UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

GEOLOGY OF THE SOUTH-CENTRAL PART OF THE NEW RIVER MESA QUADRANGLE, CAVE CREEK AREA, MARICOPA COUNTY, ARIZONA

By

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Open-File Report

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ABSTRACT

A small area north of Cave Creek, Arizona, contains key stratigraphic and structural information bearing on the Cenozoic development of the mountain and desert regions of Arizona. The area contains elements of the two physiographic regions. The northern and western parts are high mesas containing flat lying interbedded Tertiary volcanic and sedimentary strata. These deposits can be traced southward across the physiographic boundary where they are tilted and down faulted into the desert region.

Seven bedrock units were revealed by geologic mapping at 1:12,000 scale. They are, in ascending stratigraphic order: (1) a basement of Precambrian schist, granitic rock, and diabase (300 meters exposed), (2) fanglomerate derived from the crystalline rocks, of probable early and middle Oligocene age (0-152 m thick), (3) andesite of possible middle Oligocene age (225 m thick), (4) interbedded sediments and volcanics of Oligocene and Miocene age (30-320 m thick), and (5) resistant cliff forming basalt flows of middle Miocene age (125-180 m thick) that cap the high mesas.

Regional uplift of an exposed Precambrian terrane occurred ∿38-30 m.y. ago, accompanied by erosion of the basement and deposition of fanglomerate. Regional volcanism began ∿30 m.y. ago, apparently with the extrusion of andesite, followed by deposition of alkali basaltic flows, tuff, lake beds, and alluvium in one or more irregularly closed basins, formed as a result of faulting and volcanism. A transition from calc-alkali and alkali volcanism to olivine basalt volcanism of the Hickey

Formation occurred approximately 15 m.y. ago. The interval 14.5-11 m.y. saw the deposition of olivine basalt flows of the New River Mesa formation, which cap the high mesas and correlate with basalt of the Hickey Formation. Topographic development of the mountain-desert region boundary occurred with collapse of the basalts of the New River Mesa formation into the desert region. This may have occurred at the time of initial subsidence of the Verde basin, ∼7.5 m.y. ago.

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Chapter 1

INTRODUCTION

PURPOSE

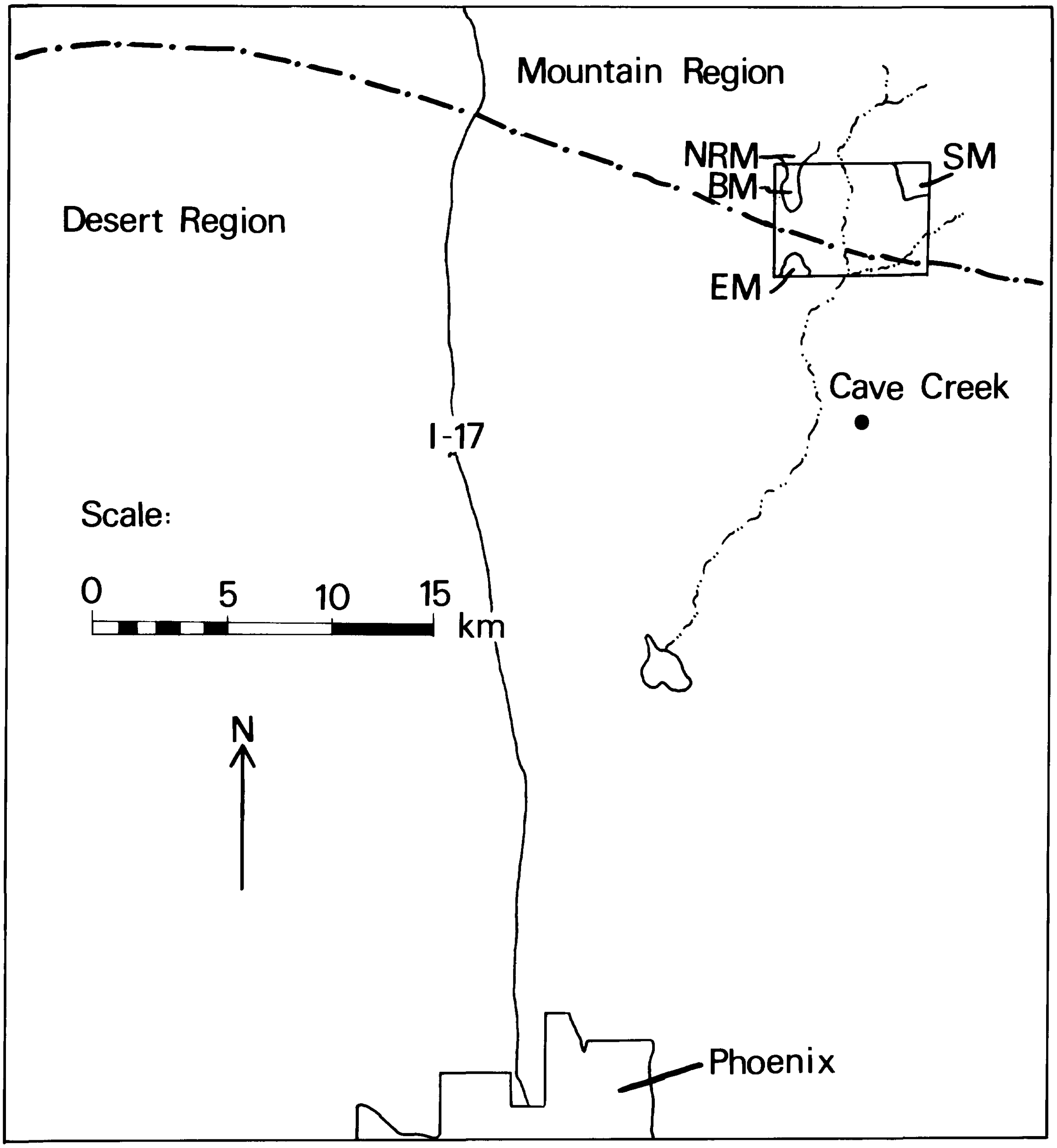
The purpose of this work was to investigate the Cenozoic geologic history of an area that includes the structural boundary (Transition Zone) between the Colorado Plateau and the Basin and Range Provinces in Arizona. This boundary also marks the physiographic boundary between the mountain and desert regions of Arizona (Ransome, 1919, 1923, 1932; Wilson, 1962). By detailed geologic mapping and the measurement of stratigraphic sections, it was hoped that key information on the structural and physiographic development of the provinces could be obtained. It was also hoped that information pertaining to the sedimentary and depositional environments of the Tertiary rocks could be obtained.

LOCATION AND ACCESS

The area of study is about 45 km north of Phoenix and 9 km north of the town of Cave Creek, Arizona (Plate 1). Approximately rectangular in shape, it encompassess 39 square km and is 6.9 km in an east-west direction and 5.5 km in a north-south direction. The area lies in the south-central part of the New River Mesa 7.5' quadrangle, bounded by latitude 33°53'20"N to 33°56'22"N, and longitude 111°59'03"W to 111°54'31"W.

Plate 1

Index map showing physiographic features within the map area; BM = Black Mesa, EM = Elephant Mountain, NRM = New River Mesa, and SM = Skull Mesa, the terms Desert and Mountain Regions are after Ransome (1919, 1923, 1932), and Wilson (1962).



Index Map

Pl. 1: New River Mesa quad OF Rept.

Access to the northern and southern parts of the area is by Forest Service Road 48, which follows the drainage from Cave Creek. The western and eastern parts, and the high mesas, are accessible only by foot or horseback.

METHOD OF STUDY

Field work was begun in March 1977 and completed in March 1978. Geologic mapping using aerial photography was carried out at 1:24,000 scale. Photographs GS VAOB (5-63)-(5-66) and (5-45)-(5-48) at 1:32,000 scale provided stereoscopic coverage of the area. The geologic map was compiled at 1:12,000 scale on a stable topographic base, employing the Analytical Plotter Coordinatograph (AP/C) at the U.S. Geological Survey's Field Center, Flagstaff, Arizona.

Five stratigraphic sections were measured using a Jacob staff and Brunton compass (see Appendix A). The terminology of McKee and Weir (1953) was used for the description of stratification and cross-stratification of the tuffaceous and fanglomerate units. Sixty thin sections were made of representative materials for petrographic description. The classification scheme of Wentworth and Williams (1932) was used for the description of tuffaceous rocks. Colors were assigned using the Geological Society of America rock color chart.

GEOMORPHOLOGY

The northern and western parts of the area are high mesas consisting of essentially flat-lying interbedded sedimentary and volcanic strata of Tertiary age. The southern and eastern parts are small hills in which Precambrian metamorphic and intrusive rocks, and middle

Oligocene (?) andesitic rocks are exposed. The Precambrian rocks are remnants of a once large mountain system that extended diagonally across Arizona (Wilson, 1939). Quaternary alluvial deposits and fault block topography typical of Basin and Range terrain are encountered in the southern part of the area.

Cave Creek, an intermittent stream, bisects the area in an essentially north-south direction, and is the principle stream course in the area. It has an average fall of 18 meters per kilometer toward the south, and presently occupies a narrow channel within a relatively broad valley. Precambrian units are exposed in most places along the channel.

Maximum relief in the area is 737 meters. The highest point, 1432 m above sea level, is on Black Mesa near the western boundary. The lowest point, 695 m, is on Cave Creek at the southern margin.

PREVIOUS WORK

Early geologic work was done in conjunction with mining for gold, silver, copper, and iron ore in Precambrian schist and along the margins of Precambrian granitic bodies (Ricketts, 1887; Lewis, 1920). Lewis (1920) mapped the Precambrian rocks of the area at 1:187,500 scale. He described the various units and how they related to mineralization, but attempted no correlation with other Precambrian units of Arizona.

Reconnaissance geologic mapping in the area was done for the geologic map of Maricopa County and Arizona State geologic map by Wilson and others (1957). Townsend (1967) geologically mapped an area immediately southwest of the study area for the Cave Creek Municipal Park.

Lindsay and Lundin (1972) described an oreodont from a lithic tuff near the base of an interbedded volcanic and sedimentary sequence exposed near Cave Creek and reported a K-Ar age of 22.4 ± 2.6 m.y. (early Miocene) for a basaltic flow that directly overlies the tuff in which the oreodont was found.

From U-Pb zircon dating, an age of 1770 ± 10-1820 m.y. is reported for Precambrian rocks north of the area of study (Anderson and others, 1971), and this age may apply to similar Precambrian rocks of the New River Mesa quadrangle. Anderson (1978), investigating possible Precambrian volcanic-plutonic arc sequences extending across central and southeastern Arizona, has proposed four major belts, one of which includes Precambrian rocks of the Cave Creek-New River area.

Chapter 2

STRATIGRAPHY

INTRODUCTION

Seven bedrock units, ranging from Precambrian to late middle Miocene have been mapped geologically at 1:12,000 scale (Figure 1). Their ages range from Precambrian to late middle Miocene. Their general descriptions and thicknesses are summarized in Plate 2. The Precambrian basement, consisting of metamorphic and intrusive rocks,is locally overlain by a fanglomerate of probable early to middle Oligocene age, and by andesite of probable middle Oligocene age. These units crop out topographically low in the map area. In slopes leading to the high mesas are interbedded lakebed, basalt, and tuff of the Chalk Canyon formation of middle Oligocene to middle Miocene age. A series of middle Miocene basalt flows cap the high mesas, forming prominent cliffs. Quaternary colluvium, talus, and landslide deposits are found on the slopes and at the base of the mesas and Holocene alluvium is found along Cave Creek.

PRECAMBRIAN ROCKS

Three types of Precambrian rock; schist, granitic rocks, and diabase, were mapped (Figure 1, Plate 2). Precambrian rocks are extensively exposed along Cave Creek and in low hills in the southern and eastern parts of the area. These rocks, in most exposures are deeply weathered and stained by iron and manganese oxides.

Plate 2

Generalized stratigraphic column.

Miocene	Mnr	125–180m	Basalt; cliff–former
	MOccu	0–138m	Lakebed,tuff&trachybasalt
	MOccl	30–303m	Tuff, olivine basalt & trachybasalt
Oligocene	Oa	~225m	Andesite
	Ofg	0–152m	Fanglomerate
Precambrian	p€d	>300m	Diabase
	p€g		Granitic rocks
	p€s		Schist

Scale:

150m

0

Pl. 2: New River Mesa quad
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Schist

Chlorite schist is the most abundant Precambrian rock in the area, and has resulted from regional metamorphism of shale, sandstone, and rhyolitic to basaltic flows (Wilson and others, 1959; Anderson and others, 1971; Anderson and Blacet, 1972; Anderson and Silver, 1976). Outcrops occur in the southeastern and northern parts of the area, where the schist forms steep hills. The schist is dusky green (5G 3/2) in color when fresh, and weathers to a dark yellowish-brown (10YR 4/2). Quartzite beds interbedded in the schist have a consistent strike of N42°-45°E and are presumably evidence of relict bedding (Lewis, 1920).

Thin section analysis reveals that coloration of the schist results from abundant chlorite and minor epidote. Grain types include abundant chlorite, quartz, feldspar, and scattered lithic rock fragments and epidote. The grains average less than 0.75 mm in size. Chlorite grains display a preferred orientation along cleavage trends (see Structure, Cleavage, Plate 9). Fracturing and suturing is commonly present in the quartz. Plagioclase, displaying albite and carlsbad-albite twinning, is the most abundant feldspar, with subordinate potassium feldspars. Alteration of the feldspars to clay and calcite can be observed in some grains. The lithic rock fragments consist of very fine-grained quartz and potassium feldspar. Epidote is found exclusively in association with chlorite and probably represents a alteration produce of clay minerals during regional metamorphism.

Interbedded with the schist is slate, phyllite, and quartzite. The slate and phyllite are mostly grayish olive green (5GR 3/2) and very dusky purple red (5P 2/2) in color. Kink folding and cleavage can be observed in some of these units in the field (see Structure, Cleavage,

Plate 9). The quartzite is very pale orange (10YR 8/2) where fresh, and weathers to a grayish orange (10YR 7/4). It consists dominantly of very fine-grained quartz, and contains subordinate potassium feldspar and rare cubes of pyrite. The quartzite in some cases, is observed as prominent beds, 5 to 7 meters thick, which on aerial photographs, can be traced for several kilometers.

The schist in the Cave Creek area is similar to, and can be correlated with Precambrian schist elsewhere in central Arizona (Lansphere, 1968; Anderson and others, 1971; Anderson and Blacet, 1972; Martinsen, 1975; Anderson, 1978). Anderson and others (1971); Anderson and Silver, 1976) have dated similar rocks in the Jerome area at 1770 $\pm$ 10 m.y., which presumably is the age for schist of the Cave Creek area. Such an age would place the Cave Creek schist in the Yavapai Series, a provincial time-stratigraphic assignment defined as the interval from 1770 $\pm$ 10 m.y. to 1820 m.y. (Anderson and Creasy, 1958; Lansphere, 1968; Anderson and others, 1971; Anderson and Blacet, 1972; Anderson and Silver, 1976). Regional metamorphism which produced the schist presumably occurred 1760-1790 m.y. ago, Anderson and others (1971) and Anderson and Silver (1976).

Granitic Rocks

Two types of granitic rocks; quartz monzonite and quartz diorite, are found in the area. Both have intruded the schist. Outcrops occur in the central and southwestern parts of the area, where the granitic rocks form steep hills. The best exposures are along Cave Creek and its tributaries.

In hand specimen, the quartz monzonite is phaneritic and non-porphyritic. It is grayish orange pink (10YR 8/2) when fresh. However, most exposures are stained by hematite producing a pale reddish brown (10R5/4) color. The quartz monzonite consists dominantly of quartz, potassium and plagioclase feldspar, and subordinate biotite (altered to chlorite).

In thin section the quartz monzonite displays a hypidiomorphic-granular texture. Grain size average 2.5 mm. Orthoclase is the major feldspar, and plagioclase, perthite and microcline are subordinate. The plagioclase feldspar is oligoclase and has an average composition of An_{28}. The feldspar grains are anhedral to subhedral. Potassium feldspar displays abundant carlsbed-albite twins. Some alteration to clay or calcite is observed in all feldspar grains. Some of the quartz grains are sutured and exhibit undulose extinction patterns as a result of stress during the rock's history. Graphic and myrmekitic textures are abundant in the quartz. Sericitization is observed in some quartz grains especially along fractures. Chlorite is found scattered through the thin sections observed and has presumably formed from the alteration of biotite. No conclusive evidence for metamorphism in the quartz monzonite can be observed in hand specimen or petrographic analysis.

The quartz monzonite locally is intruded by a dense, grayish olive green (5G 3/2) rock. In hand specimen the rock is phaneritic and non-porphyritic. Plagioclase feldspar occurring as white laths in a groundmass of mafic minerals that have been altered to chlorite can be observed with the aide of a hand lens and in thin section. No firm identification can be made, because of abundant alteration, but the mineralogy is suggestive of a diabase.

Quartz diorite, texturally phaneritic and greenish black (5GY 2/1) in color, is found irregularly distributed throughout the quartz monzonite. The greenish color of the rock reflects alteration of mafic minerals to chlorite and epidote.

Thin section analysis of the quartz diorite reveals a hypidiomorphic-granular texture and an average grain size of 1.5 mm. Quartz is abundant as subhedral and euhedral grains, comprising more than ten percent of the total grains observed (visual estimate). In some cases it has been altered to sericite. Some minor fracturing of quartz grains is observed. Andesine (An_{32}) is the dominant feldspar and potassium feldspar and perthite are subordinate. The feldspars display abundant albite and carlsbad albite twinning and have been altered in some instances, to clay.

The exact age of the quartz monzonite and quartz diorite intrusions are not known, but isotopic ages for granitic rocks of central and southern Arizona, ranging from 1375 to 1820 m.y. have been reported by several workers (Damon and others, 1962; Livingston, 1962a, b; Livingston and others, 1967; Livingston and Damon, 1968; Anderson and others, 1971). The Ruin quartz monzonite, northeast of the map area in the Sierra Ancha and Bronco Ledges regions, has been dated by K-Ar on biotite and by the U-Pb isotopic method on zircons at 1420 m.y. (Livingston, 1962a, 1962b; Livingston and others, 1967; Livingston and Damon, 1968). The relative proximity and similar composition of the Ruin quartz monzonite, suggest a similar age for the Cave Creek intrusions.

Diabase

Diabase dikes and sills intrude the schist and granitic rocks. Such intrusions have not previously been reported from the area. The diabase is nonporphyritic and phaneritic, with a "salt and pepper" appearance and greenish black (5G 2/1) color. Elongate greenish black prisms of hornblende are the most obvious phenocrysts. Some are as much as 2 cm in length. Feldspar occurs as white laths interstitial to the hornblende. Other common minerals include epidote, calcite, and chlorite. A pronounced baked zone, medium light gray (N6) in color separates the diabase from the country rock that it intrudes. The baked zone is dense and microcrystalline. The diabase does not appear to have undergone the metamorphism that has effected the schist and granitic rocks.

Petrographic analysis reveals that the diabase has a hypidiomorphic texture and an average grain size of 3 mm. Hornblende is the dominant phenocryst and occurs as subhedral to euhedral crystals. It is green to greenish brown in color and displays strong biregringence. The hornblende has formed at the expense of pyroxene (augite) presumably as the result of reactions within the magma, and in places has been altered to epidote and chlorite (Williams, Turner and Gilbert, 1954). Both potassium and plagioclase feldspars are present. Extensive alteration of the feldspars to clay, calcite, sausserite, and sericite has occurred. Alteration is so great that anorthite contents of the plagioclase laths could not be determined. Magnetite is the only accessory mineral and it occurs interstitially or as subhedral to euhedral inclusions in hornblende.

The exact age of the diabase dikes and sills is unknown. But similar diabases have been reported and dated at 1150-1200 m.y. by several workers throughout central Arizona (Silver, 1960; Damon and others, 1962; Livingston and Damon, 1968; Smith and Silver, 1975). It is possible that the diabase found in the Cave Creek area is similar in age to these diabases.

TERTIARY ROCKS

Tertiary deposits include, in ascending stratigraphic order: (1) a fanglomerate of probable early to middle Oligocene age, (2) local andesite flows of probable middle Oligocene age, (3) interbedded lakebed, basalt flows and tuff of middle Oligocene to middle Miocene age (Chalk Canyon formation) and (4) flows of the middle Miocene New River Mesa formation, which cap the high mesas. Together, these deposits have a thickness of more than 800 meters.

Fanglomerate

Unconformably overlying the Precambrian rocks, and unconformably underlying the Chalk Canyon formation (see Chapter 2, Stratigraphy, Chalk Canyon formation), is a deposit consisting of angular to subrounded, poorly sorted, pebble to boulder size Precambrian crystalline and metamorphic detritus, interbedded with finer, better sorted material. The detritus in this deposit include Precambrian schist, slate, phyllite, quartz monzonite, quartz diorite, and diabase (see Appendix A, Measured Sections, Skull Mesa, West Central units 1 and 2, Southwest unit 1, and New River Mesa unit 1). The detritus, which is not weathered or rotted, was derived from subjacent Precambrian rocks. Outcrops of this deposit are found at the base of high mesas in the northern and eastern parts of the area.

Bull (1972) has described in detail the criteria for recognition of alluvial fan sequences or fanglomerates. Some of the criteria include: (1) alluvial fans are generally oxidized, (2) they have a variety of deposition types, (3) alluvial fans display a great variety in sorting and particle size, and (4) they commonly consist of thick sequences of water laid deposits. The deposit found in the map area was examined using these criteria. Outcrops of the deposit are characterized by steep slopes and cliffs (Figure 2a) and have been oxidized to moderate reddish orange (10YR 6/6) color (Bull's criteria (1)). The deposit is at best crudely stratified. However, in the southern and western parts of Skull Mesa, poorly-sorted, pebble- to boulder-sized material is interbedded with well bedded coarse-grained sandstone containing scattered pebbles (see Appendix A, Measured Sections, Skull Mesa, West Central, unit 1 and Southwest, units 1 and 2), (Bull criteria (2) and (3)).

Coarser-grained materials (pebble- to boulder-size) are set in a matrix of clay stained by iron oxides (further evidence for Bull's criteria (1)). Finer material is in turn cemented by iron-stained clay and calcite cement.

A maximum thickness of 152 meters is measured, for the deposit, in Chalk Canyon. The well-bedded nature, abundant cross stratification, and crude rounding of most of the grains in the finer deposits indicates probable deposition by water (Bull's criteria (4)). It would appear from comparison with Bull's criteria for alluvial fans, that this deposit is a fanglomerate.

Mid-Tertiary fanglomerates interbedded with fluviatile arkosic sandstones occur throughout central and southern Arizona (Lasky and Webber, 1949; Wilson, 1962; Stuckless and Sheridan, 1971; Sheridan, 1978; Eberly and Stanley, 1978; Gomez and Elston, 1978; Elston, personal communication, 1978). Fanglomerate deposits similar in lithology and physical properties to those in the map area are found overlying the Precambrian rocks 35 km to the north in the Bloody Basin (Gomez and Elston, 1978; Elston, personal communication, 1978). Stuckless and Sheridan (1971) report an

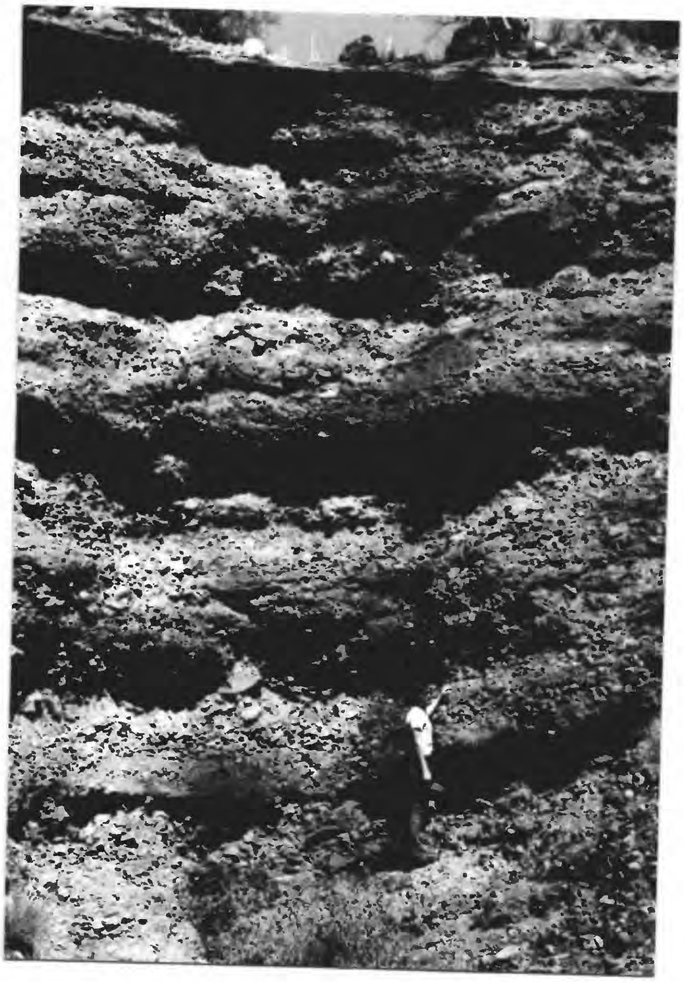

Figure 2

Photographs of pre-volcanic fanglomerate

(a) General view, showing crude stratification

Fig. 2a: New River Mesa quad
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Figure 2

Photographs of pre-volcanic fanglomerate

(b) Closeup

New River Mesa quad
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arkosic conglomerate in the Superstition Mountains of south-central Arizona, and this conglomerate predates volcanism in the area of the Superstition Mountains. Potassium-argon ages indicate that volcanism began approximately 29 million years ago (mid-Oligocene) (Stuckless and Sheridan, 1971; Sheridan, 1978). The arkosic conglomerate is believed by them to be time equivalent to the White Tail Formation of early mid-Oligocene age (Ransome, 1904, 1919; Peterson, 1954; Heindl, 1958, Melton, 1965). Fluviatile arkosic sandstones and interbedded fanglomerates, of Eocene to late Oligocene age, are common in Cenozoic basins throughout the desert region of southwestern Arizona (Lasky and Webber, 1949; Eberly and Stanley, 1978).

The poor sorting, large particle size, and angular nature of the clasts indicate that the fanglomerate of the Cave Creek area has undergone little transportation (Figure 2b). Deposition presumably occurred following an increment of uplift that resulted in a sharply irregular topography. No clasts of volcanic origin have been found in the fanglomerate, indicating that its deposition locally predates volcanism of Tertiary age (Damon, 1964, 1971).

Andesite

A series of andesite flows found in the map area have been assigned a Cretaceous-Tertiary age on the Arizona state geologic map (Wilson and others, 1957). These rocks lie unconformably on the Precambrian schists and granitic rocks and are overlain by tuff and basalt of the Chalk Canyon formation. The andesite is found as plugs and associated short flows. The rock is deeply weathered in most hillside exposures. It is characteristically grayish orange in color (10YR 7/4). In most places it is an andesitic porphyry (Jackson, 1970; p. 292), that has a densely microcrystalline, medium gray (N5) groundmass (see Appendix B, Andesite). Hornblende is the most obvious phenocryst, occurring as elongated, greenish-black prisms that have poorly developed terminations. Some hornblende phenocrysts are as large as 7 mm in length. Dark-green, stubby prismatic phenocrysts of pyroxene are subordinate. Xenoliths of badly altered wall rock are found locally. Dense, fine-grained aggregates of greenish crystals are also present at places, and may record the deuteric alteration of feldspar to saussurite, an albite-epidote mixture (Jackson, 1970).

From stratigraphic relations, the andesite predates all other Tertiary volcanic rocks of the region. In the map area (Figure 1) basalt and tuff of the overlying Chalk Canyon formation can be seen to lap onto and against andesite plugs north of Elephant Mountain. The contact between the andesite and Chalk Canyon is sharp, and no soil or zone of weathering was observed. A clear stratigraphic relationship between the andesite and fanglomerate can not be determined from field relations because the two units are not in direct contact. However, andesite clasts have not been observed in the fanglomerate, even where exposures of the two units are only 150 meters apart. The lack of andesitic clasts, and the presence of a sharp unweathered contact with flows of the Chalk Canyon formation suggest that the andesite flows are younger than the fanglomerate and may reflect the initial phase of middle Tertiary volcanism, in the map area.

The exact age of the andesite is not known. However, it appears to postdate the fanglomerate of early to middle Oligocene age (see Chapter 2, Stratigraphy, Fanglomerate) and predates the Chalk Canyon formation of middle Oligocene to middle Miocene age (see Chapter 2, Stratigraphy, Chalk Canyon formation, Age and Correlation). From these lines of evidence a middle Oligocene age is postulated for the andesite.

Deposits characterized by chaotic arrays of subrounded cobbles and boulders of andesite are found in former topographic lows between and on the slopes of the andesitic plugs. Some boulders are as much as 1.5 meters in diameter.. These deposits are similar in characteristics to those described by Parsons (1969) as mudflows. The presence of round andesitic rock fragments in a clay matrix indicates that these mudflows probably took place after solidification of the andesite lava. This suggests that the mudflows are sedimentary deposits and not lahars which form as the result of primary volcanic activity. The mudflows in the map area predate the middle Oligocene to middle Miocene Chalk Canyon formation (see Chapter 2, Stratigraphy, Chalk Canyon formation, Age and Correlation). This stratigraphic relation is best observed at Sugarloaf Mountain where the mudflow is overlapped by basal beds of the Chalk Canyon formation (Figure 1 and Appendix A, Sugarloaf, unit 1).

Chalk Canyon Formation

Introduction. The high mesas are underlain by interbedded sedimentary and volcanic deposits and are here named informally the Chalk Canyon formation, for exposures in Chalk Canyon,a tributary to Cave Creek in the map area (Figure 1). Unconformities are recognized at the base and top of the formation and an unconformity within the formation allows it to be subdivided into lower and upper members. Rock types within the two members are similar and therefore are discussed together. The type section is designated in west central Skull Mesa and is described in Appendix A. Exposures of the Chalk Canyon formation are found throughout the area with excellent exposures in the slopes beneath Black Mesa, New

River Mesa, and Skull Mesa (Figures 1 and 3). The overall thickness of the formation changes little from west to east, although large differences are seen in the thickness of the members. Strata of the Chalk Canyon formation thin and wedge out to the south and terminate against Precambrian rocks and extrusive andesites. A maximum thickness of more than 300 meters is found near Black Mesa and New River Mesa (Figure 1).

General Makeup. The lower member consists of interbedded basalt, trachybasalt, and tuff. On New River Mesa and Black Mesa, the lower member consists of five units (see Appendix A, Measured Section, Black Mesa units, New River Mesa units). They are, in ascending stratigraphic order: (1) a thick trachybasalt flow, (2) a crystal tuff with conglomerate at the base, (3) an olivine basalt flow, (4) a crystal tuff with interbedded lapilli tuff, and (5) a trachybasalt flow (Plate 3). The basal trachybasalt flow can be traced to the north and east of Black Mesa. It wedges out to the south against Precambrian rocks and the middle Oligocene andesite. The thickest exposure of the lower member, 303 meters, is found on New River Mesa. The lower member becomes somewhat thinner to the southeast toward Skull Mesa and pinches markedly further to the south. The thinnest section, 30 meters, occurs on the north side of Elephant Mountain.

The upper member consists of interbedded marl, dolomite, alluvium, trachybasalt, and tuff (Plate 3, Appendix A, Measured Sections). On the northeast part of Elephant Mountain the marl, dolomite, and tuff units become interbedded with thick trachybasalt flows (Figure 1). Marl and dolomite are abundant and flows and tuffs are thinner and have less lateral continuity than units in the lower member. The thickest exposure

Figure 3

Stratigraphic units on Black Mesa and Sugarloaf; View is to the northwest, pЄg = Precambrian granitic rocks, Oa = Oligocene Andesite, MOccl = Miocene-Oligocene Chalk Canyon formation lower member, MOcuu = Miocene-Oligocene Chalk Canyon formation upper member, Mnr= Miocene New River Mesa basalt, b = basalt (both olivine basalt and trachybasalt), lbt = interbedded lakebed and tuff, t = tuff, BMF = Black Mesa fault, SMF = Sugarloaf Mountain fault.

New River Mesa quad
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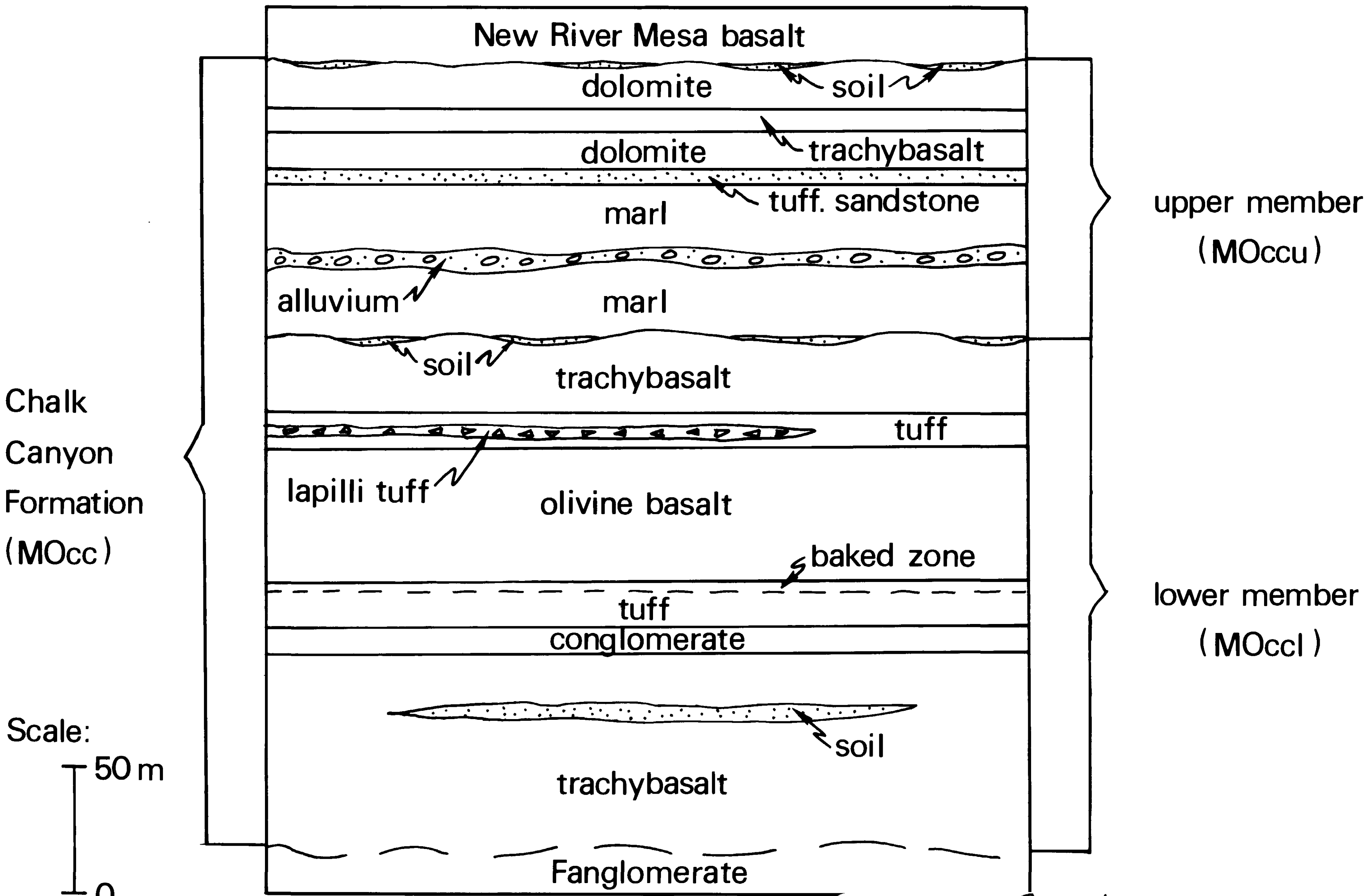
Plate 3

Generalized stratigraphic section of the Chalk Canyon formation.



Pl.3 New River Mesa quad O-F Report

of the upper member, 138 meters, occurs on Black Mesa (Appendix B). The upper member pinches out to the north in New River Mesa and becomes thinner in the other directions.

Lithology and Interpretation. Tuff of the Chalk Canyon formation is mostly reworked, although some airfall tuff is present (Appendix B). Evidence for reworking includes well developed stratification, and sparse to abundant mudcracks, channels, and planar cross-stratification. The term tuff here refers to consolidated pyroclastic material that has grains less than 4 mm in size (Wentworth and Williams, 1932; William, Turner and Gilbert, 1954). Consolidated pyroclastic material in which some material has a grain size of 4-32 mm is referred to as lapilli tuff.

Tuff of the Chalk Canyon formation is dominantly fine- to medium-grained (0.5-2 mm) and has angular to subrounded grains. Exposures are characterized by steep slopes and a very pale orange (10YR 8/2) color. Glass, quartz and feldspar are the most common grain types. Stratification of the tuff ranges from very thick bedded to laminated (McKee and Weir, 1953).

An intermediate to silica rich source is suggested, for the reworked tuffs, by the abundance of quartz, alkali feldspar, and sodic plagioclase. The exact source of these tuffs is not known, but based on reconnaissance mapping, they may have come from vents north and east of this study area. The stratification and sedimentary structures discussed above, coupled with petrographic evidence (Appendix B), indicates that a majority of these tuffs were probably reworked by water.

Beds of lapilli tuff and conglomerate occur in intervals of fine-grained tuff (Plate 3). These interbedded units are distinctive and have moderately large lateral extents. They thus have served as marker horizons for mapping. The lapilli tuff consists of angular to subangular clasts of glass, volcanic, metamorphic and igneous rock fragments in a devitrified glass matrix (see Appendix B, Chalk Canyon formation, Reworked Tuffs). Lapilli horizons seen in the western part of the area, can be traced southward from New River Mesa to Black Mesa, Sugarloaf Mountain, and to the base of Elephant Mountain. Thicknesses of individual lapilli units range from 15 to 75 cm. Lapilli tuff is observed only in the lower member.

The conglomerate contains subangular to subrounded, pebble-sized clasts. Precambrian metamorphic and intrusive rocks, derived from the closely adjacent basement, are dominant, and Tertiary volcanic rocks subordinate (see Appendix A, Black Mesa, unit 5 and Appendix B, Chalk Canyon formation, Basal Conglomerate). The clasts are bounded by silica cement and a tuff matrix. The conglomerate is crudely stratified, and moderate orange pink (5YR 8/4) in color. It ranges from 0 to 30 meters in thickness. It is found locally in the western and southwestern parts of the area, north of Elephant Mountain and Skull Mesa, and along the eastern margins of Sugarloaf, Black Mesa and New River Mesa (Figure 1). The best exposures of this unit are south of Black Mesa. The unit is thickest in the southwestern part of the area and becomes thinner toward the north and east. Three different map units are unconformably overlain by the conglomerate. They include Precambrian granitic rocks, andesite and the basal trachybasalt flow of the Chalk Canyon formation. The conglomerate is disconformably overlain by the lowermost tuff beds of the lower member.

The abundance of Precambrian detritus in the conglomerate indicates that the Precambrian basement was still exposed in nearby areas when the conglomerate was deposited.

In outcrop, the dolomite and marl range from very pale orange (10YR 8/2) to grayish orange (10YR 7/4) in color (Plate 3). The grains are subangular to subrounded and include quartz, feldspar, calcite, biotite, Tertiary volcanic rock fragments and Precambrian clasts. These beds are firmly to well-cemented by calcite, dolomite and clay, and form steep slopes and local cliffs.

The dolomite and marl beds contain silt to fine sand-size particles, and are thick bedded to laminated. Subordinate contorted beds formed by slumping are present in places. Abundant burrowings, and borings are found at certain horizons (Figure 4). Calcite and silica have filled many of the borings. The burrowings and borings are subparallel and perpendicular to bedding, respectively. Straight and U-shaped burrows are found. Other evidence of life include horizontal tubes that have internal structure, and organic material. The horizontal tubes are as much as 12 cm in length and 2.5 cm across. Thin sections of the tubes show that they consist of algae, pelloids and micrite (Appendix B). The origin of these horizontal algal tubes is uncertain, but perhaps they represent the rolling, possibly during periods of aggitation, of algal mats or bodies that had formed on the surface of playa-like lakes. The rolling of algae, as a result of wave action, into balls and tubes, has been reported for Tertiary and modern shallow lakes by Smith (1950) and Arnold (1947). Analysis of the lakebeds for pollen was undertaken by Dr. Richard Hevly, of the Biology Department at Northern Arizona University, but none has been found to date.

Deposition of the marl and dolomite units probably occurred in a shallow lake. The angularity of the terrigeneous particles, indicates that they were mostly derived from pyroclastic ejecta settling into the

Figure 4

Borings and burrowings in marl.

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lake. Other detritus, especially of volcanic and metamorphic origin, was brought in by tributaries. The presence of fine-grained, early stage dolomite indicates an arid climate during deposition of some of the lake beds. The marls occur lower stratigraphically than the dolomite and were probably deposited in a fresh water environment (Plate 3). From this stratigraphic relationship it would appear that the upper member of the Chalk Canyon formation was deposited during a period of increasing aridity. A similar period of increasing aridity is reported for the southern and western Arizona during middle to late Miocene time (Eberly and Stanley, 1978). Deposition to the south of the Luke Salt during middle Miocene time may correlate time wise with deposition of the dolomite (Eaton and others, 1972; Eberly and Stanley, 1978).

The tuffaceous sandstones contain well-sorted, fine- to medium-sand size grains. Grains include tuff, pumice, glass, and well-altered volcanic detritus. The sandstone characteristically is thin bedded and displays small scale tabular planar cross-stratification. The sandstone beds have fairly continuous lateral extents within the marl and dolomite sequences. At places they are interbedded with very thinly bedded air-fall tuff. The tuffaceous sands were formed as the consequence of re-working of pyroclastic ejecta that periodically covered the landscape.

Subsilicic flows are present in the Chalk Canyon formation and include olivine basalt and trachybasalt (alkali rich basalt) (Plate 3). In most exposures the flows are deeply weathered. Where fresh, the flows break into sharp, jagged blocks. Columnar jointing, fractures filled with calcite and zones of vesicles are common. Vesicles, 1 to 3 cm across, are commonly filled or rimmed with calcite and zeolite. Thicknesses of individual and composite flows range from 3 to 118 meters. Pinching out and merging of flows is common throughout the area. In general, flows in the lower member are laterally more continuously than those of the upper member.

Olivine basalt flows are found only in the lower member and have a densely microcrystalline, dark gray (N3) groundmass (Plate 3) (see Appendix A; Black Mesa unit 7, New River Mesa unit 5). In outcrop they weather to a grayish red (10YR 4/2) color. Olivine is the most obvious phenocryst, occurring as light green crystals that alter to iddingsite. Some olivine phenocrysts are as large as 5 mm in length. Subordinate dark green, stubby prismatic phenocrysts of pyroxene and white laths of plagioclase can also be observed with a hand lens.

Trachybasalt is the dominant flow type in the Chalk Canyon formation. These flows are medium gray to medium dark gray (N5-N4) or brownish gray (5YR 4/1) in color. Pyroxene and brown laths of biotite having poorly developed terminations are the dominant phenocrysts. Olivine is subordinate. The groundmass contains some glass and is mainly microcrystalline.

Trachybasalt originates from a magma that is potassium rich (Williams, Turner,and Gilbert, 1954). The biotite found within the trachybasalts flows is primary, and has not formed as a result of alteration of other mafics. Evidently it was the last mineral to crystallize out of the magma, and probably came from a potassium rich residual magma.

Contacts. The Chalk Canyon formation lies unconformably on Precambrian rocks and the middle Oligocene fanglomerate and andesite. It is unconformably overlain by basalt flows that cap New River Mesa, Black Mesa, Elephant Mountain, and Skull Mesa. In most places the basal contact of the Chalk Canyon formation is concealed by colluvium and talus.

However, exposures of this contact can be seen in arroyos west of the Skull Mesa, and east of Black Mesa and New River Mesa. In general, the basal contact is irregular and as much as 30 meters of relief can be observed locally southwest of Skull Mesa. On New River Mesa, the basal trachybasalt of the Chalk Canyon formation rests on the fanglomerate. A soil approximately 10 meters thick marks the contact. The soil consists of altered cobbles of trachybasalt cemented by carbonate. South of Black Mesa, where tuffs overlie the Precambrian, a basal conglomerate, described in Appendix B, is observed at the base of the Chalk Canyon formation. Clasts of andesite are present in the base of the tuff southwest of Sugarloaf, where the tuff overlaps the andesite.

Throughout the area, the uppermost trachybasalt of the lower member is overlain by tuff, and marl and dolomite of the upper member. The members are separated by an irregular contact having as much as 10 meters of relief. The contact is characterized by local thin conglomerates, of altered volcanic rocks, up to 1 meter thick. The underlying trachybasalt flow is fractured and the fractures are filled by tuff, marl and dolomite. In places trachybasalt cobbles are present in the basal two meters of the upper member.

The upper contact of the Chalk Canyon formation is concealed in most places by colluvium and talus, derived from the overlying basalt flows that cap the high mesas, but can be found in a few arroyos. A thick soil, 2-5 meters thick, separates the Chalk Canyon formation from the basalt that caps the high mesas.

Age. Faunal age control for the Chalk Canyon formation is provided by a primitive ungulate mammal, an oreodont, that has been described by Lindsay and Lundin (1972). The oreodont was found near the base of the Chalk Canyon formation in a lithic tuff (Figures 5a, 5b). This is the only oreodont recorded from Arizona and is the oldest mammal known from the state. Oreodonts are well represented in Oligocene deposits of the Great Plains and Great Basin. However, Miocene oreodonts are more numerous and widespread in the geologic record of western North America (Lindsay and Lundin, 1972).

Lindsay and Lundin (1972) assigned the oreodont to the Oreodontinae subfamily of Mercyoidondontidae (Schultz and Falkenback, 1956), a group restricted to the early Oligocene of the western United States (Wilson and others, 1968). Bruce Lander of the U.S. Geological Survey, Menlo Park, California, has further assigned the Cave Creek specimen to the early Chadronian genus Limnenetes platyceps Douglas (Lander, 1977). However, after re-examination during the summer of 1978 of the Cave Creek specimen, Lander has concluded that it is not a member of the Oreodontinae subfamily and not Chadronian in age (Bruce Lander, written communication, 1978). He has placed it instead in the Leptancheniicae subfamily or probable early Orellan age, based upon the relatively large size of the tympanic bullae. The tympanic bullae of the Cave Creek specimen closely resembles those found in individuals of Leptauchenia from earliest Orellan strata in Wyoming. Leptauchenia individuals are larger than their Chadronian ancestors, but smaller and less inflated than their Whitneyan descendants (Lander, 1977). The Cave Creek specimen has a slightly shorter lower dentition suggesting that it represents a smaller individual than those from Wyoming, and more closely resembles younger individuals from the lower part of the Orella member of the Brule Formation in Nebraska (late early Orellan in age). Schultz and Falkenbach (1968) have assigned the individuals from Nebraska to the species.

Figure 5

Photographs of oreodont locality

(a) Overview, lt = lithic tuff containing oreodont, b = basalt

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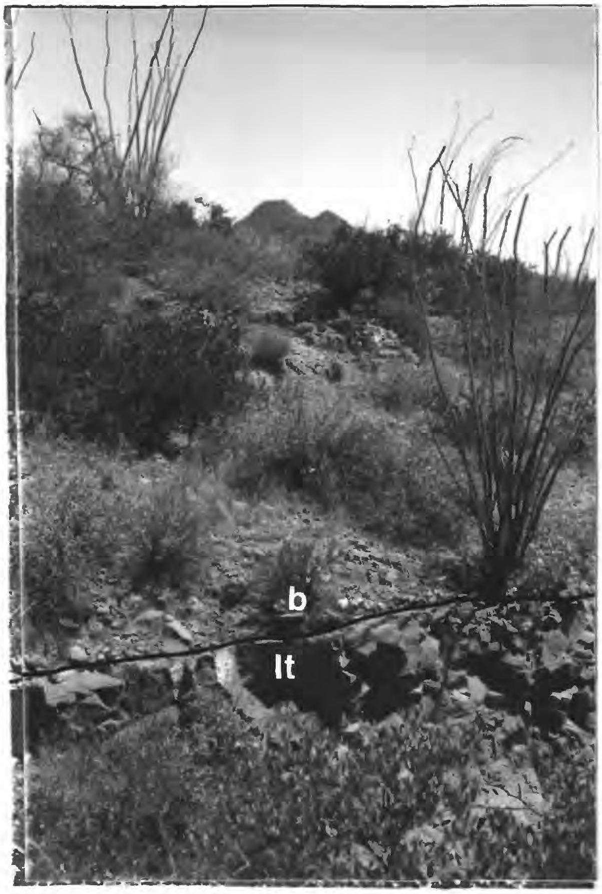

Figure 5

Photographs of oreodont locality

(b) Closeup; lt = lithic tuff containing oreodont, b = basalt

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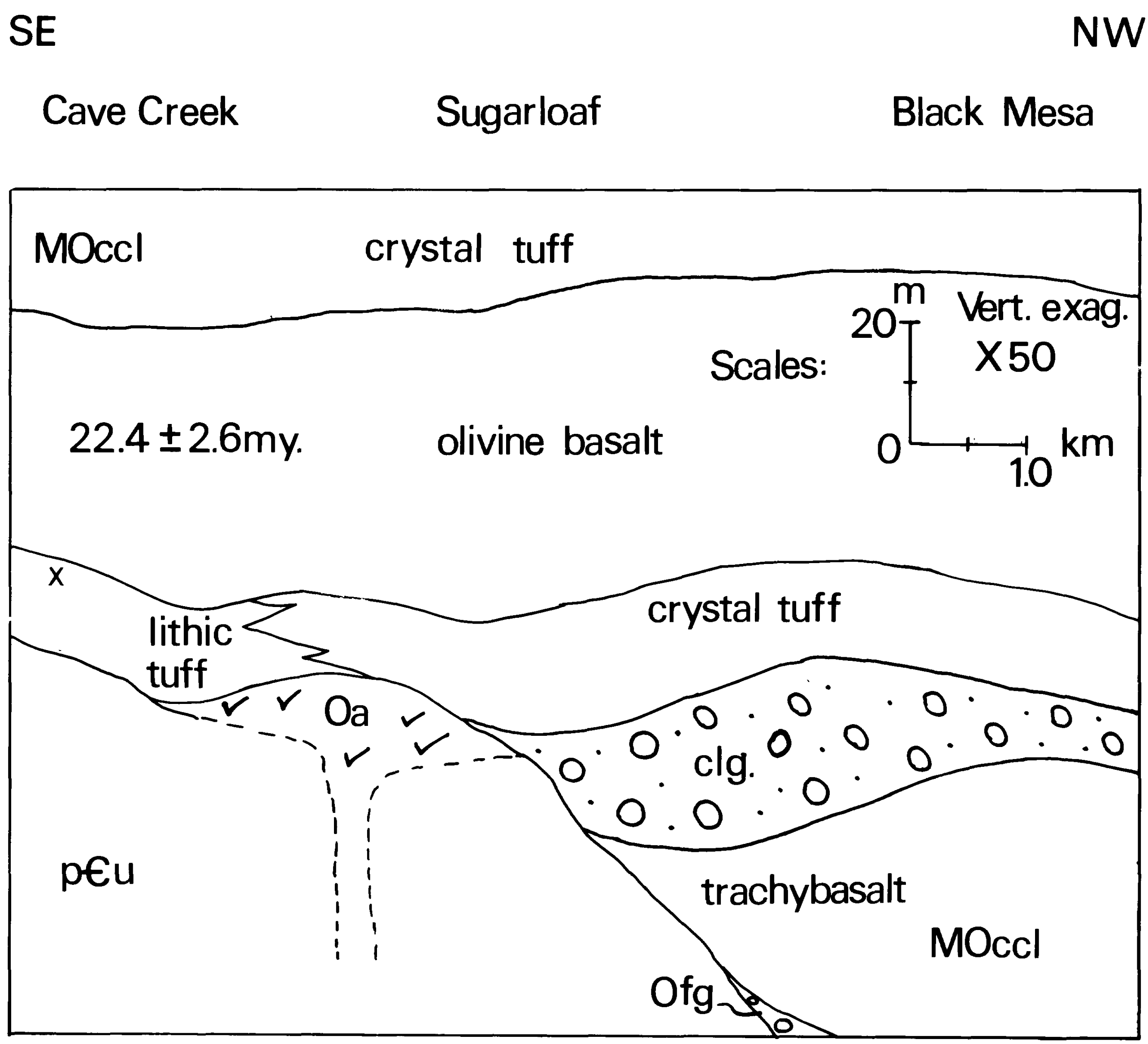
Hadroleptauchenia eiseleyi. The small size of the Cave Creek specimen relative to ancestral and descendant populations suggests that it may be a climatically induced dwarf that existed during an interval of increasing aridity (Lander, 1977). The data presented suggests a middle Oligocene age (∿29-32 m.y.) for the Cave Creek oreodont and the lower part of the Chalk Canyon formation.

In Cave Creek the lithic tuff containing the middle Oligocene oreodont is overlain by an olivine basalt. The tuff presumably rests directly on Precambrian rocks. An early Miocene age of 22.4 ± 2.6 m.y., was obtained by K-Ar whole rock analysis for the basalt (Lindsay and Lundin, 1972). This would indicate a hiatus of about 8 m.y. between deposition of the tuff and the basalt. In the field, the contact between the lithic tuff and basalt is relatively sharp, and locally is marked by a 1-2 meter thick soil. A zone of alteration is also present in the upper two meters of the tuff. Geologic mapping has established that the tuff containing the oreodont extends northwest to Sugarloaf, Black Mesa, and New River Mesa (Plate 4) where a change in lithology takes place. The tuff grades laterally into a crystal tuff that is marked by a conglomerate at the base. Stratigraphically, the tuff containing the oreodont is the lowest tuffaceous unit in the Chalk Canyon formation, and is underlain by the basal trachybasalt flow.

In summary, the faunal and radiometric ages for the Chalk Canyon formation strongly suggest that the basal units of the lower member are middle to late Oligocene in age. The remainder of the units within the lower member and the upper member would appear to be early to middle Miocene in age.

Plate 4

Correlation of units of the lower member of the Chalk Canyon formation (MOccl), from Cave Creek to New River Mesa; pЄu = Precambrian undivided, Ofg = Oligocene fanglomerate, Oa = Oligocene andesite, X = oreodont horizon.



Pl. 4 New River Mesa quad
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Summary and Correlation. The interbedded alluvium, volcanic strata and lakebeds (marl and dolomite) of the Chalk Canyon formation are characteristic of mid-Tertiary deposits in central Arizona (Wilson, 1962) and southwestern Arizona (Eberly and Stanley, 1978). Similar deposits occur in a wide area surrounding Cave Creek, and can be seen around Black Canyon City and Lake Pleasant, west and north of Cave Creek, in and west of Chalk Mountain near the Verde River, east of Cave Creek, and in tilted fault blocks of the desert region south of the Cave Creek (Wilson, 1962; Gomez and Elston, 1978). These deposits are overlain by a basalt sequence that is traceable into basalts of the Hickey Formation (14.5-11 m.y.) in the Black Hills (McKee and Anderson, 1971; Elston, written communication, 1978). From field observations and stratigraphic position, the Chalk Canyon formation appears equivalent, if not identical to the deposits found at Lake Pleasant, Black Canyon City, and Chalk Mountain (Wilson and others, 1957; Lance, 1960; Wilson, 1962). Detailed mapping and stratigraphic studies are needed before firm correlations can be made. However, the distribution and extent of the mid-Tertiary lakebeds, volcanic rocks and alluvium indicate that they were probably deposited in one or more large basins which presumably formed as a result of both faulting and volcanism (Lance, 1960; Eberly and Stanley, 1978; Gomez and Elston, 1978; Elston, in press).

Regional volcanism started about 29 m.y. ago (middle Oligocene) in the Superstition Mountains, 40 km southeast of Cave Creek. Volcanism thus may have started about this time, or even slightly earlier, in the Cave Creek area. The first stages of volcanism were calc-alkaline and alkaline in composition (Lipman and others, 1972; Christiansen and Lipman, 1972; Sheridan, 1978), the latter corresponding to the flows found in the Chalk Canyon formation. A transition to olivine basalt volcanism about 18-15 m.y. ago, or middle Miocene, has been well documented in this part of Arizona (Suneson and Sheridan, 1975; Sheridan, 1978) and throughout the Basin and Range Province (Lipman and others, 1972; Christiansen and Lipman, 1972). The transition to basalt volcanism also corresponds with the end of deposition of the Chalk Canyon formation and the beginning of deposition of olivine basalt equivalent to the Hickey Formation of the Black Hills (Anderson and Creasy, 1958; McKee and Anderson, 1971).

New River Mesa Basalt

A series of cliff-forming olivine basalt flows, cap the high mesas and unconformably overlie the Chalk Canyon formation. These flows are here being named the New River Mesa basalt. The maximum exposed thickness is 180 meters on the east side of Black Mesa, where as many as eight flows are present. The sequence thins to the east and on Skull Mesa is 125 meters thick. Soils consisting of carbonate-cemented pebbles and cobbles of weathered and altered volcanic rocks as much as 2.5 meters thick, separate the individual flows. A soil, 2-5 meters thick, separates the New River Mesa basalt from the underlying Chalk Canyon formation.

The basalt has a microcrystalline, medium dark gray (N4) groundmass that contains abundant phenocrysts of pyroxene, olivine altered to iddingsite, and scattered plagioclase. Phenocrysts are as much as 5 mm in length. Columnar jointing and zones of vesicles are common in outcrop. The vesicles are 1 to 2 cm across, and many are filled or rimmed with calcite. Where fresh, the basalt breaks into sharp, jagged blocks. Outcrops are grayish brown (5YR 3/2) in color and the rocks have not been weathered deeply (see Measured Sections, Appendix A).

The flows have been traced from the air, northward 100 km to the Black Hills where they correlate with basalts of the Hickey Formation (Anderson and Creasy, 1958; McKee and Anderson, 1971; Eberly and Stanley, 1978; Gomez and Elston, 1978; Elston, written communication, 1978). McKee and Anderson (1971) have dated Hickey basalts in the Black Hills at 14.6 to 11.1 m.y. Eberly and Stanley (1978) report a radiometric date of 15 ± 2.1 m.y., northwest of the map area (34°04'20"N, 112°06'30"W), for the basal flow of a thick basalt sequence that overlies tuff and clastics. From this date they postulate that the basalt sequence is part of the Hickey Formation. A Hickey age is therefore inferred by field correlation and radiometric dating in the surrounding areas (McKee and Anderson, 1971; Eberly and Stanley, 1978) for the New River Mesa basalt that caps the high mesas in the Cave Creek area.

QUATERNARY DEPOSITS

Landslide

Landslide deposits are recognized by an uneven, hummocky terrain any by structurally chaotic materials. In the map area landslide deposits are found mainly in the north particularly along the western slope below Skull Mesa (Figure 1). Here, the fanglomerate, the overlying Chalk Canyon formation, and locally even the New River Mesa basalt, have been involved in large mass movement toward Cave Creek. The landslide deposits form benches along Cave Creek. A large landslide, a part of which is shown in the northern part of the map area, displays a distinct pull-away at its head beneath the west side of Skull Mesa. The landslide probably was formed when clay in sediments of the Chalk Canyon formation became saturated with water, leading to movement of material downslope. The times of landslide formation are not known, but may correspond to wet periods during the Pleistocene.

Colluvium and Talus

Deposits of colluvium and talus are found mainly on slopes beneath high mesas and near the base of steep hills. Thicknesses vary, but are of the order of about 5 meters. The colluvium and talus deposits consist of angular to subrounded sand- to boulder-size clasts of andesite, basalt, metamorphic and crystalline intrusive rocks, and tuff. Basaltic detritus is the dominant constituent. Extensive colluvium and talus deposits, with boulders as large as 3 meters across, are found between Black Mesa and Elephant Mountain, in the southwest part of the area (Figure 1). Fracturing of the rocks during faulting and subsidence is the most likely cause for the coarse blocks. Large deposits of colluvium and talus are also found in the valley formed by Cave Creek. In the western parts of Skull Mesa and Black Mesa, material mapped as colluvium and talus locally includes landslide (Figure 1).

Alluvium

Alluvium is present along Cave Creek and Cottonwood Creek, and in small tributaries (Figure 1). It consists of angular to rounded, sand- to boulder-size (up to 3 meters across) detritus of Precambrian metamorphic and intrusive rocks, andesite, basalt, and tuff. The alluvium is mostly unconsolidated, although in places it is well cemented by calcite. Low terraces of alluvium flank Cave Creek, near the junction with Cottonwood Creek.

Heavy rains and flooding during February and March of 1978 led to increased deposition of alluvium in the flood plains of Cave and Cottonwood Creeks, and caused minor changes in their stream courses.

REGIONAL CORRELATION OF THE CENOZOIC ROCKS

Eberly and Stanley (1978) have studied in detail the stratigraphy and geologic history of several Cenozoic basins in southern and western Arizona. Correlation of the Cenozoic rocks was attempted using radiometric ages determined from K-Ar ratios in the volcanic rocks. The correlated ages were used in combination with geologic and seismic data to subdivide the Cenozoic deposits into two unconformity-bound stratigraphic units; an older Unit I (Eocene to late Miocene in age) and a younger Unit II (late Miocene to Holocene in age). The boundary between the two units is an unconformity resulting from subsidence, block-faulting, and erosion during development of the Basin and Range structural province.

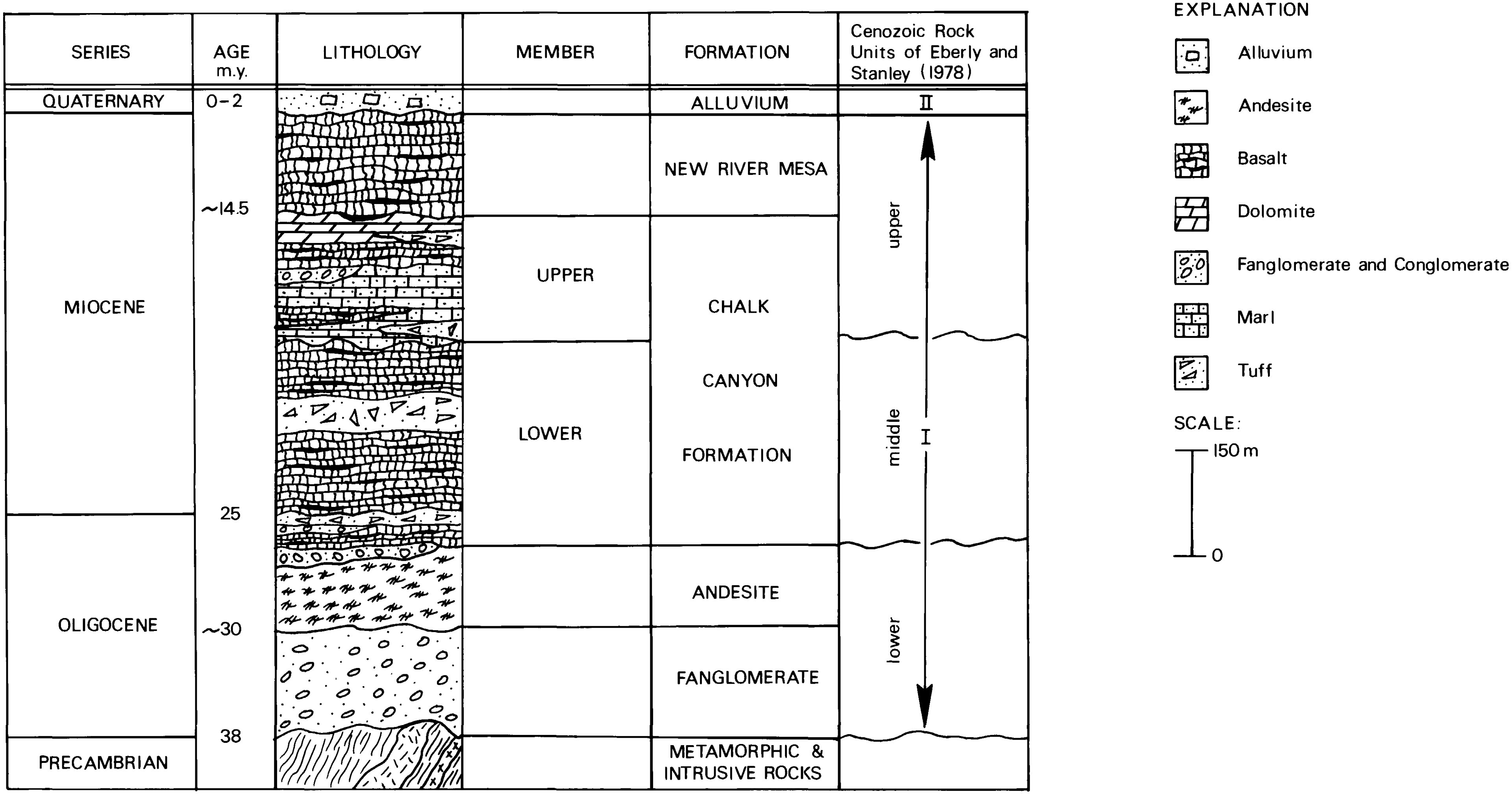
Unit I rocks rest on pre-Eocene bedrock, that includes Precambrian granitic and gneissic rock and in rare cases Paleozoic strata. It includes all rock deposited between post-Laramide alluviation (~53 m.y. ago, early Eocene), and the first movement of Late Miocene block faulting (about 7.5 m.y. ago in the Cave Creek area). Rocks of Unit I can be subdivided into three subunits: (1) a lower subunit of interbedded Eocene to late Oligocene fanglomerate, fluviatile arkosic sandstone, conglomerate and some of the earliest mid-Tertiary volcanic extrusions, (2) a middle subunit of volcanic rocks interbedded with sedimentary rocks deposited during the period of volcanic activity associated with a mid-Tertiary orogeny (middle Oligocene to middle Miocene) (Damon, 1964), (3) an upper subunit of extrusive volcanic rocks and interbedded sediments separated from the other two subunits by a sharp unconformity.

Unit II rocks were deposited in subsiding trough-like basins starting in late Miocene time after Basin and Range block faulting, and near the Phoenix area include thick bodies of evaporites. These evaporite deposits were first investigated and called the Luke Salt by Eaton and others (1972). Eberly and Stanley (1978) based on radiometric dates of volcanic rocks above and below the salt have provisionally bracketed its deposition between 10.5 and 14.9 m.y. (middle Miocene). However, caution is advised in interpreting the radiometric dates because of a large uncertainty factor (± 4.5 m.y.).

Cenozoic rocks of the Cave Creek area can be provisionally classified using the scheme proposed by Eberly and Stanley (Plate 5). The Tertiary rocks in the map area belong exclusively to the Unit I deposits, because they were deposited before Basin and Range faulting. Further subdivision of the Tertiary rocks to the subunit level is also possible (Plate 5). The fanglomerate and andesitic rocks are similar to strata found in the lower subunit of Unit I. Deposition of the predominantly volcanic lower member of the Chalk Canyon formation corresponds to the middle Tertiary orogeny of Damon (1964, 1971) and to deposits of the middle subunit (Plate 5). The sharp unconformity between the lower and upper members of the Chalk Canyon formation is similar to the contact between the middle and upper subunits of Unit I. Deposits of the upper subunit are represented, in the map area, by the interbedded lakebed, tuff, and basalt of the upper member of the Chalk Canyon formation and the capping New River Mesa basalt. An increase in aridity is observed within the upper subunit (Eberly and Stanley, 1978). Evidence for this,

Plate 5

Correlation of Cenozoic rocks in map area with regional units of Eberly and Stanley, (1978).



Pl. 5 New River Mesa quad O-F Report

in the Cave Creek area, is the change from marl to dolomite within lake-beds of the upper member (Plates 3 and 5). Unit II rocks occur only in the Quaternary deposits of the map area, and include alluvium, colluvium and talus, and landslides.

Chapter 3

STRUCTURE

INTRODUCTION

The structural geology in the map area has been produced by extensional forces during development of the boundary between the Colorado Plateau and Basin and Range Provinces (Ransome, 1919, 1923, 1932; Wilson and Moore, 1959; Wilson, 1962; Davidson and Cooley, 1964; Damon and Mauger, 1966; Hayes, 1969; Damon and others, 1973; Loring, 1976; Eberly and Stanley, 1978). Following deposition of the Chalk Canyon formation and New River Mesa basalt the essentially horizontal strata of Black Mesa and New River Mesa were faulted, tilted and dropped down to the south and southwest into the desert region. Tilted fault blocks, containing beds of the Chalk Canyon formation and New River Mesa basalt are exposed in the desert region south of the map area (Plate 6). Faulting in the Cave Creek area took place after deposition of the New River Mesa basalt of post-Hickey age. Recent work to the north of the study area in the mountain region suggests that faulting might have started approximately 7.5 m.y. to 10 m.y. ago which is the time of subsidence and structural impoundment of drainage in the Verde basin (Elston and others, 1974; Nations, 1974; Gomez and Elston, 1978; Elston, 1978; McKee and Elston, personal communication, 1978).

FAULTS

Faults in the map area trend northwest (N20 -55 W) and north-northwest (N0°-30°E) and are generally high angle (>65°) and normal (see Geologic Map, Figure 1). Northwest and north-northwest faults are common in central Arizona (Wilson, 1939, 1962; Anderson, 1951; Anderson and Creasy 1958; Martinsen, 1975; Eberly and Stanley, 1978). The trends of these faults roughly correspond to joint patterns observed in the rocks of Precambrian age (see Structure, Joints; Plate 10). This would imply that they were controlled by Precambrian structures or zones of weakness. Probably these faults represent renewed movement along Precambrian faults, which has been observed throughout Arizona (Wilson, 1939, 1962; Anderson, 1951; Anderson and Creasy, 1958; Anderson and others, 1971; Lucchitta, 1974; Huntoon, 1974; Shoemaker and others, 1974; Martinsen, 1975; Elston and Scott, 1976).

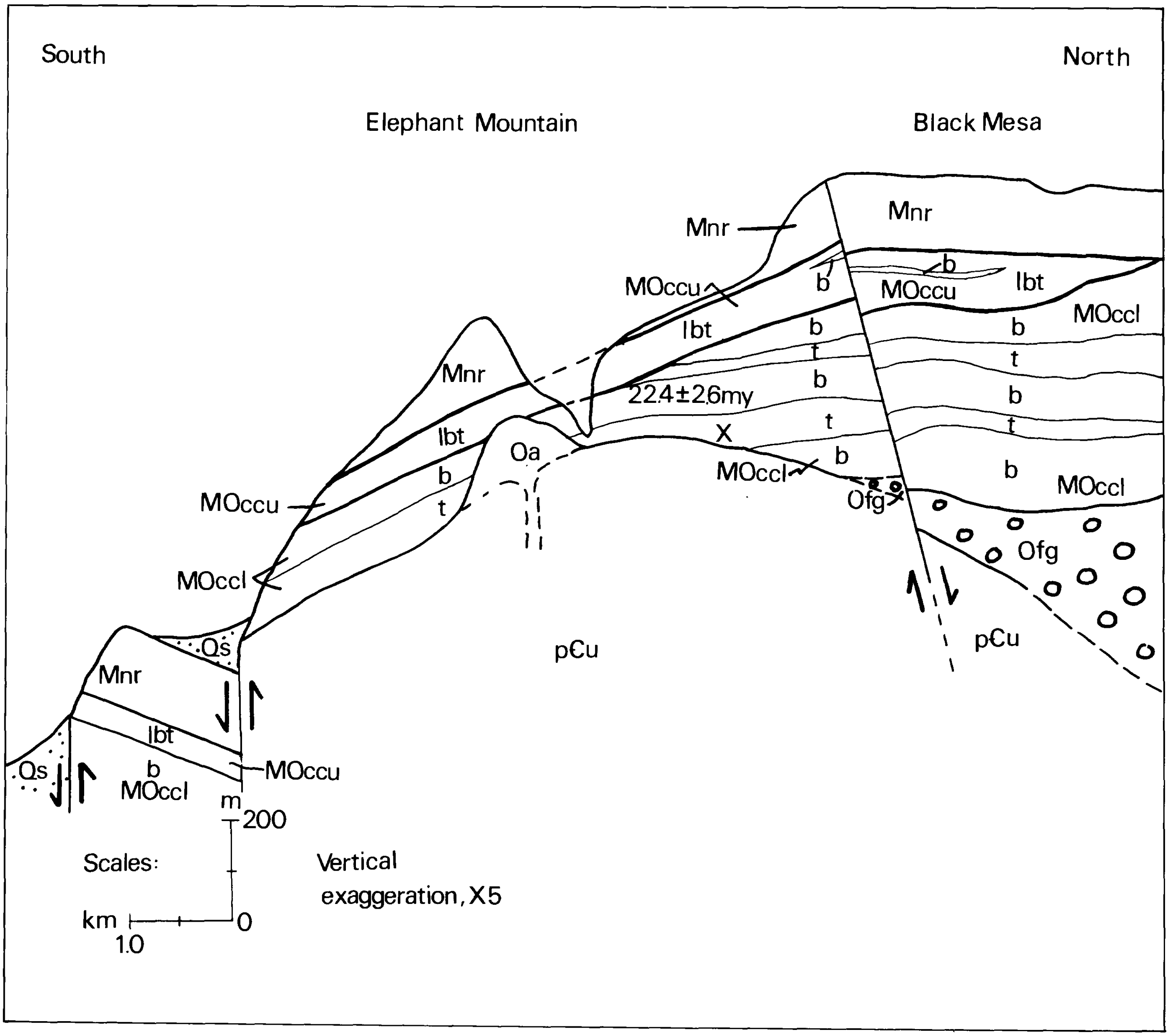
Northwest Trending Faults

The northwest trending faults occur south of Black Mesa (see Geologic Map, Figure 1). Strata are displaced down to the south and southwest along a series of nearly parallel southwest dipping faults. Displacements along the northwest trending faults range from 10 to 60 meters.

The Black Mesa fault is the major northwest trending fault. It is best exposed on the southeast side of Black Mesa (see Geologic Map, Figure 1). Southeast of Black Mesa the fault strikes N5°W and dips 65°-72°NE, until it reaches the best of Black Mesa, where its trend changes abruptly to N55°W with a dip of 70°W. Displacement diminishes to the west and the fault dies out approximately 1 km southwest of Black Mesa.

Plate 6

North-South cross section, generalized; pꞒu = Precambrian undivided, Ofg = Oligocene fanglomerate, Oa = Oligocene andesite, MOccl = Miocene-Oligocene Chalk Canyon formation lower member, MOccu = Miocene-Oligocene Chalk Canyon formation upper member, Mnr = Miocene New River Mesa basalt, b = basalt, lbt = interbedded lakebed and tuff; t = tuff, X = oreodont locality.



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The Black Mesa fault does not follow the displacement pattern observed in the other northwest trending faults. Rocks of the Chalk Canyon and New River Mesa formations have been down-faulted more than 60 meters to the north and northeast. A simple model seems to explain the cause of this seemingly anomalous displacement (Plate 7). Sometime after deposition of Tertiary strata exposed in Black Mesa and New River Mesa (Step 1), subsidence occurred to the south (Step 2), marking initial development of Basin and Range structures of the desert region. Rotation of a block extending from Black Mesa south to Elephant Mountain, occurred with the definition and development of the boundary between the mountain and desert regions (Step 3). Materials on the rotated block were highly fractured at this time producing material for large deposits of colluvium and talus that now mantle the slopes.

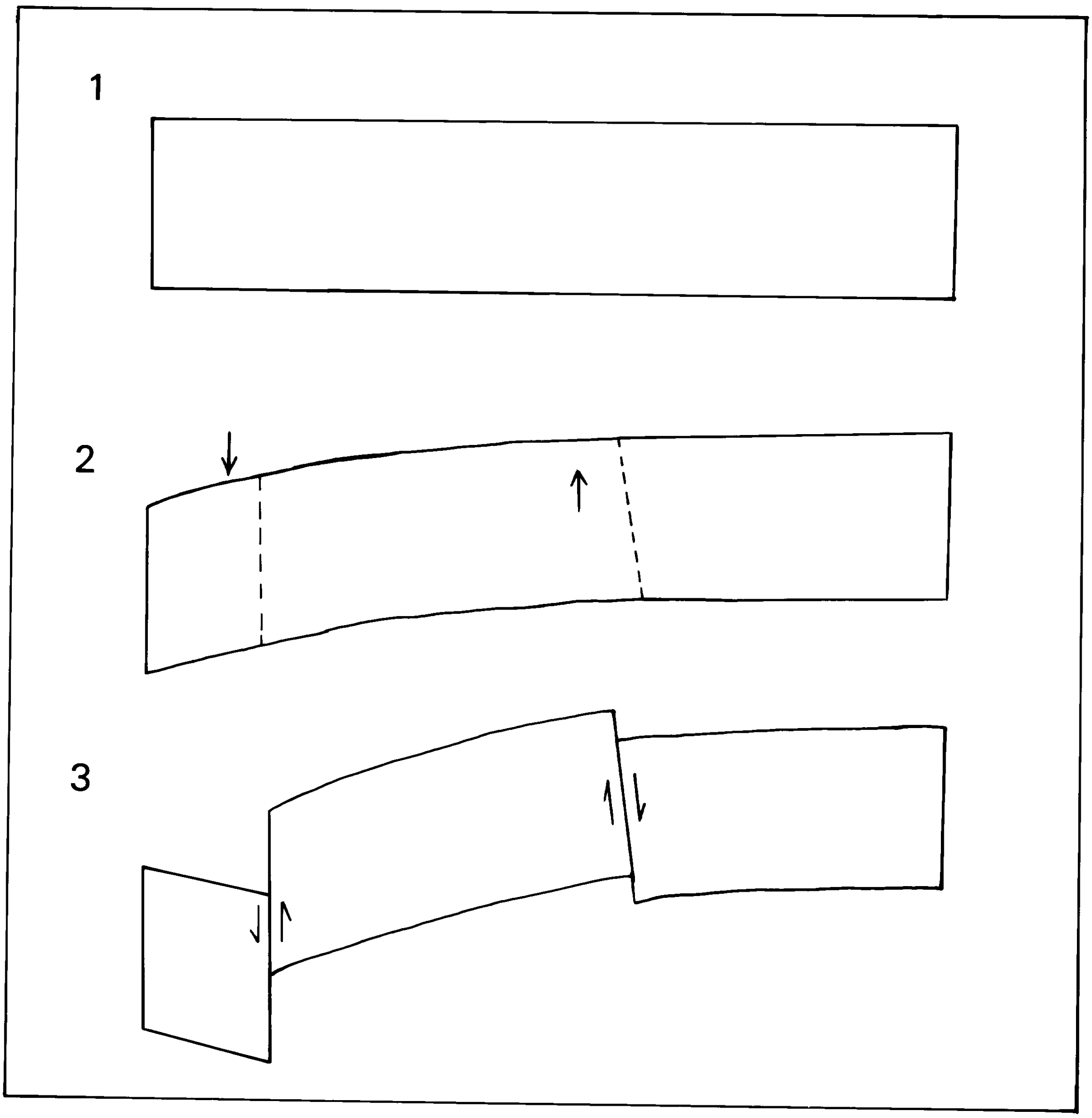
North-Northeast Trending Faults

The north-northeast trending faults are commonly concealed by Quaternary deposits. Strata are displaced down to the east along southeast dipping fault planes, with a maximum vertical displacement of approximately 300 meters (see Geologic Map, Figure 1).

The principal north-northeast trending fault is the Sugarloaf Mountain fault. Beds of the Chalk Canyon formation and New River Mesa basalt have been downfaulted over 300 meters across this fault from Black Mesa to form Sugarloaf Mountain. The Sugarloaf Mountain fault can be traced northward approximately two kilometers across an area of colluvium and talus. Its trace is marked by deflections in stream courses. The Sugarloaf Mountain fault merges with northwest trending faults to the south.

Plate 7

Structural model for the development of the Black Mesa fault; (1) ($\sim$11 m.y.) Essentially horizontal strata following deposition of the New River Mesa basalt, (2) ($\sim$7.5 m.y.) Bending and warping of strata as a result of subsidence to the south, (3) ($<$7.5 m.y.) Rotation of the block south of the Black Mesa fault with definition and development of the mountain-desert boundary.



Pl. 7 New River Mesa quad
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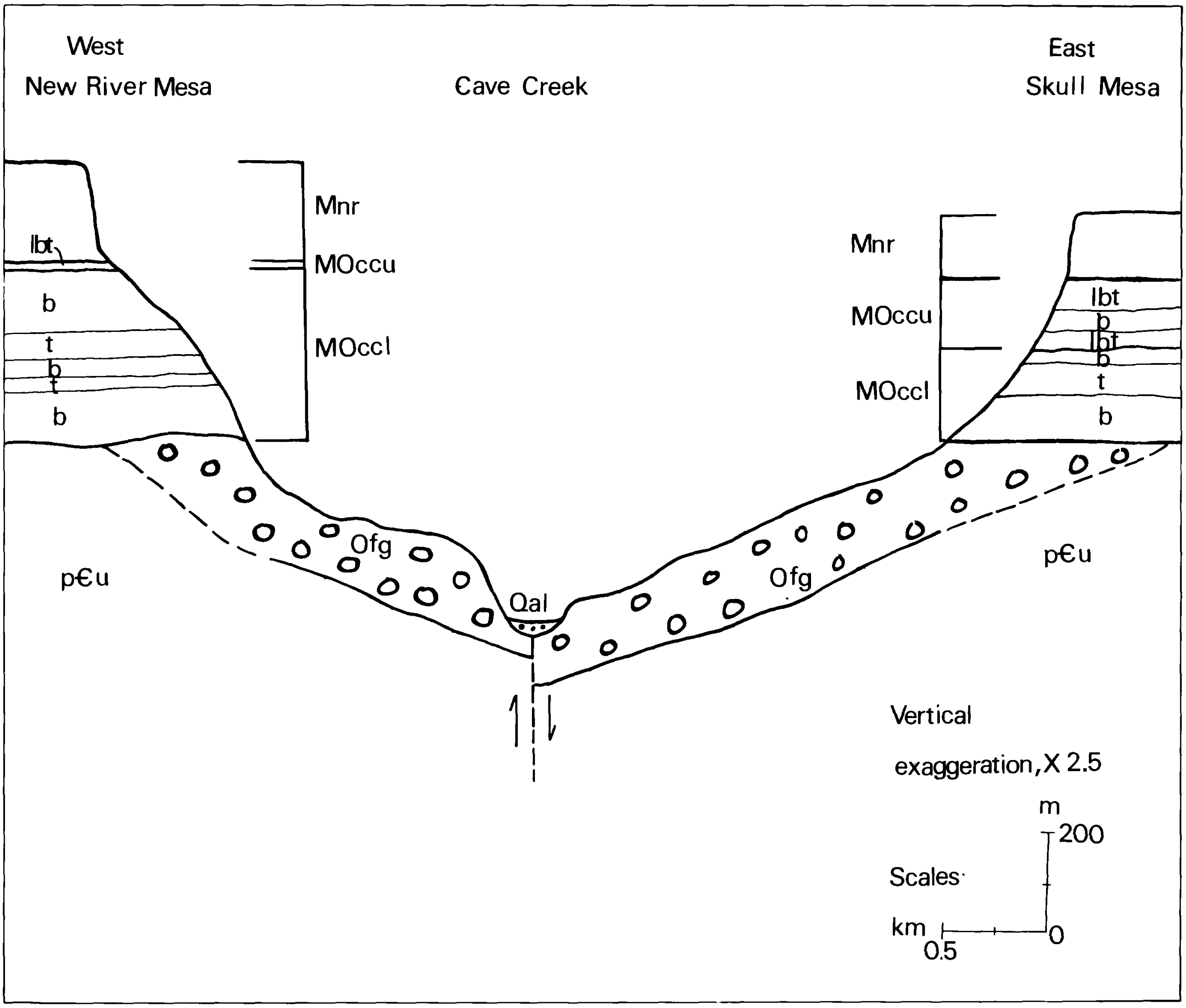
Plate 8

East-West cross section, generalized; p6u = Precambrian undivided, Ofg = Oligocene fanglomerate, MOccl = Miocene-Oligocene Chalk Canyon formation lower member, MOccu = Miocene-Oligocene Chalk Canyon formation upper member, Mnr = Miocene New River Mesa basalt, Qal = Quaternary alluvium, b = basalt, lbt = interbedded lakebed and tuff, t = tuff.



Pl. 8 New River Mesa quad
O-F Report

A north-northeast trending fault concealed by Quaternary deposits is inferred along Cave Creek in the northern part of the area (see Geologic Map, Figure 1 and Plate 8). This is deduced from the straightness of the stream channel and an apparent stratigraphic displacement of strata on the northern part of Skull Mesa and New River Mesa (see Geologic Map, Figure 1; Structural Cross Section B-B').

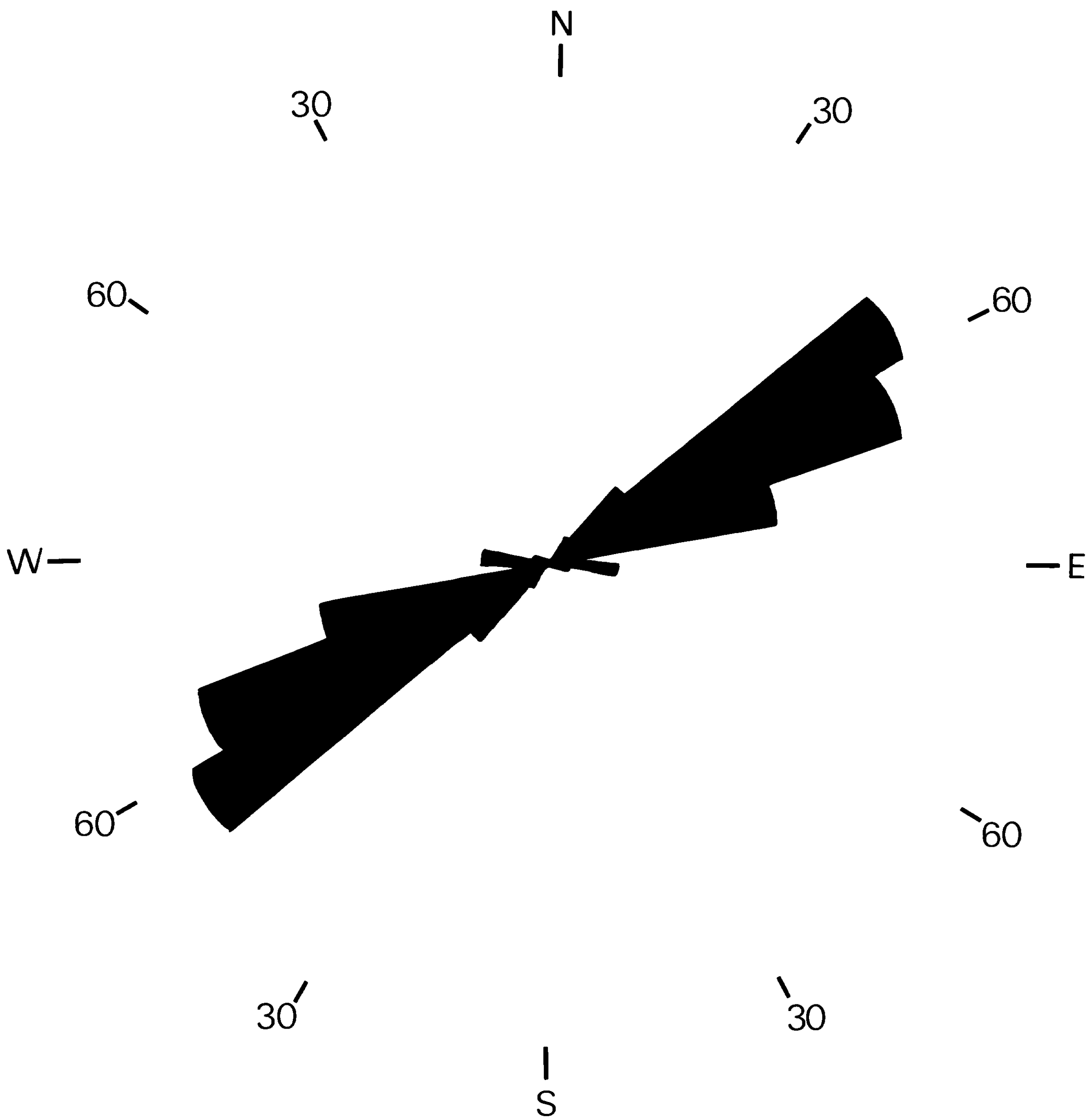
CLEAVAGE

Slaty cleavage occurs throughout the schist and in the interbedded slate and phyllite. The cleavage is especially well developed in rocks having abundant chlorite and other platy minerals. One hundred and forty measurements of cleavage were obtained in Precambrian rocks in the south and southeast parts of the map area. Plotted on a rose diagram (Plate 9), they show trends of N50°-80°E, with a dominant peak at N50°-60°E. The cleavage does not coincide with the strike of the relict bedding of the schist but has formed at the angle to it.

Chi square and angular dispersion tests were applied to the cleavage data to statistically determine if a preferred orientation is present. A Chi square value (X^2) of 57.68 was obtained, which indicates a significant orientation to the 99th percentile. Angular dispersion (r) varies inversely with the amount of dispersion in the data (Zar, 1974; p. 314). It is a measure of concentration, and varys from 0, where the dispersion is so great that a mean angle cannot be described, to 1.0, where all the data is concentrated in the same direction. An r value of 0.9107 was obtained for the cleavage data, indicating a very strong concentration.

Plate 9

Rose diagram of cleavage measurements in the Precambrian schist.



Pl. 9 New River Mesa quad
O-F Report

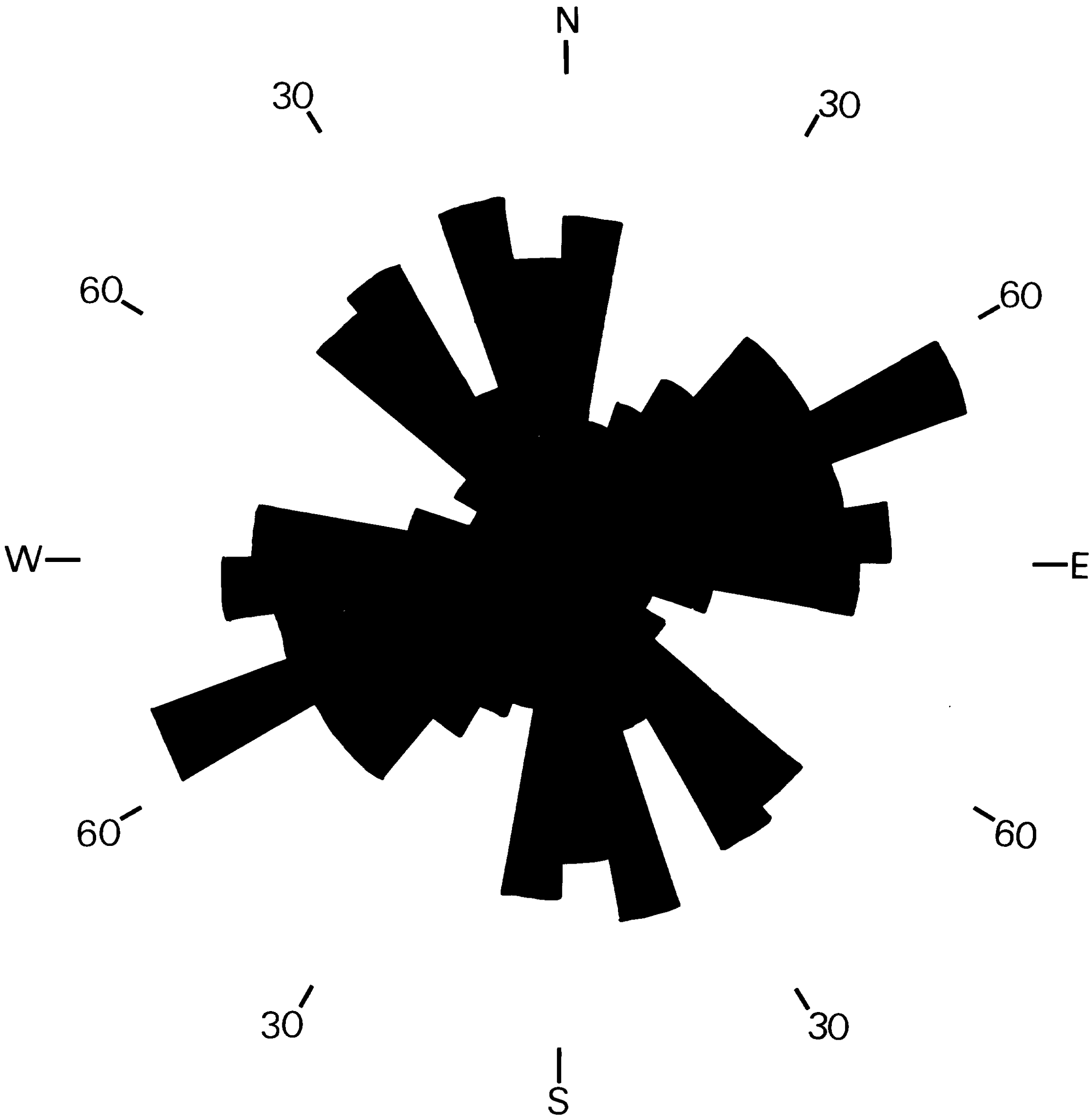
JOINTS

Jointing is abundant in the Precambrian rocks. The joints display plumose structures, which suggests they may have formed as a result of horizontal rifting or extension as opposed to shearing (Melton, 1929; Hodgson, 1961; Roberts, 1961; Bankwitz, 1965, 1966; Dennis, 1972; Hobbs, Means and Williams, 1976). Two hundred and fifty-one measurements of joint directions were made. A rose diagram shows that they strike in nearly all directions (Plate 10). The most prominent joints in the Precambrian rocks trend N60°-70°E and N0°-20°W. Northwest and northeast trending joints in the study area correspond with regional structural trends in central Arizona (Lausen and Wilson, 1925; Wilson, 1939, 1962; Anderson, 1951; Anderson and Creasy, 1958; Martinsen, 1975; Rehrig and Hendrick, 1976). Dikes of the Precambrian diabase in the map area are generally parallel to the joints, suggesting that emplacement was joint controlled.

Chi square and angular dispersion tests similar to those used on the cleavage data, were applied to the joint data. A Chi square value of 39.79 coupled with an angular dispersion value of 0.6551 indicates no significant concentration to the joints at the 95th percentile level.

Plate 10

Rose diagram of joint measurements in the Precambrian rocks.



Pl. 10 New River Mesa quad
O-F Report

Chapter 4

GEOLOGIC HISTORY

The first decipherable geological event in central Arizona was a period of regional warping and faulting that led to the development of a geosynclinal trough approximately 2000 m.y. ago (Wilson, 1962). The extent of the trough is not known (Copper and Silver, 1954), but it has been suggested that it extended diagonally to the northeast across the present North American continent in the general direction of the Sonoran-Ontarian geosyncline (Schuchert, 1923; Damon and Giletti, 1961). Sinking of the geosyncline, about 1770-1820 m.y., (Anderson and others, 1971) led to deposition of interbedded shale, sandstone and rhyolitic to basaltic flows of the Yavapai Series (Anderson and Creasy, 1958; Livingston and Damon, 1968; Anderson and others, 1971; Anderson and Blacet, 1972; Anderson and Silver, 1976). Both marine and non-marine conditions existed within the geosyncline (Anderson and Creasy, 1958; Wilson, 1962; Livingston and Damon, 1968; Anderson and others, 1971; Anderson and Blacet, 1972; Martinsen, 1975; Anderson and Silver, 1976). Regional metamorphism occurred about 1760-1790 m.y., affecting both the sediments and volcanic rocks of the Yavapai Series (Anderson and others, 1971; Anderson and Silver, 1976). The quartz monzonite and quartz diorite intruded the schist about 1420 m.y. ago or about the same time the Ruin quartz monzonite was intruded in the Sierra Ancha and Bronco Ledges regions (Livingston, 1962a, 1962b; Livingston and others, 1967; Livingston and Damon, 1968). Uplift and faulting corresponding to the

Mazatzal Revolution of Wilson (1939), probably affected the area approximately 1730 m.y. (Anderson and Silver, 1976). Uplift was followed by increased erosion until the area had been reduced to a series of rolling hills and small mountains by early Paleozoic time. Precambrian sedimentary rocks are absent in the Cave Creek area, though it is possible that they were deposited and subsequently eroded. Intrusion of diabase sills and dikes in the granitic and metamorphic rocks, occurred about 1150 m.y. ago, the time of intrusion of diabase sills in central Arizona, east of the map area in the Sierra Ancha Mountains (Livingston and Damon, 1968; Smith and Silver, 1975).

Paleozoic and Mesozoic rocks are absent, but it is possible that strata equivalent to that found in northern and southern Arizona were once present (Cannery and others, 1967). Southern and central Arizona appears to have served as a source area for the continental sediments of Triassic, Jurassic, and early Cretaceous age deposited in the Plateau area of northern Arizona (Wilson, 1962). During late Cretaceous and by early mid-Tertiary time, the Cave Creek area was eroded down to Precambrian metamorphic and crystalline rocks.

From regional considerations, and evidence in the Cave Creek area, regional uplift probably began in central Arizona in latest Eocene to middle Oligocene time (∿38-30 m.y. ago). Uplift was accompanied by increased erosion and the deposition in topographic lows of the prevolcanic fanglomerate (Melton, 1965; Eberly and Stanley, 1978) (Plate 11b). Similar fanglomerates also were being deposited in the Bloody Basin, Superstition Mountains, and in Cenozoic basins throughout southern and western Arizona about this time (Melton, 1965; Stuckless and Sheridan, 1971; Gomez and Elston, 1978; Eberly and Stanley, 1978). Volcanism

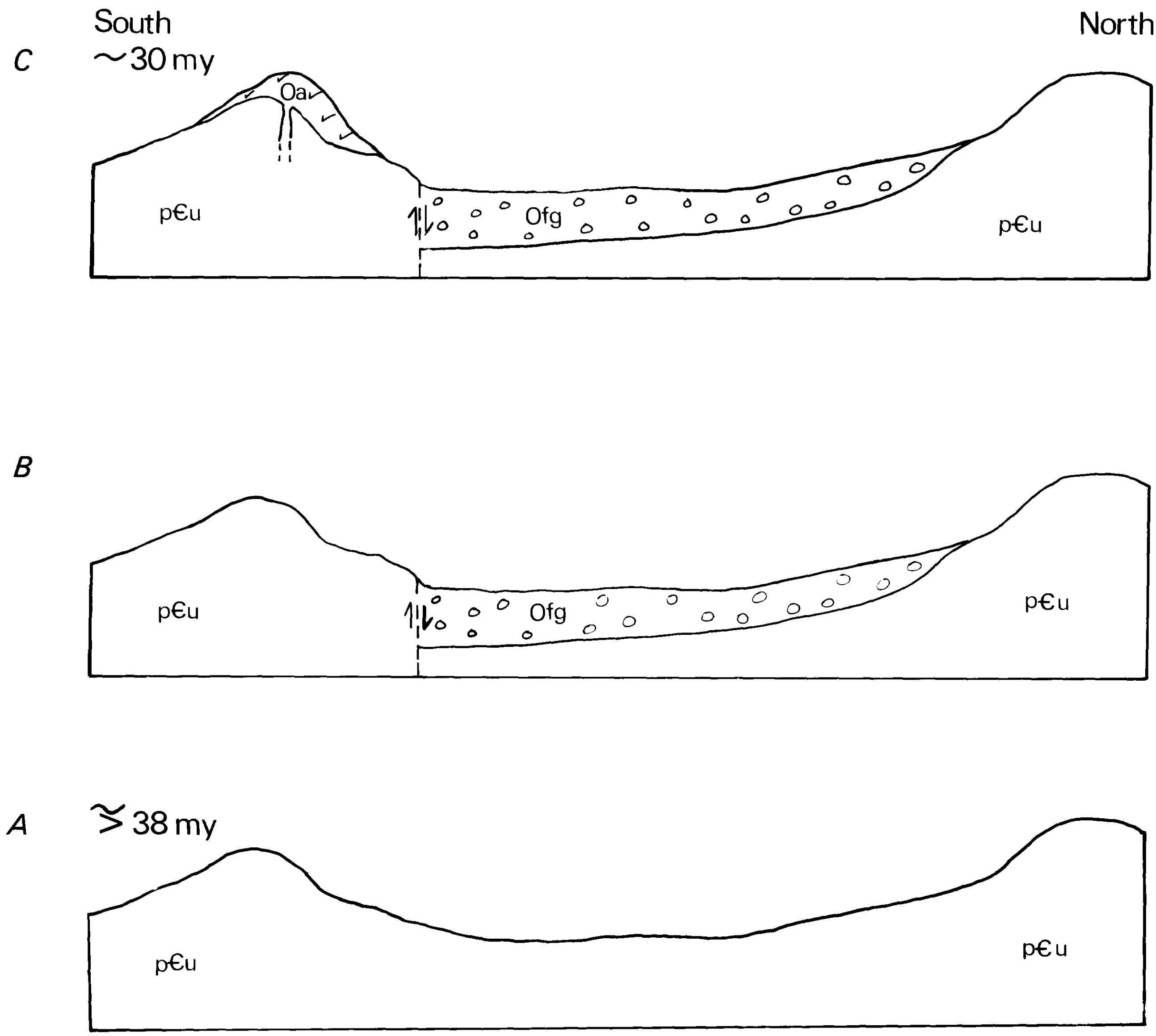
Plate 11

Diagrams summarizing the Tertiary geologic history of the Cave Creek area.

(a) $\stackrel{\sim}{>}38$ m.y.: Erosion of the terrane into a series of rolling hills, pGu = Precambrian undivided.

(b) $\gtrsim 30$ m.y.: Uplift and deposition of fanglomerate in faulted basins, Ofg = Oligocene fanglomerate.

(c) ~ 30 m.y.: Extrusion of andesite as plugs and short flows, Oa = Oligocene andesite.



Pl. 11 New River Mesa quad
O-F Report (continued on p. 69)

started in the mid-Tertiary (~30 m.y. ago) (Damon, 1964, 1971). In the Superstition Mountains, volcanism began approximately 29 m.y. ago or in middle Oligocene time (Fodor, 1968; Stuckless, 1969, 1971; Sheridan and others, 1970; Stuckless and Sheridan, 1971; Malone, 1972; Suneson, 1976; Sheridan, 1978). The discovery of a middle Oligocene oreodont (Lindsey and Lundin, 1972; Landers, written communication, 1978) indicates that volcanism started in the Cave Creek area at about this time or perhaps slightly earlier. Andesite volcanics record the initial volcanism in the area (Plate 11c). Andesite volcanism presumably closely followed deposition of the fanglomerate. Alkali volcanism accompanied by deposition of lake beds and alluvial materials took place from middle Oligocene into middle Miocene time (30-15 m.y.). During this time the Chalk Canyon formation was deposited in a large irregularly closed basin or series of basins that formed as a consequence of faulting and volcanism (Plate 11d). A transition from calc-alkali and alkali volcanism to basaltic volcanism occurred about 15-18 m.y. ago (Christiansen and Lipman, 1972; Lipman and others, 1972; Suneson and Sheridan, 1975; Sheridan, 1978). This corresponds to the end of Chalk Canyon deposition and the extrusion of the New River Mesa basalts about 14.5 m.y. (Plate 10e), which corresponds to basalt of the Hickey Formation to the north (14.5-11 m.y. ago).

Development of the present physiography of the mountain and desert regions (Ransome, 1919, 1923, 1932; Wilson, 1962) began sometime after deposition of the New River Mesa basalt. Collapse of the desert region to the south and southwest, and faulting of Tertiary and Precambrian strata probably occurred about 7.5 m.y. ago (Plate 11f), at the time of subsidence and structural impoundment of drainage in the Verde Basin (Elston and others, 1974; Loring, 1976; Elston, 1978; Gomez and

Plate 11

Diagrams summarizing the Tertiary geologic history of the Cave Creek area.

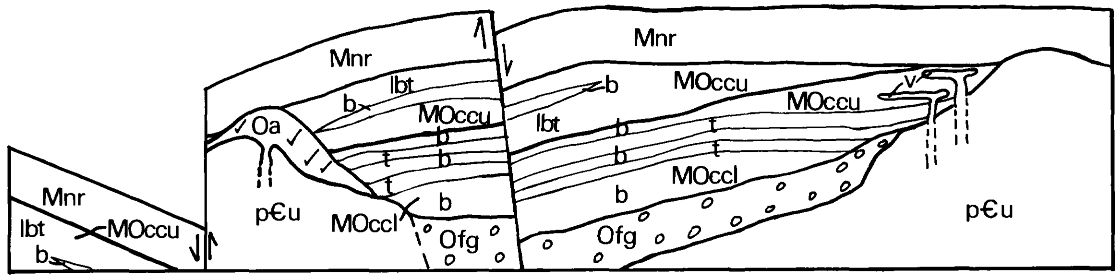
(d) $\sim$30-15 m.y.: Deposition of interbedded alluvium, basalt, lakebed, and tuff of the Chalk Canyon formation in irregularly closed basins, MOccl = Miocene-Oligocene Chalk Canyon formation lower member, MOccu = Miocene-Oligocene Chalk Canyon formation upper member, b = basalt, t = tuff, lbt = interbedded lakebed and tuff, v = vent.

(e) 14.5-11 m.y.: Extrusion of the New River Mesa basalt (Hickey Formation), Mnr = Miocene New River Mesa basalt.

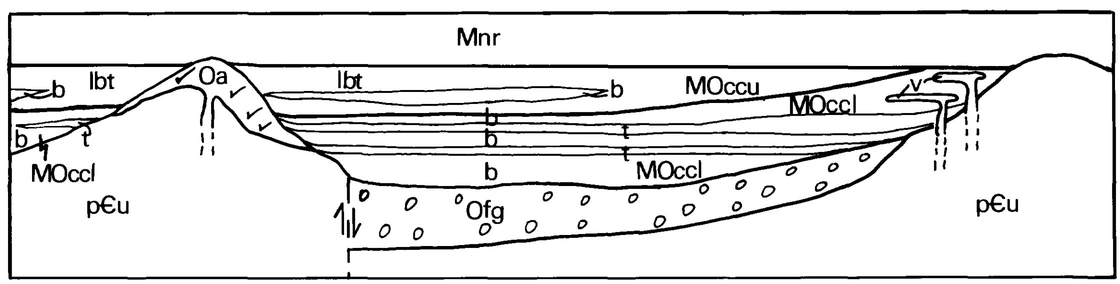
(f) $\gtrsim$7.5 m.y.: Structural and physiographic definition and development of the present mountain-desert region boundary.

South North

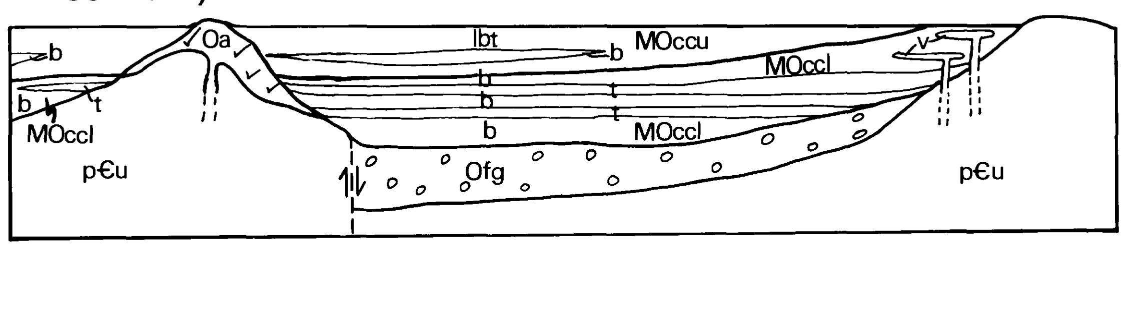
F ~ 7.5 my



E 14.5–11 my



D ~30–15 my



Pl. 11 New River Mesa quad
O-F Report (Continued from p. 66)

Elston, 1978; McKee and Elston, personal communication, 1978).

The present day Cave Creek drainage had its inception after deposition of the New River Mesa basalt, very likely in the interval 11-7.5 m.y. ago. Major downcutting presumably occurred since collapse of the desert region some 7.5 m.y. ago. Downcutting of the narrow channelway presumably occurred during the Quaternary. During the past 2 m.y. or so, extensive deposits of colluvium and talus deposited formed on the slopes beneath the mesas, and local deposits of travertine and alluvium accumulated in the major drainages and their tributaries. Landslides occurred on the northwest side of Skull Mesa, possibly during wet periods in the Pleistocene.

Chapter 5

MINING

Mining has played a role in the development of the Cave Creek area. Indians, in search of malachite and azurite, were the first to explore the hills north of Cave Creek. They used these copper carbonates as pigments for their body, and for garments and pottery decorations. The Spanish, interested in gold and silver, may have worked some of the Indian diggings in the late 1500's but soon abandoned them. The oldest definite signs of mining in the Cave Creek area are from the early 1870's. The Continental Mine was recorded in 1873 and this was followed by the Yellow Jacket and Lion Mines in 1875. By 1876 mining was at its peak, and only a few mines were developed after 1877. Mining concentrated in Precambrian schist, granite porphyry dikes and along the margins of Precambrian and early Tertiary granitic batholiths. Deposits of copper, gold, silver, tungsten, molybdenum and vanadium were discovered, but only the copper and gold deposits were notably productive.

Gold production amounting to about $250,000 was made, mostly prior to 1900. The largest producers of gold were the Phoenix and Maricopa properties which are located along the south central margin of the map area. Production in these mines was from quartz and jasper lenses and stringers that cut through the schist (Ricketts, 1887; Lewis, 1920; Wilson and others, 1937). Besides gold, small deposits of molybdenum and vanadium were also found.

The most successful operation in the Cave Creek mining district has been the Red Rover Mine (Lewis, 1920). Established in 1882, this mine is located approximately 16 km northeast of the town of Cave Creek. A vertical shaft more than 275 meters deep was sunk into the schist and an intruding porphyry sill. At the surface the deposit consists of copper carbonates that contained as much as 2000 oz. of silver per ton (Lewis, 1920). The principal deposits were between the 300 and 500 ft. levels and shows masses 3 to 4 ft wide of copper (azurite and malachite) containing 400-700 oz. of silver per ton. Major production at the Red Rover Mine occurred from 1882 to 1917 during which $200,000 in copper and silver was recovered. Between 1917 and 1953, it was operated intermittently with production totaling 6,000 tons.

Future prospecting in the Cave Creek area may be for uranium. Exploratory drilling for uranium is currently being carried out in the map area in Precambrian rocks. Assessment of the economic potential of the Tertiary deposits has not yet been undertaken, but recent discoveries of uranium in Cenozoic tuffs in Nevada and Arizona, may indicate that similar deposits could be present in the Cave Creek area.

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APPENDIX A

MEASURED SECTIONS

SKULL MESA

West Central

Unit	Sub-unit Thickness (meters)	Cumulative Thickness (meters)
New River Mesa basalt		
11. Olivine basalt; medium dark gray, (N4), weathers to a grayish brown, (5YR 3/2), microcrystalline groundmass, with abundant phenocrysts of olivine altered to iddingsite, pyroxene and plagioclase, some phenocrysts as large as 6 mm; small vesicles, most lack internal filling, some filled with calcite; unit forms prominent cliff on mesa; breaks into jagged blocks; soil and relief of 2 to 5 meters observed at basal boundary, numerous conglomerates within flow sequence indicates multiple flows.	85.3	85.3
Total New River Mesa basalt.	85.3	
Unconformity		
Chalk Canyon formation		
upper member		
10. Conglomerate; pale yellowish brown, (10YR 6/2); consisting of poorly sorted,	22.8	86.7

subangular to subrounded pebbles and cobbles of Precambrian gabbro, quartz monzonite, metavolcanic, and other metamorphic rock, also Tertiary andesite and basalts; well-cemented by clay matrix and forms prominent cliff; contact with underlying unit is gradational, more clasts of Tertiary volcanic rock and fewer Precambrian clasts in the upper 10 meters, color also changes in upper 10 meters to pale reddish orange, (10YR 6/4), due to the alteration of volcanic rock fragments.

9.	Interbedded marl and tuffaceous sandstone; generally pinkish gray, (5YR 8/1), weathers to a very pale orange (10YR 6/6); consists of moderate-well sorted subrounded grains of tuff and pumice, also scattered laths of biotite; well-cemented, calcareous; thick bedded; ledge-former; lower contact concealed.	20.8	63.9
8.	Trachybasalt; generally medium to medium dark gray, (N5-N4), when fresh, weathers moderate brown (5YR 4/4); microcrystalline groundmass, with abundant altered phenocrysts of olivine, biotite, and pyroxene; cliff former; deeply	24.0	43.1

weathered on surface (15 cm deep); both lower and upper contacts concealed.

7.	Covered interval.................................	12.2	19.1
6.	Interbedded crystal tuff, tuffaceous sand, conglomerate and marl; generally very pale orange, (10YR 8/2), weathers to medium yellowish orange, (10YR 6/6); very fine grained with subrounded grains of quartz, feldspar (plagioclase), pumice, lithic clasts and scattered biotite; conglomerates contain scattered coarse-grained to pebble-size pieces of basalt and tuff; dominantly calcareous cement with silica cement and clay in tuffaceous sands; crystal tuff and some alluvial units present; steep slope and cliff former; upper contact concealed; undulating lower contact, with as much as 3-5 meters of relief.	6.9	6.9
	Total upper member........................	86.7	

Unconformity

lower member

5.	Trachybasalt; generally medium to medium dark gray (N4-N5) when fresh, weathers to a moderate brown, (5YR 4/4), micro-crystalline groundmass with abundant altered phenocrysts of olivine, biotite, and pyroxene; cliff former: deeply weathered	7.6	128.6

on surface; lower contact fractured and filled with calcite; undulating and fractured upper contact, filling in of fractures with material from overlying unit.

4. Lithic tuff; generally grayish yellow, (5YR 8/4); poorly sorted, subangular to subrounded, coarse grains of abundant basic and intermediate volcanic clasts, that have been altered to iron oxides, also scattered tuff and pumice; forms steep slopes; color is the result of weathering of the volcanics.	5.0	121.0
3. Interbedded reworked (crystal and lithic) and airfall tuff dominantly pinkish gray, (5YR 8/1), weathers to a very pale orange, (10YR 8/2); consists of poorly to moderately sorted angular to subrounded grains of abundant glass, tuff, pumice and lithics, lithics include altered volcanics and Precambrian detritus; airfall tuffs are white (N9) and consist of angular to subangular, very fine grains of abundant glass and scattered quartz; all units are thin to very thinly-bedded; well cemented by silica or clay matrix; forms cliffs and steep	10.7	116.0

	slopes; lower contact concealed by basalt rubble.		
2.	Trachybasalt; generally medium to medium dark gray when fresh, weathers moderate brown (5YR 4/4); microcrystalline groundmass, with abundant phenocrysts of biotite, and pyroxene, with some scattered phenocrysts of olivine altered completely to bowlingtonite, phenocrysts less than 5.0 mm in size; also spherical patches of glass; cliff former; weathered on surface in most exposures; vesicles (less than 2 cm across), filled with calcite and zeolite; lower contact is unconformable with fanglomerate.	85.3	85.3
	Total lower member........................	128.6	
	Total Cave Creek formation................	215.3	
	Unconformity		
	<u>Fanglomerate</u>		
1.	Fanglomerate; moderate reddish brown, (10YR 4/6), weathers moderate reddish orange, (10YR 6/6); consists of very poorly sorted, angular to subangular small pebbles to small boulders of schists, phyllite, granite, diorite, and gabbros; poorly-moderately cemented by calcite and clay matrix; massive	152.4	152.4

bedding; blocky splitting; some interbedded coarse grained, calcareous cemented sandstones; basal contact covered by alluvium of Cave Creek; section offset approximately 500 meters to the south at contact with overlying flow.

Total Fanglomerate (incomplete) 152.4

Southwest

Unit		Sub-unit Thickness (meters)	Cumulative Thickness (meters)
	New River Mesa basalt (Incomplete)		
15.	Olivine basalt, generally medium dark gray, (N4), weathers to a grayish brown (5YR 3/2); microcrystalline groundmass, with abundant phenocrysts of olivine, pyroxene, and plagioclase as large as 5 mm; small vesicles (0.5-1 cm), most lack internal filling; forms prominent ridge on top of Skull Mesa; breaks into jagged blocks; lower contact is concealed, contact placed at break in topography at top of mesa.	14.4	120.6
14.	Olivine basalt; generally medium dark gray (N4), weathers to a grayish brown, (5YR 3/2); microcrystalline groundmass, with abundant phenocrysts of olivine, pyroxene and plagioclase; small vesicles (0.5-1 cm), lack internal filling; prominent cliff and steep slope former; breaks into jagged blocks; conglomerates of altered volcanic rocks within sequence indicates multiple flows; lower contact concealed by steep slope of talus.	48.6	106.2

13. Covered interval..............................39.5 57.6

12. Olivine basalt; generally medium dark gray (N4), weathers to a brownish gray, (5YR 4/1); microcrystalline groundmass, abundant phenocrysts (1-3 mm) of rusty brown mineral (appears to be altered olivine), pyroxene and plagioclase; abundant small vesicles (3-5 mm) with calcite filling; very weathered in most outcrops; breaks into jagged sharp blocks; slope and cliff former; basal contact a soil zone, 2 meters thick, with calcite filled structures.

New River Mesa basalt (incomplete)......................................120.6

Chalk Canyon formation

upper member

11. Tuffaceous sandstone; dominantly very pale orange, (10YR 7/4); medium grained, unidentified red colored grains, abundant small pebbles of pumice (angular); poorly cemented (friable), calcareous; massive in outcrop; splits readily into rounded small blocks; slope former; upper 2.0 meters very prominent baked zone of altered volcanics, gray purple (5PR 4/2) in color; undulating lower contact, with as much as 1 meter of relief. 19.9 50.3

10.	Trachybasalt; generally medium dark gray (N4) weathers to a brownish gray, (5YR 4/1); microcrystalline groundmass, with very abundant phenocrysts (1-3 mm) of a rusty brown mineral (probably altered mafic minerals); abundant small vesicles (3-5 mm); breaks into jagged sharp blocks when fresh; cliff former; upper and basal contact both very irregular, and fractured, with calcite filling fractures at both contacts.	21.3	30.4
9.	Interbedded marl and tuffaceous sandstone; generally very pale orange, (10YR 8/2), weathering to a grayish orange (10YR 7/4); coarse- to very coarse-grained, angular to subangular clasts of tuff, basalt and chert, with abundant flakes of phlogopite and muscovite; very friable, calcareous cement; forms rough horizontal beds, but for most past massive; breaks into small blocks; lower contact irregular, with tuffaceous material filling fractures in underlying unit.		

Total upper member........................50.3

Unconformity

lower member

8.	Trachybasalt; generally medium light gray, (N5), weathers light brown gray to brownish gray, (5YR 6/1 to 5YR 4/1); micro-crystalline groundmass, comprised of abundant phenocrysts of a red brown colored mineral (altered olivine) scattered pyroxene and glass; well-cemented; breaks into jagged blocks; cliff former; pyrolusite stain ($Mn\ O_2$) found on outcrops; upper contact very irregular with overlying tuff, relief of 5 meters observed along contact, erosion suggested; lower contact well fractured, with calcite filling fractures.	33.4	218.2
7.	Crystal-Pumice tuff; dominantly white, (N9), weathers very pale orange to grayish orange, (10YR 8/2 to 10YR 7/4); fine- to medium-grained, poorly sorted, comprised of abundant subangular to subrounded grains of tuff, pumice, scattered basalt, mica flakes and unidentified tan mineral, friable, poorly cemented, siliceous; also interbedded very fine to fine grained sandstone; very porous; unit qrades upward into a coarse- to very coarse-grained sandstone interbedded with vitric tuff; upper most	31.9	184.8

3.04 meters a baked zone (color, light brown 5YR 6/4).

6.	Basalt; generally medium dark gray, (N4), weathers pale yellowish brown to moderate yellow brown, (10YR 6/2 to 10YR 4/6); altered olivine and pyroxene observed; very vesicular in spots, with vugs filled with calcite, vesicles generally less than 2 sm in size; forms prominent cliffs; lower (1-2 meters) of unit well fractu: ed, (calcite filled).	9.1	152.9
5.	Crystal tuff; generally white, (N9), weathers very pale orange, (10YR 8/2 to 10YR 7/4); fine to medium grained, poorly-moderately sorted, comprised of subangular to subrounded grains of abundant tuff (some scattered small pebbles) and scattered flakes of muscovite, black and red accessory minerals; moderately well cemented, siliceous; interbedded with coarse to very coarse grained lithic tuff; crystal tuff is finely laminated, well-bedded for most part, with some massive units, small scale crossbedding and minor channels present; basal contact covered by basalt.	25.8	143.8

4.	Trachybasalt; generally medium dark gray to dark gray, (N4 to N3), weathers grayish red, (10YR 4/2); microcrystalline groundmass, with abundant small phenocrysts of altered mafics in a dark gray groundmass; very dense; forms prominent cliff, breaks into jagged blocks; very resistant to weathering and erosion; both lower and upper contacts concealed by basalt rubble.	118.0	118.0
	Total lower member........................	218.2	
	Total Chalk Canyon formation..............	268.5	
3.	Covered interval............................	10.0	10.0
	<u>Fanglomerate</u>		
2.	Sandstone; generally moderate reddish brown, (10YR 4/6), weathers moderate reddish orange, (10YR 6/6); consisting of poorly sorted, angular to subangular coarse- to very coarse-sand sized grains, of abundant clear quartz, feldspars and scattered small pebbles of schist, phyllite, quartz monzonite, diorite and diabase; poorly to moderately cemented, calcareous; some crude bedding; blocky splitting; steep slope former and cliff-former: lower contact gradational with basal unit; upper contact covered by basalt colluvium and talus.	20.0	130.7

Unconformity

1.	Fanglomerate; generally moderate reddish brown, (10YR 4/6) weathers moderate reddish orange, (10YR 6/6); consists of very poorly sorted, angular to subangular, small pebbles to small boulders of schist, phyllite, granite, diorite, and gabbros; poorly cemented by calcareous cement and clay matrix; massive bedding; blocky splitting; steep slope former; interbedded with caorse- to very coarse-grained, calcareous sandstone; basal contact with underlying Precambrian very irregular, indicates a period of erosion.	110.7	110.7

Total Fanglomerate (including sandstone and fanglomerate).............130.7

SUGARLOAF

Unit		Sub-unit Thickness (meters)	Cumulative Thickness (meters)
	New River Mesa basalt		
9.	Olivine basalt; generally medium gray, (N4), weathers to a moderate yellowish brown to dark yellowish brown (10YR 5/4-10YR 4/2); microcrystalline groundmass, contains scattered phenocrysts of olivine, pyroxene, and plagioclase (2-6 mm); breaks into jagged blocks; prominent cliff-former; vesicles (1-2 cm), filled or rimmed with calcite and zeolite; conglomerates of pebble- to cobble-sized altered volcanic rocks separate flows; columnar jointing present.	125.1	125.1
	Total New River Mesa basalt................	125.1	
8.	Concealed interval..............................	27.4	27.4
	Chalk Canyon formation		
	upper member		
7.	Interbedded marl, tuffaceous sand, and alluvium; dominantly very pale orange, (10YR 7/4); poorly sorted, comprised of angular to subangular particles of tuff and basalt, with some grains being	20.8	20.8

subrounded, also very abundant small to medium size tuff pebbles; poorly-moderately cemented, calcareous; massive for most part with some thin beds (0.1-0.2 m) of fine grained tuffaceous sands; matrix calcareous; slope former; fractured near upper contact, with calcite filling; color changes to a pale red - moderate reddish orange, (10YR 6/2 - 10R 6/6) in upper 15 meters along with a fining in grain size, fine to medium grained near upper contact; upper contact concealed by basalt rubble.

Total upper member........................20.8

Unconformity

<u>lower member</u>

6.	Trachybasalt; generally medium light gray to medium gray, (N6-N5), weathers to a moderate yellowish brown, (10YR 5/4); microcrystalline groundmass, with scattered olivine phenocrysts; breaks into jagged blocks; very competent unit; prominent cliff former; with small vesicles (0.5-0.2 cm), some filled with calcite; upper 15 meters of unit well fractured, with calcite and tuffaceous sand filling fractures, upper contact is a conglomerate, with small to large cobbles of basalt surrounded by	68.3	152.5

	tuffaceous sands, extreme irregular nature to upper contact.		
5.	Crystal tuff; white, (N9), weathers to a very pale orange (10YR 7/4); poorly sorted; subangular to subrounded, fine to medium sized grains of tuff, glass, and opaques; poorly-moderately cemented, siliceous; interbedded with coarse to very coarse crystal tuffs, vitric tuff, lapilli tuff, and fine grained tuff; steep slope and cliff former; upper 3.5 meters contain scattered small pebbles of quartz, tuff and basalt; color grades into a grayish orange color (10YR 7/4), at contact with overlying basalt.	173.3	84.2
4.	Olivine basalt; generally medium dark gray to dark gray, (N4-N3), weathers to a moderate yellowish brown, (10YR 5/4); microcrystalline groundmass, with scattered olivine phenocrysts; breaks into jagged blocks; very competent unit; steep slope and cliff former; small vesicles (0.5-2.0 cm) some filled with calcite; lower contact is placed at conglomerate (2 meters), indicates old erosional surface and unconformity with underlying basalt unit; unit weathered and fractured.	198.8	66.9

3.	Olivine basalt; generally medium dark gray to dark gray, (N4-N3), weathers to a moderate yellowish brown, (10YR 5/4); microcrystalline groundmass, with scattered olivine phenocrysts, breaks into blocks; very competent unit; steep slope and cliff former; small vesicles (0.5-2.5 cm), most filled with calcite; lower contact with tuffaceous sandstone very irregular, contact placed at a conglomerate, calcite filling spaces between basalt cobbles in conglomerate.	39.5	47.1
2.	Crystal tuff; dominantly pinkish gray, (YR 8/1), weathers to a grayish orange (10YR 7/4); poorly sorted, fine to medium grained, angular to subangular grains of tuff, also scattered pebbles and small cobbles of tuff, andesite, and basalt; moderately cemented, siliceous; some bedding but for the most part massive; interbedded with very fine tuff units and coarse to very coarse lithic tuffs; slope former; with definite baked zone starting 1.9 meters below upper contact with overlying basalt; becomes coarser grained (coarse to very coarse sand size) at upper contact,	7.6	7.6

color changes to a grayish red purple, (5PR 4/2).

Total lower member.........................152.5

Total Cave Creek formation (both upper and lower)...................173.3

Concealed Zone; basalt colluvium and talus...............................21.9 21.9

Unconformity

Andesite

1. Andesite mudflow; generally medium light gray to light gray, (N6-N7); very poorly sorted, subangular to subrounded, large pebble to small boulder size pieces of andesite in clay matrix; chaotic, no bedding; forms small cliff; boulders up to 1.5 meters in diameter observed; irregular contact with underlying andesite; wedging of this unit to the south against andesite plug is observed. 39.5 39.5

Total Andesite.............................39.5

BLACK MESA

Unit		Sub-unit Thickness (meters)	Cumulative Thickness (meters)
	New River Mesa basalt		
13.	Olivine basalt; generally dark gray, (N3), weathers to a grayish brown, (5YR 3/2); microcrystalline groundmass, with abundant phenocrysts of olivine and pyroxene; very vesicular in places; vesicles small for most part (0.5-2 cm), some larger (2-4 cm); forms prominent cliffs and very steep slopes; breaks into jagged blocks; also interbedded soils which indicates multiple flows; lower 10 meters well fractured, with calcite filling fractures.	168.0	168.0
	Total New River Mesa basalt...............	168.0	
	Unconformity		
	Chalk Canyon formation		
	upper member		
12.	Dolomite; generally very pale orange, (10YR 8/2), weathers to a grayish orange, (10YR 7/4); moderately sorted, fine sand sized dolomite with rare clast of basalt and andesite; subrounded to rounded silt	18.0	108.1

	to very fine sand size particles; well cemented; dolomite massive for most part, with some slumping and convolute bedding in thinly bedded units; splits in jagged blocky pieces; steep slope and cliff former; lower contact with basalt very irregular, material from this unit fills fractures in underlying basalt; boring and burrowing also present.		
11.	Trachybasalt; generally dark gray, (N3), weathers to a brownish gray, (5YR 4/1); microcrystalline groundmass, with abundant olivine, biotite, and pyroxene phenocrysts, (some large as 0.5 cm); scattered small vesicles (0.5-1 cm), most rimmed with calcite; splits into jagged blocks; basal and upper contacts very fractured, with fractures filled by calcite.	6.8	89.3
10.	Interbedded marl, tuffaceous sandstone and alluvium; generally very pale orange, (10YR 8/2), weathers to a grayish orange, (10YR 7/4); marls are well sorted, subangular to subrounded and very fine to fine grained for most part, with	82.5	82.5

abundant small pebbles of tuff, trachybasalt and basalt; moderately well cemented by carbonate and silica; also contains well sorted, subangular to rounded, fine to medium grained sands (tuffaceous) consisting of abundant tuff with some very scattered biotite laths; alluvium deposits are poorly sorted, subangular to subrounded, and made up of pebbles and cobbles of basalt; small scale trough and planar cross stratification observed; marl splits into blocks; contains abundant borings and burrowings; also some inter-bedded chert units present in marls.

Total upper member........................108.1

Unconformity

lower member

9. Trachybasalt; generally medium light gray to medium gray, (N6-N5), weathers to a light olive, (5Y 6/1); micro-crystalline groundmass, with abundant phenocrysts of a red-brown mineral (altered olivine), with very scattered pyroxene; scattered very small (~0.5 cm) vesicles, some rimmed with calcite; breaks into jagged blocks, base of 30.0 201.6

	unit extremely irregular.		
8.	Crystal tuff; generally very pale orange, (10YR 8/2); weathers to a grayish orange, (10 YR 7/4); well sorted, subrounded to round, fine to medium sand size grains consisting of abundant pumice, quartz, glass, and scattered flakes of muscovite and phlogopite; also interbedded coarse to very coarse grained lithic tuff unit; units are moderate-well cemented, siliceous; also interbedded lapilli and vitric tuff; crystal tuff is well bedded (horizontal); splits into blocks; slope former; basal contact fairly conformable.	12.8	171.6
7.	Olivine basalt; medium gray to medium dark gray, (N5-N4), weathers to a brownish gray (5YR 4/1); fine grained groundmass with scattered badly altered olivine phenocrysts (0.5 cm); some small scattered vesicles with calcite filling; prominent cliff former; lower 2 meters of flow well fractured; lower contact is a conglomerate soil, 2 meters thick;	52.5	158.8

some columnar jointing present.

6. Crystal-pumice tuff; generally very pale orange, (10YR 8/2), weathers to a grayish orange, (10YR 7/4); very poorly sorted, angular to subangular, coarse to very coarse grain, pumice, quartz and glass with very scattered metamorphic rock fragments; also some interbedded very fine-medium grained tuffaceous sands; poorly cemented, siliceous; horizontal beds, with some simple low angle cross strata; this unit forms mostly steep slopes; channelling also present; basal contact with lower unit gradational.	16.3	106.3
5. Conglomerate; generally very pale orange, (10YR 8/2), weathers to a grayish orange, (10YR 7/4); poorly sorted, subangular and subrounded small pebbles (6 cm), of schist, phyllite and granite, with and Tertiary basalt; some interbedded coarse to very coarse sand size units also present; moderately well cemented, siliceous; massive with some horizontal beds; splits into	10.0	90.0

blocks; forms steep slopes and cliff, upper contact gradational lower contact concealed by basalt and sandstone rubble.

4.	Glassy flow; generally moderate olive brown (5Y 4/4), glassy groundmass, with abundant laths of biotite; does not appear to be weathered greatly; abundant vesicles and vugs filled with unidentified zeolites and calcite; splits in jagged blocks; cliff former; basal contact concealed; unit well fractured in most outcrops.	12.0	80.0
3.	Concealed interval.............................	9.0	68.0
2.	Soil; generally pale red purple, (5PR 6/2); consists of poorly sorted small cobbles to small boulders, angular to subangular clasts of altered andesite, trachybasalt; poorly cemented (friable), siliceous and calcareous; no bedding is definable; massive; splits along cobble boundaries into blocks; forms cliffs and pinnacles; possible erosional soil surface, basal contact is extremely irregular.	4.5	59.0
1.	Trachybasalt; generally medium light gray, (N5), weathers light brown gray, (5YR 6/1 - 5YR 4/1); microcrystalline	54.5	54.5

groundmass, glass, and biotite laths present; well fractured with fractures filled by calcite, breaks into jagged blocks, small vesicles (0.5 cm); prominent cliff former; basal contact concealed by basalt rubble.

Total lower member
(incomplete)............................201.6

Total Chalk Canyon formation
(incomplete)............................309.7

NEW RIVER MESA

Unit		Sub-unit Thickness (meters)	Cumulative Thickness (meters)
	New River Mesa basalt		
14.	Olivine basalt; generally medium dark gray to dark gray, (N4-N3), weathers grayish red, (10YR 4/2); microcrystalline groundmass, abundant phenocrysts of olivine, pyroxene and plagioclase (2-5 mm); vesicular toward basal contact, basal contact is well fractured; prominent cliff former.	93.1	157.2
	Total New River Mesa basalt...............157.2		
	Unconformity		
13.	Lithic tuff; generally grayish red purple, (5PR 4/2), weathers pale red purple, (5PR 6/2); composed of poor to moderately sorted, subrounded, fine to medium grained volcanic fragments (basalt, andesite), and glass fragments; well cemented, siliceous; finely bedded for most part, massive unit also present; unit becomes coarser (coarse-very coarse sand) in upper 0.05 meters; slope former.	6.1	64.1

12.	Olivine basalt; generally medium dark to dark gray, (N4-N3), weathers grayish red, (10R 4/2); microcrystalline groundmass, with pyroxene, plagioclase, and olivine phenocrysts, vesicular toward base, some scattered vesicular bands are present higher in flow; columnar jointing present; basal contact concealed by basalt rubble; prominent cliff former.	58.0	58.0
	Total New River Mesa basalt...............	157.2	
	<u>Chalk Canyon formation</u>		
	<u>upper member</u>		
11.	Interbedded marl and tuffaceous sandstone; generally very pale orange, (10YR 8/2), weathers grayish orange pink, 5YR 7/2); consists of poorly sorted, angular to subangular, very fine to fine grained, abundant quartz, basalt fragments and some glass, firmly cemented, calcareous; massive unit for most part, with some poorly developed bedding; breaks into rough blocks; interbedded medium-very coarse tuffaceous sand, and small pebbles of basalt and tuff toward base; irregular nature to basal contact; steep slope former.	13.0	13.0

Total upper member........................13.0

Unconformity

<u>lower member</u>

10.	Trachybasalt; generally medium dark, (N4), weathers pale yellowish brown to moderate yellow, (10YR 6/2 to 10YR 5/4); microcrystalline groundmass with abundant small phenocrysts of moderate reddish brown, (10R 6/6), to moderately reddish brown, (10R 4/6), color mineral, possibly altered mafics; very vesicular in spots, with vugs filled with calcite and zeolite, vesicles generally less than 2 cm; forms prominent cliffs; basal contact placed where unit becomes a conglomerate and well fractured, with calcite filling the fractures.	24.3	284.5
9.	Trachybasalt; generally dark gray, (N4), weathers pale yellowish brown to moderate yellow, (10YR 6/2 to 10YR 5/4); very fine to fine grained; abundant small phenocrysts of moderate reddish brown to moderate reddish brown, (10YR 6/6 to 10YR 4/6), mineral; very vesicular in spots, with vugs filled with calcite; vesicles generally less than 2 cm in size; forms prominent cliff; basal contact irregular.	24.3	260.6

8.	Trachybasalt; generally medium dark gray (N4), weathers pale yellowish brown to moderate yellow, (10YR 6/2 to 10YR 5/4); very fine to fine grained, abundant small phenocrysts of moderate reddish brown to moderate reddish brown, (10YR 6/6 to 10YR 4/6); minerals possibly altered mafics; very vesicular in spots, with vugs filled with calcite, vesicles generally less than 2 cm in size; forms prominent cliffs; basal contact irregular.	39.5	235.9
7.	Crystal tuff; generally very pale orange, (10YR 8/2), weathers grayish orange, (10YR 7/4); consisting of well sorted, angular to subangular, medium to coarse sand-size particles, with abundant very small pebbles of tuff and scattered grains of a very hard mineral; poor to moderately cemented, siliceous; massive bedding; interbedded vitirc and lapilli tuffs; fractures into blocks; very porous; lower contact gradation with underlying lower unit; steep slope former.	18.6	196.4
6.	Crystal tuff; generally bluish white, (5B 9/1), weathers to a very pale orange (10YR 8/2), moderately sorted, sub-angular to subrounded pieces of medium	31.9	177.8

	sand sized glass, tuff, quartz, and biotite with very abundant grains of a hard gray volcanic lithic; well cemented, siliceous; finely laminated for most part, with some thick bedded units of lapilli and vitric tuff; rock breaks along bedding forming sheets; mud cracks found in some units; unit becomes coarser upward, with increasing amounts of tuff and lithics; contact with underlying basalt concealed; steep slope former.		
5.	Olivine basalt; generally medium dark gray, (N4), weathers pale yellowish brown to moderate yellow brown, (10YR 6/2 to 10YR 5/4); microcrystalline groundmass, with abundant small phenocrysts of moderate reddish brown to moderate reddish brown (10R 6/6 to 10R 4/6) mineral (altered olivine); very vesicular, with vesicles being generally less than 2 cm in size; massive for most part; forms prominent cliffs; lower 3.0 meters of unit well fractured, (calcite filled).	37.9	145.9
4.	Crystal tuff; generally bluish white, (5B 9/1), weathers to a very pale	27.0	108.0

orange, (10YR 8/2); comprised of abundant poor to fair sorted, angular to subangular, coarse to very coarse grained, tuff and quartz, and scattered metamorphic rock fragments, glass and biotite; poorly cemented, siliceous; beds mostly massive, with some finely laminated interbedded fine grain tuff, small scale planar cross strata, and minor channelling present; unit weathers into friable, massive blocks; a cliff former; basal contact is gradational with lower unit.

3.	Conglomerate; generally bluish white, (5B 9/1), weathers to a very pale orange, (10YR 8/2); consists of moderately-poorly sorted, angular to subrounded small pebbles to small cobbles of phyllite, schist, quartz monzonite, and diorite, and microcrystalline basalt; well cemented by coarse to very coarse sand size particles, siliceous; prominent cliff former; interbedded with very coarse sandstone; unit grades upward into coarse-very coarse sandstone; lower contact concealed by basalt and tuff rubble.	5.0	81.0
2.	Trachybasalt; generally medium light	76.0	76.0

gray, (N5), weathers light brown gray to brownish gray, (5YR 6/1 to 5YR 4/1); microcrystalline groundmass, olivine, biotite, and pyroxene phenocrysts present, most well altered, glass present; small vesicles (<0.5 cm), some calcite filled, becomes more vesicular toward top, vesicles become larger; prominent cliff former; contact with underlying unit irregular and fractured (filled with calcite).

Total lower member........................248.5

Total Chalk Canyon formation..............297.5

Unconformity

Fanglomerate (incomplete)

1. Fanglomerate; generally moderate reddish orange, (10YR 6/6); weathering moderate orange pink (10R 7/4), composed of poorly sorted, angular to subrounded, very coarse sand to large cobble size, phyllites, schist and granite; poorly cemented, siliceous; no determinable bedding, slope former; unconformable with overlying basalt unit. 22.8 22.8

Fanglomerate (incomplete)..................22.8

APPENDIX B

PETROGRAPHIC DESCRIPTIONS

OF THE TERTIARY ROCKS

FANGLOMERATE

Thin sections for this analysis were obtained from samples of:

Number of thin sections observed	Location	Unit number (see Appendix A)
1	Skull Mesa West Central	1
1	Skull Mesa Southwest	2

Two thin sections of the fine-grained stratified materials were examined. Grains comprise 70 percent of the fanglomerate in thin section (visual estimate). Calcite cement and a clay matrix make up the remaining 30 percent (visual estimate). Metamorphic and igneous rock fragments are the dominant grain types. Subangular pieces of schist, phyllite, granite, and diabase, with hematitic rims, formed from the alteration of iron silicates to oxides, are the grain types found.

Quartz occurs as either polycrystalline aggregates or single grains having undulose extinction. Graphic (quartz intergrown with potassium feldspar) and myremkitic (quartz intergrown with plagioclase feldspars) textures are observed in many of the igneous lithics (Figure 6) (Williams, Turner and Gilbert, 1954; Kerr, 1959). Sericitization along fractures and the edge of grains is the major alteration produce of quartz derived from metamorphic materials. Corrosion of quartz, from reaction with iron oxides, is a minor alteration.

Microcline is the dominant feldspar, with lesser amounts of perthite and plagioclase. Gridiron or quadrille twinning structures (Kerr, 1959) distinguish microcline from the two other types of feldspar. Most feldspars have been altered, in some degree, to clays, with sericitization occurring, but as a minor type of alteration. Minor mineral types

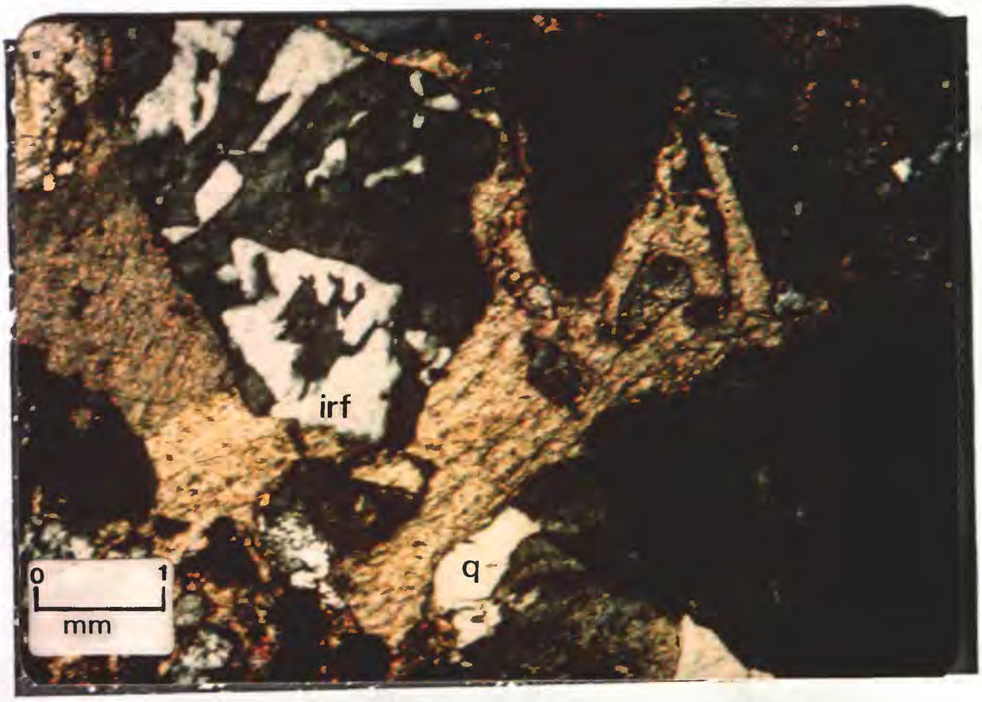

Figure 6

Photomicrograph of the fanglomerate; under crossed nicols and low power, irf = igneous rock fragment, q = quartz.

Fig. 6 New River Mesa quad
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include biotite, sericite, and highly altered iron silicates and oxides.

Calcite cement is the major binding agent. The cement occurs in the pore space, and resulted from carbonate-rich fluid percolating through the rock. A clay matrix stained with iron oxide is also found. The apparent source of the clay is from alteration of felsic minerals within the Precambrian terrane during deposition.

ANDESITE

Texturally, the andesites are holocrystalline, porphyritic and intergranular. Hornblende, plagioclase, and pyroxene are the major minerals found in a cryptocrystalline groundmass. Plagioclase microlites surround the hornblende and pyroxene and often display pilotaxitic textures with some of the larger phenocrysts (Figure 7). This is a result of alignment subparallel to flow. Lithic fragments occur as angular grains that have been altered to hematite and magnetite.

Hornblende is the most dominant large phenocryst, having a size range of 0.5 mm to 7.0 mm. It occurs mostly as subhedral laths, with poorly developed terminations or euhedral basal sections that have a cleavage pattern characteristic of amphiboles. In plane light, the hornblende grains are various tones of green or brown. Under crossed nicols, middle second order interference colors are observed. Pleochroism is present and strong, with intensity and color being governed by grain orientation. Some grain edges and interiors are replaced with iron oxides, and an unidentified low birefringence, cryptocrystalline material. The replacement has given rise to a ragged appearance to the hornblende. In certain instances, the replacement is complete and only the outline of a grain or pseudomorph remains. The cryptocrystalline material may be granular mixtures of augite and magnetite formed by the

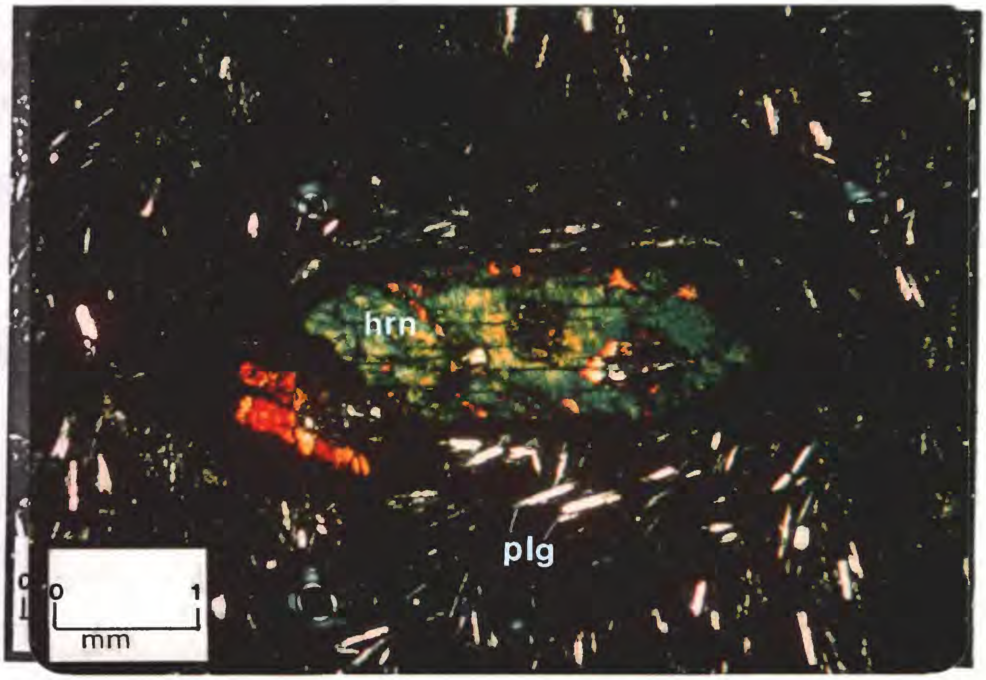

Figure 7

Photomicrograph of the andesite; under crossed nicols and low power, hrn = hornblende, plg = plagioclase.

New River Mesa quad
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reaction of hornblende, with the magma, following the suggestion of Williams, Turner and Gilbert (1954, p.95).

Minor scattered grains of lamprobolite (basaltic hornblende; Rogers, 1940) also occur. Lamprobolite is similar to hornblende, but can be distinguished by a smaller extinction angle (5-10°) and stronger pleochroism.

Plagioclase microlites display clustering or a glomeroporphyritic texture, whereas the larger laths are mostly isolated from each other. Albite twinning is common. Rarely, carlsbad-albite twins may also be observed. The average An content is An_{43} ("a" - normal method) with a range of An_{34} to An_{57}. Two types of plagioclase can be recognized; andesine averaging An_{40} and labrodorite averaging An_{53}. The ratio of andesine to labradorite is approximately 3:1. Most plagioclase phenocrysts have a dusty appearance resulting from alteration to clay.

Pyroxene is present as scattered clusters of subhedral phenocrysts and in reaction rims around hornblende. Phenocrysts range in size from 1 to 2 mm. Pyroxene grains are colorless in plane light and display middle second order interference colors under crossed nicols. Twinning, with {100} as the twin plane, was observed in one grain. Inclined extinction, with angles of 30° to 44°, suggests that clinopyroxenes, rather than ortho-pyroxenes are present.

Corroded grains of potassium feldspar, ranging in size from 0.75 mm to 4.0 mm, and displaying first order gray interference colors, were observed in one of the thin sections. Alteration to clay and sericite is responsible for the ragged appearance of most phenocrysts. Simple carlsbad twinning is the most common twin form. The potassium feldspars have a low value of less than 12° and are biaxial negative, indicating that they are probably sanidine.

Magnetite if found in all thin sections, either as subhedral phenocrysts in the groundmass, or as anhedral forms in reaction rims on hornblende. Phenocrysts are cubical in shape and less than 0.5 mm in size.

CHALK CANYON FORMATION

Basal Conglomerate

Thin sections for this analysis were obtained from samples of:

Number of thin sections observed	Location	Unit number (see Appendix A)
2	Black Mesa	4

A very coarse-grained sand unit within the basal conglomerate was examined in thin sections. A clastic texture was observed, with grains comprising 75 percent of the unit and a zeolite cement the remaining 25 percent (visual estimate). Some grains are in contact with each other, but most of them "float" in the cement. Metamorphic and igneous lithics are the dominant grain types. Subangular to subrounded pieces of schist, phyllite, granite, and diabase occur. Subordinate pieces of highly altered basic and intermediate volcanics, and partially devitrified glass are also observed.

Several substances rim the grains. Hematite, resulting from the alteration of iron silicates and iron rich lithics, forms discontinuous rims around most grains. Surrounding the hematitic rims is a fibrous, crystalline substance, having a low birefringence. Continuous rims of this substance occur on all of the grains observed. The crystal structure and optical properties suggest that this is a zeolite.

Quartz occurs as either polycrystalline aggregates or single grains with an undulose extinction pattern. Graphic and myrmekitic textures are observed in many of the igneous lithics. Quartz in the metamorphic lithics is sutured and stretched. Sericitization, along fractures and the edges of grains, is the major alteration product of quartz. Corrosion of quartz, as a result of reaction with iron oxide, is a minor type of alteration.

Microcline and perthite are the dominant feldspars with lesser amounts of plagioclase. Gridiron or quadrille twinning structures distinguish microcline from the two other types of feldspar. Most feldspars have been altered, in some degree, to either clay or sericite.

Glass is characterized by well-fractured grains. Devitrification has occurred in most grains, along edges and fractures, but it is rarely complete. Devitrification products include clay (montmorillonite), quartz, and feldspar. Minor mineral types include biotite, sericite, and highly altered iron silicates and oxides.

Zeolite cement is the only binding agent. The cement occurs in pore spaces and resulted from zeolite fluids percolating through the rock. One possible source of zeolite is from the devitrification of glass in the overlying tuff. Groundwater moving through the tuff becomes rich in zeolite and precipitates it in the conglomerate. Another possible source is from the overlying basalt flows, with groundwater again acting as the transporting agent of the zeolite. In many places, two or more stages of cementation can be observed. Cement is first precipitated around grain edges. Additional rims of crystals are formed with the influx of zeolite-rich fluids. The final result is the filling of the pore spaces by a series of rims that roughly parallel the shape of the pore (Figure 8).

Figure 8

Rims of zeolite cement in basal conglomerate; under crossed nicols and medium power.

New River Mesa quad
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Reworked Tuffs and Tuffaceous Sandstone

Thin sections for this analysis were obtained from samples of:

Number of thin sections observed	Location	Unit number (see Appendix A)
4	Skull Mesa West Central	3, 4, 6, 8
4	Skull Mesa Southwest	5, 7, 9. 11
6	Sugarloaf	2, 5, 7
5	Black Mesa	5, 6, 8
5	New River Mesa	4, 6, 7, 11, 13

Most of the tuffs in the Chalk Canyon formation have been reworked and are in some cases tuffaceous sandstones. The evidence for reworking includes rounding and fracturing of grains within the tuff and the presence of stratification, both on a microscopic and megascopic scale (see Chapter 2, Stratigraphy, Chalk Canyon Formation, Lithology and Interpretation). Crystals and glass are the dominant grain types (Figure 9) and are randomly scattered throughout the tuffs. Cement types include silica, calcite, and authigenic clay derived from the devitrification of glass and pumice.

Quartz is observed in all of the thin sections. Most quartz grains are subangular to subrounded in shape. Quartz occurs as either single grains with dominantly nonundulose extinction, or as polycrystalline aggregates. Fractured and stressed grains have undulose extinction patterns.

Alkali and plagioclase feldspars are observed in most thin sections. Sanidine and orthoclase are the alkali feldspars present. Orthoclase occurs subordinately to, and is distinguished from sanidine by a cloudy appearance, due to incipient alteration, and a larger 2V. The plagioclase crystals observed mostly display albite twinning with rarer carlsbad-albite and pericline twins. Zoning is observed in some of these feldspars. Most of the plagioclase occurs as laths. Composition of the plagioclase feldspars range from oligoclase to andesine of An_{26}-An_{40} ("a" - normal method; Kerr, 1959).

Iron oxides, mostly in the form of magnetite and hematite, are scattered throughout the thin sections observed. Magnetite occurs either as discrete grains or as an alteration product from the breakdown of iron silicates. Hematite is observed exclusively in association with altered iron minerals and volcanic rock fragments.

Biotite and hornblende occur in minor amounts. These iron oxides are recognized by a moderate birefringence and pleochroism. Biotite is generally observed as irregular brown platy grains and can be distinguished from hornblende by its better developed cleavage. Biotite is parallel or subparallel to stratification. Hornblende occurs as fractured, greenish-brown laths and is less abundant than biotite. Most biotite and hornblende crystals are rimmed by a rusty red mixture of magnetite and hematite. Total alteration to iron oxides is observed in some grains. Minor alteration of biotite to chlorite also occurs.

Less common crystal types include chalcedony, calcite and puroxene. Chalcedony occurs in vugs or veinlets. It is characterized in cross nicols by a wavy extinction pattern and aggregate structure (Kerr, 1959). Chalcedony can be distinguished from the zeolites by a lower birefringence.

Calcite is observed as a secondary interstitial filling in some thin sections. It is especially abundant in the coarser grained lithic

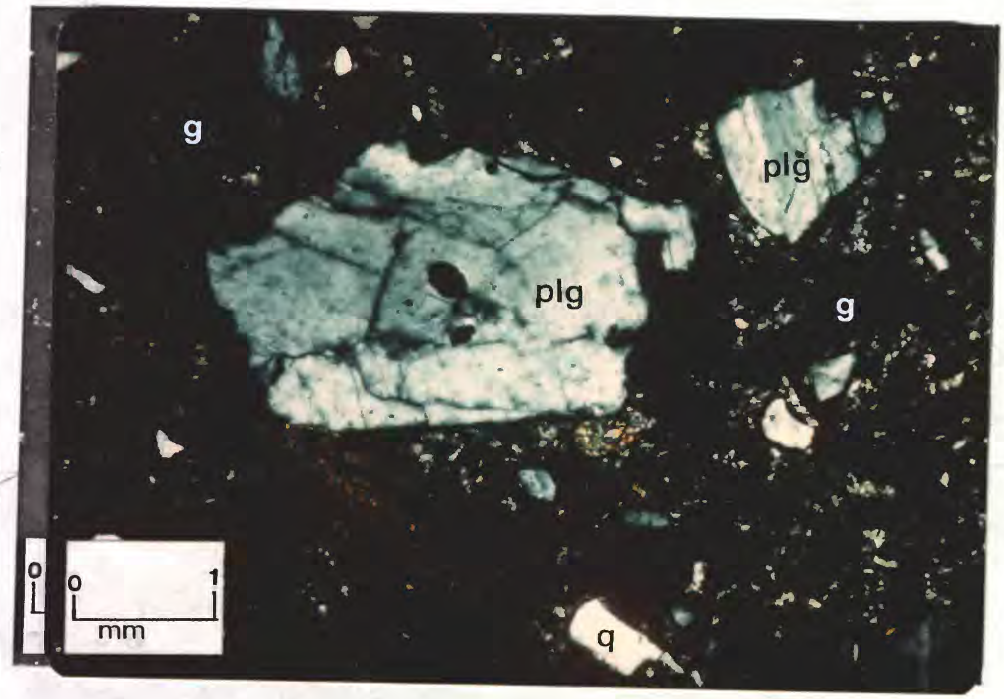

Figure 9

Photomicrograph of a crystal tuff; under crossed nicols and low power, g = glass, plg = plagioclase feldspar, q = quartz.

New River Mesa quad
OF Report

tuffs which have moderate to good porosity. Precipitation of calcite probably followed the percolation of calcium carbonate rich fluids through these tuff units.

Pyroxene is rare in the tuffs and is found only in one thin section. A positive identification cannot be made, but the moderate second order interference colors and an inclined extinction pattern distinguish it as a clinopyroxene.

Glass appears as angular to rounded, well fractured grains. Glass shards are absent. In plane light the glass fragments are pale brown with a dusty appearance. Under crossed nicols, the fragments are isotropic or have very low order interference colors resulting from strain. Many glass particles display concentric fractures or a perlitic texture. This texture has resulted from the dehydration of the glass.

Glass is chemically unstable with time and breaks down or devitrifies into more stable substances. Various degrees of devitrification, ranging from partial to total replacement, can be observed in the glass particles. The glass fragments generally alter to authigenic silicates (Figures 10a, 10b). Authigenic clay is the most common devitrification product. Clay occurs as massive microcrystalline aggregates restricted mostly to grain edges and fractures. In plane light it appears as dusty-brown rims surrounding glass fragments. Under crossed nicols it displays moderate second order interference colors. The clay observed in the Chalk Canyon tuffs is probably montmorillonite following the suggestions of Kerr (1959) and Williams, Turner and Gilbert (1954).

Many glass fragments have been altered to crypto- and microcrystalline materials. These devitrification products are characterized by a low birefringence (first order grays) and aggregate structure.

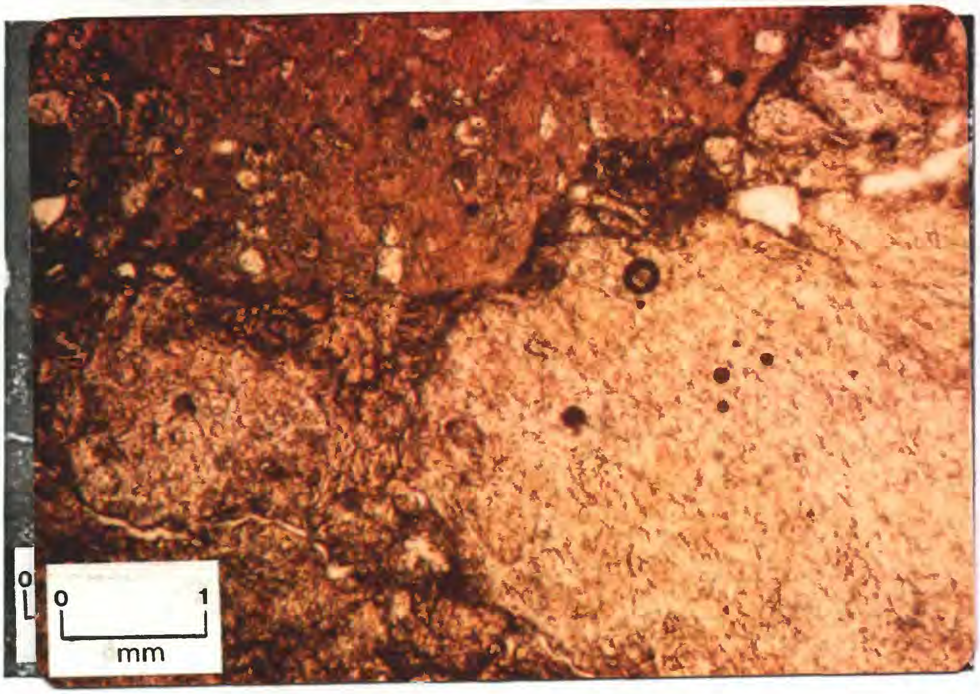

Figure 10

Alteration in vitric tuff

(a) Rounded glass fragments seen in plane light and under low power.

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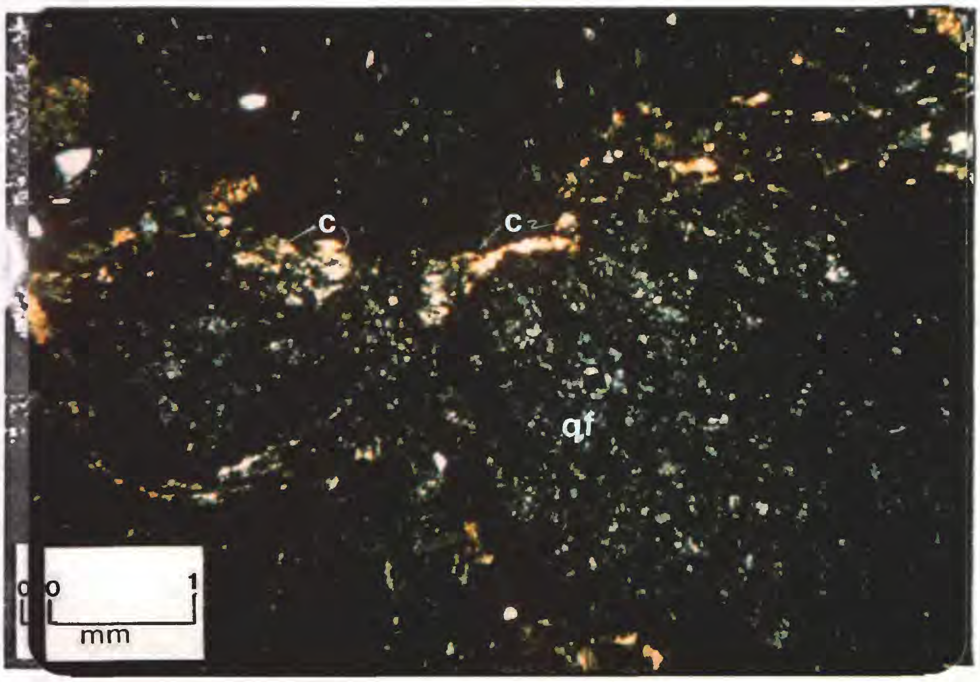

Figure 10

Alteration in vitric tuff

(b) Rounded glass fragments seen in polarized light and under low power; rimmed by clay (montmorillonite) and interiors altered to a felsic mixture of quartz and feldspar, c = clay, qf = felsic alteration.

New Rider Mesa Quad
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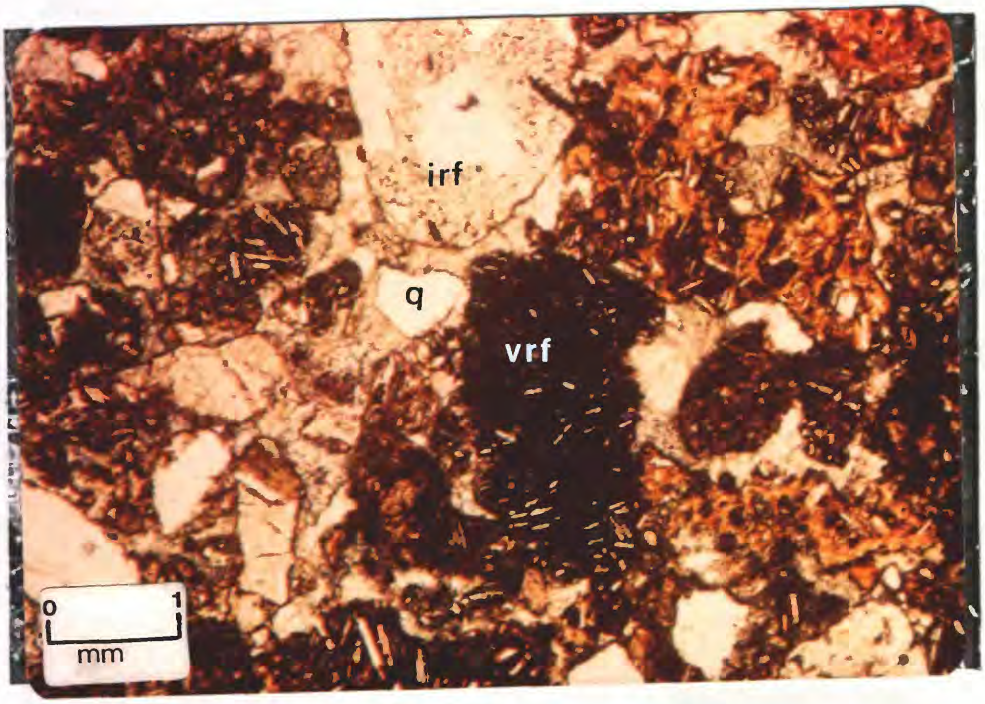

Figure 11

Photomicrographs of a lithic tuff; under uncrossed nicols and low power, irf = igneous rock fragment, q = quartz, vrf = volcanic rock fragment.

New River Mesa quad
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Williams, Turner and Gilbert (1954) suggest that these aggregates are dense felsitic mixtures of quartz, and orthoclase or sodic plagioclase.

Zeolites occur as minor devitrification products. They are present as small platy crystals, less than 0.25 mm in size, lining fractures and veinlets. A low to moderate birefringence characterized the zeolites. The crystal form and optical properties of the zeolites are suggestive of searlesite, a sodium boronite zeolite, which is found as a devitrification product in tuffs (Sheppard and Gude, 1968).

The optical properties of pumice are very similar to those of glass. Pumice differs from glass in that it is made up of elongated, tabular pore spaces, which gives it a fibrous texture. Most of the pumice fragments are collapsed and show some stretching as a result of compaction. Devitrification of pumice is dominantly to a dense felsic mixture of quartz and feldspar. Minor alteration to zeolite and clay is also observed.

The lithics in the tuffs can be subdivided into two types -- accessory; derived from volcanic rock, and accidental; derived from the subvolcanic basement (Williams, Turner and Gilber, 1954). The accessory lithics are rusty red in color, in most cases as a result of the alteration of mafics and iron silicates to iron oxides. These volcanic rock fragments are basaltic to andesitic in composition (Figure 11). Accidental rock fragments include Precambrian igneous and metamorphic detritus that are rimmed with hematite.

Airfall Tuffs

Thin sections for this analysis were obtained from samples of:

Number of thin sections observed	Location	Unit number (see Appendix A)
2	Sugarloaf	2, 5

The major constituent of the airfall tuffs are glass shards (Figure 12). Globular, cusp- and lune-shaped fragments can be observed (Williams, Turner and Gilbert, 1954). The cusp- and lune-shaped fragments are a result of the exploding of roughly globular bubbles. These explosions produce curved plates which represent fragments of the bubble walls (Ross and Smith, 1961). Most glass fragments display stretching and flattening as a result of compaction. The glass fragments float in a matrix of dust-like material. Many of the airfall tuffs are thinly laminated in thin section, with occasional thin cross laminae being observed. Particle size and the concentration of ash is fairly constant within laminae, but differ between laminae. Devitrification is not uniform within the airfall tuffs. The most abundant devitrification products are felsic mixtures of quartz and feldspar, following the suggestion of Williams, Turner and Gilbert (1954, p. 157). The felsic mixtures are characterized by a low birefringence. Minor alteration to authigenic clay also occurs. Some laminae appear more susceptible to alteration than others.

Crystals are very minor and are generally less than 0.50 mm in size. They comprise approximately 10% of the rock (visual estimate) and include quartz, sanidine, plagioclase ($\sim An_{35}$), hornblende, biotite, and iron oxides. Most of the crystals are angular in form and fractured. Biotite plates and hornblende laths occur parallel and subparallel to stratification. Some of the quartz and feldspar crystals show minor

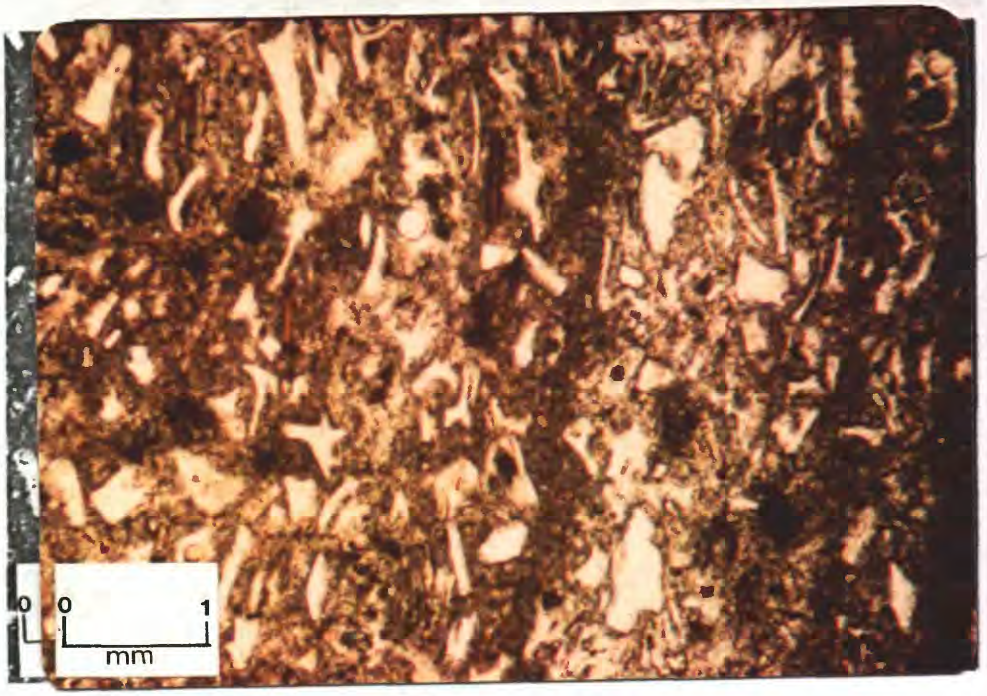

Figure 12

Photomicrograph of an airfall tuff; uncrossed nicols and low power, glass fragments are angular, cuspate and lunate, interstitial to the glass is a fine ash.

New River Mesa quad
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alteration to sericite. Accessory and accidental rock fragments were absent in the thin sections examined.

Olivine Basalts

Thin sections for this analysis were obtained from samples of:

Number of thin sections observed	Location	Unit number (see Appendix A)
1	Sugarloaf	3
1	Black Mesa	7

Texturally, the olivine basalts are holocrystalline, porphyritic and intergranular. Olivine, plagioclase, and pyroxene are the major phenocrysts, and are found in a microcrystalline groundmass. Small phenocrysts of plagioclase, pyroxene, and olivine can be recognized in the groundmass. Plagioclase microlites surround the olivine and pyroxene phenocrysts, often displaying a piliotaxitic texture.

The olivine phenocrysts are generally fractured and range in size from 0.1 mm to 2.0 mm. Most phenocrysts are subhedral in form and have a 2V approaching 90°, which is indicative of magnesium-rich olivine. In plane light, olivine is dominantly colorless, though some phenocrysts are light green. Under crossed nicols, upper second order interference colors are observed. All olivine phenocrysts display evidence of alteration. Numerous alteration products can be observed (Figure 13). Most grains have been altered to a strongly pleochroic bottle green substance that also displays a fibrous texture and low to middle second order interference colors (Figure 13). This substance may be chlorite or xyolite (ferrigeneous chrysolite), as suggested by Winchell and Winchell (1961, p. 380). Another common alteration product of olivine, is a brown

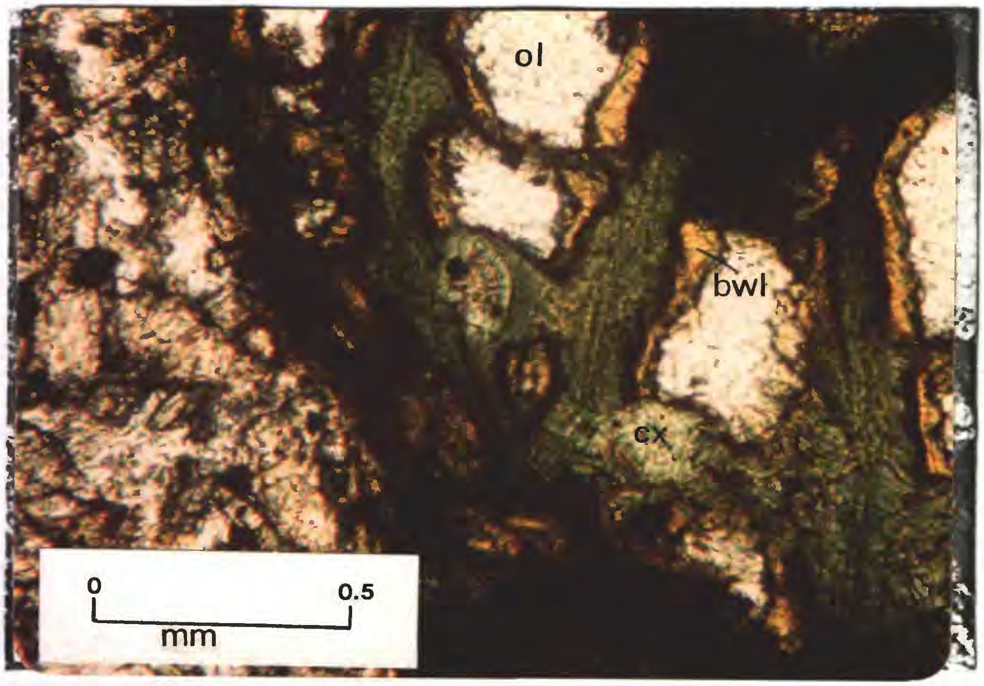

Figure 13

Alteration products of olivine; under uncrossed nicols and medium power, bwl = bowlingtonite, cx = chlorite or xyolite (?), ol = olivine.

New River Mesa quad
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non-pleochroic substance, characterized by moderate second order interference colors (Figure 13). Deer, Howie and Zussman (1964, p. 19) refer to this substance as bowlingtonite (a fibrous variety of saponite). Bowlingtonite is variable in composition and does not consist of a single phase, but is a mixture of more than one mineral. An investigation by Wilshire (1958) of bowlingtonite has shown that is consists of smectite-chlorite together with serpentine and/or chrysolite and minor amounts of talc, mica, quartz, and saponite. Iddingsite occurs as a rare alteration product of olivine in these flows. It is characterized by a reddish brown color and high birefringence. Like bowlingtonite, iddingsite is a multimineral substance (Deer, Howie and Zussman, 1964, p. 18). Sun (1957) has shown that iddingsite consists of goethite, amorphous silica, and magnesium oxide.

Pyroxene crystals display middle second order interference colors under cross nicols, and are faintly pleochroic and pale brown in plane light. Pyroxene occurs both as scattered subhedral or euhedral phenocrysts which range up to 1 mm in size, and microlites less than 0.30 mm. The pyroxene crystals show no evidence of alteration but contain inclusions of magnetite. Commonly, pyroxene phenocrysts cluster together to form glomeroporphyritic textures. An extinction angle of 36°-45°, and 2V ranging from 45°-60° can be observed, and are indicative of augite. Simple twinning also occurs in some grains.

Plagioclase is the most abundant crystal type and occurs exclusively as microlites in the groundmass. The microlites range in size from 0.1 mm to 0.5 mm. Orientation of the plagioclase phenocrysts appears to be random, but pilotaxitic textures can be observed around some olivine and pyroxene phenocrysts. Albite twinning is common, but carlsbad-albite and pericline twins can be found rarely. Distributed uniformly throughout the thin sections examined, the plagioclase microlites are labadorite in composition, averaging An_{55} (Michel-Levy method and "a" normal method).

Magnetite is found in all thin sections, either as subhedral to euhedral phenocrysts in the groundmass, or as anhedral forms in association with the chlorite-xyolite alteration products. Phenocrysts are cubical in shape and less than 0.1 mm in size.

Trachybasalts

Thin sections for this analysis were obtained from samples of:

Number of thin sections observed	Location	Unit number (see Appendix A)
1	Skull Mesa West Central	2
1	Skull Mesa Southwest	4
4	Black Mesa	1, 3, 9, 11
3	New River Mesa	2, 8, 9

Trachybasalts are an intermediate rock type between trachytes and phonolites, and olivine and oligoclase basalts (Williams, Turner and Gilbert, 1954, p. 57). They grade into phonolites and trachytes by increasing the amount of alkali feldspar at the expense of plagioclase. An increase in the amount of plagioclase reverses this process and results in olivine and oligoclase basalts (Williams, Turner and Gilbert, 1954, p. 57). Most of the trachybasalt flows display holocrystalline, porphyritic and intergranular textures, but some contain glass in minor amounts. Olivine, pyroxene, biotite, and plagioclase are the major primary minerals (Figure 14). The groundmass consists of plagioclase, pyroxene, and in

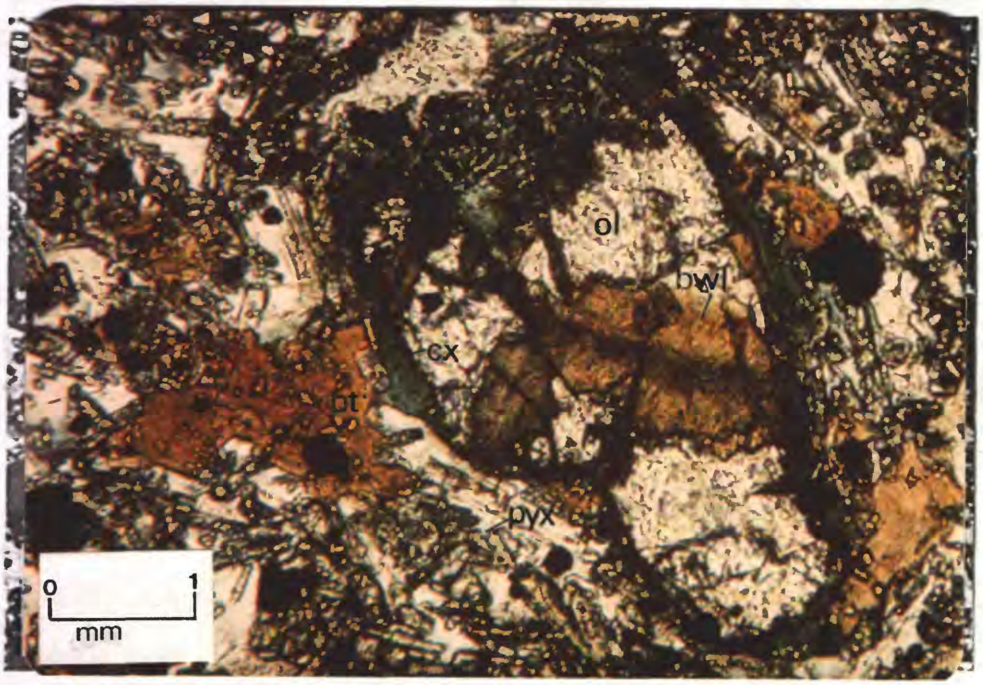

Figure 14

Photomicrograph of a trachybasalt; under uncrossed nicols and low power, bt = biotite, bwl = bowlingtonite, cx = chlorite or xyolite (?), ol = olivine, pyx = pyroxene.

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some flows, glass. Plagioclase microlites display pilotaxitic textures around the edges of the larger olivine, biotite and pyroxene phenocrysts.

Olivine grains are highly fractured, subhedral and have a 2V approaching 90°, which indicates magnesium-rich olivine. They occur only as separate phenocrysts, and have a size range of 0.25 mm to 8.0 mm. All grains of olivine display alteration, especially on grain edges and along fractures (Figure 14). Numerous types of alteration products can be observed, with some grains being replaced completely. The alteration products include bowlingtonite, serpentine, chlorite, xyolite, and magnetite.

Pyroxene is present as scattered clusters of subhedral and euhedral large phenocrysts, and small phenocrysts in the groundmass. Phenocrysts range in size from 0.5 and 8.0 mm. Pale brown and greenish brown colors are observed in plane light. An inclined extinction pattern and 2V ranging from 50°-65° suggest that augite is present. Twinning, with {100} as the twin plane, and hourglass extinction are observed in some grains.

Plagioclase is the most abundant phenocryst, occurring mostly as microlites in the groundmass, though some scattered laths were observed. Ranging in size from less than 0.1 mm to 0.5 mm, the microlites show well developed pilotaxitic textures. Albite twinning is dominant, but rarer pericline and carlsbad-albine twins are also present. Distributed fairly uniformly throughout the thin sections examined, the plagioclase microlites average An_{45} and range from An_{39} to An_{54} (andesine to labradorite). Alteration is rare, but some grains have been partially replaced by clay.

Biotite occurs in relatively abundant amounts in the trachybasalts (Figure 14). It is observed mostly as subhedral laths which exhibit parallel extinction. Pleochroism is present and moderate in intensity. In plane light, the biotite grains are shades of brown. Under crossed nicols, upper second order interference colors and "birds-eye" extinction are observed. Most grain edges are replaced by iron oxides. The replacement has given rise to a ragged appearance. In certain instances, the replacement is complete, and only a pseudomorph remains. Alteration to chlorite also occurs, but is infrequent. Inclusions include magnetite and apatite.

Potassium feldspars occur scattered throughout the groundmass and are interstitial to plagioclase microlites. Rarely, they are observed as phenocrysts with carlsbad twinning. Potassium feldspars can be distinguished from plagioclase by a lower relief. Grains are clear, for the most part, and have low 2V values, which are suggestive of sanidine. Alteration to clay is observed in some grains.

Glass occurs as clear patches in the groundmass in plane light. Under crossed nicols it is isotropic, except along fractures where it displays very low order interference colors. In some of the thin sections, the glass occurs as roughly spherical bodies, containing abundant small phenocrysts (<0.5 mm) of plagioclase, pyroxene, and olivine. Some of the glass "bubbles" have been partially or completely altered to zeolite.

Fractures and veinlets in the trachybasalts are filled with calcite and zeolites. The zeolites appear mostly as rims around the larger vesicules, with calcite filling the interiors.

Marl and Dolomite

Thin sections for this section were obtained from samples of:

Number of thin sections observed	Location		Unit number (see Appendix A)
2	Skull Mesa	West Central	6, 9
1	Skull Mesa	Southwest	9
2	Black Mesa		10, 11
1	New River Mesa		11

The marl and dolomite units of the upper member contain relatively abundant amounts of detrital material. In the dolomite observed, terrigeneous grains make up 10 percent of the rock and micritic dolomite the remaining 90 percent (visual estimate). Terrigeneous grains are even more abundant in the marl where they comprise 25 to 35 percent of the rock (visual estimate). The major terrigeneous grains include quartz, plagioclase and potassium feldspars, and volcanic and metamorphic rock fragments. Other grain types observed, in minor amounts, are glass, pumice, iron oxides, and silicates. The grains are angular to subrounded in shape, with many of the minerals maintaining subhedral forms.

Dolomite occurs exclusively as micrite (<0.04 mm) (Figure 15). The small crystal size and absence of large discernable rhombohedrals indicate that the dolomite was probably formed early in the rock's history. Detrital grains float within the dolomite and are generally not in contact with each other (Figure 16).

In the marl, most of the carbonate is found as sparry calcite. Small amounts of micrite are also present. Organic debris is abundant in the marls as pelloids, or lumps, having no distinctive shape. Algal

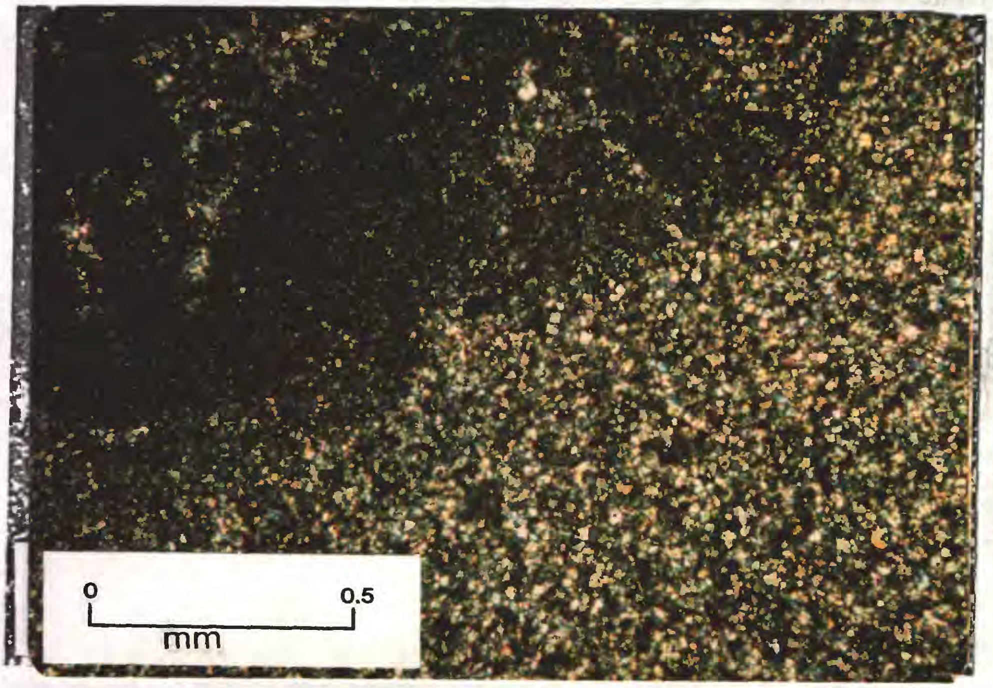

Figure 15

Photomicrograph of a dolomite; under crossed nicols and medium power.

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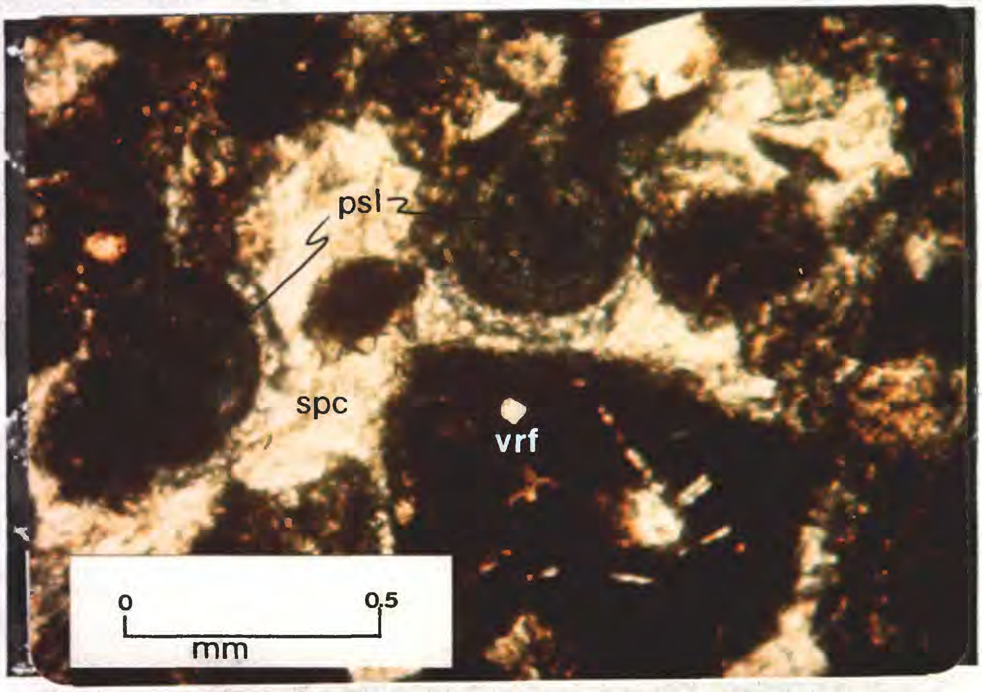

Figure 16

Photomicrograph of a marl; under crossed nicols and medium power, psl = pisolite, spc = sparry calcite, vrf = volcanic rock fragment.

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coatings are observed on all terrigeneous grains. Also occurring are rare, moderately well developed pisolites (Figure 16).

Most quartz grains display uniform extinction, characteristic of a volcanic origin. Some of the quartz is derived from metamorphic rocks and shows a wavy extinction resulting from strain. Dolomite has replaced the edges of some quartz grains.

Potassium and plagioclase feldspars are found in the marls and dolomites. Microcline displays a distinctive gridiron extinction pattern and is probably derived from metamorphic and igneous rocks. Orthoclase is scattered throughout the slides studied and in some cases shows carlsbad twinning. Plagioclase grains are lath shaped with some rounding of the edges. Albite twinning is the only twin form observed in the plagioclase. These feldspars are andesine to labradorite in composition (An_{33}-An_{53}; "a" normal method; Kerr, 1959). Recognizable iron oxides include magnetite and hematite. The oxides are found in association with altered iron rich volcanic rock fragments.

The volcanic rock fragments have been altered to iron oxides and are generally subrounded in shape. The fragments are basic to intermediate in composition. Schist fragments are the dominant metamorphic rock fragments observed. They consist of sutured and well-fractured quartz grains, and muscovite laths. Tuff and other igneous rock fragments occur in minor amounts.

Glass and pumice fragments found in the marl and dolomite units were probably derived from pyroclastic units in the area. Most of these fragments have been partially altered to clays.

Biotite, muscovite, and pyroxene were observed scattered throughout most of the marl and dolomite units. Biotite and muscovite occur as laths that are parallel to stratification. In some instances, the biotite has been partially altered to iron oxides. Pyroxene grains display an inclined extinction and second order reds and blues, which are indicative of a clinopyroxene. Because of the optical randomness, and scarcity of the grains, a more specific determination could not be made.

New River Mesa Basalts

Number of thin sections observed	Location	Unit number (see Appendix A)
1	Skull Mesa Southwest	14
2	Black Mesa	13

Three thin sections from across the section were examined. Most of the flows display holocrystalline, porphyritic and intergranular textures. The groundmass consists of small phenocrysts (<0.5 mm) of olivine, pyroxene, plagioclase, and magnetite. Some of the basalts contain trachylyte (basaltic glass), in minor amounts, in the groundmass.

Plagioclase is the most abundant phenocryst. Plagioclase feldspars occur either as large, distinctive laths or microlites in the groundmass. Ranging in size from 0.1 mm to 4.0 mm, laths commonly cluster together to form glomeroporphyritic textures. Orientation of the microlites appears random, but some weakly developed pilotaxitic textures can be observed around olivine and pyroxene phenocrysts. Albite twinning is dominant, though carlsbad-albite twins are also found. Distributed uniformly throughout the thin sections examined, the plagioclase laths are labradoritic in composition and average An_{63} (Michel-Levy method). Alteration of the plagioclases are not found, but some grains contain inclusions of olivine and augite.

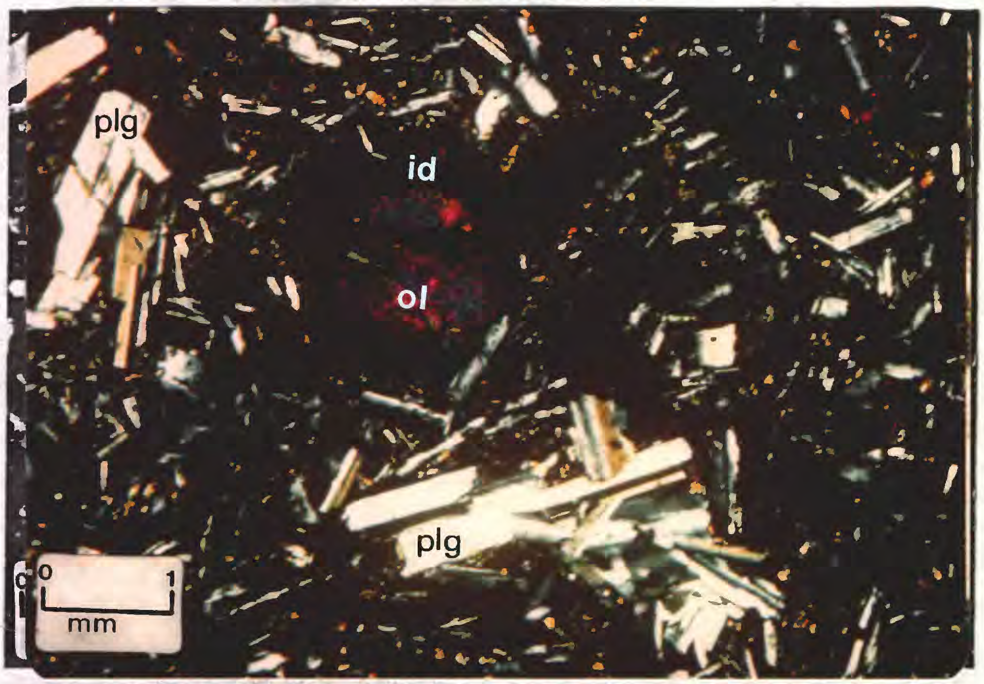

Figure-17

Photomicrograph of an olivine basalt from the New River Mesa basalt; under crossed nicols and low power, id = iddingsite, ol = olivine, plg = plagioclase.

Olivine phenocrysts range from fresh crystals to grains completely replaced by iddingsite and magnetite (Figure 17). The olivine is highly fractured, subhedral, and has a 2V approaching 90° indicative of magnesium-rich olivine. The olivine occurs mostly as separate phenocrysts. Olivine also occurs in the groundmass and has a size range of 0.1 to 5.0 mm. Clustering (glomeroporphyritic texture) of olivine phenocrysts can also be observed. Maximum interference colors observed are upper second order yellow and reds.

Pyroxene crystals display middle second order interference colors under crossed nicols and are pale green in plane light. Most pyroxene grains have ragged appearance and are surrounded by clusters of plagioclase microlites. Pyroxene occurs both as scattered subhedral to euhedral phenocrysts, which range up to 5.0 mm in size, and microlites less than 0.5 mm. Pleochroism is seen best in sections cut parallel to {100} but is very weak. An extinction angle of 36°-51°, and a 2V of approximately 60° can be observed and is indicative of augite. Twinning also occurs in some grains.

Magnetite is present as subhedral or euhedral grains scattered throughout the groundmass, or is anhedral when replacing olivine. In reflected light, magnetite has a metallic luster. Crystal size is less than 0.4 mm with some grains as small as 0.01 mm.

Calcite was observed rimming and filling vesicles. It is a secondary mineral, characterized by rhombohedral cleavage and an extremely high birefringence, producing high order interference colors.

The petrographic results in this study closely resemble those reported for the Hickey basalts by Lehner (1958) in the Black Hills, and Scott (1974) in the Verde Valley.