STRATIGRAPHY AND PETROLOGY OF THE MINETA FORMATION IN PIMA AND EASTERN COCHISE COUNTIES, ARIZONA

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I hereby recommend that this dissertation prepared under my direction by Donald Wayne Clay

entitled STRATIGRAPHY AND PETROLOGY OF THE MINETA FORMATION IN PIMA AND EASTERN COCHISE COUNTIES, ARIZONA

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ABSTRACT

The Mineta Ridge area contains a sequence of Oligocene to Early Miocene sedimentary and igneous rocks. The Oligocene sedimentary rocks are separated into three members of the Mineta formation: the conglomerate member, the middle limestone member, and the upper detrital member. A rhyolite flow lies at the base of the conglomerate member. These rocks lie in fault contact on Precambrian and Paleozoic metamorphic and sedimentary rocks, and in fault and depositional contact on granite. The Banco beds (Miocene [?]-Pliocene [?]) overlie unconformably the Mineta formation; the Mineta is in fault contact with the Soza beds.

The Mineta formation was deposited as an alluvial plain or floodplain from a nearby source area that initially had a high relief. Lakes developed in the depositional area, and fresh water algal limestones were deposited. Several tens of feet of gypsum deposited in the upper beds of the Mineta represent the development of an arid climate.

The strike of the Mineta formation is northwest, and it dips steeply (50° to 85°) to the northeast. It is on the tilted edges of the Mineta that the Turkey Track Porphyry has intruded and flowed to form what is now the surface capping of Mineta Ridge.

Precambrian (?) and/or Paleozoic (?) meta-sedimentary rocks, and undifferentiated Paleozoic and Mesozoic rocks make up the sections exposed in the White Ridge vicinity. These rocks rest in presumed fault contact on the Catalina Gneiss--the rock making up the core of the Rincon Mountains. These sedimentary and meta-sedimentary rocks also strike northwest and dip steeply to the northeast.

The petrography of the Mineta formation reveals that these older rocks, or rocks lithologically similar to them, contributed many of the fragments from which the Mineta formation is composed. Other contributing rock sources consist of volcanics, which are not identified in the area of this study, and granites, which may be those exposed locally. The Catalina Gneiss is conspicuously absent in this suite of contributing source rocks, which suggests that it was not exposed to erosion at the time the Mineta formation was accumulating. Other studies have revealed the date of cooling, and thus the completion of metamorphism of the Catalina Gneiss to be about 26.8 $\pm$ 1.7 million years, and this is now generally considered to be the age of up-doming of the Rincon-Santa Catalina Mountains. The age of the Mineta formation has been determined by a fossil rhinocerous jaw to be Late Oligocene to Early Miocene. A Late Oligocene age is substantiated by a recent K-Ar age of the Turkey Track Porphyry from Mineta Ridge. This age (26.3 $\pm$ 2.4

million years) of the Mineta formation is after the deposition and after the tilting.

INTRODUCTION

Location and Accessibility

Mineta and White Ridges are located along the eastern foothills of the Rincon Mountains. The area includes parts of T. 13 S. and R. 18 and 19 E., Redington and Bellota Ranch Quadrangles, Pima and Cochise Counties, Arizona (Figs. 1 and 2).

The area is accessible by ranch roads leading from the Redington Road. The Tertiary rocks of the Mineta formation are exposed along the Canada Atravesada wash from the Bar LY Ranch to Roble Canyon, and are easily reached with a pickup truck. A second ranch road leads past a series of tanks, and provides access to the Paleozoic section. Beyond Big Tank, this road requires a four-wheel-drive vehicle. The road leads to several abandoned mining prospects, and terminates at the Bar LY Ranch. The area south and west of the Bar LY Ranch is largely inaccessible to vehicles, except for trails shown on the topographic quadrangle maps that can be negotiated by a four-wheel-drive vehicle.

Physical Features

The elevation of the Bar LY Ranch is 3250 feet. The highest elevation in the mapped area is the summit of Chimney Peaks, 5314 feet. The total relief is 2064 feet.

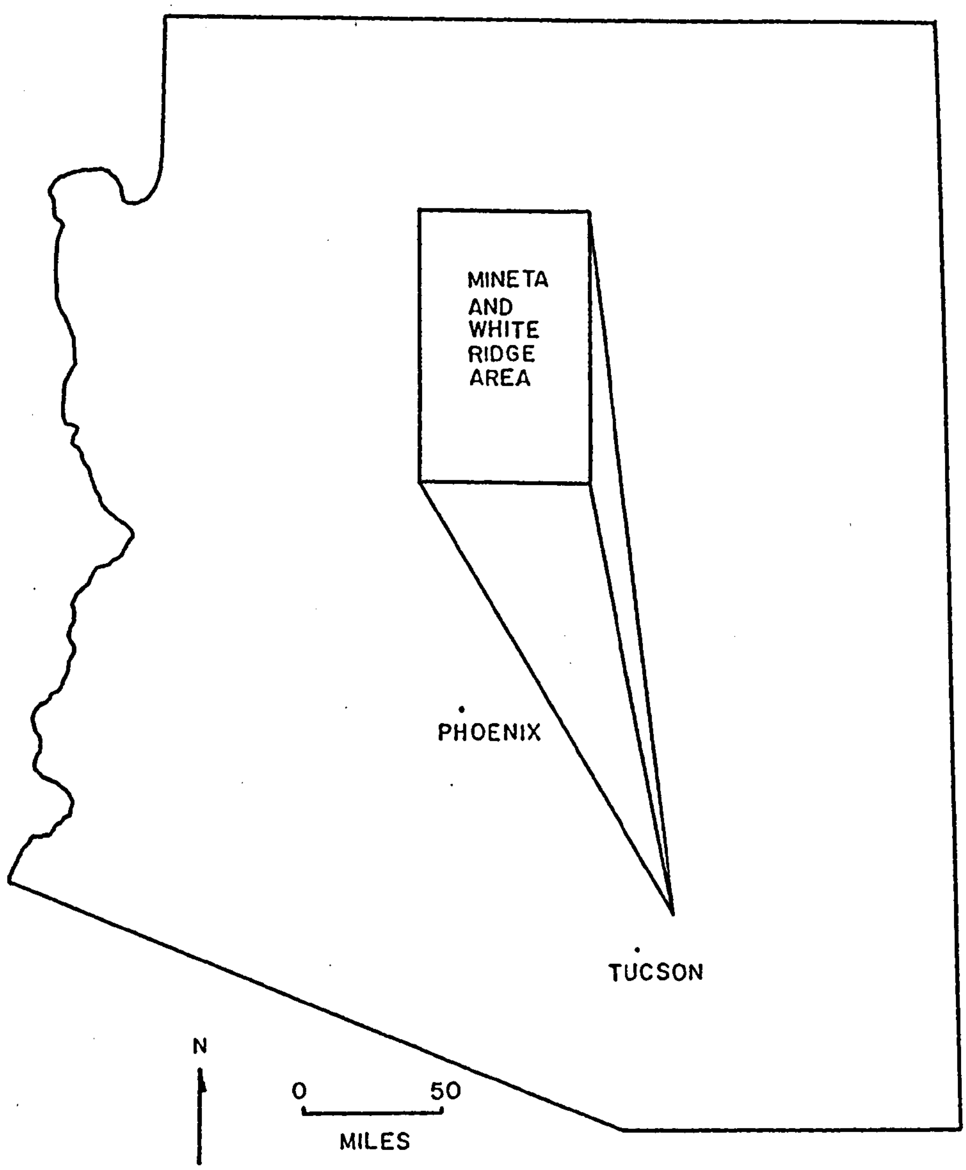


Fig. 1. Index map of the Mineta and White Ridge Area.

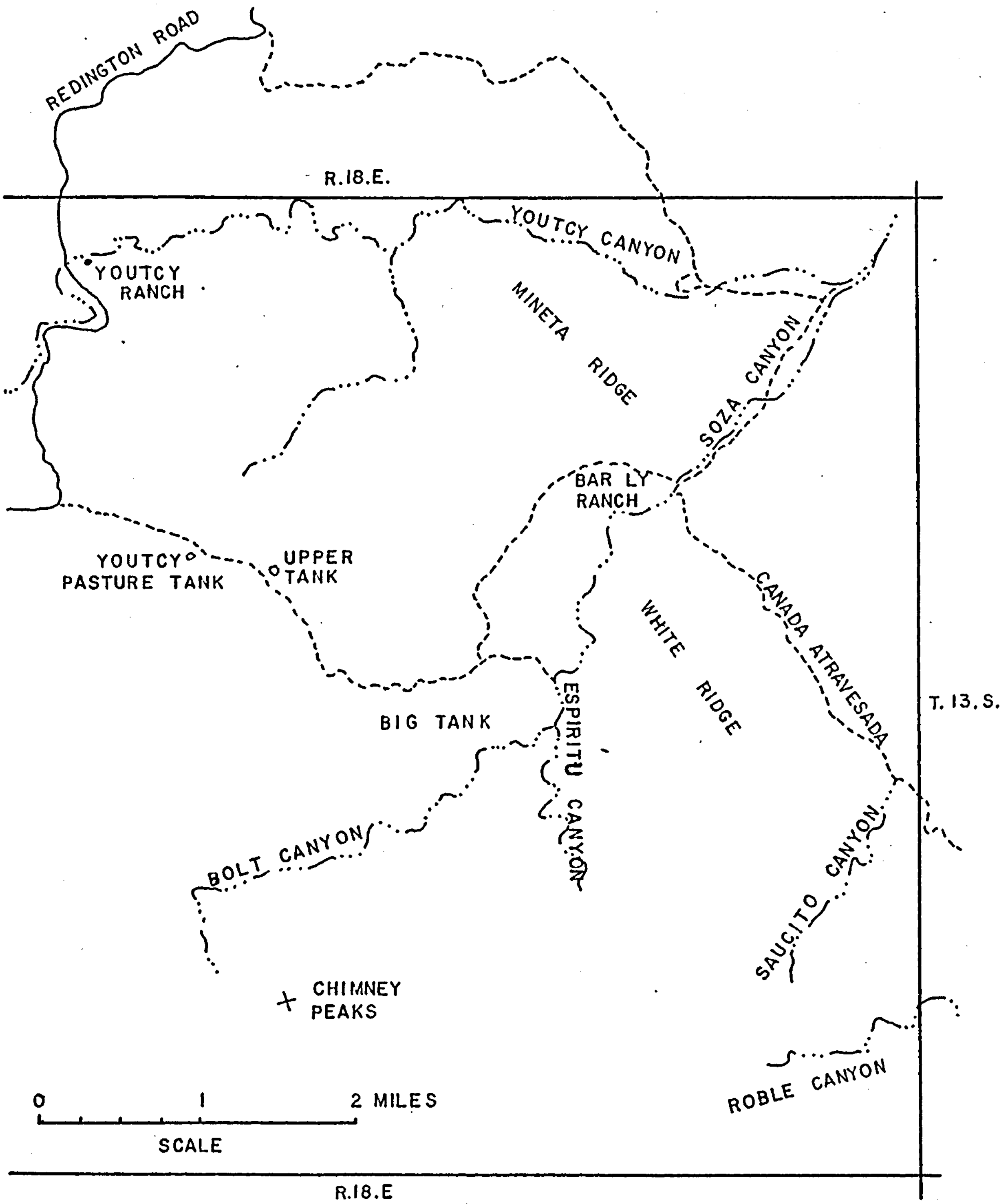


Fig. 2. Index map of geographic features in the Mineta and White Ridge Area.

Drainage of the area is into Soza and Roble Canyons and then into the San Pedro River. Major tributaries of Soza Canyon are the northern part of Canada Atravesada, Youtcy, and Espiritu Canyons. Those tributaries of Roble Canyon are Saucito Canyon and the southern part of the Canada Atravesada (drainage is both north and south from a divide). All of these canyons provide good outcrops for study. Espiritu Canyon is the steepest, with its walls rising as much as 750 feet. The other canyons have walls rising from 400 to 500 feet at maximum.

Climate and Vegetation

The summer months are hot and hinder field operations. Daily temperatures commonly exceed 100 degrees in the summer. Water is scarce during these months; however, it can be obtained at the Bar LY Ranch and usually from a well at Roble Canyon. After summer rains, springs are common and provide small quantities of water for limited periods of time.

Vegetation is typical of the lower Sonoran flora. The stream beds contain abundant mesquite and palo verde trees that provide welcome shade during the summer. The slopes and ridges support stands of common cactus and other desert plants. The more common types are saguaro, cholla, prickly-pear, barrel, ocotillo, and lecheguilla. In elevations above 4000 feet, juniper is common.

Larger forms of wildlife observed during field operations include deer, javelina, and mountain lion.

Previous Studies

A portion of the area of this report was originally mapped by Chew (1952). In 1962 Chew summarized his thesis in a shorter paper. Cooper (1961) included an analysis of the Turkey Track Porphyry and considered it as a possible correlation guide. Mielke (1965) studied samples of the Turkey Track Porphyry from the Mineta Ridge area in his regional study on trace elements of the Turkey Track. The Mineta Ridge area was also included as part of a reconnaissance study at a scale of 1:250,000 by Creasy, Jackson, and Gulbrandsen (1961).

Several recent theses and dissertations cover areas near this study. Three theses areas are to the northwest: Broderick (1967) mapped Piety Hill and the surrounding area; Raabe (1959) mapped in an area just northwest of Piety Hill, and overlapped with the Buehman Canyon area mapped by McKenna (1966). Miles (1965) mapped the area around Lechequilla Peak, two miles south of the area of this report, and Plut (1968) mapped an area one mile south of that mapped by Miles.

Purpose of Study

The Mineta formation, with its associated intrusive rocks, principally the Turkey Track Porphyry, have been used for a decade as a reference in southeastern Arizona for middle Tertiary sedimentation. The purpose of this study was to characterize the source area and the environment of deposition of the Mineta formation and attempt to acquire additional evidence in support of the age of the Mineta formation.

Field and Laboratory Procedure

A geologic map (Fig. 3) and geologic cross-sections (Fig. 4) (both in pocket) of the Mineta formation and associated rock units was prepared. Stratigraphic sections of the Mineta formation were measured and sampled for laboratory analysis. Sections of Paleozoic and Mesozoic rocks lying to the west of the Mineta formation were described and spot sampled for petrographic identification.

In the laboratory 160 thin sections of the limestone and sandstone beds were prepared; heavy minerals were collected and described from 30 samples; 33 siltstone samples were examined by X-ray diffraction techniques to aid in the identification of clay minerals; 25 matrix samples of conglomerate units were examined with the binocular microscope to determine their composition; 31 pebble counts of the conglomerate member, plus random counts in the Soza and Banco beds were taken in the field.

PRE-MINETA ROCKS

Pinal Schist

Along the southwestern boundary of the Mineta formation a sequence of low-grade metamorphic rocks crops out. These rocks are predominantly schistose to phyllitic, and closely resemble the Pinal Schist that is widely exposed in southern Arizona. The texture and lithology varies only slightly over the area of investigation from a muscovite-rich phyllite to a muscovite schist.

The original rocks appear to have been largely sandstones and shales. A number of beds or lenses of incompletely altered sandstones and shales are present throughout the unit.

Foliation within the Pinal Schist ranges from N. 50° E. to N. 80° E., the more easterly orientation being characteristic of the northern exposures. Dips are steeply inclined to the northwest from 55 to 75 degrees.

All contacts between the schist and other rocks in this area are faulted. To the northeast the schist is in fault contact along the Mineta Fault with the Mineta formation a rhyolite flow. To the northwest, the schist is in fault contact with undifferentiated Paleozoic and Mesozoic rocks, and to the southwest it is in reverse fault contact with rocks of Cretaceous age.

Fig. 5. Outcrop of Pinal Schist in Roble Canyon.

A well-dissected topography has formed on the schist with well-defined ridge lines and smooth slopes. Outcrops are best exposed in the deeper valleys, as the slopes and hills are commonly covered by debris.

The age of these metamorphic rocks has been considered Precambrian in all previous publications. The author also presumes a Precambrian age, based on the similarities with the Pinal Schist and the greater intensity of metamorphism of this rock when compared with Paleozoic (?) rocks with which the schist is in fault contact.

Precambrian (?)-Lower Paleozoic (?) Rocks Undifferentiated

Non-fossiliferous, metamorphosed sedimentary rocks presumably of the Precambrian Apache Group (?) and/or rocks of Lower Paleozoic (?) age crop out extensively in T. 13 S., R. 18 E., in sections 8, 9, 15, and 16, and along upper Soza Canyon and White Ridge, and at Chimney Peaks in section 28. Similar appearing rocks were mapped by Broderick (1967) along the Redington Road.

Exposures along the Youtcy Pasture Tank road probably represent the oldest of the outcrops. The section strikes northwest and dips steeply northeast, consisting of approximately 600 feet of marble and interbedded quartzite and schist overlain by about 600 feet of quartzite that contains minor amounts of schist and marble.

The marble is fine grained and light gray (N7) (Rock Color Chart Committee, 1948) to light bluish gray-white (5 B 8/1). It is thin to medium bedded with some beds as thick as three feet. Parts of the marble are laminated, the coarser laminae consisting of discontinuous chert bands. The rock is characterized by chert pebbles, nodules, and lenses, that, along with the bedding, have undergone extensive contortion by plastic flow (Fig. 6). The lowest exposed beds contain some rounded quartz pebbles as large as one inch in diameter. These rocks are interbedded with subordinate thicknesses of quartzite and of schist.

The quartzite is a very pale orange (10 YR 8/2), and commonly weathers to reddish brown with light and dark colored bands several millimeters in thickness. It is medium grained and locally shows faint cross-bedding. Bedding thickness is two feet or less.

Contacts with crystalline rocks--porphyritic granite, aplite granite, and Catalina Gneiss--are presumed to be faulted.

A similar section consisting predominantly of marble, is well exposed in Soza Canyon, southwest of the Bar LY ranch house, and over much of White Ridge and Chimney Peaks. These marbles are non-fossiliferous, or at least any fossils originally present were destroyed by metamorphism.

Fig. 6. Folding characteristic of plastic deformation.

Precambrian (?) and/or Paleozoic (?) marble containing chert lenses.

Metamorphism and lack of fossils prevent identification of these formations at this time.

In the lower part of the section the marble contains quartz pebbles, often stretched to elongate lenses or a disk shape. The marble is fine to medium grained and light to dark gray with tints of blue, green, and olive. The uppermost unit is white. Bedding is thick and massive in the lower portion; the middle portion is thinner bedded and forms broken cliffs and slopes; and the upper units are also thickly bedded and massive. Interbedded sand units are present as well as chert nodules, lenses, and layers. The chert and sandy beds are commonly contorted, indicative of the plastic deformation which has affected the entire section. Red shale and red to black schist are interbedded with the marble, particularly in the lower two-thirds of the section.

The marble is in contact with the Catalina Gneiss in Soza Canyon and across White Ridge. The contact is covered at White Ridge, but in Soza Canyon it is fully exposed and interpreted as depositional. Metamorphism has modified this contact and the texture and color of both rock units are changed at the contact.

The contacts between these marbles and the Mineta formation are faulted wherever observed. The contact between the marble and the Catalina Gneiss was walked out along the exposure at Chimney Peaks, but nowhere was the contact directly observed.

Upper Paleozoic and Cretaceous Rocks

In the southwestern part of the mapped area, from Roble Canyon northward to White Ridge, a sequence of unmetamorphosed Upper Paleozoic rocks and Lower Cretaceous rocks of the Bisbee Group is exposed. These beds are in fault contact with Pinal Schist to the east and in presumed fault contact with Catalina Gneiss to the west (Fig. 3). A measured section at Roble Canyon is described in the Appendix. It is typical of the sequence, but does not accurately represent the thickness or total lithology because of faulting.

The general strike of the strata is northwest, with a steep northeasterly dip. The section forms smooth but steep grass-covered slopes with local outcrops of resistant limestone or conglomerate beds. The best exposures are in the valleys.

The oldest part of this section is largely composed of limestones that are fine to medium grained, light to medium gray, and generally thickly bedded. Fossils are common in some beds. Brachiopods, horn corals, and crinoid stems are most commonly represented. No attempt has been made to identify the fauna.

Overlying the limestone is a sequence of grayish-red (5 R 4/2) to blackish-red (5 R 2/2) fine grained sandstone, siltstone, and mudstone, mottled with buff and light gray areas. Commonly it appears sheared or broken, with numerous calcite veins filling the fractured zones. The sandy portions are moderately sorted, subrounded quartzarenites, containing several per cent plagioclase, and cemented by calcium carbonate. They are interbedded with non-fossiliferous limestones. Because of repetition it is not possible at this time to determine where these red beds fit within the section.

A coarse-grained conglomerate composed largely of limestone pebbles and boulders, that is probably equivalent to the Glance Conglomerate, is exposed in Roble and Saucito Canyons. This calcirudite forms imposing exposures and thus is a marker bed that can be easily identified.

In Roble and Saucito Canyons, parts of this unit are repeated four times as the section is traversed. The unit is interbedded with a distinctive maroon sandstone and siltstone unit, and non-distinctive limestones, sandstones, and shales.

The geographic distribution of the conglomerate covers about 1.5 square miles in the area mapped. It is well exposed only in Roble and Saucito Canyons, although the unit is known to extend for at least one mile south of Roble Canyon.

Lithologically similar conglomerates are found in Buehman Canyon on the eastern side of the Catalina Mountains, on the western side of the Rincon Mountains south of Tanque Verde Ridge, and in the Empire Mountains.

The suggested correlation with the Glance Conglomerate of Early Cretaceous age is based upon similar textures, lithology, and bedding characteristics. The lithology of described sections of Glance Conglomerate depends largely upon the regional geology. Gilluly (1956, p. 71) points out that if the Glance rests on limestone or dolomite then pebbles of that composition are common.

The conglomerate is a very coarse grained calcirudite with a light to medium gray color imparted largely by the gray color of the numerous limestone fragments making up the unit. Calcium carbonate is the cement, binding the unit into the most resistant and thickest bedded of the principal stratigraphic units making up the section of Roble Canyon.

Boulders several feet in diameter are common in the coarser beds of the conglomerate, but even in these beds the average diameter of large fragments is about six inches. The conglomerates are interbedded with coarser- and finer-grained beds including sandstone. The coarser beds always have the thickest bedding. Beds as thick as ten feet are typical.

The pebbles and boulders that make up this conglomerate consist almost totally of limestone derived from several sources, including upper Paleozoic limestones containing crinoid stems, brachiopods, and horn corals. Other fragments consist of non-fossiliferous limestones and sandstones, plus quartz and chert.

The thickest measured section is 415 feet, in Roble Canyon. The upper contact is faulted with the Pinal Schist, and the lower contact with the Paleozoic (?) rocks is not well exposed, so this thickness must be considered a minimum value.

Pre-Mineta Igneous and Metamorphic Rocks

Catalina Gneiss

Catalina Gneiss forms the western boundary of the mapped area. Although the unit has not been mapped in detail, it is of interest because of its contact relations with other rocks described in this paper.

The Catalina Gneiss is a yellowish gray (5 Y 7/12) rock composed largely of feldspar, quartz, and biotite. In the mapped area, it is represented as an augen gneiss with porphyroblasts of feldspar averaging perhaps one-half inch in length.

Numerous dikes, commonly composed either of quartz or a very pale pink aplite, are present in the gneiss. The dikes can be easily plotted on aerial photographs. Their observed orientations on photographs are approximately N. 30° E. to N. 60° E. In the field, however, many dikes are also noted to be nearly parallel to the foliation, cross-cutting it at small acute angles.

Damon, Erickson, and Livingston (1963), based upon K-Ar dates for micas, suggest that the cooling of the Catalina Gneiss was completed by Late Oligocene to Early Miocene time. They report that the apparent average age of cooling is 26.8 $\pm$ 1.7 million years.

Porphyritic Granite

In the north-central part of the mapped area, a coarse-grained porphyritic granite crops out (Fig. 3). This granite is unnamed and its internal structures have not been mapped, but because of its relative position with other units considered in this paper, the rock is of interest here.

Topographically it forms low rolling hills that are in marked contrast to the surrounding more rugged topography carved on other rock types.

The composition of this rock is similar to the Happy Valley Quartz Monzonite described by Plut (1968) in the Happy Valley Quadrangle a few miles to the south.

In hand specimen, the granite is a coarse-grained grayish orange pink (10 R 8/2) porphyritic rock weathering to a moderate pink (5 R 7/4) and containing large phenocrysts of pink potash feldspar.

In thin section the rock is estimated to contain 30 per cent quartz, 40 per cent orthoclase feldspar, 25 per cent plagioclase (Ab98-An2), and five per cent mafics. The rock is a holocrystalline, phaneritic rock with a heterogranular texture.

Basic dikes have intruded the granite, and are particularly abundant near faults.

The granite forms the northern and northwestern contact of the Mineta formation, and also is exposed in several small scattered outcrops within the Mineta formation. The granite is overlain by the Mineta formation in depositional contact, but the stratigraphic position of the Mineta formation at most outcrops suggests that some contacts have been modified by faulting. To the south the granite forms part of the footwall of the Espiritu Fault, and is brought into contact with Paleozoic rocks and the Catalina Gneiss. The western contact has been interpreted largely from aerial photographs since outcrops are scarce and generally of poor quality.

The age of the granite is unknown. It may be as young as Tertiary or as old as Precambrian. The granite is older than the Mineta formation since the Mineta is depositional upon the granite, and many of the fragments in the basal conglomerate member of the Mineta are derived from this granite. The granite is certainly younger than the Precambrian Pinal Schist since it contains schist and phyllite xenoliths derived from that unit. Damon et al. (1963) have obtained dates indicating metamorphism occurring in the Santa Catalina and Rincon Mountains as late as Late Oligocene to Early Miocene. This granite is not metamorphosed, and therefore, may be post-metamorphism in age.

Aplite Granite

An aplite granite crops out in the same general area as the porphyritic granite discussed above and is in contact with it. Its color is grayish pink (5 R 8/2) weathering to a moderate pink (5 R 7/4) on exposed surfaces.

In thin section the aplite is estimated to contain 35 per cent quartz, 40 per cent orthoclase feldspar, 22 per cent plagioclase feldspar (Ab_{92}-An_8), and three per cent mafics and miscellaneous minerals. The rock is holocrystalline and phaneritic, with a fine-grained, equigranular texture.

The contacts of this rock have not been mapped, but are considered as faults based on aerial photograph interpretation.

The age of the aplite is unknown. No evidence is recorded to suggest a relative age between the aplite and the porphyritic granite.

Rhyolite

South of the Bar LY Ranch a rhyolite of probable flow origin lies below the sedimentary rocks of the Mineta formation. The lower contact of the rhyolite is faulted against the Pinal Schist and undifferentiated Paleozoic (?) rocks and the upper contact is unconformable below the Mineta.

The rhyolite contains fragments of the underlying metamorphic rocks, but no inclusions of the Mineta formation. These rock fragments are oriented into flow layers that tend to parallel the contacts.

The rhyolite is yellowish gray (5 Y 8/1) with some iron oxidation causing rust-colored bands on weathered surfaces. It contains scattered pyrite cubes surrounded by oxidation halos. Small quartz veins are also common.

Three thin-sections of the rhyolite were examined and the estimated percentages of the minerals are as follows: quartz, 25 per cent; potash feldspar, 40 per cent; plagioclase feldspar (Ab_{88}-An_{12}), 30 per cent; mafics plus miscellaneous minerals, five per cent. Texturally it is an extrusive, holocrystalline, microgranular rock.

The age of the rhyolite can be determined only generally. The rhyolite contains metamorphic inclusions and must therefore be younger than the metamorphic rocks, and based on its stratigraphic position, it is older than the Mineta formation.

OLIGOCENE SEDIMENTARY ROCKS

Mineta Formation

Eighteen years ago the stratigraphy and structure of Mineta Ridge was mapped and reported by Chew (1952), who described and informally named the Mineta formation. In the decade that followed other workers correlated the Mineta formation with sections that are lithologically similar and within the same general age range. Some of these sections are within a few miles of Mineta Ridge, while others lie throughout southern Arizona.

Brennan (1957, 1962) proposed a tentative correlation of the Mineta formation with the Pantano Formation on the basis of ". . . lithologic similarity and periods of deformation . . . ." The Helmet Fanglomerate as described by Cooper (1960), the Cloudburst Formation of Heindl (1963), and the Rillito beds described by Pashley (1966) have been tentatively correlated with the Mineta formation upon the same basis.

Chew refers to a section exposed on the east side of the San Pedro River in the vicinity of Teran Wash that is lithologically similar to portions of the Mineta formation. Others have commented on the lithologic similarity of the Mineta with Cretaceous deposits in southeastern Arizona, principally some of the rocks in the Bisbee Group.

In general these sections are typical alluvial and fluvial sediments devoid of fossils, thereby placing the burden of correlation upon similar physical properties. This is hazardous, but necessary when more concrete evidence is lacking. Chew was fortunate in having recovered the partial remains of the jaw of a young rhino from a thin fetid limestone unit within the upper part of the Mineta formation. This single fossil, dated and reported as Late Oligocene to Early Miocene by J. F. Lance (Chew, 1952; Wood, 1959) has been the sole basis of paleontological correlation for the Mineta formation and its physically correlative rocks. In addition, the Turkey Track Porphyry occurs intrusively in, and as flows on, the Mineta, and therefore post-dates the Mineta. Cooper (1961) suggested that the presence of Turkey Track ". . . is a valid though somewhat rough marker for regional correlation."

The Mineta formation consists of a sequence of Tertiary continental sediments with intervening sills, intrusions, and possible flows of andesitic to basaltic composition. These sediments rest on a crystalline complex of intrusive rocks, Precambrian schists, and Paleozoic metasedimentary rocks. The Mineta formation strikes northwest and dips steeply to the northeast. The total exposure of the Mineta extends a little over seven miles in its linear direction along strike.

The total thickness cannot be determined with accuracy, partly because of near-bedding-plane faults that eliminate and repeat parts of the section, and secondly because of the difficulty of exact correlation of similar-appearing units to develop a true composite section (Fig. 7). A reasonable thickness is in the order of 2100 feet, determined by measurement of five sections, and by correlating as closely as possible between these sections.

Textural and mineralogical composition of the formation lends itself to a simple separation into three members. Chew (1952, 1962) chose to apply the textural and compositional criteria to each of these three members, i.e., conglomerate member, limestone member, and upper detrital member for the lower, middle, and upper units respectively. In this report the same subdivisions are used.

Terminology and Classification System

The author has adapted the system of Folk (1968) in classifying the terrigenous rocks and Folk's limestone classification for the carbonate rocks. Since the reader may not be familiar with Folk's system a diagram of his terrigenous rock classification is given in Fig. 8. This system is designed primarily for use with sandstones, and therefore, some modification of terminology seemed in order to adapt this system to conglomerate samples. This

Fig. 7. Generalized stratigraphic sections of the Mineta formation.

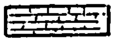
<u>Explanation</u>:

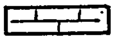
Mineta formation:

Upper detrital member

Gypsum 

Sandstone and siltstone 

Limestone 

Limestone member 

Conglomerate member 

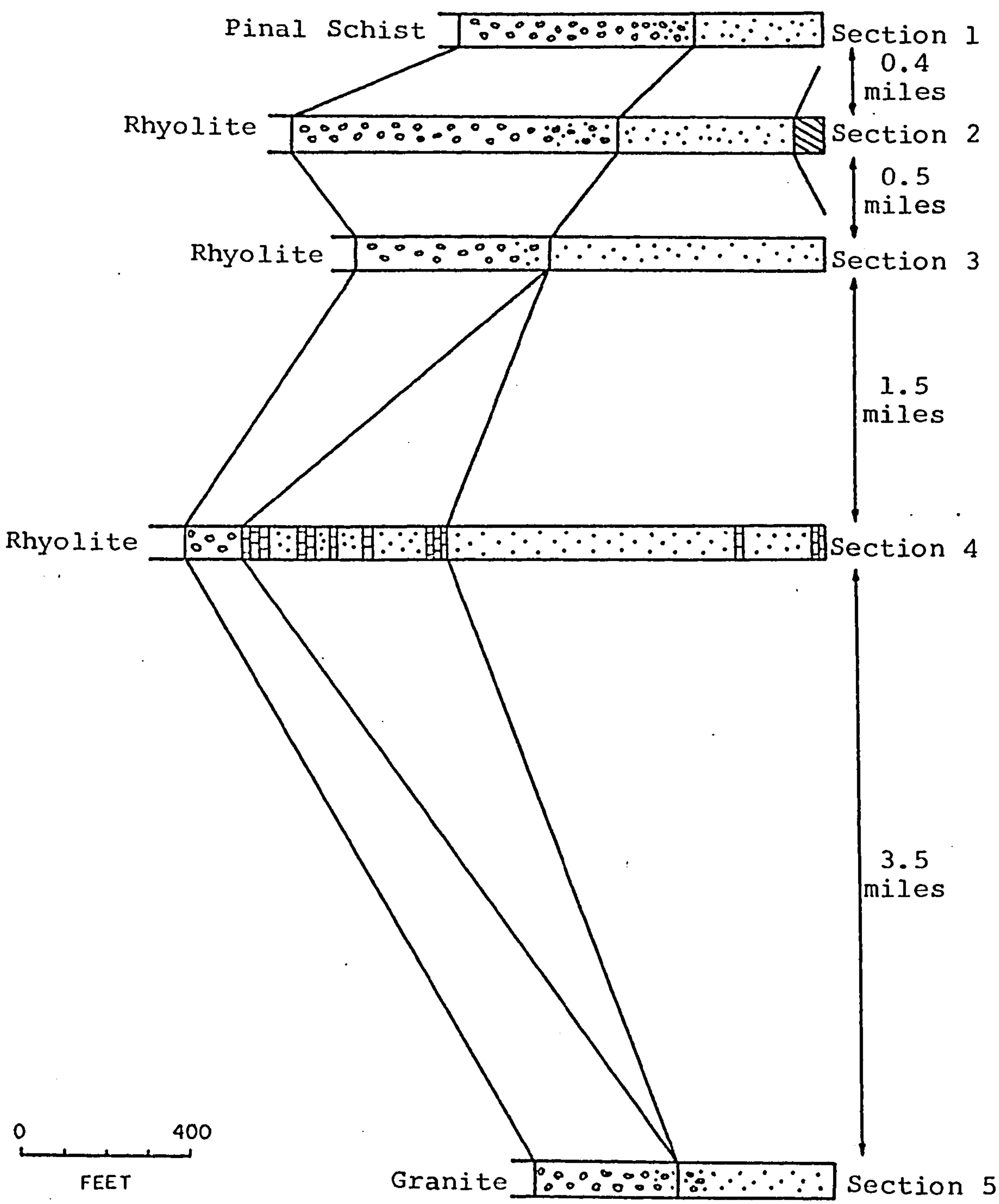


Fig. 7. Generalized stratigraphic sections of the Mineta formation.

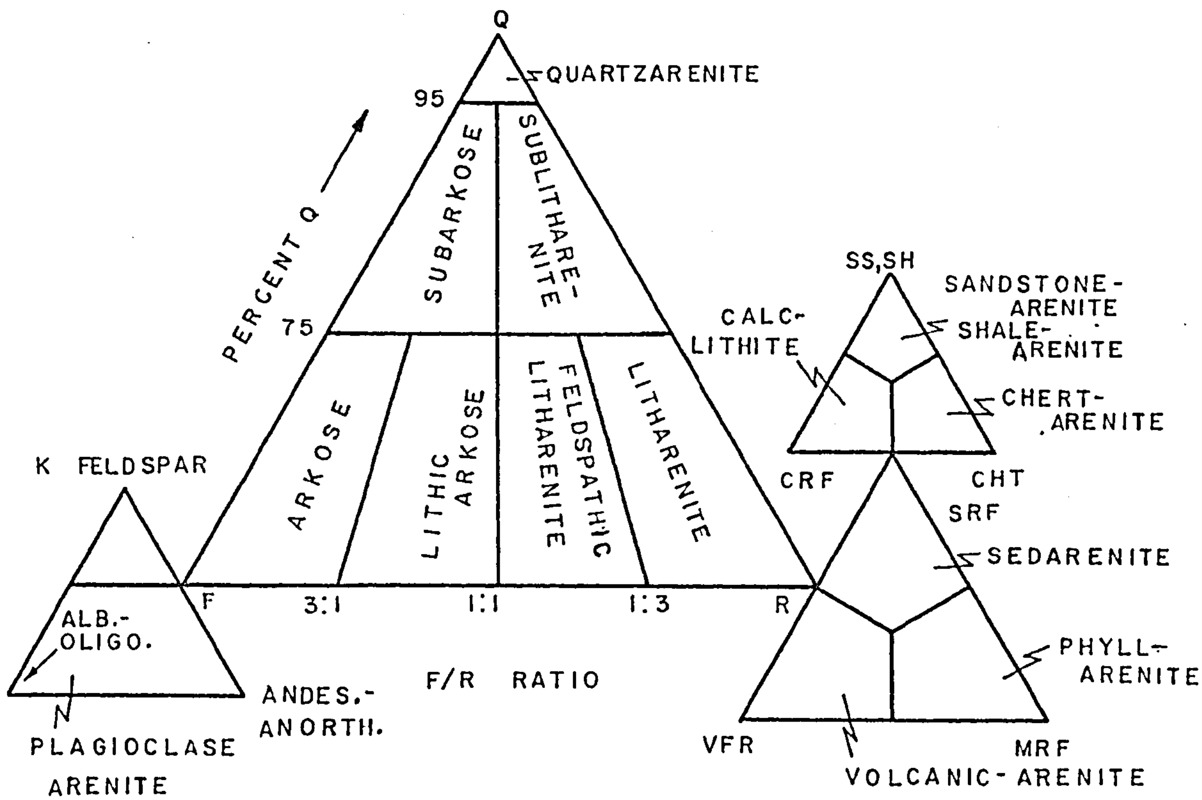


Fig. 8. Folk's (1968) classification of terrigenous rocks.

Explanation of symbols: Q = quartz; F = feldspar; R = rock fragments; VFR = volcanic rock fragments; MRF = metamorphic rock fragments; SRF = sedimentary rock fragments; CRF = limestone rock fragments; CHT = chert rock fragments; SS = sandstone; SH = shale.

was done by supplanting the term rudite for arenite. Thus, for example, the term litharenite becomes lithrudite.

Petrography of the Mineta Formation

Conglomerate Member

Lithologically the conglomerate member grades from a feldspathic lithrudite to an arkose with numerous vertical gradations and lateral facies changes.

The color of the conglomerate member depends largely upon the composition of the mineral and rock fragments the unit contains, as well as the hematite in the matrix and as grain coatings. These fragments, along with other sediment properties, allow the member to be separated into two distinguishable units. These units are a lower medium light gray (N6) feldspathic lithrudite, and an upper grayish red (10 R 4/2) feldspathic to arkosic conglomerate and sandstone. Both units change laterally to true arkosic facies.

Fragments of Pinal Schist, Paleozoic limestones, and volcanics contribute to the gray color. The pinks and reds are inherited partly from granitic rocks. Hematite is abundant in the matrix and as grain coatings.

The composition of the conglomerate member was determined by pebble count measurements in the field and from collection of selected samples of the sandy matrix and interbedded sandy layers. The pebble counts and matrix samples were taken at uniform intervals, exposures permitting, of the sections described in the Appendix. The procedure in making the pebble counts was to mark off a circle 18 inches in diameter, and then, starting at the middle count each pebble larger than about four millimeters, working in an enlarging circle. Each pebble was marked with a dot to insure that it would not be counted twice. From 100 to 200 pebbles were counted for each sample. The results of these counts are tabulated in Table I and Fig. 9.

The matrix samples collected were examined as hand specimens and with the binocular microscope (Table II). Between 100 and 400 grains larger than coarse sand were counted for each specimen. Seven of these samples were suitable for thin sections.

The pebble counts reveal that the gravel fractions of the conglomerate member range in composition from arkose to lithrudite with 20 of the 31 samples belonging to the feldspathic lithrudite clan, and seven to the arkose clan. Of the 31 total samples, nine are classified as calclithites, and 13 as volcanic rudites. It is interesting to note that seven of the nine calclithites belong to the lower feldspathic lithrudite; and all the arkoses and lithic arkoses belong to the upper feldspathic to arkosic unit. This suggests that the color of the conglomerate member depends at least partly upon the composition of the mineral and rock fragments the unit contains.

Table I. Pebble counts of the conglomerate member.

Sample Number	Per cent Granite rock frag. Quartz	Per cent VRF	Per cent MRF	Per cent SRF	Rock Name[a]
68-11A	28.4	2.4	0.8	61.6	Lithrudite
68-12A	25.2	2.5		72.4	Lithrudite
68-13A	49.7	1.9	5.6	38.6	Feldspathic Lithrudite
68-14A	47.7	3.7	0.9	47.8	Feldspathic Lithrudite
68-16A	39.8	4.8		55.6	Feldspathic Lithrudite
68-17A	43.9	10.6	0.9	44.8	Feldspathic Lithrudite
68-21A	39.7	27.4	3.0	22.2	Feldspathic Lithrudite
68-22A	99.9				Arkose
68-20B	48.0	20.6	4.0	26.5	Feldspathic Lithrudite
68-21B	40.5	32.5	7.0	20.0	Feldspathic Lithrudite
68-22B	38.1	38.1	1.9	22.1	Feldspathic Lithrudite
68-23B	52.2	30.8	9.2	8.0	Feldspathic Lithrudite
68-24B	32.0	39.8		25.7	Feldspathic Lithrudite
68-26B	35.4	32.4	3.0	28.3	Feldspathic Lithrudite
68-27B	20.6	39.3	3.6	36.6	Lithrudite
68-28B	45.5	24.2	3.0	27.3	Feldspathic Lithrudite
68-29B	45.2	47.1		7.7	Feldspathic Lithrudite
68-4D	30.0	46.0	2.0	22.0	Feldspathic Lithrudite
68-1D'	37.5	42.8	3.6	16.4	Feldspathic Lithrudite
68-2D'	49.6	35.4	1.8	13.3	Feldspathic Lithrudite
68-3D'	48.7	37.0	5.4	9.0	Feldspathic Lithrudite
68-4D'	69.8	22.0	3.7	4.6	Lithic Arkose
68-23E	96.0	1.0	1.0	2.0	Arkose
68-25E	98.5	0.5		1.0	Arkose
68-38E	99.0			1.0	Arkose
68-40E	99.0			1.0	Arkose
68-15F	93.6	1.8	2.7	1.8	Arkose

Table I.--Continued

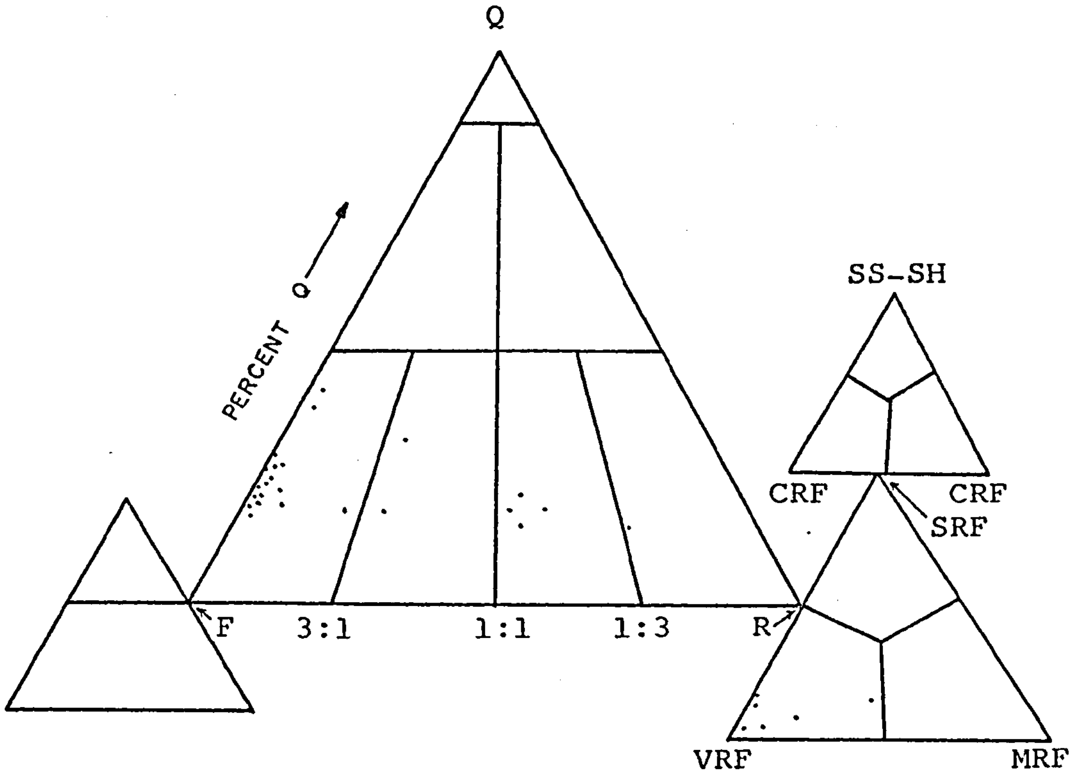
68-17F	48.7	38.0		13.2	Feldspathic Lithrudite
68-18F	70.8	2.0	9.9	18.8	Arkose
68-20F	42.0	2.5	15.5	41.0	Feldspathic Lithrudite
68-21F	48.5	2.2	11.1	39.8	Feldspathic Lithrudite

[a]Folk's (1968) arenite term has been replaced by rudite where appropriate.

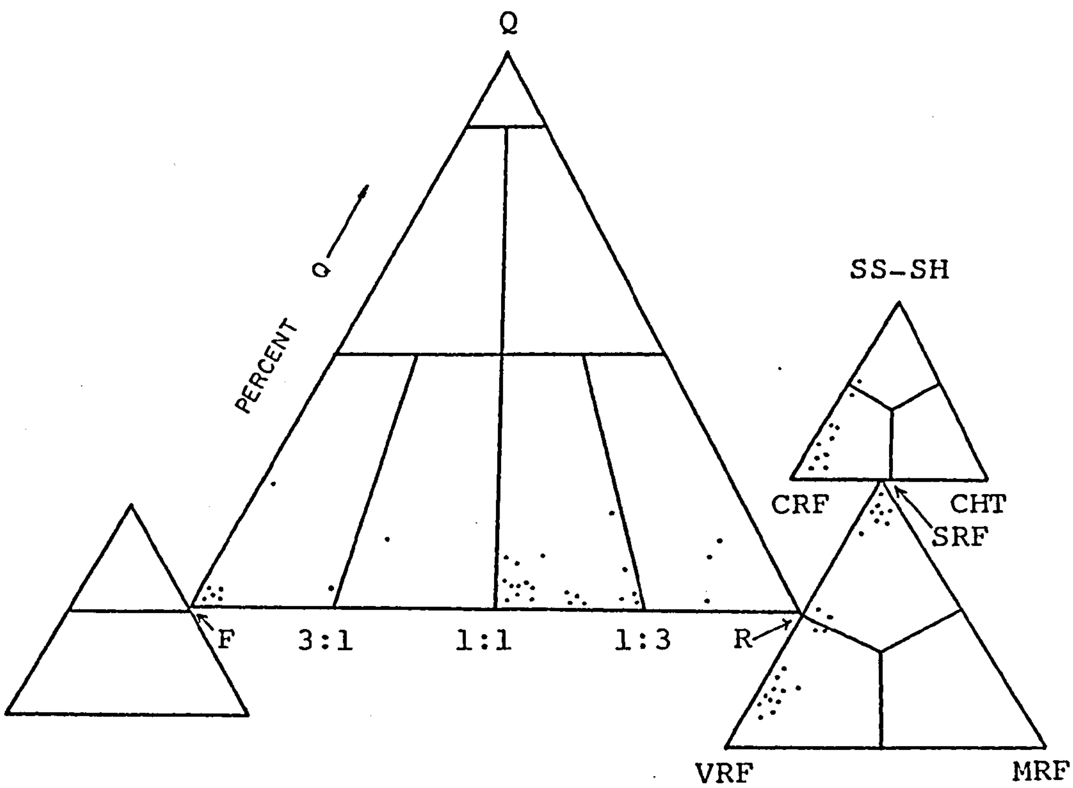
Fig. 9. Classification of the conglomerate member.

(a) Matrix samples of the conglomerate member, identified from hand specimens.

(b) Pebble counts of grains over 4 millimeters in diameter.



(a)



(b)

Fig. 9. Classification of the conglomerate member.

Table II. Hand specimen examination of matrix samples of the conglomerate member.

Sample	Qtz.	Feld.	MRF	VRF	SRF	Name
68-2A	63.5	23.6	2.1	6.7	4.15	Lithic Arkose
68-15A	51.0	20.0		22.0	7.0	Feldspathic Litharenite
68-18A	70.0	28.2	0.4	0.9		Arkose
68-19A	55.0	45.0				Arkose
68-20A	70.0	30.0				Arkose
68-23A	54.4	40.6		5.0		Arkose
68-24A	56.6	43.5	1.6			Arkose
68-25A	40.5	59.5				Arkose
68-1B	54.3	31.9		9.6	4.3	Lithic Arkose
68-3D	59.5	40.5				Arkose
68-3D'	57.5	18.2		20.6	3.8	Feldspathic Litharenite
68-4Da	45.0	25.0		30.0		Feldspathic Litharenite
68-5D	58.3	41.7				Arkose
68-6D	40.6	57.7	0.5			Arkose
68-7D	43.6	56.4				Arkose
68-21E	30.0	23.0		47.0		Litharenite
68-22E	42.1	57.8				Arkose
68-24E	52.0	38.0		10.0		Arkose
68-26E	55.0	45.0				Arkose
68-39E	42.1	57.4				Arkose
68-41E	55.0	45.0				Arkose
68-1F	54.7	38.9		6.3		Arkose
68-16F	60.2	32.6	1.6	5.7		Arkose
68-19F	40.0	25.0	15.0	15.0	5.0	Feldspathic Litharenite
68-22F	47.8	43.4	8.9			Arkose

The granitic rock fragments are all very similar to the porphyritic granite and aplite described above. Quartz is largely inter-grown with the feldspar to form the granitic rock fragments and does not exist in large quantities as individual grains within the gravel-size range.

Volcanic rock fragments consist of a gray rhyolite that may be from the unit immediately underlying the Mineta formation, and purple and brown andesites. Neither of the andesites appear porphyritic in hand specimen, although the volcanic fragments identified in thin section do have tiny phenocrysts. No known source rocks similar to the andesites can be identified nearby.

All the metamorphic rock fragments are schists and phyllites probably derived from the Pinal Schist and the interbedded schists of Paleozoic age that are exposed to the west. Any fragments of marble or quartzite present are considered as sedimentary fragments for purposes of classification.

It is interesting to note that not a single fragment of gneiss was identified. Apparently deposition of the member was completed before the Catalina Gneiss had been uncovered.

Limestone and sandstone fragments are abundant and exhibit several different colors and textures that can be matched in a general way with the exposed sections of Paleozoic rocks to the west.

The largest fragment identified in the pebble counts measured two feet in diameter, although in most samples the largest fragment measured several inches. The average grain size of the pebbles counted varied from four millimeters in some samples to 15 millimeters in others.

The pebbles and boulders are subangular to subrounded, and not even the largest fragments are well rounded, suggesting a short distance of transport.

Twenty-five samples of the sandy matrix were examined in hand specimen and with the binocular microscope. The grain composition of these samples indicates that most are arkoses rather than feldspathic litharenites, as the classification of the field pebble counts indicated. Several explanations may account for this difference. First, only three of these samples are from the feldspathic lithrudite unit, and two of these three are feldspathic litharenites. All the other matrix samples are from the feldspathic unit, which in field pebble counts are mostly arkoses and lithic arkoses. Secondly, by the time fragments have been reduced to sand-size, the ratio of quartz, feldspar, and rock fragments will change.

The grain size of the matrix samples ranges from medium-grained to slightly gravelly coarse-grained sand. The granitic rock fragments identified in the pebble counts are represented in the matrix samples by quartz and feldspar. The same metamorphic, volcanic, and sedimentary rock fragments are identified in the matrix samples, with no additional rocks recognized.

Seven thin sections of the matrix samples were examined and are reported in Table III and Fig. 10. These samples are poorly to moderately sorted, submature sandstones with a standard deviation from 0.65Ø to 1.15Ø. The composition and grain characteristics are similar to that described above for the pebble counts and matrix samples and for the samples of the upper detrital member.

Cementation prevented the complete disaggregation of samples and size analysis by sieving. However, 21 of these matrix samples were crushed and sieved to recover minerals from the 3Ø and 4Ø fractions. Their identification is reported in Table IV.

The amount of crushing necessary to free the heavy mineral grains from other minerals ranged from moderate with the use of a rubber cork, to the rigorous use of an iron mortar and pestle. In viewing the separated "heavies" with a microscope, broken grains could easily be spotted and were avoided in making point counts. Henningsen (1967), after crushing consolidated sediments, studied the effects of the ratios of unbroken heavy mineral grains and concluded that ". . . their results approximately represent the actual heavy mineral distribution . . . ." Nevertheless the

Table III. Petrology of terrigenous sediments.

Sample Number	Rock clan	Rock name	Textural name
68-1A	Feldspathic Litharenite	Volcanic arenite	Slightly gravelly medium sandstone
68-3A	Feldspathic Litharenite	Volcanic arenite	Granular medium sandstone
68-4A	Subarkose	Subarkose	Medium siltstone
68-5A	Lithic Arkose	Lithic Arkose	Medium sandstone
68-6A	Feldspathic Litharenite	Volcanic arenite	Medium sandstone
68-7A	Feldspathic Litharenite	Volcanic arenite	Silty fine sandstone
68-9A	Quartzarenite	Quartzarenite	Silty fine sandstone
68-10A	Lithic Arkose	Lithic Arkose	Coarse sandy siltstone
68-2B	Feldspathic Litharenite	Volcanic arenite	Silty fine sandstone
68-3B	Lithic Arkose	Lithic Arkose	Slightly cobbly silty medium sandstone
68-5B	Lithic Arkose	Lithic Arkose	Silty fine sandstone
68-7B	Subarkose	Subarkose	Coarse sandy siltstone
68-8B	Sublitharenite	Volcanic arenite	Silty fine calcareous sandstone
68-10B	Sublitharenite	Volcanic arenite	Medium calcareous siltstone
68-13B	Sublitharenite	Volcanic arenite	Medium calcareous siltstone
68-25B	Feldspathic Litharenite	Volcanic arenite	Silty fine sandstone
68-1C	Subarkose	Subarkose	Silty fine sandstone
68-4C	Sublitharenite	Volcanic arenite	Coarse sandy calcareous siltstone
68-5C	Subarkose	Subarkose	Coarse sandy calcareous siltstone
68-6C	Sublitharenite	Volcanic arenite	Coarse sandy calcareous siltstone
68-11C	Arkose	Arkose	Medium siltstone
68-12C	Lithic Arkose	Lithic Arkose	Coarse sandy siltstone
68-18D	Arkose	Arkose	Coarse sandy siltstone

Table III.--Continued

68-20D	Arkose	Arkose	Silty very fine sandstone
68-21D	Arkose	Arkose	Sandy medium siltstone
68-23D	Arkose	Arkose	Silty very fine sandstone
68-27D	Subarkose	Subarkose	Fine siltstone
68-7E	Arkose	Arkose	Silty fine sandstone
68-8E	Arkose	Arkose	Silty very fine-grained sandstone
68-9E	Lithic Arkose	Lithic Arkose	Silty fine sandstone
68-10E	Feldspathic Litharenite	Volcanic arenite	Slightly pebbly coarse sandstone
68-11E	Lithic Arkose	Lithic Arkose	Silty medium sandstone
68-12E	Lithic Arkose	Lithic Arkose	Silty very fine sandstone
68-13E	Lithic Arkose	Lithic Arkose	Silty medium sandstone
68-14E	Arkose	Arkose	Silty fine sandstone
68-15E	Arkose	Arkose	Silty fine sandstone
68-16E	Arkose	Arkose	Silty fine sandstone
68-17E	Lithic Arkose	Lithic Arkose	Slightly pebbly medium sandstone
68-18E	Lithic Arkose	Lithic Arkose	Silty fine sandstone
68-19E	Lithic Arkose	Lithic Arkose	Medium sandstone
68-20E	Lithic Arkose	Lithic Arkose	Slightly pebbly medium sandstone
68-4F	Lithic Arkose	Lithic Arkose	Silty medium sandstone
68-6F	Subarkose	Subarkose	Coarse sandy siltstone
68-10F	Lithic Arkose	Lithic Arkose	Silty very fine sandstone
68-13F	Subarkose	Subarkose	Coarse sandy siltstone

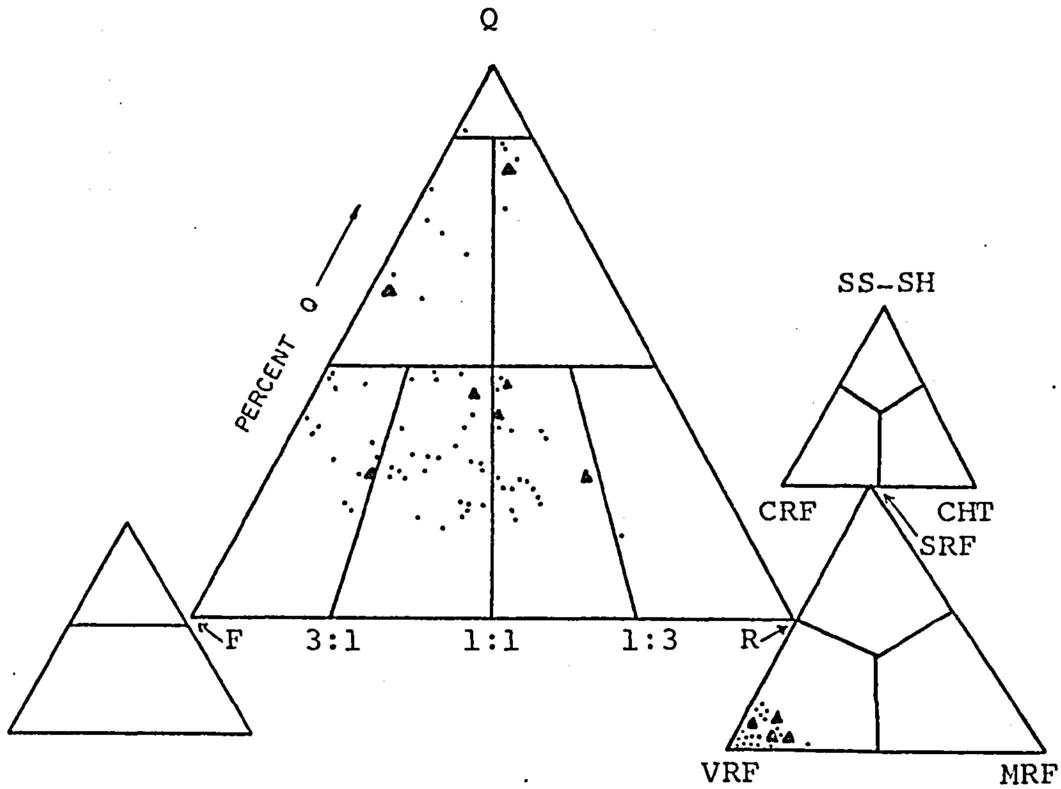


Fig. 10. Classification of sandstones.

Sandstone samples from the upper detrital member are represented by a dot. Sandstone samples from the conglomerate member are represented by a triangle.

Table IV. Percentage of heavy minerals from the matrix samples of the conglomerate member.

Sample number	Barite	Apatite	Zircon	Epidote	Garnet	Hornblende	Miscellaneous
68-2A	97.4	2.4	0.3				
68-15A	96.7	1.7					1.6
68-18A	78.1	11.8	7.3				2.7
68-19A	94.7	2.9	1.6		0.4		0.8
68-23A	32.1	46.3	3.1		1.0		9.8
68-24A	56.3	30.3	3.4		0.5		9.6
68-25A	83.0	6.0	1.0			2.5	7.5
68-1B	72.2	23.8	1.6	2.4			
68-3D	37.2	51.6	6.7		1.5	0.3	2.1
68-5D	39.9	52.5	0.3		2.7		2.0
68-6D	57.4	33.2	2.9		2.7	0.3	3.7
68-7D	51.3	40.2	1.9		4.1	0.4	2.2
68-3D'	54.4	32.1		2.7			
68-21E	58.1	16.2	10.8	1.4	9.5		4.1
68-22E	57.5	35.1	4.3		2.5		0.7
68-39E	31.3	55.1	9.5	2.4			2.4
68-41E	82.6	8.9	4.2			0.8	3.4
68-1F	76.8	10.4	7.6			0.6	4.1
68-16F	56.8	34.9	2.9			1.9	2.4
68-19F	93.0	0.9	2.3				3.7
68-22F	99.0	0.5					0.5

percentages given here should probably be considered only as an indication of the order of magnitude of the representative mineral.

Two hundred to 300 grains were counted from each sample. Although the percentages of individual minerals range widely between samples, barite and apatite are present in all samples, and zircon in all but three.

Barite is the most abundant mineral in all but four samples and ranges from 31.3 to 99.0 per cent. In most samples it ranges from about 50 to 70 per cent. Optic figures are difficult to obtain on the barite because of the numerous opaque inclusions, cloudy appearance, and iron oxide stain; but a biaxial positive figure can be obtained on some fragments. The barite grains have a very ragged appearance with irregular shapes.

Barite is an authigenic mineral and hence is of little value in characterizing sediment provenances.

Apatite is present in all samples and ranges from 1.7 to 55.1 per cent in abundance. It consists of platy to prismatic subangular grains and subhedral to euhedral grains. They are colorless, sometimes with a slight yellowish or bluish tint, and often somewhat cloudy or dirty in appearance.

Apatite is derived from acidic igneous rocks and pegmatites.

Zircon is present in all but three samples, and ranges from zero to 10.8 per cent, but is usually present in amounts of three to five per cent. The color ranges from a yellowish brown to pink. The grains consist mostly of fresh euhedral pink crystals that show very little abrasion.

Zircon is derived from both volcanic and plutonic igneous rocks.

Epidote is present in small quantities in several samples. It is pale yellow-green. The grains are equidimensional to elongated and subrounded to rounded. Epidote is derived mostly from metamorphosed igneous rocks, but is common to many types of igneous and metamorphic rocks.

Garnet is present in nine of the samples but represents only a few per cent of the total grains. The garnet is subhedral to euhedral, and pale yellow pink in color.

Hornblende represents a very minor portion of a few samples, and consists of angular to subangular green varieties and subhedral brown varieties.

Miscellaneous minerals are present in each sample and consist of only a few grains of one or more of the following: rutile, represented by reddish brown elongate grains that are rounded to subrounded; a very few grains of subrounded, yellow-brown tourmaline; rare grains of augite or enstatite; and biotite.

Opaque minerals consist mostly of hematite and abundant magnetite. A ratio of 1:1.6 opaque to non-opaque minerals was determined by examination of four samples.

It is interesting to note that Metz (1963) reported apatite, zircon, and barite, to be the three most abundant heavy minerals in his study of the Pantano Formation. All three minerals are common to the present study of the Mineta formation.

The rock fragments of the conglomerate member are well cemented with calcium carbonate, so that outcrops form bold erosional cliffs and hogbacks with steep dip slopes (Fig. 11). In addition to cementation, calcite has filled most of the fractures; however, quartz is common to some fractures.

Both the feldspathic lithrudite and arkosic units are very well bedded, with thin laminae of finer grained sandy portions showing better sorting, graded bedding, and cross-bedding (Figs. 11 and 12). Lateral intertonguing prevents the tracing of these laminae for more than a few yards. Generally the feldspathic lithrudite is the coarser of the two units, although numerous large rock fragments from a few inches to a foot or more across are present in both units. These are embedded in a matrix of finer material (Fig. 13).

(a) General bedding and erosional exposures of the lower part of the conglomerate member.

(b) Characteristically thick bedded conglomerate with a sandy matrix.

Fig. 11. Outcrops of the conglomerate member.

(a) Textural characteristics of the conglomerate member.

(b) Typical bedding of the sandy interbeds in the upper part of the conglomerate member.

Fig. 12. Textural and bedding characteristics of the conglomerate member.

(a) Subangular to subrounded rock fragments of the
conglomerate member.

(b) Granite rock fragments in an arkosic matrix of the
conglomerate member.

Fig. 13. Typical textures of the conglomerate member.

The grain size of the arkose decreases toward the top of the unit as it grades into an arkosic sandstone of brick red color.

Limestone Member

Major lacustrine environments developed twice in the mid-Tertiary basin in which the Mineta formation was deposited. The first episode of lake development is represented by a sequence of limestones and mudstones termed the limestone member in this report. The second episode is represented by limestone beds within the upper part of the upper detrital member, dated by a fossil as Late Oligocene to Early Miocene.

The limestone member of this study corresponds to the limestone member of Chew (1952). It consists of a sequence of at least six major and many minor layers of thick- to very thick-bedded, fine- to medium-crystalline algal calcarenites and calcilutites interbedded with shale, mudstone, and feldspathic litharenites.

The limestone samples were collected from the sections of the Mineta formation described in the Appendix. Sixty limestone thin-sections were examined, and the results are reported in Table V. Forty-two of these samples are from the limestone member; twelve are from the limestone sequence in the upper part of the upper detrital member, in which the fossil rhinoceros jaw was recovered; and six

Table V. Classification of limestones

Sample number	Rock name
68-4B	Algal Biopelmicrite IIbp:La
68-6B	Biomicrite IIb:La
68-16B	Micrite IIIM:L
68-8C	Algal Micrite IIIM:L
68-9C	Micrite IIIM:L
68-11C	Silty Micrite IIIM:L
68-1LsD	Algal Biopelsparite Ibp:La
68-Ls2D	Algal Biopelmicrite IIbp:La
68-Ls3D	Algal Biopelsparite Ibp:La
68-1D_3	Algal Biomicrite IIb:La
68-1D_4	Algal Biopelsparite Ibp:La
68-1D_5	Algal Pelmicrite IIp:La
68-1D_6	Algal Pelsparite Ip:La
68-1D_7	Algal Pelsparite Ip:La
68-5D_1	Algal Biopelmicrite IIbp:La
68-5D_2	Algal Biopelsparite Ibp:La
68-5D_3	Algal Biopelsparite Ibp:La
68-5D_4	Algal Biosparite Ib:La
68-5D_5	Algal Biosparite Ib:La
68-5D_6	Algal Biopelsparite Ibp:La
68-5D_7	Algal Biopelsparite Ibp:La
68-8D_1	Algal Biopelsparite Ibp:La
68-8D_2	Algal Biopelsparite Ibp:La
68-8D_{2a}	Algal Biopelsparite Ibp:La
68-8D_3	Algal Biosparite Ib:La
68-8D_4	Algal Biosparite Ib:La
68-8D_{4a}	Algal Biomicrite IIb:La
68-8D_5	Algal Biosparite Ib:La
68-8D_6	Algal Biomicrite IIb:La
68-8D_7	Algal Biosparite Ib:La
68-18D	Silty Micrite IIIM:L
68-1E	Algal Biosparite Ib:La
68-2E	Algal Biomicrite IIb:La
68-3E	Algal Pelsparite Ip:La
68-4E	Algal Pelmicrite IIp:La
68-5E	Micrite IIIM:L
68-6E	Algal Biomicrite IIb:La
68-27E	Algal Biosparite Ib:La
68-28E	Algal Biopelmicrite IIbp:La
68-29E	Algal Biopelsparite IBp:La
68-30E	Algal Biopelmicrite IIbp:La
68-31E	Algal Micrite IIIM:La
68-32E	Algal Micrite IIIM:La
68-33E	Algal Biosparite Ibp:La

Table V.--Continued

68-34E	Algal Biopelsparite	Ibp:La
68-35E	Algal Biosparite	Ib:La
68-36E	Algal Biosparite	Ib:La
68-37E	Algal Biosparite	Ib:La
68-2F	Algal Pelmicrite	IIp:La
Ls-1	Algal Biomicrite	IIb:La
Ls-2	Algal Biopelsparite	Ibp:La
Ls-3	Algal Micrite	IIIM:La
Ls-4	Algal Biosparite	Ib:La
Ls-5	Algal Biopelsparite	Ibp:La
Ls-6	Algal Biopelsparite	IIbp:La
M-16	Algal Biomicrite	IIb:La
S-35	Algal Biosparite	Ib:La
S-30	Algal Biopelsparite	Ibp:La
S-34	Algal Biopelsparite	Ibp:La
S-36	Algal Biomicrite	IIb:La
S-6	Algal Pelsparite	Ip:La

samplēs are from thin interbeds of limestone and marly limestone within the upper detrital member.

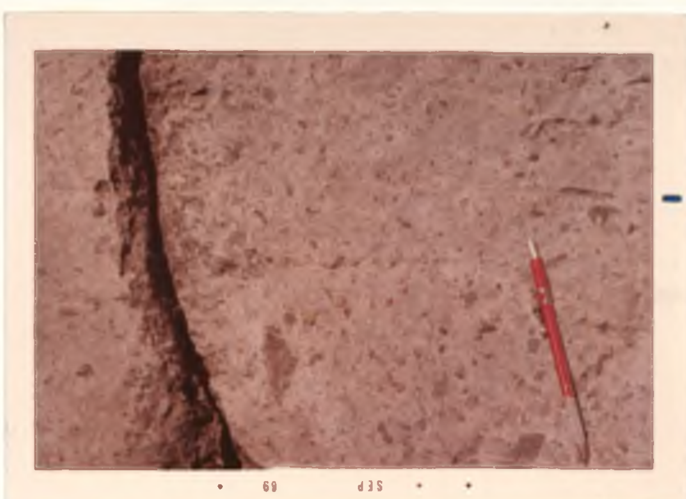
In hand specimen the samples of the limestone member are fine-grained, light to dark gray and black, and weather to light and medium gray. In most samples allochems are visible that can only be identified as algal-appearing features. These allochems weather into relief on the rock surface giving it a very rough appearance (Fig. 14). Calcite veins are numerous in some beds. No distinguishing characteristics by which beds from one outcrop can be correlated with specific beds in another outcrop have been recognized.

Limestones of the upper part of the upper detrital member are distinct enough from those of the limestone member that they can generally be distinguished in the field. The limestones of the upper detrital member are gray to black fetid limestones that commonly are bleached to light gray and orange on weathered surfaces. The algae of these fetid limestones are concentrated in certain beds, and in hand specimen elongated fragments and stem-like plant remains express a parallel orientation.

In thin section, 34 of the samples are sparry allochemical rocks, 18 are microcrystalline allochemical rocks, and eight are microcrystalline rocks.

Terrigenous constituents, largely of silt-size quartz, range from zero to two or three per cent in most

(a) Hogbacks of limestone beds separated by non-resistant siltstones.



(b) Surface texture of an outcrop of the limestone member showing algal forms weathering into relief.

Fig. 14. Erosional and textural features of the limestone member.

samples. In three samples the terrigenous content is over 10 per cent and consists largely of quartz with minor amounts of feldspar.

The allochemical constituents are mostly of algal fragments, including pellets, oolites and pisolites, plus intraclasts of these allochems.

The allochemical rocks are inhomogeneous. The allochems generally are in open packing with a random or patchy distribution, and are well cemented in a matrix of microcrystalline or sparry calcite. Porosity appears to be moderate. Sparry calcite has largely filled fractures, vugs, and much of the existing intergranular porosity between allochems. The sparry calcite is in part replacement of the existing matrix and in part filling of pore space.

Little or no orientation of allochems is noticeable in thin section. In some sections, however, particularly those rich in pellets and elongated fragments, some noticeable parallelism with bedding plane surfaces is apparent. Acetate peels and hand samples with larger surfaces than the thin sections often reveal an orientation of elongated fragments.

Chert is present in some samples as nodules replacing the calcite matrix or replacing the sparry calcite around the perimeter and in the interiors of allochems (Fig. 15). The chert is chalcedonic, commonly with

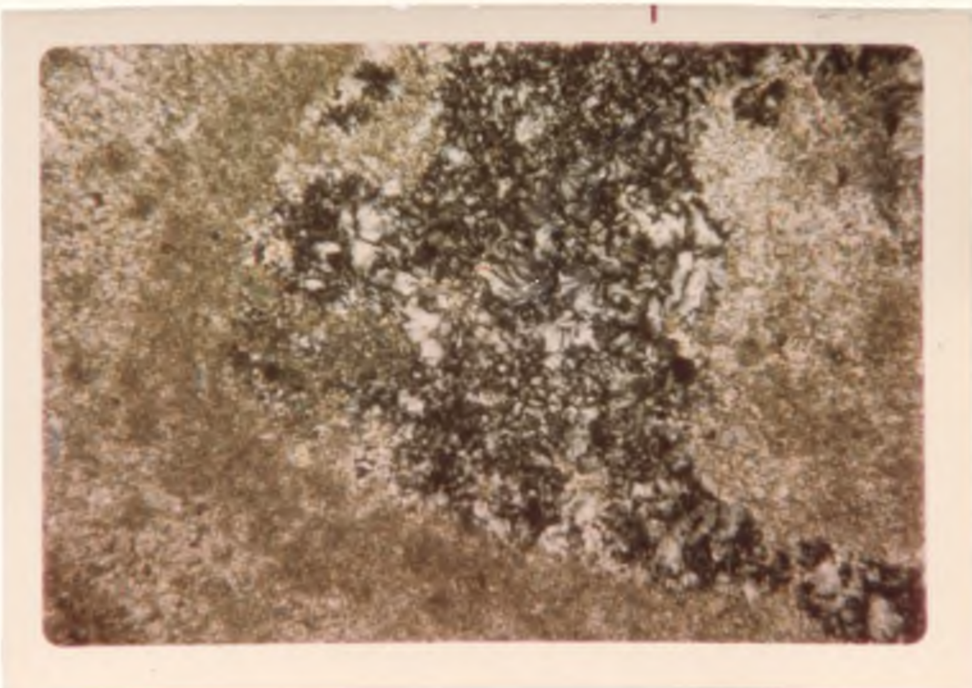


Fig. 15. Chert replacement of allochems.

Photomicrograph of chert replacing sparry calcite of an algal intraclast. 40 X.

radiating fibers. The nodules are circular in shape, and range from 0.5 to 1.5 millimeters in diameter.

The algae comprising the allochems of the limestones in the Mineta formation belongs to the Phylum Schizophyta (blue-green algae), "Section" Spongiostromata, and Sub-section Oncolithia.

Johnson (1961), in describing the Spongiostromata, stated that these fossils ". . . show no clear or usable microstructure. They consisted originally of a mat or felt of fine algal threads which was rather loose in some cases and apparently fairly dense in others. . . . Calcium carbonate appears to have been precipitated around the algal threads forming a mold of the algal and enclosed debris."

Oncolites are unattached forms often consisting of algal pisolites and nodular forms that are encrusted with algal layers (Johnson, 1961).

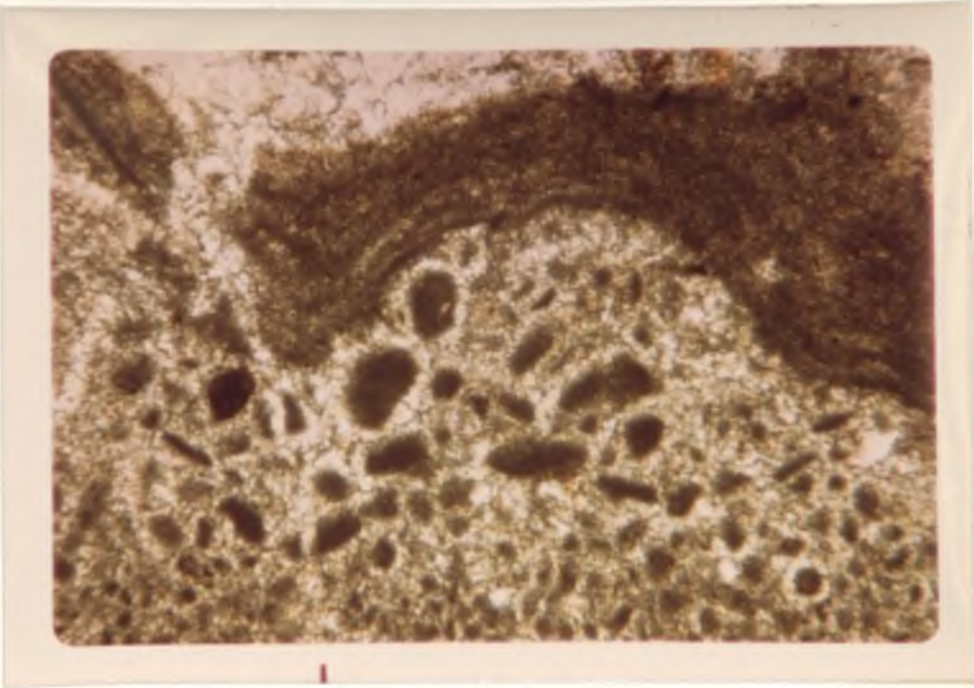
The oncolites of the Mineta formation consist of several types that commonly grade into each other.

Algal pellets are perhaps the most abundant forms (Fig. 16). They are circular to elliptical in shape, with the semi-major axis of the larger pellets about 0.5 millimeters in length. The pellets are typically well rounded, devoid of internal structure, and are composed of micrite-size calcite colored a dark brown, probably as a result of organic material. A few elongate or cylindrical pellets are present (Fig. 16) with an average length of about three

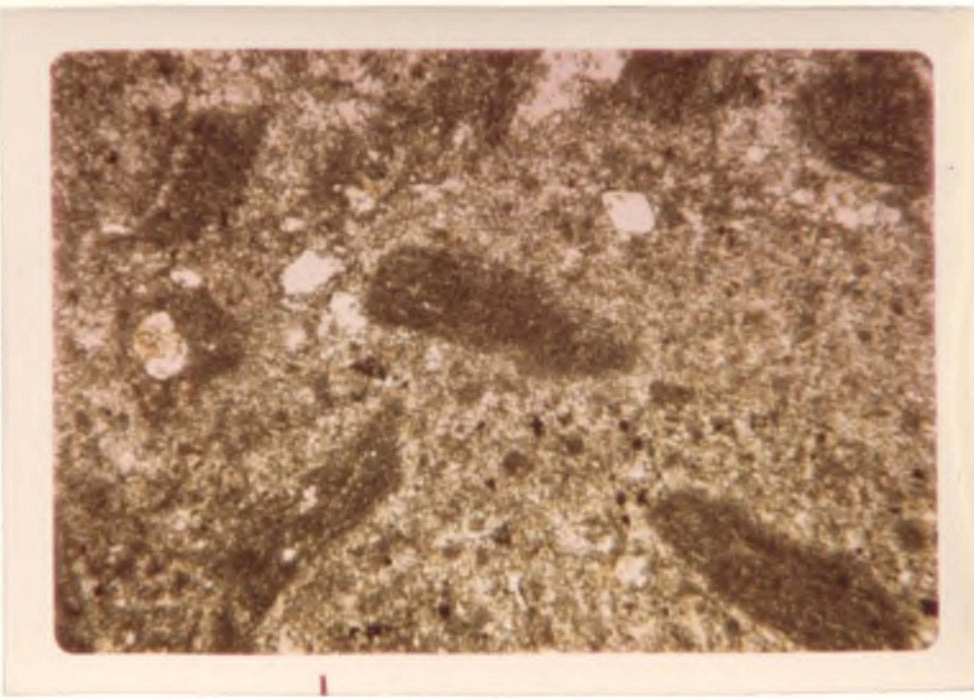
Fig. 16. Algal pellets.

(a) Photomicrograph of intraclast containing algal pellets, that is enclosed in a circumcrust of algal micrite. 40 X.

(b) Photomicrograph of elongate algal pellets. 40 X.



(a)



(b)

Fig. 16. Algal pellets.

times the width. They range as large as one millimeter in length. Wolf (1965) outlines how algal pellets can be formed by the abrasion of other algal material.

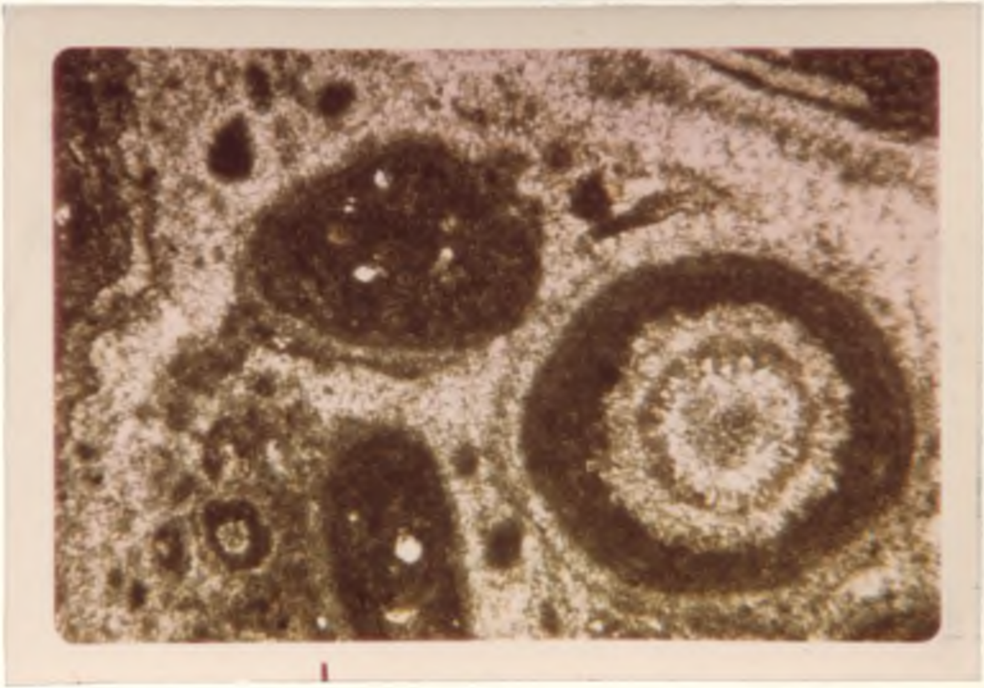
Algal oolites are very common. They consist of a nucleus of dark microcrystalline calcite that may be pellets, and nuclei of sparry calcite that may be replacement of some organic feature. The nuclei are surrounded by one or more concentric layers of dark algal micrite and sparry calcite. The thickness of these layers ranges widely to more than one millimeter. The thicker layers are nearly always, but not exclusively, composed of sparry calcite. The oncolites and pisolites are well rounded and nearly spherical in shape.

Pellets are common in granuloid aggregations, generally accompanied by algal oolites and algal pisolites to form algal lumps (Fig. 17). Intraclasts of these allochems and broken crust fragments are sometimes present. These lumps have circumcrusts of one or more alternating layers of sparry calcite and dark brown algal micrite. These layers of calcite commonly are thin, about 0.05 to 0.1 millimeters in thickness. Compound algal lumps in which one or more lumps are enclosed by circumcrusts of calcite to form a larger unit are common. Locally, the encrusting calcite layers of two oolites or pisolites will grow together to form a composite lump that may be somewhat dumbbell-shaped.

Fig. 17. Algal intraclasts and oolites.

(a) Photomicrograph of oolites and pellets. 40 X.

(b) Photomicrograph of algal intraclast with circum-crusts of algal micrite. 40 X.



(a)

(b)

Fig. 17. Algal intraclasts and oolites.

Most of the lumps are irregular in shape conforming to the architecture of the enclosed material.

Intraclasts plus fragments of crusts and elongated fragments are usually present. Most of these are crusted on one side or completely encrusted in a circumcrust of calcite (Fig. 17).

The encrusting layers of these oncolites are irregular in thickness and may pinch out or swell. This is particularly true for the algal lumps and intraclasts.

Weiss (1969) believes that the layers on oncolites in the Flagstaff Formation (Paleocene and Eocene) are varves.

Encrusting material noted on some oncolites overlaps previously formed crusts. Weiss (1969) attributes encrusting of this kind to "(1) the breaking of an oncolite and subsequent overgrowth upon it of younger varves," and/or ". . . (2) the suppression of growth or the abrasion of part of an oncolite while still soft, followed by overgrowth of younger material."

Environmental Significance of the Algae

Microcrystalline and microcrystalline allochemical rocks indicate formation in areas where current action is ineffective in winnowing, and thus, in general, correspond to a low energy environment. Sparry allochemical rocks indicate a high energy environment where currents have winnowed out carbonate mud and abraded and sorted the allochems.

Many of the allochems are broken fragments of oncolites that may or may not have added succeeding layers of calcite. All of these allochems indicate that current action was effective enough to break apart these fragments, abrade them, and then prevent them from being buried while additional micrite layers were added.

If the layers of calcite encrustations are truly varves, then the allochems would need to exist as discrete units in the depositional environment for some time, perhaps several years, before burial.

An attempt to determine the degree of rounding of allochems would no doubt be misleading, because the character and structure of oolites, etc., are rounded initially. The rounded pellets may indicate abrasion.

Johnson (1961) commented that algal features in general require an adequate circulation of water in order to maintain a luxuriant growth. He also pointed out that since algae are plants, they require well-illuminated water for photosynthesis, and that algae is characteristically indicative of shallow water, usually very shallow water.

With the predominance of sparry allochemical rocks, the orientation and character of algal allochems within them, and the interbedded sandstones, siltstones, and mudstones, the environment of deposition of these limestones is characterized as shallow water deposition in a lake with generally effective currents.

Upper Detrital Member

The upper detrital member consists of interbedded red and maroon arkosic conglomerates, sandstones, and siltstones, maroon, yellow and green mudstone, and local lenses of interbedded gray limestone. The uppermost part of the section becomes very silty and grades into thick sequences of bedded gypsum. Some parts of the gypsum are very pure and others have a high silt content.

The composition of the upper detrital member was determined from samples collected during the course of measuring and describing the sections reported in the Appendix of this paper. Samples were collected from nearly uniform intervals plus occasional spot samples of selected beds.

Thin sections were prepared of the sandstones, limestones, and a few of the coarser grained siltstones. Descriptions of the limestone beds are included with the previous discussion of the limestone member (Table V). Heavy minerals were recovered from a few crushed sandstone samples, and X-ray identification was obtained of clay minerals from a few samples of siltstones and mudstones.

From thin sections, point counts were made of 200 to 300 grains for each of the samples listed in Table III.

Figure 10 is a plot of the composition of samples as determined from thin section. Of the 63 samples plotted, 37 are arkoses or lithic arkoses and 14 are feldspathic litharenites. Only one sample is a quartzarenite and only one a litharenite. The feldspathic nature of these rocks is well illustrated.

Volcanic rock fragments are predominant over sedimentary and metamorphic rock fragments in every sample resulting in the rock name volcanic-arenite for all samples of the litharenite, sublitharenite, and feldspathic litharenite clans (Fig. 8).

The grain composition of these rocks consists of quartz, potash and plagioclase feldspars, rock fragments, and minor quantities of accessory minerals; micas, chert, and heavy minerals.

The percentage of quartz in the samples of the upper detrital member ranges from 32.5 to 95 per cent. The quartz is evenly distributed in each of the samples. The grain size varies from less than 0.05 millimeters to two millimeters but is mostly from about 0.08 to 0.2 millimeters. In most samples the grain size is estimated to be about the same size to perhaps slightly larger than that of the feldspars. The grains are characteristically xenomorphic and sub-angular to subrounded, with the larger grains estimated to be slightly better rounded. If so, the difference in rounding is small, and the author feels that caution should be used in drawing interpretations. The average grain of quartz is not much different in roundness than the feldspar. The feldspars are characteristically subhedral in shape. The surfaces of the quartz are commonly clear, but hematite stain has partially coated the surfaces of grains in a few samples. No etching or other surface features are noted. Extinction is straight to slightly undulose in most grains. A rare grain would show a strongly undulose extinction. Inclusions are few, and consist mostly of aligned vacuoles and microlites.

Based upon Folk's (1968, p. 70) genetic classification of quartz types, the quartz grains in the sandstone member would be classified as "plutonic."

Feldspar is abundant in the sandstone member and consists of both potash and plagioclase, ranging from about five to 45.6 per cent. In most samples, the plagioclase is slightly to far more abundant than potash feldspar. The potash feldspar consists mostly of orthoclase and rare grains of microcline. Some orthoclase exhibits carlsbad twinning. The plagioclase ranges in composition from about Ab_{75}-An_{25} to Ab_{50}-An_{50} with rare fragments showing a slightly higher An composition.

The feldspar grains are evenly distributed except where volcanic fragments have altered in place and released tiny plagioclase crystals. In these areas the tiny grains are locally concentrated.

The grain size of the feldspars ranges from extremely fine, less than 0.05 millimeters, to coarser grains as large as one millimeter or more in diameter. The larger grains are potash and plagioclase subhedra and anhedra and have a source other than from the volcanic fragments described below. The diameter of these larger grains seems to be slightly smaller than quartz, and was determined by measurement of a number of grains to average about 0.1 millimeters in some samples to 0.15 millimeters in other samples. The roundness is slightly better in the coarser grains, but is still subangular to subrounded. Subhedral to euhedral grains are fairly common and suggest a short distance of transportation.

Many of the feldspar grains are partially replaced by calcite. Although the grains being replaced represent a minority of the feldspar population, they are quite obvious in thin section. Grain contacts are etched; many have large embayments of calcite within them. Commonly a ghost crystal of feldspar is present having been largely replaced by calcite but still retaining identifiable twinning. Hematite is also present as a coating on some grains.

Two source areas are interpreted for these feldspars. The very small idiomorphic plagioclase and potash feldspars are identical to those found as small phenocrysts in the volcanic rocks. Secondly, the larger feldspars, because of their freshness and subhedral shapes, are apparently derived from nearby crystalline plutonic or from metamorphic source rocks. It is highly unlikely that they have been derived from other sedimentary rocks.

Rock fragments of several different compositions are common to the samples. They range in abundance from a trace to 38.5 per cent of the sample. These fragments are mostly of volcanic origin; only a few samples contain any fragments of sedimentary or metamorphic origin.

Three different types of volcanic fragments are present; two types are common in most samples. These three volcanic groups are separated on the basis of their texture and color under polarized light. One group is medium gray with very numerous tiny unidentifiable feldspar laths or needles with their long axes oriented into flow lines. The matrix is dark and aphanitic. The second type has a dark gray to black matrix in polarized light, with larger feldspar laths of both plagioclase and orthoclase in carlsbad twins as large as 0.1 millimeters in diameter and 0.4 millimeters in length, although most are smaller. These euhedral phenocrysts are less numerous than the feldspar laths in the first volcanic type, and their lack of concentration probably also accounts for the darker color of the matrix. They are also oriented into flow lines. The third type has a black, dense matrix with phenocrysts that are not as highly ordered into flow lines as the first two types, and the grains are subhedral to anhedral in shape. Quartz may or may not be present in all three types. Many of the samples contain other miscellaneous volcanic fragments that are similar to, but perhaps not identical to, those described.

The grain characteristics of these fragments are similar, and are discussed as a group. The volcanic fragments are randomly scattered to evenly distributed in the samples. Their grain size and shape ranges more widely than the quartz or feldspar, with size ranging from approximately 0.2 millimeters to several millimeters. They may be subequant to elongate and subrounded to rounded. Rounding tends to increase with increasing grain size. Partial alteration of matrix and feldspars to clay has occurred in some samples, and like the feldspar grains described above, some of the volcanic rock fragments are partially replaced by calcite. Replacement occurs within the interior of the specimens as well as along grain boundaries.

The source areas of these volcanic fragments may be from a greater distance than the feldspars described above, based upon their higher degree of rounding. The source rocks seem to be shallow intrusives and/or extrusives of rhyolitic to andesitic composition.

The sedimentary rock fragments consist of rare grains of limestone or composite grains of quartz sandstone or detrital chert. The metamorphic fragments are rare and consist of schist or phyllite. Volumetrically they represent about one per cent of the total fragments.

Chert is present in several samples replacing the calcite cement. It is the radiating chalcedonic type described in the limestone member, and is far less abundant in the upper detrital member.

Other minerals present consist of biotite and muscovite, and heavy minerals.

Heavy minerals were collected from eight samples of the upper detrital member. The same mineral suite was found in these samples as in the conglomerate member, although the relative frequency is somewhat different than in the conglomerate member (Table VI).

Thirty-two samples of siltstone and mudstone beds from the upper detrital member were selected from those collected in the course of field studies, and examined by the X-ray diffraction method to determine the clay mineral composition. A Norelco X-ray diffractometer using Ni-filtered Copper K-alpha radiation at 40 kilovolts and 20 milliamps with a slit system of one degree was used for the analysis. Samples were scanned through a two theta range of four degrees to 68 degrees at a speed of two degrees of two theta per minute.

Illite is the most important clay mineral and is in every sample. Chlorite is present in lesser amounts, and is identified in most samples. In addition to the clay

Table VI. Percentage of heavy minerals from the sands of the upper detrital member.

Sample number	Barite	Apatite	Zircon	Epidote	Garnet	Hornblende	Miscellaneous
68-7A	50.0	34.4	3.5	7.1	1.9		2.5
68-8B	26.8	13.7	7.9	50.4		0.8	
68-10B	76.1	19.7		1.3	1.5		1.4
68-13B	83.0	10.6		5.0		0.7	0.7
68-21D	74.8	9.3	2.5	6.7		0.8	6.7
68-23D	19.5	7.0	8.4	61.0			4.1
68-4E	62.6	7.5	1.7	9.6	6.4	1.6	11.2
68-10F	89.8	7.2	0.8				2.4

minerals, quartz, feldspars, and calcite have easily identifiable peaks.

According to Grim (1951), illite is the dominant clay mineral in calcareous lacustrine sediments as well as being common in marine environments. It forms in an alkaline environment in the presence of potash. Chlorite requires an alkaline environment and the presence of magnesium. Both illite and chlorite must form sometime during diagenesis or later, according to Grim, since these clay minerals are more abundant in ancient than in recent sediments.

Kaolinite is not compatible in the same environment with illite and chlorite. Kaolinite forms in low pH environments, where leaching is active and alkalies are either absent or removed as rapidly as they are formed (Grim, 1951).

The presence of illite and chlorite in these sediments suggests that both potassium and magnesium ions are being supplied by the source areas, and that leaching is incomplete. Potassium is apparently being supplied by acid igneous rocks, and magnesium probably by the various volcanic rocks which were identified in the pebble counts and thin section studies reported earlier in this paper. The lack of, or incomplete leaching may reflect a temperate or semi-arid climate.

An attempt to disaggregate the grains of the upper detrital member by placing the sample in warm hydrochloric acid failed. Consequently a conventional size analysis by sieving could not be undertaken. It was then decided that the mean grain size, standard deviation, and textural maturity, should be determined from thin sections. The procedure used is described by Folk (1968).

The median grain size ranges from 0.05 in some samples to 0.35 millimeters in other samples. The graphic standard deviation on the phi scale ranges from 2.05Ø to 0.35Ø. However, most samples range from about 0.8Ø to about 1.0Ø, and are thus poorly to moderately sorted, and sub-mature. Texturally the samples are fine-grained silty sandstones to slightly gravelly medium-grained sandstones.

Coarse sandstones and conglomerates represent only a small portion of the upper detrital member. These coarser grained sediments contain abundant rock fragments, predominantly of plutonic and volcanic origin, and are similar to those samples described of the conglomerate member. These conglomerates are commonly characterized by well rounded rhyolite pebbles one to two inches in diameter or smaller.

The upper detrital member, like the conglomerate member, is well cemented with calcium carbonate. Hematite is common and forms a stain on grains and matrix. The sandstone beds are a few inches to a foot or more thick and generally form resistant ledges. Graded bedding is a common feature of the sandstones and conglomerates, and cross-bedding can be found in some units, particularly the coarser grained beds. The sandstones are interbedded with siltstones, mudstones, and limestones.

Ripple marks are sometimes found in the green mudstones. Although small, with wave length and amplitude of approximately 15 millimeters and one millimeter, respectively, they are still easily recognized as asymmetrical types, suggestive of current origin. Not enough exposures are present to make a study of the ripple marks, but their presence is significant as an indication of aqueous environments.

In the field the upper detrital member is noted to have an abundance of mica which lies with its basal cleavage parallel to the depositional surfaces. Sunlight reflecting from these mica flakes gives the sandstones, siltstones, and mudstones the appearance of being slightly metamorphosed. Indeed, some visitors to the area over the last decade have suggested that this section may have been slightly metamorphosed, but petrographic examination reveals no evidence of metamorphism.

Stratigraphy of the Mineta Formation

Conglomerate Member

The basal contact of the conglomerate member is depositional on the Pre-Oliogocene (?) rhyolite flow in the southern part of the area. South of Soza Canyon, the Mineta Fault forms the basal contact with Paleozoic (?) meta-sedimentary rocks and the Precambrian Pinal Schist. North of Soza Canyon, the conglomerate member is in both depositional and faulted contact with the porphyritic granite. At two locations, one approximately one-half mile south and the other one and one-quarter mile northwest of the Bar LY Ranch, the conglomerate member lies with nonconformity on the porphyritic granite. The arkosic unit of the conglomerate resembles its igneous source rock very closely since there has apparently been limited movement of the clastic fragments before their deposition and cementation.

The upper contact of the conglomerate member is depositional with the limestone member over most of the area, although bedding plane movements may exist along portions of the contact. South of the Saucito Canyon the limestone member, having thinned stratigraphically and perhaps structurally as well, is not present. The conglomerate member grades upward into the finer grained strata of the upper detrital member with complete conformity and progressive decrease in grain size.

The contact between the feldspathic lithrudite unit and the lithic arkose unit is gradational through a zone of five or six feet. At some outcrops the contact is represented by a fault of small displacement. These faults cannot be traced from one outcrop to the next, as they represent small slippages along the bedding planes, or nearly parallel to them as the section was tilted.

The orientation of the conglomerate member is variable, but the strike approximates N. 55° W. and the dip about 65 degrees northeast.

The total measured thickness of the conglomerate member is 730 feet. The gray feldspathic lithrudite measures 412 feet and the arkosic conglomerate is 318 feet thick at its maximum. The thickness of individual beds within these units varies from a few inches to a few feet; the coarser grained portions generally have the thicker bedding.

No difficulty arises in recognizing the conglomerate member because its lithology and grain size differs from that of the other members. Consequently the unit can be correlated throughout the Mineta Ridge area. This is fortunate, for these sediments occur in fault blocks north of Soza Canyon and correlation would be difficult if the lithology was not unique. South of Soza Canyon, the conglomerate member is in its proper stratigraphic sequence.

Limestone Member

The limestone member lies stratigraphically above the conglomerate member and below the upper detrital member.

The lower contact is depositional on the conglomerate member, but at some localities the contact has been disturbed by bedding plane movements.

The upper contact with the upper detrital member is also depositional, and it too commonly has been the site of bedding plane movements. Many of the individual limestone beds have undergone bedding plane slippage. Generally these faults dip a little steeper than the bedding.

Figure 18 is a Brunton-compass and tape traverse map of the limestone and upper detrital members at measured section four. It illustrates the stratigraphic relationships.

The measured thickness of the limestone member at section four is 472 feet. This value includes both limestone and interbedded siltstone and mudstone beds. The total thickness of the limestone beds in section four is 173 feet.

North of the Bar LY Ranch, exposures of the limestone member are isolated and discontinuous. The best exposure is near the northern end of the area and consists of a fault wedge, bounded partly by the Espiritu Fault.

The best continuous exposure of the limestone member is south of the Bar LY Ranch (Fig. 3) where individual beds

Fig. 18. Brunton-compass and tape traverse map of the limestone member at measured section 4.

Explanation:

Mineta formation

Tmu upper detrital member

Tml limestone member:
Blue is predominantly limestone;
yellow is predominantly siltstone

Tmc conglomerate member

Tr Rhyolite

Strike and dip of strata

Contact between beds and members

Fault

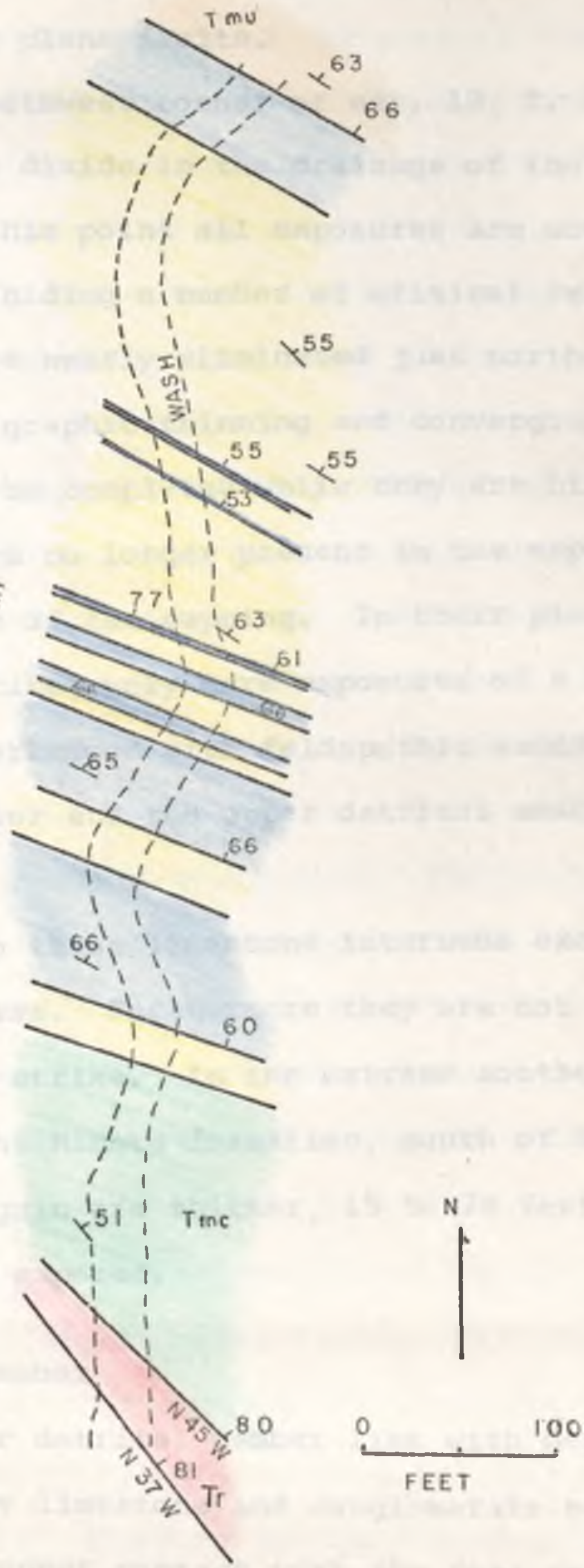


Fig. 18. Brunton-compass and tape traverse map of the limestone member at measured section 4.

thicken and thin stratigraphically and in response to the bordering bedding plane faults.

In the southwest corner of sec. 19, T. 13 S., R. 19 E., there is a divide in the drainage of the Canada Atravesada. At this point all exposures are covered by terrace gravels, hiding a number of critical relationships. The limestones are nearly eliminated just north of this capping by stratigraphic thinning and converging faults, and the process must be completed while they are hidden from view, for they are no longer present in the exposures immediately south of the capping. In their place, projecting along strike, only rare exposures of a few inches of limestone interbedded with feldspathic sandstones of the conglomerate member and the upper detrital member are present.

Rarely do these limestone interbeds exceed a few inches in thickness. Furthermore they are not present at all places along strike. In the extreme southern end of the outcrop of the Mineta formation, south of Roble Canyon, the limestones again are thicker, 15 to 20 feet of limestone beds being exposed.

Upper Detrital Member

The upper detrital member lies with depositional contact above the limestone and conglomerate member in most exposures. The upper contact with the Soza and Banco beds is unconformable in the northern part of the area, and faulted in the southern part of the area by the Banco Fault. The Turkey Track Porphyry is intrusive into the upper detrital member, and also lies as a probable flow on the tilted and truncated edges of the upper detrital member.

The total thickness of the upper detrital member (measured as a composite section and including the evaporite unit) is 960 feet. The evaporite sequence is 70 feet thick. Since this is a composite section, and the opportunity for omission or repetition of portions of the section is great, this thickness must be considered approximate.

In contrast to the limestone member, the upper detrital member contains only a few limestone beds and only rare bedding plane fault. It differs from the conglomerate member only in grain size. The gradational character of the upper detrital member with the conglomerate member makes it difficult to locate precisely the contacts in the northern and southern parts of the area, where the limestone member is absent, but elsewhere it can be easily traced and identified.

Between the drainage divide of the Canada Atravesada in the SW ¼, sec. 19, and Soza Canyon, the interbedded conglomerates and sandstones of the upper detrital member can easily be traced since they form an almost continuous outcrop, bounded on the west by the limestone member and on the east by the Banco beds.

South of the drainage divide of the Canada Atravesada, the limestone member is absent, and the contact of the conglomerate and upper detrital member is gradational. Modern stream gravels have covered much of the section because the stream is flowing along strike on the upturned edges of these steeply dipping sediments. Thus the valley is a subsequent valley, formed along the strike of the siltstones.

In the upper part of the upper detrital member a sequence of interbedded and thinly to thickly bedded limestone layers separated by beds of siltstone and sandstone crops out. These limestone beds vary in thickness from a few inches to several feet. These thicknesses, like those of beds in the limestone member, are partially controlled by nearly parallel bedding plane faults. The total thickness of this sequence is approximately 15 feet at section four, but thickens to about 30 feet west of Horse Mountain.

South of the Bar LY Ranch, exposures of these limestone beds can be traced for only short distances north and south of Horse Mountain. At Horse Mountain, the relationships of the limestone are complicated by the structures involved with an andesite intrusion that makes up the bulk of the hill. For short distances to the south however, the limestone beds can be traced easily, and contain interbedded siltstones. A few of the contacts appear to have had slippage along them, but the overall structure is quite simple.

North of the Bar LY Ranch the relationships are more complicated. Correlation of individual beds of limestone is nearly impossible. The beds are faulted so that one horizon can be followed for only a few feet before it becomes discontinuous. It is as though a box of matches was dropped or spilled, with each match representing one limestone bed. From Fig. 3, it is seen that this area is at the points of intersection of the Mineta formation with the Espiritu Fault and other structures of the older Paleozoic rocks to the west.

These limestone beds have been identified in Fig. 3. The basis for making the separation is that the limestones are interbedded between the siltstones of the upper detrital member over much of the central part of the area, and it was considered desirable to map them separately since they contain the only fossil at Mineta Ridge, and thus become a time marker.

Topographically the upper detrital member differs in the northern and southern sectors. To the north the topography is characterized by gentle dips and small rolling hills with a few dip slopes on the more resistant sandstones. The southern part is characterized by persistent hogbacks. The southern section dips steeply to the northeast (60° to 90° with local overturning) and the softer, finer grained units are easily eroded, leaving well-cemented coarse-grained sandstones and pebble conglomerate beds up to several feet in thickness as erosional hogbacks giving the area a picturesque topographic pattern (Fig. 19).

Evaporites, located in the upper part of this unit, can be followed along strike for a distance of 2.2 miles, from Roble Canyon northwest beyond Saucito Canyon. Possibly the evaporites represent a facies of the interbedded limestone units south of the limestone exposures, for they are found in the upper part of the section almost along strike with the limestones. The section is covered in the SW ¼ sec. 13, south of which only evaporites are found and north of which only limestones are found with no evaporites.

Origin of Color in the Mineta Formation

The origin of hematite pigment in red beds is a controversial topic with two principal schools of thought. One favors the concept that hematite forms in soils of tropical and subtropical climates and is later transported to new sites of deposition, perhaps in a desert basin. The hematite according to this concept, is detrital.

The second school of though suggests that hematite forms after deposition through alteration of iron-bearing detrital grains.

Miller and Folk (1955) presented evidence demonstrating that the important factor in the formation of

(a) Hogbacks typical of the Mineta formation just north of Roble Canyon.

(b) Typical exposure of the evaporite deposits within the upper detrital member.

Fig. 19. Hogback ridges and evaporites in the upper detrital member.

(a) Characteristics of bedding in the upper detrital member. The right side of the photo shows a small bedding plane fault cutting through a sequence of beds.

(b) Red, yellow, purple, and green siltstones of the upper detrital member.

Fig. 20. Bedding characteristics of the upper detrital member.

red beds is that they are derived from a source area rich in magnetite and ilmenite. Once this condition has been met the probability of a red sediment developing depends on local conditions, favored by oxidizing conditions at the site of deposition. One can conclude then, that red beds form authigenically in either continental or marine environments and in both humid and arid climates.

In the strata they studied they found magnetite and ilmenite in the red sediments, but absent or nearly absent in gray, green, or white sedimentary rocks. They suggest that the magnetite and ilmenite have been removed by solution from the reduced zones.

Keller (1953) referred to red beds in the Rocky Mountain region that are spotted green. He suggested the red color is due to ferric oxide. If the ferric oxide is reduced by H_2S and then dissolved by carbonate water, the rock will then display a pale, gray-green color. He maintains the green color had been present all along, but masked by the ferric oxide.

Walker (1967b) studied Pliocene to Recent sediments in the coastal desert areas of Baja California, Mexico. He found that the Recent alluvium is rich in unstable iron-bearing accessory minerals, but there has been no significant staining by ferric oxide. The older sediments are all stained by ferric oxide. Walker presented evidence that hematite in the red sediments has formed through intra-stratal alteration of iron silicates and ilmenite and magnetite in a hot arid or semi-arid climate.

Walker summarized by implying that there are six critical factors in the formation of the hematite pigment in the Baja California red beds. At least the first five of the six critical factors described by Walker are satisfied in the Mineta formation. Those factors are listed below, each followed by its application to the Mineta formation.

1. "The presence of iron-bearing detrital grains . . . in the original sediment." In the Mineta formation, volcanic rock fragments and magnetite are abundant. Magnetite is present in greatest abundance in the yellow, greenish yellow, and buff sediments, and least abundant in red beds. Apparently intra-stratal alteration has already converted the magnetite into hematite in the red beds but the process is incomplete in sediments of other colors.
2. "Post-depositional conditions favoring intrastratal alteration of the iron-bearing grains." Intra-stratal alteration of the magnetite has and probably still is taking place. In those beds of a color other than red, the magnetite shows that alteration has taken place. Hematite halos surround magnetite grains and as the hematite forms it spreads out staining the local area (Fig. 21).

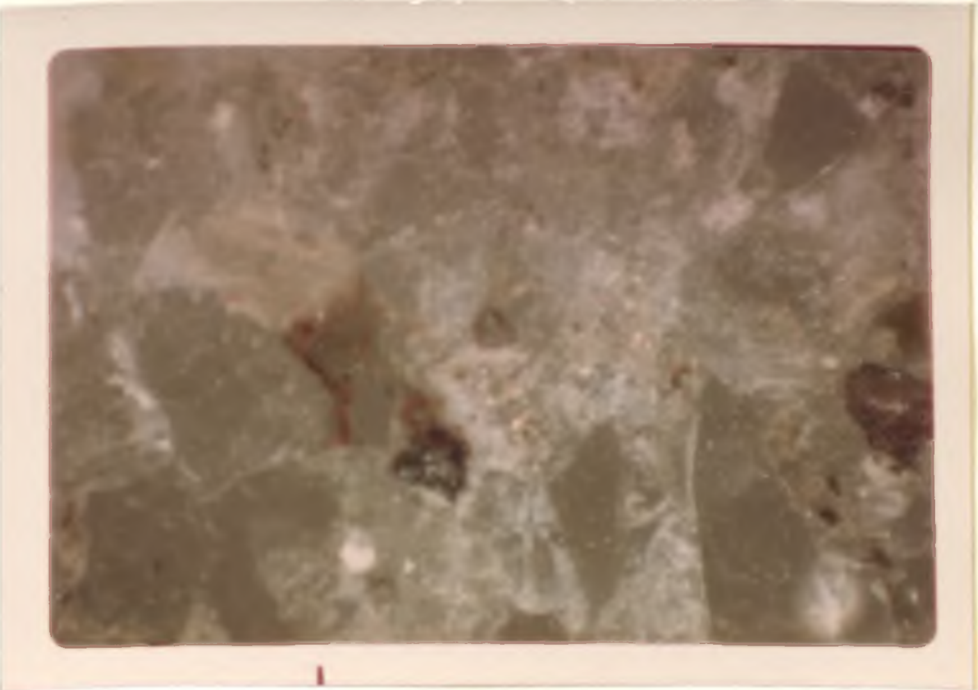


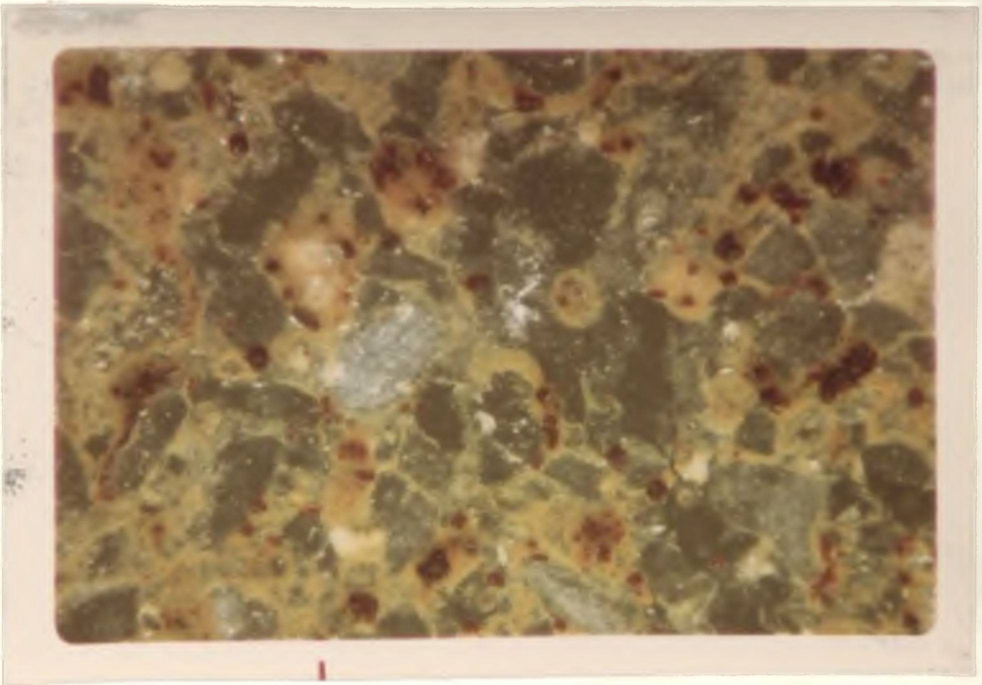
Fig. 21. Hematite forming from magnetite grains. Photomicrograph in reflected light. 10 X.

3. "An interstitial Eh-pH environment which favors formation of ferric oxide. . . ." The Eh-pH conditions have obviously been met since the process is occurring, and limonite appears to be the initial stage of formation (Fig. 22). Most of the buff and yellowish green beds contain considerable limonite as pigment, and in most of these beds the limonite is gradually being replaced by hematite.
4. "Absence of subsequent reduction of the ferric iron." If the ferric iron had been reduced the red color of the sediments would then be destroyed as well as the magnetite that is in abundance in the non-red sediments.
5. "Enough time for alteration of the iron-bearing grains, and for the limonite derived from the process to be subsequently converted to hematite." Limonite is being converted to hematite, although this step apparently has not been fully completed.
6. "Possibly elevated temperature." The temperature probably has increased since Pleistocene time. Walker however, is relating this to surface conditions during and after deposition, and he states that he is not certain it is necessary where long intervals of aging are involved.

Fig. 22. Limonite (a) and hematite (b) pigments in sandstone.

(a) Photomicrograph in reflected light showing abundant magnetite altering to produce limonite in the matrix. 10 X.

(b) Hematite has replaced limonite and results in a reddish stain of the matrix. Note the absence of magnetite. Photomicrograph in reflected light. 10 X.



(a)

(b)

Fig. 22. Limonite (a) and hematite (b) pigments in sandstone.

The process of alteration has not been completed in the Mineta formation. Perhaps these non-red sediments were buried too quickly and were not allowed to age properly as referred to in Walker's factor number 6. Walker, however, visualized intrastratal alteration occurring even in oxygenated waters below the water table. Perhaps in these beds the Eh-pH has remained marginal for most of the time since their deposition

Keller (1953) in the results of a study on green sediments concluded that the green color of most sedimentary rocks is due to the presence of illite. The ferric and ferrous iron and the nature of its combination within a silicate framework characterize the green minerals.

Grim (1951) pointed out that a green color does not necessarily mean a reducing environment, and that in most cases, red and yellow colors probably means oxidizing conditions.

In conclusion, the red and yellow sediments of the Mineta formation are considered to have derived their color after deposition by oxidation of iron-bearing minerals (principally magnetite) in-situ. The green colors are due to the presence of illite.

Source Area and Environment of Deposition of the Mineta Formation

Folk (1968) maintained that there are five points that need to be considered in characterizing the source area and the environment of deposition of terrigenous rocks. These five points are listed below, followed by the related characteristics of the Mineta formation.

1. Tectonics of the source area. The tectonics of the source area of the Mineta formation is visualized as consisting of two elements, vertical deformation and volcanic activity. Evidence relating to vertical deformation of the source area is found in the textures of the sedimentary rocks. The basal beds of the Mineta consist of conglomerates that become progressively finer grained higher in the section, grading through sandstones to siltstones in the upper part. This sequence suggests a source area that was initially high and with time was worn to more gentle slopes. Secondly, block faulting that pre-dates deformation of the Mineta is characteristic of the Paleozoic and Mesozoic rocks lying immediately to the west. Thirdly, the metamorphism of the Catalina Gneiss and uplift of the Santa Catalina-Rincon Mountains is considered to be a process of vertical deformation.

The second element relating to the tectonics of the source area is volcanic activity. The composition of the Mineta formation reveals an abundance of volcanic rock fragments and within the upper part of the upper detrital member, a bed of volcanic ash.

2. Paleogeology of the source area. This is best determined by the rock fragments and mineralogy derived from the source area. The examination of sediments reported on earlier in this paper reveal that the most abundant rock types are plutonic and volcanic, with subordinate amounts of Paleozoic and Mesozoic sedimentary rocks, and minor quantities of schist and phyllite.

With the exception of the volcanic fragments, these are rock types that can be identified in the area lying west of Mineta Ridge. The source area of the volcanic rocks can not be identified in the area of this report. It should be pointed out again that no rock fragments can be attributed to the Catalina Gneiss. This indicates that although the source area was rising, the gneiss was apparently not exposed at the time of deposition of the Mineta formation.

3. Tectonic framework of the depositional site. This refers to the size and shape of the depositional basin and its relation to the source area. In the present study it is difficult to determine the size of the basin in which sediments accumulated because of the limited exposure of the Mineta formation. Only the truncated edge of these sediments is

visible. Consequently, one has no way of knowing if this represents a small local basin, or if it was many square miles in area. Alluvial fan or fanglomerate sediments (as the author interprets them to be) normally form some sort of wedge-shaped or prism-shaped deposits covering a relatively local area and thinning greatly away from the source area. The angularity and freshness of the clastic sediments suggest a fairly local source area, as may be the case in prism-shaped basins. The lacustrine deposits are perhaps lens-shaped and probably also of small areal extent.

4. Dominant depositional environment. The Mineta formation is interpreted as a sequence of continental sediments deposited on alluvial plains or floodplains with intermittent lakes developing as drainage was impeded.

The lacustrine environment is represented by algal limestones, the algae being blue-green varieties, which are characteristic of lacustrine environments. Secondly, the presence of mudstones and marls, some of which contain small current-formed ripple marks suggest a water environment. Thirdly, a sequence of evaporites in the upper part of the sandstone sequence suggests the presence of a water body.

The clastic sediments are tectonic arkoses and sublitharenites which, because of their numerous unstable rock and mineral fragments must have been deposited fairly rapidly. The climate (see below) is interpreted as temperate, perhaps bordering on semi-arid so the above factor of quick burial need not be as critical as in a more humid climate. Nevertheless, the freshness of feldspars and volcanic rock fragments suggests rapid burial. The sand grains were found to be poorly to moderately sorted and submature, and since textural maturity is largely a function of the environment of deposition, this can be interpreted that the energy available to sort the sediment was moderate to low, as would be the case in fairly rapid burial of sediment by sluggish streams on alluvial fans and floodplains. Alluvial fans and plains are also characterized by stream channel cross-bedding, which is found to be common particularly in the sandy portions of the conglomerate member.

The general chemical environment of deposition is one of oxidation represented by the red and yellow iron oxide coloring of the sediments. Illite and chlorite of the siltstones and mudstones require an alkaline environment.

5. Climatic effects. The climate of the source and depositional areas is presumed to be temperate to semi-arid. If the climate was more humid one would

expect to see a stronger weathering effect on the mineral and rock fragments. At least examples of both weathered and fresh feldspars and volcanic rock fragments should be present. If the climate was more arid, lake environments as persistent and reoccurring as those in the Mineta formation probably would not exist. Secondly, evaporites are only in the upper part of the section, stratigraphicallly far above the limestone member, but possibly associated with the limestone beds present within the upper detrital member. This would indicate that semi-arid to arid conditions are not typical of the lower part of the formation. Ineffective leaching of alkalines indicated by the presence of illite and chlorite suggest a temperate or dryer climate.

In summary, the environment of deposition and the source area of the Mineta formation can be visualized as follows: The source area lay to the west of the Mineta formation and consisted, at least in part, of uplifted portions of granitic rocks, possibly the porphyritic granite and aplite of this report, plus lesser contributions of limestones and sandstones similar to the Paleozoic and Mesozoic rocks reported in this paper and schist or phyllite from the Pinal Schist or the Paleozoic rocks. The location of the volcanic source area has not been identified.

The conglomerate member probably was deposited as a broad alluvial fan at the base of these newly uplifted source areas.

The exposures of the limestone member suggest that lakes were present in the Mineta Ridge area during the Late Oligocene-Early Miocene. The coarse red clastics of the conglomerate member were replaced by lacustrine limestone as the lake environment developed on the aerated slopes of the alluvial fan or plain upon which clastic deposition had been taking place. Beyond the shore lines of the lakes alluvial deposition continued contemporaneously with the formation of the fresh water carbonates. Wet seasons and rise of water level allowed deposition of carbonates instead of clastics and dryer times and lower water levels allowed clastics to encroach over the limestones. The result is an intricately interbedded sequence of limestones, mudstones, and siltstones. This interbedding is well demonstrated throughout the Mineta Ridge area. An almost cyclic pattern must have developed, the mudstone being deposited at times when the source areas were contributing a greater abundance of clastics, and carbonates were forming when fewer clastics were contributed and ponding developed.

The predominantly lacustrine environment of the limestone member gradually evolved again into one of a major alluvial plain, represented by the upper detrital member. The upper portion of this unit indicates that the alluvial plain oscillated for some time from alluvial plain and floodplain to marsh and lacustrine conditions. Gypsum deposits bring to a close the history of lacustrine environments, and represent the presence of a more arid climate than had existed earlier. Gradually the alluvial conditions again became predominant and are represented by additional sequences of siltstones.

Age of the Mineta Formation

The only fossil fragments to be found in the Mineta formation were recovered from those limestone beds in the upper part of the upper detrital member. They were identified by J. F. Lance and reported by Chew (1952) and Wood (1959) as Diceratherium sp., a rhinoceros of probable Late Oligocene to Early Miocene age. Chew (1952) listed the fragments as ". . . a few teeth and part of a jaw or maxillary from a young rhinoceros."

The Turkey Track Porphyry intrudes the Mineta formation along Mineta Ridge. Samples from this exposure have been collected and dated at the Laboratory of Isotope Geochemistry at The University of Arizona by the potassium-argon method. The age obtained is 26.3 ± 2.4 million years (Damon, Geochronology Department, University of Arizona; personal communication, March 1970). The age of the upper part of the Mineta formation is then well documented by the fossil and by the radio-isotope dates on the Turkey Track Porphyry.

The youngest part of the Mineta formation must be no older than about 26 million years, the approximate Oligocene-Miocene boundary.

Radio-isotope evidence from the Rincon and Santa Catalina Mountains indicates that the age of many granites, and the age of metamorphism of the gneisses are Tertiary (Giletti and Damon, 1961). Damon and others (1963) report an average cooling date of 26.8 $\pm$ 1.7 million years for the Catalina Gneiss. Considering this cluster of Tertiary ages for igneous rocks and for metamorphism, it would seem reasonable to assign the porphyrityc granite and aplite granite to a Middle Tertiary age. Structural and stratigraphic evidence from Mineta Ridge would preclude an age younger than Late Oligocene for these rocks.

The lithologic features of the conglomerate and upper detrital members have been compared with those of the Cretaceous Bisbee Group, which is widely exposed in southeastern Arizona. Lithologic similarities admittedly do exist, but perhaps to a lesser extent than with the modern stream gravels accumulating in the area today. Repetition of similar lithologic facies at different geologic times is indeed common. In general, continental deposits of alluvial plain origin derived from igneous and volcanic source rocks do not furnish a unique criteria for correlation.

Perhaps the Cretaceous correlations have seemed reasonable to some since much of the finer-grained section of the upper detrital member seems at first glance to be slightly metamorphosed. It has been pointed out earlier, however, that there is no petrographic evidence of metamorphism.

A summary of arguments for an Oligocene age follows: The entire section of the Mineta formation is lithologically similar. Each member is noted to interbed or exist in depositional contact with the overlying units. The entire Mineta is then seen as a continuous depositional sequence representing alluvial plain and lacustrine environments, with no significant hiati. Secondly, the suggestions from radio-isotope data and the presence of the fossil indicate an Oligocene age.

Possible Correlations of the Mineta Formation

The Mineta formation has been compared and tentatively correlated with a number of other formations in southeastern Arizona. These correlations have been based largely upon similar lithologic characteristics, presence of intrusive bodies, some of which have been dated, and upon general characteristics and period of deformation.

Brennan (1957, 1962) and Metz (1963) suggested a correlation between the Pantano Formation and the Mineta formation. The author agrees that a time equivalence between these units probably exists. In addition to the gross lithologic similarities mentioned by Brennan and Metz, the author found that the heavy mineral composition reported by Metz (1963) consists of the same suite, and to some degree the same general frequency as is present in the Mineta formation.

The stratigraphic sections of these formations are similar, but it is not possible to match any portion of them. If they are truly correlative one could expect similarities, but matching of individual beds would be surprising. Fluvial sediments will reflect the general lithology of the source areas, but local conditions in the source area and in the environments of deposition will influence the resulting deposits, creating facies changes and variations in thickness and texture.

The Helmet Fanglomerate as described by Cooper (1960), the Cloudburst Formation (Heindl, 1963), and the Rillito Beds as described by Pashley (1966) have all been tentatively correlated with the Mineta formation.

LATE MIOCENE (?)-PLIOCENE (?) SEDIMENTARY ROCKS

Younger conglomerates and sandstones lie exposed to the east of the Mineta formation. These were called the Soza beds and Banco beds by Chew (1952). Neither unit has been mapped in detail. The present study treats these beds in reconaissance fashion, except where they are in contact with the Mineta formation.

The most accessible exposures lie in Soza and Roble Canyons.

Soza Beds

Petrology

The composition of the Soza beds is quite variable. The rock fragments it contains have come from a multitude of sources, many of which can be locally identified; Turkey Track Porphyry from Mineta Ridge, granitic and metamorphic rocks, presumably from west of the Mineta formation, and a multitude of volcanic and other rock fragments. The deposits are interbedded with finer and coarser layers and in general are poorly sorted, and have sub-angular to sub-rounded grains. Several lava flows are interbedded in the lower part of the section.

In Soza Canyon, the lower part of the section is composed largely of volcanic fragments and metamorphics. As one goes up-section, that is, by traveling west in Soza Canyon, a few fragments of Turkey Track Porphyry are present. These increase in abundance farther west, closer to exposures of Turkey Track. The fragments are vesicular and contain amygdaloidal fillings. Very probably these fragments represent the eroded top portion of the Turkey Track Porphyry at Mineta Ridge. Higher in the section granitic fragments are more common, and the unit resembles the lithology of the Banco beds.

The Roble Canyon facies is somewhat different from that of Soza Canyon. Metamorphic fragments dominate the lithology; granitic fragments are of secondary importance. Down-section the major change is texture. The sand-silt fraction becomes more important, and consequently the metamorphic and granitic rock fragments make up a smaller percentage of the total sample. Neither a sharp lithologic change nor an unconformity was noted in the reconaissance mapping of Roble Canyon, however a reversal in dip is present, along what is probably the extension of a fault exposed in Soza Canyon (Fig. 23).

A hand specimen examination, including a visual count of megascopic grains, is given as an illustration of the contributing source rocks. The sample is from Roble Canyon and would be classified as a feldspathic phyllrudite

Fig. 23. Reconnaissance geologic map of the Soza and Banco beds.

Explanation:

Miocene (?)-Pliocene (?)

Banco beds	Tb
Soza beds	Ts

Oligocene

Turkey Track Porphyry	Ttv
Mineta formation	Tm

Strike and dip of strata

Contact: Dashed where approximately located

Fault: Dashed where approximately located

Intermittent stream

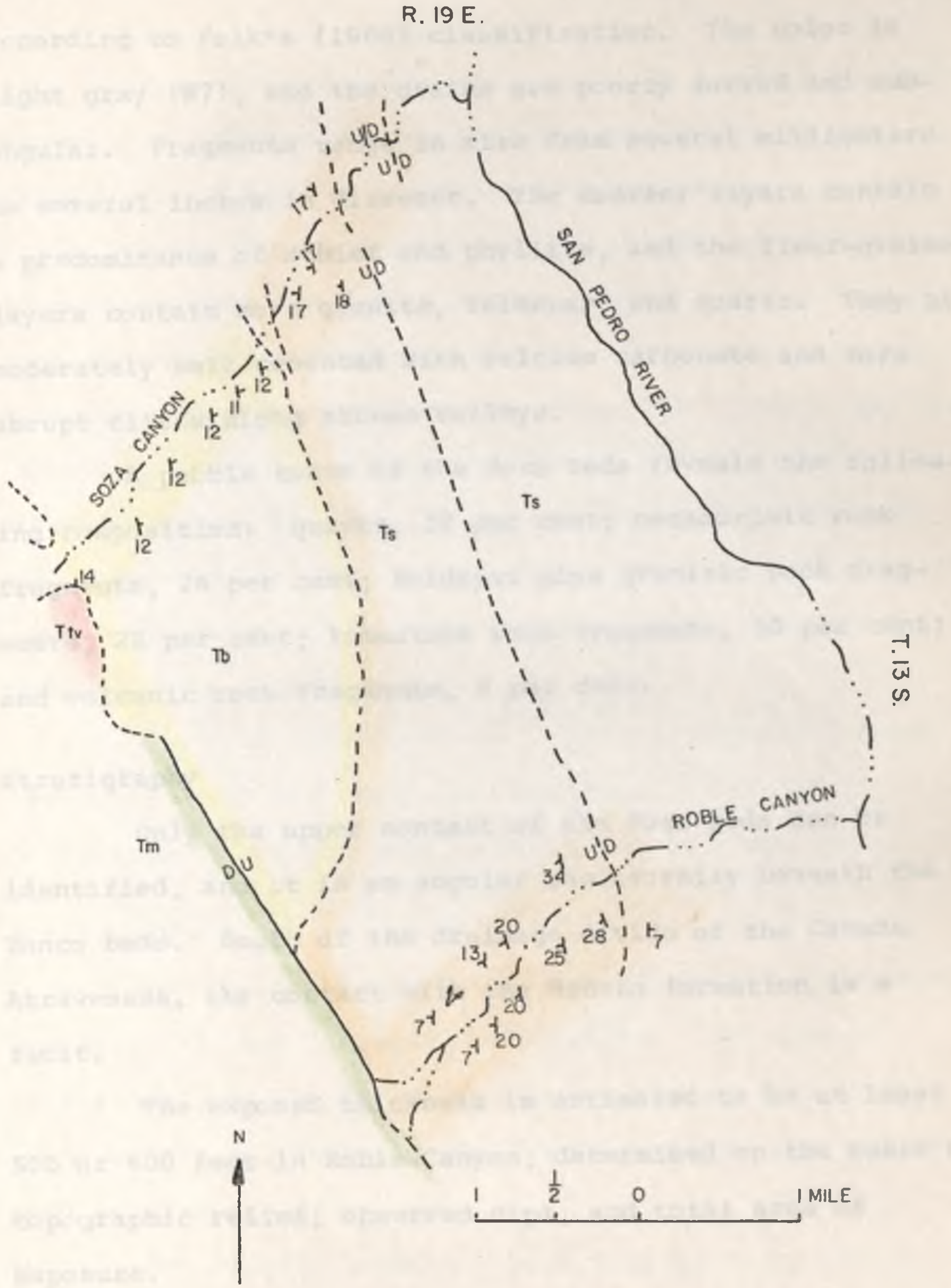


Fig. 23. Reconnaissance geologic map of the Soza and Banco beds.

according to Folk's (1968) classification. The color is light gray (N7), and the grains are poorly sorted and subangular. Fragments range in size from several millimeters to several inches in diameter. The coarser layers contain a predominance of schist and phyllite, and the finer-grained layers contain more granite, feldspar, and quartz. They are moderately well cemented with calcium carbonate and form abrupt cliffs along stream valleys.

A pebble count of the Soza beds reveals the following composition: quartz, 32 per cent; metamorphic rock fragments, 24 per cent; feldspar plus granitic rock fragments, 28 per cent; limestone rock fragments, 10 per cent; and volcanic rock fragments, 6 per cent.

Stratigraphy

Only the upper contact of the Soza beds can be identified, and it is an angular unconformity beneath the Banco beds. South of the drainage divide of the Canada Atravesada, the contact with the Mineta formation is a fault.

The exposed thickness is estimated to be at least 500 or 600 feet in Roble Canyon, determined on the basis of topographic relief, observed dips, and total area of exposure.

The beds strike uniformly north, and dip 15° to 25° to the west.

Banco Beds

Chew (1952) applied the name Banco beds to the thick sequence of arkosic conglomerates overlying the Mineta formation, and locally overlying the Soza beds.

These conglomerates are pinkish gray (5 YR 8/1), and in hand specimen they are a poorly sorted, angular to subangular arkosic conglomerate with the large fragments having a diameter of 2 to 5 millimeters (Fig. 24). Individual beds contain fragments considerably larger. These fragments are moderately cemented with calcium carbonate and form semiresistant ridges. Calcite veins as much as 2 feet in thickness are found along fracture zones of this unit in the northern part of the area.

A typical sample of the Banco beds contains quartz estimated at 38 per cent, feldspar 34 per cent, granitic rock fragments 26 per cent, and biotite at 2 per cent.

Stratigraphy

The Banco beds form the eastern border of the Mineta formation and the Turkey Track Porphyry. The contact separating these units is depositional in the northern portion and faulted along the Mineta Fault in the southern part of the area (Fig. 25).

The exposed thickness is estimated to be 200 to 300 feet. The total thickness is probably much greater.

Fig. 24. Banco beds.

(a) Unconformable contact of Banco beds (light colored) against the Mineta formation (red).

(b) Terrace capping overlying the upper detrital member at section 4

Fig. 25. Banco beds and Quaternary terrace cappings.

Age of the Soza and Banco Beds

The Soza and Banco beds are considered to be Miocene or Pliocene on the basis of their structural and stratigraphic position. The Soza beds contain fragments of Turkey Track Porphyry and are thus post-emplacement of this rock, i.e., younger than 26 million years. The Banco beds lie with angular unconformity upon the Soza beds, and are therefore, younger.

Neither unit was involved in the structural disturbance that deformed the Mineta formation, but both the Soza and Banco beds have been faulted and tilted, indicating that they are older than recognized Pleistocene valley-fill type deposits of southeastern Arizona.

Paleoenvironment of the Soza and Banco Beds

The environment of deposition of the Soza and Banco beds was probably a large alluvial plain that spread out from a newly uplifted source area to the west.

QUATERNARY AND LATE TERTIARY (?)
TERRACE GRAVELS

Composition of all the terrace gravels in the area are similar, but local influences alter the percentages of individual rock fragments. In general, they consist of a sand-silt matrix which encloses fragments of the nearby metamorphics, granitic rocks, limestones, and sandstones of the Mineta formation and various volcanics. These are loosely cemented with caliche.

The larger fragments average 5 millimeters in some samples to 2 centimeters in diameter in other samples, and are sub-rounded, commonly disk shaped, and poorly sorted. Locally faint cross-bedding is present in the finer-grained portions.

Only a few remnants of these terrace cappings are found in the area (Fig. 25). They lie unconformably above the Mineta formation.

MIDDLE TERTIARY INTRUSIVE ROCKS

Turkey Track Porphyry

The principal igneous body that has intruded the Mineta formation is the Turkey Track Porphyry, exposed from Horse Mountain, one mile southeast of the Bar LY Ranch, northeast to Youtcy Canyon, forming the surface capping on Mineta Ridge for a distance of about three miles. Throughout much of this distance its thickness is over 100 feet, and reaches 250 feet in some places.

The Turkey Track is also exposed at numerous other places in south-central Arizona. Nearby localities include outcrops on the east and west sides of the San Pedro Valley. Miles (1965) reported Turkey Track in the Happy Valley area several miles south of Mineta Ridge.

Contacts

The contact between the Turkey Track Porphyry and the Mineta formation is intrusive at most outcrops. The contact of the Mineta is baked and lenses or segments of beds of sandstone and siltstone sometimes several feet in length appear as inclusions within the porphyry. The contact in places is parallel to the stratification and in other places truncates the stratification. Thus it may appear both concordant and discordant (Figs. 26 and 27).

(a) Contact between the Mineta formation and the Turkey Track Porphyry. At this exposure the Turkey Track Porphyry is slightly discordant.

(b) Three sill-like bodies of andesitic composition have intruded the Mineta formation. The hills are capped by Turkey Track Porphyry.

Fig. 26. Contact relations of Mineta formation and the Turkey Track Porphyry.

(a) North end of Mineta Ridge. Turkey Track Porphyry caps the hills and overlies the upper detrital member.

(b) View northwest along the Canada Atravesada wash. Horse Mountain, an intrusive plug is at right center.

Fig. 27. Exposures of Turkey Track Porphyry.

North of the Bar LY Ranch the Turkey Track is in depositional contact along its eastern boundary with the Banco beds.

Small dikes and plugs of the Turkey Track Porphyry intrude the Espiritu Fault, and they are also widely scattered along White Ridge. These features are of a scale too small to plot on the map.

Younger igneous rocks, in the form of dikes and sills, are intrusive into the Turkey Track.

Petrology

The petrology of the Turkey Track Porphyry has been investigated by numerous workers. Cooper (1961) suggested that the Turkey Track can be used as a correlation guide on the basis of its petrographic and chemical data. He described several areas where Turkey Track is exposed, including the Mineta Ridge area.

Mielke (1965) investigated the trace elements found in the Turkey Track. Four of the specimens he analyzed came from Mineta Ridge--his description follows:

> The feldspar phenocrysts average one-half inch in length and although highly altered appear close to An_{50} in composition. Augite is present in small euhedral to subhedral phenocrysts highly altered to uralite (?) and brown ferruginous material. Opaque inclusions of magnetite are found in the phenocrysts. The groundmass is composed of augite, feldspar laths of indeterminate composition, magnetite, clay minerals, and some glass. Tiny fractures cutting through some specimens are filled with calcite. The composition of the rock is about 40 per cent andesine-labradorite, 14 per

cent augite-uralite, 5 per cent magnetite, 20 per cent ground mass feldspar, 20 per cent glass and clay minerals, and less than 1 per cent calcite vein filling.

Internal Structures

The Turkey Track is noted for its large plagioclase phenocrysts. At Mineta Ridge the phenocrysts are oriented. Near the contact with the Mineta formation these phenocrysts are often parallel to the baked contacts.

Near the top of Horse Mountain and alone Mineta Ridge, a few places can be found in the Turkey Track where amygdaloidal fillings have formed in vesicles. Ordinarily the Turkey Track is not a vesicular rock, so this probably indicates a position near the top of the unit. The intrusion must have approached, or perhaps flowed out onto the surface at several locations. Abundant vesicular Turkey Track boulders with amygdaloidal fillings are found among the gravels of the Soza beds. The fillings are chalcedonic quartz that show radial growth from a nucleus.

A third type of internal structure is found near the top of Horse Mountain, where rudimentary columnar jointing, typical of flows and near surface intrusions, is in the Turkey Track Porphyry.

Age

The stratigraphic position of the Turkey Track indicates that it is younger than the Mineta formation and older than the Banco and Soza beds.

The radiometric age of the Turkey Track Porphyry has been determined in several areas where it is exposed. These dates cluster about the Oligocene-Miocene boundary. Damon (personal communication, March 28, 1970) has recently obtained a date of 26.3 $\pm$ 2.4 million years from a sample of Turkey Track Porphyry collected from the Mineta Ridge area.

Associated Intrusives

Immediately southeast of the Bar LY Ranch an andesite mapped as "Ti" on Fig. 3, is intrusive into the Turkey Track. The intrusive also occurs in the form of a number of dikes, some of which can be seen along the stream valley of the Canada Atravesada. This intrusive is a little darker in color, finer-grained, and lacks the phenocrysts of the Turkey Track. The intrusion of this body into the Turkey Track indicates its younger age. This same rock, or one texturally and lithologically similar, appears in outcrops north of the Bar LY Ranch as sills and dikes lying below the Turkey Track Porphyry, but within the Mineta formation.

Mafic dikes and plugs intrude and contort the evaporite sequence of the Mineta formation. These are quite variable in composition and texture, and no attempt was made to study them. Mafic dikes intruding the porphyritic granite and older rocks do not intrude the Mineta formation, and are therefore definitely older.

STRUCTURE

General Statement

Stratification is the most obvious primary structure of the Mineta-White Ridge area. The sedimentary rocks do, however, contain a number of other sedimentary structures. Within the Mineta formation graded-bedding and cross-bedding in many of the sandstone units, small ripple marks in some mudstone units, imbrication of pebbles in some conglomerates, and laminations of algal growths in the limestones are present. Graded-bedding, cross-bedding, and rare pebble imbrication are present in the clastic units of the Paleozoic and Mesozoic rocks.

The igneous rocks also contain some primary structures. Plagioclase and hornblende crystals are aligned along flow directions in the Turkey Track Porphyry, and amygdaloidal fillings are in the higher portions of that unit.

All of these primary structures have been discussed in conjunction with the sections on stratigraphy.

Two major orogenies and perhaps several lesser disturbances are recorded in the rocks of the Mineta-White Ridge area. A Precambrian orogeny is recorded by the metamorphosed rocks of the Pinal Schist. Foliation of this rock is oriented strongly to the northeast, as it is in many areas of southeastern Arizona. This is the deformation Wilson (1939) referred to as the Mazatzal Revolution.

The second major orogeny is represented by metamorphism, igneous intrusions, and faulting. The complexity of the structures and lack of fossils by which the rocks and events can be accurately dated requires tentative age assignments to be placed on many events. Metamorphism and uplift of the Catalina Gneiss is considered by Damon and others (1963) to have been completed by Late Oligocene-Early Miocene time. Although no age assignments can be made, this was perhaps followed by intrusion of porphyritic and aplite granite. Northerly and some easterly faults that do not cut the Mineta formation may be related to this deformation.

The last phase of orogeny that is recorded in this area is represented by a northwest structural orientation of the Mineta formation. This trend parallels the northwest trend of the Rincon Mountain block, and includes the general strike direction of the Mineta formation, and the Mesozoic and Paleozoic sections, many fault orientations within these units, and the orientation of intrusive dikes, sills, plugs, and flows within the Mineta formation.

During the post-faulting interval, the Turkey Track Porphyry and its associated dikes and plugs found access for intrusion along the structural zone of the Canada Atravesada.

In Pliocene time, minor uplifts again occurred and are recorded by faults and small intrusions in the Soza and Banco beds.

Precambrian Deformation

Regional metamorphism and deformation are recorded in the structures of the Pinal Schist. The dominant northeast and east-northeast strikes of foliation is in accordance with measurements in other areas of southeastern Arizona. Ransome (1904), working in the Bisbee district, and later in the Ray-Miami district (1919), reported a northeasterly strike of the foliation in the Pinal Schist. Ross (1925) reported this same trend in the Aravaipa-Stanley area, as did Gilluly (1956) in central Cochise County, and Cooper and Silver (1964) in the Dragoon quadrangle.

This trend is nearly at right angles to the trends of later deformation in southeastern Arizona and has been attributed to deformation of early Precambrian age. Wilson (1939) referred to deformation of this age as the Mazatzal Revolution.

In the southern part of the mapped area, near Roble Canyon, the foliation of the Pinal Schist strikes N. 55° - 65° E. Proceeding northward these trends become east-northeast averaging approximately N. 80° E. The foliation dips strongly to the north-northwest, 55 to 75 degrees throughout the entire exposure. Small assymmetric and overturned folds are found associated with faulting, and are therefore interpreted as drag folds.

Pre-Mineta Metamorphism and Igneous Activity

Catalina Gneiss

The age of cooling in the Catalina Gneiss has been determined for areas in the Santa Catalina-Rincon Mountains by Damon and others (1963) to be about 26.8 $\pm$ 1.7 (s.d.) million years. Damon and others stated "The rather uniform K-Ar dates for micas from the Catalina Gneiss indicate that the uplift had progressed to the point that metamorphism had terminated by Upper Oligocene-Lower Miocene time."

Foliation measurements in the Catalina Gneiss were taken in three different portions of the mapped area. It was hoped that measurement of the foliation along the contact zones with the sedimentary sections would help identify the character of those contacts. The foliation is most easily recognized by planar arrangements of biotite minerals. Along the Youtcy Pasture Tank road random measurements were taken from a strip about ¼ mile wide and 2 miles long and paralleling the contact with the section of metamorphosed sediments. Figure 28 is a rose diagram of the measurements taken along this strip. There is a strong preferred orientation at N. 10° W., with a much smaller secondary maxima at N. to N. 10° E. The foliation

14a

Fig. 28. Foliation and joint measurements in the Catalina Gneiss.

(a) Strike of foliation in the Catalina Gneiss measured along the Three Tanks Road.

(b) Joint measurements of the Catalina Gneiss measured at the same locations as the foliation.

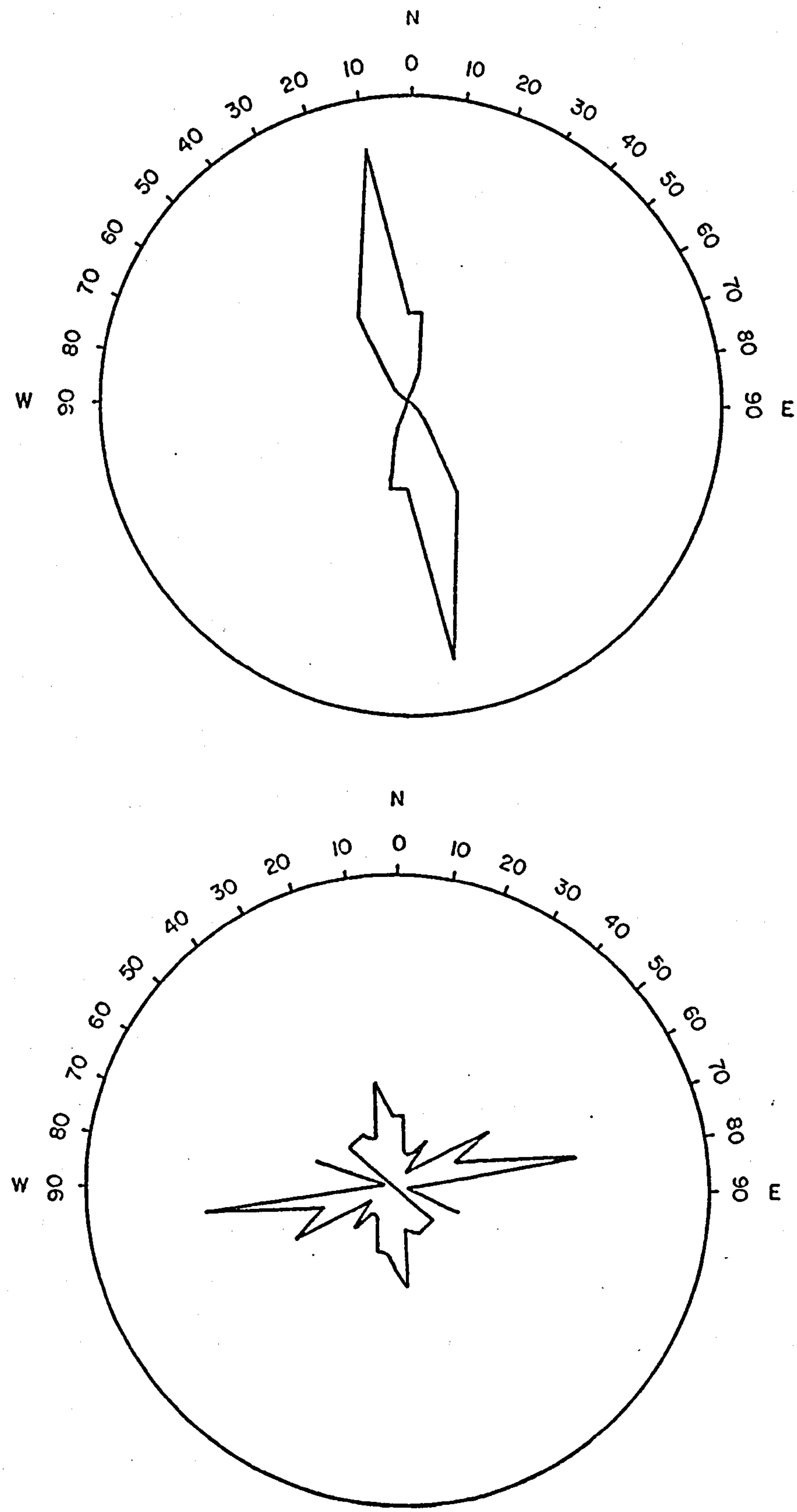


Fig. 28. Foliation and joint measurements in the Catalina Gneiss.

dips northeast from about 30 degrees to nearly vertical. There does not seem to be a marked change in the foliation as the contact is approached. If the Paleozoic (?) section was faulted, then its emplacement was not severe enough to greatly affect the Catalina Gneiss, or measurements were not taken from a large enough area to reveal a changed orientation.

Pashley (1966) recorded about a dozen foliation measurements in the Catalina Gneiss in an area to the west of the sedimentary contact. His measurements show a strong easterly orientation, that is, at nearly 90 degrees to the measurements recorded in this report.

Dikes, which often parallel the foliation, can be plotted on aerial photographs. A few miles west of the sedimentary contact these dikes are seen to curve from a northerly trend to an easterly trend matching those foliation measurements plotted by Pashley.

Joint measurements taken at the same locations as the foliation measurements are plotted in Fig. 28. This pattern shows a maxima at 90 degrees to the foliation, and a secondary maxima at N. 10° W., parallel to the foliation. Several minor maxima occur at intermediate angles.

These same trends of foliation and joint measurements are found in the areas plotted along White Ridge and at the head of Roble and Saucito Canyons.

Metamorphism

Throughout a large portion of the Lower Paleozoic (?) section schist is found to be interbedded with sandstones, quartzites, and marbles.

The foliation of this schist strikes northwest and dips 20 to 50 degrees to the northeast, generally paralleling the strike and dip of the stratigraphic units. Faulting has created local variations in both strike and dip, but the northwest direction of strike is predominant.

The age of this metamorphism is not determined with certainty. Possibly the metamorphism is the same as that which metamorphosed the Catalina Gneiss. If so, some explanation must be given as to why Late Paleozoic and Mesozoic rocks were not affected. Perhaps the metamorphism was contact metamorphism and did not affect the entire thickness of the sedimentary cover. The younger and stratigraphically higher rocks might have escaped this activity.

Igneous Activity

The original rocks into which the porphyritic granite was intruded can be only partially identified within the area of this study. The granite is in fault contact with Lower Paleozoic (?) and Mesozoic rocks and in presumed fault contact with the Catalina Gneiss, and in both fault and depositional contact with the Mineta formation.

The granite is presumed to have intruded the Catalina Gneiss and the Pinal Schist. Schist fragments are found as inclusions within the granite at several places. These inclusions cannot positively be identified as belonging to either the Pinal Schist or the interbedded schists of Paleozoic (?) age; however, the absence of inclusions of quartzite and marble with which the interbedded Paleozoic (?) schists are associated lends strength to the supposition that they are from the Pinal Schist.

The aplite granite is in presumed fault contact with the porphyritic granite, the Catalina Gneiss, and the Lower Paleozoic (?) section. No suggestions of its host rock can be made from the present study. Neither the aplite granite nor the porphyritic granite have internal structures or textures reflecting metamorphism, and therefore they are presumed to be post-metamorphism in age.

The porphyritic granite and the aplite granite, as well as all the older rocks, contain basic dikes that have intruded joints and fault zones. These dikes do not intrude the Mineta formation and thus demonstrate the pre-Mineta age of the above described features.

Faulting and Associated Features

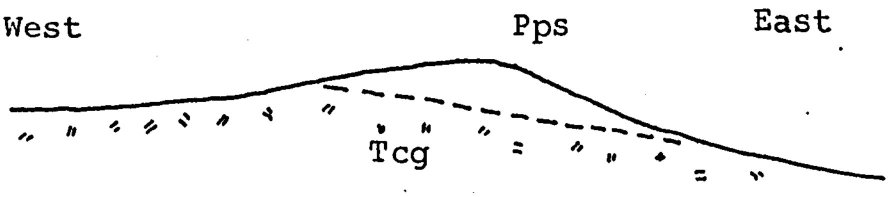
Upper Soza Canyon to Redington Road

In the interval between upper Soza Canyon and the Redington Road, rocks of Early Paleozoic (?) or Late

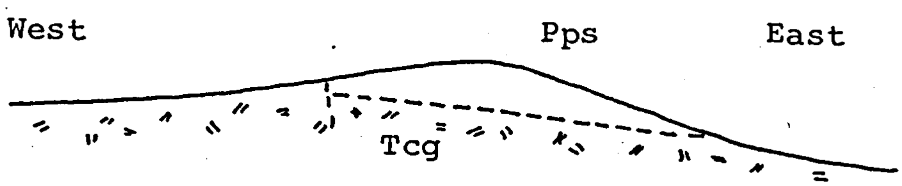
Precambrian (?) age are brought into contact with Catalina Gneiss along presumed northwest striking faults (Fig. 29). Exposed contacts are rarely found, and where they are found positive interpretations are difficult to make. The topography is irregular and the contacts usually form nearly straight traces across the landscape with only small V's discernible as they cross the larger valleys, suggesting that the contact dips steeply.

At some places the nearly straight contact truncates the strike of the sedimentary rocks (Fig. 3). These contacts are best interpreted as faults. Elsewhere the contact is uncertain. It is nearly parallel to the strike and dip of the sedimentary rocks; however, at some places it does appear to dip a little steeper than the strata. Soft caliche-rich zones are usually present along the contact. In some other parts of the mapped area quartz, aplite, and basic dikes intrude the contact zone. Drag folding distinct from the plastic folding found throughout the section, can not be identified. There is no lithologic or depositional evidence of an unconformity. This criterion is neither conclusive of faulting nor of depositional contacts.

The northeastern contact of these meta-sedimentary rocks with the Catalina Gneiss is quite different. This contact is poorly exposed since it is along the dip slope of the sedimentary rocks and therefore largely masked by float debris. In walking out the contact, it forms large



(a) Upper Precambrian (?) and/or Lower Paleozoic (?) rocks (Pps) dipping steeply (40 to 60 degrees) northeast, in contact with Catalina Gneiss (Tcg). The western contact is relatively straight and may be interpreted as the surface trace of a low angle fault.



(b) The same situation as in (a) above, however, in this interpretation the western contact has been modified by a high angle fault.

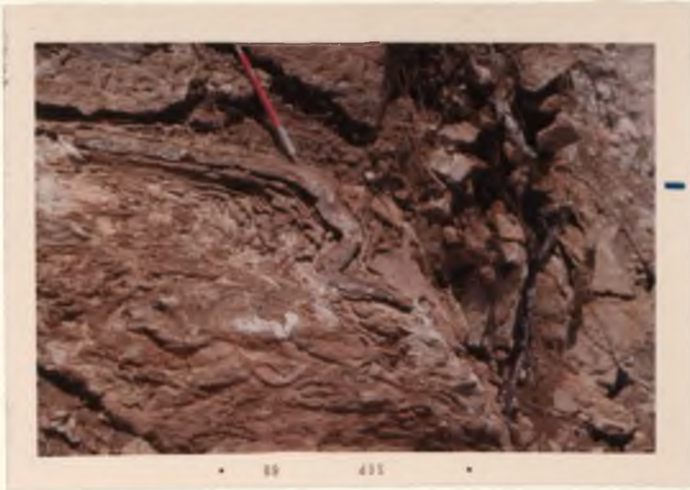
Fig. 29. Possible interpretations of contact relations of meta-sedimentary rocks and the Catalina Gneiss.

V's as it crosses stream valleys and thus apparently dips rather gently toward the southwest.

Perhaps the best evidence to suggest faulting is circumstantial. The elevation of the Catalina Gneiss along the western contact of the meta-sedimentary rocks is about 3840 feet. Along the east side of the meta-sediments the elevation of the contact is about 3840 to 3680 feet. This suggests that the floor of the gneiss is nearly horizontal or dipping gently eastward. The strata and the western contact dips steeply, 45 to 70 degrees. The slope gradient formed on the gneiss is too gentle for the contact to be depositional. A preferred hypothesis is diagrammatically represented in Fig. 29, and is described below.

The meta-sedimentary rocks rest on a low angle fault that is presumed to be of gravitational origin. Sometime after reaching the present site, the southwestern contact was modified by high angle normal faulting.

The movement on this basal fault might have been either thrust or gravitational, but by examining the internal structures of the strata a past history of gravitational stresses can be suggested. These Paleozoic (?) or older rocks, as well as the marble units found higher in the Paleozoic (?) section, reveal evidence of plastic deformation. In many exposures the bedding planes have been warped into small overturned and recumbent folds with their axial planes inclined down (Fig. 30). These patterns are most



(a) Drag folding indicating down dip movement (to the right) of overlying strata (Espiritu Canyon).

(b) Drag folding in marble indicates the overlying strata moved to the left (Soza Canyon).

Fig. 30. Drag folding in Paleozoic (?) marble.

often seen in those marble units containing chert nodules or layers, or in marbles with thinly interbedded sandstones and quartzites. The folding present in the massive sandstone and quartzite units are similar, but smaller and less pronounced than those found in the marbles.

To explain the folding as a consequence of thrusting would be difficult. One would expect that under the compressive forces necessary to produce thrusting, zones of weakness would be selected or created that would serve as the loci for deformation. The result would be localized zones of faulting with accompanying drag folds.

It is the writer's contention that gravitational movements were responsible for the creation of the small bedding plane faults and the drag folds. These rocks were presumably dipping moderately and probably in an easterly direction. It seems reasonable that the section was located to the west and higher on the flanks of the Rincon Mountains since an east-west cross-section would reveal in general a progressive increase in age to the west, and since similar Paleozoic (?) rocks are exposed farther west at Chimney Peaks. Thus, since gravitational stress patterns seem to have occurred within the section it seems reasonable to suggest that the entire section might have been emplaced by similar movements.

At the northwestern end of the exposures, near the Redington Road, several small hills occur as outliers of gently to steeply dipping strata (up to 66 degrees) overlying Catalina Gneiss. Since the beds are generally steeply dipping, and since the contacts again appear to have a gentle dip, a low angle fault contact is suggested.

As one follows the section southeastward to upper Soza Canyon the section is nearly eliminated by an east trending fault that brings Catalina Gneiss into contact on the southwest.

Northeast of the Youtcy Pasture Tank two north-trending high angle faults cut across the entire section. Only small slivers of the marble and quartzite are present south of these faults, along with aplite granite and Catalina Gneiss. Quartz veins have intruded the fault zone to form a number of northwesterly-trending dikes.

This same condition seems to prevail in the exposures along the Jeep trail leading from Big Tank to the Blue Goose mineral claim. Freshly bull-dozed exposures show marble and quartzite slivers sandwiched between gneiss by faults of small displacement. This may suggest that deformation took place under high pressure and temperature.

Northeast of the Youtcy Pasture Tank two north-trending high angle faults cut across the entire section and bring Catalina Gneiss to the surface. Only a small portion of the sedimentary section has been preserved on this uplifted block.

Bolt Canyon to Soza Canyon

The interval between Bolt Canyon and upper Soza Canyon is made structurally complex by the numerous rock types present in small exposures and with the lack of distinguishing features, positive identification of strata is not possible in all cases.

The redbeds of Late Paleozoic (?) or Mesozoic age can be traced as a thin fault sliver for a short distance to the northwest and southeast of the Blue Goose mineral claim at Soza Canyon. To the northwest the overlying limestone beds disappear quickly and the redbeds are in fault contact with the porphyritic granite. Basic dikes have intruded the contact and can be followed a short distance northwest beyond the last red bed exposure.

In Bolt Canyon, limestones that appear structurally and possibly stratigraphically above the redbeds overlie Catalina Gneiss as a result of a nearly horizontal fault. The fault plane dips gently to the north and is marked by a gouge zone more than one foot thick. The sedimentary rocks are exposed only on the north side of Bolt Canyon, on the south side only Catalina Gneiss is exposed. North of Bolt Canyon the limestones and red beds exposures are generally not good, and contact relations are undetermined.

Espiritu Fault

Espiritu Canyon is carved along the trace of an imposing north-striking fault referred to in this report as the Espiritu Fault. In all exposures where the fault plane is observed it dips steeply to the west from 54 to 61 degrees. The fault can be traced on aerial photographs for some distance south of the mapped area where it appears to be displacing Catalina Gneiss.

South of Bolt Canyon Paleozoic (?) rocks are exposed in the hanging wall of a graben with Catalina Gneiss making up the footwall. The Espiritu Fault and a parallel north-trending fault dipping 71 degrees east form the boundaries of this graben. Catalina Gneiss is in the footwall of both faults. The sediments are terminated on the south against Catalina Gneiss by one of a series of easterly-trending faults.

Immediately south of upper Soza Canyon the Espiritu Fault brings the porphyritic granite into contact with Lower Paleozoic (?) rocks. In this vicinity the fault plane has been intruded by a diabase dike which dips 54 degrees to the west. This dike can be followed to the north for some distance.

North of upper Soza Canyon the lower members of the Mineta formation are exposed along the west side of the Espiritu Fault in contact with Lower Paleozoic (?) rocks. The conglomerate and limestone members of the Mineta are well exposed, but the upper detrital member is poorly exposed in this location, and the trace of the Espiritu Fault becomes obscured. Projecting north along strike of the fault the beds of the upper detrital member are highly disturbed, with blocks of limestone oriented in a jumbled fashion. These orientations possibly reflect movement on the Espiritu Fault.

At several places along the trace of this fault Turkey Track Porphyry has intruded the fault zone as small linear bodies. They are possibly dikes, although the linear extent of each body can be traced for only a few yards. The most significant observation regarding these small Turkey Track bodies is that they have intruded the fault zone, and slickensides on the Turkey Track indicate that these small bodies have themselves been displaced by later movement suggesting that fault movement is both pre- and post-Turkey Track emplacement.

Dates of movement on the Espiritu Fault earlier than pre-Oligocene-Miocene are not possible to ascertain with certainty.

Chimney Peaks

Chimney Peaks lies on the western edge of the mapped area. The peaks are one mile east of Espiritu Canyon and nearly two miles south of Big Tank. The summits of these two peaks rise 1000 feet above the elevation at Big Tank.

They are important in this study because they represent an outlier of steeply dipping Lower Paleozoic (?) marble resting with presumed fault contact on the Catalina Gneiss. The rocks represent part of the same Paleozoic (?) section found in Soza and Espiritu Canyons, and on White Ridge. Here, as elsewhere, the marbles are cherty, the shales have been changed to slates and schists, and plastic folding plus small bedding plane faults are common to the section.

The contact between the Catalina Gneiss and the Paleozoic section is largely covered by debris from the Paleozoics. A large portion of the perimeter was examined without observing the actual contact.

Strike and dip measurements show greater irregularity around the perimeter than through the central portion of the exposure, and aplite dikes have intruded along the northwestern contact.

Fracture patterns, faults, and dikes in the Catalina Gneiss do not cut the Paleozoic (?) section and are therefore pre-emplacement of this Paleozoic (?) section. The dikes do not show effects of the metamorphism of the Catalina Gneiss, and must therefore be of a later age. This places the date of emplacement of the Paleozoic (?) section as post 26.8 million years, the age of cooling and metamorphism of the Catalina Gneiss (Damon et al., 1963).

These observations, suggesting fault emplacement of the Chimney Peaks section, are similar to those discussed above. They require a low angle fault.

It is significant that this section is higher and lies farther to the west than the other Paleozoic (?) rocks reported, because it demonstrates that a more extensive Paleozoic (?) section did exist farther west toward the mountains.

White Ridge and Soza Canyon

Exposures are poor to non-existent along the top and eastern dip slope of White Ridge. It is covered by loose blocks and talus that masks exposures. Excellent outcrops are found in Soza Canyon and along the smaller tributaries draining White Ridge.

The Lower Paleozoic (?) section of marble plus minor interbedded quartzite and schist layers overlies the Catalina Gneiss. The upper portion of this section is the same as at Chimney Peaks.

The rocks of this section strike northwest and dip moderately to steeply to the northeast. This orientation varies somewhat along faults (Fig. 3).

The basal contact of the Paleozoic (?) section with the Catalina Gneiss can be observed at two places in Soza Canyon only a few tens of yards apart. One, a fault contact striking east and dipping 39 degrees north is in a prospect

(a) Paleozoic (?) marble with chert weathering into relief.

(b) Paleozoic (?) marble in contact with underlying Catalina Gneiss (Soza-Espiritu Canyons).

Fig. 31. Contact relations and weathering of Paleozoic (?) marble.

pit located near the southwest corner of sec. 15, T. 13 S., R. 18 E. The overlying marble is oriented N. 27° W. and dips 19 degrees northeast. A second contact is only a few yards down Soza Canyon from the prospect, but the nature of this contact is in doubt. It has some aspects of being intrusive into the marble, but it may have been mobilized during metamorphism to similate some intrusive characteristics.

A short distance down Soza Canyon, that is, up section, the Catalina Gneiss reappears for a short distance as a presumed fault block. Several other westerly and northwesterly faults cut the section in Soza Canyon, two of these having identifiable stratigraphic displacements of several tens of feet. One additional fault of unknown magnitude strikes north to northeast and is identified by discordant strikes and dips of strata on opposite sides of the canyon. It can be projected northward across the Mineta formation where discordant measurements are also found.

Contorted bedding, similar to that previously described is typical of the section in Soza Canyon.

A short distance to the west of Soza Canyon the section forms the footwall of the Espiritu Fault and is here brought into contact with the porphyritic granite and the Mineta formation. To the northeast it is in fault contact with the Mineta forming the hanging wall.

Along the crest of White Ridge the contact with the Catalina Gneiss is covered, but gentle dips of the marble and the gently dipping contact suggest possibly a depositional contact. Several small faults can be identified along the tributaries draining White Ridge. They have measurable displacements of a few yards, and they can be traced on aerial photographs by the displacement of drainage trends.

Interval Between Roble Canyon and White Ridge

The Upper Paleozoic and Cretaceous rocks exposed in Roble and Saucito Canyons are bounded by northwest-trending structures. A fault is presumed to form the southwestern contact with the Catalina Gneiss. The contact is not well exposed. The best outcrops are in Roble and Saucito Canyons where the contact zone is intruded by basic dikes. A close approximation of its strike at Roble Canyon is N. 25° W., with a dip of 44 degrees northeast. Here, and throughout its length, the contact is semi-parallel to the strike of the sedimentary section; however, it does truncate the strata slightly.

This contact is best interpreted as a fault even though exposures do not allow detailed examination. The section of Upper Paleozoic and Cretaceous rocks is unmetamorphosed and lies upon the Catalina Gneiss whose metamorphism is dated in the Rincon-Santa Catalina Mountains as

Oligocene-Miocene. Large quartz dikes within the Catalina Gneiss seem to be associated with the foliation and joint patterns, and are post-metamorphism in age. These dikes do not intrude the sedimentary section. A post-metamorphism emplacement of the section seems obvious.

The northeastern contact is a high angle fault with probable reverse movement bringing the Pinal Schist of the hanging wall into contact with the sedimentary section. The fault strikes southeast between Saucito and Roble Canyons, but at Roble Canyon it turns almost due south and can be traced on aerial photographs for some distance. The sedimentary section is gradually wedged out, bringing Pinal Schist into contact with the Catalina Gneiss south of the mapped area.

The fault dips 70 degrees northeast at Roble Canyon, but this is along the bend of its strike, and it is thought to dip at gentler angles through most of its course. Near this contact a series of smaller and parallel faults are found in both units. Bedding of the coarse-grained and resistant Glance Conglomerate is not affected much by these faults, but the schist is badly broken and warped into numerous drag folds illustrating reverse movement. The fault zone has also been intruded by basic dikes.

In Roble Canyon the rocks are fairly well exposed and they reveal several small northerly and northwesterly high angle faults dipping to the east as well as bedding plane faults. The amount of movement along most of these faults is probably small and minor drag folding suggests normal movements (Fig. 32). These faults are most common in the upper parts of the canyon and where the red shales and siltstones have provided slippage planes. Several of these small faults are nearly horizontal and the drag folding on them suggests minor thrusting. Only the larger of these structures are plotted on Fig. 3.

In addition, two other faults are suggested by repetitions of parts of the section. The easterly block is upthrown in both cases, bringing the red beds and the Glance Conglomerate to the surface. The fault planes are not observed, but their location and presence is demonstrated by the repeated sections and the change in strike and dip of the sedimentary rocks.

The Saucito Canyon Fault is represented by several nearly vertical east-northeast-trending faults that cut obliquely across the canyon. The Pinal Schist forms the footwall of this fault as the schist is again brought into contact with the Upper Paleozoic and Cretaceous rocks. The fault planes are well exposed in the canyon where scarps 20 feet and more still retain slickensides. These slickensides suggest that the northern block is upthrown, and since this block consists of the older rock, the slickenside measurements seem valid. Dip on the fault plane indicates a nearly

(a) Drag folding along a possible thrust fault.

(b) Relatively large drag fold indicating movement of overlying strata to the left.

Fig. 32. Drag folding in Roble Canyon.

vertical cip to the south, although the plane is warped and locally overturned.

There are several small spurs to this fault, one of which reveals thrust movement.

Lying south of Saucito Canyon, a parallel fault is strongly suggested by aerial photographs to extend across the sedimentary section, although it can not be traced on photos into the Pinal Schist or Catalina Gneiss. An attempt to locate this fault in the field was not successful as the exposed bedrock is very spotty.

Northwest of Saucito Canyon the contact separating the sedimentary rocks and the Pinal Schist is a presumed fault that dips approximately 50 degrees northeast. Although the movement can not be identified it is reasonable to presume that the schist, being the older rock, lies on the uplifted block. If this is true, then the fault is a reverse fault.

About one and one-half miles north of Saucito Canyon the Pinal Schist is again found in fault contact with rocks of Paleozoic age. The fault trends north-northeast and ends abruptly against the Mineta Fault. The dip cannot be measured along the available exposures. The fault is identified by the presence of schist on one side of the hill and Paleozoic sedimentary rocks on the opposite side. The fault zone has also been intruded by basic dikes. The schist shows drag folding in most exposures, but there are many small localized faults and it is difficult to identify a particular fold as being a response to movement along the larger fault.

Mineta Fault

A normal fault brings the Mineta formation into contact on the west with older igneous rocks, meta-sedimentary rocks of Paleozoic (?) age, and the Precambrian Pinal Schist. This fault, herein called the Mineta Fault, is exposed in Roble and Soza Canyons. In Roble Canyon the Pinal Schist of the footwall has been warped into a gentle drag fold at the contact indicating normal movement. The bedding of the overlying Mineta formation is truncated slightly by the fault in the vicinity of Roble Canyon. The fault disturbs both the Mineta and pre-Mineta rocks, and represents the major break limiting the western exposure of the Mineta formation.

The Mineta Fault strikes northwest and dips steeply to the northeast. At Roble Canyon the measured dip is 47 degrees northeast, however farther north it is steeper than this, ranging from 50 to 70 degrees. At Soza Canyon the dip is considerably steeper than that of the Mineta formation. The dip is generally less related to the dip of the bedding in the Mineta than are the small bedding plane faults lying higher in the section.

A rhyolite forms the hanging wall of the fault through much of the area southeast of Horse Mountain, and the Pinal Schist makes up the footwall. To the southeast, the rhyolite thins and disappears along the fault, the lower portion of the conglomerate member forming the contact. The fault gradually cuts higher into the section until much of the lower portion of the conglomerate member has been eliminated. The gradual convergence of this fault with the Banco Fault is effective in eliminating the Mineta formation at the south end of the mapped area.

A mile south of the Bar LY Ranch the fault cuts at an acute angle through the conglomerate and limestone members until in Soza Canyon only a few feet of these units are preserved. The upper detrital member is warped into several broad anticlines and synclines.

Northwest of the ranch the Mineta Fault brings the conglomerate member into contact with porphyritic granite of the footwall. The dip of the conglomerate member varies considerably in this region, from moderate dips to nearly vertical. The conglomerate member is gradually wedged out by this fault at the north end of Mineta Ridge.

Canada Atravesada Fault Zone

The region southwest of the Bar LY Ranch is accessible by a wash named the Canada Atravesada. This is the name the author has chosen to use in describing the bedding plane structures of the Mineta formation.

Chew (1952) had originally mapped the Mineta Fault as a reverse fault, and he considered the bedding plane faults as imbricate thrust sheets. He gave no evidence for his conclusion, indeed, there is no evidence to support large scale reverse or thrust movements. Folding, independent of a minor amount of drag does not exist in the Mineta formation.

The author interprets these features as small scale bedding plane faults of gravitational origin.

The use of the term small scale means that the displacement is probably only a few feet, and that movement is confined to a specific member, i.e., limestone member or upper detrital member. Although there may be some overriding of individual beds within a member, the major stratigraphic units are in their normal depositional sequence. This movement has not disrupted the general stratigraphic relations.

The author envisions a sequence as follows. As the Rincon Mountain block was uplifted in post-Mineta-pre-Turkey Track time the pile of Tertiary sediments that had accumulated since the previous orogenic phase, was steeply tilted to the east with dips averaging from 50 to 70 degrees. Tensional forces were induced by this uplift, and zones of weakness developed along the bedding contacts of the Mineta formation, and in particular in the limestone member. These stresses were gravitational in origin and they caused bedding plane faults to develop between competent and incompetent strata. Movement would be much like that of a tilted deck of cards.

Movements along the faults were facilitated at many locations by the presence of mudstone and siltstone between the limestone beds. These interbedded incompetent layers absorbed much of the stress and locally were brecciated, pulverized to fault gouge, and warped into drag folds suggesting normal movement (Fig. 33). As slippage took place the faults broke across intervening strata, both along strike and dip, coalescing and separating in a fashion that tends to both repeat and eliminate parts of the section (Fig. 33).

Some evidence suggests that this sort of process along dip can take place. Figure 31 is a photo of competent and incompetent units within the upper detrital member, and it illustrates how gravitational structures of this type can develop. Gravitational stress has caused the competent members to overturn. Upon fracturing it will move in a manner very similar to that described above. The competent units will override younger incompetent members.

Field evidence supporting this hypothesis consists of a few small exposed faults, a minor amount of drag folding (Fig. 34) that can be seen at widely scattered

(a) Gravitational drag fold formed in sandstone of the upper detrital member.

(b) Drag fold formed along bedding of siltstone interbedded between limestone strata (limestone member).

Fig. 33. Drag folding in the Mineta formation.

(a) Drag fold within the limestone member indicating normal movement of the bedding along a bedding plane fault.

(b) Drag fold within the siltstones of the upper detrital member. The pick handle is oriented approximately along the axial plane.

Fig. 34. Drag folding in the limestone and upper detrital member.

locations, siltstone at the contacts that is often broken or even pulverized and sometimes permeated with caliche deposits. These contact zones are often much softer than the same rock units a few feet from the contact. In the field and on aerial photographs the strikes of individual limestone beds separate or converge upon one another, sometimes merging together, sometimes completely truncating and eliminating beds (Fig. 35). Beds appear and disappear along strike in a fashion that is difficult to interpret as depositional. Figure 36 is an enlarged tracing from an aerial photograph of the strike and visible trend of selected individual limestone beds.

Toward the southeast the limestone member is stratigraphically thinning, and individual beds are not as thick as they are farther north. Part of the thinning is probably a result of these gravitational structures.

Northwest of the ranch the structure is more complex and since the limestone member is only locally present, the bedding plane features typical of the southern region can not be identified. The bordering faults of the uplifted block of White Ridge have disrupted the Mineta formation, and drastically altered the orientation of the strata. Irregular strikes and jumbled outcrops of the upper detrital member express this disorientation. To follow an individual bed for more than a few yards is often impossible. Outcrops

(a) Warping of individual limestone beds in the limestone member. Note the variation in thickness of the section from the top to the bottom of the hill.

(b) Limestone member showing individual limestone beds converging and separating along small bedding plane faults.

Fig. 35. Bedding plane faults in the limestone member.

Fig. 36. Tracing of limestone outcrops of the limestone member.

Tracing from an enlarged aerial photograph, showing the general strike trend of limestone beds within the limestone member.

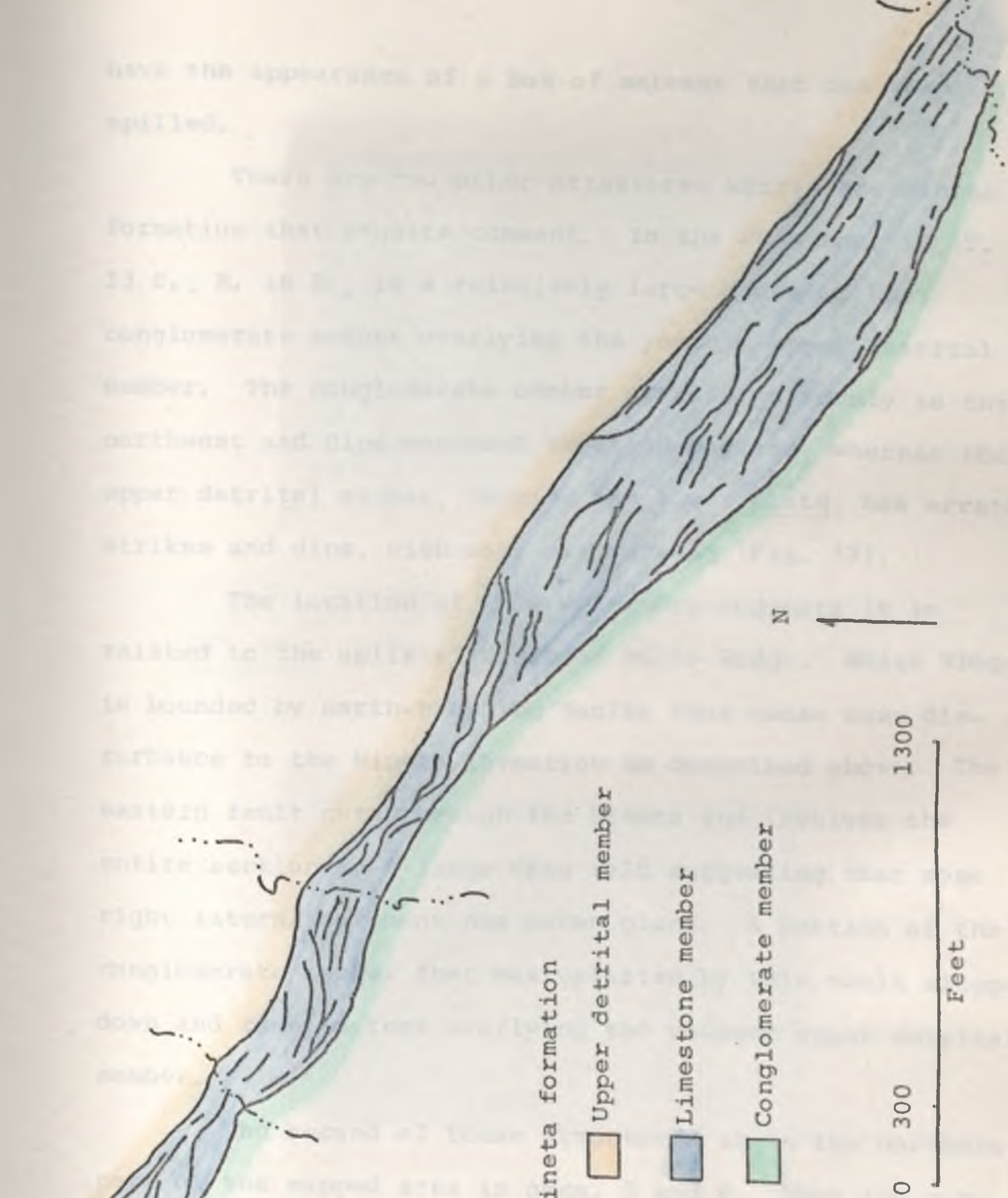


Fig. 36. Tracing of limestone outcrops of the limestone member.

have the appearance of a box of matches that has been spilled.

There are two other structures within the Mineta formation that require comment. In the NE ¼ sec. 14, T. 13 S., R. 18 E., is a relatively large block of the conglomerate member overlying the younger upper detrital member. The conglomerate member strikes uniformly to the northwest and dips eastward about 40 degrees, whereas the upper detrital member, forming the lower plate, has erratic strikes and dips, with some overturning (Fig. 37).

The location of this structure suggests it is related to the uplifted block of White Ridge. White Ridge is bounded by north-trending faults that cause some disturbance to the Mineta formation as described above. The eastern fault cuts through the Mineta and involves the entire section in a large drag fold suggesting that some right lateral movement has taken place. A portion of the conglomerate member that was uplifted by this fault slipped down and came to rest overlying the younger upper detrital member.

The second of these structures is in the northern part of the mapped area in secs. 3 and 4. Here the conglomerate member forms the eastern contact of the Mineta formation and is unconformably overlain by the Banco beds and by the Turkey Track Porphyry. The conglomerate member is also in fault contact with the upper detrital member.

(a) Bedding characteristics of the sandstone and siltstone in the upper detrital member. Note siltstone beds in the lower right are truncated along a bedding plane slippage.

(b) Conglomerate beds of the conglomerate member lying with fault contact above the younger upper detrital member. Orientation of bedding is different in the two members.

Fig. 37. Bedding and contact relations of the upper detrital member.

The fault is covered by the Turkey Track over much of this distance, but the contact is exposed in the vicinity of a canyon that cuts across Mineta Ridge. The conglomerate member strikes northwest and dips northeast, whereas the upper detrital member strikes northeast and dips northwest. Caliche has been deposited in the contact zone where it is exposed.

Pliocene (?) Faulting

The Banco Fault borders the Mineta formation on the east in the area south of the Bar LY Ranch. South of the drainage divide of the Canada Atravesada the fault brings evaporites of the upper detrital member into contact with the Soza beds. North of this point the Banco beds are in contact with the evaporites. A fault scarp is well preserved, forming a nearly vertical drop of twenty feet or more (Fig. 38). Its trace can be easily followed on aerial photographs and in the field.

The fault dips approximately 70 degrees to the northeast, toward the younger rocks, indicating that the fault is either a high angle reverse fault, or it is normal and the fault scarp represents an obsequent fault-line scarp.

Both possibilities can be considered. If the fault is reverse, it represents the only large scale reverse fault affecting the Mineta formation. The obsequent

Fig. 38. Evaporites in contact with Banco Fault and with an intrusive plug.

(a) Fault scarp of the Banco Fault with the Soza beds forming the scarp and gypsum of the upper detrital member in the foreground dipping into the fault.

(b) Gypsum (light color) dipping steeply in a drag fold formed by the intrusion of a basic plug (dark colored).

(a)

(b)

Fig. 38. Evaporites in contact with Banco Fault and with an intrusive plug.

fault-line scarp is possible since drainage on the Canada Atravesada is cutting into the softer siltstones and evaporites of the footwall, while the scarp face of the hanging wall is composed of moderately well cemented conglomerates. Drag folding in the evaporites is unreliable because of the intense slumping and local overturning of these beds.

The tilting of the Mineta formation produced small easterly and northeast fractures along which minor amounts of movement have taken place. These faults are nearly vertical with generally the south side being upthrown. Displacement on most of these fractures has been only a few feet. A number of dikes, sills, and plugs in the southern part of the area have intruded along some of these fractures. They cannot be traced into the Soza beds, and therefore they pre-date Soza depositon.

Faulting in the Soza beds appears to be later than the previously mentioned structures that have disrupted the Mineta formation. These are a series of northwest-trending normal faults, the most important of which are near the San Pedro River in Soza Canyon. Here the faults have tilted the Soza beds and provide access for the emplacement of igneous rocks.

Displacements on a smaller scale are found throughout the Soza and Banco sections. These smaller faults show only a few feet of slippage on each break.

Along the eastern boundary of the Mineta formation there are several small easterly normal faults with only a few feet of displacement, that cut the Mineta formation, the Turkey Track Porphyry, and the Banco beds.

STRUCTURAL CONTROL OF CENOZOIC IGNEOUS ACTIVITY

Igneous activity has played a large part in the geologic history of Mineta Ridge. Probable flows and intrusions of dikes, sills, and plugs, from andesite to basaltic composition, took place during several intervals following deposition, tilting, and faulting of the Mineta formation.

Horse Mountain is the southern-most exposure of Turkey Track Porphyry in the Mineta formation and is considered to be an intrusive plug rising some 250 feet above the valley floor (Fig. 27). Its contact with the Mineta formation is definitely intrusive. The Mineta is well exposed on two sides of Horse Mountain and shows some folding, random orientations, and crushing effects that one expects accompanying intrusions. Blocks and lenses of the Mineta formation are found throughout the porphyry. The dip of the Mineta, which is steep both north and south of Horse Mountain, has here been drastically changed in angle and direction and has locally been reduced to nearly horizontal. Drag folding is locally present in the contact zones.

Phenocryst orientations were measured throughout the exposure of the Turkey Track Porphyry at Mineta Ridge in hopes that they would yield data toward solving the problem of intrusive or flow origin at Mineta Ridge. Sites for measurement were chosen where both nearly horizontal and vertical exposures can be viewed. In this way, the exposures could be checked for both planar and linear orientations. The orientations of the longest axis of feldspar phenocrysts were recorded after examining a number of crystals to be certain the measurement is truly typical. The generalized lineation pattern and their plunge is plotted on Fig. 3. Figure 39 represents rose diagrams of these linear measurements. Figure 39b represents measurements south of the Bar LY Ranch, including Horse Mountain, and Fig. 39a represents measurements north of the Bar LY Ranch. The southern measurements seem to be uniformly oriented to the north-northwest, paralleling the trend of the porphyry. Near the Bar LY Ranch, where the younger andesite (plotted as Ti on Fig. 3) has intruded the Turkey Track Porphyry, lineation measurements are random. No doubt the intrusion has affected the orientations of this zone.

North of the Bar LY Ranch there is a tendency in many places for the orientations to strike and plunge into the contacts with the Mineta formation. Within the interior of the porphyry, orientations are somewhat random, although there is an overall tendency of a northwest orientation. The rose diagrams of these measurements show two maxima and several sub-maxima. It is obvious that these orientations

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Fig. 39. Orientation of plagioclase phenocrysts from the Turkey Track Porphyry.

(a) Measurements of the long axis of plagioclase phenocrysts from the Turkey Track Porphyry in the north of Soza Canyon.

(b) Measurements of the long axis of plagioclase phenocrysts from the Turkey Track Porphyry in the area south of Soza Canyon.

(c) Combined diagram of plagioclase phenocryst orientations from the Turkey Track Porphyry covering its entire exposure at Mineta Ridge.

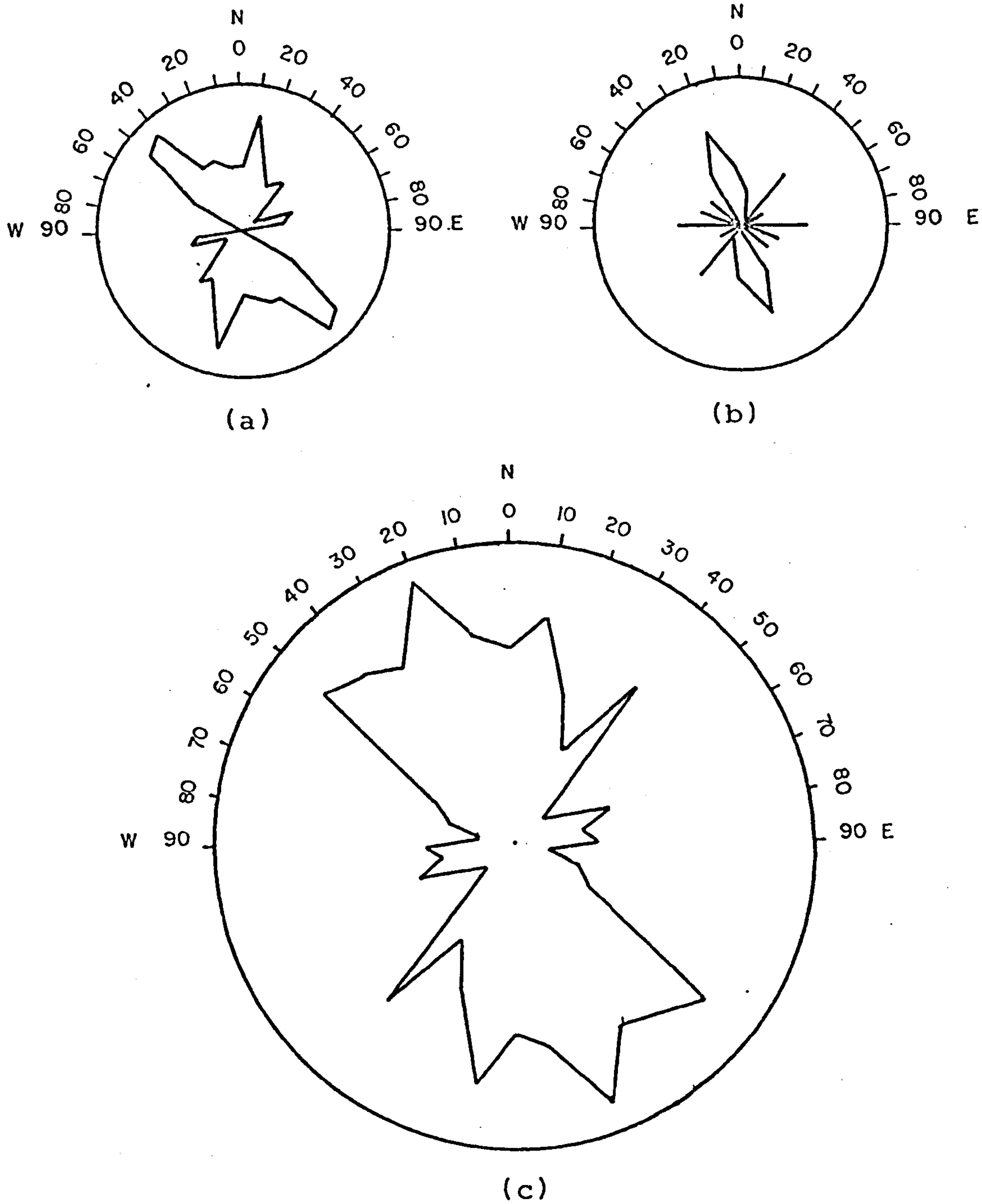

Fig. 39. Orientation of plagioclase phenocrysts from the Turkey Track Porphyry.

are much more random, suggesting that the fluid had more freedom of movement, as one might expect of surface flows.

The color of the porphyry varies from deep maroon to green. Sometimes a change in color will take place over a distance of a few yards. The maroon may represent the oxidation state of iron at the times of emplacement of the porphyry. The maroon color suggests availability of oxygen and may then represent very near surface or surface conditions.

Examination of the outcrop patterns, contact characteristics, internal and external structures, and fault associations, indicate that the Turkey Track, as well as all later generations of dikes and sills are permissive intrusions, that is, they have been intruded along zones of structural weakness. The Turkey Track was emplaced along the structural intersection of major north and northwest trends. The northwest trend includes the steeply inclined bedding and bedding-plane faults of the Mineta formation, and the Mineta and Banco Faults. The north trend includes the Espiritu and Horse Canyon Faults. Horse Mountain is also along the east flank of a large drag fold in the Mineta formation.

Structural intersections must have provided loci of weakness in the surface rocks, and provided channel ways for the magma to approach the surface.

South of Horse Mountain igneous activity is represented by a series of dikes, sills, and one small plug in the evaporites at Roble Canyon. These have all intruded along tension fractures or bedding and are oriented in a northeasterly direction.

The normal faulting of the Soza beds has also provided access for the intrusion and extrusion of andesitic and basaltic lavas.

SUMMARY OF GEOLOGIC HISTORY

Structural and Stratigraphic Events

Several structural and stratigraphic events can be identified in the rocks of the Mineta Ridge area.

The earliest episode of orogenic activity that can be identified is the metamorphism and deformation of the Pinal Schist. This metamorphism has been defined as the Mazatzal Revolution in other areas by Wilson (1939).

Deposition of sedimentary rocks took place during Late Precambrian (?), Paleozoic, and Mesozoic times. Some of these sediments, those of Late Precambrian (?) and Early Paleozoic (?) age were metamorphosed, probably at the same time as the Catalina Gneiss, in Middle Tertiary time. These were probably followed by the emplacement of porphyritic granite and aplitic granite.

These granite stocks are assigned to the Tertiary, based upon their association with the Precambrian (?) and Paleozoic (?) rocks and the Mineta formation, plus radio-isotope dates on other granitic rocks in the Rincon and Santa Catalina Mountains.

The next phase was the extrusion of rhyolite which has been assigned an Early Tertiary (?) age based on its position within the stratigraphic section.

After emplacement and subsequent uplift, erosion of granitic rocks, volcanic rocks, and the meta-sedimentary rocks provided debris for the oldest sediments at Mineta Ridge, the Mineta formation. Several outcrops can be observed in which the Mineta formation is in non-conformable contact upon the porphyritic granite. The basal arkosic conglomerate beds of the Mineta were followed by interbedded mudstones and lacustrine limestones, then by interbedded sandstones, siltstones, and mudstones, in a transitional alluvial environment. The environment gradually shifted back to lacustrine conditions in which were formed interbedded mudstone, gray limestone and beds of black fetid limestone rich in algae and other plant remains. This is the deposit in which a rhinoceros jaw, dated as Late Oligocene to Early Miocene, was recovered and identified by J. F. Lance. These beds were followed by additional clastic and evaporite deposits.

After deposition of the alluvial plain sequence, but prior to deposition of the Soza and Banco beds, a third period of deformation ensued. This later orogenic phase involved vertical uplift of the Rincon Mountain block producing new structural breaks, and probably reactivating movement on older major structural breaks, modifying the contacts of Precambrian (?) and Paleozoic (?) metamorphic, sedimentary rocks and plutonic rocks, and steeply tilting the entire section. The tilting of these sediments induced gravitational adjustments, resulting in small scale bedding plane faults.

This episode produced or re-activated north- and northwest-trending fault orientations in the Paleozoic and Mesozoic rocks, and imposed a northwest orientation on the Mineta formation. Tension joints developed normal to the bedding of the Mineta, i.e., northeast. Some of these joints were converted into faults, displacing the bedding a few inches to several feet.

This set the stage for the next act. The structural intersection of north and northwest-trending faults and open easterly joints allowed andesitic to basaltic magma to move upward forming dikes, sills, plugs, and probable lava flows.

The oldest and most important phase of this igneous activity involved the intrusive emplacement and possible flow of a large volume of Turkey Track Porphyry. Many of the later dikes cut the Turkey Track Porphyry.

The emplacement of these bodies brought to a close the third major structural event, which was followed by unconformable deposition of gravels that make up the thick sequence of the Soza beds.

The last phase of deformation in Pliocene (?) time is evidenced by normal faulting of the Soza beds. This movement resulted in the tilting of these conglomerates to the west, allowing magma to work its way up the fault zone forming intrusions and basaltic lava flows. Upon the eroded surface of the tilted Soza beds, the Banco beds accumulated with angular unconformity. The uplift that provided a renewed energy source for the accumulation of the Banco beds is documented by the angular unconformity.

CONCLUSIONS

The source rocks of the Mineta formation consist principally of granitic rocks, including the porphyritic granite and possibly the aplite described in this report, and volcanic rocks of a general rhyolitic to andesitic composition. Other contributors include the Pinal Schist, and Younger Precambrian (?), Paleozoic and Mesozoic sedimentary and meta-sedimentary rocks that are exposed to the west of the Mineta formation.

Fragments of these rocks were deposited along the base of uplifted source areas on alluvial plains and flood-plains and in lakes as ponding developed. The climatic environment of both source and depositional areas was probably temperate, changing to semi-arid as the later sediments were deposited. The chemical environment of the depositional area was one of oxidation.

The age of the Mineta formation is determined as Late Oligocene based upon the presence of a vertebrate fossil and a radio-isotope date of the Turkey Track Porphyry. The lithologic and structural characteristics of the area also suggest a Middle Tertiary age for the Mineta formation.

The Mineta formation as previously mapped consisted of imbricate thrust sheets. The present interpretation considers these to be small bedding plane faults with normal movement within a conformable and interbedded stratigraphic sequence.

In the area west of the Mineta formation, rocks of Precambrian, Paleozoic, and Mesozoic age occur in fault blocks and some rest with fault contact upon the Catalina Gneiss. Many of these rocks have internal deformation that suggests a formation under gravitational stresses.

APPENDIX

DESCRIPTION OF MEASURED SECTIONS

Section 1

Partial section of the Mineta formation measured at Roble Canyon in the SE 1/4, sec. 30, T. 13 S., R. 19 E., Redington quadrangle, Cochise County, Arizona. Strike approximately N. 45° W., dip approximately 70° NE.

Miocene (?)-Pliocene (?)

Soza beds (unmeasured):

Feldspathic phyllrudite: light gray (N7); cliff former.

Oligocene

Mineta formation:

Unit No.		Thickness in feet	Cumulative thickness in feet
11	Subarkose: brick red, medium grained, moderately sorted; calcite cement; interbedded with fine grained sandstone and siltstone; forms slope with resistant sandstone exposed as ridges; graded bedding and some faint cross-stratification; upper part covered...........................	142	844
10	Subarkose: brick red, medium grained, pebbly, moderately sorted, calcite cement; interbedded with sandy and silty beds of several feet thickness; faintly cross-stratified; strike N. 44° W.; dip 66° NE; lower contact is a normal fault of small displacement........	147	702

Unit No.		Thickness in feet	Cumulative thickness in feet
9	Conglomerate and pebbly sandstone, arkosic: medium reddish brown to maroon; fine to medium grained; calcite cement; moderately resistant, thickly bedded; lower contact conformable, upper contact faulted............................	64	555
8	Conglomerate, arkosic: medium reddish brown to maroon; medium grained, moderately to poorly sorted; calcite cement; graded bedding, faint cross-bedding; interbedded with coarse sandstone: strike N. 45° W., dip 74° NE.......	54	491
7	Conglomerate: feldspathic lithrudite; reddish gray; fine to medium grained; calcite cement; interbedded sandstone..................	12	437
6	Sandstone; feldspathic litharenite; reddish brown to maroon; coarse grained; moderately sorted; pebbly: calcite cement; moderately resistant; graded bedding and faint cross-bedding.....................	4	425
5	Conglomerate: feldspathic lithrudite; medium gray; medium grained; poorly sorted; calcite cement; very resistant; interbedded with coarse sandstone; strike N. 40° W., dip 71° NE...........................	50	421
4	Sandstone: sublitharenite; reddish gray; medium to coarse grained; moderately sorted; calcite cement; graded bedding, conglomerate interbeds.............................	25	371

Unit No.		Thickness in feet	Cumulative thickness in feet
3	Conglomerate, feldspathic lithrudite: medium gray; medium to coarse grained; poorly sorted, calcite cement; very resistant; interbedded sandstone is medium sorted; graded bedding and faint cross-stratification.....................	126	346
2	Conglomerate, lithrudite: light medium gray; very coarse grained; poorly sorted, very resistant; gradational; strike N. 23° W., dip 84° NE.........................	88	220
1	Conglomerate, lithrudite: light gray; very coarse grained; poorly sorted, calcite cement, resistant; graded bedding; lower contact unconformable......................	132	132
	Total of Mineta formation:	844	
	Rhyolite: yellowish gray; many inclusions; flow layers; upper contact unconformable, lower contact presumed faulted................................	21	

Section 2

Partial section of the Mineta formation measured in the NW 1/4, sec. 30, T. 13 S., R. 19 E., Redington quadrangle, Cochise County, Arizona.

Miocene (?)-Pliocene (?)

Soza beds (unmeasured):

Feldspathic phyllrudite: light gray (N7); cliff former.

Oligocene

Mineta formation:

Unit No.		Thickness in feet	Cumulative thickness in feet
3	Gypsum: white; interbedded with silt layers; lower contact gradational, upper contact faulted......	70	1202
2	Conglomerate and interbedded sandstone: grayish red (10R 4/2); poorly to moderately sorted; calcitic cement; upper portion largely covered....................	720	1132
1	Conglomerate: feldspathic lithrudite; medium-light gray (N6); very coarse grained, calcite cement; interbedded with finer-grained layers; lower contact unconformable..........................	412	412
	Total of Mineta formation:	1202	

Rhyolite:

	Yellowish gray (5Y 8/1); inclusions and flow layers; upper contact unconformable, lower contact presumed faulted...........	38

Section 3

Partial section of the Mineta formation measured in the NW 1/4, sec. 30, T. 13 S., R. 19 E., Redington quadrangle, Arizona.

Miocene (?)-Pliocene (?)

Soza beds (unmeasured):

Feldspathic phyllrudite: light gray (N7); ridge former.

Oligocene

Mineta formation:

Unit No.		Thickness in feet	Cumulative thickness in feet
28	Covered:	12	1121
27	Andesitic sill: greenish black; upper and lower contacts covered...	15	1109
26	Siltstone: light reddish brown; gypsiferous; thin bedded, laminated; lower contact gradational............................	29	1094
25	Siltstone: reddish brown; slightly calcareous, thin bedded and laminated.........................	16	1066
24	Siltstone, sandy: grayish green, weathers light-gray green; slightly calcareous; thin bedded, graded with thin sandy beds; upper half covered..........................	216	1050
23	Siltstone, sandy: gray green; calcareous; thin bedded and interbedded with thin brown sandstone layers that weather yellow brown; faint cross-bedding in sandstone...	136	834

Unit No.		Thickness in feet	Cumulative thickness in feet
22	Siltstone: reddish brown; interbedded with fine grained sandstone; medium brick red; calcitic cement; thin bedded; graded bedding........	44	698
21	Siltstone: reddish gray beds and greenish gray beds; calcareous; interbedded with medium grained sandstone; graded..................	17	654
20	Sandstone, arkosic: brick red; medium grained; well sorted, calcitic cement; graded, and slightly cross-bedded; interbedded with finer-grained sandstone and siltstone.........................	25	637
19	Sandstone: reddish brown; coarse grained; similar to unit 20; largely covered....................	32	612
18	Sandstone, pebbly: reddish brown to brick red; coarse grained; moderate to poorly sorted; calcitic cement; well bedded and graded; slightly cross-bedded; section is partially covered..................	36	580
17	Sandstone; pebbly: reddish gray to brick red at top; coarse grained; calcitic cement; forms ledges, graded, and slightly cross-bedded; calcite joint filling; beds of fine sandstone and siltstone interbedded; lower contact faulted..............	47	544
16	Sandstone, arkosic: light red; coarse grained; calcitic cement; well bedded with interbedded siltstone; upper contact faulted...	6	497
15	Sandstone, pebbly: light reddish gray; coarse grained; calcitic cement; miscellaneous rock fragments; imbricated; resistant beds a few inches to a foot in thickness; graded, and faint cross-bedding; contacts are faulted..............	4	491

Unit No.		Thickness in feet	Cumulative thickness in feet
14	Sandstone, pebbly: brick red, weathers to brownish red; coarse grained; calcitic cement; graded with resistant and non-resistant layers; imbricated pebbles; upper contact faulted, lower contact conformable......................	6	487
13	Conglomerate, arkosic: reddish gray; medium grained, poorly sorted; calcitic cement; resistant bedding; pebbly and sandy layers; graded, discontinuous sandy lenses.	23	481
12	Sandstone, pebbly: reddish gray; coarse grained; poorly to moderately sorted; medium bedded, graded, and slightly cross-bedded.............	6	458
11	Conglomerate, arkosic: reddish gray; medium grained; poorly sorted; calcitic cement; resistant; graded............................	43	452
10	Sandstone, arkosic: brick red; medium grained; calcitic cement; thin bedded, semi-resistant; faintly cross-bedded; graded.......	9	409
9	Conglomerate: medium gray; coarse grained (pebbles and boulders), poorly sorted, calcitic cement; imbricated; very resistant and thick bedded; sandy and pebbly matrix...........................	27	400
8	Sandstone, arkosic: reddish gray; medium grained; moderately sorted; calcitic cement; graded, and faintly cross-bedded; interbedded silty layers......................	7	373
7	Conglomerate: medium gray; coarse grained (pebbles and boulders); calcitic cement; very resistant thick bedded units; imbricated; gradational......................	168	366

Unit No.		Thickness in feet	Cumulative thickness in feet
6	Conglomerate: medium gray; calcitic cement; similar to unit 7; upper 32 feet largely covered...	40	198
5	Conglomerate, pebbly: medium gray; poorly sorted; calcitic cement; imbricated; graded bedding.........	4	158
4	Conglomerate, arkosic: medium gray; calcitic cement; boulders to several feet in diameter; very thick bedded; very resistant; a two foot thick pebble bed at 22 feet; gradational contacts.........................	40	154
3	Conglomerate, arkosic: medium gray; coarse grained; similar to unit 2, but contains a larger number of sandy interbeds; lower contact undeterminable....................	64	114
2	Rhyolite: light gray, weathers to reddish gray; contains numerous xenoliths; authogenic pyrite; upper contact is undetermined, lower contact is faulted................	28	50
1	Conglomerate, arkosic: medium gray; coarse grained; large boulders common; poorly sorted, calcitic cement; very resistant, thick bedded; sandy layers are moderately sorted; graded bedding, and faint cross-bedding; contacts faulted....	22	22
	Total thickness of Mineta formation	1121	

Rhyolite (unmeasured):

Light gray, weathers to reddish gray; similar to unit 2; upper and lower contacts presumed to be faulted..........................

Section 4

Partial section of the Mineta formation measured in the NW 1/4, sec. 24, T. 13 S., R. 18 E., Redington quadrangle, Pima County, Arizona.

Miocene (?)-Pliocene (?)

Banco beds (unmeasured):

Conglomerate: pinkish gray (5YR 8/1); calcitic cement; semi-resistant; pebbles are arkosic and two to five millimeters in diameter.

Oligocene

Mineta formation

Unit No.		Thickness in feet	Cumulative thickness in feet
	Upper detrital member:		
22	Sandstone and siltstone: pale maroon; poorly cemented with calcite; thinly bedded; overlain unconformably by the Banco beds....	10	1490
21	Tuff: white to yellowish gray (5YR 8/1); thin bedded, moderately indurated.........................	10	1480
20	Sandstone and siltstone: medium brownish gray (5YR 6/1); calcitic cement; interbedded with dark gray organic limestone; forms slopes....	115	1470
19	Conglomerate: light olive gray (5Y 5/2); interbedded with sandstone and siltstone, grayish red (5R 4/2), and limestone, dark gray (N3); graded bedding..........	70	1355
18	Limestone, algal: dark gray (N3); numerous plant remains; interbedded with sandstone and siltstone; conformable contacts..............	15	1285

Unit No.		Thickness in feet	Cumulative thickness in feet
17	Mudstone and siltstone: light olive gray (5Y 5/2), and light brownish gray (5YR 6/1); flaggy; interbedded with thin beds of sandstone and conglomerate; gradational..............................	440	1270
16	Sandstone, arkosic: medium brownish gray (5YR 6/1); calcitic cement; thinly bedded; one foot thick bed of oolitic limestone near the base.	155	830
15	Sandstone with conglomerate: medium gray (N5); coarse grained; numerous volcanic fragments; calcitic cement; well bedded; graded bedding....................	20	675
14	Sandstone: greenish gray (5G 6/1); weathers maroon; fine grained; calcitic cement; thinly bedded; interbedded with imcompetent mudstone..............................	55	655
	Limestone member:		
13	Limestone, algal: medium light brownish gray (N 6/1); generally badly fractured in outcrop; siltstone interbeds...................	45	600
12	Siltstone: light olive gray (5Y 5/2); very thinly bedded; interbedded with thin beds of limestone, the thickest 1.8 feet.............	218	555
11	Limestone, algal: dark gray (N3); blocky; thickly bedded; contains small nodules of chalcedony........	5	337
10	Siltstone: light olive gray (5Y 5/2); calcareous; thinly bedded; breaks with sharp edged chips......	10	332
9	Limestone, algal: medium brownish gray (N 5/1); thickly bedded.......	8	322

Unit No.		Thickness in feet	Cumulative thickness in feet
8	Siltstone: light olive gray (5Y 5/2); calcareous; thinly bedded; breaks with sharp edged chips......	16	314
7	Limestone, fossiliferous: medium dark brownish gray (N 4/11); abundant algal fragments; thickly bedded; blocky; contains inter-formational breccia................	8	298
6	Siltstone: similar to unit 8.......	8	290
5	Limestone, algal: dark gray (N3); blocky; individual beds two to four feet thick....................	39	283
4	Siltstone: light olive gray (5Y 5/2); calcareous; thinly bedded; breaks with sharp edged chips......	26	243
3	Limestone, algal: medium gray (N5); thickly bedded, massive...........	68	217
2	Siltstone: similar to unit 4.......	21	149
	Conglomerate member:		
1	Conglomerate: feldspathic lithrudite; light olive gray (5Y 5/2); and grayish red (5R 4/2); coarse grained; calcitic cement; thickly bedded; interbedded sandstone; upper contact conformable, lower contact unconformable..............	128	128
	Total thickness Mineta formation	1490	
	Rhyolite:		
	Light yellowish brown; numerous zenoliths and flow layers; lower contact presumed faulted...........	40	

Section 5

Partial section of the Mineta formation measured in the NW 1/4, sec. 3, T. 13 S., R. 18 E., Redington quadrangle, Arizona.

Miocene (?)-Pliocene (?)

Banco beds (unmeasured):

Conglomerate: pinkish gray (5YR 8/1); coarse grained, pebbles are granite fragments two to five millimeters in diameter, calcitic cement; semi-resistant; lower contact concealed.

Oligocene

Mineta formation

Unit No.		Thickness in feet	Cumulative thickness in feet
	Upper detrital member:		
9	Subarkose: maroon to reddish brown; coarse grained, calcitic cement; thin bedded, graded bedding; upper contact with Banco beds concealed; lower contact covered.............	27	700
8	Covered...........................	340	673
	Conglomerate member:		
7	Conglomerate: feldspathic lithrudite; reddish brown; coarse grained with numerous sandy interbeds, calcite cement; graded bedding; strike N 50° W.; dip 65° NE........	21	333
6	Conglomerate: feldspathic lithrudite; largely covered; similar to unit 7...........................	27	312
5	Conglomerate: feldspathic lithrudite; similar to unit 7...........	138	285

Unit No.		Thickness in feet	Cumulative thickness in feet
4	Sandstone, subarkose: reddish brown; coarse grained, pebbly, poorly sorted, calcitic cement; graded bedding, cross bedding......	25	147
3	Conglomerate: arkosic; reddish brown to maroon; medium to coarse grained; calcite cement; very resistant; interbedded sandstone; sandy beds show graded bedding and faint cross-bedding; strike N 50° W., dip 67° NE....................	34	88
2	Conglomerate: feldspathic lithrudite; maroon to red brown; coarse grained, poorly sorted, calcitic cement; thickly bedded; gradational contacts..........................	8	80
1	Conglomerate: feldspathic lithrudite; maroon to reddish brown; coarse grained, poorly sorted, calcitic cement; thickly bedded; interbedded sandstone is gradational with the coarser layers; lower contact with granite is covered; strike N 50° W., dip 55° NE............................	80	80
	Total thickness of Mineta formation	700	

Section 6

Partial section of Younger Precambrian (?) and/or Lower Paleozoic (?) rocks measured in the SE 1/4, sec. 8, and the SW 1/4, sec. 9, T. 13 S., R. 18 E., Bellota Ranch quadrangle, Pima County, Arizona.

Pre-Mineta

Granite: porphyritic; grayish orange pink (10R 8/2); holocrystalline, phaneritic, with a heterogranular texture.

Younger Precambrian (?) and/or Lower Paleozoic (?):

Unit No.		Thickness in feet	Cumulative thickness in feet
6	Quartzite: olive gray (5Y 4/1); weathers to moderate reddish brown (10R 4/6); medium grained; thinly laminated; interbedded with schist; pale reddish brown (10R 5/4); coarse grained; lower 75 feet has erratic orientations and contains aplite dikes and thin slivers of granite; contact is covered, but presumed to be fault...............	427	1278
5	Quartzite: similar to unit 6; largely covered, but beds up to two feet crop out along the dip slope; 18 inch bed of marble crops out seven feet from top................	80	851
4	Quartzite: pale reddish brown (10R 5/4) to brownish gray (5YR 4/1); medium grained; laminated; lower 30 feet interbedded with marble; light gray (N7); both rocks are highly contorted; strike N. 75° E., dip 19° NE.............	124	771
3	Marble: light gray (N7), weathers to pale red (10R 6/2); fine to medium grained; thin bedded; interbedded with quartzite similar to unit 4; contorted bedding; strike N. 70° E., dip 20° NW.............	153	647

Unit No.		Thickness in feet	Cumulative thickness in feet
2	Marble: greenish gray (5GY 6/1); fine grained; cherty and sandy in some beds; bedding about one feet thick; contorted bedding; interbedded quartzite is cross-bedded; large intervals are covered; fault in middle of section changing strike from N. 80° E., to N. 60° W.	384	494
1	Marble: greenish gray (5GY 6/1); fine grained; cherty; bedding about two feet thick; finely laminated and contorted; upper 36 feet is covered; strike N. 80° E., dip 48° NW; lower contact with Catalina Gneiss is covered..................	110	110
	Total section	1278	

Soza Canyon Section

Younger Precambrian (?) and/or Lower Paleozoic (?) rocks measured in Soza Canyon from the SE 1/4, sec. 15, to the SW 1/4, sec. 11, T. 13 S., R. 18 W., Redington quadrangle, Pima County, Arizona.

Oligocene

Mineta formation:

Conglomerate, sandstone, and limestone:

Younger Precambrian (?) and/or Lower Paleozoic (?)

Unit No.		Thickness in feet	Cumulative thickness in feet
16	Marble: white (N9); medium grained; minor amounts of quartz and chert, bedding about one foot thick; highly contorted..................	125	2377
15	Schist: light gray (N7), thinly foliated, micaceous................	25	2252
14	Quartz sill: pinkish gray (5YR 8/1), weathers pale red (10R 6/2); contains minute pink feldspars; very resistant cliff former.............	34	2227
13	Diabase sill: moderately resistant.	122	2193
12	Conglomerate: gray to brownish gray; well rounded and stretched quartz and limestone pebbles up to one foot length, most measure several inches in length...........	56	2071
11	Marble: very light gray (N8); rusty brown weathered surface; fine-grained; massive; resistant; becomes sandy with quartz pebbles and abundant chert in upper part.......	85	2015

Unit No.		Thickness in feet	Cumulative thickness in feet
10	Marble: dolomitic; greenish gray (5G 6/1); yellowish gray on weathered surfaces; fine grained; very thick bedded; numerous sandy layers and chert layers; intensly folded and contorted; gradational contacts..........................	80	1930
9	Marble: dolomitic; greenish gray (5G 6/1) to light bluish gray (5B 7/1); fine grained; massive; thick bedded; sandy interbeds; contorted; slaty in the upper part.	255	1850
8	Marble: dolomitic; light medium bluish gray (5B 6/1); medium grained; pebbly....................	40	1695
7	Marble: medium dark gray (N4); fine grained; flaggy; becomes massive in upper part and similar to unit 8; red shale at base..................	175	1645
6	Fault zone.........................	55	1470
5	Marble: light gray (N7), to medium light gray (N6), weathers greenish gray and weathered surface appears sandy; fine grained; medium to thickly bedded, laminated, forms broken cliffs and slopes; fault 85 feet from the top; contacts faulted...........................	590	1418
4	Marble: greenish gray (5GY 6/1), weathers to light olive gray (5Y 6/1), and a rough sandy texture; fine grained; very resistant; contorted bedding; abundant quartz layers in lower part...............	395	828
3	Marble: light gray (N7); weathers to light olive gray (5Y 6/1) and a rough sandy texture; fine grained; finely laminated; massive; resistant; interbedded with sandstone and chert lenses; sandstone is slightly		

Unit No.		Thickness in feet	Cumulative thickness in feet
	cross-bedded; contorted; upper 45 feet is largely covered............	245	433
2	Marble: medium greenish gray (5GY 5/1); highly altered and contorted; stretched quartz pebbles; very resistant; lower contact with Catalina Gneiss originally faulted, but disturbed by metamorphism......	155	188
	Catalina Gneiss: fault block separating unit 1 and 2.		
1	Marble: light greenish gray (5GY 8/1); fine grained; highly altered; numerous stretched quartz pebbles and lenses; massive; both lower and upper contacts with Catalina Gneiss; upper contact originally faulted, lower contact originally depositional, disturbed by metamorphism..	33	33
	Section thickness..................	2377	

Roble Canyon Section

Section measured in the NE 1/4, sec. 36, T. 13 S., R. 18 E., to the SE 1/4, sec. 30, T. 13 S., R. 19 E., Redington quadrangle, Cochise County, Arizona.

Precambrian:

Pinal Schist:

Schist and phyllite: medium gray; muscovite rich; contains beds of incompletely altered sandstone and shale.

Paleozoic and Cretaceous (undifferentiated):

Unit No.		Thickness in feet	Cumulative thickness in feet
20	Conglomerate: calcirudite; light to medium gray; poorly sorted, fragments up to several feet diameter consist of fossiliferous and unfossiliferous limestone, sandstone, quartz, and chert; calcite cement; very resistant, very massive and very thick bedded (10 to 12 feet $\pm$); gradational with finer and coarser beds; upper contact faulted with Pinal Schist, lower contact probable fault....................	415	2015
19	Sandstone: buff to dark gray; medium grained; calcite cement; medium bedded, contains limonite concretions that weather loose; interbedded with black shale that is folded and contorted; upper contact is a probable fault........	193	1636
18	Sandstone: buff; interbedded with black shale, and gray to buff limestone; calcitic cement; medium bedded; gradational units; upper 36 feet is covered.................	107	1443
17	Covered............................	25	1436

Unit No.		Thickness in feet	Cumulative thickness in feet
16	Conglomerate: calcirudite; light to medium gray; identical to unit 20 except finer grained; scour and fill; interbedded with black shale and light gray, cross-bedded sandstone; strike N. 25° W, dip 40° NE.	68	1411
15	Covered, probable fault............	6	1343
14	Limestone: buff; fine grained; medium bedded; both upper and lower contacts covered, probable faults; strike E-W, dips 40° N.............	30	1337
13	Covered, probable fault............	42	1307
12	Conglomerate: calcirudite; similar to unit 20 except not as coarse grained, thinner bedded, and a larger portion of the section consists of interbedded sandstone.....	224	1265
11	Sandstone: maroon and buff; fine grained; interbedded with buff limestone; upper contact covered, lower contact probable fault.......	160	1041
10	Sandstone: white; weathers to rusty brown; medium grained; calcitic cement; thickly bedded; cross-bedded; upper contact is covered, lower contact probable fault.......	55	881
9	Conglomerate; medium gray; medium grained; calcitic cement; thick bedded (to four or five feet); rounded pebbles of white and black quartzite; upper contact is probable fault.............................	33	826
8	Covered............................	72	793
7	Limestone; shaly: black; weathers dark grayish black; upper contact is covered.........................	8	721

Unit No.		Thickness in feet	Cumulative thickness in feet
6	Limestone: calcarenite; medium gray; pebbly; thick bedded; appears similar to some fragments found in unit 20..............................	70	713
5	Limestone: calcarenite; medium gray color; fine to medium grained; thin bedded; becomes shaley in upper part and is darker gray; gradational into upper and lower units.............	40	643
4	Conglomerate: calcirudite; medium gray; coarse to very coarse grained; appears identical with unit 20; fault 65 feet from top; upper contact gradational, lower contact probable fault....................	205	603
3	Limestone: crinoidal biosparite; medium gray; coarsely crystalline; massive, ridge former; drag folding near lower contact; both contacts covered but presumed to be faulted.	160	398
2	Sandstone: deep maroon; slightly mottled with a bleaching of color; fine grained; thin bedded; numerous calcite-filled fractures; appears internally disrupted; lower contact gradational, upper contact covered, thought to be fault...............	219	238
1	Sandstone: buff; weathers reddish-buff; medium grained; calcitic cement; thick bedded; overlies Catalina Gneiss with presumed faulted contact; contact strikes N 25° W, dip 44° NE...............	19	19
	Total section.....................	2015	

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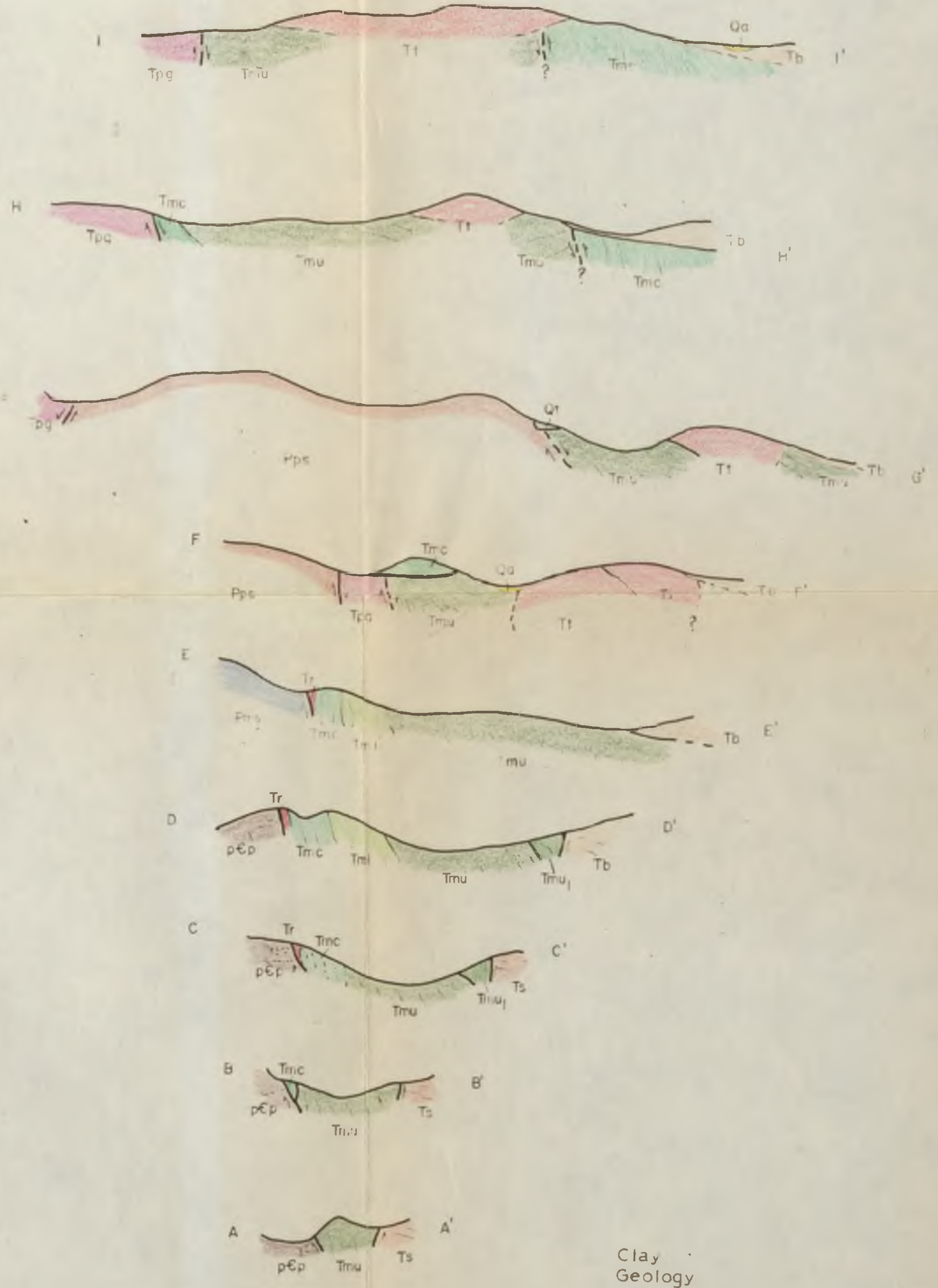
FIGURE 4
GEOLOGIC CROSS SECTIONS OF THE MINETA FORMATION



Clay
Geology
Dissertation
1970

Geology by D. Clay

Figure 4

FIGURE 3
GEOLOGIC MAP OF THE MINETA-WHITE RIDGE VICINITY

PIMA AND COCHISE CO., ARIZONA