particular mineral.

Twenhofel and Tyler (1941), p. 67, stated that a good, heavy liquid for mineral separations should be:

- (1) inexpensive
- (2) liquid at room temperature
- (3) of low viscosity
- (4) easily diluted or concentrated
- (5) chemically inert
- (6) of low volatility
- (7) easily prepared or purchased
- (8) non-poisonous
- (9) transparent
- (10) not readily decomposed by heat or light

No liquid contained all of these properties, but bromoform and acetylene tetrabromide were close enough to suit most practical needs.

Pettijohn (1949), p. 96, stated that heavy minerals (usually less than 0.1 percent of a rock) were either the very stable accessory minerals of the parent rock or the less stable but more abundant mafic minerals of the parent rock. Heavy minerals are important tools of correlation and are aids in determining the source of the sediments. However, Le Roy (1950), p. 133, cautioned that extremely rare heavies should be neglected in analyzing a rock, since their presence or absence is merely a matter of chance. Also he said authigenic minerals should be rejected as a source tool, but may have value for correlation purposes.

Different techniques have been used to determine the resistance of a mineral to weathering, but these methods are not always reliable, since different investigators may disagree on the stability of a given mineral (Pettijohn, 1949, p. 490).

Table 1. Descriptions of sample localities.

Sample : Number :	Member : Name :	Chert :	Description and Location
5	Hollenberg	Yes	N. side of road; 3 ft. above base; SE $\frac{1}{4}$ SE $\frac{1}{4}$, Sec. 30, T. 6 S., R. 4 E., Clay Co.
27	"	No	N. side of road; 5 ft. above base; SE $\frac{1}{4}$ SE $\frac{1}{4}$, Sec. 30, T. 6 S., R. 4 E., Clay Co.
30	Herington	No	N. side of road; base; SW $\frac{1}{4}$, Sec. 25, T. 19 S., R. 3 E., Marion Co.
31	"	Yes	N. side of road; 2 $\frac{1}{2}$ ft. above base; SW $\frac{1}{4}$, Sec. 25, T. 19 S., R. 3 E., Marion Co.
32	"	Yes	S. side of road; lower massive zone; NW $\frac{1}{4}$, Sec. 24, T. 7 S., R. 5 E., Riley Co.
33	"	No	N. side of road; upper platy zone; SW $\frac{1}{4}$, Sec. 13, T. 7 S., R. 5 E., Riley Co.
8	Cresswell	Yes	N. side of road; 2 ft. above base; SE $\frac{1}{4}$ SW $\frac{1}{4}$, Sec. 28, T. 8 S., R. 6 E., Riley Co.
6	Stovall	Yes	E. side of road; W $\frac{1}{2}$ W $\frac{1}{2}$, Sec. 33, T. 8 S., R. 6 E., Riley Co.
9	Towanda	No	N. side of road; NW $\frac{1}{4}$, Sec. 3, T. 9 S., R. 6 E., Riley Co.
18	Fort Riley	No	S. bank of stream, S. of road; E $\frac{1}{2}$, Sec. 34, T. 8 S., R. 6 E., Riley Co.
10	Kinney	No	N. side of road; Center, Sec. 27, T. 11 S., R. 8 E., Geary Co.
1	Funston	Yes	S. side of stream; ls. in middle sh.; Center, Sec. 1, T. 21 S., R. 7 E., Chase Co.

Table 1. (Cont.)

Sample : Number :	Member : Name :	Chert :	Description and Location
11	Funston	No	E. side of road; SW $\frac{1}{4}$ NW $\frac{1}{4}$, Sec. 33, T. 10 S., R. 8 E., Riley Co.
4	Crouse	Yes	E. side of road; upper zone; NW $\frac{1}{4}$ SW $\frac{1}{4}$, Sec. 25, T. 19 S., R. 7 E., Chase Co.
14	"	No	N. side of road; Center, Sec. 27, T. 11 S., R. 8 E., Geary Co.
20	Middleburg	No	N. side of road; E $\frac{1}{2}$, Sec. 27, T. 11 S., R. 8 E., Geary Co.
2	Eiss	Yes	Outcrop in field; upper zone; SE $\frac{1}{4}$, Sec. 26, T. 19 S., R. 7 E., Chase Co.
23	"	Yes	E. side of road; NW $\frac{1}{4}$, Sec. 1, T. 19 S., R. 8 E., Chase Co.
3	"	Yes	E. bank of Tuttle Cr. Dam spillway; Center, Sec. 18, T. 9 S., R. 8 E., Pottawatomie Co.
12	"	No	N. side of road; E $\frac{1}{2}$, Sec. 27, T. 11 S., R. 8 E., Geary Co.
16	Morrill	Yes	E. bank of Tuttle Cr. Dam spillway; lower zone; Center, Sec. 18, T. 9 S., R. 8 E., Pottawatomie Co.
17	"	No	S. side of road; E $\frac{1}{2}$, Sec. 26, T. 11 S., R. 8 E., Riley Co.
34	Cottonwood	Yes	Outcrop on Bluemont Hill; 2 ft. above base; SE $\frac{1}{4}$, Sec. 7, T. 10 S., R. 8 E., Riley Co.
35	"	No	Outcrop on Bluemont Hill; below chert zone; SE $\frac{1}{4}$, Sec. 7, T. 10 S., R. 8 E., Riley Co.
36	"	Yes	Outcrop in Sunset Park; 2 ft. below top; SW $\frac{1}{4}$ SE $\frac{1}{4}$, Sec. 13, T. 10 S., R. 7 E., Riley Co.

Table 1. (Concl.)

Sample Number :	Member Name :	Chert :	Description and Location
37	Cottonwood	No	Outcrop in Sunset Park; top zone; SW $\frac{1}{4}$ SE $\frac{1}{4}$, Sec. 13, T. 10 S., R. 7 E., Riley Co.
38	"	Yes	Abandoned quarry on Stag Hill; 2 ft. below top; NW $\frac{1}{4}$, Sec. 26, T. 10 S., R. 7 E., Riley Co.
39	"	No	Abandoned quarry on Stag Hill; top zone, NW $\frac{1}{4}$, Sec. 26, T. 10 S., R. 7 E., Riley Co.
15	Neva	No	Abandoned quarry on Bluemont Hill; upper zone; SE $\frac{1}{4}$, Sec. 7, T. 10 S., R. 8 E., Riley Co.
26	"	Yes	W. side of road; 2 ft. above base; NW $\frac{1}{4}$ NW $\frac{1}{4}$, Sec. 23, T. 15 S., R. 11 E., Lyon Co.
28	"	No	E. side of road; base; NW $\frac{1}{4}$ NW $\frac{1}{4}$, Sec. 23, T. 15 S., R. 11 E., Lyon Co.
22	Barr	No	W. side of Bluemont Hill road; SE $\frac{1}{4}$, Sec. 7, T. 10 S., R. 8 E., Riley Co.
24	Howe	No	W. side of Bluemont Hill road; SE $\frac{1}{4}$, Sec. 7, T. 10 S., R. 8 E., Riley Co.
7	Bennett	Yes	N. bank of draw; near top; Center, Sec. 23, T. 15 S., R. 11 E., Lyon Co.
19	"	No	S. bank of draw; 10 ft. below chert zone; Center, Sec. 23, T. 15 S., R. 11 E., Lyon Co.
13	Long Creek	No	W. side of road; SE $\frac{1}{4}$, Sec. 7, T. 10 S., R. 8 E., Riley Co.
25	"	Yes	Outcrop on hillside over 142 Mile Cr.; near top; NE $\frac{1}{4}$, Sec. 26, T. 15 S., R. 11 E., Lyon Co.
29	"	No	Outcrop on hillside over 142 Mile Cr.; just below chert zone; NE $\frac{1}{4}$, Sec. 26, T. 15 S., R. 11 E., Lyon Co.
21	Americus	No	R.R. cut below Bluemont Hill; SE $\frac{1}{4}$, Sec. 7, T. 10 S., R. 8 E., Riley Co.

PROCEDURE OF INVESTIGATION

Determining Units and Areas To Be Sampled

The tremendous quantities of residual flint gravel lying on the prairie in a belt approximately 30 miles wide from the Nebraska line to Oklahoma came essentially from the Florence, Schroyer, and Threemile limestones and were responsible for the naming of the Flint Hills of Kansas. These three limestone units are not the only chert producers in this area, however. Most of the limestones of the Chase and Council Grove groups, the approximate upper and lower limits of the Flint Hills, are either sparsely cherty or intermittantly cherty. Before a comprehensive study of these units could be made, it was necessary to determine the most suitable outcrops for selecting samples.

Moore, et al. (1951) mentioned most of the limestone members that contained siliceous geodes and nodules, and O'Conner (1953), and Moore, et al. (1951) gave localities where samples could be obtained. Also project reports of Kansas State Highway Commission field-survey geologists were consulted for additional references.

It was decided that all of the important limestone units of the Chase and Council Grove groups of the Wolfcampian Series would be sampled, except the previously mentioned Florence, Schroyer, and Threemile limestone members already studied by Hartig (1954). Only one sample was taken from the non-cherty members: Towanda, Fort Riley, Kinney, Middleburg, Burr, Howe,

and Americus limestones; and usually two or more samples were taken from each of the cherty members: Herington, Cresswell, Stovall, Funston, Crouse, Eiss, Morrill, Cottonwood, Neva, and Long Creek limestones. Also the Hollenberg limestone immediately above the Herington limestone, and the Bennett shale bioherm of the Council Grove group of northern Lyon County (locally a 25-foot limestone) were sampled, since both were cherty. Where possible, it was planned to sample both a cherty zone and a zone not known to contain chert at each selected outcrop of a cherty member.

Securing Samples From the Field

In collecting limestone specimens for laboratory analysis, three different sampling methods were used, depending upon the type of outcrop. Spot samples, or single samples taken from one particular point (Krumbein and Pettijohn, 1938, p. 13), were selected when the limestone had only one horizontal bed of chert. This method was used when these zones were thin, since it was desired that only the limestone immediately adjacent to a chert or siliceous nodule be termed a cherty limestone.

Channel samples, or continuous samples from top to bottom, were collected from the non-cherty limestones that showed a complete, unweathered outcrop. Twenhofel and Tyler (1941), p. 21, termed these samples "chipping" samples if the rock was quite hard. Broken fragments of rock of approximately equal size were chipped at regular intervals the entire vertical distance of the

outcrop and normal to the bedding.

The third sampling method used was a modified combination of a spot sample and a channel sample. This method was used for the collection of non-cherty samples if the outcrops were incomplete or badly weathered, and for the cherty samples if the chert was not confined to a definite zone, but was more or less randomly scattered.

In each case, a number six paper bag was used to retain the sample of about five pounds, and the name, lithologic description, outcrop description, geographic location, and vertical position in the outcrop were plainly printed in pencil on the outside of the bag. Special care was taken, in each case, to secure an ample amount of sample, and to make certain that the sample collected was as fresh and free from contaminants as the circumstances of the outcrop allowed.

The following equipment was used in collecting samples from the field: a standard geologic pick-hammer (tapering to a point at one end), a chisel, a 10-power hand lens, a small bottle of 1 : 1 hydrochloric acid for differentiating silica from carbonate, a trench shovel, a hand level and five-foot Jacob's staff (divided into tenths of a foot) for measuring sections, a book of Kansas county maps for determining the geographic location of the outcrop, The Kansas Rock Column by Moore, et al. (1951) for determining the stratigraphic position of the outcrop, a bundle of number six paper bags, and a soft pencil.

Determined effort was used at this early stage of the

research to prevent experimental error from creeping into the sampling. However, errors that might occur at this stage of this type of research problem includes: contamination of the sample from rock fragments above or below the desired unit or from adhering dust, the "personal" element of error (Twenhofel and Tyler, 1941, p. 21) in selecting rock chips, and the mislabeling of the sample as to geographic or stratigraphic position.

Sample Preparation In Laboratory

The laboratory phase of the research in which the sample was prepared for petrographic analysis has been subdivided into four convenient divisions: (a) rock preparation, (b) acid treatment, (c) heavy mineral separation, and (d) preparation of detrital slides.

Rock Preparation. In each case, the first step in the laboratory preparation of the rock fragments was to remove all of the rock chips from one sack at a time and thoroughly clean each piece. Usually this was done by scrubbing each rock fragment with a wire brush under a stream of hot water to remove extraneous dirt and rock dust. In some cases, however, certain weathered portions had to be chipped off with a hammer to expose only a completely fresh core of rock.

Next, each sample was crushed to approximate "pea" size (about #4 screen mesh) in a jaw crusher. To prevent contamination and mixing of samples, the jaws of the crusher were rubbed clean with a dry cloth between each crushing, and the crushed

sample was returned to the same sack that the larger rock fragments were taken from. Care was taken at this point to save both the crushed pieces and the rock dust. Pulverization finer than "pea" size was not used because of possible danger in breaking the grains of the insoluble residue.

In order to obtain a representative sample from the heterogeneous assortment of rock fragments, the contents of the paper sacks were emptied into a Jones sample splitter and mixed one at a time. Between samples, the splitter was air blown to remove the previous rock dust. The Jones sample splitter consisted of eight alternating chutes that led into two pans, one placed on either side of the sample splitter. After the initial halving, these pans were emptied back into the splitter, one at a time, with reserve pans receiving the falling rock fragments. This was repeated four or five times until the sample was thoroughly mixed and until one of the pans contained the approximate desired amount. The exact weight at this stage of the preparation was not important, but from 400 to 750 grams of sample were usually saved for acid treatment, depending upon the apparent silty nature of the limestone. The rest of the crushed sample was returned to the original paper sack and saved in case a future error required starting again.

Errors that sometimes enter in this phase of the research include: contamination from unclean apparatus, inadequate mixing of the crushed rock, and preparing an insufficient amount of sample.

Acid Treatment. The crushed and thoroughly mixed sample was placed into a clean two-quart glass jar. Usually eight samples were prepared at a time. Together they were placed under a blower-type hood to expell the acid fumes as they were evolved. Either a solid Pyrex glass rod, fire polished at both ends, or a wooden stick was used as a stirrer. Eventually only the former was used, however, since pieces of wood fiber became excessive contaminants in the final sample. A small amount of water, just enough to cover the sample, was then poured into the jar to prevent the initial application of acid from reacting too vigorously. Thirty-six percent CP reagent hydrochloric acid (muriatic acid) was used as the carbonate solvent. Although Milner (1952), p. 244, Krumbein and Pettijohn (1938), p. 314, Swineford (1955), p. 99, and others have declared that this acid treatment is likely to remove certain of the heavy minerals, notably apatite, Reed (1924), found no visable effect on apatite after it was boiled in 50 percent hydrochloric acid for one hour.

The application of hydrochloric acid to crushed limestone was a very delicate operation, and after a few unhappy experiences, the author became firmly aware of this. Only a small amount of acid was added at a time, or the bubbly froth would have risen too rapidly in the jar and spilled over the top, carrying much valuable sample with it. Constant stirring and only small additions of acid helped to remedy this.

When further additions of acid ceased to cause a visible reaction, the jars were allowed to stand for awhile, in case

unseen carbonate particles still remained undissolved. Then water was added, filling the jar to the top. This allowed the solid material to settle to the bottom leaving the liquid relatively clear. The supernatant liquid was then siphoned off and the process again repeated. After five or six washings, if no acid odor or taste could be detected, the material, now termed insoluble residue (LeRoy, 1950, p. 140), was ready to be wet screened.

In the initial screening, a U.S. #270 sieve (0.053 mm. aperture) was used, with the insoluble residue from the two-quart jars being poured directly onto the sieve as it was held beneath the water tap. The silt and clay particles that passed through the sieve were washed down the drain, while the coarser particles, after being washed on the screen for 10 to 15 minutes, were subsequently washed into a filter paper and placed in an oven for drying. Between samples, the screen was washed upside down under forced water to remove any grains trapped in the screen apertures.

After thorough drying, and while the grains were still hot from the oven, the sample was placed in a U.S. #200 sieve (0.074 mm. aperture) for dry screening. The material that was retained on this screen was saved for future binocular examination and labeled "coarse residue" on the outside of the original filter paper. The grains that passed through the screen were then subjected to a heavy mineral separation.

In the foregoing procedure, care was taken to prevent: the

sample from frothing too rapidly, chips of glass from the stirring rod or glass jar from contaminating the sample, splashing of the sample from one jar into another, and particles from adhering to the screen and combining with another sample.

Heavy Mineral Separation. The procedure for separating the heavy minerals from the lights, in this investigation, was modified from the standard method used by Milner (1952), p. 63, LeRoy (1950), p. 132, and Krumbein and Pettijohn (1938), P. 343. A separatory apparatus consisting of a glass funnel mounted with a short piece of Tygon plastic tubing and a pinch clamp was filled with tribromomethane (bromoform, CHBr_3) and covered with a watch glass to prevent excessive evaporation. The mineral grains, still hot from the drying oven, which had passed through the previous screening, were poured into the bromoform. The heating was important since any water or air left coating a grain might have prevented that grain from sinking in the bromoform.

After two or three hours of periodic stirring with a mounting needle, the heavy minerals were completely settled to the bottom of the tube, leaving the lights, essentially quartz, chalcedony, opal, the feldspars, and volcanic ash, floating on top. The pinch clamp was then opened, allowing the heavies to fall into a lower funnel containing a filter paper and draining into a dry beaker. Immediately after the heavies were drained, the clamp was closed to prevent the lights from leaving the top funnel.

When the bromoform had drained from the filter paper, it was poured back into the original bottle, and the heavies were washed two or three times with 95 percent ethyl alcohol, the leachate being saved for future reclamation of the dissolved bromoform. The lights were then treated in a similar manner, both the heavies and lights being kept for future preparation in the filter paper in which they were collected. For the sample identification, each filter paper, folded and clipped with the grains inside, had the following information printed on the outside: the sample number, the limestone member name, cherty or non-cherty, the sample location, and whether coarse or fine. Usually four samples were run at a time, using the above procedure.

Twenhofel and Tyler (1941), p. 79, warned against the use of a filter paper to catch the heavy minerals, since complete recovery of the grains from the filter paper was almost impossible. If very few heavies were anticipated, this would be good advice. However, most investigators used filter paper because it was much quicker.

Krumbein and Pettijohn (1938), p. 331, stated that an improper heavy mineral separation may be due to any of the following causes:

.....to convection currents in the separating fluid, to entrapment of grains of one density within the bulk of the fraction of opposite density, to inclusions with the mineral grain or to attachment of other mineral grains of either lower or higher density or to alteration products which cause density to differ from theoretical value, to extreme fineness of size which causes

the material to "ball up" or settle with extreme slowness, or to smallness of difference in density between grains and liquid.

A correct proportion of time spent stirring the grains and letting them settle alleviated most of these problems. Care was also exercised in maintaining a specific gravity high enough to float calcite, quartz, and the feldspars (specific gravity about 2.7) (Krumbein and Sloss, 1953, p. 107), the normal specific gravity for bromoform at room temperature being 2.86. This prevented contamination of too many lights in the heavy mineral slides.

Preparation of Detrital Slides. The procedure used in this investigation for mounting the detrital slides was modified from the standard procedure used by Tickell (1939), p. 62, Krumbein and Pettijohn (1938), p. 361, Twenhofel and Tyler (1941), p. 168, and many others.

A thoroughly cleaned glass slide was laid on a hot plate, and semi-liquid Canada balsam was applied to the hot glass with a Pyrex applicator. This was allowed to cook for several minutes until the right consistency of the balsam was attained. A test for determining when the balsam was ready was to remove a small amount of balsam on the end of a mounting needle. If this small droplet cracked under the pressure of the fingernail, then the balsam was cooked sufficiently. Overcooking discolors the balsam, and with undercooking, the droplet on the mounting needle will not crack when under pressure.

When the balsam was ready, previously heated detrital

grains were sprinkled onto the cooking balsam with a micro-spatula, and a cover glass was immediately laid on top. The heating was necessary to remove any moisture or air film around the grains. Any trapped air bubbles could usually be removed from the balsam by gently sliding the cover glass to and fro over the grains. This also pushed the excess balsam out from under the glass cover. When this was done, the slide was removed from the hot plate and allowed to cool. A small gummed label, placed on the end of each slide, listed the name of the limestone, whether cherty or non-cherty, the sample number, whether light or heavy, and the outcrop location.

In each case, the lights were used to make the first slides, since they were considerably more numerous and the slides could be rejected if not made properly. There were seldom any excess heavy grains, therefore these slides had to be made with extreme caution.

During the making of detrital slides, it was important that any extra activity in the same room be kept to a minimum, since any dust stirred into the room might have caused serious contamination of the slides.

Sample Analysis

Standard petrographic techniques were used in the analysis of the detrital slides with certain adaptations being made to fit the particular problem.

First of all, each of the light slides was carefully and

Thoroughly scanned with the medium power objective to determine the presence and amount of volcanic ash and opal. Since the former was isotropic, had a very low relief, was usually completely colorless, and occurred as very thin plates, it was extremely difficult to see the ash grains at all. However, the author soon discovered that by inserting the mica test plate just beneath the analyzer, the grain boundaries of the ash particles became much more pronounced, and the volcanic ash was thus easily identified.

The heavy slides were also scanned but with the purpose of determining the identity of all of the heavy mineral grains present and the approximate percentage of each mineral. During this analysis any unusual mineral found present, or any mineral found in great excess, was carefully noted. In cases of an unusual mineral suite, and if abundant heavies were present, a heavy mineral count was made.

In the case of the lights, a mineral count was made for every slide with either 100 or 200 grains being counted and identified. When a mineral count was made, a mechanical stage was attached to the stage of the microscope so that an unprejudiced traverse could be made whereby only those grains that touched the center crosshairs were counted.

Another microscopic technique used for mineral identification was the oil immersion method described by Tickell (1939), p. 74, Milner (1952), p. 166, and others. By this method the index of refraction of mineral grains was compared to that of

various known oils by immersing the mineral grains into the oils. This was an excellent means of mineral identification and helped greatly in determining the volcanic ash from the opal.

Although the petrographic microscope was an invaluable tool for the purpose of mineral identification, little could be learned from petrographic studies about the textural characteristics of a rock. For this purpose the binocular microscope was employed. The coarse residue retained on the US #200 mesh sieve prior to the bromoform separation was saved with the hope that a binocular study of the coarse fraction would be an aid in interpreting the results of the petrographic analyses.

The coarse residue was screened before the examination into three fractions, finer than US #120 mesh (0.125 mm.), finer than US #35 mesh (0.50 mm.), and coarser than US #35 mesh. Each of these fractions was placed into the depressions of a black spot plate and examined under a fluorescent lamp. Any diagnostic minerals or mineral forms were then carefully noted for each size fraction.

RESULTS OF ANALYSES

Types of Cherts Sampled

Before the results of this thesis can be discussed, it should be mentioned that each of the different types of cherts sampled for this study were different from each other in lithologic appearance and probably also in origin. Therefore,

Plate III was included in this study to show the different types of cherts represented by the 17 cherty limestone samples.

Six categories of chert appearance were chosen with a possible seventh one not shown. The first, the nodular chert, is probably the most abundant form of chert in this area. In addition to the Cresswell (8), the Stovall (6), and the Cottonwood (34), (36), and (38), this type is found in the Florence, Schroyer, and Threemile limestones. This type of chert occurs as oddly shaped, round edged, completely irregular nodules. The fracture is subconchoidal and the fresh breaks give a waxy, glazed porcelain luster.

The type 2 chert was found in only the Hollenberg (5) and is probably related to the type 1 chert. This chert was black and occurred in long, wide, flat plates parallel to the bedding of the limestone. The chert zone in the limestone was quite narrow vertically and was probably of limited extent horizontally.

The type 3 chert was typical of the Herington limestone throughout Kansas and was representative of samples #31 and #32. It consisted of disseminated quartz and chalcedony geodes and compact chalcedonic masses that may have been completely filled-in geodes. These chert masses did not show the conchoidal fracture of the type 1 and 2 cherts, but rather a rough, jagged break.

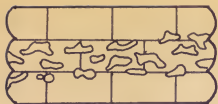
The type 4 chert was more of a catch-all category and included those borderline masses and granules of chalcedony and

EXPLANATION OF PLATE III

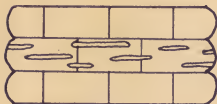
The different types of the cherty limestones sampled in this thesis and the members from each type.

- Type 1. Nodules; large, irregularly shaped, rounded masses of chert. Cresswell (8), Stovall (6), Cottonwood (34), (36), (38), Bennett (7), Schroyer, Threemile, and Florence.
- Type 2. Thin plates; black colored plates parallel to bedding. Hollenberg (5).
- Type 3. Geodes and compact masses; quartz and chalcedony geodes with small scattered masses of chalcedony. Herington (31) and (32).
- Type 4. Disseminated granules and small masses; usually occurring along bedding planes, the grains usually pink with or without drusy quartz present. Funston (1), Eiss (2), (23), and (3), Neva (26), and Long Creek (25).
- Type 5. Jagged seams along bedding planes; (shown in Plate IV). Crouse (4).
- Type 6. Chalcedonic veins (not chert); veins of chalcedony cutting either parallel to bedding or through more than one member diagonally. Morrill (16).

PLATE III



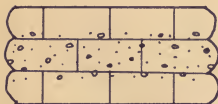
Type 1. Nodules.



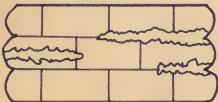
Type 2. Thin plates.



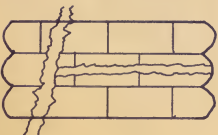
Type 3. Geodes and compact masses.



Type 4. Disseminated granules and small masses.



Type 5. Jagged seams along bedding planes.



Type 6. Chalcedonic veins (not chert).

quartz that may or may not be termed true chert. Usually these granules and masses were disseminated along definite planes parallel to the bedding and showed sporadic occurrences horizontally. Samples from this type of cherty limestone were the Funston (1) representing the small masses, the Neva (26) representing the granules, and the Eiss (2), (23), and (3) and Long Creek (25) representing both small masses and granules. In the cases of the Eiss and Long Creek samples, the chalcedony was pink in the outcrop.

The fifth type of chert was represented by the Crouse (4) and appeared as a jagged seam of chert that paralleled the bedding. Plate IV shows the appearance of this chert in the outcrop. In no way did it resemble the type 1 nodules, but the cavernous appearance of this chert in the outcrop may have suggested that the limestone contained geodes at one time.

The last type of chert was found in the Morrill (16) and appeared as a vein of chalcedony that ran parallel to the bedding. This vein or seam was related to a similar vein found running diagonally through the underlying Florena shale. Further trace of the same vein was not found, but if it continued diagonally down through other members, a possibility of epithermal genesis would be suggested. Possibly the chalcedony in the Long Creek (25) may in part have been formed in this manner.

Another possible type not shown in Plate III are those limestones whose fossils were partially or completely replaced by silica. Many of the samples including the megascopically

EXPLANATION OF PLATE IV

Figs. 1 and 2 show two views of the jagged chert seam in the Crouse limestone. Both photographs were taken at the same outcrop located in the NW $\frac{1}{4}$, SW $\frac{1}{4}$, Sec. 25, T. 19 S., R. 7 E., Chase County.

PLATE IV



Fig. 1.



Fig. 2.

non-cherty Fort Riley (18), Eiss (12), Herington (30), Neva (28) and Bennett (19), showed chalcedonic spines and shells that were obviously calcium carbonate originally.

Presence of Ash and Amorphous Silica

Volcanic Ash. The volcanic ash found in the detrital grains of the limestones studied were divided into two arbitrary categories, shards and semi-shards. The shards were ash grains that still retained sharp or relatively sharp corners and edges and showed almost no evidence of alteration. The semi-shards usually showed pitting on the surface, rounded corners, and sometimes partial birefringence indicating that the ash grains were altering to chalcedony or quartz. Plate V shows examples of shards from three different samples.

Table 2 shows the occurrence and form of the ash found and the index of refraction of the ash grains where determination was possible.

In no case was the volcanic ash abundant. Thousands of grains of the light residue were examined to determine the presence of the ash in each limestone sample, and in no sample did the percentage of ash exceed one and a half percent. If no ash was found in the permanent slides, at least two more slides were prepared and examined for the presence of ash. In 10 samples, ash was found only once, thus making it impossible to determine the index of refraction. In most of the other cases, however, other ash grains were found during the oil immersion study.

EXPLANATION OF PLATE V

- Fig. 1. Aggregate of clear, angular shards from the Neva limestone (26).
- Fig. 2. A slightly rounded shard from the Cottonwood limestone (36) partly covering a grain of chalcedony in the lower left of the picture.
- Fig. 3. An extremely thin shard from the Howe limestone (24) showing the typical curved edges and sharp corners.

All pictures were taken with uncrossed nicols and 450 magnification.

PLATE V



Fig. 1.



Fig. 2.



Fig. 3.

Table 2. Presence of ash and amorphous silica in samples.

Sample Number	Member Name	Type : Chert	Ash : Form	Index of Refraction	: Amorphous Silica
5	Hollenberg	2	Shard	1.50<n<1.51	Chal.-Opal, Opal
27	"	-	Shard	n=1.51	Chal.-Opal
31	Herington	3	Shard*	n<1.54	---
30	"	-	Shard	n<1.51	Chal.-Opal
32	"	3	Shard*	n<balsam	Chal.-Opal, Opal-Ash
33	"	-	---	---	Opal-Ash
8	Cresswell	1	Semi-shard	n>1.48	---
6	Stovall	1	---	---	---
9	Towanda	-	---	---	Chal.-Opal, Opal
18	Port Riley	-	Semi-shard	1.51<n<1.52	---
10	Kinney	-	Shard	1.47<n<1.48	---
1	Funston	4	Semi-shard	n>1.48	Opal
11	"	-	---	---	---
4	Crouse	5	Semi-shard*	n<balsam	Chal.-Opal, Opal-Ash
14	"	-	Shard	n<1.51	Opal-Ash
20	Middleburg	-	Shard	n<1.52	---
2	Biss	4	Semi-shard*	n<balsam	Chal.-Opal, Opal
23	"	4	---	---	---
3	"	4	Shard	1.51<n<1.52	---
12	"	-	---	---	---
16	Morrill	6	---	---	Opal-Ash
17	"	-	Shard	1.49<n<1.50	Chal.-Opal, Opal-Ash
34	Cottonwood	1	Shard	n<1.52	Chal.-Opal
35	"	-	---	---	Chal.-Opal
36	"	1	Shard*	n<balsam	---
37	"	-	Shard	n=1.48	Chal.-Opal
38	"	1	Semi-shard*	n<balsam	---
39	"	-	Semi-shard	n>1.51	Opal
15	Neva	-	Semi-shard*	n<balsam	Opal
26	"	4	Shard	1.51<n<1.52	Opal-Ash
28	"	-	Shard*	n<1.54	---
22	Burr	-	---	---	Chal.-Opal
24	Hove	-	Shard	1.49<n<1.50	Chal.-Opal
7	Bennett	1	---	---	Chal.-Opal, Opal-Ash
19	"	-	---	---	Chal.-Opal
13	Long Creek	-	Shard*	n<balsam	Opal-Ash
25	"	4	Shard*	n<1.50	---
29	"	-	---	---	Opal-Ash
21	Americus	-	---	---	---

* Indicates ash found only once.

In Table 2, when no upper or lower limits were indicated, the index of the ash could only be indicated as higher or lower than the oil in which the grain was immersed when discovered.

Amorphous Silica. In determining the indices of refraction of the volcanic ash, other grains were discovered that were similar to, but not identical with it. These grains were usually isotropic and all had an index less than balsam, but their index and optical appearance indicated that they were a different material from the ash. These grains were divided into three categories: opal, chalcedonic-opal, and opal-ash.

The opal, in each case, was classified by its low index of refraction and complete isotropism. In cases where a single grain of opal was found in the permanent slides, it was identified by its high relief (as compared to ash). A possible replacement of celestite by opal was discovered in the heavy fraction of the Cottonwood (39). The grain was undoubtedly opal, and it showed the same cleavage edges and angles that are characteristic of celestite. With this one exception, the rest of the opal showed no characteristic form.

Chalcedonic-opal was so named because of its obvious intermediate position between low index, completely isotropic opal and higher index, completely birefringent chalcedony. These grains had an index of refraction ranging from 1.44 to 1.51 or higher. The degree of birefringence was related roughly to the index of refraction, the higher the index, the greater the amount of birefringence. These grains were distinguished mainly by their lacy or bubbly appearance.

Opal-ash was a name given to those grains whose appearance and optical properties were intermediate between opal and volcanic ash. Its index of refraction showed the same variance and range as the chalcedonic-opal, but its appearance was usually glassy and showed evidence of partial alteration and crystallization.

These minerals are also included in Table 2 to show the relationship of their occurrence to that of volcanic ash.

Light and Heavy Mineral Analysis

It was believed that a clue concerning the chert genesis might be obtained by a qualitative and quantitative evaluation of the light and heavy minerals. With the aid of a mechanical stage, a traverse of the lights was run resulting in an unbiased approximation of the percentages of the minerals present. Either 100 or 200 grains were counted, depending upon the desired need for accuracy. In the case of the heavies, usually too few grains were present for the effective use of the traverse method, so each grain in the slide was identified with the percentages of each mineral present then being determined. After examining a few heavy slides it became apparent that, with few exceptions, the mineral grains present were the varieties most resistant to weathering and transportation. These exceptions were authigenic minerals, and were carefully noted.

Light Minerals. The light minerals found were quartz, chalcedony, orthoclase, plagioclase, microcline, and the various

Table 3. Mineral analyses of lights, heavies, and coarse residue.

Sample Number	Member Name	Type of Chert	Quartz	Quartz aggr.	Chal. (spec.)	Chal. (wavy)	Chal. (yel.-bn.)	Chal.-Opal	Opal-Ash	Opal	Volcanic ash	Plagioclase	Orthoclase	Microcline	Total Lights	Unusual Heavies	Coarse Residue
5	Hollenberg	5	23	7	10	119	36	1	1	1	1	1	1	1	200	80% cel.	
27	"	-	37	111	32	2	8	2							200	garnet, <5% cel., pyrite	
31	Herington	3	5	93	93	2									100	9% muscovite, <5% cel.	Qtz. & cel. crystals
30	"	-	4	95								1			100	85% muscovite, <5% cel., pyrite	Spines, Qtz. & cel. crystals
32	"	3	31	8	33	3	3	1				1	6	1	100	85% muscovite, <5% cel., pyrite	
33	Cresswell	-	28	14	30	2						13	13		100	70% muscovite, <5% cel., pyrite	
8		1	69	3	14	9							4		100	numerous heavies, pyrite	Fossil frags., pyrite crystal
6	Stovall	1	1	4	87	8									100	<5% cel., pyrite	Chal. spines
9	Towanda	-	1	1	1		94	3							100	60% cel.	Dirty gray grains
18	Fort Riley	-	7	19	40		20					1	7	4	100	90% muscovite, <5% cel., pyrite	Fossil frags.
10	Kinney	-		9	73		18								100	pyrite	
1	Funston	4	12	103	75	7	3								200	60% pyrite, 30% cel.	Pyrite, white molds
11	"	-		1	97		2								100	<5% cel., pyrite, 1 apatite, few heavies	Molds
4	Crouse	5	48	7	89	26	9	19	2						200	normal suite, few normal suite	10% Limonite
14	"	-	8	15	87		89					1			200	(sample lost)	
20	Middleburg	-	4	3	19		73								100	pyrite	
2	Eiss	4	3	5	84	1	7								100	pyrite, few heavies	1 Large grain of pumice (ash)
23	"	4	3	73			23					1			100	pyrite, few heavies	Molds

Table 3. (Concl.)

Sample Number	Member Name	Type of Chert	Quartz	Quartz aggr.	Chal. (spec.)	Chal. (wavy)	Chal. (yel.-bn.)	Chal.-Opal	Opal-Ash	Volcanic ash	Plagioclase	Orthoclase	Total Lights	Unusual Heavies	Coarse Residue
3	Eiss	4	20		12	61				1	2	4	100	90% cel., pyrite	Rosettes of pink chal. in bands
12	"	-	2		70		27				1	100	<5% cel.		Fossil frags., molds
16	Morrill	9	5	5	185		5						200	60% pyrite, 20% cel.	Nolds
17	"	-	33	17	101	26	2	3	18				200	approx. 100% cel., pyrite	Qtz. crystals grow- ing from banded chal.
34	Cottonwood	1		1	71	14	14						100	5% cel.	
35	"	-	1	2	89	3	4	1					100	1 grain cel.	
36	"	1	5	1	66	19	9						100	60% muscovite, <5% cel., 1 grain siderite	
37	"	-	5	2	63	18	8	2		1	1	100	40% muscovite, 10% siderite, <5% cel., pyrite		
38	"	1		5	83	12							100	40% muscovite, <5% cel., pyrite	
39	"	-			83	17							100	75% muscovite, <5% cel.	
15	Neva	-	1	2	42		55						200	50% cel., pyrite	
26	"	4	77	5	24	66	28						200	70% cel.	
28	"	-			99	1	11	1					100	30% cel., pyrite	
22	Burr	-	1	2	85								100	60% cel.	
24	Hove	-	4	7	83		6						100	<5% cel.	
7	Bennett	1	6	4	22	27	30	11					100	tourmaline, pyrite	Qtz. & cel. crystals Some chal. spines
19	"	-		1	81	2	7	9					100	pyrite	Qtz. crystals, molds
13	Long Creek	-	14		170	1	15						200	approx. 100% cel.	Fossil frags., large ant. clay aggregates
25	"	4	27	9	5	9	50						100	approx. 100% cel.	Spines, qtz. crystals Abundant cel.
29	"	-			91								100	approx. 100% cel.	Qtz. & cel. crystals, limonite
21	Americus	-	16	7	69	3			9	3	2	100	<5% cel.		limonite Spheres of hematite, Molds

forms of amorphous silica and ash. Since chalcedony was the most abundant mineral present, ranging up to 100 percent, it was believed that its form might be more significant than its relative amount. Therefore, three types of chalcedony were identified and counted; fibrous chalcedony or chalcedony showing a wavy extinction, yellow-brown chalcedony, and speckled or "salt and pepper" chalcedony.

The fibrous or wavy chalcedony showed every gradation from a much lower index of refraction mineral (opal or ash) to quartz. Therefore, the limits of this mineral included all those grains with a sufficiently high birefringence to indicate complete crystallization, but not those grains crystallized enough to give a quartz interference figure. These grains all showed a wavy, indistinct extinction and graded into the other forms of chalcedony.

Examples of members where this form was common are the Eiss (3) with 61 percent, the Hollenberg (5) with 59½ percent, the Neva (26) with 33 percent, and the Bennett (7) with 27 percent. These samples were all from cherty localities.

The yellow-brown chalcedony was usually colored enough to mask the interference colors with the yellow color being caused by the scattering of light from submicroscopic pores (Pelto, 1956). Examples of this type are the Towanda (9) with 94 percent, the Middleburg (20) with 73 percent, the Neva (15) with 55 percent, the Long Creek (25) with 50 percent, and the Crouse (14) with 45½ percent. All but the Long Creek (25) were from

non-cherty localities.

The speckled chalcedony showed a myriad of blinking white and black specks as the stage of the microscope was rotated. This type also showed strong evidence of being a transitional stage between the amorphous chalcedonic-opal and quartz. When the specks of this type became large enough to show a clear, distinct extinction, the grain was no longer called chalcedony, but was considered an aggregate of quartz. Examples where speckled chalcedony was abundant are the Neva (28) with 99 percent, the Funston (11) with 97 percent, the Herington (30) and (31) with 95 and 93 percent respectively, the Morrill (16) with 92½ percent, the Long Creek (29) with 91 percent, and the Cottonwood (35) with 89 percent.

Quartz was found as both individual grains and as aggregates or clusters. This distinction was made in the light mineral analyses, because it was believed that much or most of the quartz aggregates were derived from the speckled chalcedony, whereas the individual quartz grains were either detrital or derived from the fibrous, wavy chalcedony. A third type of quartz was the euhedral, doubly-terminated quartz crystals found in the lights of the Howe (24), the Eiss (3), and the Long Creek (25), and in the coarse residue of the Herington (30) and (31), the Morrill (17), the Neva (26), and the Bennett (19). Only in the case of the Herington limestone were these quartz crystals evident in the hand specimen.

The feldspars comprised a significant fraction of the lights only in the case of the Herington (32) and (33). The former showed 20 percent feldspar (one percent microcline, six percent orthoclase, and 13 percent plagioclase), and the latter showed 26 percent feldspar (13 percent each of orthoclase and plagioclase). All of the biaxial negative feldspars were identified as orthoclase unless the distinctive grid twinning of microcline was present.

Very little volcanic ash was encountered in the traverse counts of the light fraction, ash being found only in the Hollenberg (27) and (5), the Herington (32), the Fort Riley (18), and the Eiss (3). Opal was encountered in the Hollenberg (5) only. Opal-ash formed nine percent of both the Morrill (17) and the Long Creek (29) and two percent of the Crouse (4). Chalcedonic opal, on the other hand, was included in the mineral counts of 11 limestones, the most abundant being the Bennett (7) with 11 percent and the Bennett (19) and Crouse (4) with nine percent.

Heavy Minerals. In only five of the 39 limestone samples were the heavy grains in excess of the amount needed to make one slide. These samples were the Funston (1), Long Creek (13), (25), and (29), and the Morrill (17), and in each of these cases, the excess was due to the mineral, celestite (SrSO_4).

After examination of a few heavy mineral slides, it was believed that an accurate count of the resistant detritals was not important for the purposes of this investigation. Therefore, the heavies in each slide were identified with only the unusual

minerals, the authigenic minerals, and the hyper-abundant minerals being especially noted. The resistant minerals that were more or less characteristic of all of the heavy slides were magnetite, muscovite, garnet, tourmaline, rutile, kyanite, zircon, green and brown hornblende, hematite, and small amounts of biotite, andalusite, ilmenite, chlorite, titanite, corundum, and sericite. Also in the Funston (11), one grain of apatite was observed.

Abnormal amounts of the detrital heavy minerals were found in the Bennett (7) with large amounts of tourmaline, the Hollenberg (27) with excessive garnet grains, and nine different samples with muscovite in excess of 40 percent of the heavy fraction and ranging to 95 percent in the Herington (30) and (31).

Only three authigenic heavies were found, siderite, pyrite, and celestite. The siderite was found in small amounts in only two samples, the Cottonwood (37) with 10 percent and the Cottonwood (36) with one grain. These siderite grains appeared as equant rhombohedrons with very high birefringence and an index of refraction for both the ordinary and extraordinary rays higher than balsam.

Pyrite was present in 19 of the samples, but in significant amounts in only two, the Funston (1) with 60 percent pyrite, and the Morrill (16) also with 60 percent. The only euhedral pyrite found was in the Cresswell (8) where one octahedron was discovered in the coarse residue.

Celestite was by far the most common heavy mineral, occurring

in 30 out of 38 samples (one sample, the Middleburg, was accidentally destroyed before the analysis was completed). Four samples, the Long Creek (13), (25), and (29), and the Morrill (17) contained approximately 100 percent celestite in the heavy minerals. Much of the celestite, as observed through the binocular and petrographic microscopes, was found to occur as small euhedral crystals.

It was noticed that the appearance of the celestite was highly variable. The Hollenberg (5), for example, contained more than 80 percent celestite in the heavy fraction, but very few of the grains were distinguishable because of a veneer of clay over almost every grain. The Neva (15), on the other hand, showed crystal clear grains of celestite. Also the celestite appeared both as jagged, dog-toothed grains, and grains that showed almost no characteristic cleavage or crystal faces.

Coarse Residue Analysis

In the examination of the coarse residue, the shape of the mineral and rock fragments was considered more important than the identification of the minerals themselves, although the obvious minerals were noted.

No volcanic shards, as such, were noted in the coarse residue of any of the samples. However, in the Eiss (2), a lustrous, fibrous grain, just large enough to be caught on the US #35 mesh screen was noted. Thinking that it was a grain of gypsum, the fragment was crushed and immersed in a 1.54 index

EXPLANATION OF PLATE VI

Figs. 1 and 2 show four of the crushed fragments from the pumice grain found in the coarse residue of the Eiss limestone (#2). The two smaller grains in Fig. 1 and the grain in Fig. 2 show the elongate, fibrous character of the glass, and the larger grain in Fig. 1 shows the air vesicles that enabled the pumice fragment to float a great distance.

(80 Magnification with uncrossed nichols.)

PLATE VI



Fig. 1.



Fig. 2.

oil and examined with the petrographic microscope. It then became apparent that this crushed fragment was a piece of pumice, since the fragments were completely isotropic, had an index of refraction less than the 1.54 oil, and contained vesicles of elongate air bubbles. Plate VI shows some of the crushed fragments from this pumice grain.

Since this fragment was obviously too large to have been air transported, and since so delicate a grain could not have been a regular stream-transported detrital grain, the only possible way to account for its presence was to assume that the grain was ejected directly into the ocean near the parent volcano. From there the bubble-filled grain must have floated a great many miles before becoming water-logged and eventually sinking to the ocean bottom.

Chalcedony was obviously the most abundant mineral in the coarse residue and occurred in many different forms, especially brown and white sugary aggregates, pink and white massive grains, fossil replacements, and odd, curled molds that may have been microfossils. Echnoid spines were especially abundant in the Herington (30), the Stovall (6), the Neva (28), and the Bennett (19). Other fossil fragments were found in abundance in the Cresswell (8), the Fort Riley (18), the Eiss (12), and the Bennett (7).

Euhedral, doubly terminated quartz crystals, were found present in abundance in the Herington (30) and (31), the Neva (26), the Howe (24), and the Long Creek (25). Singly terminated

quartz crystals growing out of banded chalcedony were discovered in one sample, the Morrill (17). These findings correlated pretty well with the findings of the finer residue studies.

Celestite was also found in abundance in the coarse residue that correlated with the celestite in the fines. This celestite was usually recognized by its crystal clear appearance, and by the sharp angular cleavage fragments that are typical of celestite. Celestite euhedral crystals were found in the coarse residue of the Herington (31) and (30), the Neva (26), and the Long Creek (25).

Other noticable mineral assemblages in the coarse fraction were large amounts of limonite (about 10 percent) in the Crouse (4); abundant muscovite in the Herington (30) and (31) and the Fort Riley (18); small spherules of hematite in the Americus (21); and pink banded rosettes of chalcedony in the Biss (3).

CONCLUSIONS

Origin of the Cherts

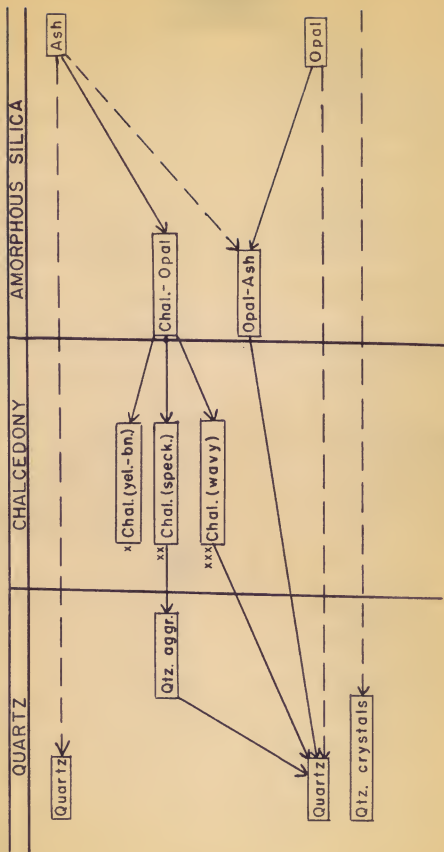
Due to the diversity of the cherts from which the limestones were sampled, no general theory as to the origin of the cherts can be postulated. However, evidence was such that each cherty limestone, taken by itself, can be discussed in regard to the origin of its chert. In the following discussion, each of the cherty limestones will be discussed in chronologic order, starting with the oldest.

EXPLANATION OF PLATE VII

Paragenesis of authigenic quartz and chalcedony.

This plate shows the relationships of the various forms of authigenic silica and ash. The straight lines between the different forms of silica represent relationships observed from microscopic evidence. The broken lines represent suspected relationships in which no intermediate steps are believed present. The most frequent occurrences of the three types of chalcedony, whether in cherty or non-cherty limestones, is also indicated.

PLATE VII



x=Chalcedony type common to non-cherty limestones.

xx=Chalcedony type found in both cherty and non-cherty limestones.

xxx=Chalcedony type common to cherty limestones.

←----- = Suspected relationships without intermediate stages.

←----- = Observed microscopic relationships.

Long Creek Limestone. To begin with, this unit was different from any others studied in that two of the three samples came from a very badly weathered outcrop. Since volcanic ash is believed to be relatively unstable under surface weathering conditions, it was possible that most of the ash that was formerly present had either been dissolved by surface waters or altered to chalcedony. Although only traces of ash were found present in samples #13 and #25, ash must have been abundant at one time to account for the presence of the amorphous opal-ash in the non-cherty samples #13 and #29. The absence of any opal-ash in the only cherty sample, #25, may have been due to the fact that the silica from the ash was all aggregated into the disseminated chalcedony granules.

Bennett Shale Bioherm. Although no ash was discovered in the Bennett, relatively large amounts of chalcedonic-opal were found in both the cherty (#7) and the non-cherty (#19) sample, and some opal-ash was found in the cherty sample. Also both samples showed an abundance of silicified fossil fragments indicating a large source of silica from somewhere. Whether this source was ash or not cannot be proved, but the abundant organic remains might indicate an ash fall that was completely dissolved in the sea water. An abundance of siliceous organisms is usually a good indication of an ash fall (Shrock, 1948, p. 91), and the calcareous organisms may have been the cause of the silica precipitation in the form of a gel (Rube, 1929). Further work would be needed to prove this, however.

Neva Limestone. All three samples of the Neva showed the presence of ash, however, only the cherty sample, #26, showed more than a trace or showed the presence of opal-ash. This is a good indication that the small amount of disseminated chert granules was due to an ash genesis. The ash present throughout the rest of the unit was evidently not abundant enough to aggregate into megascopic chert nodules.

It was possible that in this and other limestones, there was some accumulation of the ash into chert. But if the amount of ash was small, these aggregates of chert would not be conspicuous in an outcrop, and may be noticed only microscopically as chalcedony grains.

Cottonwood Limestone. Of the six samples of Cottonwood limestone, only one failed to show at least a trace of ash, and all but two had additional chalcedonic-opal or opal. From this evidence it seems apparent that the origin of the chert was due, at least in part, to the volcanic ash.

The failure of the ash to occur more abundantly in the cherty zones than in the non-cherty can only be hypothesized. Although the lithology of the Cottonwood limestone is renowned for its constant appearance and thickness, the location of the chert zones in the unit itself is nowhere near constant, but rather is known to occur in almost any position from top to bottom. This inconsistency on the position of the chert would indicate a similar inconsistency in the ash occurrence. Also the fact that chert in the Cottonwood is usually sparse would

indicate that only some of the ash was used up in this way, the rest remaining disseminated in unaltered form throughout the member.

Morrill Limestone. The possibility that the silica in the Morrill may have been of epithermal (low temperature hydrothermal) origin has already been discussed. This might be indicated if veins of silica could be found that extended vertically across more than one other member. If this were not the case, then the chalcedonic vein would more likely be a cold water replacement phenomenon, the silica being deposited in natural fissures or joint cracks by subsurface ground waters. However, since this was not a field problem, and the necessary concluding evidence is not known, the true origin of the chalcedony can only be hypothesized.

In sample #17, the non-cherty sample, evidence in the form of shards, abundant opal-ash, and some chalcedonic-opal was found that would imply that the unit contained chert. Since it did not, it must be assumed that conditions were not right for the accumulation of the silica from the ash, and the silica remained disseminated throughout the member in small amounts, or as "micro-chert". In the coarse residue, quartz crystals were seen growing out of small, banded, chalcedonic concretions or nodules. This evidence would support the theory that the authigenic quartz was a result of excess silica that was not used up in the process of chert formation.

In a sense, this sample would have to be labeled "cherty",

with the "chert" appearing as tiny grains of chalcedony crystallizing to quartz, the silica having come from volcanic ash.

Eiss Limestone. Of the four samples of Eiss, one cherty sample, #2, showed a trace of ash and some opal and chalcedonic-opal. This might indicate that the process just described in the Morrill was carried a little farther. The silica actually accumulated into visible chert grains, thus tending to deplete the available silica from the volcanic ash. The fact that the silica in the Eiss and in the Morrill were of similar origin was indicated by the presence of similar banded chalcedony rosettes in the coarse residue of both samples, the only difference between the two units being the more advanced degree of silica accumulation in the Eiss.

Crouse Limestone. Although the cherty sample of the Crouse, #4, contained only a trace of ash, it contained abundant chalcedonic-opal and some opal-ash. This would indicate that the degree of alteration of the ash was more complete than in the non-cherty sample, #14, that showed more ash but much less opal-ash and no chalcedonic-opal.

There is also another possibility that should be considered here. In the case of the Crouse, #4, the chert occurred in long, jagged, extremely irregular seams that may have suggested an origin from subsurface ground waters moving through the member, dissolving the limestone, and leaving a deposit of chert behind. If this were true, the volcanic ash that was present in the

limestone would have altered to the more stable forms of silica as was true with the Crouse sample, #14, that showed no evidence of ground-water action. The source for the silica for this type of chert, in that case, would probably be from dissolved silica fragments, such as ash, siliceous fossils, silicates, etc. that the ground waters dissolved while percolating through the units above.

Funston Limestone. The conditions in the Funston were just the opposite of that in the Crouse, the ash and opal being found in the cherty sample, #1, rather than the non-cherty sample, #11. This would be the expected situation if it is accepted that the ash is the source of the silica for the chert. The presence of a few shards adjacent to the cherty zone in such a limestone would probably mean that those shards were the last few remnants of a large ash fall, the bulk of the ash having been already altered or dissolved to form a silica gel, the forerunner of the chert. The fact that the few remaining shards were deposited more slowly with the normal sediments might explain why these ash grains did not alter also, the other sediments having formed a network of protection from the percolating solutions and thus preventing alteration.

Stovall Limestone. Although the chert nodules in this thin limestone were very numerous, there was no direct evidence that this ash came from altered volcanic ash. Possibly the origin of the chert in the Stovall was similar to that of the Bennett. That is, the presence of abundant chalcedonic spines

in the Stovall may have indicated that the chert was due to replacement, either diagenetic or epigenetic. The source of the silica is still problematical. It may have been ash dissolved in sea water, as discussed with the Bennett, or it may have been from dissolved siliceous fragments, as discussed with the Crouse.

Cresswell Limestone. Since only one sample of the Cresswell was collected, no comparison can be made concerning the presence of ash in different localities. However, since that one sample did have ash, it was possible that the few sparse chert nodules in the Cresswell were formed in somewhat the same manner as has already been discussed under the Cottonwood and Funston cherts.

Herington Limestone. The origin of the chert in the Herington limestone is less clear than that of the other limestones discussed. This is because the ash was absent in one non-cherty sample, #33, present as a trace in the two cherty samples, #31 and #32, and present in larger amounts in the other non-cherty sample, #30. Also amorphous silica was present in three of the samples, #30, #32, and #33, in minor amounts.

Since geodes are typically present in most or all Herington outcrops, perhaps it might be advantageous to discuss the origin of geodes.

Siliceous geodes may be formed in at least two ways, through shrinkage and dehydration of a former gel-like mass, and through solution and redeposition in a limestone by subsurface ground-



waters. Since the former does not seem too applicable in this case, only the latter will be considered. Evidence of doubly terminated quartz crystals found in two of the Herington samples seem to support the hypothesis of solution and redeposition by ground-waters.

The presence of chert nodules together with the geodes may mean that either these nodules were the source of the silica for the ground-water, or possibly the nodules are genetically related to the geodes in that they are merely geodes that have been filled completely full of silica. In the hollow geodes, the quartz crystals lined only the interior of the geode, the rest of the material being chalcedony. In the case of the chert nodules, this chalcedony filled the entire cavity leaving no room for the growth of quartz crystals.

Hollenberg Limestone. Since ash was present in the Hollenberg in relatively large amounts, it is likely that the ash had some part to play in the formation of that chert. However, field evidence had indicated that this chert was most likely secondary replacement rather than direct precipitation. This evidence appeared in the form of siliceous pseudomorphs after halite. These cherty "salt hoppers" have been found scattered throughout the area of the sample outcrop and are believed to come from the same or nearly the same horizon as the chert limestone sample #5.

Therefore, the role of the ash in the formation of the chert was as a source of silica for the replacing waters. Whether this replacement was diagenetic or epigenetic is not known for certain.

However, from the extremely disturbed appearance of the outcrop, the replacement was most likely diagenetic.

Ash in the Non-cherty Limestones

The question should now be answered why four out of seven of the non-cherty limestones contained ash and no chert, and nine out of 15 of the non-cherty zones in the cherty limestones contained at least a trace of ash. From this evidence it must be assumed that volcanic ash is a normal constituent of almost all sedimentary rocks at least as a trace component. Only when the ash fall was in major proportions is chert likely to result from ash in sediments. And even then, conditions must be right for the ash to go into solution in the sea water and be redeposited or dissolved by ground-waters and subsequently redeposited, or accumulate in some other way for chert to be found. When these conditions are not right, only partial accumulation or no accumulation of the silica at all, is the result. When the silica has partially accumulated, "micro-chert" may be formed, that is, chert or chalcedony too small to be recognized in the outcrop as chert. It is possible that the Fort Riley, Kinney, Middleburg, and Howe are examples of this.

General Conclusions

In addition to the specific origin suggested for each of the cherty limestones, general conclusions can be made concerning the research and results of this study.

First of all, it was found that not all cherty limestones contain volcanic ash, and not all limestones with ash are chert bearing megascopically.

It is now believed that the presence of volcanic ash in all types of sediments is to be expected, and if enough insoluble residue of any particular unit is examined, ash would probably be found present in all sedimentary rocks.

Along with this, it is believed that the lack of reference to volcanic ash in the experimental results of sedimentary mineral analyses is due, in a large part, to the extreme difficulty in seeing and correctly identifying volcanic ash.

The evidence was thoroughly convincing that different cherts are formed in many different ways, possibly a different way for each different chert.

Finally, there does appear to be a direct relation of volcanic ash to chert, chalcedony, and other forms of silica.

ACKNOWLEDGMENTS

The author would like to extend his sincere thanks and appreciation to his major professor, Prof. Arthur B. Sperry, emeritus head of the Department of Geology and Geography, for his continued help, guidance, and encouragement throughout the course of the research.

He also thanks the Engineering Experiment Station for financial aid received for a part of the work.

To Carl F. Crumpton, Research Geologist for the Kansas State Highway Commission, goes the author's deep gratitude for his kind assistance and suggestions throughout the laboratory phase of the problem. The author's association with Mr. Crumpton, while working as his assistant during most of the research, was especially appreciated and helpful.

To all others who offered assistance and suggestions, the author expresses his thanks.

BIBLIOGRAPHY

- Bain, H. F., and E. O. Ulrich.
Origin of Potosi chert in Southeast Missouri. U.S.G.S.
Bull. 267:27. 1905.
- Bastin, E. S.
Relations of cherts to stylolites at Carthage, Missouri.
Jour. Geol. 41:371-381. 1933.
-
- Paragenesis of the Tri-state jasperoid. Econ. Geol.
46:652-657. September - October, 1951.
- Bramlette, M. N.
The Monterey formation of California and the origin of its
siliceous rocks. U.S.G.S. Prof. Paper 212. 1946.
- Fettke, Charles R.
Tiga bentonite in Pennsylvania and adjacent states. Am.
Assoc. Petrol. Geol. Bull. 36:2038-2040. October, 1952.
- Flowers, Russell R.
Lower middle Devonian meta-bentonite in West Virginia.
Am. Assoc. Petrol. Geol. Bull. 36:2036-2038. October, 1952.
- Folk, Robert L.
Petrology of lower Ordovician cherts in central Pennsylvania.
Geol. Soc. Am. Bull. 60:1969. December, 1949.
- Folk, Robert L. and Charles E. Weaver.
A study of the texture and composition of chert. Am. Jour.
Sci. 250:498-510. July, 1952.
- Frye, J. C., and Ada Swineford.
Silicified rock in the Ogallala formation. State Geol. Sur.
of Kansas. Bull. 64, Part 2. 1946.
- George, W. C.
The relation of the physical properties of natural glasses
to their chemical composition. Jour. Geol. 32:353-372.
1924.
- Glock, W. S.
The use of the terms chert and flint. Iowa Acad. Sci., Proc.
27:167-173. 1920.
- Goldman, M. I.
Petrographic evidence on the origin of the Catahoula sand-
stone of Texas. Am. Jour. Sci. 4th series. 39:261-287.
1915.

- Grabau, A. W.
Principles of stratigraphy. New York: A. G. Seiler, 1924.
- Grim, Ralph E.
Clay mineralogy. New York: McGraw-Hill, 1953.
- Hartig, Robert L.
Minor petrographic constituents of some Permian rocks. Unpublished M. S. thesis, Kansas State College, Manhattan, Kansas, 1954.✓
- Hauser, Ernst A.
Genesis of clay minerals. Problems of clay and laterite genesis. A symposium. pp. 100-106. New York: Am. Inst. of Mining and Metallurgical Engineers, 1952.
- Heinrich, E. William.
Microscopic petrography. New York: McGraw-Hill, 1956.
- Keller, W. D.
Petrography and origin of the Rex chert. Geol. Soc. Am. Bull. 52:1279-1298. 1941.
- Kerr, Paul F., and J. L. Kulp.
Reference clay localities - United States. Reference clay minerals. Am. Petrol. Inst. Project 49. New York: Columbia University, 1949.
- Krumbein, W. C., and F. J. Pettijohn.
Manual of sedimentary petrology. New York: Appleton - Century - Crofts. 1938.
- Krumbein, W. C., and L. L. Sloss.
Stratigraphy and sedimentation. San Francisco: W. H. Freeman, 1953.
- Krynine, Paul D.
Petrology, stratigraphy, and origin of the Triassic sedimentary rocks of Connecticut. State Geol. and Nat. Hist. Sur. of Connecticut, Bull. 73. Hartford. 1950.
- Kuenen, P. H.
Marine geology. New York: John Wiley and Sons, 1950.
- Lahee, Frederic H.
Field geology. 5th ed. New York: McGraw-Hill, 1952.
- LeRoy, L. W., editor.
Subsurface geologic methods. A symposium. Golden, Colorado: Colorado School of Mines, 1950.

Markley, Lewis C.

Mineralogy of cherts as a factor in the use of siliceous aggregates for concrete. Unpublished M. S. thesis, Kansas State College, Manhattan, Kansas. 1953.

Milner, Henry B.

Sedimentary petrography. 3rd ed. London: Thomas Murby, 1952.

Moore, R. C., J. C. Frye, J. M. Jewett, Wallace Lee, and H. G. O'Conner.

The Kansas rock column. State Geol. Sur. of Kansas, Bull. 89. 1951.

Moore, R. C., J. M. Jewett, and H. G. O'Conner.

Geology, mineral resources, and ground-water resources of Chase County, Kansas. State Geol. Sur. of Kansas, Vol. 11, Part 1. 1951.

Newell, M. D., J. K. Rigby, A. G. Fischer, A. J. Whiteman, J. E. Hickox, and J. S. Bradley.

The Permian reef complex of the Guadalupe Mountains region, Texas and New Mexico. San Francisco: W. H. Freeman, 1953.

O'Conner, Howard G.

Geology, mineral resources, and ground-water resources of Lyon County, Kansas. State Geol. Sur. of Kansas, Vol. 12, Part 1. 1953.

Pelto, Chester H.

A study of chalcedony. Am. Jour. Sci. 254:32-50. January, 1956.

Pettijohn, F. J.

Sedimentary rocks. New York: Harper and Bros. 1949.

Pirsson, L. V.

The microscopical characters of volcanic tuffs - a study for students. Am. Jour. Sci. 4th series. 40:191-211. 1915.

Reed, B. D.

Some methods for heavy mineral investigations. Econ. Geol. 19:320-337. 1924.

Reiche, Parry.

A survey of weathering processes and products. Rev. ed. Albuquerque: Univ. of New Mexico Press. 1950.

Rogers, Austin F., and Paul F. Kerr.

Optical mineralogy. 2nd ed. New York: McGraw-Hill, 1942.

- Ross, C. S.
Altered Paleozoic volcanic materials and their recognition.
Am. Assoc. Petrol. Geol. Bull. 12:143-164. 1928.
- Roy, C. J.
Silica in natural waters. Am. Jour. Sci. 24:3393-403.
1945.
- Rubey, William W.
Origin of the siliceous Nowry Shale of the Black Hills
region. U.S.G.S., Prof. Paper 154:153-170 1929.
- Shrock, R. S.
Sequence in layered rocks. New York: McGraw-Hill, 1948.
- Sosman, R. B.
The properties of silica. New York: The Chemical Catalog
Company, Book Department, 1927.
- Spock, L. E.
Guide to the study of rocks. New York: Harper and Bros.,
1953.
- Swineford, Ada.
Petrography of upper Permian rocks in South-Central Kansas.
State Geol. Sur. of Kansas, Bull. 111. 1955.
- Swineford, Ada, and J. C. Frye.
Petrographic comparison of Pliocene and Pleistocene volcan-
ic ash from Western Kansas. State Geol. Sur. of Kansas,
Bull. 64, Part 1. 1956.
- Taliaferro, N. L.
Contraction phenomena in cherts. Geol. Soc. Am. Bull. 45:
189-232. 1934.
-
- Some properties of opal. Am. Jour. Sci., Bull. 5th series.
30:450-474. 1935.
- Tarr, W. A.
Origin of chert in the Burlington limestone. Am. Jour. Sci.
4th series. 44:409-452. 1917.
-
- The origin of chert and flint. Univ. Missouri Studies.
1: no. 2. 1926.
-
- The Miami-Picher zinc-lead district. Econ. Geol. 28:463-
479. 1933.

- Tickell, F. G.
The examination of fragmental rocks. Palo Alto, California: Stanford University Press, 1939.
- Trefethen, J. M.
Some features of the cherts in the vicinity of Columbia, Missouri. *Am. Jour. Sci.* 245:56-58. January, 1947.
- Twenhofel, W. H.
The chert of the Wreford and Foraker limestones along the state line of Kansas and Oklahoma. *Am. Jour. Sci.* 4th series. 47:407-429. 1919.
-
- Principles of sedimentation. 2nd ed. New York: McGraw-Hill, 1950.
- Twenhofel, W. H. and S. A. Tyler.
Methods of study of sediments. New York: McGraw-Hill, 1941.
- Twiss, Page C.
The non-carbonate mineralogy of some Permian and Pennsylvanian limestones. Unpublished M. S. thesis, Kansas State College, Manhattan, Kansas, 1955.
- Van Tuyl, F. M.
The origin of chert. *Am. Jour. Sci.* 4th series. 45:449-456. 1918.
- Verhoogan, J.
Mechanics of ash formation. *Am. Jour. Sci.* 249:729-739. October, 1951.
- Weaver, Charles E.
Mineralogy and petrology of some Ordovician K-bentonites and related limestones. *Geol. Soc. Am., Bull.* 64:921-944. August, 1953.
- White, D. E.
Diagenetic origin of chert lenses in limestone at Scyatal, State of Queretaro, Mexico. *Am. Jour. Sci.* 245:49-55. January, 1947.
- Williams, Howel, Francis J. Turner, and Charles M. Gilbert.
Petrography. San Francisco: W. H. Freeman, 1954.
- Winchell, A. N., and H. Winchell.
Elements of optical mineralogy; Part II, Description of minerals. 4th ed. New York: John Wiley & Sons, 1951.
- Wood, Horace E., 2nd.
Oligocene faunas, facies, and formations. *Geol. Soc. Am., Memoirs* 39:83-92. June, 1949.

PETROGRAPHIC ANALYSES OF THE INSOLUBLE RESIDUE
OF THE PERMIAN CHASE AND COUNCIL GROVE LIMESTONES
WITH REGARD TO THE ORIGIN OF CHERT

by

ROBERT OLDS WILBUR

B. S., Kansas State College
of Agriculture and Applied Science, 1954

AN ABSTRACT OF A THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Geology and Geography

KANSAS STATE COLLEGE
OF AGRICULTURE AND APPLIED SCIENCE

1956

Previous investigations at Kansas State College had revealed a close relationship between the chert-bearing limestones and the presence of volcanic ash. This ash was present both in the chert nodules and in the adjacent limestones, but was reported to be absent in the non-cherty limestones. It was the purpose of this investigation to further study the Permian limestones, both cherty and non-cherty, by examining their insoluble residues. It was hoped that notable differences in the mineral suites and character of the cherty and non-cherty limestones might be a valuable aid in determining the origin of the chert.

All of the limestones in the Chase and Council Grove groups of the Wolfcampian Series were sampled except the Florence, Schroyer, and Threemile cherty limestones previously sampled, and two lesser limestones. In addition, the Hollenberg limestone immediately above the Chase group in the Sumner group was also sampled.

Collections were made in seven counties, all in the general area of the Flint Hills physiographic province, with the majority of samples coming from the Manhattan area.

Since most of the limestones in the Chase and Council Grove groups were sparsely or intermittently cherty, samples of the same unit were usually collected from both a cherty and a non-cherty outcrop, or from a cherty and a non-cherty zone in the same outcrop. Where the member was always non-cherty only one sample was collected. It was noted in the field that the cherts

studied did not show the same outcrop appearance, but were divided into six arbitrary categories: nodular, thin platy, geodes and compact masses, disseminated granules and small masses, jagged seams parallel to the bedding, and chalc-
edonic veins not necessarily parallel to the bedding.

In the laboratory, the samples were cleaned, crushed, and treated with hydrochloric acid, to remove the carbonates, and were screened to one-sixteenth millimeter size. These sand grains were separated into light and heavy fractions by immersing the grains in bromoform (sp. gr. of 2.86) and allowing the heavies to settle and the lights to float. These residues were then made into permanent detrital slides by imbedding the grains in Canada balsam.

Three techniques were employed in examining the insoluble residue and determining the minerals present. A petrographic microscope was used for most of the mineral identification with a mechanical stage being used in the mineral counting to obtain an unbiased sample of the grains. For index of refraction work, the oil immersion method was used, with the index of the grain being compared to the index of a known oil. A binocular microscope was used to examine the coarse, insoluble residue.

Chalcedony was the most abundant constituent in the light slides with three forms being recognized, speckled chalcedony that graded into aggregates of quartz, fibrous chalcedony that showed a wavy extinction and appeared to grade from amorphous silica to quartz, and yellow-brown chalcedony.

Volcanic ash was usually a trace constituent and appeared as thin, angular films of natural glass called shards, or as partly rounded and slightly altered grains called semi-shards.

Other amorphous silica was observed in the form of opal, chalcedonic-opal (or amorphous silica with a lacy appearance that graded into chalcedony), and opal-ash (a material with properties intermediate between opal and ash, usually showing weak birefringence).

Other light minerals present were quartz and the feldspars.

Varying amounts of the usual expected resistant heavy minerals were present in all of the heavy mineral slides. These were magnetite, muscovite, garnet, tourmaline, rutile, kyanite, zircon, hornblende, hematite, and lesser amounts of biotite, andalusite, ilmenite, chlorite, titanite, corundum, sericite, and apatite. Authigenic celestite was a common constituent along with some pyrite and siderite.

In the coarse fraction a large grain of volcanic pumice was noted in one sample. The presence of numerous bubbles in the fragment indicated that it must have floated a great distance from its source before becoming waterlogged and settling to the bottom.

It was concluded from these studies that cherts are formed in more ways than one, although the presence of volcanic ash was an indication that ash was an important factor in the formation of certain cherts. The ash was a source of silica for percolating ground waters, was dissolved in the sea water and later

directly precipitated in the form of a gel, or was a source for diagenetic accumulation. Some of the chert studied was also believed due to organic silica, and possibly one siliceous limestone was either of epithermal or cold ground water origin.

In general, it was concluded that: cherty limestones do not necessarily contain ash, and ash is not always an indication of chert; ash is probably a constituent of most or all sedimentary rocks in varying amounts; different cherts are formed in different ways; and the rarity of references to ash in other works is due to the extreme difficulty in recognizing and interpreting ash in sediments.

