# PETROGRAPHICAL AND PALEOENVIRONMENTAL STUDY OF THE GLORIETA SANDSTONE NEAR ROWE, NEW MEXICO

A Thesis

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Master of Science



by

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## ABSTRACT

The Glorieta Sandstone outcrops along Glorieta Mesa in southeastern San Miguel County. The type section was chosen along the mesa one mile west of Rowe, New Mexico by Needham and Bates in 1943. A petrographic study of the Glorieta at the type section reveals that it is a quartz arenite cemented variously by clay, calcite, silica, and hematite. The formation was deposited in the near-shore zone as a beach and bar complex in a semi-arid climate. Source areas included highlands on the Uncompahgre, Sierra Grande, and Pedernal uplifts.

The Glorieta was deposited in saline waters with a high alkalinity. The diagenesis of the Glorieta was controlled by changes in pH of interstitial waters and by compaction. Silica was dissolved from detrital quartz and possibly from diatom shells while calcite precipitated. A lowering of the pH by microbiological activity, chemical reactions, or adsorption by clays caused the precipitation of silica as doubly or singly terminated crystals. Compaction caused fracturing of some quartz grains and pressure solution of silica. Calcite recrystallized into rhombs. Later percolation of ground waters through the formation dissolved the calcite. Locally calcite re-precipitated wedging apart the fractured quartz grains and between the quartz overgrowths.

The upper Glorieta at the type section could be quarried for use as dimension stone. If near-by markets

should evolve, clay-bearing horizons might be used as foundry sand, and other beds could be used as fracturing or abrasive sand.

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## ILLUSTRATIONS

## PURPOSE AND SCOPE

The Glorieta Sandstone of New Mexico poses important stratigraphic and economic problems to the petroleum explorationists and developers of dimension stone. Because of its wide distribution throughout part of New Mexico, its persistent lithology, its bold topographic expression, and its stratigraphic position between the underlying Yeso Formation and the oil-producing San Andres Limestone, the Glorieta has been recognized as a formation since 1943 when Needham and Bates designated the type section. However, with the exception of theses done by Huntington in 1949 and by Huber in 1961, there has been no detailed petrographic and paleoenvironmental work. It is the purpose of this thesis to present detailed descriptive work on the type section of the Glorieta Sandstone near Rowe, New Mexico, and to present an interpretation of the depositional environment and diagenesis of the formation.

## AREA OF STUDY

The type section of the Glorieta Sandstone is located on the escarpment of Glorieta Mesa one mile west of the town of Rowe in San Miguel County, New Mexico. The exact location of the section studied is shown in Figures 1 and 2. The access and exposure are very good. Field work was done mainly in the last weeks of August.

## METHOD OF STUDY

Samples were collected beginning in the Yeso Formation as it began to change from the characteristic pale reddish brown massive rounded slopes to the thin bedded grayish red and light gray slope-forming sands interbedded with thin limestones. Every change in mode of weathering, color, and bedding was documented and samples were taken. This procedure continued up through the entire Glorieta and to the top of the San Andres Limestone in order that both contacts might be studied. Color designation was taken from the 1963 "Rock Color Chart" distributed by the Geological Society of America, New York, N. Y.

Thinsections were made from each horizon in the section (Plate 1) represented by a rock number and/or by alphabetical division. Whenever possible sections were taken oriented with a north arrow so that east-west and north-south thinsections could be made. A total of 240 thinsections were made, 64 from the Yeso Formation, 159 from the Glorieta Sandstone, and 17 from the San Andres Limestone. The cement was so weak that most of the samples were impregnated using a vacumn pump and a plastic cement.

The thinsections were examined for grain size, sorting, grain shape, grain contacts, mineral components, porosity, grain deformation, cement, and indications of geochemical conditions during and after the time of deposition. Much of this data is in the rock descriptions in the Appendix.

ACKNOWLEDGMENTS

Many thanks are due to Dr. Christina Lochman-Balk for her supervision and aid. Dr. Frank Kottlowski and Mr. Max Willard were also ready with valuable advise throughout the study. I am indebted to all three.

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Deepest gratitude will always be felt for the kind hospitality of Mrs. C. M. Creamer and family of Rowe, New Mexico.

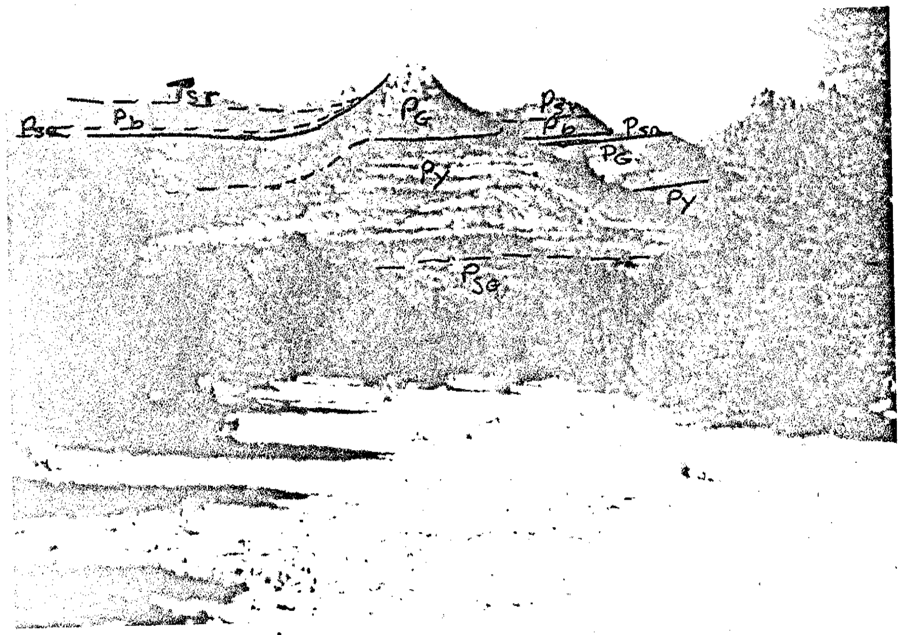


Figure 1: Photograph of the type section of the Glorieta Sandstone at Glorieta Mesa.

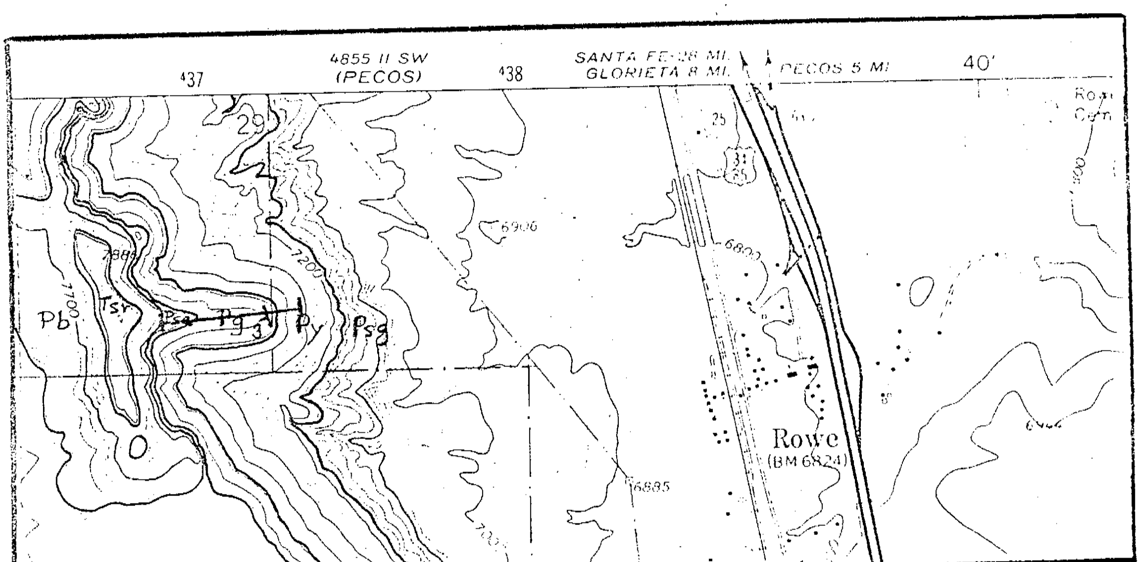


Figure 2: Topographic map with geology of the type section. Topographic map taken from Rowe quadrangle 7.5 minute series, 1966.

| | | | |
|---|---|---|---|
| Psg | Sangre de Cristo Fm. | Psa | San Andres Ls. |
| Py | Yeso Fm. | Pb | Bernal Fm. |
| Pg | Glorieta Ss. | Tsr | Santa Rosa Ss. |

⊢———⊣ Line of section

## REGIONAL STRATIGRAPHY

Permian stratigraphy in the south central United States is intricately linked to tectonic features. The Pennsylvanian and early Permian Periods were times of numerous pulsations. Block mountains were raised intermittently and cyclic sedimentation was common. In such a setting the thin continuous beds of the Glorieta Sandstone were deposited.

The Glorieta extends over northeastern New Mexico into Oklahoma and Texas. An equivalent sandstone sheet, the Cedar Hills Sandstone, is recognized in Kansas (Dixon, 1967; Irwin and Morton, 1969). In the northwestern part of New Mexico, the Glorieta Sandstone outcrops in Rio Arriba County (Anderson, 1970), in the Zuni Mountains (Smith, 1954 and 1959), in the Navajo Indian Reservation (Cooley and others, 1969), and around the San Juan basin (Read, 1951). The formation is present in central New Mexico (Wilpolt and Wanek, 1951). The Glorieta thins to a feather edge in the direction of the Delaware basin in southeastern New Mexico (King, 1942).

Major structural elements of the late Pennsylvanian and early Permian are shown in Figure 4. According to Dixon (1967), the most active tectonic element from middle Pennsylvanian through early Permian was the Pedernal uplift. The Glorieta Sandstone, the San Andres Limestone, and the Bernal Formation thin over the northern portion of this uplift. The high percentage of sand in the San

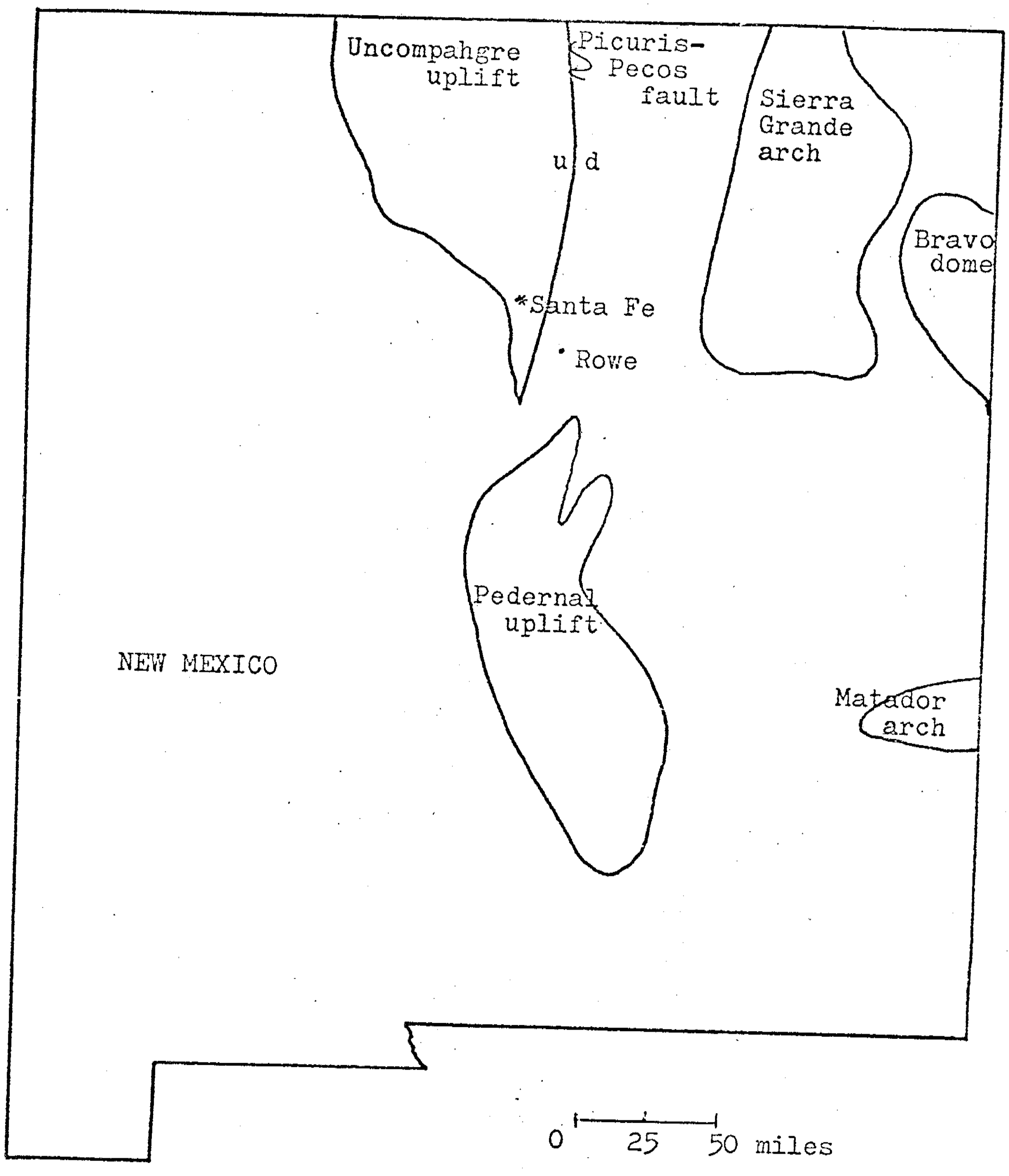


Figure 3: Major structural elements in late Pennsylvanian and early Permian. Taken from Miller, et al., 1963; Kottlowski, 1960; Irwin and Morton, 1969; and Dixon, 1967.

Andres close to the edge of the uplift compared to the percentage of sand in the San Andres farther away suggests that local highlands still existed in Leonardian time. The Triassic Santa Rosa Sandstone contains fragments of Precambrian rocks in its conglomerates, but it does not thin over the Pedernal axis. It is concluded that the Precambrian was exposed on the Pedernal uplift through Permian time, but by late Triassic, only a few small positive areas remained uncovered by sediments (Hock, 1970).

The Sierra Grande arch and the Bravo dome are other possible sources for Permian detritals. From stratigraphic relations in the southern Sangre de Cristo Mountains, Miller, et al., (1963) determined that this area was probably not positive during Morrowan and Desmoinesian time. They conclude that the Sierra Grande arch probably did not develop until late Pennsylvanian or Permian time. However, in the Oklahoma panhandle and adjoining areas of Texas and New Mexico the Glorieta is deposited on the Precambrian of the southern Sierra Grande uplift (Irwin and Morton, 1969). In Colfax and Union Counties, New Mexico, isopach studies suggest that a central portion of the Sierra Grande uplift was positive during deposition of the Yeso, Glorieta, and San Andres (Dixon, 1967). From these studies it is concluded that the Sierra Grande uplift was a source of clastics for the Sangre de Cristo Formation, the Yeso Formation, and the Glorieta Sandstone.

A third positive area is the Uncompahgre-San Luis uplift. In the Glorieta quadrangle, the Sangre de Cristo Formation thins significantly to the west toward this uplift. Permian formations also exhibit this thinning, but to a lesser degree than the Pennsylvanian formations (Budding, in press). This southermost extension of the Uncompahgre uplift was probably not an important source area for the clastics of the Glorieta, but the northern part of the Uncompahgre must have been significant. The Yeso, Glorieta, and San Andres thin in this direction (Tanner, 1963; Dixon, 1967). The Yeso and Glorieta probably intertongue with the Sangre de Cristo Formation and the San Andres passes laterally northward into an evaporite facies. These relationships are obscured by pre-upper Leonardian erosion (Rascoe and Baars, 1972).

## LOCAL STRATIGRAPHY AND GEOLOGICAL HISTORY OF THE UPPER PECOS VALLEY AND SOUTHERN SANGRE DE CRISTO MOUNTAINS

Miller, Montgomery, and Sutherland (1963) have determined the major sequence of events from the Precambrian through the Cenozoic in the area of the southern Sangre de Cristo Mountains and Upper Pecos Valley. Basement rock in this area consists of Precambrian schists, phyllites, quartzites, gneisses, hornfels, felsites, granites, and pegmatites. Prior to the Mississippian Period, orthoquartzites of the Del Padre Sandstone and limestones of the Devonian Espiritu Santo Formation were deposited on this basement. From textures and lithologies it is concluded that the area was a shallow sea. The rocks of highlands were metaigneous. The Embudo granite was apparently not exposed at this time.

The major structure in the Precambrian was the north-south trending Picuris-Pecos fault (Figure 3). Movement on this fault prior to the Mississippian arched and recrystallized the Del Padre Sandstone and the Espiritu Santo Formation. During the Mississippian, the area remained a shallow sea, and the Terrero Formation was deposited as a sparsely fossiliferous limestone.

In early Pennsylvanian time (Morrowan), further activity on the Picuris-Pecos fault resulted in uplift of the Precambrian metasedimentary area extending from the northern edge of the present day Santa Fe County northward into present day Colorado. This structural feature is called the Uncompahgre-San Luis uplift. To the east of the Uncompahgre uplift, alluvial deposits formed in what is known as the Taos trough. To the south of the uplift, marine shelf deposits were formed. In early Desmoinesian a secondary source supplied feldspars from the south to these shelf deposits. This source was probably the Pedernal uplift.

In late Desmoinesian time, renewed uplift along the Picuris-Pecos fault exposed granite as far south as the city of Santa Fe. Feldspar increases abruptly from 1 to 15 per cent to greater than 30 per cent in the Alamitos Formation and its equivalent, the upper arkosic member of the Madera Formation. The units consist of intercalated limestones, shales, siltstones, and arkoses. These are the deposits of the last major marine invasion of the shelf and trough areas during the Pennsylvanian. Rapid lateral and vertical changes in lithology are common during this time span (Miller, et al., 1963).

In northeastern New Mexico the Sierra Grande uplift was positive and the Sangre de Cristo Formation was deposited during the Missourian and Virgilian Epochs and perhaps into the Permian Wolfcamp. The Sangre de Cristo Formation is the first appearance of a red bed sequence. The formation consists of dark maroon silts and mudstones interbedded with brown and tan cross bedded sandstones, arkoses and thin limestone beds containing marine or fresh water fossils (Johnson, 1969). Miller, et al. (1963), Tanner (1963), Johnson (1969), and Budding (in press) agree that this is a continental deposit of coalescing alluvial fans, flood plains, deltas, and channel fills. Lakes and ponds as well as marine bodies of water probably covered this area from time to time.

In late Wolfcampian there was renewed activity on the Apishapa-Sierra Grande uplift. The Sangre de Cristo Formation continued to be deposited in a narrow strip between the Sierra Grande and the Uncompahgre uplifts. In the area around Pecos, New Mexico, the Sangre de Cristo is overlain by the reddish brown sandstones and siltstones of the Yeso Formation. Conformable over this is the Glorieta Sandstone. The relict ancestral Rocky Mountain uplift became active in northeastern New Mexico and central Colorado sometime in Leonardian. The Yeso and Glorieta were removed from this uplift in the southern Sangre de Cristos by erosion (Rascoe and Baars, 1972).

Huntington (1949) believed that the Yeso deposition was continental. Tanner (1963) interpreted the deposit as that of a tidal flat with possible beach deposits in the upper part. Johnson (1969) suggested that the Yeso was deposited in shallow marine waters on a broad flat coastal plain. Huber (1961), working in the Joyita Hills of Socorro County, interpreted the environment to be that of a delta facies grading upward to that of a beach. Hock (1970) argues that the lower portion of the Yeso was deposited in a saline epicontinental sea and the upper portion in a normal shallow agitated sea. The major point of agreement in these interpretations is that the upper portion of the Yeso is significantly different from the lower portion.

The environment of deposition of the Glorieta Sandstone has also been variously interpreted. Huntington (1949) suggests that the deposit was formed on a stable marine shelf. Huber (1961), Tanner (1963), and Johnson (1969) interpret the Glorieta as a nearshore deposit of beach, bar, and channel. Hock (1970) believes that the lower portion of the Glorieta is eolian with a sand source from the west. The deposition of the upper portion he believes was controlled mainly by marine processes. He assumed that the climate was arid to semi-arid. On the basis of the weathering of feldspars, Huber (1961) suggests that the climate was humid temperate to semi-arid. Tanner (1963) from paleomagnetic data finds that the state of New Mexico was positioned at 20 degrees south of the Permian equator. He emphasizes the presence of Pennsylvanian coal beds in the Pecos River Valley as evidence that the climate was warm.

The San Andres Limestone in northern New Mexico was deposited as the Ancestral Rocky Mountain uplift was being eroded. In the southeastern Pecos Valley the San Andres attains a thickness of 30 feet. The formation passes laterally to an evaporite facies in the northwestern Pecos Valley (Rascoe and Baars, 1972).

Hock (1970) and Tanner (1963) believe that the San Andres Limestone is an open marine formation. Huber (1961) interprets it as a lagoonal facies in the Joyita Hills area. In Socorro County, in the Joyita Hills, and north of the Pedernal uplift there are two to three sandstone beds in the basal portion of the San Andres Limestone. These are interpreted by Huber and Hock to be regressions of the sea.

After the deposition of the San Andres Limestone, the Bernal Formation was deposited as reddish brown sandstones and siltstones in conformable sequence. Near Bernal in San Miguel County the formation contains beds of gypsum. Johnson (1969) interprets the Bernal as a shallow water marine deposit on a broad flat coastal shelf.

The Santa Rosa Sandstone in the Pecos area is a pale red to light brownish gray sandstone cemented by reddish brown clay. Layers of red shale are common. Johnson (1969) suggests that the formation was the beach deposit of a transgressing sea. He notes the presence of an unconformity between the Santa Rosa and the Bernal. Tanner (1963) interprets the Santa Rosa Sandstone as a continental deposit, and the sequence from Sangre de Cristo through Santa Rosa Sandstone as a single transgressive-regressive sequence.

PREVIOUS SEDIMENTATION STUDIES ON THE GLORIETA SANDSTONE

Hock (1970) studied the Permian and Triassic section of the Pedernal uplift in the area of Clines Corners, Torrance County, New Mexico. He described the upper Yeso unit as pale red to reddish brown siltstones and sandstones interbedded with gypsum and limestone. The units are thick bedded. Quartz grains in the sandstones are very fine and angular. Limestone beds are light gray, porous, crystalline, and generally muddy.

The Glorieta described by Hock is a clean white cliff-forming sandstone with an abundance of iron-oxide coating on the grains. In the lower thirty feet it is thin bedded with large scale cross beds. Quartz grains are fine, well rounded, frosted, and pitted. The upper portion of the Glorieta contains fewer cross beds and becomes thick to very thick bedded. Size and angularity of quartz grains increases. Some iron concretions are found. Cementation in general is described as loose, and the rock is friable.

The San Andres Limestone along the northern Pedernal uplift is a gray, finely crystalline, non-porous limestone. It is thick bedded and sparingly fossiliferous. Gypsum is found in the formation in this area. A relatively high per cent of sand in the limestone is found close to the axis of the uplift compared to the per cent of sand to the east and the west. All of the Permian formations thin over the Pedernal axis.

Huber (1961) studied petrographically the Yeso-Glorieta-San Andres sequence in the Joyita Hills of Socorro County, New Mexico. The only feature apparently separating the upper Yeso Formation and the Glorieta Sandstone in this area is the change in color from maroon to white. Fine to medium well rounded quartz grains are characteristic of this entire sequence.

The San Andres Limestone of the Joyita Hills contains several sandstone beds in the carbonate sequence. The limestone section contains abundant broken fossil fragments. Huber interprets the upper Yeso-Glorieta as a beach deposit and the San Andres Limestone as lagoonal carbonate deposition.

Huntington (1949) did heavy mineral analyses of three sections of the Glorieta Sandstone: in the northern part of Chupadera Mesa, Socorro County; in southwestern San Miguel County; and the type section near Rowe. In this latter area, Huntington found that the basal layers of the sandstone could be distinguished by the concentration of silts and clays and iron oxide cement. Most of the quartz grains, 46 per cent, fall in the size range of fine sand. Quartz grains constitute approximately 90 per cent of the total rock in this lower section.

In the upper beds of the type section, Huntington found that 70 per cent of the quartz grains fall in the medium sand size range, and the dominant cement is carbonate. The percentage of heavy minerals in the upper Glorieta is lower than the percentage in the lower portion, and quartz consists of 97 per cent of the total rock.

According to Huntington, the most abundant heavy minerals are zircon and tourmaline, which compose respectively 27 and 25 per cent of the heavy mineral suite. Three colors of tourmaline are present in the rock samples. These are light yellow, dark brown, and indigo blue. Grains of this mineral and of quartz are proportionally more angular in the lower portion of the Glorieta than in the upper portion.

Iron oxides constitute 17 per cent of the heavy mineral suite. Other heavy minerals found were: magnetite, 15 per cent; leucoxene, 7 per cent; ilmenite, 5 per cent; and traces of rutile, garnet, epidote, hornblende, and muscovite (Huntington, 1949).

In general the present petrographic study of the Glorieta agrees with the work of Huntington. Grain size does increase up section. The heavy minerals found in Huntington's analysis are present in thinsection. However, dominant cements are seen to fluctuate more than Huntington suggests, and the presence of an additional cement, chert, is discerned from thinsection. Microcline, orthoclase, perthite, and plagioclase fragments are also found, as well as igneous and metamorphic rock fragments.

CLASSIFICATION SCHEMES

Five classification schemes are used in the naming of rock samples taken at the Glorieta type section. Folk's 1968 sandstone classification scheme, shown diagramatically below, is used for all sandstones. His method of naming sandstones is also employed.

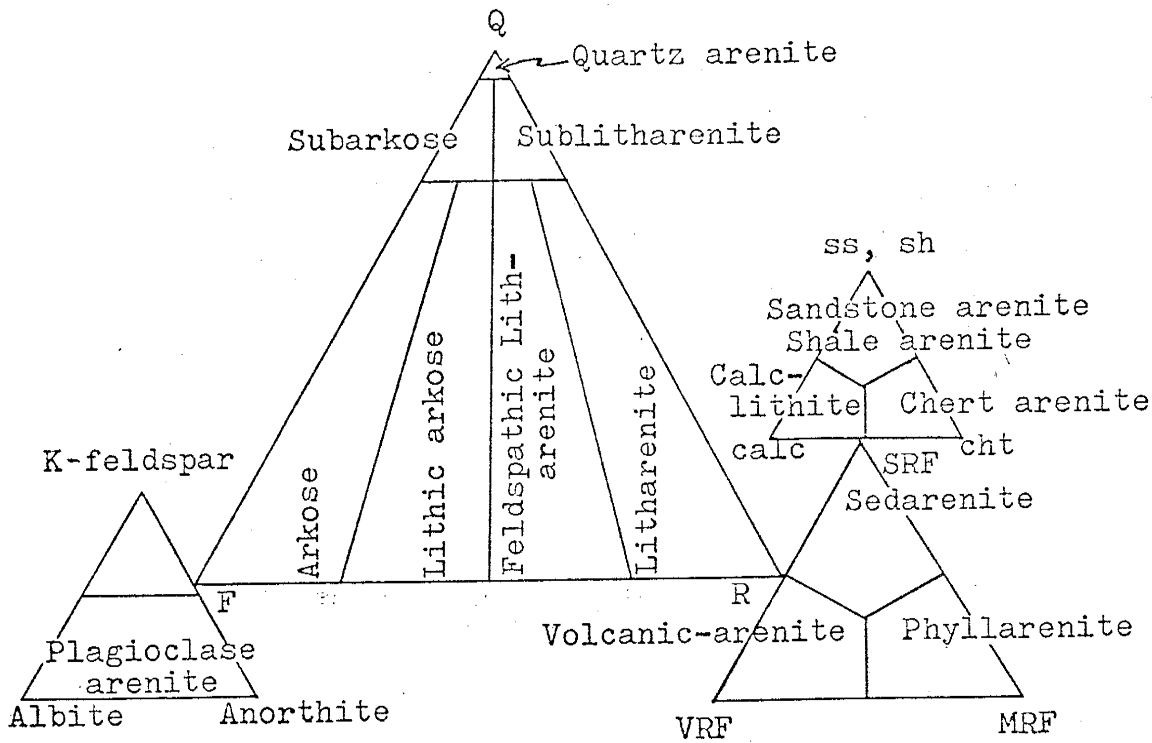


Figure 4: Folk's 1968 sandstone classification scheme.

The advantages of this scheme are clarity, simplicity, and attention to all major detrital components. The major disadvantage is that Folk's triangle ignores the cement or matrix. Because clay plays an important part in determining depositional environment and diagenesis, a modification of Folk's triangle which combines the ideas of Dott (1964) and Picard (1971) is used. Figure 5 is a schematic diagram of this. The boundary between arenites and wackes is placed at an arbitrary 25 per cent clay based on the work of Picard (1971) and Dapples (1972). Picard's classification scheme is used for rocks which either fall out of the size range of sand or contain greater than 50 per cent clay. This is presented in Figure 6.

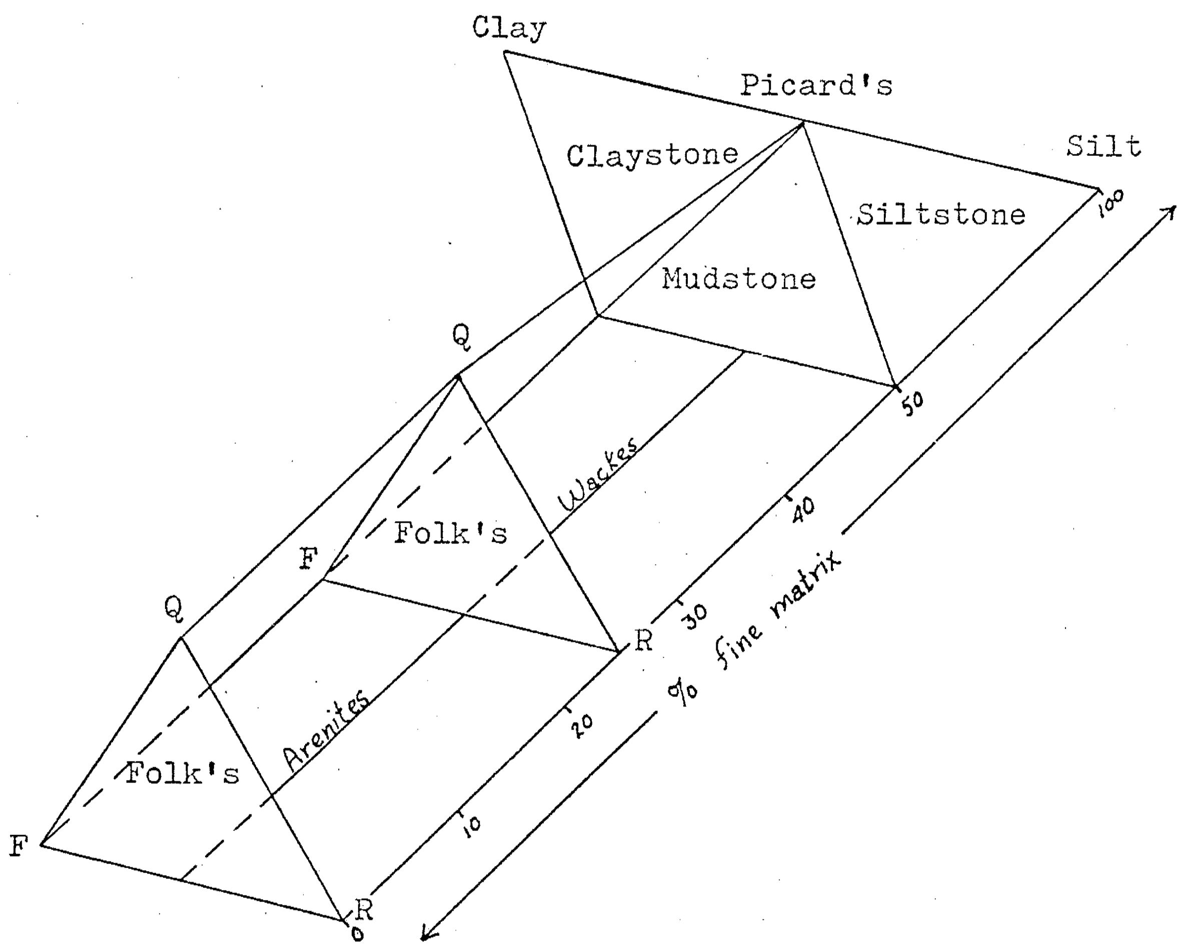


Figure 5: Schematic diagram linking Folk's and Picard's classification schemes.

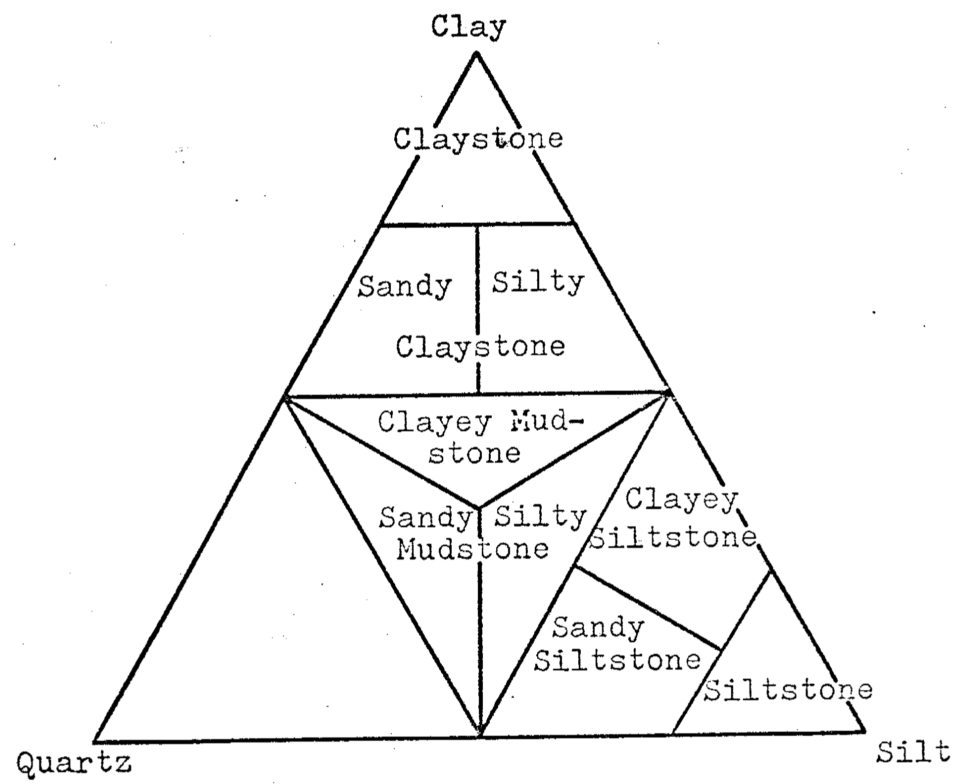


Figure 6: Picard's 1971 classification of fine-grained sedimentary rocks.

With regard to carbonate as a rock type and as a cement, two other classification systems are used. Folk's classification of limestones is used for the carbonate rocks. This classification is presented in "Petrology of Sedimentary Rocks," 1968. Dapples 1971 classification of carbonate cements is used in order to facilitate interpretation of the diagenesis of the carbonate cemented rocks. It is presented in outline form in Figure 7.

Figure 7: Dapples 1971 classification of carbonate cement in quartzose sandstones.

I. Cementation without destruction of the grain-supported framework
   A. Crystallization in a single event filling interstitial space as a simple adhesive
      1. Without mineralogic reaction
      2. Incorporating clay minerals already present in intergranular space
   B. Crystallization as part of dual events
      1. Filling pore space following partial welding of quartz grains
      2. Recrystallization into single or compound crystals in a mixture of quartz and carbonate grains after partial welding has taken place

II. Cementation with destruction of the grain-supported framework
   A. By crystallization and volume expansion
      1. In interstitial pores to produce local expansion
      2. In porous grains, causing rupture and rotation of grains
      3. Around sand nucleii to form small concretions in situ
      4. As large poikilitic crystals
   B. By replacement of silicate mineral grains
      1. Without destruction of bedding
      2. By development of large concretions which destroy bedding

FIELD DESCRIPTION OF THE TYPE SECTION

Strata ranging in age from Permian to Triassic are exposed on the Glorieta Mesa escarpment near Rowe. The beds dip into the mesa three degrees southwest and can be traced along the mesa escarpment in both directions for at least ten miles.

Permian rocks exposed on the mesa escarpment include the Sangre de Cristo Formation, the Yeso Formation, the Glorieta Sandstone, the San Andres Limestone, and the Bernal Formation. The upper Sangre de Cristo Formation consists of medium to coarse light gray arkosic sandstone. It is underlain by interbedded brown and red sandstones. It is massive bedded and contains many intraformational conglomerates and cross beds. Grains are sub-angular and cemented with sparry calcite (Budding, personal communication).

The Yeso Formation consists of a pale reddish brown bimodal sandstone or siltstone, poorly cemented and generally poorly sorted. It is massive bedded and forms steep rounded slopes. White spots from two to ten mm and lenses ranging from a few centimeters to several meters are abundant. One persistent white sandstone unit is prominent on the slope of the lower 251 feet of the Yeso.* The upper 50 feet changes to thin bedded units which are more dominantly gray than the lower Yeso. There are two five foot limestone units in the upper Yeso. The lower

* The total thickness of 301.0 feet measured by Needham and Bates is used for this calculation.

limestone is pinkish gray with dark specks of detrital hematite and laminations of clayey micrite. Fine quartz and silt are persistent in layers of the limestone. An abundance of vugs and a dismicrite texture is notable in the lower limestone unit. Bedding is very thin to thin.

The basal portion of the upper limestone unit of the Yeso is a one-foot pale red cross-bedded silty dismicrite which consists of approximately 30 per cent vugs in the upper portion. Cross bedding is visible in hand specimen because hematite delineates the layers of limestone. Small "faults" are visible in thinsection. Quartz, microcline, plagioclase, hematite, hornblende, muscovite, and zircon occur in this basal layer.

A two and one half foot light gray arenaceous dismicrite tops the pale red limestone. Silt sized quartz and iron oxide are the only inclusions. Vugs constitute approximately 20 per cent of the total rock.

The Glorieta Sandstone consists of medium, fine, and very fine sandstones with thin clay layers interspersed. Color ranges from grayish orange to very pale orange. The major cements are clay, calcite, and silica. The formation is poorly indurated in general, but forms a steep cliff. Bedding ranges from platey to very thick bedded. Cross bedding is frequent and indicates a source from the north or northeast as the work of Tanner (1963) also shows. The lower contact was picked in the field on the basis of the abrupt color change from pale reddish brown and light gray to grayish orange. Petrographic evidence supports this position of the lower contact.

At the top of the cliff-forming portion of the Glorieta Sandstone there is a 20 foot slope covered by angular chips of light gray limestone. There are three one-foot beds of sandstone outcropping in this covered area: one at four feet above the cliff; one at six feet above the cliff; and one at eight feet above the cliff. Needham and Bates (1943) apparently placed the contact at the top of the highest exposed sandstone bed. From this horizon they measured 20 feet of San Andres Limestone, 12 feet of covered slope and 8 feet of cliff-forming limestone beds. At the base of the cliff the beds consist of a calcareous sandstone interbedded with five mm lenses of limestone (Figure 8). This is the first appearance of limestone noted in this section. For this reason I placed the Glorieta-San Andres contact at the base of the cliff-forming limestone beds.

In a roadcut some 12 miles northwest of the type section along Interstate 25 the Glorieta-San Andres contact is exposed. The area is faulted, and the San Andres is recrystallized and probably thinned. The top bed of the Glorieta in this outcrop is a bimodal coarse and very fine, poorly sorted, calcareous sandstone. Under it is a very fine sandstone with clay and calcite cement in excess of 15 per cent of the total rock. The lowest bed of the Glorieta sampled here was a siltstone cemented

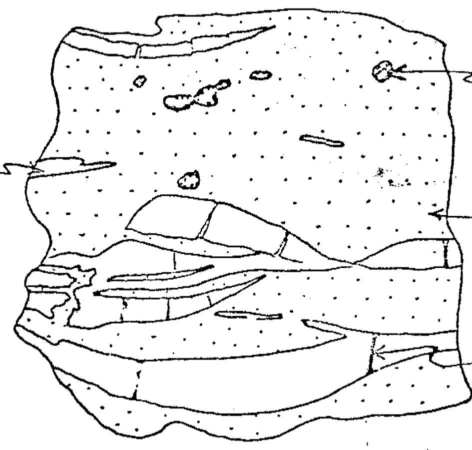


Figure 8: Slabbed section of RSA 2 showing the relationship of limestone lenses to the calcareous sandstone.

with calcite and clay.

The three sandstone units exposed on the slope above the cliff-forming Glorieta are calcitic bimodal quartz arenites. RG 100d is a calcitic bimodal subarkose. The similarity to the uppermost Glorieta at the roadcut is striking. The slope-forming area between and above the three exposed beds presumably consists of poorly cemented sandstones and siltstones characteristic of the upper Glorieta at the type locality.

Platey to laminated bedding and grayish to very pale orange color characterize the San Andres Limestone at the type section. The formation becomes thin bedded at the top and very porous. Vugs and a hydrogen sulphide odor are common throughout. No evidence of fossils was found.

Above the San Andres is the pale reddish brown Bernal Formation which consists of interbedded siltstone and sandstone. Bedding is thin and slabby. This unit weathers to a splintery gravel on slopes. The upper Bernal consists of a very light gray siltstone or very fine sandstone.

Capping the mesa is the Triassic Santa Rosa Sandstone. The lower portion of this formation is a pale red to light brownish gray basal conglomerate consisting of pebbles approximately 23 mm in size in a matrix of granules slightly larger than two mm. The first 40 feet, according to Needham and Bates, consists of these conglomerates and cross bedded sandstones. The bedding is massive and weathers rounded. This part of the formation is cliff-forming. Sixty-four feet of pale red shaley sandstone overlie the lowest division of the Santa Rosa. The middle section is very thin bedded. The top fourteen feet of the Santa Rosa is a coarse, light colored, massive bedded sandstone (Needham and Bates, 1943).

## TERRIGENOUS ROCKS--UPPER YESO FORMATION

The upper Yeso Formation is dominated by wackes. It is characterized by angular silt and very fine sand in a red clay matrix. Several samples are bimodal, displaying a second set of medium to coarse well rounded sand grains (Plate 2). Sorting in the first samples (RY 10 to RY 13 and RY 19 to RY 24) is poor. As the Yeso-Glorieta contact is neared, well sorted material becomes more common. Carbonate in the clay cement becomes more abundant, and white laminations are seen in hand specimen. In beds close to the contact, most of the red color comes from hematite coating quartz grains rather than red clay. Quartz grains are better rounded. These relationships are shown diagramatically in Plate 1.

Detrital minerals in the Yeso include quartz, microcline, andesine, hornblende, muscovite, magnetite, ilmenite, hematite, and zircon. Rock fragments include at least two types of igneous rock and a claystone.

Quartz is distributed between two sizes, an angular fine fraction and a rounded coarse fraction. Extinction is straight to slightly undulose in both single and composite grains. Composite grains are few and equigranular. Some unidentified inclusions are present in single grains.

Microcline grains exhibiting characteristic grid twinning are present as angular to rounded grains in the Yeso. Plagioclase grains also occur. By use of the

PLATE 2

PLATE 2:

Fig. 1: RY 13 Characteristic red and white layers of the Yeso Formation. x8. Plane polarized light. Coarse silt to very fine sandstone: clayey immature quartz wacke with red claystone lenses. Angular quartz grains. Rounded orthoclase. Hematitic clay with calcite stringers. Floating and tangential contacts. Coastal plain deposit.

Fig. 2: RY 21 Characteristic red wacke of the Yeso Formation. x8. Crossed nicols. Very fine sandstone and coarse sandstone: clayey bimodal quartz wacke. Sub-angular quartz grains in red clay matrix. Layer of calcite cement. Floating contacts. Coastal plain deposit.

PLATE 2:


Figure 1: RY 13

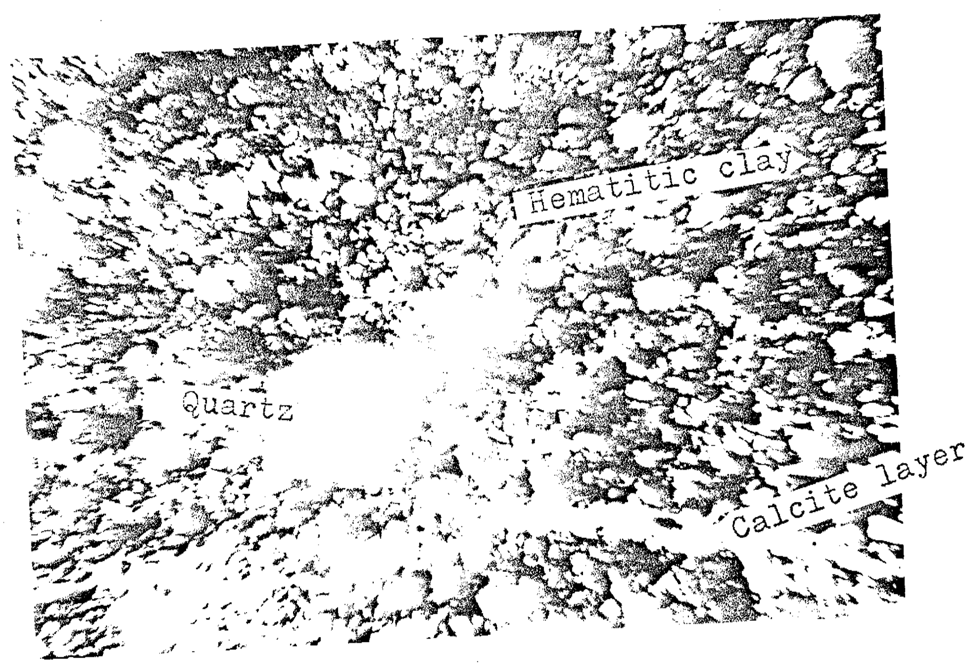


Figure 2: RY 21

Michel-Levy method, the plagioclase grains are determined as approximately An-42 in composition.

The orthoclase grains appear brownish under reflected light because of incipient alteration. Some orthoclase grains in the uppermost Yeso display overgrowth (Figure 1, Plate 3).

Hornblende occurs in the highest beds of the Yeso as elongate laths. Pleochroism is marked. Birefringence is in the upper second order. No interference figures were obtained due to the small size of the fragments.

Zircon occurs in the Yeso Formation as terminated crystals and as sub-rounded grains. Fragments are too small to get an interference figure.

Rutile occurs as elongated irregular grains in the Yeso. The color is reddish brown in reflected light.

Three opaque mineral types are present in the Yeso. The magnetite is small black angular grains and crystalline aggregates. Ilmenite occurs in the characteristic skeleton structure and hematite as small irregular opaque grains with blood red rims under crossed nicols. Occasionally hematite also occurs as a dark spot in the red clay.

Muscovite appears as small flakes associated with clay. The shape is rarely distorted.

There is no evidence that the red clay which acts as a cement in the Yeso Formation was precipitated. The flakes of clay do not arrange themselves at right angles to the detrital grains. The possibility exists that the

PLATE 3

PLATE 3:

Fig. 1: RY 38 Uppermost Yeso Formation. x80. Crossed nicols. Medium sandstone: clayey immature quartz arenite. Sub-rounded quartz, single and composite grains. Orthoclase showing overgrowth after calcite deposition in pores. Mainly clay cement. Calcite spotty. Tangential, straight, and concavo/convex contacts. Coastal plain deposit.

Fig. 2: RG 17 Lowermost Glorieta Sandstone. x8. Plane polarized light. Medium to fine sandstone: highly calcitic supermature quartz arenite. Rounded quartz grains. Sub-rounded orthoclase with hematitic clay rim forming solution armoring. Calcite cement recrystallized during diagenesis and after silica overgrowth. Large grains of calcite shown by the dark tones of the cement on the right and the light tones of the cement on the left. Hematite rims around grains and hematite filling the pores. Contacts tangential, straight, and concavo/convex. Beach and bar deposit.

PLATE 3:

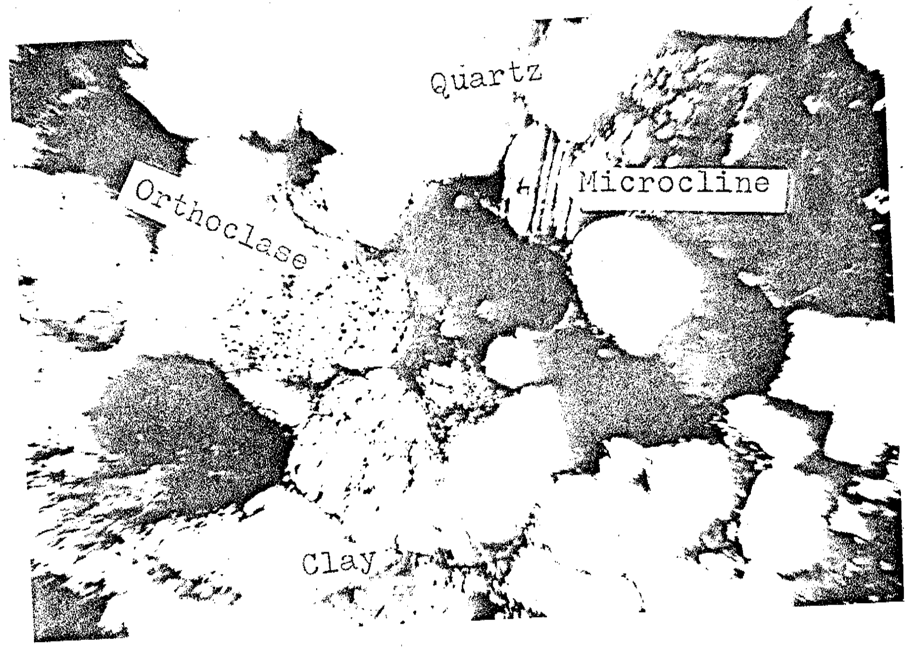


Figure 1: RY 38

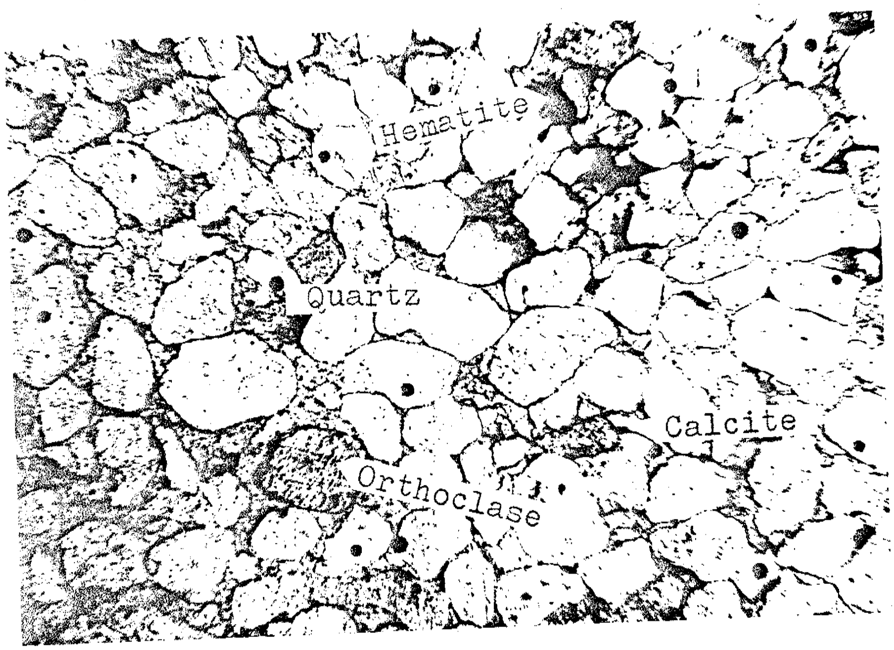


Figure 2: RG 17

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vex.

composition of the clay may have been altered by post-depositional chemical reactions or that the lattice framework of the clays may have been altered during diagenesis. It is assumed in this paper that the clays of the Yeso are detrital and probably not significantly metamorphosed since the time of deposition.

Samples of the Yeso Formation were stained with benzidene dihydrochloride. Most stained bright blue, implying the presence of montmorillonite. As the Yeso-Glorieta contact was neared, the samples showed either no reaction or a blue-green color. Blue-green color suggests that the clay in that sample may be mixed-layer illite-montmorillonite. The sample showing no reaction may contain kaolinite or a non-reactive montmorillonite. The only method of positive identification is through x-ray analysis, and this method was not employed in the present study.

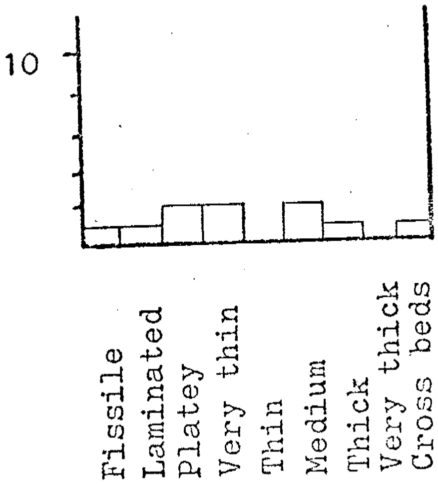
Orthochemical constituents of sedimentary rocks are defined as those substances which are "produced chemically within the basin of deposition and show little or no evidence of significant transportation or aggregation into more complex entities" (Folk, 1968). The calcite cement and probably some of the hematite in the Yeso Formation are the only orthochemical constituents of the sandstones. Crystallization of the calcite was apparently penecontemporaneous with deposition of the formation and took place in a single event filling interstitial pores or being deposited as thin calcite layers. There is no destruction of the grain fabric. This form of precipitation produced the white spots and layers commonly found in hand specimen throughout the Yeso Formation.

TERRIGENOUS ROCKS--GLORIETA SANDSTONE

The designated contact between the Yeso Formation and the Glorieta Sandstone at the type section is marked by a distinct change in physical properties. The uppermost Yeso is a white sandstone bed. The lowermost Glorieta is a yellow sandstone bed. Sorting changes from moderate to poor in the uppermost Yeso to very well to well sorted in the lowermost Glorieta. Grain size changes from the very fine sand of the uppermost Yeso to fine to medium sand of the lowermost Glorieta. Cement changes from dominant clay with calcite filling some pores to a dominant calcite cement. The uppermost Yeso and lowermost Glorieta are shown in photomicrographs RY 38 and RG 17 (Plate 3).

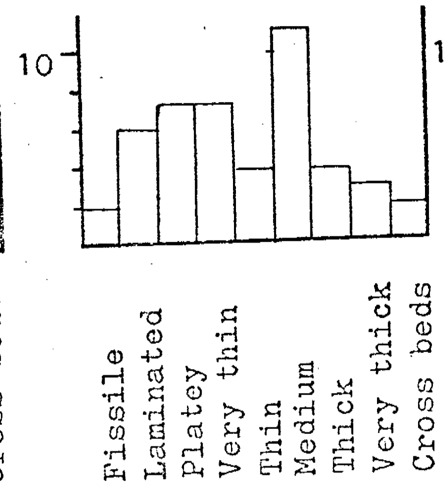
The Glorieta Sandstone in this paper will be divided into three units for the purpose of discussion. The three units are separated by two thin silty claystone layers (RG 33 and RG 65b). The basis for this division is the presence of the claystones and the change in thickness of bedding among the three units shown in Figure 9.

Folk (1968) recognizes four stages in the textural maturity of clastic sediments on the basis of physical properties: immature, submature, mature and supermature. The immature stage is characterized by over five per cent



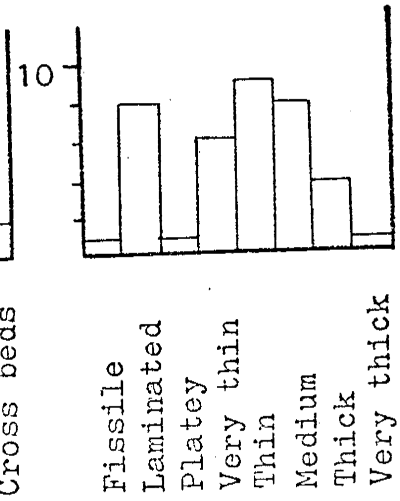

Unit 1

Lower Glorieta



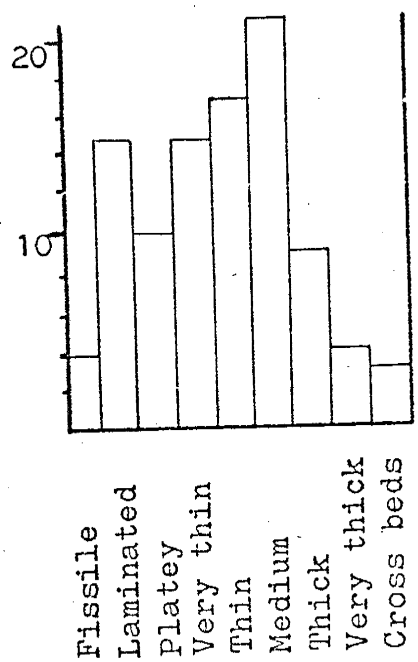

Unit 2

Middle Glorieta




Unit 3

Upper Glorieta




Total Glorieta

Figure 9. Thickness of bedding in the lower, middle, and upper Glorieta, and in the total Glorieta. Histogram scale is 1:1 with measured intervals.

terrigenous clay matrix; the submature by poor sorting and under five per cent clay matrix; the mature by little or no clay with well sorted sand grains; and the supermature by little or no clay with well sorted and well rounded sand grains. Plotting maturity of the Glorieta sediments shows several cycles of immature to supermature sediments (Plate 1). The relationship of textural maturity to grain size is shown in Figure 10. 51.6 per cent of the thinsections studied contained largely fine sand grains; 35 per cent contained medium sand grains; 11.9 per cent contained very fine sand grains; less than 2 per cent of the thinsections contained coarse silt grains or coarse sand grains. The one coarse silt in the Glorieta is immature, and medium sands are concentrated in the mature and supermature stages of textural maturity.

The basal Glorieta (unit 1) consists of grayish orange to very pale orange quartz arenites. 75 per cent of the beds sampled are mature or supermature. Thin bedding dominates the sequence. Grains range from fine to medium in size. Three of the bedding units are bimodal in size distribution. The sediments are very well to well sorted. Grain shapes are based only on 0.1 mm grains as these are found in almost every unit of the Glorieta. In the basal Glorieta most of the grains are sub-angular to sub-rounded. The relation of maturity to time is almost linear as one goes up section in the lower Glorieta. Supermature sediments give way to immature sediments with no major

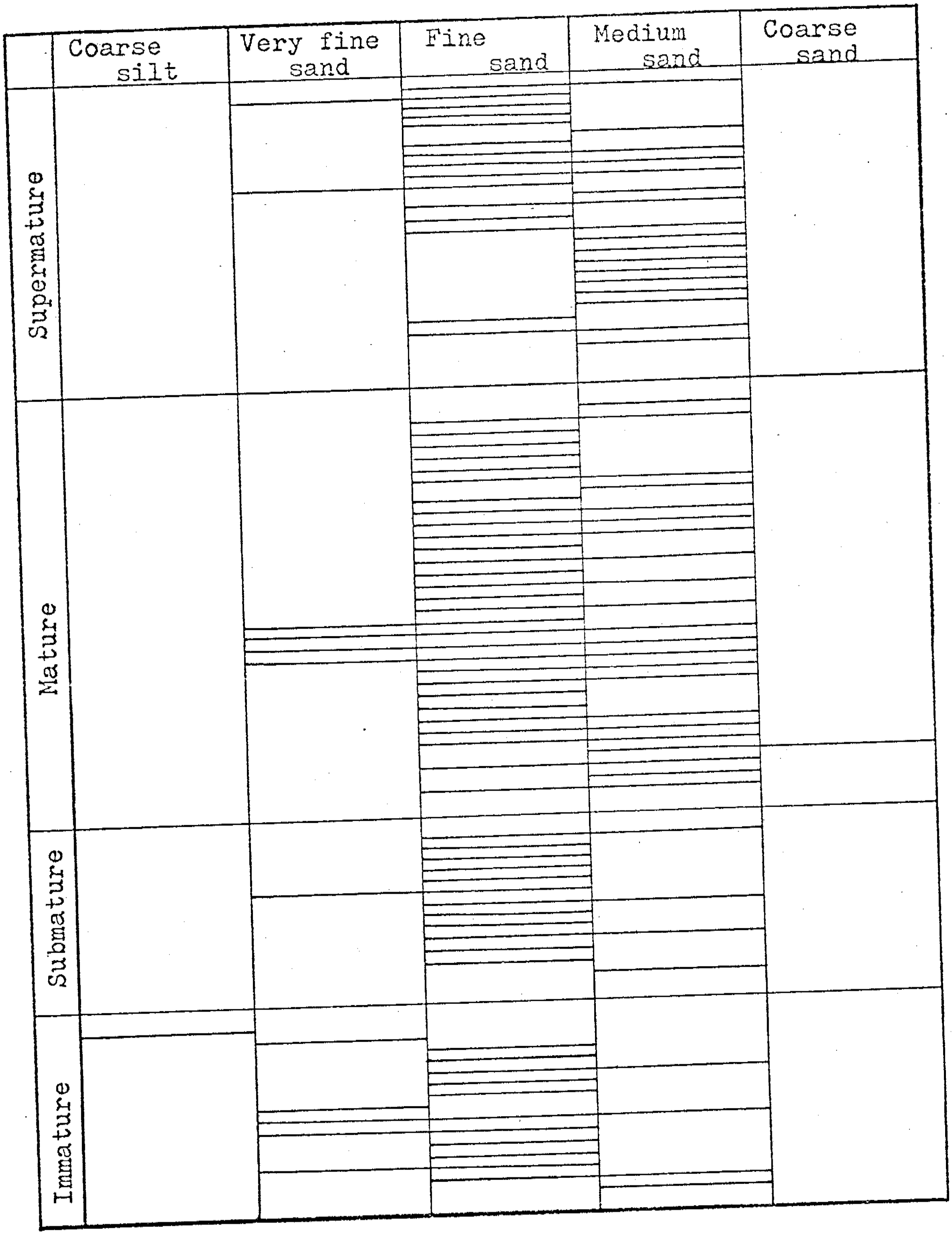



Figure 10. Maturity versus grain size. Glorieta Sandstone only, textural maturity.

fluctuations.

In the middle Glorieta (unit 2), color and sandstone classification varies. Mature and supermature quartz arenites constitute 65 per cent of the rocks in this section; submature quartz arenites are 13.5 per cent; immature quartz arenites are 16 per cent. One quartz wacke and one claystone are present. A 10 cm bed of dismicrite occurs midway in this unit. Clay, quartz, and hematite form layers which are visible in hand specimen in this limestone bed. Grayish orange, pale orange, white, yellowish brown, and grayish purple beds are dominant in this part of the formation. Stylolites are common. Bedding is relatively thicker with thin layers in between. Cross beds are present in both the lower and middle Glorieta. Current groove casts are also found. Weathering of round knobs on some of the flatter surfaces suggests the presence of some intraformational conglomerates.

The grain size of the middle portion of the Glorieta fluctuates from very fine to medium. The majority of the thinsections show lithology in the fine size range. A series of eight hard-to-define cycles going from mature to immature is evident from close analysis. These are defined graphically in Plate 1. Sorting in each cycle generally goes from high to moderate or poor. Rounding varies from angular to well rounded and does not seem to show relationship to the cycles.

Grayish orange and very pale orange quartz arenites characterize the upper portion of the Glorieta (unit 3). Supermature and mature beds constitute 56 per cent of this unit; submature and immature quartz arenites are each 18 per cent; quartz wackes are 8 per cent. Most of the supermature and mature beds are concentrated toward the top. Relatively more thin and laminated beds are characteristic of the upper unit than elsewhere.

Median grain size in the upper Glorieta falls in the medium size range. Ill-defined cycles from mature to immature sediments are present in this unit. Sorting varies from very good to moderate in most cycles. Grains are mainly well rounded in this unit of the Glorieta.

DETRITAL COMPONENTS OF THE GLORIETA

When plotted on Folk's 1968 sandstone classification triangle, almost all of the beds in the Glorieta fall into the area reserved for quartz arenites. The per cent specific quartz generally falls between 98 and 100. There are two exceptions. One is the silty claystone, RG 65b, which contained 94 per cent quartz and equal amounts of feldspar and rock fragments. The other exception is the top exposed bed of the Glorieta. This unit falls into the subarkose field of Folk's classification system.

Quartz grains in the Glorieta are both single and composite. Single grains show straight to undulose extinction. A few contain vacuoles, and in a few tourmaline and rutile needles are present as inclusions. A brown or red clay stain is common. Fractured grains with calcite in the fractures are present in some beds as shown in Figure 11. Composite grains show both straight and undulose extinction. Some composite grains are equigranular; others are elongated and bimodal. Overgrowth is common in most beds, both as secondary enlargement or outgrowths.

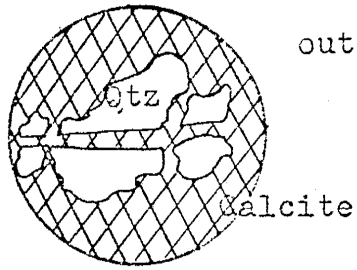



Figure 11. RG 31b. Quartz grain with fractures filled with calcite.

Some of the quartz in the Glorieta is definitely sedimentary. Reworked overgrowths are frequently found ( Figure 12). Occasionally a grain will be stained with a brown or red clay which contrasts sharply with the cementing clay.

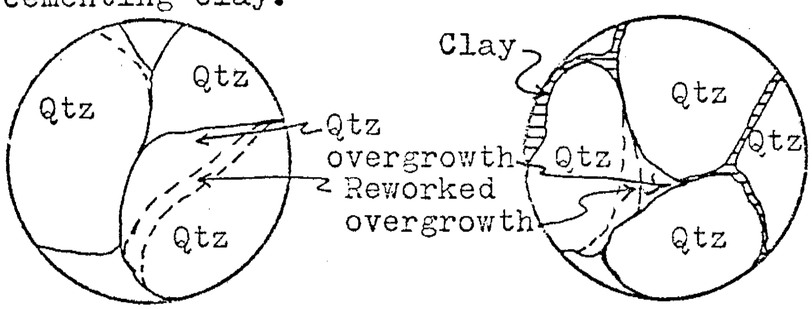



Figure 12a. Evidence for reworked overgrowth overgrown a second time during diagenesis of the Glorieta. Note euhedral quartz overgrowth. RG 51.
12b. RG 78f. Evidence for reworked overgrowth.

There is some controversy between Blatt (1967) and Folk (1969) as to what characteristics, if any, distinguish metamorphic and igneous quartz. Blatt's study suggests that quartz released from schists apparently weathers to grains of the fine sand size range. Quartz released from plutonic and gneissic rocks falls into the range of coarse sand. Blatt suggests that quartz grains which are composite, bimodal, elongated, and with a preferred crystallographic orientation are derived from a metamorphic source. He feels that quartz grains showing strongly undulose extinction from both igneous and metamorphic rocks are selectively destroyed by abrasion. His study shows no difference in degree of undulatory extinction existing between plutonic and gneissic rock types.

Folk, on the other hand, feels that strongly undulatory quartz is an index of stretched metamorphic rocks and that quartz grains with straight extinction have a plutonic source. He is willing to accept as metamorphic quartz those composite quartz grains of fine sand size which have straight extinction and those sheared composite quartz grains which contain elongated undulose members with crenulate boundaries.

Most of the quartz in the Glorieta is of the single grain, straight to slightly undulose type. Folk would say that the source was plutonic; Blatt would say that the first-cycle fine quartz must be from a schistose source. The question must be left open.

Composite grains of quartz in the Glorieta Sandstone exhibit mainly straight extinction and straight boundaries. This may be because of the small grain size. The grains divide themselves into those which are equigranular and those which are elongated and bimodal. I will assume that most of the elongated and bimodal composite quartz grains are metamorphic. The source of the equigranular composite grains may be either plutonic or metamorphic.

Feldspar fragments in the Glorieta Sandstone are dominantly microcline and orthoclase. The grains of microcline vary from angular to rounded, from altered to overgrown, from fractured to whole. The majority of the microcline fragments are fresh, unaltered, and unweathered. Examples of these characteristics are in Figure 1, Plate 11, and Figures 2, Plates 3 and 5. In several cases quartz overgrowths have engulfed both angular and embayed microcline, as shown in the sketches of Figure 13.

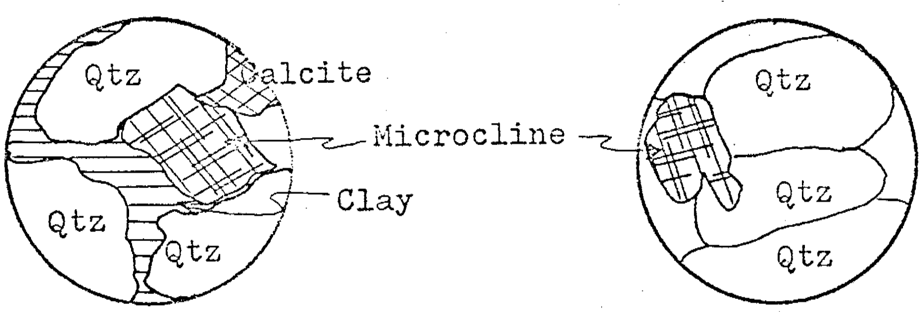



Figure 13 a. RG 21. Angular microcline enclosed by quartz overgrowth.
13 b. RG 25b. Embayed microcline enclosed by quartz overgrowth.

In general the grains of orthoclase are unaltered and unweathered. However, most are clouded with bubbles and some clouding is due to incipient alteration products. A few grains clearly show cleavage (Plate 3, Figure 2; Plate 5, Figure 1; Plate 6, Figures 1 and 2; Plate 7,

PLATE 4

PLATE 4:

Fig. 1: RG 92 Typical upper Glorieta. x8. Crossed nicols. Medium sandstone: siliceous supermature quartz arenite. Overgrown quartz. Straight to undulose extinction. Well compacted. Straight and concavo/convex contacts. Beach deposit.

Fig. 2: RG 23 Evidence of pressure solution. x80. Crossed nicols. Fine sandstone: highly siliceous calcitic mature quartz arenite showing pressure solution. Overgrown quartz. Clay and chert matrix. Sutured and mosaic contacts. Beach deposit. Glorieta Sandstone.

PLATE 4:

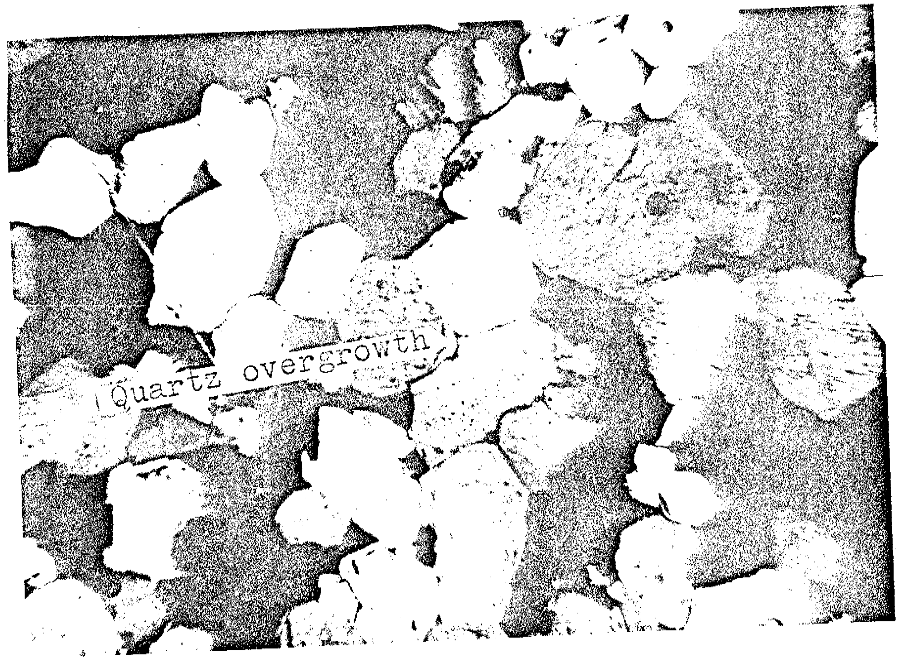



Figure 1: 92

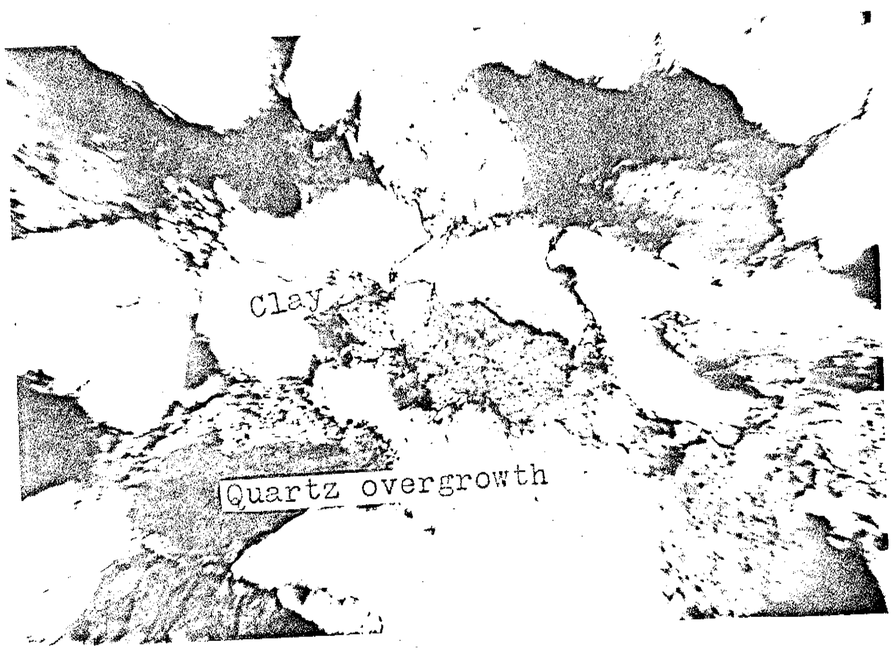



Figure 2: RG 23

PLATE 5

PLATE 5:

Fig. 1: RG 45 Stylolitic seams of the Glorieta Sandstone. x8. Plane polarized light. Fine sandstone: siliceous clayey immature quartz arenite. Overgrown quartz. Orthoclase. Angular microcline. Muscovite in clay cement. Concavo/convex and sutured contacts.

Fig. 2: RG 71 Microcline encompassed by quartz overgrowth. x80. Crossed nicols. Very fine sandstone: clayey immature quartz wacke. Sub-rounded, sub-angular, and chemically altered quartz. Rounded microcline grain apparently overgrown by quartz when the grain was angular. Clay cement. Glorieta Sandstone.

PLATE 5:

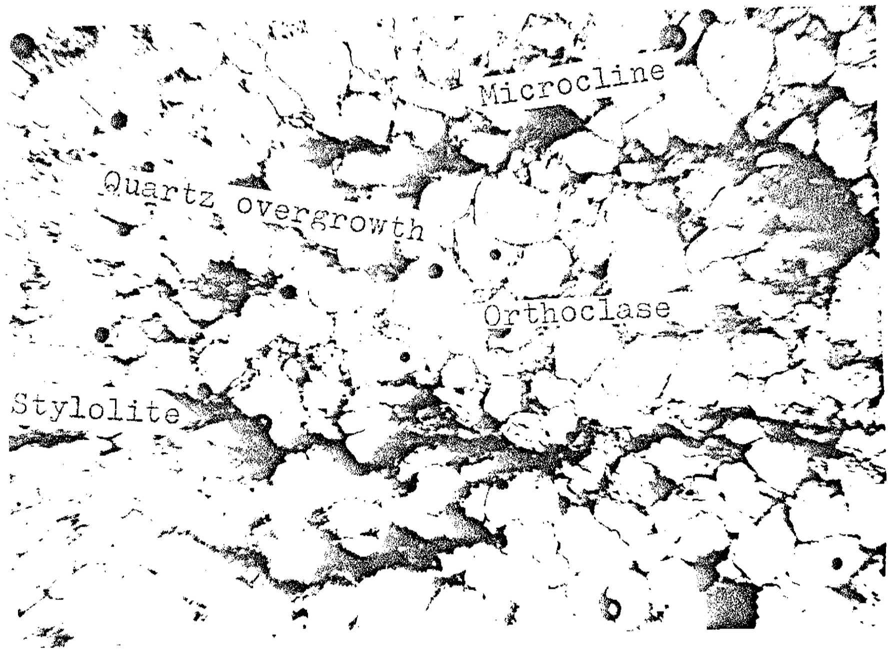



Figure 1: RG 45

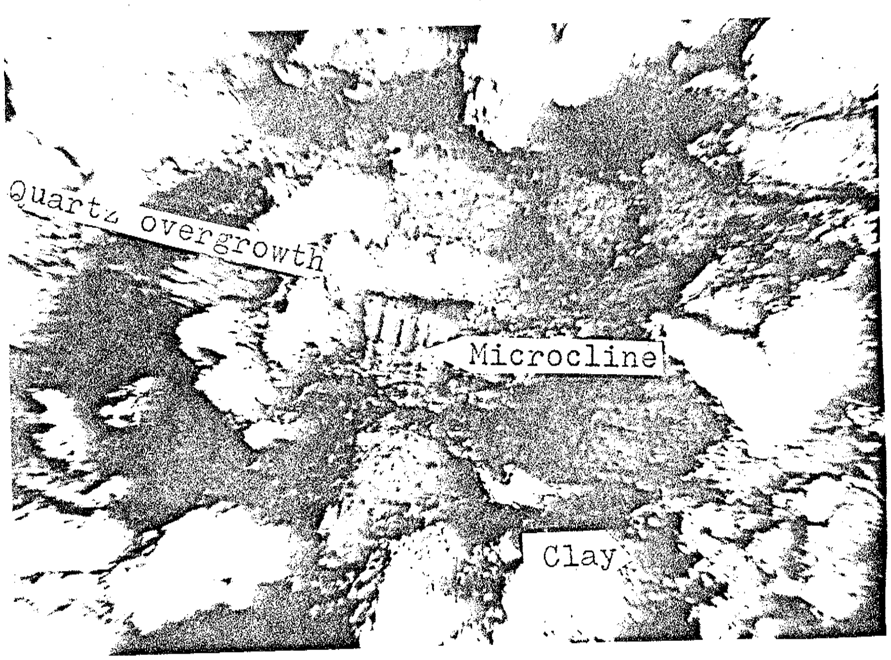



Figure 2: RG 71

PLATE 6

PLATE 6:

Fig. 1: RG 61 Muscovite in clay, Glorieta Sandstone. x80. Plane polarized light. Medium sandstone: clayey immature quartz arenite bordering on wacke. Chemically attacked quartz. Orthoclase. Red clay. Muscovite. Floating, tangential, and straight contacts.

Fig. 2: RG 65b Authigenic hematite octahedra and aggregates in red and white clays. x8. Plane polarized light. Silty claystone: layers of hematitic and non-hematitic clay. Angular quartz. Rounded orthoclase. Hematite in octahedra and aggregates. Glorieta Sandstone.

PLATE 6:

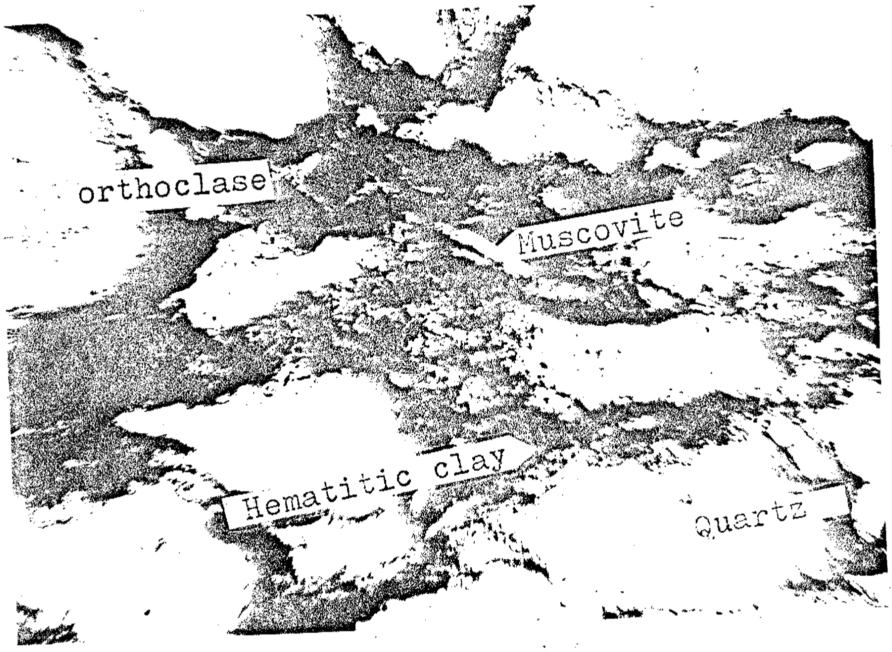



Figure 1: RG 61


Figure 2: RG 65b

PLATE 7

PLATE 7:

Fig. 1: RG 38 Primary clay matrix of the Glorieta Sandstone. x80. Crossed nicols. Very fine sandstone: clayey immature quartz wacke. Sub-angular and chemically altered quartz. Chemically altered orthoclase. Clay cement.

Fig. 2: RG 73 Primary quartz silt matrix of the Glorieta Sandstone. x8. Crossed nicols. Fine to very fine laminated sandstone: immature quartz arenite. Sub-angular quartz. Matrix of quartz silt. Evidence of pressure solution in parts of the rock where this matrix is not present.

PLATE 7:

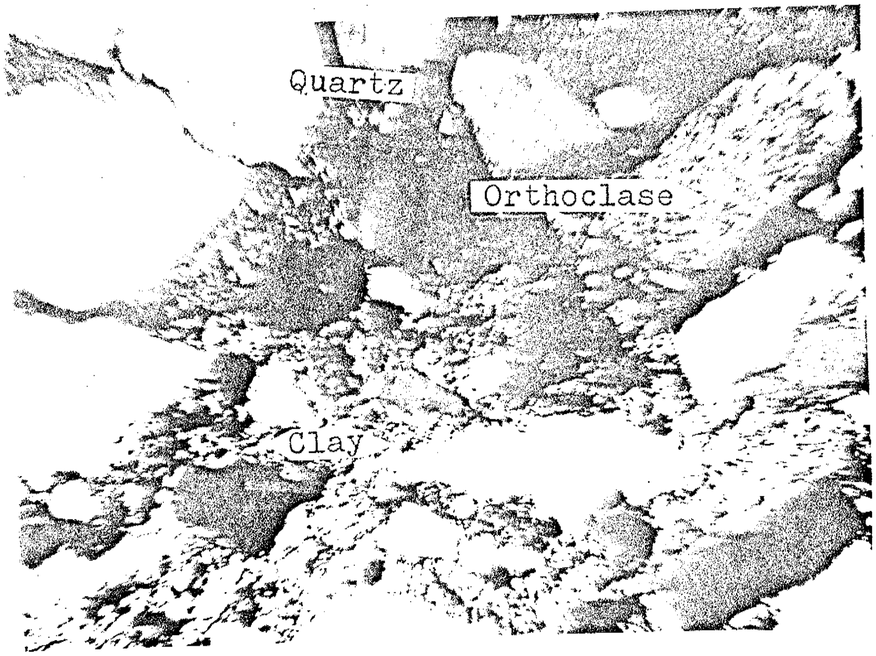



Figure 1: RG 38

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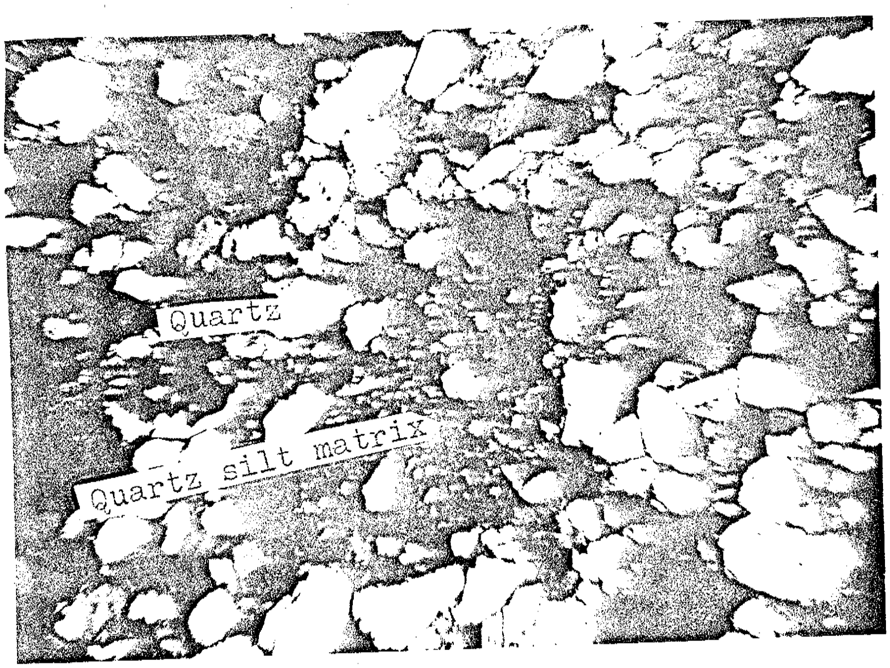


Figure 2: RG 73

PLATE 8

PLATE 8:

Fig. 1: RG 33 Primary clay matrix in claystone of the Glorieta Sandstone. x80. Plane polarized light. Silty claystone. Angular silt. Microcline. Hematitic and white clay.

Fig. 2: RG 55 Clay rims under quartz overgrowth. x80. Crossed nicols. Medium sandstone: siliceous mature quartz arenite. Original quartz grains outlined by clay rim. Beach deposit of the Glorieta Sandstone.

PLATE 8:

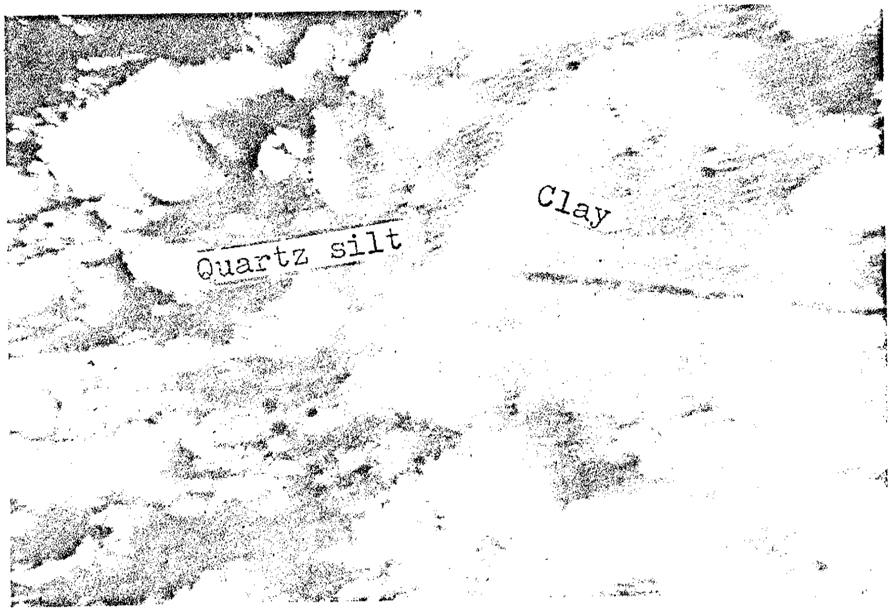


Figure 1: RG 33

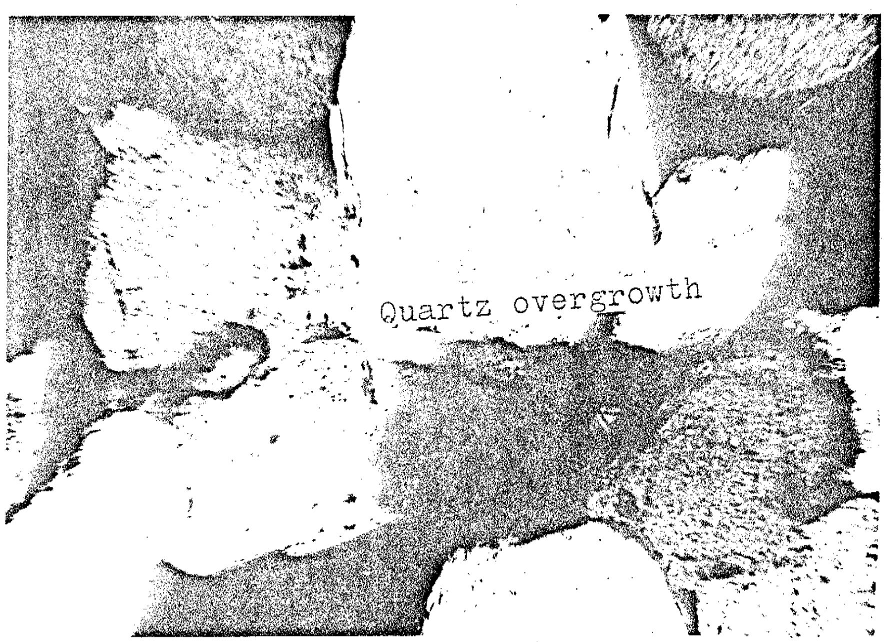


Figure 2: RG 55

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PLATE 9

PLATE 9:

Fig. 1: RG 80 Typical Glorieta Sandstone containing clay and silica overgrowths. x8. Plane polarized light. Fine sandstone: clayey mature quartz arenite. Overgrown quartz with straight to undulose extinction. Microcline grains. Clay cement. Straight, concavo/convex contacts. Beach deposit.

Fig. 2: RG 78b Recrystallized calcite rhomb. x80. Plane polarized light. Fine sandstone: calcitic bimodal mature quartz arenite. Hematite outlines rhomb. Chemically altered quartz. Floating grains. Glorieta Sandstone.

PLATE 9:

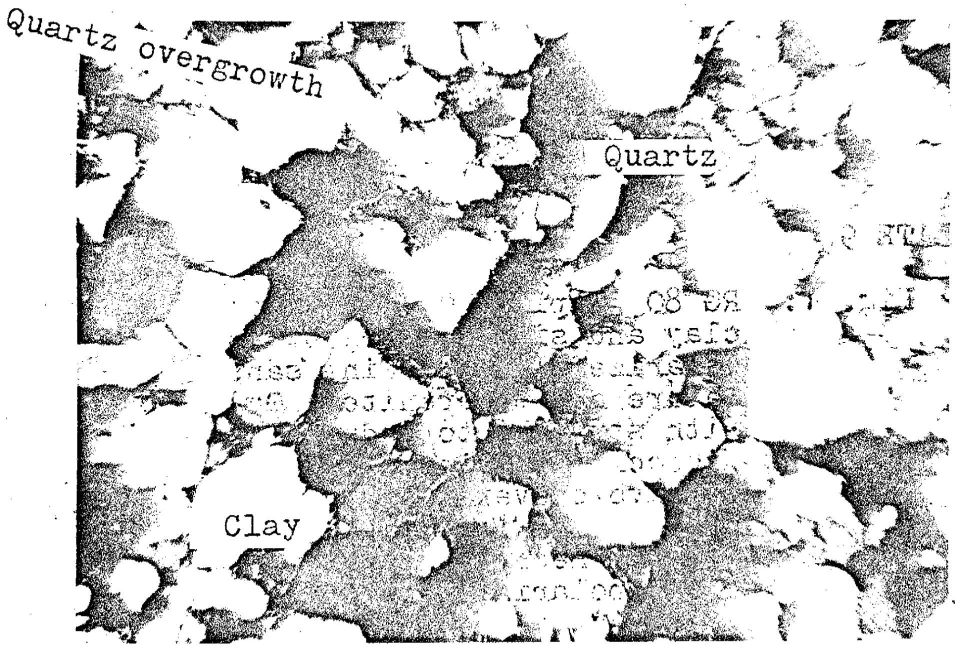


Figure 1: RG 80

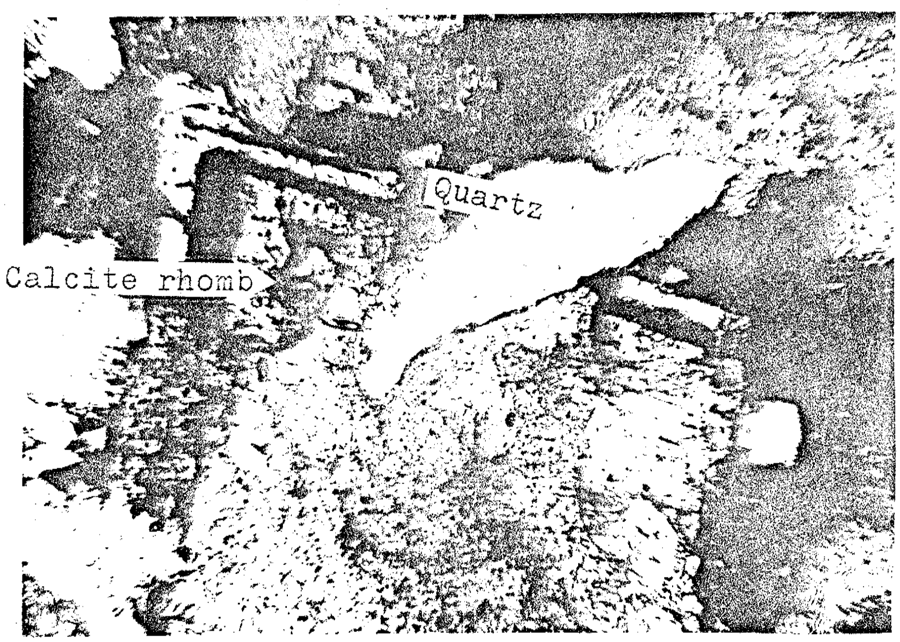


Figure 2: RG 78b

PLATE 10

PLATE 10:

Fig. 1: RG 50b Hematite in pore spaces and in calcite cement. x8. Plane polarized light. Fine sandstone: calcitic mature quartz arenite. Sub-rounded quartz. Hematite in pores, detrital, and as spots in calcite. Orthoclase altered by calcite. Unidentified fragment in center, birefringence masked by brown color. Calcite poikiloblastic, wedges quartz. Glorieta Sandstone.

Fig. 2: RG 94 Hematite concretion in the Glorieta Sandstone. x8. Plane polarized light. Fine sandstone: siliceous supermature quartz arenite. Hematite concretion surrounded by calcite cement. Quartz grains floating to tangential in area of concretion. Beach deposit.

PLATE 10:

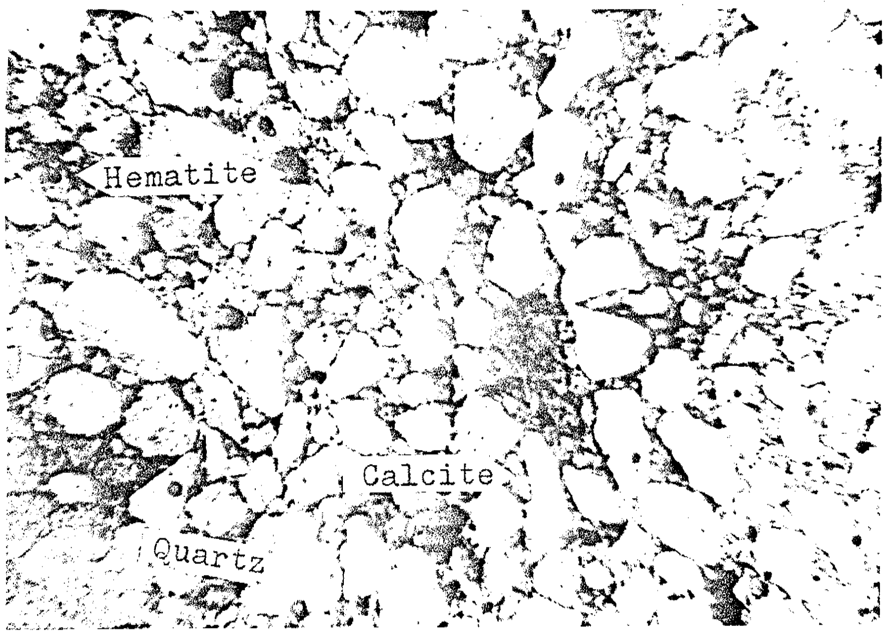


Figure 1: RG 50b

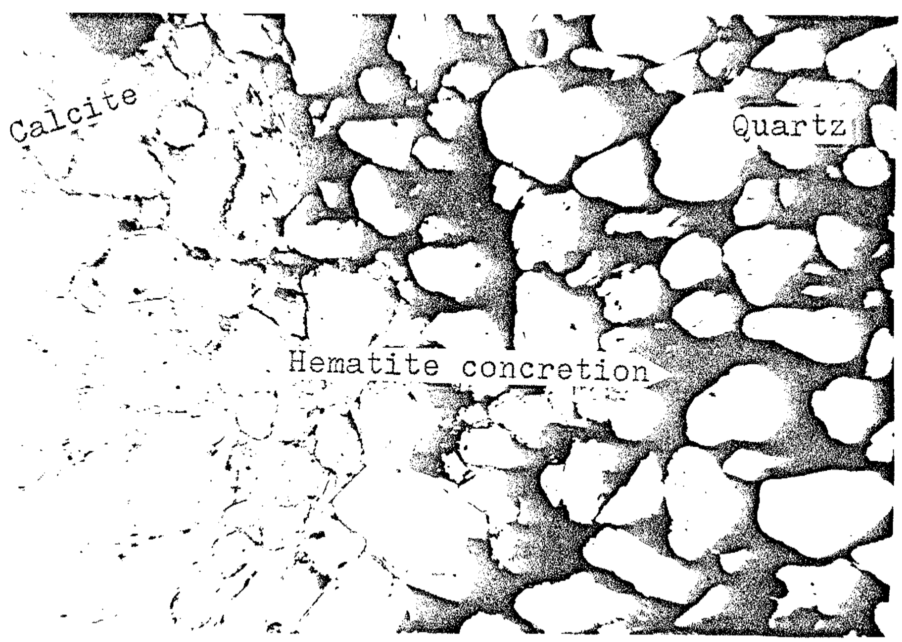


Figure 2: RG 94

PLATE 11

PLATE 11:

Fig. 1: RG 100d Uppermost bed of the Glorieta Sandstone. x8. Crossed nicols. Fine to very fine sandstone: calcitic bimodal mature subarkose. Sub-rounded to sub-angular quartz. Weathered orthoclase. Rounded microcline. Calcite cement.

Fig. 2: RSA 1 Lower San Andres Limestone. x8. Plane polarized light. Dismicrite showing silt-sized quartz and hematite-stained cracks. Grains and aggregates of hematite.

PLATE 11:

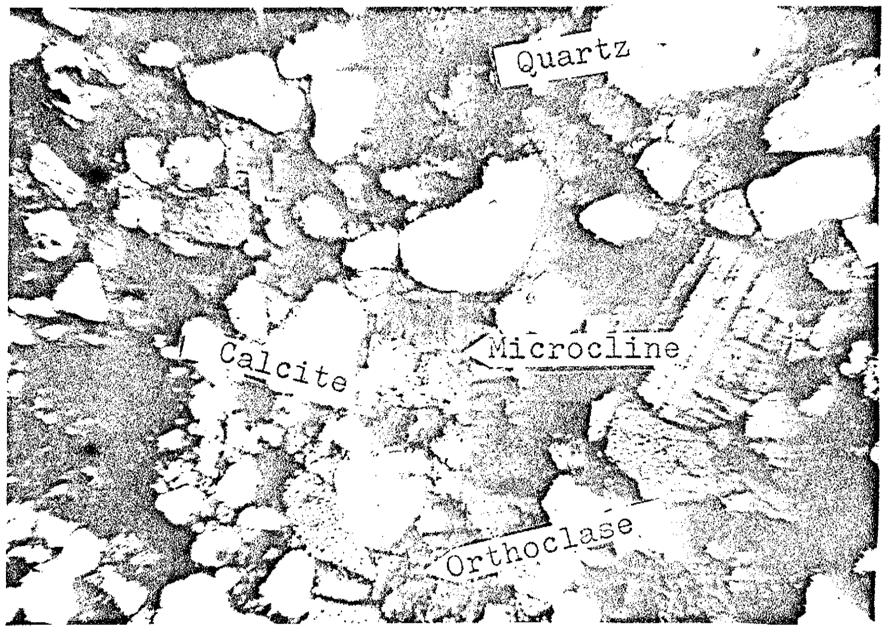


Figure 1: RG 100d

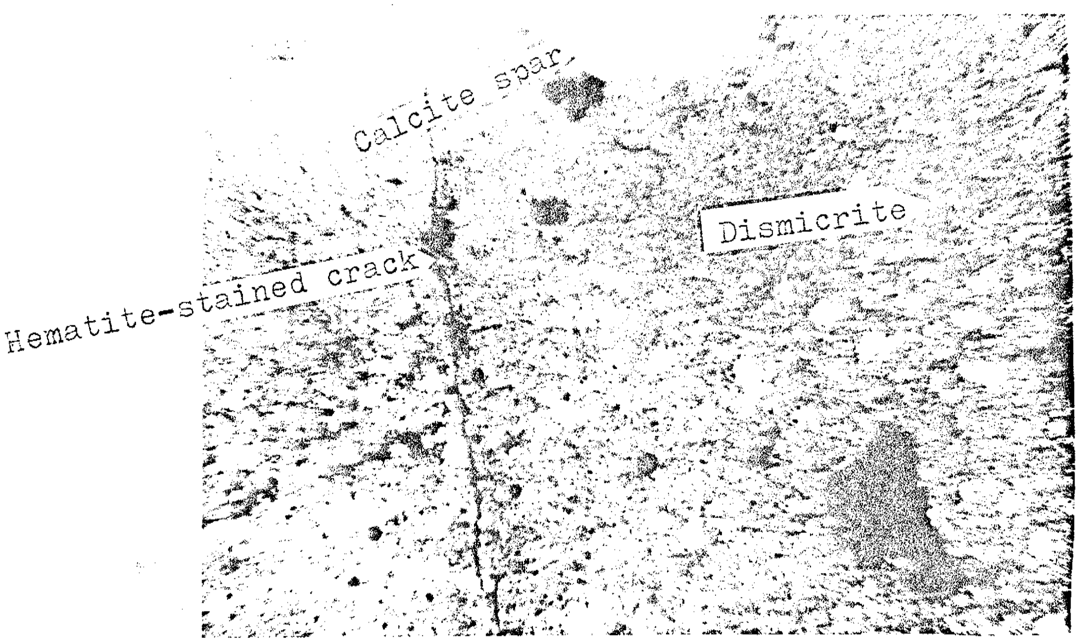


Figure 2: RSA 1

Figure 1; and Plate 11, Figure 1). The upper beds of the Glorieta contain noticeably altered and embayed orthoclase in contrast to the lower beds (Figure 14). Overgrowths of feldspar are abundant throughout.

Perthite also occurs in the Glorieta, but it is not as abundant as microcline and orthoclase.

Plagioclase of approximately the same composition as that in the upper Yeso Formation, An-42, is found in the middle Glorieta. In addition, plagioclase fragments in the range An-60 to An-70 are present.

Among accessory detrital minerals of the Glorieta are hornblende grains. The mineral is pleochroic from clear to brown, from brown to gold, or from pale green to olive brown. Extinction varies from 24 to 30 degrees. Birefringence is masked by the brown color or around upper second order, a bright blue. Relief is high. Grains of hornblende are elongated and rounded.

Pleochroic grains of green epidote occur throughout the middle and upper Glorieta. Extinction is parallel to the direction of cleavage. Birefringence is middle to lower second order. Relief is high. Grains are prismatic and angular.

Zircon fragments in the Glorieta Sandstone vary in shape from elliptical grains to grains which retain the prismatic terminations. The former are more common. In reflected light the mineral is colorless or light yellow with high relief. Zircon appears to be more common in

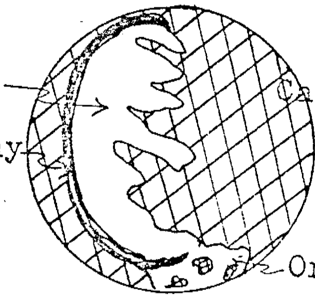


Figure 14. RG 100a. Calcite etching of orthoclase. Note authigenic overgrowth of orthoclase containing spots of calcite.

the lower Glorieta.

Three types of tourmaline occur in the Glorieta. Alkali tourmaline occurs as rounded to sub-rounded grains which are colorless under reflected light. Birefringence is lower first order. There are two types of iron tourmaline. The first is pleochroic from yellow to olive and occurs as prismatic sub-rounded crystals. Birefringence is second order yellow. The second tourmaline is pleochroic from pale green to olive brown. Grains range from very well rounded to sub-angular. Birefringence is upper second order blues and greens. All the tourmalines exhibit extinction parallel to the long axis. Irregular fractures are present in some.

Garnet occurs in the Glorieta as irregularly shaped grains exhibiting very high relief and irregular fractures. The grains are clear under reflected light and isotropic under crossed nicols. Only a few grains were found in the present study.

Leucoxene was not found in thinsection as often as

Huntington found it in his study. Only one clearly identified isotropic grain was noted in a thinsection from the middle Glorieta.

Opaque detritals of the Glorieta include ilmenite, magnetite, hematite, and possibly limonite. Ilmenite occurs as dark black aggregates with angular edges. Magnetite is steel black cubes or aggregates concentrated mainly in the middle Glorieta. Hematite and unidentified iron oxides appear to be mainly authigenic and persistent throughout the formation. A few individual grains or aggregates may be detrital.

Muscovite occurs in the Glorieta as flakes less than one mm in length. In every case, the muscovite is associated with or engulfed by clay. Krauskopf (1967) reports that very tiny flakes of muscovite may be formed from kaolinite in soils or shales even at ordinary temperatures. These flakes may also be the weathering products of schists or igneous rocks.

DETRITAL ROCK FRAGMENTS OF THE GLORIETA

The major rock types found in the Glorieta at the type section are igneous rock, chert, and schist fragments. Sparse fragments of slate or shale and phyllite also occur in the middle and upper portion of the Glorieta. In three thinsections pieces of chalcedony are present. Fragments of brown claystone occur throughout the entire formation. Red claystone occurs sparingly in the middle and upper Glorieta. Limestone rock fragments are assumed to have been present at the time of deposition.

Igneous rock fragments of various kinds are the most common of rock detritals. Dark brown, light brown, reddish brown, brown, gray, and green fragments with plagioclase laths occur in the Glorieta. In addition there are micaceous rock fragments which may be either igneous or metamorphic.

Fragments of schists and phyllites appear consistently throughout the Glorieta Sandstone. Most are angular grains with small golden flecks under crossed nicols. Some contain quartz. The flecks contain only a hint of orientation usually, and are too small to be identified petrographically. Schistose fragments are tentatively distinguished from igneous by the lack of plagioclase laths.

PRIMARY MATRIX OF THE GLORIETA SANDSTONE

Of the thinsections studied, 38.8 per cent are cemented dominantly by silica; 35 per cent are cemented by carbonate; and 26.2 per cent are cemented by clay and hematite. Volumetrically, carbonate is probably more abundant than silica because it cements some of the thicker sedimentary units and also because the per cent total rock is higher than the per cent total rock of silica cement. Volumetrically clay is probably the least dominant cement because clayey units are generally thin, but it also is the most persistent cement. Clay rims under silica overgrowths or clay in carbonate is found in almost every thinsection where clay is not the dominant cement.

The three types of cements in the Glorieta may be divided into primary matrix and authigenic cements. Primary matrix is defined as the clay or the smallest of bimodal detrital components which are produced during sedimentation. An example of the small granular detrital element of primary matrix is shown in Plate 7, Figure 2. These coarse silt-sized particles apparently filled cracks and pores of the Glorieta as it was being deposited.

None of the clays in the Glorieta are observed to form at right angles to detrital grains. It is therefore assumed that the clays are primary (detrital) rather than authigenic. Rarely clay is found etching quartz.

The content of clay in the formation ranges from 82 per cent total rock in a claystone to negligible in quartz arenites. Clay rims are common in quartz arenites (Plate 4, Figure 1; Plate 8, Figure 2). When stained with benzedine dihydrochloride, the majority of clayey beds showed the brilliant blue color of montmorillonite. A few beds turned a light blue-green with the stain; these beds probably contain mixed layer illite-montmorillonite clays or a potassium rich montmorillonite. The clays of RG 38 and RG 71 showed no reaction with the stain. In thinsection, these clays consist of bright whitish yellowish flakes. This fits Folk's description of illite or sericite, but the presence of kaolinite or a non-reactive montmorillonite must not be ruled out.

AUTHIGENIC CEMENTS

Authigenic cements of the Glorieta may be divided into those that formed penecontemporaneously or soon after deposition and those that formed somewhat later during diagenesis. The ones which I believe precipitated soon after deposition are chert, chalcedony, and some calcite. Cements which formed during diagenesis include calcite, silica, feldspar, and hematite.

Chert and chalcedony are found in pore spaces and intricately associated with clays of the Glorieta. Chalcedony is relatively rare; chert is more common but never as abundant as the cement of silica overgrowth. A sketch of grain, clay, and chert relationships is shown below.

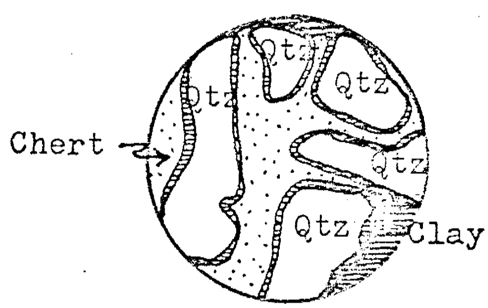


Figure 15. RG 61. Chert cementing clay rimmed quartz.

Microcrystalline calcite which was apparently formed penecontemporaneously with deposition of the Glorieta occurs at the base of the middle Glorieta and in the top beds of the Glorieta. There is no recrystallization.

Elsewhere calcite has been recrystallized during diagenesis, both with and without wedging. In places the calcite is recrystallized into large poikiloblastic grains enclosing several quartz fragments (Plate 3, Figure 2). In the middle and upper Glorieta the calcite recrystallized into rhombs outlined by hematitic clay and still containing enclosed quartz fragments (Plate 9, Figure 2).

Another occurrence of orthochemical calcite is in pore spaces of the Glorieta. This calcite may have formed relatively recently in the diagenetic history due to infiltration from the overlying San Andres Limestone. It is found as a spotty cement throughout the Glorieta.

Silica overgrowths are profuse throughout the Glorieta in beds not dominated by clay matrix. Obvious reworked overgrowths are present and overgrown in their turn. (Figure 12). At another extreme are quartz grains overgrown with single or double terminations (Figure 16). In the upper Glorieta quartz overgrowths apparently formed after calcite precipitated (Figure 17); in other parts of the formation the relationship is not so clear. There are two possible sources of silica cement in the Glorieta. One is pressure solution. There is evidence for this in the stylolites, sutured grains, and quartz overgrowths present in many beds (Plate 4, Figures 1 and 2; Plate 5, Figure 1). The other is silica from an exterior source trapped interstitially in pores of the formation.

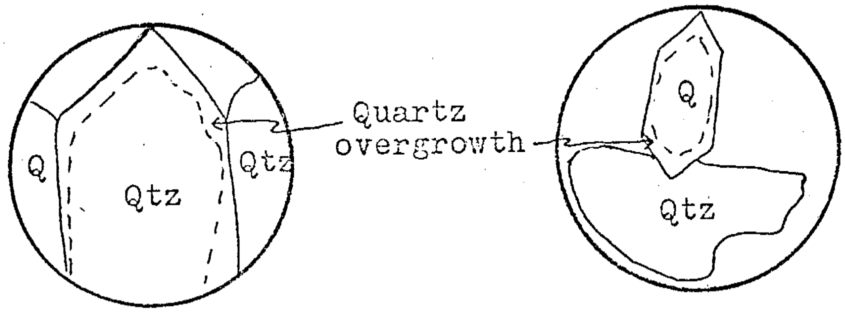


Figure 16a. RG 43. Euhedral quartz overgrowth.
16b. RG 72c. Doubly terminated quartz overgrowth.

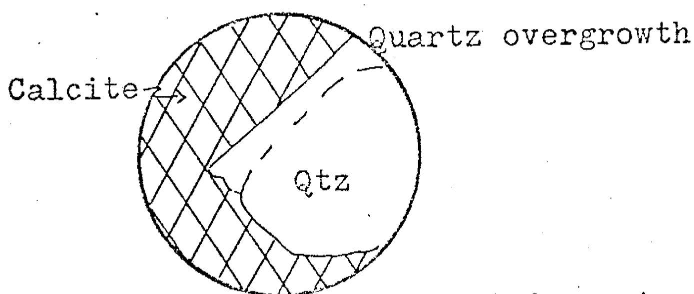


Figure 17. RG 100b. Straight sided quartz overgrowth implying that the calcite was present when the overgrowth occurred.

Feldspar overgrowths are found filling pore space next to feldspar (Figure 18) or as overgrowths over a clay rim (Figure 14).

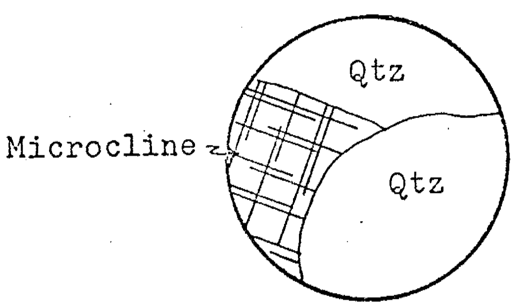


Figure 18. RG 41c. Authigenic microcline.

Hematite is present in the Glorieta in many forms. It acts as a cement filling pore spaces or forming concretions which cement a group of quartz grains Plate 10, Figures 1 and 2). In addition, hematite is present in disseminated form in some clays and most calcite and as irregular aggregates in these cements. (Plate 6, Figures 1 and 2; Plate 9, Figure 9). Hematite replaces magnetite, forming cubes which are blood red under crossed nicols. It is very difficult in most cases to ascertain the exact place of hematite in the sequence of diagenetic events. There is evidence that the hematite etches quartz (Figure 19). There is also evidence that it precipitates after calcite (Figure 20).

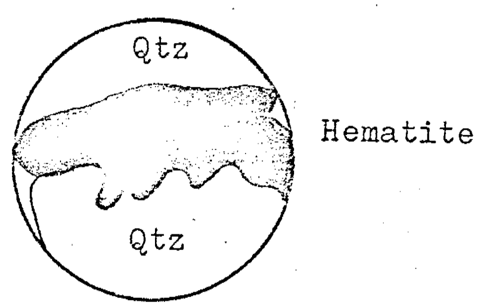


Figure 19. RG 25a. Hematite etching quartz.

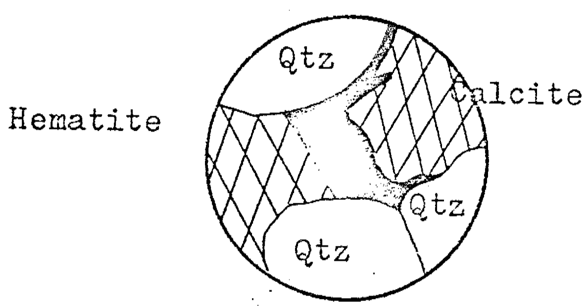


Figure 20. RG 39a. Straight boundary between hematite and calcite infers that calcite precipitated first.

ORTHOCHEMICAL ROCKS

Orthochemical rocks at the type section of the Glorieta include two dismicrite units in the upper Yeso Formation, a thin (1 cm) micrite in the middle Glorieta, and the San Andres Limestone. These units and some of the calcitic quartz arenites in the Glorieta were stained with alizarin red and a mixture of alizarin red/potassium ferricyanide. All of the rocks stained as ferrous calcite.

Yeso limestones are characterized by light gray color and thin to very thin bedding. Quartz silt and disseminated iron oxide are present in both units. The lower unit contains pseudo-oolites and an abundance of eye-shaped vugs. In the lower part of the unit, the vugs are filled by calcite spar. In the upper portion of the unit, the vugs are open or only lined with calcite. The top of the unit consists of approximately 40 per cent calcite-lined vugs.

The base of the upper Yeso limestone unit borders on a calcitic siltstone. This basal portion is distinctive for its pale red color and small scale cross bedding. A micro-fault is seen on the slabbed surface of the hand specimen. Fragments of quartz, microcline, An-42, magnetite, hematite, hornblende, muscovite, and zircon are present. An upper layer of this red portion consists of approximately 30 per cent unfilled vugs.

Above the vuggy layer is a light gray silty dismicrite. This unit contains the eye-shaped vugs typical of the

Yeso limestones.

The limestone unit of the middle Glorieta, RG 53, is a pale yellowish orange clayey dismicrite. Quartz and iron oxide are present in the clayey layers, giving the rock a laminated appearance. The sandstone unit below this limestone consists of a fine sand cemented by silica and showing evidence of pressure solution. The sandstone unit above RG 53 consists of a calcitic mature bimodal fine to very fine sandstone. Rounded detrital carbonate grains in this unit are outlined by hematitic clay.

The basal beds of the San Andres Limestone consist of thin lenses of silty dismicrites and calcitic quartz arenites. The dismicrites are light gray in hand specimen. Calcitic quartz arenites are pinkish gray. Silt-sized quartz is angular; fine sand sized quartz is often rounded. Iron oxides occur as fuzzy aggregates. Hematite stains cracks which appear in the pure micrite and silty micrite lenses (Figure 8 and Plate 11, Figure 2). Microcline and orthoclase fragments are present. Pseudo-oolites occur in sandy layers of the limestone (Plate 12, Figure 1). Veins and eye-shaped vugs are commonly filled with sparry calcite.

The upper portion of the San Andres Limestone consists of clayey dismicrites displaying bedding from platey to very thin. Color ranges from light brownish gray to grayish orange. Magnetite, hematite, and clay are present throughout. Dissolution by acetic and dilute

PLATE 12

PLATE 12:

Fig. 1: RSA 2a Pseudo-oolites of the San Andres Limestone. x8. Plane polarized light. Possible fossil fragment. Centers of pseudo-oolites recrystallized to spar in some cases.

Fig. 2: RSA 4i Dismicritic texture of the upper San Andres Limestone. x8. Plane polarized light. Clayey dismicrite. Calcite layer and recrystallized eyes characteristic of the upper San Andres. Color is extremely dark orange in reflected light; clay is present in disseminated form.

PLATE 12:

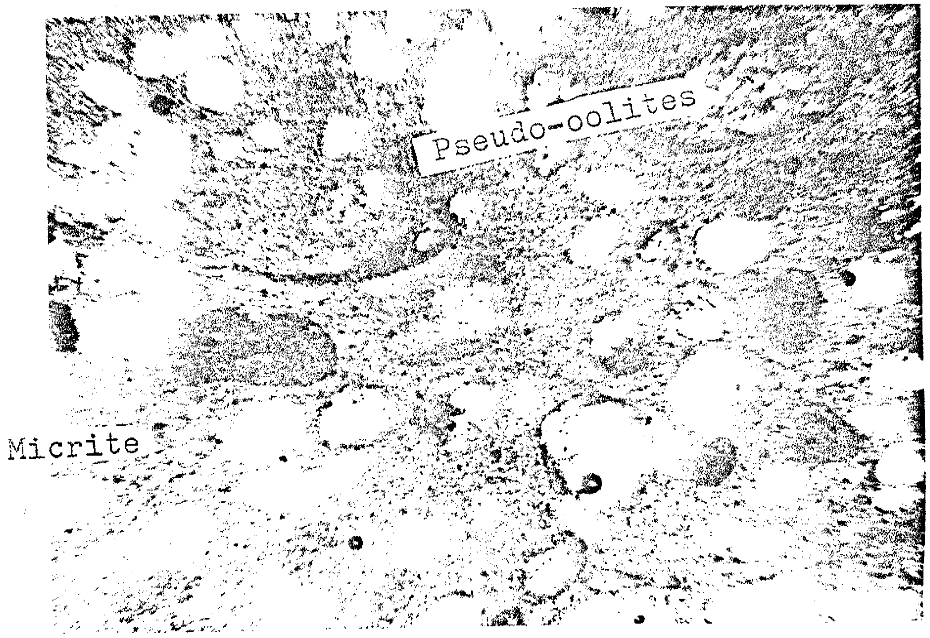


Figure 1: RSA 2a

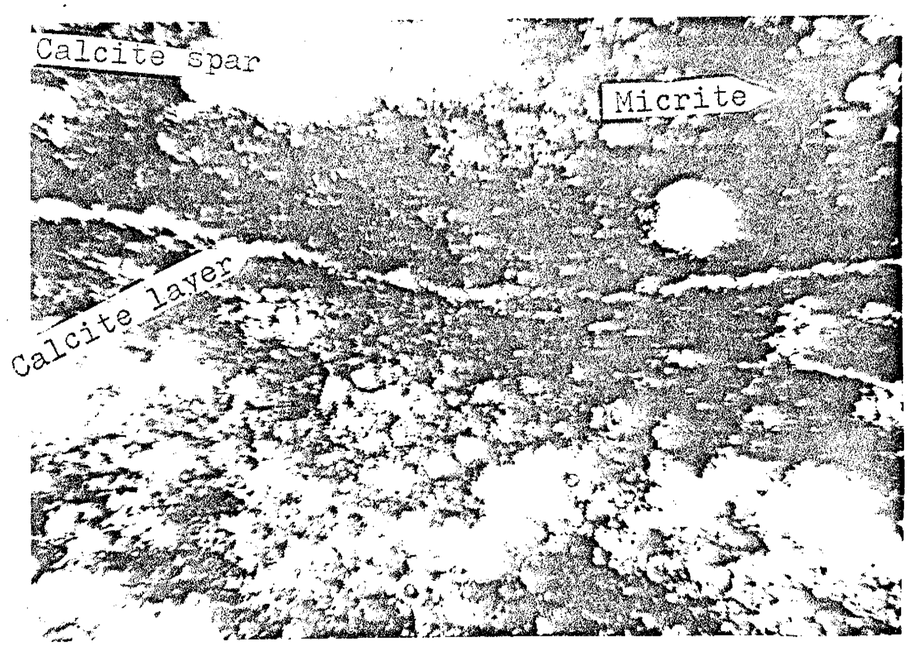


Figure 2: RSA 4i

hydrochloric acids revealed that hydrocarbons are present in some beds of this upper portion. Sparry calcite also appears in round or eye-shaped vugs and in thin horizontal laminations (Plate 12, Figure 2). In the upper layers most of the vugs are unfilled.

DIAGENESIS

The diagenetic history of the Glorieta Sandstone extends through several geologic periods and at least one major orogeny, the Laramide. The diagenesis is therefore complex and thoroughly enmeshed in time. Nevertheless, some conclusions may be reached about the diagenesis from petrographic evidence.

Evidence of packing and compaction may be seen in the crowding of grains in all samples except those which contain abundant carbonate cement or clay matrix. Floating and tangential contacts are found in the latter sandstone units, perhaps because a primary matrix or fluid acted as a cushion during compaction. As shown in Figure 21, the dominant grain contact in the Glorieta is straight sided. These contacts occur with fluid expulsion and better packing due to compaction. Further packing results in pressure solution at grain contacts and the formation of concavo/convex, sutured, and finally mosaic contacts. Concavo/convex and sutured contacts are found in subordinate amounts in fine and medium sand size ranges in the Glorieta. The presence of various types of contacts points out the basic inhomogeneity of hydrochloric acids revealed that hydrocarbons are present in some beds of this upper portion. Sparry calcite also appears in round or eye-shaped vugs and in thin horizontal laminations (Plate 12, Figure 2). In the upper layers most of the vugs are unfilled.

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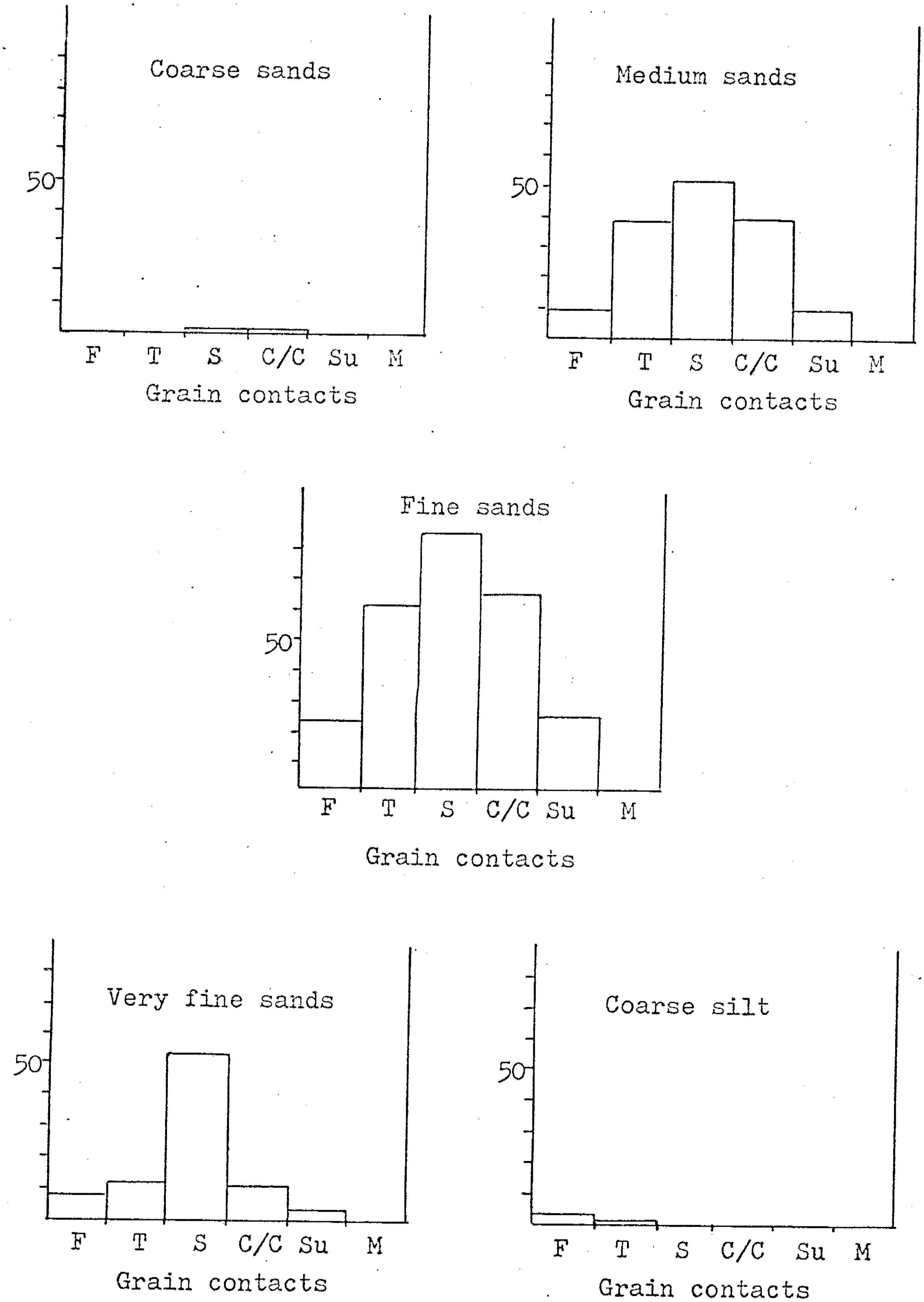



Figure 21: Relationship of grain size to grain contacts. Abbreviations are given in Appendix. Histogram scale is 1:1 with measured intervals.

the rock. The effects of packing and compaction seem totally random in any given sandstone unit.

CEMENTATION

Clay and iron oxide films are common on quartz, orthoclase, and limestone fragments in the Glorieta. These films were evidently formed before other diagenetic processes. The rims on recrystallized calcite rhombs, however, must have occurred sometime after or during compaction. Much of the hematite in the Glorieta appears to be authigenic.

Silica overgrowths in the Glorieta are profuse. The overgrowth occurred mainly during compaction of the formation, filling pore space and blocking porosity. In many beds the cementing by silica is spotty, leaving some pores unblocked or filled with calcite or clay. In a few beds overgrowth is virtually nonexistent. These are the siltstones and sandstones dominated by clay or carbonate cement.

There appear to be two sources of the secondary silica in the Glorieta. One was the pressure solution which occurred during compaction of the Glorieta. A second was silica trapped in the interstitial pore waters at the time of or shortly after deposition. The presence of overgrowths forming crystal faces on the quartz suggests this source. Such overgrowths are formed before much compaction takes place (Rapson, 1964). Recent geochemical studies shed some light on this problem.

Wollast and De Broeu (1970) have studied the change in dissolved silica content of the Scheldt estuary. They wanted to provide some insight as to why oceans have such a low silica content (ave. 5 ppm) compared to the rivers that feed them (13 ppm). Their study strongly suggests that when dissolved silica reaches saline waters where diatoms normally live, the diatoms consume the silica. Upon the death of the diatoms, the shells are deposited with sediment and later redissolved in the interstitial pores. The chemical requirements for this situation would be moderate to high salinity and high alkalinity. The interstitial silica content is evidently kept to an equilibrium value in the presence of kaolinite by the formation of a more siliceous clay. In the absence of kaolinite, the silica from diatom shells would accumulate until pressure would cause evacuation upward or chemical conditions would become such that precipitation could occur (Wollast and De Broeu, 1970).

The reaction by which kaolinite would control the dissolved silica content of interstitial waters is as follows:

kaolinite + dissolved silica + alkaline or alkaline-earth ions $\longrightarrow$ illites, montmorillonites + $xH^+$, or chlorites (Wollast and De Broeu, 1970).

Previously it was stated that clays which precipitate in the basin of deposition would form at right angles to grain surfaces. Clays in the Glorieta do not exhibit this characteristic. However, there is no evidence that clays which form by the equation stated above would align perpendicular to grain surfaces. Therefore it is possible that the source of the montmorillonites may be either alteration of kaolinite clays, weathering from previous sedimentary units, or winnowing by waves from offshore marine sediments. For the moment I would like to follow the conjecture that the montmorillonites were formed mainly by alteration of kaolinite.

First I would like to assume optimum conditions for the dissolving of diatom shells in interstitial pores. This would mean moderate to high salinity and high alkalinity. Experiments on pressure solution have revealed two very relevant facts. One, the more saline the formational water, the more pressure solution occurs. Two, simultaneous pressure and quartz overgrowth have been found experimentally only in alkaline solutions (Renton, et al., 1969). From this experimental evidence and the abundance of silica overgrowths in the Glorieta, I feel that these first two conditions were met in this formation.

Next I will assume that the original clay in the Glorieta was kaolinite, and that it altered to montmorillonite. As can be seen from the equation on page 75, this reaction would increase the acidity of the intraformational water. It is generally agreed that at 25°C the solubility of silica increases with a pH greater than 9 (Krauskopf, 1967; Stumm and Morgan, 1970). As the pH is lowered, it is possible for silica to precipitate. This would account for the quartz overgrowths which formed crystal faces in the Glorieta before compaction.

Whether or not the kaolinite-to-montmorillonite reaction is the correct mechanism for lowering the pH and causing silica to precipitate must be left open to question. It is also possible that the clays reached the Glorieta as detrital montmorillonite. Micro-organisms could then have lowered the pH, and the same effect would be achieved.

The second most important reaction taking place in the pH range of alkaline to less than 9 is that which forms calcite. All of the calcite in the Glorieta Sandstone approaches ankerite in composition. For a system at 25°C and total carbonate concentration less than $10^{-3}$ M, ferrous calcite is stable below a pH of 10 (Stumm and Morgan, 1970). This would mean that ferrous calcite could precipitate before quartz as the pH was lowered. Evidence for this situation is seen in Figure 17. Etched quartz grains and etched overgrowths provide evidence that the pH rose again above 9 after silica overgrowths had precipitated.

Cementation by carbonate may be produced by precipitation in the basin of deposition, by solution of fossil fragments or detrital grains, or by introduction late in diagenesis.

Calcite in the Glorieta Sandstone was produced by all three methods at different times in the diagenesis of this formation.

Calcite which precipitated in the basin of deposition without apparent wedging of grains is present in the uppermost beds of the Glorieta (RG 100a-100d). The calcite precipitated incorporating detrital clay minerals. Calcite which precipitated in the basin of deposition and destroyed the grain-supported framework by crystallization and volume expansion is found in lower beds of the Glorieta. Beds RG 30-32 contain calcite which expanded in interstitial pores and in porous or fractured quartz grains. Beds RG 82-83 contain calcite which expanded in pores only.

An example of the calcite which precipitated as a part of dual events without grain wedging is the microcrystalline calcite found spottled in beds previously overgrown with silica. This calcite was probably introduced late in the diagenetic history of the Glorieta. Calcite of this type is found in beds RG 21-23, 34-35, 48-52, 63-64, and 80.

A second example of carbonate cementation as a part of dual events is found in beds RG 54 and RG 64a. Allochemical limestone fragments mixed with detrital quartz grains are welded together by a calcite cement in these units, one of which overlies the thin micrite layer of the Glorieta. The source of limestone fragments in RG 64 is unknown. It is probable that solution of limestone fragments provided most of the calcite cement in the lower and middle Glorieta. Large poikiloblastic crystals of carbonate are probably the result of this solution. These crystals are found in the lowermost Glorieta (RG 17-20) and in RG 50-60. Point counts of thinsections of these rock units reveal that the carbonate content is between 17 and 21 per cent of the total rock. The cementation apparently took place after silica overgrowth.

RECRYSTALLIZATION, ETCHING, AND REPLACEMENT

Recrystallization of carbonate is evidenced by distinct rhombs outlined by iron oxide. Two major causes of recrystallization are recognized. One is chemical stabilization. The second is crystal reorganization due to increased compactive pressure (Rapson, 1964). The fact that all the carbonates stained as calcite suggests that crystal reorganization is the major reason for recrystallization of carbonates of the Glorieta.

Calcite etching of quartz, orthoclase, and microcline is rarely found in the Glorieta. It is difficult to place the etching in the sequence of diagenetic events. However, silica and orthoclase overgrowths are occasionally etched, implying that calcite reactions with these grains took place late in the diagenetic history of the Glorieta. In instances where reworked overgrowths are etched as in the upper Glorieta there is no indication of when the reaction occurred.

The replacement of magnetite octahedra by hematite occurs under oxidizing conditions by the following reaction:

$$\underset{\text{(magnetite)}}{2\ Fe_3O_4} + 2\ OH^- \rightleftharpoons \underset{\text{(hematite)}}{3\ Fe_2O_3} + H_2O + 2\ e^-$$

As can be seen from this equation, the pH must be alkaline for hematite to form. Oxidation is extremely slow below a pH of 6 (Stumm and Morgan, 1970). The relative time of replacement in the Glorieta Sandstone is not known.

AUTHIGENIC MINERALS

Hematite cement occurs as a precipitate in pore spaces and in hematite-rich clays. Studies by Van Houten, (1968) indicate that the latter occurrence is due to the aging or hydration of amorphous or dehydrated ferric oxide pigment present in muds at the time of deposition. The source of the precipitate may be *in situ* alteration of iron silicates or alteration of magnetite (Van Houten, 1968).

The precipitation of iron (III) oxide is strongly dependent on the concentration of $OH^-$ ions and the presence of organic material. Ions of $OH^-$ show strong affinity for $Fe^{+3}$. A decrease in $OH^-$ concentration in an oxidizing environment leads to precipitation of $Fe_2O_3$. At some point in the diagenesis of the Glorieta, the iron-bearing formation waters must have become acid enough to precipitate hematite.

Muscovite also may have been precipitated authigenically in units deficient in dissolved silica.

The reaction for this is as follows:

$$3 \text{ kaolinite} + 2 K^+ \rightleftharpoons 2 \text{ mica} + 2 H^+ + 3 H_2O$$

Equilibrium depends on the ratio of potassium ion to hydrogen ion. Estimated values of $K^+/H^+$ which favor formation of mica at ordinary temperatures are in the general range of ground and surface waters which have been in contact with feldspar-bearing rocks. The crystallization of muscovite could have occurred during compaction of the Glorieta, or it may have been inherited from the distributive area.

## DEDUCTIONS FROM EVIDENCE OF DIAGENESIS

The diagenesis of sedimentary rocks is the product of particular physical-chemical conditions existing at the time of and after deposition. A record of these conditions is left by grain relationships and by certain authigenic index minerals such as silica, iron oxides, and iron-rich calcite. Table 1 is a summary of the physical-chemical conditions existing from the time of deposition of the Glorieta to the present day.

High to moderate salinity and a high alkalinity are assumed in the Glorieta at the time of deposition. These conditions resulted in the solution of silica and possibly the precipitation of calcite. Some of the etching of quartz grains may have occurred at this time. Clay and iron oxide particles began adhering to detrital grain surfaces in this very

Table 1: Relationship of diagenetic processes to depositional environment. Adapted from Rapson (1964), modified by work of Wollast and De Broeu (1971), Stumm and Morgan (1970), and this paper.

| DIAGENESIS IN MACROENVIRONMENT | DIAGENESIS IN MICROENVIRONMENT | PHYSIOCHEMICAL ENVIRONMENT (in interstitial pores) | SEDIMENTARY ENVIRONMENT |
|---|---|---|---|
| A. Physical factors | | | |
| 1. Clastic clay and iron oxide adheres to clay. | | | Shore zone in which detrital clays from offshore and terrestrial sources accumulate. |
| 6. Moderate compaction concurrent with precipitation of silica from pressure solution. | Compaction inhibited by clays and quartz matrix. | Moderate pressure. Rapid loading. | Moderate to low sediment accumulation. Rapid lithification. |
| B. Chemical factors | | | |
| 2. Removal of silica from solution mainly due to biological activity of diatoms, also by adsorption on clays and co-precipitation. | | Moderate to high salinity. | Saline waters mix with fresh water. |
| 3. Dissolving of dead diatom shells to put silica in solution in interstitial pores. | Precipitation of ferrous calcite. Quartz etching possible. | Moderate to high salinity, pH > 9. | Shore zone. Slightly restricted shallow water. |

Table 1, cont.

| MACROENVIRONMENT | MICROENVIRONMENT | PHYSIOCHEMICAL | SEDIMENTARY |
|---|---|---|---|
| B. Chemical factors, cont. | | | |
| 4. Possible alteration of kaolinite to montmorillonite. | Detrital montmorillonites present. | Decrease in alkalinity. | Shore zone. |
| 5. Precipitation of some silica as terminated quartz overgrowths. | Precipitation of silica. Precipitation of hematite. | pH < 9. Strongly oxidizing. | Saline waters in confluence with fresh waters. |
| 7. Recrystallization. | Carbonate recrystallizes during compaction into rhombs outlined by hematite. | Alkaline. | Rapid loading increases overburden. Moderate pressure. |
| 8. Precipitation of ferrous calcite. | Precipitation of iron-rich calcite from intraformational solutions. | Highly alkaline. | Water percolates through formation. |

early stage of diagenesis.

A decrease in alkalinity due either to chemical reactions, adsorption by clays, or microbiological activity then caused silica to precipitate as doubly and singly terminated quartz overgrowths. This decrease in alkalinity allowed the continuous precipitation of ferrous calcite and possibly the beginning of the precipitation of hematite cement. The pH must have been less than 9, and the conditions oxidizing.

Load pressure after this period in diagenesis then caused the pressure solution which yielded quartz overgrowths throughout the formation. During compaction the carbonate in units dominantly cemented by calcite recrystallized into rhombs outlined by iron oxide.

The final event in this sequence was the introduction of calcite late in diagenesis. One source of this latest cement was probably the overlying San Andres Limestone. A second source may have been dissolution of detrital carbonate grains in the Glorieta. Whatever the source, highly alkaline calcite-bearing waters must have percolated through parts of the Glorieta. Wedging between overgrown quartz and etching of quartz overgrowths by calcite suggest that at least locally the pH of formation waters rose above 9 after the major precipitation of silica from pressure solution.

The preceeding sequence of events is postulated for almost all of the bedding units in the Glorieta. Units high in clay matrix would be affected only by factors 1, 4, and 6 on Table 1. Upper carbonate units of the Glorieta Sandstone would be affected only by factors 1 and 3.

Fractured quartz grains and straight grain contacts lead to two further deductions about the diagenesis of the Glorieta. Experiments on pressure solution have shown that with very rapid loading or with a lack of formation water, fractures form in the quartz (Renton, et al., 1969). The presence of fluids in the Glorieta is assumed due to abundant overgrowth. Therefore the only plausible explanation for fractured grains is rapid loading. This would be expected with deposition of terrestrial beds such as the conglomerate at the base of the Santa Rosa Sandstone. The straight grain contacts dominant in the Glorieta suggest that although loading was rapid, pressure was only moderate.

## DEDUCTIONS ABOUT PROVENANCE FROM DETRITAL COMPONENTS

The stratigraphy of the Glorieta Sandstone in the area of the type section has been worked out by Johnson (1969), Budding (in press), and Read, et al. (1944). Tanner (1963) has described depositional features. I would like to stress only two things from these articles. One, north of the type section in the Glorieta quadrangle, the Glorieta Sandstone is comparatively coarser than at the type section. Pebble beds in the Glorieta of this area contain quartz, chert, and rare limestone fragments (Budding, in press). Two, still farther north in the Sangre de Cristo Mountains, there is no Glorieta to be found (Miller, et al., 1963). The Glorieta appears to have been intertongued with redbeds of the Sangre de Cristo Formation and later eroded from the area.

Northeast-southwest current directions taken from cross beds and the presence of equivalent red beds to the north suggest a source area in this direction, possibly the Ancestral Rocky Mountain uplift. Detrital fragments support this supposition.

Sedimentary rock fragments include chert, limestone, chalcedony, red and brown claystone. Limestone and red claystone fragments suggest the reworking of parts of the underlying Yeso Formation. Fine sized quartz grains may also have been reworked from this formation. Possible sources for limestone and chert fragments include the Terrero Formation and upper portions of the Pennsylvanian La Pasada and Alamitos Formations (Miller, et al., 1963). Brown claystone and sandstones are found in the La Pasada and Alamitos Formations. Quartz overgrowth is found in both of these formations. It is not known if quartz from the Sangre de Cristo Formation contains overgrowths.

Acid igneous rock sources are indicated by the presence of igneous fragments in the Glorieta. Basic igneous rock fragments are also found. Metamorphic sources include schists, slates, and phyllites. Possibly some of the elongated composite quartz with several sizes of crystal units may have come from gneisses as well as schists.

Possible sources of metamorphic and igneous rock fragments in north central New Mexico include the Precambrian Vadito Formation, Precambrian granites and pegmatites, dikes, and amphibolites. Gabbroic dikes contain plagioclase of the composition An-30 to An-45 such as is found in the Glorieta. Epidote, bright blue-green hornblende, and andesine plagioclase are found in amphibolites in the Glorieta quadrangle. In this area is also found an augen amphibolite containing plagioclase of composition An-60 to An-70 (Budding, in press). These would account for all the plagioclase and igneous or metamorphic rock fragments found in the Glorieta at the type section. However, peculiar conditions would have had to exist at the time of deposition for north central New Mexico to have been the sole source of detrital fragments in the Glorieta, assuming that highlands existed at this time.

Recent studies of the east coast of the United States and the west coast of Mexico have shown that almost one half of the sediments of the barrier beaches come from reworking sands of the adjacent continental shelves (Curray, 1969a). Also, stratigraphic studies have shown that highlands on the Pedernal and Sierra Grande uplifts existed at the time of deposition of the Glorieta and must have contributed some sediment.

# DEDUCTIONS AS TO ENVIRONMENT OF DEPOSITION FROM DEPOSITIONAL FEATURES

The Glorieta Sandstone at the type section is overlain by the San Andres Limestone. In the upper 35 feet of the Yeso Formation there are two five-foot beds of limestone. Depositional features which these limestones have in common include eye-shaped vugs and pseudo-oolites. Eye-shaped vugs may form either by currents reworking limestone mud, by soft sediment deformation, or by the action of burrowing organisms (Folk, 1968). The presence of cross beds and micro-faults in RY 35 suggests that the first method of formation was most important in the two upper limestone units of the Yeso. Such an environment is found in protected lagoons or on shallow platforms on the lee side of barrier beaches.

The origin of the eye-shaped vugs and veins in the San Andres Limestone is less clear. In view of the hydrocarbons and the large amount of clay present, winnowing by currents is rejected as the dominant cause of vugs and veins. Instead, I feel that soft sediment deformation and/or the burrowing actions of organisms caused this texture. The environment of deposition was again that of shallow water, probably a lagoon which received an abundance of clay. Lack of fossils suggests that, as in the Glorieta, salinity was high during deposition of the San Andres Limestone.

The origin of pseudo-oolites is controversial.

Some geologists feel that the structures may be pellets produced by marine organisms. Others feel that they are produced by sub-aqueous erosion of previously consolidated calcilutites. Still others feel that they are produced penecontemporaneously in calcitic silts and muds by an aggregation process controlled by current winnowing. The presence of detrital quartz grains where these pseudo-oolites are found suggests that winnowing of carbonate in the presence of quartz grains may have caused the formation of these structures.

The marine limestones above and below the Glorieta coupled with the presence of chert and chalcedony cement in some units is evidence for the marine nature of the Glorieta Sandstone. It is generally agreed that the shore zone is the area of accumulation of sheet sands (Curray, 1969b; Swift, 1969; and Selley, 1970). Two environments of deposition in this zone may give rise to sheet sands. One is a delta facies which is characterized by an erosional basal conglomerate, an abundance of cross beds, and upward fining. None of these features are common in the Glorieta. The second environment is that of barrier beach islands. These sands have transitional bases, mainly flat beds, and upward coarsening (Selley, 1970). All of these properties are true of the Glorieta at the type section.

A barrier beach is defined as "a sedimentary complex, generally of sand or gravel, separating an open body of water such as the sea or ocean from an enclosed or partially enclosed body of water such as a lagoon" (Curray, 1969a). Typical modern beach ridges are parallel to the shore and spaced approximately 50 meters apart in groups of 10 to several hundred. If sedimentation is relatively greater than subsidence, the area between beach ridges may be filled with sands and/or clays.

The formation of sheet sands during a regression of the sea is postulated to occur as the accretion of beach ridges along a shore. Longshore bars, an element of the near-shore zone which is parallel to the coast but below most tide levels, are believed to be built above sea level by wave action of the retreating sea to become beach ridges (Curray, 1969a).

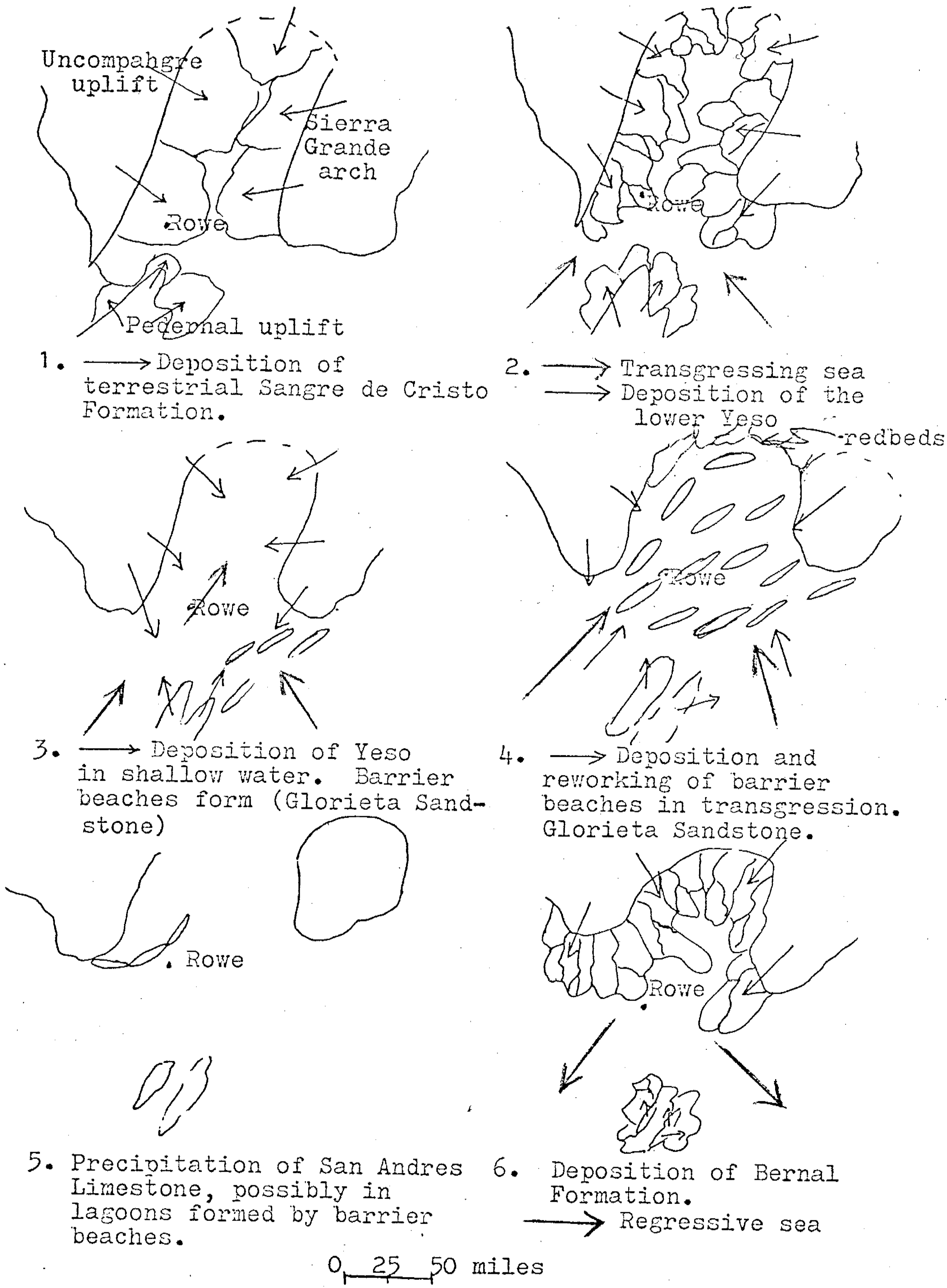
Sheet sands formed during the transgression of the sea would require formation of beach ridges which would become longshore bars as the sea level rises. These sands would be winnowed by waves in the formation of beach ridges and later reworked as longshore bars.

The Glorieta contains several maturity cycles in which the textural maturity goes from supermature or mature to immature. There are four possible reasons for these cycles. One, eustatic changes in sea level may have caused micro-regressions in the overall transgression of the body of water. Where a barrier beach had existed at one moment in geological time, withdrawal of the sea would have left a clayey lagoonal deposit; overlapping of the sea would leave an offshore deposit. Two, minor tectonic uplift or subsidence may have occurred. Three, seasonal variations may have produced changes in the type of sediment delivered to the basin. Rapid burial may then have preserved these changes. Four, the variations may have been caused by surf acion or fresh water confluence redistributing barriers and creating new lagoonal areas. A change of season could have been an indirect cause in this case.

Figure 22 is a schematic diagram of what I have postulated as the depositional sequence following uplifts in the late Pennsylvanian to early Permian in northern New Mexico. Until more detailed field studies are done on the late Paleozoic, this diagram will remain unsubstantiated. It is presented merely to clarify the process by which I feel that the Glorieta at the type section was deposited. The diagram draws heavily on environments of deposition postulated by other geologists for the Sangre de Cristo Sandstone and the Bernal Formation.

Tectonic conditions required for deposition of a sheet sand require either a constant rate of subsidence of the basin of deposition or a stillstand. Quiescent tectonic conditions such as these presume a prolonged period of weathering from source rocks and lengthy reworking by surf. According to Folk, only in arid or semiarid climate will rounded unweathered feldspar and quartz of similar grain size be found under these tectonic

Figure 22: Schematic sequence of events postulated from study of type section.



conditions. The Glorieta Sandstone was deposited in a semi-arid climate. The presence of montmorillonites probably indicates only a sedimentary clay-rich source rock.

ECONOMIC USES

The potential economic value of the Glorieta Sandstone lies in its use as dimension stone, high silica sand, or a reservoir for oil and natural gas. At the type section the Glorieta is cemented too loosely and contains too much calcite cement for use as dimension stone. Beds in the upper Glorieta (RG 80 to RG 94) below the top carbonate sands are cemented dominantly by silica and could be quarried.

The Glorieta Sandstone where it is cemented by clay appears to have characteristics suitable for use as a foundry sand. It has sufficient cohesiveness to hold together when moist and enough permeability to permit water vapor and gases to escape. High degree of sorting and quartz composition make it ideal. Properties of refractoriness and strength would have to be checked in the laboratory. The Glorieta might also be valuable as a fracturing or abrasive sand. These uses would be dependent mainly on nearness to market (Bates, 1969).

Oil and natural gas are suspect in sheet sands evolving in the near-shore zone. Both marine and lagoonal facies which encompass these sands are potential sources of hydrocarbon. Traces of hydrocarbon were found in the San Andres Limestone. However, no traces were found in the Glorieta at the type section. Whether the Glorieta may act as a reservoir for hydrocarbons in another area must be determined by further stratigraphic and petrologic studies.

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# APPENDIX

Appendix: Rock descriptions of samples taken at the type section of the Glorieta Sandstone near Rowe, New Mexico. Rock numbers shown on stratigraphic section, Figure 3.

Bedding thickness:
- Fissile: <1/16"
- Laminated: 1/16"-1/4"
- Platey: 1/4"-1"
- Very thin bedded: 1"-6"
- Thin bedded: 6"-1'
- Medium bedded: 1'-2'
- Thick bedded: 2'-4'
- Very thick bedded: 4'-6'
- Massive bedded: >6'

Parenthesis following color name contain numerical color designation of the 1963 Rock Color Chart distributed by the Geological Society of America, New York, N. Y.

Abbreviations of grain contacts:
- F Floating
- T Tangential
- S Straight
- C/C Concavo/convex
- Su Sutured
- M Mosaic

Yeso Formation:

RY 10 Coarse and very fine sandstone: clayey bimodal immature quartz arenite.

Red (10 R 5/2) with white spots. Thick bedded. Forms steep rounded slopes. Weathers red (10 R 5/2) with very light gray (N8) spots.

Poor sorting, Angular, sub-angular, sub-rounded grains.

Qtz, single grain, straight to undulose; composite grain, elongated bimodal. Microcline, orthoclase. Spotty calcite cement.

RY 11 Coarse silt: clayey bimodal immature quartz wacke.

Pale reddish brown (10R 5/4). Massive to platey bedding. Steep slope former. Weathers pale reddish brown (10 R 5/4).

Moderately sorted. Angular grains.

Qtz, single grain, straight extinction. Muscovite.

RY 12 Fine and very fine sandstone: clayey calcitic bimodal immature quartz wacke.

Pale reddish brown (10 R 5/4) with white spots and thin white laminae. Thick bedding. Weathers to rounded bumps on smooth surfaces. Weathers pale red (10 R 6/2).

Moderate sorting. Angular grains.

Qtz, single grain, straight extinction. Muscovite. Hematite. Rounded microcline.

RY 13 Coarse silt to very fine sandstone: clayey immature quartz wacke with red claystone lenses.

Pale reddish brown (10 R 5/4). Platey bedding. Cliff former. Contains lenses of light gray and darker streaks. Weathers pale red (10 R 6/2).

Poorly sorted. Angular grains.

Qtz, single grain, straight extinction. Microcline. Montmorillonite clay. Spotty calcite cement.

RY 14 Very fine and medium sandstone: clayey calcitic bimodal quartz wacke.

Pale reddish brown (10 R 5/4) with color laminations. Medium bedding. Cliff former. Weathers pale reddish brown (10R 5/4).

Well sorted. Angular grains.

Qtz, single grain, straight and undulose. Microcline.

RY 15 Coarse and very fine sandstone: clayey bimodal quartz wacke.

Pale reddish brown (10 R 5/4). Cliff former. Weathers to angular fragments 30 cm in length. Weathers pale reddish brown (10 R 5/4).

Poorly sorted, Angular grains.

Qtz, single grain, straight to undulose. Orthoclase, microcline. Red clay. Hematite. Patchy calcite.

RY 16 Very fine sandstone to coarse silt: clayey calcitic immature quartz wacke.

Pale reddish brown (10 R 5/4). Thick bedded. Cliff former. Weathers pale reddish brown (10 R 5/4).

Very well sorted. Angular grains.

Qtz, single grain, straight extinction. Calcite in pores.

RY 17 Very fine sandstone to coarse silt: clayey immature quartz wacke.

Pale reddish brown (10 R 5/2) with white lenses. Platey bedding. Re-entrant. Weathers pale reddish brown (10 R 5/2).

Very well sorted. Angular grains.

Qtz, single grain, straight to undulose. Microcline. Hematite. Calcite in pores.

RY 18 Very fine sandstone: clayey immature quartz arenite.

Pale red (10 R 6/2) with white spots. Laminated to platey bedding. Cliff former. Weathers pale red (10 R 6/2).

Moderate sorting. Angular grains.

Qtz, single grain, straight to undulose. Rounded microcline. Calcite in pores and lenses.

RY 19 Very fine sandstone: clayey submature quartz arenite with hematitic clay lenses.

Pale reddish brown (10 R 5/4) with white lense on top. Thick bedded. Cliff former. Weathers pale reddish brown (10 R 5/4).

Poorly sorted. Angular grains.

Qtz, single grain, straight extinction. Orthoclase. Muscovite. Hematite. Spot ty calcite.

RY 20 Fine sandstone: clayey calcitic immature quartz wacke.

Light gray (N 7). Laminated bedding. Re-entrant. Weathers pale red (10 R 6/2).

Poor sorting. Angular grains.

Qtz, single grain, straight to undulose. Spot ty calcite.

RY 21 Very fine and coarse sandstone: clayey bimodal immature quartz wacke.

Reddish brown (10 R 4/4). Laminated bedding and layers of calcite in clay. Re-entrant. Weathers reddish brown (10 R 4/4).

Poor sorting. Angular and rounded grains.

Qtz, single grain, straight to undulose. Calcite, hematite, and montmorillonite clay.

RY 22 a--Very fine sandstone: clayey hematitic quartz wacke
b--Coarse siltstone

Grayish red (10 R 4/2). Medium bedded. "a" contains white sandstone lenses 30 x 120 cm. Cliff former. Weathers grayish red (10 R 4/2).

Poor sorting. Angular grains.

Qtz, single grain, straight extinction. Rounded microcline

RY 23 Very fine sandstone: clayey calcitic immature quartz wacke.

Pale reddish brown (10 R 5/4). Very thick bedded with platey beds at the base. Cliff former. Weathers grayish red (10 R 4/2).

Poor sorting. Angular or rounded grains.

Qtz, single grain, straight to undulose. Calcite and hematite in streaks.

RY 24 Fine sandstone: calcitic submature quartz arenite.

Pinkish gray (5YR 9/2). Thin bedded. Cliff former. Weathers pinkish gray (5 YR 9/2).

Poorly sorted. Rounded to angular grains.

Qtz, single grain, straight to undulose. Microcline. Calcite in pores.

RY 25 Coarse silt and fine sandstone: clayey immature bimodal quartz wacke.

Well sorted. Angular grains.

Qtz, single grain, straight extinction. Muscovite and hematite in montmorillonite clay.

RY 26 Very fine sandstone: clayey immature quartz wacke.

Grayish red (10 R 4/2). Thick bedded. Cliff former. Weathers grayish red (10 R 4/2). Some color lamination.

Poor sorting. Angular to sub-angular grains.

Qtz, single grain, straight extinction. Microcline, angular. Spotty calcite cement.

RY 27 Fine sandstone: clayey calcitic immature quartz wacke.

Grayish red (10 R 4/2). Thin bedded. Re-entrant. Weathers grayish red (10 R 4/2).

Poor sorting. Angular and rounded grains.

Qtz, single grain, straight extinction. Muscovite. Hematite streaks. At the base, clay is dominant; at the top, calcite is dominant and recrystallized into rhombs. Some calcite-lined vugs.

RY 28 Dismicrite.

Light gray (N 7). Two 12 mm layers of micrite.

RY 29 Dismicrite.

Pinkish gray (5 RY 8/1) with dark specks. Very thin to thick bedded. Cliff former at base, slope former toward top. Weathers pale yellowish brown (10 YR 6/2). Contains detrital quartz silt, well sorted. Stains as ferrous calcite. Dark specks are iron oxide. Top layers are 40 to 50 per cent vugs lined with calcite.

RY 30 Fine sandstone: clayey immature quartz wacke.

Pale reddish brown (10 R 5/4) topped by a white sandstone lense. Thick bedded. Rounded, re-entrant. Weathers pale reddish brown (10 R 4/4).

Poor sorting. Sub-rounded grains.

Qtz, single grain, straight to undulose. Hornblende. Altered orthoclase. Igneous rock fragment. Hematite. Red clay and fine silt matrix.

RY 31 Fine to very fine sandstone: clayey immature quartz arenite.

Reddish brown (10 R 4/4) with light gray (N 7) streaks. Thin bedded. Re-entrant. Weathers reddish brown (10 R 4/4) with light gray (N 7) streaks.

Poorly sorted. Rounded and sub-angular grains.

Qtz, single and composite grains, straight to undulose extinction. Altered orthoclase. Hematitic clay cement.

RY 32 Silty claystone.

Grayish red (10 R 4/2) with very light gray (N 8) laminations. Laminated bedding. Cliff forming. Weathers same as fresh.

Poor to moderate sorting. Sub-rounded grains.

Qtz, single grain, straight extinction. Rounded microcline. Igneous rock. Montmorillonite clay. Calcite in pores.

RY 33 Fine sandstone: clayey immature quartz arenite.

Grayish orange pink (10 R 8/2). Very thin bedding. Lenses. Re-entrant. Weathers same as fresh.

Moderately to well sorted. Rounded to sub-angular grains.

Quartz, single grain, straight extinction. Sub-angular microcline. Igneous, metamorphic, and chert fragments. Montmorillonite clay. Calcite in pores.

RY 34 Fine sandstone: clayey calcitic immature quartz wacke.

Grayish red (10 R 4/2). Medium bedded. Cliff forming. Weathers grayish red (10 R 3/2).

Poorly sorted. Angular grains.

Qtz, single grain, straight to undulose. Chert and metamorphic grains. Calcite in pores. Vuggy.

RY 35 Silty dismicrite with abundant iron oxide.

Pale red (10 R 6/2). Cross bedding of 60 mm length. Microfaults. Cliff forming. Weathers light gray (N 7). Contains very well sorted angular quartz silt, straight to undulose extinction. Microcline. Plagioclase An-42. Black opaque, probably magnetite. Hematite. Hornblende. Muscovite. Zircon.

RY 36 Silty dismicrite.

Light gray (N 7). Thick bedded. Cliff forming at base, slope forming farther up. Weathers pale yellowish brown (10 YR 6/2). Stains as ferrous calcite. About 20 per cent vugs.

RY 37 Very fine sandstone: clayey hematitic immature quartz wacke.

Reddish brown (10 R 4/4) with white spots. Platey bedding. Poorly exposed, slope forming. Weathers reddish brown (10 R 4/4).

Moderately sorted. Angular to sub-rounded grains. F to S grain contacts.

Qtz, single grain with straight extinction, some inclusions. Plagioclase An-40 to An-50. Ilmenite skeleton. Zircon. Clay rock and igneous rock fragments. Hematite. Spotty calcite cement. Montmorillonite test negative.

RY 38 Medium to fine sandstone: clayey immature quartz arenite.

Pinkish gray (5 YR 8/1). Very thick bedded. Rounded slope former. Weathers pinkish gray (5 YR 9/1).

Poorly sorted. Angular to sub-rounded grains. F to C/C grain contacts.

Qtz, single grain, straight to slightly undulose; composite grain, undulose. Microcline. Plagioclase. Ilmenite. Clay rocks and two types of igneous. Spotty calcite. Some quartz overgrowth. Stains as K-rich montmorillonite.

Glorieta Sandstone:

RG 17 Medium to fine sandstone: Highly calcitic supermature quartz arenite.

Grayish orange (10 YR 7/4). Platey bedding. Slope forming. Weathers dark yellowish brown (10 YR 4/2). Some vugs.

Very well to well sorted. Rounded grains. T to C/C contacts.

Qtz, single grain, straight to undulose extinction. Angular microcline. Magnetite. Chert and two types of igneous rock fragments. Cement mainly calcite (17 % total rock). Some quartz overgrowth. Clay stains as montmorillonite. Calcite recrystallized into large poikiloblastic grains with no apparent wedging.

RG 18 Fine to medium sandstone: calcitic supermature quartz arenite.

Very pale orange (10 YR 8/2). Very thin bedded. Cliff forming. Weathers grayish orange (10 YR 7/4).

Well to very well sorted. Sub-rounded grains. T, S, and C/C grain contacts.

Qtz, single and composite, straight to undulose extinction. Rounded microcline. Igneous fragments. Mainly calcite with disseminated hematite cement. Some quartz overgrowth. Clay stains as montmorillonite.

RG 19 Fine to medium sandstone: calcitic submature quartz arenite.

Pale yellowish orange (10 YR 8/6) with white lenses. Platey bedding. Slope former. Weathers dark yellowish orange (10 YR 6/6) with white lenses.

Moderately sorted. Sub-angular to sub-rounded grains. Mostly T contacts, also S and C/C.

Qtz, single and composite, straight to undulose. Microcline. Some chalcedony cement. Calcite cement being dissolved out. Qtz overgrowth. Hematite.

RG 20 Medium sandstone: calcitic mature quartz arenite.

Grayish orange (10 YR 7/4) with white lenses. Thin bedded. Cliff former. Weathers dark yellowish orange (10 YR 6/6).

Well to very well sorted. Sub-angular to sub-rounded. Mostly T, also S and C/C grain contacts.

Qtz, single and composite grain. Microcline. Brown claystone fragments. Calcite cement with iron oxide.

RG 21 Fine to medium sandstone lens: calcitic mature quartz arenite.

Grayish orange (10 YR 7/4). At thickest is 30 cm o 12 inches. Cliff former. Weathers moderate yellowish brown (10 YR 5/4).

Well sorted. Sub-angular to sub-rounded. T, S, and C/C contacts.

Qtz, single grain, straight to undulose, some with vacuoles; composite grain, straight to undulose. Microcline, altered and angular, also rounded. Tourmaline. Brown claystone, igneous rock fragments. Calcite in rhomb shapes. Qtz overgrowth. Some iron oxides.

RG 22 Fine sandstone: calcitic mature quartz arenite.

Very pale orange (10 YR 8/2). Thin bedded. Lenses. Cliff former. Weathers grayish orange (10 YR 7/4).

Well sorted. Sub-angular to sub-rounded. S, C/C, and sutured contacts.

Qtz, single grain, straight to undulose, some with vacuoles; composite, straight to undulose. Microcline, rounded. Weathered plagioclase. Metamorphic fragments. Quartz overgrowth.

RG 23 Fine sandstone: highly siliceous calcareous mature quartz arenite.

Grayish orange (10 YR 7/4). Thin bedded. Cliff former. Weathers pale yellowish brown (10 YR 6/2).

Well to very well sorted. Sub-angular grains. S, C/C, mostly Su grain contacts.

Qtz, single grain with straight extinction. Rounded microcline. Brown claystone, phyllite, igneous rock fragments. Quartz overgrowth with obvious pressure solution. Iron oxide.

RG 24 Fine sandstone: siliceous mature quartz arenite.

Pale orange (10 YR 7/2). Thin bedded. Cliff former. Weathers pale yellowish brown (10 YR 6/2).

Well sorted. Sub-angular to sub-rounded. Mostly S contacts, also C/C and Su.

Qtz, single grain, straight extinction, some with rutile needle inclusions; composite grain, straight extinction. Microcline, rounded. Brown claystone, igneous rock fragments. Hematite cubes. Qtz overgrowth. Hornblende.

RG 25 Very fine to fine sandstone: siliceous supermature quartz arenite.

Very pale orange (10 YR 8/2) to grayish orange (10 YR 7/4). Medium bedding. Cliff former. Weathers pale yellowish brown (10 YR 6/2).

Well sorted. Sub-rounded grains. T, S, and C/C contacts. Mostly S.

Qtz, single and composite, straight and undulose. Microcline, rounded, some overgrowth. Metamorphic, brown igneous rock fragment. Hematite outlines some grains. Qtz overgrowth.

RG 26 Fine to medium sandstone: mature bimodal quartz arenite.

Grayish orange (10 YR 8/4). Very thin bedding. Cliff former. Weathers grayish orange (10 YR 7/4).

Well sorted. Sub-angular to sub-rounded. T, S, C/C, and Su grain contacts.

Qtz, single grain, straight to undulose; composite grain. Rounded and angular microcline, some slightly weathered. Plagioclase. Rounded tourmaline. Metamorphic, brown igneous rock fragments. Iron oxides. Qtz overgrowth. Qtz silt matrix or calcite cement.

RG 27 Fine sandstone: siliceous supermature quartz arenite.

Very pale orange (10 YR 8/2) with white streaks. Thin bedded. Cliff former. Weathers pale yellowish brown (10 YR 6/2).

Well to very well sorted. S and C/C contacts.

Qtz, single grain, straight to undulose; composite, straight extinction. Few vacuoles or inclusions. Orthoclase. Altered microcline. Plagioclase An-43. Siltstone, igneous rock fragments. Hematite. Chert, clay cement. Qtz overgrowth.

RG 28 Fine sandstone: mature quartz arenite.

Grayish orange (10 YR 7/4). Medium bedding. Cliff forming. Weathers pinkish gray (5 YR 8/1).

Well to very well sorted. S and C/C contacts.

Qtz, single and composite grain, straight to undulose. Microcline. Metamorphic, igneous rock fragments. Hematite. Qtz overgrowth. Reworked overgrowths also.

RG 29 Fine sandstone: supermature quartz arenite.

Grayish orange (10 YR 7/4). Laminated bedding. Slight re-entrant. Weathers a pale yellowish brown (10 YR 6/2).

Well to very well sorted. Sub-rounded grains. T, S, and C/C grain contacts.

Qtz, single and composite, straight to undulose. Sub-angular microcline, slightly weathered. Brown claystone, metamorphic rock, and light brown igneous rock fragments. Hematite. Qtz overgrowth.

RG 30 Fine sandstone: siliceous mature quartz arenite.

Grayish orange (10 YR 8/4). Thick bedded with cross bedding laminae. Cliff former. Weathers pale yellowish brown (10 YR 6/2). Current grove casts.

Well sorted. Sub-angular. S to C/C contacts.

Qtz, single and composite, straight to undulose. Some rutile inclusions. Orthoclase. Rounded microcline. Zircon. Brown claystone, metamorphic rock, gray igneous rock fragments. Hematite cubes. Qtz overgrowth.

RG 31 Fine sandstone: highly calcitic submature bimodal quartz arenite.

Grayish orange (10 YR 7/4) with white lenses. Very soft, mostly covered. Slope former. Weathers pale yellowish brown (10 YR 6/2).

Moderately sorted. Sub-angular. F, T, S, and C/C grain contacts.

Qtz, single grain, straight to undulose, some rutile inclusions; composite grains. Rounded microcline. Hematite rim on some quartz. Magnesium tourmaline. Magnetite. Calcite cement (35 % total rock) wedges some quartz interstitially. Clay stains as montmorillonite.

RG 32 Fine sandstone: calcitic clayey bimodal submature quartz arenite.

Grayish orange (10 YR 8/4). Soft, thin bedded. Re-entrant. Weathers grayish orange (10 YR 7/4).

Moderate to poor sorting. Sub-angular to sub-rounded. F, T, and S grain contacts.

Qtz, single grain, straight to undulose, some with rutile inclusions; composite. Rounded microcline, possibly overgrown. Hematite concretions. Calcite wedges in pores.

RG 33 Silty claystone.

Pale yellowish orange (10 YR 7/6). Fissile bedding. Re-entrant. Weathers dark yellowish orange (10 YR 6/6).

Fair sorting. Sub-rounded grains. F contacts.

Qtz, single grain, straight to undulose; composite, elongated and bimodal. Microcline, sub-rounded. Brown claystone fragments. Hematite. Stains as montmorillonite clay.

RG 34 Fine to medium sandstone: siliceous supermature quartz arenite.

Grayish orange (10 YR 7/4). Medium bedded. Cliff former. Weathers dark yellowish orange (10 YR 6/6).

Well sorted. Sub-rounded grains. S, C/C, mostly Su contacts.

Qtz, single grain, straight to undulose; composite grain. Rounded microcline, overgrown. Gray claystone, igneous rock fragments. Magnetite or ilmenite. Hematite. Clay, some calcite cement. Qtz overgrowth.

RG 35 Fine sandstone: calcitic supermature quartz arenite.

Grayish orange (10 YR 7/4) with white spots. Very thin bedded. Weathers moderate yellowish brown (10 YR 5/4). Porous.

Well sorted. Sub-rounded grains. F or C/C grain contacts. Some grains fractured.

Qtz, single grain, straight to strongly undulose, some vacuoles. Composite grain also. Microcline, rounded, overgrown. Hematite. Calcite in pores; no apparent wedging. Qtz overgrowth.

RG 36 Medium sandstone: highly calcitic mature quartz arenite.

Very pale orange (10 YR 8/2). Medium bedded. Cliff former. Weathers grayish orange (10 YR 7/4).

Well to mederately sorted. Rounded to well rounded grains. T and S contacts.

Qtz, single grain, straight to undulose. Microcline, rounded. Plagioclase An-70?. Chert. Magnetite. Hematite and clay cements upper 3 mm.

RG 37 Fine sandstone: calcitic submature quartz arenite.

Dark yellowish orange (10 YR 6/6). Very thin bedded. Slight re-entrant. Weathers dark yellowish orange (10 YR 6/6).

Moderately sorted. Sub-rounded to rounded grains. T and S contacts.

Qtz, single grain, straight to undulose, some vacuoles; composite grain. Igneous rock fragments. Hematite.

RG 38 Very fine sandstone: clayey immature quartz wacke.

Grayish purple (5P 4/2) with white lenses. Fissile bedding. Re-entrant. Weathers grayish orange (10 YR 8/4).

Poorly sorted. Rounded grains. F to S contacts. Some fractured grains.

RG 39 a--Fine sandstone: calcitic supermature quartz arenite.
b--Medium sandstone: siliceous mature quartz arenite.

Grayish orange (10 YR 7/4). Medium bedded. Cliff former. Weathers medium grayish yellow (5 Y 8/5).

Well to very well sorted. Sub-rounded. T, S, and C/C contacts.

Qtz, single grain, straight to undulose; composite grain, equigranular. Some vacuoles. Microcline, rounded, altered. Brown claystone and igneous rock fragments. Hematite. Magnetite. Much qtz overgrowth.

RG 40 Fine sandstone: mature quartz arenite.

Grayish orange (10 YR 7/4). Medium bedded. Cliff former. Weathers dark yellowish orange (10 YR 6/6).

Well to very well sorted. Sub-angular. T, S, and C/C contacts.

Qtz, single grain, straight to undulose; composite grain, bimodal and elongated. Tourmaline inclusions. Microcline, rounded, overgrown, altered. Green and brown igneous rock fragments. Iron oxides. Qtz overgrowths.

RG 41 Fine to medium sandstone: mature quartz arenite.

Grayish orange (10 YR 7/4). Platey to thin beds. Sloped cliff. Weathers dark yellowish orange (10 YR 6/6). "a", "b", and "c" porous. Vugs outlined by limonite. "a", "b", and "c" = rock numbers.

Well sorted. Angular to rounded grains. T, S, C/C and Su grain contacts.

Qtz, single grain, straight to undulose, some vacuoles and rutile inclusions; composite, bimodal, elongated. some iron stained. Orthoclase. Perthits. Microcline, weathered, overgrown. Muscovite. Zircon. Ilmenite. Metamorphic, green, brown, and gray igneous rock fragments. Hematite. Magnetite. Brown claystone. Chert fragments. Qtz overgrowth.

RG 42 Fine to medium sandstone: mature quartz arenite.

Grayish orange (10 YR 7/4) with white spots. Very thick bedding with cross beds. Cliff former. Weathers grayish orange (10 YR 7/4) to olive gray (5 Y 4/1).

Qtz, single grain, straight to undulose, rutile inclusions; composite, bimodal and elongated. Microcline, rounded, altered, weathered. Hornblende and tourmaline, rounded. Hematite. Magnetite. Red claystone, metamorphic, brown and gray igneous rock fragments. Qtz overgrowth.

RG 43 Fine sandstone: siliceous submature quartz arenite.

Grayish orange (10 YR 7/4) with lenses and spots. Massive bedding with cross beds. Rounded cliff former. Weathers to rounded knobs. Weathers dark yellowish brown (10 YR 4/2).

Moderately sorted. Rounded grains. S and C/C grain contacts.

Qtz, single grain, straight to undulose, rutile inclusions; composite, elongated, bimodal. Rounded microcline. Hornblende. Chert, some pushed into interstices. Hematite. Qtz overgrowth. Qtz matrix.

RG 44 Fine sandstone: immature quartz arenite.

Pale orange (10 YR 7/2). Medium to platey beds. Slope former. Weathers pale yellowish brown (10 YR 6/2).

Moderately to poorly sorted. Rounded grains. S to C/C grain contacts. Fractured grains.

Qtz, single grain, straight to undulose, few vacuoles; composite grains. Microcline, rounded. Perthite. Plagioclase An-36. Brown claystone, igneous rock fragments. Hematite, some wedging qtz. Clay cement. Qtz overgrowth. Calcite spotty, replaces silica overgrowth.

RG 45 Fine sandstone: siliceous clayey immature quartz arenite with brown clay stylolites.

Grayish orange (10 YR 7/4). Platey bedding. Re-entrant. Weathers grayish orange (10 YR 7/4).

Well sorted. S, C/C, and Su grain contacts. Some fractured grains.

Qtz, single grain, straight to slightly undulose, few vacuoles; composite grains. Microcline, overgrown, altered. Plagioclase An-39. Hematite. Magnetite or ilmenite. Garnet. Zircon. Muscovite. Brown claystone, light brown igneous rock fragments. Some chalcedony cement. Qtz overgrowth. Some calcite. Red clay wedges qtz apart. Montmorillonite.

RG 46 Medium to fine sandstone: siliceous mature quartz arenite.

Pale orange (10 YR 7/2). Medium bedded. Cliff former. Weathers grayish orange (10 YR 7/4).

Well sorted. Sub-angular. S, C/C contacts.

Qtz, single grain, straight to undulose, rutile inclusions; composite grains. Rounded microcline. Light brown igneous rock fragments. Qtz overgrowth.

RG 47 Fine to very fine sandstone: submature quartz arenite.

Grayish orange (10 YR 7/4). Platey bedding. Sharply re-entrant. Weathers dark yellowish orange (10 YR 6/6).

Moderately to poorly sorted. Sub-angular to sub-rounded. S to C/C contacts.

Qtz, single grain, straight to undulose; composite. Rounded microcline. Hematite. Igneous rock fragments. Qtz overgrowth.

RG 48 Medium to fine sandstone: siliceous clayey immature quartz arenite.

Grayish orange (10 YR 7/4). Thick bedded. Cliff former. Top 30 cm has hollowed holes 23 mm in length in two parallel rows. Weathers moderate yellowish brown (10 YR 5/4).

Moderately sorted. Sub-angular to sub-rounded. Mostly S, also T, C/C grain contacts.

Qtz, single grains, straight to undulose extinction, some vacuoles and inclusions; composite grain, elongated and bimodal. Microcline, rounded. Plagioclase. Tourmaline. Chert. Metamorphic, igneous rock fragments. Hematite. Magnetite. Leucoxene. Qtz overgrowth.

RG 49 Fine sandstone: siliceous clayey mature quartz arenite.

Grayish orange (10 YR 7/4). Fissile to platey bedding. Re-entrant. Weathers dark yellowish orange (10 YR 6/6).

Well sorted. Sub-rounded. Su grain contacts. Some fractured grains.

Qtz, single grains, straight to undulose, rutile inclusions; composite, undulose extinction. Microcline, rounded. Metamorphic fragments. Hematite. Qtz overgrowth. Chert cement. Brown stylolite.

RG 50 a--Fine sandstone: clayey submature quartz arenite.
b--Fine sandstone: calcitic mature quartz arenite.
c--Fine sandstone: siliceous supermature quartz arenite.

Pale yellowish brown (10 YR 6/2). Very thick bedded. Cliff former. Weathers moderate yellowish brown (10 YR 5/4).

a--Moderately sorted. Sub-angular. T, S contacts.
b--Well sorted. Angular. F, T, S contacts.
c--Well sorted. Sub-rounded to rounded. T, S, C/C and Su contacts.

Qtz, single grain, straight to undulose, rutile inclusions, few vacuoles; composite, elongated, bimodal. Microcline, rounded, altered by calcite, also angular. Perthite. Plagioclase with fuzzy twinning. Muscovite. Hematite. Magnetite. Chert, metamorphic, igneous rock fragments. Calcite poikiloblastic with quartz inclusions; recrystallized, wedging quartz. Qtz overgrowth present. Some chalcedony cement.

RG 51 Fine to medium sandstone: siliceous supermature quartz arenite.

Grayish orange (10 YR 7/4). Very thin bedded. Cliff former. Weathers very pale orange (10 YR 8/2) to grayish orange (10 YR 7/4).

Well to moderately sorted. Sub-rounded to rounded. T, S, C/C contacts.

Qtz, single grain, straight to undulose; composite, elongated, bimodal. Microcline, sub-rounded to sub-angular, overgrown. Plagioclase, fuzzy twinning. Muscovite. Chert, metamorphic, igneous rock fragments. Hematite. Qtz overgrowth.

RG 52 Fine sandstone: siliceous mature quartz arenite.

Grayish orange (10 YR 7/4). Medium to platey bedding. Cliff former. Weathers grayish orange (10 YR 7/4) to moderate yellowish brown (10 YR 5/4).

Well to moderately sorted. Modified by pressure solution. T and S contacts at the base; C/C, Su, and M grain contacts at the top.

Qtz, single grain, straight to undulose; composite grain, undulose, bimodal, elongated. Microcline, sub-angular to rounded. Tourmaline. Chert, slate, and igneous rock fragments. Hematite. Pressure solution and qtz overgrowth. Some chert cement.

RG 53 Hematitic clayey dismicrite with clay, hematite, and quartz layers.

Pale yellowish orange (10 YR 8/6). Very thin bedded. Re-entrant. Weathers very pale orange (10 YR 8/2) to pale yellowish brown (10 YR 6/2). Stains as ferrous calcite. Rhombs formed in calcite are outlined by hematite.

RG 54 Fine to very fine sandstone: calcitic bimodal mature quartz arenite.

Grayish orange (10 YR 7/4). Medium bedded. Cliff former. Weathers brownish gray (5 YR 4/1).

Well sorted. Sub-rounded to rounded grains. Mostly T, some F and S contacts.

Qtz, single grain, straight to undulose; composite grain, straight to undulose. Abundant rutile inclusions and few vacuoles. Perthite. Microcline, rounded and overgrown or angular, overgrown, and rounded. Some altered. Hematite around grains, including carbonate grains. Detrital carbonate fragments apparently recrystallized to become part of total carbonate cement.

RG 55 Medium sandstone: siliceous mature quartz arenite.

Grayish orange (10 YR 7/4). Very thin bedded. Slope former. Weathers brownish gray (5 YR 4/1) to pale yellowish brown (10 YR 6/2). Much pore space.

Well sorted. Sub-angular to rounded grains. T, S, C/C grain contacts.

Qtz, single grain, straight to undulose; composite grain, straight to undulose, elongated, bimodal. Microcline, sub-angular, altered. Igneous rock fragments. Hematite. Magnetite. Qtz overgrowth.

RG 56 a--Fine sandstone: siliceous mature quartz arenite.
b--Medium sandstone: calcitic supermature quartz arenite.

Grayish orange (10 YR 7/4). Medium bedded. Cliff former. Weathers dark yellowish brown (10 YR 4/2) to dark yellowish orange (10 YR 7/6).

Very well to well sorted. Sub-angular to rounded. T, S, and C/C contacts.

Qtz, single grain, straight to undulose, vacuoles and rutile inclusions; composite grain, straight to undulose, elongated, bimodal. Microcline, rounded, altered. Hematite. Magnetite. Red chert, chalcedony, and igneous fragments. Qtz overgrowth. Calcite from microcrystalline to spar.

RG 57 Fine sandstone: calcitic submature quartz arenite.

Pale yellowish orange (10 YR 8/6). Medium bedded. Cliff former. Weathers grayish orange (10 YR 7/4).

Moderately sorted. Sub-rounded to rounded. T, S, C/C grain contacts. Some fractured grains.

Qtz, single grain, straight to undulose; composite grain, straight to undulose. Microcline, rounded, altered. Tourmaline. Metamorphic, igneous rock fragments. Hematite. Magnetite or ilmenite. Qtz overgrowth. Calcite 19 per cent total rock.

RG 58 Fine to medium sandstone: siliceous mature quartz arenite.

White (N 9) and pale yellowish orange (10 YR 8/6) lenses. Medium bedded. Cliff former. Weathers to small knobs. Weathered color is grayish orange (10 YR 7/4).

Well sorted. Sub-angular to sub-rounded. T, S, and C/C grain contacts. Some fractured grains.

Qtz, single grain, straight to undulose, rutile inclusions; composite grains, straight to undulose. Microcline, sub-rounded. Chert, igneous rock fragments. Hematite. Magnetite or ilmenite. Qtz overgrowth.

RG 59 Fine sandstone grading up to a medium sandstone: siliceous supermature quartz arenite.

Grayish orange (10 YR 7/4). Laminated to platey bedding, cross bedded. Slope former. Weathers moderate yellowish brown (10 YR 5/4) to pale yellowish brown (10 YR 6/2).

Well sorted. Sub-rounded to rounded. Mostly S, also T, C/C and Su grain contacts. Fractured grains.

Qtz, single grain, straight to undulose, some rutile inclusions, hematite stain; composite grain, elongated, bimodal. Microcline, overgrown and rounded, altered. Chert, igneous rock fragments. Hematite. Pressure solution, qtz overgrowth.

RG 60 Fine to medium sandstone: calcitic supermature quartz arenite.

Pale yellowish orange (10 YR 8/6). Thin bedded. Cliff former. Weathers grayish orange (10 YR 7/4).

Well sorted. Sub-rounded grains. T and S grain contacts. Fractured grains.

Qtz, single grain, straight to undulose; composite grain, undulose. Orthoclase and microcline, rounded. Hematite in carbonate. Magnetite cubes. Ilmenite. Calcite, 17 per cent total rock, recrystallized, wedges quartz.

RG 61 Medium sandstone: clayey immature quartz arenite

Very pale orange (10 YR 8/2). Laminated bedding. Re-entrant. Weathers grayish orange (10 YR 7/4).

Well sorted in 5 mm layers. Angular through rounded grains. F, T, S, C/C contacts. Fractured grains.

Qtz, single grain, straight to undulose; composite grain, undulose. Perthite. Microcline, rounded. Plagioclase An-60. Muscovite. Chert rock fragments. Hematite in clay and precipated as cement. Magnetite. Clay 22 per cent total rock. Some chert cement.

RG 62 Fine sandstone: siliceous calcitic mature quartz arenite.

Grayish orange (10 YR 7/4). Thick bedded. Cliff former. Weathers pale yellowish brown (10 YR 6/2).

Well sorted. Rounded, sub-angular and angular grains. S and C/C contacts. Fractured grains.

Qtz, single grain, straight to undulose, rutile inclusions; composite grain, undulose. Microcline, rounded. Plagioclase, altered. Metamorphic and igneous rock fragments. Iron oxide. Ilmenite. Qtz overgrowth. Evidence for two episodes of calcite invasion.

RG 63 Fine to very fine sandstone: siliceous calcitic mature quartz arenite.

Grayish orange (10 YR 8/4 and 7/4). Thick bedded. Cliff former. Weathers pale yellowish brown (10 YR6/2). Approximately 10 per cent pore space.

Very well to moderately sorted in lenses. Sub-rounded to rounded grains. T, S, C/C contacts.

Qtz, single grain, straight to undulose, rutile inclusions; composite grain, straight to undulose. Microcline, rounded, altered. Hornblende. Chert, chalcedony, phyllite fragments. Hematite in calcite and around grains. Calcite fills pores. Qtz overgrowth.

RG 64 Fine to medium sandstone: siliceous calcitic mature quartz arenite.

Grayish orange (10 YR 7/4) with dark yellowish brown (10 YR 4/2) streaks toward the top. Thick bedded. Weathers grayish orange (10 YR 7/4) to pale yellowish brown (10 YR 6/2).

Moderate sorting grading up to well sorted. Rounded to sub-rounded grains. F, T, S, C/C, and Su contacts.

Qtz, single grain, straight to undulose, rutile inclusions; composite grain, elongated, bimodal, undulose. Microcline, sub-rounded to sub-angular. Muscovite. Chert, metamorphic rock fragments. Hematite in clay outlines detrital carbonate grains. Magnetite. Calcite 42 per cent total rock. Rare qtz overgrowth; qtz etched. Calcite stains as ferrous calcite.

RG 65 a--Fine to medium sandstone: clayey immature quartz arenite.
b--Silty claystone: clayey immature quartz wacke.

Grayish orange (10 YR 7/4) with white streaks. Laminated bedding. Slope former. Weathers grayish orange (10 YR 7/4).

a--Well sorted. Sub-rounded to rounded. Most F, some T grain contacts. Fractured grains.

b--Fair sorting. Sub-angular and angular grains. Most F, some T contacts.

a--Qtz, single grain, straight to undulose; composite grain, undulose. Microcline, angular and overgrown. Tourmaline, perfect sphere. Hematite. Magnetite. Ilmenite. Some chert cement.

b--Qtz, single grain, straight to undulose. Microcline, sub-rounded. Muscovite. Chert and igneous rock fragments. Hematite, some detrital, some authigenic. Clay, 65 per cent total rock, gray and red. Montmorillonite.

RG 66 Fine sandstone: clayey immature quartz arenite.

Grayish orange (10 YR 7/4) with black streaks. Very thin bedded. Cliff former. Weathers dark yellowish orange (10 YR 6/6).

Well sorted. Sub-rounded to rounded. F, T, S grain contacts.

Qtz, single grain, straight to undulose; composite grain, undulose. Microcline, rounded. Chert fragments. Authigenic hematite. Red and gray clay 17 per cent total rock.

RG 67 Fine to medium sandstone: siliceous mature quartz arenite.

Dark yellowish orange (10 YR 6/6) with black streaks. Very thin bedded. Cliff former. Weathers moderate yellowish brown (10 YR 5/4).

Well sorted. Sub-rounded shape modified by pressure solution. F, S, C/C contacts.

Qtz, single grain, straight to slightly undulose; composite grain, straight extinction. Rounded microcline. Brown clay, phyllite fragments. Hematite.

RG 68 Medium sandstone: calcitic supermature quartz arenite.

Very pale orange (10 YR 8/2) with dark yellowish brown (10 YR 4/2) spots. Medium bedded. Cliff former. Weathers grayish orange (10 YR 7/4).

Well sorted. Sub-rounded to rounded. Mostly S, some T contacts.

Qtz, single grain, straight to undulose; composite grain, undulose. Microcline, angular to sub-rounded. Orthoclase, sub-angular. Hornblende. Hematite in calcite cement.

RG 69 Fine sandstone: clayey immature quartz wacke.

Very pale orange (10 YR 8/2). Laminated bedding. Re-entrant. Weathers grayish orange (10 YR 7/4).

Moderately to poorly sorted. Sub-rounded. F, T, S grain contacts.

Qtz, single grain, straight extinction; composite grain, straight to undulose, elongated, bimodal. Microcline, angular. Zircon. Hornblende. Authigenic hematite. Brown clay, 30 per cent total rock.

RG 70 Fine sandstone grading up to medium sandstone: siliceous supermature quartz arenite.

Very pale orange (10 YR 8/2) with dark yellowish orange (10 YR 6/6) spots. Thick bedded. Cliff former. Weathers pale yellowish brown (10 YR 6/2).

Well sorted. Sub-rounded to rounded. T and S contacts, more S as go up.

Qtz, single grain, straight to undulose; composite grain, straight to undulose, elongated, bimodal. Microcline, angular. Plagioclase, altered. Chert and igneous rock fragments. Iron oxides. Much qtz overgrowth.

RG 71 Very fine sandstone: clayey immature quartz wacke.

Pale yellowish brown (10 YR 6/2) with white lenses. Laminated bedding. Re-entrant. Weathers dark yellowish orange (10 YR 6/6) with pinkish gray (5 YR 8/2) lenses.

Well to very well sorted. Sub-rounded grains. F, T contacts.

Qtz, single grain, straight to undulose; composite grain, straight extinction. Microcline, sub-rounded, slightly altered. Rounded hornblende. Muscovite. Chalcedony, chert fragments. Igneous rock fragments. Red and brown clay 27 per cent total rock. Hematite in red clay. Negative test for montmorillonite.

RG 72 Fine to very fine sandstone grading upward to a medium sandstone: clayey immature quartz arenite grading upward to a siliceous immature quartz arenite.

Very pale orange (10 YR 8/2). Thick bedded. Cliff forming. Weathers light brown (5 YR 6/4).

Well sorted. Sub-angular, sub-rounded grains. Upper part contains rounded grains. S, C/C, and Su contacts, mostly S and no Su in upper portion.

Qtz, single grain, straight to slightly undulose, rutile inclusions; composite grains. Orthoclase. Microcline, rounded. Epidote and tourmaline, rounded. Dark brown clay, chert, phyllite, and igneous rock fragments. Authigenic hematite. Approximately 14 per cent clay cement in lower portion. Qtz overgrowth.

RG 73 Fine to very fine laminated sandstone: bimodal immature quartz arenite.

Very pale orange (10 YR 8/2) with dark yellowish orange (10 YR 6/6) streaks. Laminated bedding. Re-entrant. Weathers grayish orange (10 YR 7/4).

Well to moderately sorted. Sub-angular to sub-rounded. F, T, and S contacts.

Qtz, single grain, straight to undulose. Microcline, sub-rounded. Tourmaline, sub-rounded. Muscovite. Chert fragments. Clay cement, 22 per cent total rock. Hematite, 5 per cent total rock. Matrix of qtz silt irregularly filling pores.

RG 74 Fine sandstone: siliceous mature quartz arenite.

Grayish orange (10 YR 7/4) to very pale orange (10 YR 8/2). Very thick bedded. Cliff forming. Weathers moderate yellowish brown (10 YR 5/4).

Well sorted. Sub-angular going to rounded as go up section. Mostly S contacts, also T and C/C.

Qtz, single grain, straight to undulose; composite grain, undulose, elongated, bimodal. Orthoclase. Microcline, angular and sub-angular. Perthite. Epidote, iron rich tourmaline, zircon, and hematite. Chert, metamorphic, and two types of igneous rock fragments. Qtz overgrowth in upper portion.

RG 75 Fine sandstone: calcitic clayey immature quartz arenite.

Grayish orange (10 YR 7/4). Re-entrant, forms soil. Weathers grayish orange (10 YR 7/4).

Well sorted. Sub-rounded to sub-angular. F, T, and S grain contacts.

Qtz, single grain, straight to undulose. Microcline, sub-angular to sub-rounded. Muscovite. Chert, metamorphic, and two types igneous rock fragments. Hematite in clay. Clay and calcite 31 per cent total rock.

RG 76 Fine sandstone: siliceous mature quartz arenite.

Grayish orange (10 YR 7/4) grades up to very pale orange (10 YR 8/1). Medium bedded. Cliff forming. Weathers grayish orange grading up to pale yellowish brown (10 YR 6/2).

Well sorted. Sub-rounded to rounded. T, S, C/C. Some Su at the top of the bed.

Qtz, single grain, straight to undulose; composite grains, undulose. Microcline, sub-rounded. Chert and igneous rock fragments. Authigenic hematite in clay. Pore space from 5 to 15 per cent. Qtz overgrowth.

RG 77 Fine sandstone: clayey immature quartz wacke.

Grayish orange (10 YR 7/4). Fissile to laminated bedding. Re-entrant. Weathers grayish orange (10 YR 7/4).

Well sorted. Rounded grains. F, T, S contacts.

Qtz, single grain, straight to undulose; composite grains. Microcline, rounded. Hematite in clay. Magnetite cubes. Chert cement 7 per cent. Brown clay 24 per cent total rock.

RG 78 Fine sandstone grading upward to a medium sandstone:

a--clayey submature quartz arenite.
b--calcitic bimodal mature quartz arenite. (also c).
d--calcitic clayey mature quartz arenite. (also e).
f--siliceous mature quartz arenite with much pore space (10-15 %).

Very pale orange (10 YR 8/2) grading up to grayish orange (10 YR 7/4). Thin bedded. Cliff former. Upper weathered surface contains oblong hollows arranged in two parallel rows in the cliff. Weathers grayish orange (10 YR 7/4) grading up to pale yellowish brown (10 YR 6/2).

Well sorted. Rounded grading up to sub-rounded grains. Contacts range from F through C/C; some Su in lower portion. Fractured grains.

Qtz, single grain, straight to undulose; composite grain, straight to undulose, elongated and bimodal. Microcline, sub-rounded to rounded, some angular, some fractured, altered. Orthoclase. Chert, igneous rock fragments. Authigenic hematite in pore space and in calcite. Magnetite or ilmenite. Qtz overgrowths at base and top. Stains as ferrous calcite.

RG 79 Very fine to fine sandstone: hematitic clayey bimodal immature quartz arenite with stylolites.

Grayish orange (10 YR 7/4). Platey bedding. Re-entrant. Weathers grayish orange (10 YR 7/4) with green stain.

Well sorted. Sub-rounded grains. F through Su contacts.

Qtz, single grain, straight to undulose; composite grain, undulose, elongated, bimodal. Microcline, sub-rounded. Chert fragments, also cement. Hematite in clay, approximately 11.6 per cent total rock. Clay approximately 19 per cent total rock. Coarse silt qtz matrix.

RG 80 Fine sandstone grading up to medium sandstone: grades from clayey to calcareous to siliceous mature quartz arenite.

Very pale orange (10 YR 8/2) to grayish orange (10 YR 7/4). Very thin bedding grading up to medium bedding. Forms cliff. Weathers dark yellowish brown (10 YR 4/2).

Well sorted. Rounded grains. T, S, C/C contacts, also F in the middle of the bed.

Qtz, single grain, straight to undulose; composite grain, elongated, bimodal. Microcline, rounded. Muscovite. Phyllite. Hematite in clay. Magnetite or ilmenite. Calcite in pores. Qtz overgrowth.

RG 81 Medium to fine sandstone: clayey bimodal immature quartz arenite.

Dark yellowish orange (10 YR 7/6). Laminated bedding. Re-entrant. Weathers pale yellowish brown (10 YR 6/2).

Moderately sorted. Sub-rounded to rounded grains. F, T, S, C/C grain contacts.

Qtz, single grain, straight to undulose; composite grain, undulose. Rounded microcline. Brown and red clay. Qtz silt matrix.

RG 82 Medium to fine sandstone: calcitic bimodal submature quartz arenite.

Grayish orange (10 YR 7/4) with pale yellowish brown (10 YR 6/2) lenses. Consistent very thin bedding throughout. Fliff forming. Weathers dark yellowish orange (10 YR 6/6).

Moderately sorted. Sub-rounded to rounded grains. Most T, also F and S contacts.

Qtz, single grain, straight to undulose; composite grain, undulose, elongated, bimodal. Microcline, sub-rounded. Chert fragments. Hematite in calcite and also some crystalline. Magnetite. Calcite, approximately 20 per cent total rock, is recrystallized into rhombs, wedges qtz. Qtz overgrowth.

RG 83 Medium to fine laminated sandstone: siliceous mature quartz arenite.

Very pale orange (10 YR 8/2). Medium bedded. Cliff former. Weathers light gray (N 7).

Well sorted in layers. Rounded grains. T, S, C/C contacts.

Qtz, hematite stained, single grains, straight extinction. Microcline, rounded and altered. Red clay with qtz fragments. Sparse hematite. Qtz overgrowth and clay cement.

RG 84 Medium to coarse sandstone: siliceous mature quartz arenite.

Dark yellowish orange (10 YR 6/6) to grayish orange (10 YR 7/4). Thick bedded at base grading up to medium bedded. Cliff forming. Weathers a moderate yellowish brown (10 YR 5/4) to dark yellowish brown (10 YR 4/2).

Well sorted. Rounded grains. T, S, C/C contacts.

Qtz, single grain, straight to undulose; composite grain, undulose, elongated, bimodal. Orthoclase. Perthite. Microcline, angular to rounded, altered, fractured. Chert, metamorphic and igneous rock fragments. Hematite in clay. Spotty calcite.

RG 85 Medium to fine sandstone: clayey submature quartz arenite.

Grayish orange (10 YR 7/4). Laminated bedding. Re-entrant. Weathers pale yellowish brown (10YR6/2).

Well sorted. Rounded grains. T, S, C/C, Su grain contacts.

Qtz, single grain, straight to undulose; composite grain, undulose. Microcline, weathered, rounded. Muscovite. Red clay, chert, metamorphic, and igneous rock fragments. Hematite in clay and possibly detrital. Chert and clay cement.

RG 86 Fine sandstone: siliceous submature bimodal quartz arenite.

Grayish orange (10 YR 8/4). Medium to thick bedding. Cliff forming. Weathers yellowish brown (10 YR 5/2).

Moderately sorted. Rounded. T, S, C/C, S contacts.

Qtz, single grain, straight to undulose, rutile inclusions; composite grain, undulose extinction. Microcline, rounded. Orthoclase. Tourmaline. Garnet. Metamorphic, two types igneous rock fragments. Hematite occurs in clay and as large blobs. Qtz overgrowth.

RG 87 Medium sandstone: siliceous supermature quartz arenite.

Grayish orange (10 YR 7/4). Medium bedded. Cliff former. Weathers pale yellowish brown (10 YR 6/2).

Well sorted. Rounded grains. Most S, also T, C/C contacts.

Qtz, single grain, straight to undulose; composite grain, straight to undulose. Microcline, rounded. Two types of igneous rock fragments. Hematite occurs as blobs and outlining grains. Qtz overgrowth.

RG 88 Medium sandstone: supermature quartz arenite (cement dissolved out).

Grayish orange (10 YR 7/4). Very thin bedding. Cliff former. Grayish orange weathered color (10 YR 7/4).

Well sorted. Sub-rounded grains. T, S, C/C, and Su contacts.

Qtz, single grain, straight to undulose; composite grain, undulose, elongated, bimodal. Perthite. Microcline, rounded to sub-rounded. Hematite outlines grains.

RG 89 Medium sandstone: supermature quartz arenite (cement dissolved out).

Well sorted. Rounded grains. T, S, and C/C grain contacts.

Qtz, single grain, straight to undulose; composite grain, undulose, elongated, bimodal. Orthoclase, clear, unaltered. Microcline, altered, rounded. Hornblende. Metamorphic rock fragments. Hematite occurs in blobs.

RG 90 Medium sandstone: siliceous supermature quartz arenite.

Grayish orange (10 YR 7/4). Laminated bedding. Re-entrant. Weathers pale yellowish brown (10 YR 6/2).

Well sorted. Rounded grains. S, C/C, and Su grain contacts.

Qtz, single grain, straight to undulose; composite grain, undulose, elongated, bimodal. Microcline, rounded. Hematite occurs in clay and outlines grains. Clay and silica cement.

RG 91 Medium sandstone: siliceous supermature quartz arenite.

Grayish orange (10 YR 7/4). Thin bedded. Cliff former. Weathers dark yellowish brown (10 YR 4/2).

Well sorted. Sub-rounded to rounded grains. S, C/C, and Su grain contacts.

Qtz, single grain, straight to undulose; composite grain, elongated. Microcline, rounded. Orthoclase. Chert, gneiss, and igneous rock fragments. Hematite in clay, also replacing magnetite cubes. Qtz overgrowth.

RG 92 Medium sandstone: siliceous supermature quartz arenite.

Very pale orange (10 YR 8/2). Medium bedded. Cliff former. Weathers moderate yellowish brown (10 YR 5/4).

Well sorted. Rounded grains. T, S, C/C, Su grain contacts.

Qtz, single grain, straight to undulose; composite grains, undulose. Microcline, rounded. Zircon. Chert, brown igneous rock fragments. Hematite occurs as blobs and outlines some grains. Clay, silica, and chalcedony cements. Qtz overgrowths.

RG 93 Medium sandstone: clayey bimodal immature quartz arenite.

Very pale orange (10 YR 8/2) with grayish orange spots (10 YR 7/4). Laminated bedding. Re-entrant. Weathers grayish orange (10 YR 7/4).

Moderately sorted. Rounded grains. T, S, C/C, and Su contacts.

Qtz, single grain, straight to undulose, rutile inclusions; composite grains, undulose. Microcline, rounded to sub-rounded. Muscovite. Metamorphic rock fragments. Hematite concentrated in rounded concretions which act as a cement to qtz grains. Qtz grains in these concretions are fractured. Clay 18 per cent total rock.

RG 94 Fine sandstone: siliceous supermature quartz arenite.

Pale orange (10 YR 7/2). Thin bedded. Cliff forming. Weathers light gray (N 7).

Well sorted. Rounded grains. T, S, C/C contacts.

Qtz, single grain, straight to undulose; composite grain, undulose. Microcline, rounded. Hornblende, rounded. Chert, metamorphic, two types of igneous rock fragments. Patchy calcite cement. Hematite in 5 mm concretions and also in calcite. Qtz overgrowths.

RG 95 Fine and medium laminated sandstone: slightly calcitic supermature quartz arenite.

Grayish orange (10 YR 7/4). Very thin bedded. Cliff former. Weathers light gray (N 7).

Well sorted. Rounded grains. T, S, C/C contacts.

Qtz, single grain, straight to undulose, rutile inclusions; composite grain, undulose and elongated. Microcline, rounded. Igneous rock fragments. Calcite in pore spaces. Hematite in calcite. Qtz overgrowths.

RG 100a Fine sandstone: calcitic submature quartz arenite.

Very pale orange (10 YR 8/2). Thin bedded, mostly covered. Slope forming. Weathers dark yellowish brown (10 YR 4/2).

Moderately sorted. Rounded grains. T, S, C/C grain contacts.

Qtz, single grain, straight to undulose; composite grain, undulose, elongated. Perthite. Microcline, rounded. Chert fragments. Hematite in calcite, in pore spaces, and possibly detrital. Qtz overgrowth. Qtz and feldspar etched by calcite. Calcite lines some qtz in calcite matrix of different orientation.

RG 100b Medium sandstone: calcitic bimodal mature to supermature quartz arenite.

Very pale orange (10 YR 8/2). Thin bedded, mostly covered. Slope forming. Weathers dark yellowish brown (10 YR 4/2).

Well sorted. Rounded grains. T, S, C/C contacts.

Qtz, single grain, straight to undulose; composite grain, elongated, bimodal. Microcline, rounded to sub-angular. Orthoclase. Muscovite. Calcite in patches. Hematite in carbonate and around qtz grains. Magnetite. Qtz overgrowth.

RG 100c Medium sandstone: calcitic bimodal submature quartz arenite.

Very pale orange (10 YR 8/2). Thin bedded, mostly covered. Slope former. Weathers dark yellowish brown (10 YR 4/2).

Moderately sorted. Rounded to sub-rounded. F, T, and S grain contacts.

Qtz, single grain, straight to undulose, rutile inclusions; composite grain, undulose, elongated, bimodal. Microcline, rounded, replaced by calcite and hematite. Hematite in calcite and in pores. Magnetite.

RG 100d Fine to very fine sandstone with coarse grains: calcitic mature bimodal subarkose.

Very pale orange (10 YR 8/2). Thin bedded, mostly covered. Slope former. Weathers dark yellowish brown (10 YR 4/2).

Well to moderately sorted. Sub-rounded grains. F, T, and S grain contacts.

Qtz, single grain, straight to undulose. Perthite. Orthoclase, altered. Microcline, rounded and altered. Feldspar 6 per cent total rock, 8.6 per cent specific. Chert and igneous rock fragments. Hematite in calcite and in pores. Calcite 29 per cent total rock. Appears to have been some detrital grains. Stains as ferrous calcite.

San Andres Limestone: all of the following stain as ferrous calcite and emit a strong hydrogen sulphide odor.

RSA 1 Silty dismicrite.

Light gray (N 7) with pinkish gray (5 YR 6/2) layers. Weathers pale yellowish brown (10 YR 6/2). Silt sized quartz. Hematite stains cracks in limestone from top to bottom. Three layers of fine sandstone to coarse silt in calcite cement.

RSA 2 Calcitic quartz arenite with micrite lenses. Pinkish gray (5 YR 8/1) fine sandstone with 4-10 mm thick lenses of micrite. Very thin bedding. Forms cliff. Weathers pale yellowish brown (10 YR 6/2).

Qtz, single grain, rounded. Orthoclase, rounded to sub-angular. Microcline. Tourmaline. Magnetite.

Hematite. Calcite spar in eye shaped vugs and veins. Pseudo-oolites.

RSA 3 Clayey dismicrite.

Pale yellowish brown (10 YR 6/2) to grayish orange (10 YR 7/4). Platey bedding. Cliff former. Weathers grayish orange (10 YR 8/4 to 10 YR 7/4).

Sparse silt-sized quartz. Disseminated hematite and clay. Calcite spar in veins and eye-shaped to round vugs.

RSA 4 Clayey dismicrite.

Color varies from grayish pink (5 R 8/2), grayish orange (10 YR 7/4), very pale orange (10 YR 8/2), pale yellowish brown (10 YR 6/2), light brownish gray (5 YR 6/1). Platey to very thin bedding, some apparent cross beds. Cliff forming. Weathers dark to pale yellowish brown (10 YR 8/2 or 6/2), light olive gray (5 YR 6/1), moderate orangish pink (5 YR 8/4), grayish orange (10 YR 7/4), and very pale orange (10 YR 8/2).

Disseminated hematite, some strung out in horizontal laminations. Calcite spar in round vugs, also horizontal laminations of recrystallized calcite. In upper layers, most vugs are unfilled. Clayey, some botryoidal layers. Pseudo-oolites.

This thesis is accepted on behalf of the faculty of the Institute by the following committee:

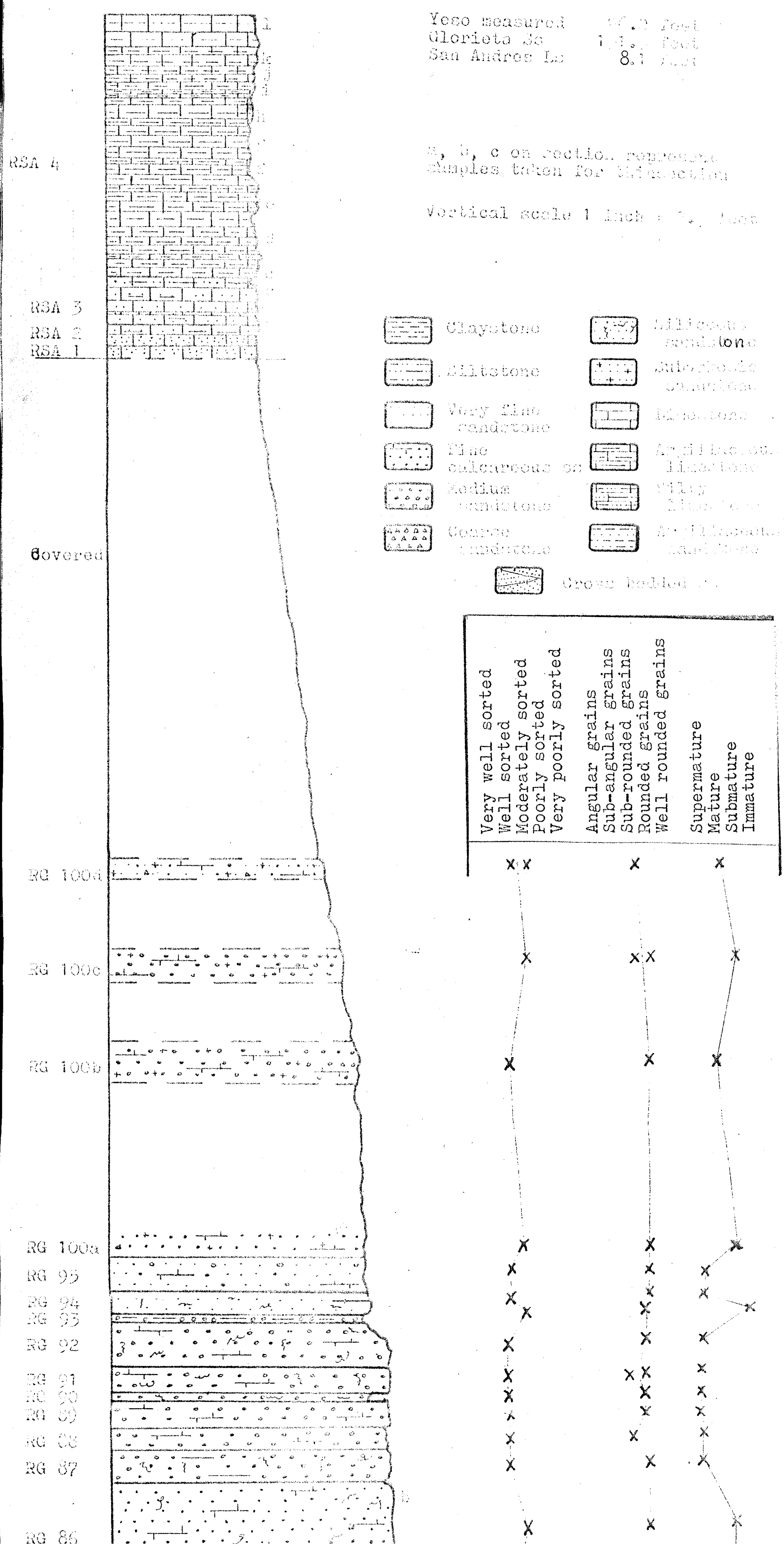
Christina L. Balk

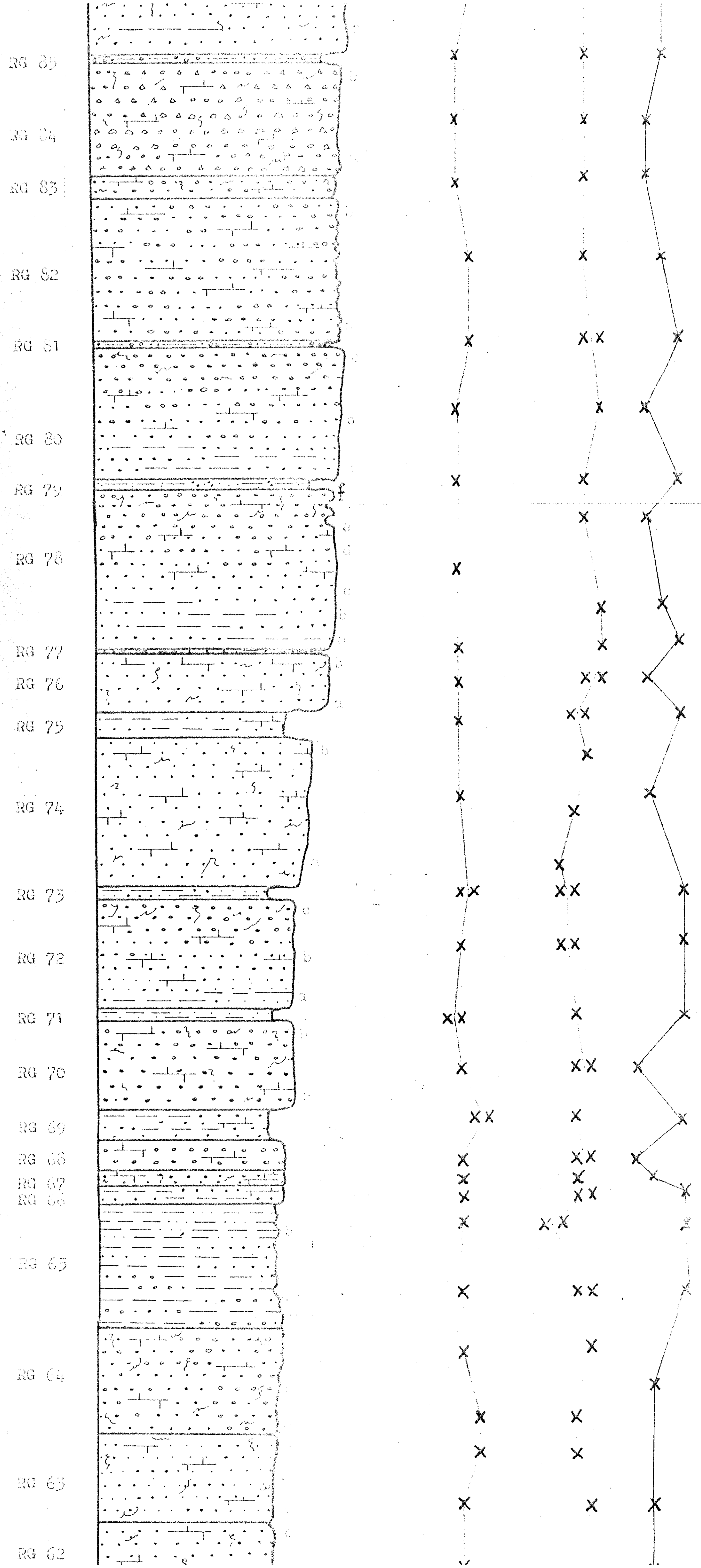
Mac E. Willard

Frank S. Kowalski

Date June 14, 1972

Plate 1: Stratigraphic section of the upper Yeso, Glorieta Sandstone, and San Andres Limestone near [illegible], New Mexico. See rock descriptions in Appendix [illegible].

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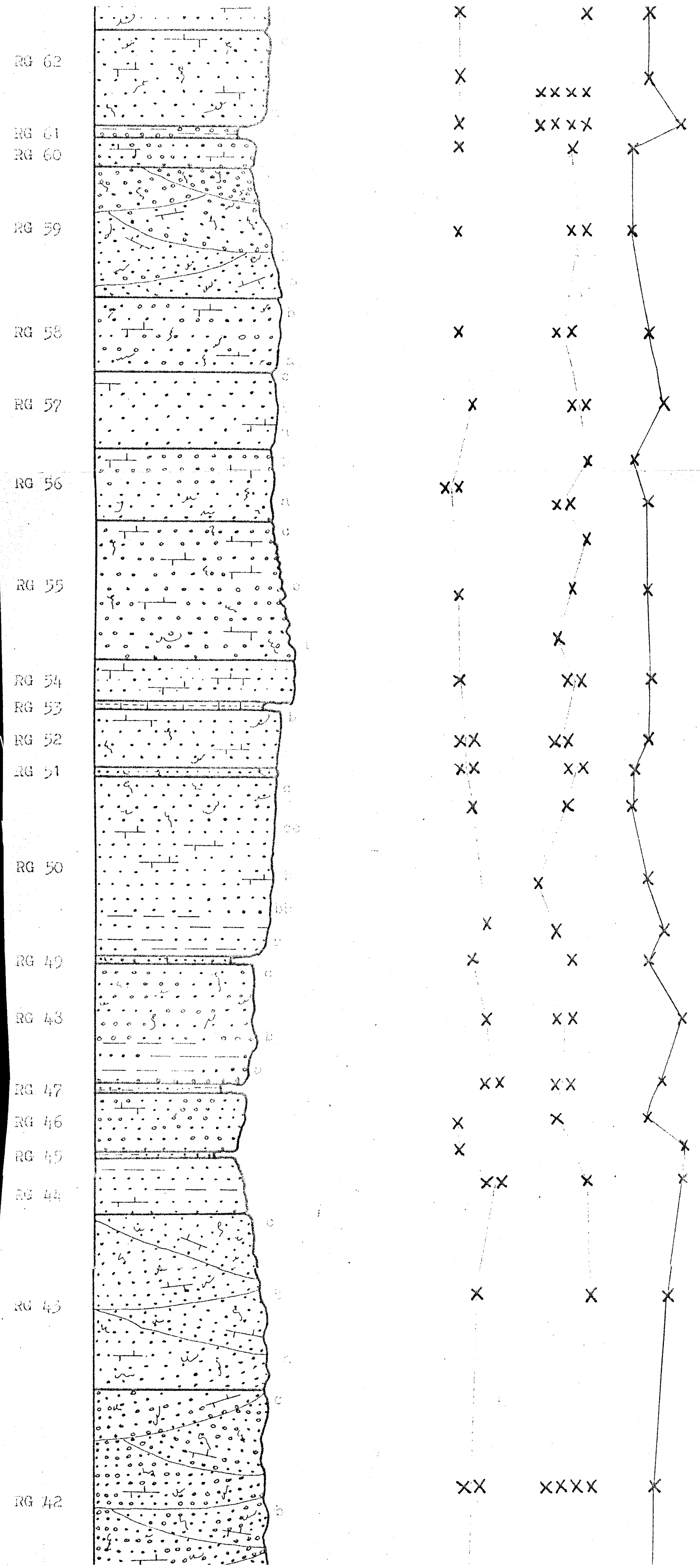
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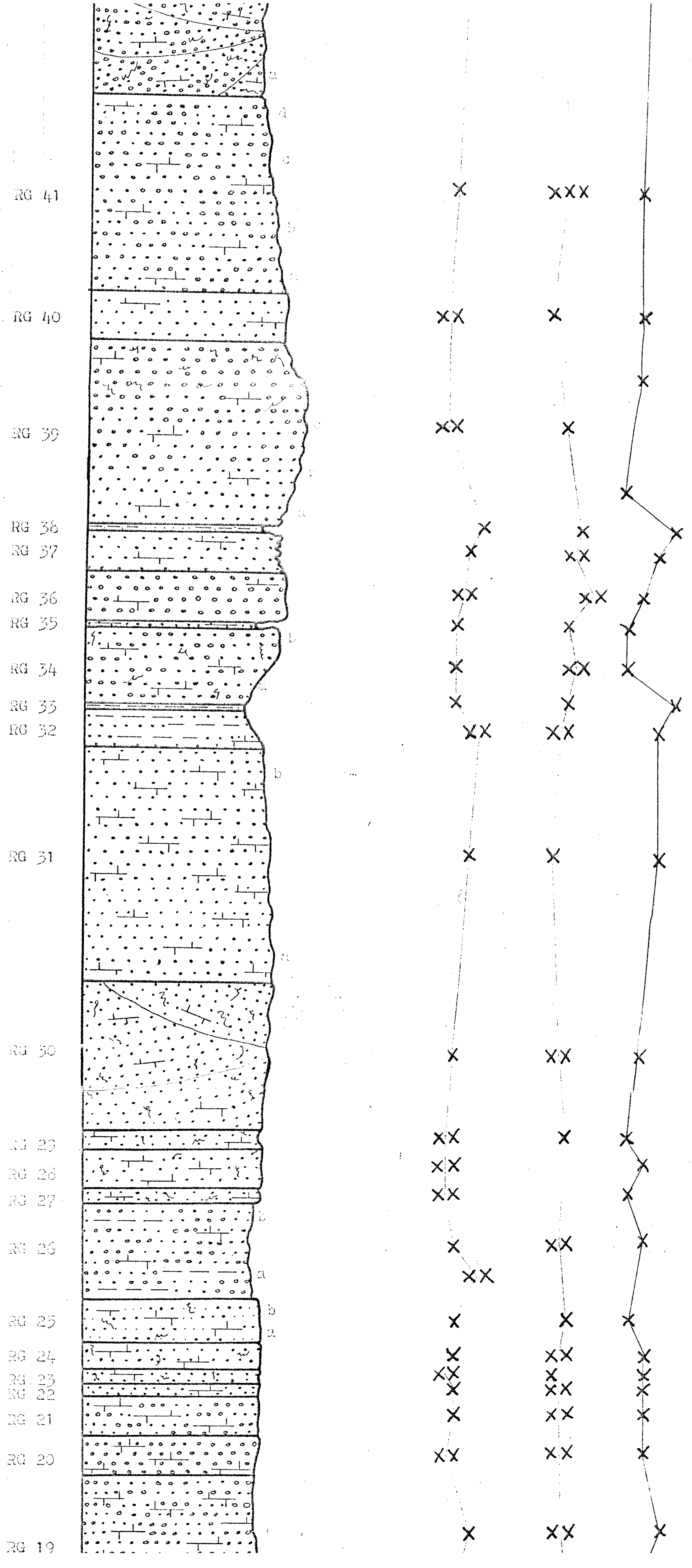

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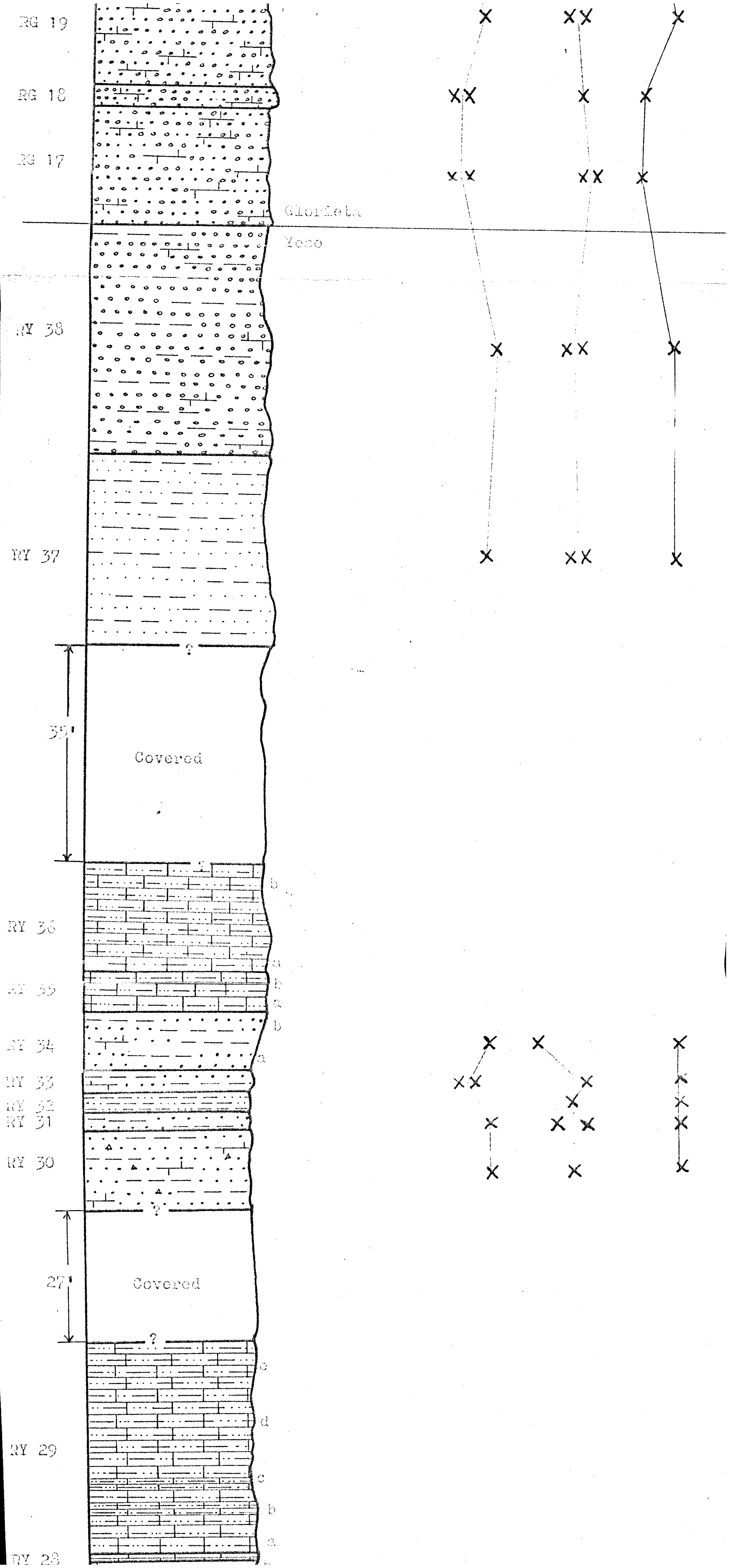

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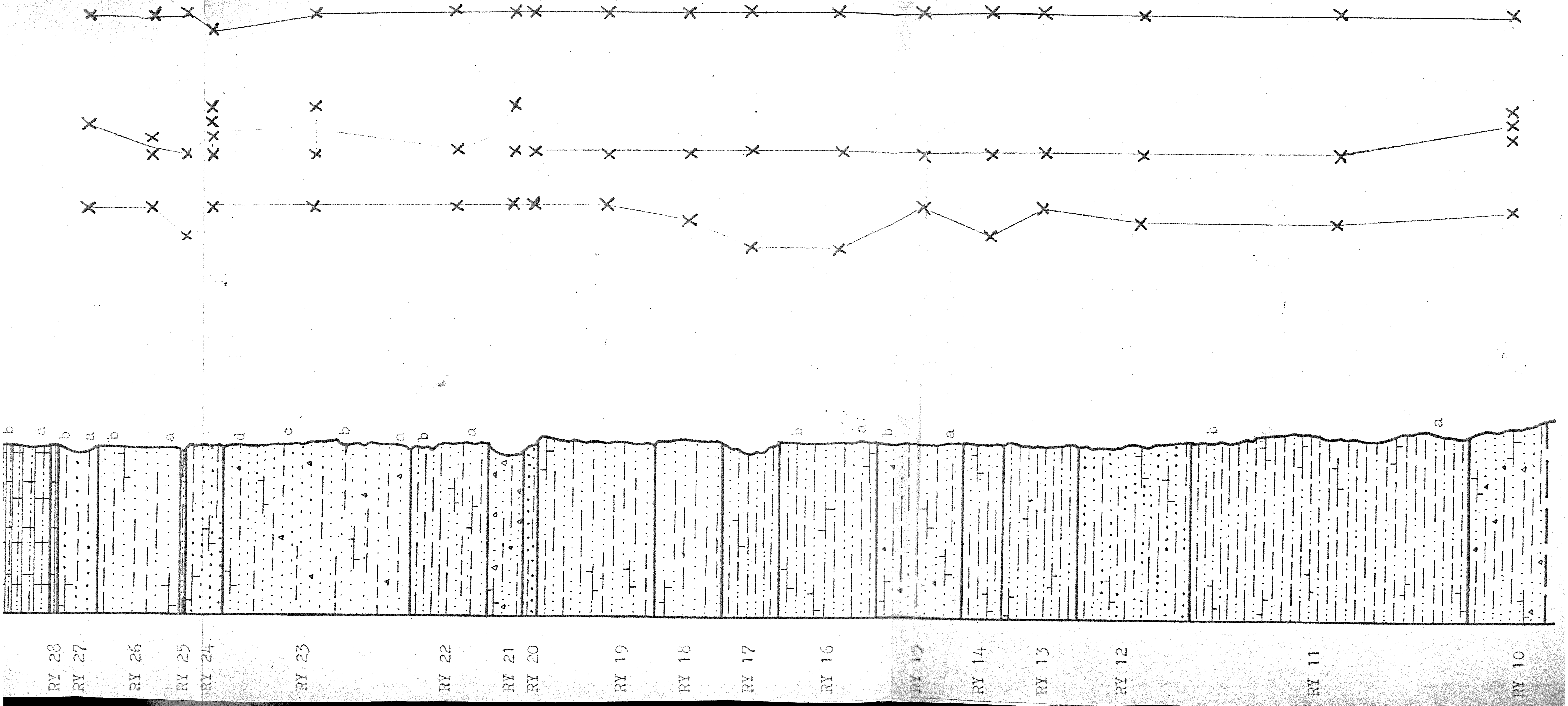

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