Paleozoic and Cenozoic Rocks in the Alpine-Nutrioso Area Apache County, Arizona

GEOLOGICAL SURVEY BULLETIN 1121-H

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By CHESTER T. WRUCKE

CONTRIBUTIONS TO GENERAL GEOLOGY

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Stratigraphy and structure of the Paleozoic and Cenozoic rocks in a 145-square-mile area in east-central Arizona

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CONTRIBUTIONS TO GENERAL GEOLOGY

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By CHESTER T. WRUCKE

ABSTRACT

The Alpine-Nutrioso area in Apache County, Ariz., adjacent to New Mexico, contains limestone and shale of Pennsylvanian or Permian age, and four Cenozoic formations consisting of sedimentary and volcanic rocks. The area comprises part of a geologically little known mountain region that separates the Colorado Plateaus from the Basin and Range province across most of Arizona. In east-central Arizona the mountain region is underlain principally by volcanic rocks. The Alpine-Nutrioso area, at the northern edge of the mountain region, is one of the few places in the region where sedimentary rocks are well exposed.

The rocks of Pennsylvanian or Permian age tentatively are correlated with the Naco group of southern Arizona. In the Alpine-Nutrioso area the Naco(?) crops out in two areas, each only a few hundred feet across, and forms a section about 40 feet thick. The Naco(?) occurs hundreds of feet higher than its usual position in the region and may not represent bedrock on which younger formations were deposited.

The oldest Cenozoic rocks in the area comprise the Datil formation, which crops out extensively in New Mexico, but has not been mapped previously in Arizona. In the Alpine-Nutrioso area the Datil formation can be subdivided into two members. The lower or sedimentary member is composed mainly of volcanic detritus and has an exposed thickness of 680 feet. The upper or andesite member is composed of porphyritic andesite about 400 feet thick. The Datil may be Eocene to Pliocene in age but probably is no younger than Miocene.

Overlying the Datil are sandstones as much as 1,200 feet thick that have many characteristics similar to the Chuska sandstone of northeastern Arizona and northwestern New Mexico. The sandstones in the Alpine-Nutrioso area, however, are referred to here as the upper sedimentary formation, for they cannot yet be correlated with other formations. The major part of the formation is composed of eolian sandstone characterized by cross-stratification in sets as much as 15 feet high and 70 feet long. The basal beds are of fluvial origin. The formation probably is older than the Bidahochi formation of Pliocene age of northeastern Arizona.

Basalt of Tertiary or Quaternary age overlies the upper sedimentary formation and forms a sequence of flows as much as 900 feet thick as well as several dikes and a neck.

The youngest formation mapped in the area is basalt thought to be Quaternary in age.

The structure of the area is characterized by nearly horizontal strata and few faults. The anomalous position of the Naco(?) indicates that the pre-Cenozoic rocks are either structurally more complex than younger formations or that the Naco(?) rocks are xenolithic inclusions in the Datil andesite. Most of the Cenozoic rocks have a gentle regional dip to the south.

INTRODUCTION

Structurally simple sedimentary and volcanic rocks of Cenozoic age in east-central Arizona adjacent to New Mexico extend northward from the Basin and Range province and lap onto the Colorado Plateaus. These rocks underlie several thousand square miles, but in spite of their great areal extent and their position at the edges of two major physiographic provinces, little information about them is available in the literature. Furthermore, the few exposures of Paleozoic strata in this part of Arizona also have not been described; they are of interest owing to their isolation from areas of widespread Paleozoic formations. The purpose of this report is to describe the Paleozoic and Cenozoic rocks in an area of 145 square miles, designated the Alpine-Nutrioso area, near the southern edge of the Colorado Plateaus in east-central Arizona (fig. 1).

The Alpine-Nutrioso area contains rocks of the Naco(?)group of Pennsylvanian or Permian age and four Cenozoic formations (fig. 2). The Datil formation, the oldest rocks of Cenozoic age, crops out over a broad area in New Mexico, but it has not been mapped previously in Arizona. Its exposures in the Alpine-Nutrioso area are the westernmost ones yet recognized. A thick eolian sandstone overlies the Datil and has many characteristics similar to the Chuska sandstone of northeastern Arizona and northwestern New Mexico. Younger formations in the area are volcanic. Formations of Cenozoic age probably cover the pre-Cenozoic strata of the area to depths of several thousand feet; consequently the presence of two small exposures of Pennsylvanian or Permian rocks hundreds of feet higher than their usual position in the region is anomalous. Some of the Cenozoic formations described in this report may provide keys for correlation with other units in east-central Arizona.

The Alpine-Nutrioso area is in mountainous terrain in southern Apache County, Ariz., and borders on New Mexico (fig. 2). The area is about 10 miles southeast of Springerville and 55 miles north of Clifton, and includes the towns of Alpine and Nutrioso.

The geology of the area was studied by reconnaissance methods during parts of July and August 1955, and in November 1959, as part of a U.S. Geological Survey project to provide data for a new geologic map of Arizona.

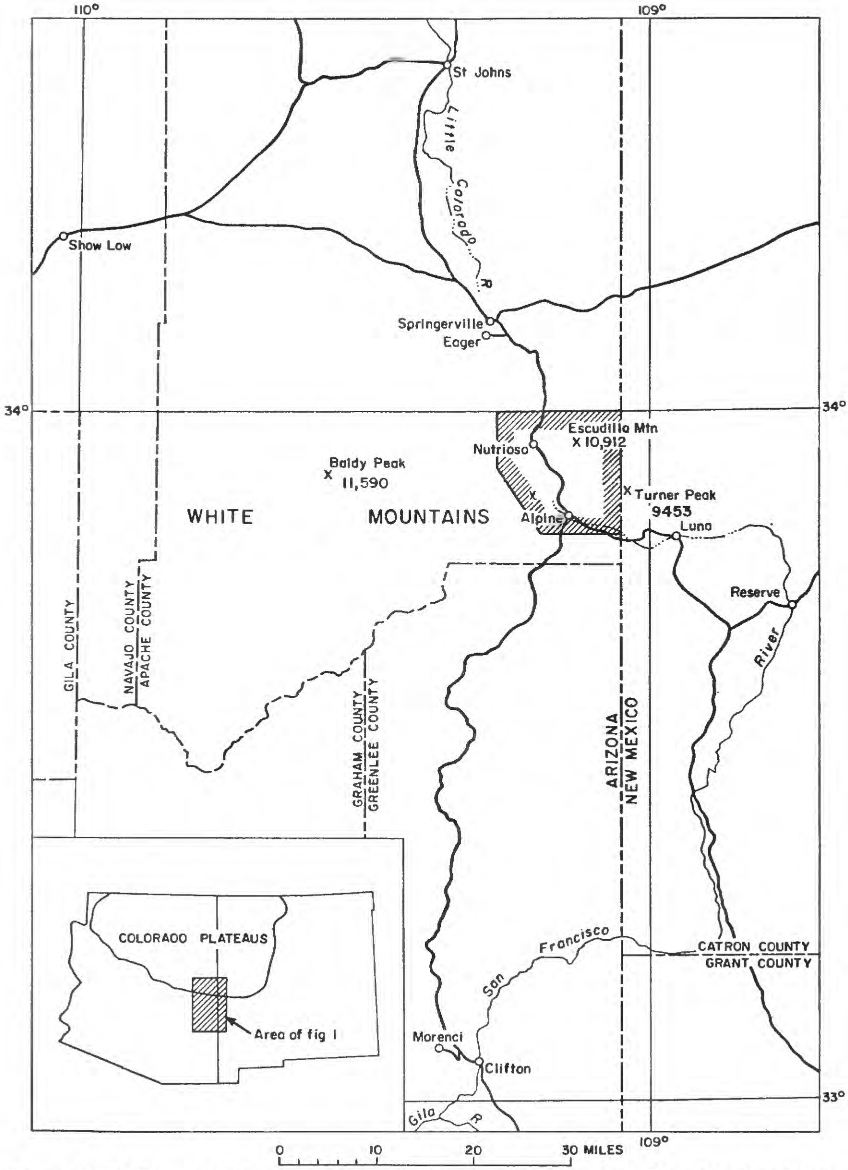

FIGURE 1.—Index map of parts of eastern Arizona and western New Mexico showing location of the Alpine-Nutrioso area.

The only previously published geologic material available on the area was written by Darton, who briefly mentioned the Tertiary rocks in his "Résumé of Arizona Geology" (1925, p. 156–158). The results of his mapping are shown on the geologic map of Arizona (Darton and others, 1924).

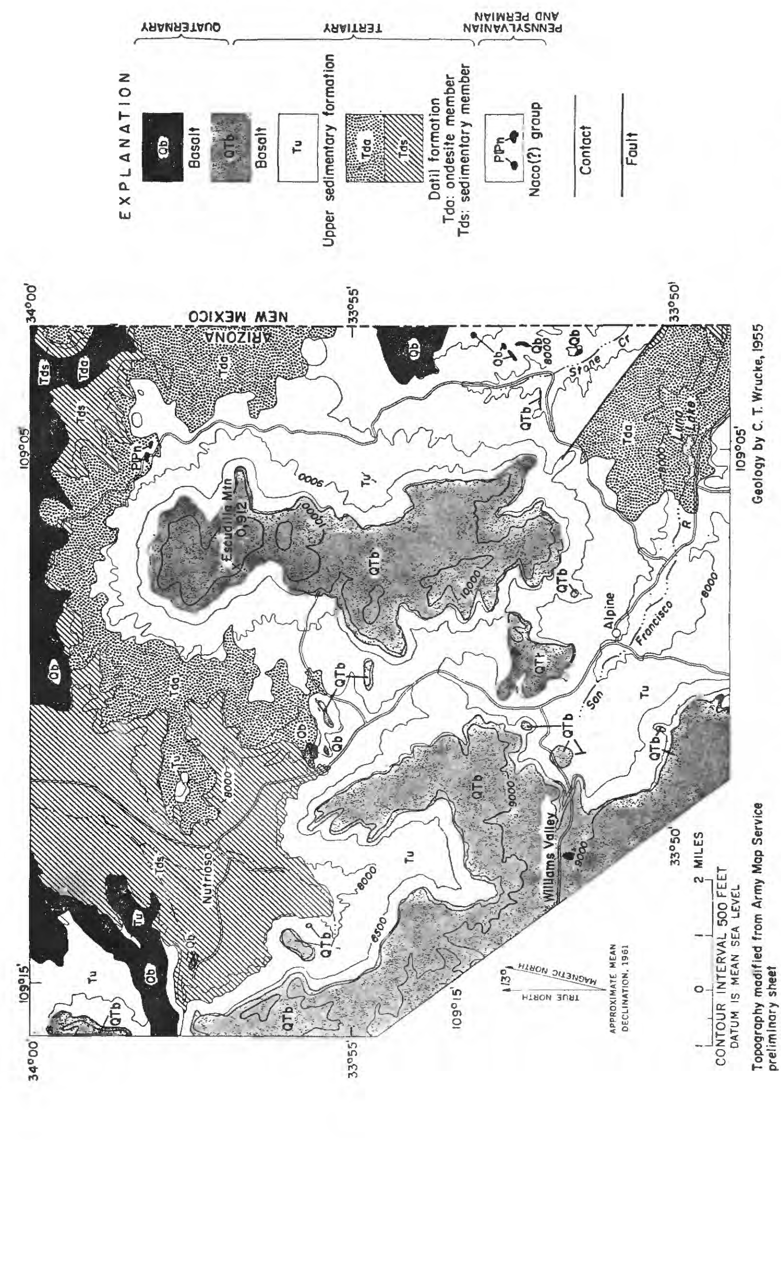

FIGURE 2.—Reconnaissance geologic map of the Alpine-Nutrioso area, Apache County, Ariz.

REGIONAL SETTING

The Alpine-Nutrioso area is at the northern edge of a wide mountain belt that extends from Arizona eastward into New Mexico and separates the Colorado Plateaus to the north from the Basin and Range province to the south. Ransome (1903, p. 10) was the first to recognize that the mountain belt formed one of three physiographic regions in Arizona; he called the others the plateau region and the desert region. His desert region is approximately equivalent to the Basin and Range province. Most geologists working in Arizona have accepted this threefold physiographic subdivision, which is useful in showing that in central and eastern Arizona the Colorado Plateaus and the Basin and Range province are not adjacent, but are separated by a mountainous region. The Alpine-Nutrioso area is a few miles northeast of Ransome's mountain region but is not separated from it by any physiographic feature. The Colorado Plateaus begins about at the northern edge of the Alpine-Nutrioso area; the Basin and Range province begins about 60 miles south of the southern border of the area.

The mountain region, generally called the White Mountains in eastern Arizona, for the most part is not rugged, though it has some of the highest points in the Southwest. In this part of the State the mountain region is an area of forest-covered highlands that rises above the semiarid mesa and flatland country of the adjacent Colorado Plateaus and descends gradually to the deserts of southern Arizona to the south. Locally, as in parts of the Alpine-Nutrioso area, slopes are steep. Extensive forests of ponderosa pine interrupted by broad meadows and grassy valleys are widespread; thick stands of Douglas-fir cover the higher mountains. Much of the belt is at altitudes above 8,000 feet, and mountains above 9,000 feet are numerous. Escudilla Mountain, altitude 10,912 feet, is the highest peak in the Alpine-Nutrioso area and one of the highest points in eastern Arizona. But Baldy Peak, 30 miles to the west, is the highest peak (11,590) in the mountain belt. The topography and flora of the belt contrast markedly with the surrounding areas.

The geology of the eastern Arizona part of the mountain belt seems rather simple. It is characterized by flat-lying to gently dipping formations of Cenozoic age that probably cover structurally simple Paleozoic and Mesozoic rocks like those on the Plateaus to the north. The Plateaus and the mountain belt are not separated, as far as is known, by any structural feature.

The Cenozoic rocks in the eastern Arizona part of the mountain belt are mostly volcanic. These volcanic rocks extend eastward into New Mexico and also northward onto the Colorado Plateaus to form one of the largest volcanic fields in the Southwest. This field might appropriately be called the White Mountains volcanic field. Though volcanic rocks are extensive in this region, sedimentary formations also exist and are particularly well exposed in the Alpine-Nutrioso area.

NACO(?) GROUP

DISTRIBUTION AND LITHOLOGY

Rocks of Pennsylvanian or Permian age, tentatively correlated with the Naco group of southern Arizona, crop out in two areas at altitudes between 8,600 and 8,700 feet on the northeast flank of Escudilla Mountain. The areas, each a few hundred feet across, are about 1 mile from the New Mexico line and can be reached by the dirt road around the east side of Escudilla Mountain. One area is crossed by the road; the other, about a quarter mile to the southeast, is a hundred yards east of the road.

Limestone is the dominant rock type, but details of stratigraphy are difficult to ascertain and sedimentary structural features are obscure owing to brecciation of the rocks and the small size of the outcrops. Sparse limestone float blocks, a foot or less in diameter, are the only indication of the Naco(?) in much of the two areas. A few exposures, as much as 6 feet across, are present in the southeastern area, but the largest exposure is along the road in the northwestern area.

The road cut in the northwestern area has yielded the most information of any exposure of the Naco(?). The east face of this cut, which is as much as 12 feet high, exposes limestone along a length of 120 feet. Here the rock is very light gray, medium grained to lithographic, and intensely brecciated. Local concentrations of brown argillaceous material emphasize the breccia fragments. A little opal also occurs between the fragments. Brown to maroon shale at the southern end of the road cut appears to underlie the limestone and gives a vague suggestion of the bedded nature of the rock.

The outcrops in the southeastern area are composed of medium- to dark-gray commonly medium-grained brecciated limestone. Unlike the rock in the road cut, this limestone has small white chert nodules but is not underlain by shale. These outcrops, though more numerous than those in the area of the road cut, have yielded little additional information.

The base of the Naco(?) is not exposed, and the top nearly everywhere is the present erosion surface. Andesite of the Datil formation locally overlies the limestone, but field relations suggest that sandstone of the upper sedimentary formation of Tertiary age probably once overlay it at most places.

The presence of Naco(?) at such high altitudes, its absence elsewhere in the area, and its relation to the surrounding Cenozoic rocks suggest that it may not represent bedrock immediately beneath the Tertiary section, but may instead be xenoliths in andesite. This possibility is discussed in greater detail under "structure."

THICKNESS

On the assumption that some of the small outcrops are parts of larger limestone masses, the exposed thickness of the Naco(?) probably is no more than a few tens of feet. The thickest well exposed section is in the road cut, but probably a section of greater thickness is in the poor exposures in the southeastern area. On the southeast side of the stream at the southeastern locality, the section is perhaps 20 feet thick; on the northwest side it may be 40 feet thick.

AGE AND CORRELATION

The age of Naco(?) in the Alpine-Nutrioso area was determined from microfossils collected in the road cut mentioned above. These fossils were studied by L. G. Henbest, who reported the following assemblange (written communication, July 10, 1956):

U.S. Geological Survey collection f-12178
- Tolypamminids
- Calcitornellids
- Textulariidae
- *Climacammina* sp.
- *Bradyina* sp.
- *Globivalvulina* sp.
- *Schubertella* sp.
- *Triticites* cf. *T. secalicus* (Say)

Regarding this collection, Henbest, in the same communication, stated:

> The maximum known time range for this assemblage is Virgil (Pennsylvanian) to early Wolfcamp (Permian) inclusive. Late Virgil or early Wolfcamp age is suggested. The *Schubertella* species listed above is identified with a slight uncertainty though it appears to be a primitive species of that genus. The evidence from the sections at hand, leaves little basis for suggesting which side of the systematic fence this limestone belongs on.

The Late Pennsylvanian or Early Permian age of this fossil assemblage means that the rocks are the same age as parts of the Naco group of southern Arizona, and the Supai formation of central Arizona. The Supai consists of reddish siltstone, claystone, and sandstone and a little limestone (Jackson, 1951), whereas the Naco is composed principally of limestone. Because the Naco(?) in the Alpine-Nutrioso area is mainly limestone and contains fossils of Naco age, it tentatively is correlated with that group.

DATIL FORMATION

The oldest formation of Tertiary age in the area consists of andesite and sedimentary rocks correlative with the Datil formation of New Mexico. Winchester (1920, p. 10), in describing the type section in the Bear Mountains of New Mexico 110 miles east-northeast of the Alpine-Nutrioso area, defined the Datil as " a series of tuffs, rhyolites, conglomerates, and sandstones" of late Tertiary age. Since Winchester's work the formation has been recognized in much of west-central New Mexico and has been extended to include rocks not present in the Bear Mountains. Willard (1959) described the rocks that have been recognized in the formation and showed that those adjacent to the Alpine-Nutrioso area, though not the same as at the type locality, are part of the Datil as it now is used. The Datil, however, has not been described in Arizona.

The Datil formation in the Alpine-Nutrioso area can be divided into two members, a lower one composed of sedimentary rocks and an upper one composed of andesite. These will be referred to here as the sedimentary member and the andesite member.

SEDIMENTARY MEMBER

DISTRIBUTION AND LITHOLOGY

The sedimentary member of the Datil formation underlies about 10 square miles in the vicinity of Nutrioso and a few smaller localities in the northeast and southeast parts of the Alpine-Nutrioso area, but it is well exposed only locally. Alluvium and thick forests cover the formation nearly everywhere. The best exposures are on the steep slopes east and northeast of Nutrioso, within 1½ miles of the town, and can be seen from the Springerville to Alpine highway.

The sedimentary member is exposed on recently dissected slopes, which include a few ledges that are 1 to 20 feet apart, and which from a distance appear in distinctive shades of green and pink. Cliffs are prominent locally, especially east of Nutrioso.

The sedimentary member is composed principally of interbedded mudstone and fine-grained sandstone in the lower part and coarse-grained sandstone and pebble conglomerate in the upper part. Volcanic graywacke locally occurs low in the formation. Bedding is indistinct in much of the fine-grained sandstone and mudstone, even on close examination, but locally is well expressed. The sandstone forms beds commonly 1 to 12 inches thick in sets that average about 10 feet in thickness; these sets alternate with mudstone a foot to several tens of feet thick. Cross-stratification of the trough type (McKee and Weir, 1953, p. 387), characterized by sets rarely as much as 2 feet long and 1 foot thick, occurs sparsely in the fine-grained sandstone; in the coarse sandstone and conglomerate, sets of cross-strata of similar form, generally 2 to 10 feet long and as much as 3 feet thick, are numerous. The member is poorly indurated.

Details of the lithology are best represented in a section exposed in a treeless scar on the northwest-facing slopes 1¼ miles northeast of Nutrioso, one-fourth mile east of the Springerville to Nutrioso highway. Here the member, overlain by andesite, is divisible into four units as follows:

	Thickness of units, in feet
Andesite, black, with conspicuous plagioclase phenocrysts.	
Unconformity.	
Sedimentary member (incomplete):	
Unit 4. Sandstone and conglomerate, interbedded. Sandstone is pale grayish pink and coarse grained. Conglomerate is composed of well-rounded pebbles of volcanic rocks of intermediate to silicic composition, and sparse limestone, arkose, and granite pebbles in matrix of coarse-grained sandstone. Stratification consists of lenticular sets of horizontal laminae to beds as much as 6 inches thick, and trough sets of cross-strata commonly 2 to 10 feet long and ½ to 3 feet thick. Poorly indurated. Forms cliffs and steep slopes	300
Unit 3. Sandstone and mudstone. Sandstone is pinkish gray, fine grained, in beds commonly 1 to 12 inches thick and sets commonly 10 feet thick. Mudstone is grayish orange pink, calcareous, locally silty; bedding indistinct but forms 6-inch-thick sets interbedded with sandstone. Poorly indurated. Forms steep slope with faint ledges 1 foot apart	100
Unit 2. Sandstone, grayish-pink to pinkish-gray, silty to fine-grained; composed of horizontal laminae to beds as much as 1 foot thick, locally cross-laminated in sets as much as 2 feet long and 1 foot thick; grayish-pink laminated mudstone occurs locally. Poorly to moderately well indurated. Forms cliff to very steep ledgy slope littered with shaly to slabby fragments. Top of unit forms conspicuous bench as much as 30 feet wide	80
Unit 1. Sandstone and mudstone, interbedded. Sandstone is pale grayish green, fine grained. Mudstone is mostly pale red. Stratification indistinct throughout most of unit, but where exposed it is in laminations and beds as much as 2 feet thick. Poorly indurated. Forms steep slopes with badland-type pinnacles as much as 20 feet high. Base of unit not exposed	200
Total of incomplete sedimentary member	680

The sandstone in much of the formation is distinctive in composition: it is low in quartz and rich in grains of calcite or fragments of silicic volcanic rocks. Sandstone of unit 4 consists of about 50 percent calcite, 25 percent albite, and 25 percent volcanic fragments and accessories. The lower units are poorer in calcite and richer in light-colored volcanic debris. Units 2 and 1 have no calcite and consist almost entirely of silicic volcanic material.

The mudstone in the member is composed dominantly of clay-size particles. A small percentage of silt, however, is present in much of the mudstone; quartz and feldspar grains that averaged 0.008 mm in diameter were seen in a thin section of a specimen from unit 2.

Green graywacke, probably low in unit 1, crops out 3 miles west of Nutrioso and also along the New Mexico border east of Luna Lake. The graywacke is fine to coarse grained, locally contains pebbles as much as 10 mm in diameter, and is composed principally of fragments of basalt and andesite embedded in a greenish matrix of clay(?) and chlorite. At least 25 percent of the graywacke is matrix. The rock is distinctive because of its moderate, almost bright, green color.

Pale green, which is characteristic of the member, is common to unit 1, whereas pale pink is dominant in higher units. Locally, where calcite is abundant, the rock is gray. The rocks are greenish owing to chlorite; they are pinkish because of reddish albite, fragments of pink silicic volcanic rocks, or fine-grained hematite.

Only unit 1 is found throughout the area. Unit 4 occurs only in the high cliffs east and northeast of Nutrioso. Units 2 and 3, though more extensive than unit 4, also exist only in the vicinity of Nutrioso. Unit 2, which forms prominent cliffs a few hundred feet above the valley floor east of Nutrioso, is not found west of the Alpine to Springerville highway. Unit 1 is the only unit that is west of the longitude of Nutrioso and probably is the only one in the northeast or southeast parts of the area.

The base of the member is not exposed in the area. It may be present within 8 miles of the area, for rocks presumed to be Tertiary in age and thought to be traceable into the sedimentary member at Nutrioso rest on the Chinle formation of Triassic age near Springerville. Some of the reddish beds a few miles southeast of Springerville resemble the Baca formation (Eocene), which underlies the Datil in New Mexico, consequently more fieldwork needs to be done to determine how much of the Tertiary section between Nutrioso and Springerville is Datil.

The upper contact is better known: between Nutrioso and the New Mexico border the member is unconformably overlain by the andesite member; south and west of Nutrioso the member is overlain by rocks younger than the Datil. Locally the contact with the andesite is disconformable and has a relief of several feet, but north of Escudilla Mountain the apparent relief is greater than 100 feet and may be the result of postdepositional folding. The contact between the sedimentary member and rocks younger than the Datil is poorly exposed.

THICKNESS

The maximum exposed thickness of the sedimentary member is 680 feet at the measured section 1¼ miles northeast of Nutrioso. If the covered slopes below the base of the measured section are assumed to be underlain by the member, as shown on the geologic map (fig. 2), the thickness in this area would be at least 1,000 feet.

ORIGIN

The sedimentary member appears to consist of materials derived principally from two sources—one volcanic, the other sedimentary. Some material may have come from granitic terrain. Deposition took place in a fluvial environment.

Units 1 and 2 consist largely of volcanic debris. Light-colored angular fragments of felsic material of low birefiringence and refractive index below balsam—probably devitrified glass—are the principal constituents. Grains of quartz and feldspar are sparse. Fragments of basalt and andesite locally are abundant, as in the graywacke of unit 1, but the light color and the composition of most rocks in these units suggest that the source area was rich in silicic tuff.

Unit 3 also is rich in fragments of silicic volcanic rocks and probably received much of its material from tuffaceous terrain. The sandstone includes numerous pumice fragments 1 to 2 mm in diameter, and the upper 10 feet of the unit contains well-rounded white cobbles of silicic tuff as much as 6 inches in diameter. Grains of feldspar are more numerous in this unit than in lower ones, but the main difference between this and lower units is that some of the siltstone beds contain abundant clastic calcite, indicative of a sedimentary origin.

Unit 4 received its material from several sources. It contains abundant volcanic debris; the pebbles and cobbles in the conglomerate came mostly from flow rocks and tuffs. The sandstone beds and the matrix of the conglomerate, though rich in volcanic material, contain at least 50 percent calcite in coarse grains. Other materials of sedimentary origin are limestone and arkose pebbles in the conglomerate. About 25 percent of the sandstone is composed of grains of pink albite, which could have been derived from the granitic terrain that supplied pebbles of red granitic rock to the conglomerate. About half of unit 4 appears to have been derived from limestone, a quarter from granite, and another quarter from volcanic rocks.

The source area of the volcanic material in the member is not known. Volcanic rocks contemporaneous in age or older than the sedimentary member are not known in the White Mountains volcanic field. If such rocks exist, they are buried by younger formations. A possible source area is eastern Catron County, N. Mex., where volcanic rocks older than or contemporaneous with the sedimentary member are widespread.

The calcite and granitic debris in the member may have come from southern Arizona, where calcareous rocks of Paleozoic age and granite of Precambrian and Mesozoic age are abundant. Southern Arizona might have been the source area if the Colorado Plateaus were elevated after deposition of the sedimentary member of the Datil. Unfortunately the age of the Datil with respect to the uplift of the plateaus has not been clearly determined. A source of carbonate rocks closer to the Alpine-Nutrioso area and at altitudes that were high enough in Datil time to have provided material for the sedimentary member is not known. The Supai formation of Pennsylvanian and Permian age, which has carbonate beds, and the Kaibab limestone of Permian age both crop out about 50 miles west of Nutrioso in the vicinity of Show Low, Ariz., but at altitudes lower than any in the Alpine-Nutrioso area. The Kaibab may occur closer than 50 miles from the area and at high altitude, but if so it is covered by Cenozoic rocks of the White Mountains volcanic field. The Naco(?) northeast of Escudilla Mountain, especially because of its nearness, would seem to be a reasonable source, but it may not have formed a highland during deposition of the sedimentary member. Instead, the Naco(?) may have attained its position after deposition of the sedimentary member—a possibility mentioned in the description of the Naco(?) and discussed further under "structure."

Most, perhaps all, of the rocks in the member were deposited under fluvial conditions. Some of the laminated mudstone in units 1, 2, and 3 may have formed as a result of ponding, but the cross-stratification of the sandstone and the conglomerate indicates that the bulk of the member was deposited in a fluvial environment.

ANDESITE MEMBER

DISTRIBUTION AND LITHOLOGY

In much of the area, porphyritic andesite, as much as 400 feet thick, unconformably overlies the sedimentary member of the Datil. The andesite crops out low on the west, north, and east sides of Escudilla Mountain and at Luna Lake. It is excellently exposured 3 miles southeast of Nutrioso and along San Francisco River downstream from Luna Lake.

The andesite is typically greenish black to brownish gray and is crowded with stubby plagioclase phenocrysts generally 1 to 5 mm long Numerous black pyroxene crystals can be seen easily with a hand lens. The groundmass is aphanitic. Locally the rock is vesicular, and the vesicles commonly are lined with a bright-green mineral having the form, occurrence, and optical properties of celadonite. No other rock in the area has this mineral or is so porphyritic.

One specimen of the andesite collected 1¼ miles northeast of Nutrioso was studied in thin section. This rock is 20 to 30 percent phenocrysts, mostly labradorite but some are augite and some hypersthene. Small crystals of magnetite are disseminated through the rock. The groundmass is composed principally of colorless poorly defined crystals of low birefringence and refractive index below balsam, and probably is mostly calcium-poor feldspar. Throughout this groundmass are numerous fine black needles that may be incipient crystals of mafic minerals. Plagioclase crystals range in size from those barely discernable in the groundmass to large phenocrysts. The texture is seriate porphyritic. The porphyritic texture, the dark color, and the calcic plagioclase phenocrysts in a less calcic groundmass were the features considered in terming the rock andesite.

An outcrop of grayish-red-purple to pale-purple silicic volcanic breccia a few hundred feet across occurs in the andesite between the two areas of Naco(?) limestone on the northeast flank of Escudilla Mountain. This breccia contains numerous angular gray to red rock fragments, ordinarily 1 to 3 mm in diameter, set in an aphanitic matrix, which contains small sparse crystals of sanidine, quartz, and biotite. Round to irregular vugs, as much as a few centimeters across, are numerous and generally are surrounded by a bleached rim a few millimeters thick. The breccia is very hard and more resistant to erosion than nearby andesite. The presence of this breccia and the nearly vertical sheeting in andesite adjacent to the southeastern area of limestone suggest the presence of an eruptive vent.

Well-indurated siltstone and tuff in irregular areas, commonly a few tens of feet across and as much as several feet thick, overlie the andesite and are mapped with it. The unweathered siltstone is light gray and is thinly cross-laminated in sets 5 to 10 mm thick; weathered exposures are yellowish gray and generally do not show the cross-lamination. The tuff, which is badly altered, is light olive gray on fresh and weathered faces and is composed of small calcite knots, as much as 2 mm in diameter, in an aphanitic matrix. The siltstone and tuff are interpreted to be remnants of rocks once extensive and distinctly older than the sandstone mapped as the next youngest formation above the andesite.

The andesite forms two contrasting types of topography: very steep slopes or areas of low relief. On the west flank of Escudilla Mountain, for example, the rock forms a bench as much as three-fourths of a mile wide; away from the mountain this bench ends abruptly in steep slopes and cliffs. Along the north side of Escudilla Mountain the member is exposed in canyons and ridges, whereas at

Luna Lake it underlies a broad area of low relief. The relatively flat areas have formed on the top of the andesite where the easily eroded overlying formation has been stripped away.

THICKNESS

The andesite is about 400 feet thick nearly everywhere in the area. Northeast of Escudilla Mountain, however, it is less than 100 feet thick, and southeast of Nutrioso it thins westward from 400 to 0 feet in about half a mile as the result of erosion before deposition of the overlying formation. Whether the unit is one flow or several is not known.

CORRELATION AND REGIONAL DISTRIBUTION

The Datil formation in the Alpine-Nutrioso area is lithologically similar to the Datil in adjacent Catron County, N. Mex., and is traceable into it. Both the sedimentary member of the formation and the andesite are shown as parts of the Datil on the geologic map of northwestern New Mexico (Dane and Bachman, 1957) and on the geologic map of the Reserve quadrangle, N. Mex. (Weber and Willard, 1959), and they are described by Willard (1959) in his report on the Tertiary stratigraphy of northern Catron County. Correlation with formations in Arizona must await more descriptions of the Cenozoic rocks in the eastern part of that State.

According to Willard's excellent summary (1959), the Datil in New Mexico is divisible into four "facies," which are sedimentary rocks, latite, rhyolite, and andesite. Latitic and rhyolitic rocks dominate in the eastern part of Catron County, whereas to the west the sedimentary rocks and andesite are more abundant; the sedimentary rocks and andesite are the only parts of the formation known to pass into Arizona.

The Datil crops out discontinuously over a broad area in New Mexico; it extends more than 100 miles east from the Arizona line and has a north-south distribution of at least 60 miles in northern and central Catron County. In Arizona the formation probably crops out only near the New Mexico border. From the Alpine-Nutrioso area the formation extends south for at least 8 miles, and it may also extend north almost to Springerville. The western limit of the Datil, though not well known, may be no more than a few tens of miles west of the New Mexico border.

AGE

No fossils have been found in the Datil formation in Arizona or New Mexico; consequently its age must be determined from underlying and overlying formations. The youngest rocks on which the

Datil formation is known to rest belong to the Baca formation of New Mexico. Wilpolt and others (1946) reported that a tooth identified by J. W. Gidley as belonging to the mammal *Palaeosyops* of middle Eocene age has been found in the Baca formation. Locally the Baca-Datil contact is gradational (Willard, 1959, p. 94); hence the Datil formation could be as old as middle Eocene.

The upper limit of the age of the Datil also is poorly known. Wilpolt and others (1946) stated that the Datil is older than the Popotosa and Santa Fe formations of New Mexico, which generally are considered to be Miocene(?) or Pliocene. The Datil appears to be older than the Bidahochi formation, which crops out in Arizona and New Mexico between Holbrook and Gallup. Repenning, Lance, and Irwin (1958, p. 129), in describing the Bidahochi, stated that the upper member has "considerable debris derived from the Datil formation * * * in west-central New Mexico and adjacent Arizona." These authors also stated that the upper member of the Bidahochi contains late middle Pliocene vertebrates and that the lower member (which does not resemble the Datil) may be early Pliocene or Miocene. The Datil, then, may be middle Eocene to Pliocene, but very likely is no younger than Miocene.

UPPER SEDIMENTARY FORMATION

A sequence of Tertiary rocks overlying the Datil formation and composed principally of cross-laminated sandstone, but also containing a few volcanic rocks is here called the upper sedimentary formation. This informal nomenclature is preferable, at this time, to a formal name because the age of the formation, its lithology, and the deposits with which it may correlate are known imperfectly.

DISTRIBUTION AND LITHOLOGY

The upper sedimentary formation is the most widespread unit in the area and is the best exposed. It underlies the flanks of Escudilla Mountain, the south and west edges of the valley in which the town of Nutrioso is located, and the valley of San Francisco River near Alpine. Though the formation crops out well locally, vegetation and rubble cover it throughout much of the area. The lower part of the formation is well exposed along Stone Creek; the upper part crops out about 3½ miles northeast of Alpine and locally along the highway from Nutrioso to Alpine, about midway between these towns. Nowhere, however, is the formation exposed from top to bottom; the most complete section probably is about 3½ miles northeast of Alpine at the south end of a prominent southeastward trending ridge.

The upper sedimentary formation is devisible into a lower and upper part on the basis of contrasting sandstone types. The lower sandstone is reddish brown and consists of thin beds, locally cross-stratified. It generally forms the lower few hundred feet of the formation, and underlies large parts of the area in the vicinity of Alpine and along the New Mexico border. The upper sandstone is pale yellowish gray and forms cross beds commonly many tens of feet long. It is one of the most conspicuous rocks in the area, not merely because of its extensive outcrops but also because of its large-scale cross-stratification. No other rock in the area is cross-stratified on such a large scale. The upper sandstone forms at least three-quarters of the formation; most of the remainder is the reddish-brown lower sandstone. Pebble conglomerate occurs locally near the base of the formation, and tuff crops out in the upper part; but these rocks form only a small percentage of the formation and are exposed at few localities.

Many features of the lower sandstone are rather uniform throughout the area, though some vary slightly laterally and vertically. The reddish-brown color is characteristic of all exposures, but in general the unit is darkest near the base. Most beds are fine grained and mottled with numerous light-gray to light-reddish-gray specks about 1 mm in diameter. Some of these specks are fragments of silicic rocks, others may be of secondary origin. Stratification varies from laminations to beds about 10 feet thick; most beds are ½ to 2 feet thick. Locally, as in the shallow road cuts at the north edge of Alpine, the sandstone is cross-stratified in sets as much as 6 feet long and 1 foot thick and contains strata that dip less than 5°. Many beds in the lower part of the formation are moderately well consolidated and tend to form steep slopes with ledges. The reddish-brown color and the thin beds are the most characteristic features of the lower part of the formation.

The lower sandstone consists mostly of gray, yellow, and reddish-brown volcanic debris. Biotite and other black minerals, though not abundant, are conspicuous accessories. Conglomeratic beds contain gray and brown pebbles and cobbles of deeply weathered volcanic rocks.

The upper yellowish-gray sandstone seems to have remarkably uniform lithology throughout the area. Wherever the color was carefully noted it was found to be light gray with a tinge of yellow. Weathered surfaces commonly are darker than fresh ones, but in bright sunlight even weathered exposures are light in color, and on casual examination many appear to be almost white. The large-scale cross-stratification has been observed throughout the vertical extent of the formation above the reddish-brown lower beds and also laterally wherever the upper part of the formation is exposed. Weak induration also is characteristic: steep slopes and cliffs exist locally because the formation is overlain by resistant volcanic rocks.

The outstanding characteristic of the large-scale cross-stratification is long sweeping laminae, curved concave upward. These laminae form lenticular and wedge-shaped sets commonly 30 to 40 feet long and 5 to 10 feet high, but sets 70 feet long and 15 feet high have been found. Their lower boundary is a flat or curved surface, which cuts off sharply laminae of underlying sets. Cross-laminae are tangential to the lower boundary of the sets. Dips as steep as 33° have been measured on the cross-laminae, but ordinarily the dips are much less. Both trough type and planar type sets are present, according to McKee and Weir's classification (1953, p. 385). Many features of the cross-stratification are similar to the cross strata McKee (1934, p. 98) described for the Coconino sandstone of Permian age in north-central Arizona.

The texture and composition of the upper part of the formation are not well known. Most of the rock in the lower few hundred feet of this upper part is very fine to fine grained, but locally it is medium grained. Most grains are subangular to subrounded. The rock is light in color because of quartz and feldspar and an abundant matrix of zeolite. The yellowish hue is due to the abundant yellow and orange fragments of felsic volcanic rocks. Scattered throughout the rock are dark rock fragments. Biotite locally is a conspicuous accessory.

A thin section of a representative specimen of the light-colored upper sandstone, collected 4 miles southeast of Nutrioso and about 200 feet above the base of the formation, has the following composition:

	Percent		*Percent*
Quartz	18	Voids	5
Feldspar	8	Matrix	25
Rock fragments	44		

The amount of quartz in this sample is surprisingly low, but under a binocular microscope other specimens appear to have no more. Most of the rock fragments are volcanic, but some are metamorphic rocks. No volcanic glass was found. The degree of compaction is poor: many grains appear to be almost floating in the abundant matrix, which is of unusual composition and thus was studied further.

The matrix is principally the zeolite mineral heulandite. In thin section most of the sand grains are seen to have a thin rim of another mineral—probably a clay—of micaceous habit, low relief, and moderate birefringence. Outside this rim and filling most or all the space between grains is heulandite, which is in euhedral to subhedral monoclinic crystals that commonly are almost rectangular and average

0.009 mm in width and slightly more in length. Faint cleavage traces parallel the length of the crystals. Extinction appears to be parallel, but the birefringence is so weak (about 0.004) that the extinction position could not definitely be determined. The refractive index is about 1.49. Locally the long dimension of the crystals is approximately normal to the adjacent sand grains, but this relation is not strongly developed; most of the heulandite is an aggregate in which individual crystals exhibit no particular orientation relative to the walls of the voids they occupy.

The presence of a zeolite was confirmed by X-ray analysis of a concentrate of the matrix. Subordinate montmorillonite, possibly from the clay rim around clastic grains or from volcanic fragments not removed in making the concentrate, also was indicated by the analysis. After the first X-ray examination, the zeolite was heated to 400° C for 1 hour and X-rayed again to determine if it was heulandite or clinoptilolite according to the definitions of Mumpton (1960). The results indicated heulandite.

The stratigraphic and lateral distribution of the heulandite are not known. X-ray analyses of two specimens from the lower sandstone and four from the lower part of the upper cross-stratified sandstone contain heulandite. The two specimens from the lower part of the formation also contain analcite.

A deposit of very-light-gray tuff as much as 100 feet thick crops out on the steep south- and east-facing slopes 3½ to 3¾ miles northeast of Alpine. Its top is about 150 feet below the top of the upper sedimentary formation. The tuff contains scattered pumice lapilli in a matrix of fine devitrified ash. Moderately strong induration and the presence of partially flattened lapilli suggest partial welding.

Three miles west-northwest of Alpine a lens of basalt, as much as 100 feet thick, occurs within the sandstone about a hundred feet below the top of the formation. This basalt has been mapped with the volcanic rocks overlying the upper sedimentary formation.

The lower contact of the formation has relief of about 1,000 feet in a distance of 4½ miles, as observed south and east of Nutrioso. West of Escudilla Mountain the basal contact dips southwest; east of the mountain it dips southeast. The amount of this dip that might be the result of folding is unknown.

The upper contact is an unconformity. On Escudilla Mountain the top of the formation is at an altitude of 10,000 feet; 3 miles west of Nutrioso it is at 8,600 feet. Folding subsequent to deposition of the formation may be responsible for part of this change in altitude, but much of it probably resulted from erosion before younger rocks were deposited.

THICKNESS

The maximum thickness of the formation is 1,200 feet at Escudilla Mountain. West of Nutrioso it is only a few hundred feet thick. The basal reddish-brown sandstone is a few hundred feet thick throughout most of the area; along Stone Creek, however, its thickness is at least 500 feet.

ORIGIN

The upper sedimentary formation is composed largely of volcanic detritus. The source area that supplied this detritus is unknown, though it presumably could have been in the White Mountains volcanic field, because volcanic rock fragments would not likely survive lengthy transport. Some of the volcanic debris that makes up the reddish-brown basal part of the formation may have come from the underlying andesite: this is suggested by its color, which becomes darker toward the base in areas underlain by andesite. Except for this andesite, volcanic rocks older than the upper sedimentary formation are not known in the White Mountains volcanic field in Arizona. A more likely, though admittedly speculative, source is in New Mexico, for volcanic rocks occur in the underlying Datil formation in the western part of that State. Some of volcanic detritus may have formed at about the same time as the sedimentary part of the formation, as suggested by the presence of tuff in the upper part of the sandstone on the steep slopes 3½ to 3¾ miles northeast to Alpine. The source of the nonvolcanic material in the formation is unknown.

The heulandite cement in the sandstone may have originated from the abundant volcanic materials of the area. In the thin sections studied there is no suggestion that heulandite replaced clastic grains. The euhedral form of the crystals and their mode of occurrence precludes their being detrital. The heulandite crusts around grains suggests an authigenic origin, and the aggregates of unoriented helandite crystals between grains indicate that the mineral crystallized rapidly enough to inhibit the formation of a succession of crusts around sand grains. The possibility of a hydrothermal origin cannot be ruled out. Heulandite is considered to form in volcanic environments; the possibility of a genetic relation between the heulandite and the large amounts of volcanic material is suggested by their proximity in the Alpine-Nutrioso area.

The sandstones in the formation probably formed in two different environments: the reddish-brown sandstone at the base likely was deposited under fluvial conditions as indicated by the conglomerates and the low-angle cross-stratification; the overlying yellowish-gray sandstone may well be of eolian origin. The large scale of the cross-stratification strongly suggests this as does the curvature and high-angle dip of the strata and the wedge shape of some of the sets. Grain sizes predominantly in the medium to fine range are characteristic of at least the lower one-fourth of the upper part of the formation; according to Wentworth (1931, p. 12) such grain sizes predominate in modern dunes of the United States.

AGE AND CORRELATION

The upper sedimentary formation can be traced from the Alpine-Nutrioso area eastward into the adjacent Reserve quadrangle, New Mexico, where it has been mapped by Weber and Willard (1959) as part of the Datil. In the Alpine-Nutrioso area, however, the upper sedimentary formation has been mapped separately because of its distinctive lithology and because there is no compelling reason to include it in the Datil. The Datil as now used in western New Mexico has not been clearly defined. The upper sedimentary formation might reasonably be correlated with the Datil, but another possibility can be entertained.

Superficially, at least, the formation resembles the Chuska sandstone of northern Arizona and nearby New Mexico. The Chuska, which has been studied in detail by Wright (1956), is a fine- to medium-grained sandstone characterized by large-scale crossbedding. Cross-strata are concave upward and are in sets 5 to 14 feet thick and as much as 150 feet long, which is comparable to the cross-stratification in the upper sedimentary formation. Significantly, perhaps, both formations locally contain heulandite, a rather rare cement for a sandstone. Furthermore the Chuska, as defined by Wright (1954), and the part of the upper sedimentary formation with large-scale cross-stratification both overlie fluvial sandstone about 250 feet thick. Also, both occur at altitudes between 8,000 and 10,000 feet and are more than 1,000 feet thick—1,900 feet for the Chuska and 1,200 for the upper sedimentary formation. Both appear to be principally of eolian origin.

The two formations differ in composition. The Chuska is composed mainly of quartz grains, but the upper sedimentary formation is rich in fragments of volcanic rocks. This difference might occur within one formation if there were more than one source area.

Wright (1956, p. 431) concluded that the Chuska is older than the Pliocene Bidahochi formation of the Hopi Buttes country of northeastern Arizona and called it Miocene(?). Repenning, Lance, and Irwin (1958, p. 124), however, believed that it may correlate with the lower member of the Bidahochi, so they tentatively assigned it a Pliocene(?) age. Fossils have not been found in either the Chuska sandstone or the upper sedimentary formation.

The similarities between the upper sedimentary formation and the Chuska are striking. For purposes of correlation, however, the likenesses should be used with caution, because the formations are 125 miles apart, and they have not been dated accurately by fossils or by their relation to other formations. The two formations cannot be more fully compared until the upper sedimentary formation has been studied in greater detail.

TERTIARY OR QUATERNARY BASALT

A sequence of basalt flows as much as 900 feet thick caps the Escudilla Mountain mass and underlies the highlands of the western and southwestern parts of the area. These flows, together with small amounts of extrusive rocks of intermediate composition, several dikes, and a volcanic neck, form the most extensive igneous unit in the area. The basalt flows extend for tens of miles west and southwest of the area and are part of the White Mountains volcanic field.

The basalt is poorly exposed throughout much of the area, but crops out well along streams, especially in Williams Valley west of Alpine. The weathered rock is brown to pale medium gray and has numerous closely spaced partings that locally give the rock a sheeted appearance. Fresh surfaces are dark gray and have reddish-brown spots, ½ to 1 mm in diameter, that represent altered olivine phenocrysts. Locally the rock is vesicular. Individual flows may be 100 feet thick or more; they have the same general appearance throughout the area.

A thin section of basalt from one flow in Williams Valley is characterized by well-developed trachytic texture and is composed principally of well-alined labradorite laths (An_{52}). Minute interstitial clinopyroxene crystals are abundant. Olivine phenocrysts, almost completely altered to iddingsite, constitute less than 5 percent of the rock. A few small hypersthene phenocrysts are present.

Locally at an altitude of about 9,600 feet at the south end of Escudilla Mountain, hornblende-bearing flow rocks are conspicuous. They are reddish brown to medium gray and are characterized by abundant alined hornblende crystals, as much as 1 cm long, set in an aphanitic groundmass. These are the only nonbasaltic rocks found in the formation.

A neck and several dikes, which may have been feeders for the basaltic flows, are intrusive into the upper sedimentary formation. One dike, 4½ miles northeast of Alpine, is 10 to 15 feet wide and several hundred feet long. Whether this dike was a feeder for the basalt flows described above or for younger flows could not be determined; it is much richer in olivine than any of the flow rocks examined. A volcanic neck 2½ miles west-northwest of Alpine probably was a vent for some of the basalt. This neck, exposed as a crudely conical hill about 500 feet high and 2,000 feet in diameter at its base, consists of basalt similar to the flow in Williams Valley. Like that flow it has a trachytic texture and small clinopyroxene crystals. The sparse olivine phenocrysts once present have been altered to masses of bowlingite and magnetite. The basalt of this mass has badly altered phenocrysts of augite instead of the hypersthene of the flows but otherwise the texture and composition of the two rocks are enough alike to suggest a genetic connection. The neck rock is pale olive gray, rather than dark gray like the flows, principally because of a lack of devitrified glass, but also because it is somewhat more altered. A basalt dike south of the neck was not investigated closely. Although the dikes and the neck described here were the only intrusive bodies seen in the area, the hornblende-bearing rocks on Escudilla Mountain suggest that others may be present.

Because Escudilla Mountain is the highest point in the area and has a thick section of basalt, it may be the loci of eruptions. Flow layers on the summit have diverse dips, some as steep as 45°, but exposures are so poor and so widely scattered that the cause of the dips could not be determined, and the possibility of a vent was neither proved nor disproved.

The sequence of basaltic rocks in the western and southern parts of the area and on Escudilla Mountain generally is 400 to 600 feet thick. A section about 900 feet thick, however, forms the highest part of Escudilla Mountain.

The age of these rocks is uncertain. They could be almost as old as the upper sedimentary formation, which may be Pliocene or older as discussed above. The rudely triangular outcrop of basalt 1½ miles northwest of Alpine crops out low in the valley of San Francisco River and is as much as 600 feet lower than some of the basalt nearby. This outcrop low in a major valley suggests that some of the basalt formed during early development of the present drainage, and might be Pleistocene in age. Until more data are obtained, however, these rocks are best considered to be Tertiary or Quaternary in age.

QUATERNARY BASALT

Basalt thought to be Quaternary in age forms scattered outcrops 6 miles northeast of Alpine and 2½ miles southeast of Nutrioso and underlies a narrow strip of ground at the northern edge of the area. This basalt extends north from the area several tens of miles and forms the tops of mesas.

The rock typically is very dark gray to black, commonly is porphyritic, and locally is vesicular. Northeast of Alpine it is black and has olivine phenocrysts; southeast of Nutrioso it is dark gray to red and is scoriaceous. The flows along the northern edge of the area differ from the rocks at these localities and from the Tertiary or Quaternary basalt of Williams Valley in containing conspicuous labradorite phenocrysts several millimeters long. A specimen of this porphyritic rock collected one-half mile south of the north edge of the area and 4 miles west of New Mexico has labradorite and olivine phenocrysts in an intergranular groundmass composed of andesine microlites and a clinopyroxene. A mode of this specimen reveals the following composition:

	Percent		Percent
Andesine microlites (An_{42})	23	Olivine	4
Labradorite phenocrysts (An_{55})	22	Magnetite	6
Augite	45		

The olivine phenocrysts are as large as 0.8 by 2 mm and commonly have a rim of iddingsite. Although the groundmass plagioclase is andesine, the rock is thought to be basalt rather than andesite because the abundance of labradorite and augite suggests a low SiO_2 content. The rock may be an andesitic basalt. Basalts from southeast of Nutrioso and from northeast of Alpine were not studied petrographically.

Several vents from which basalt of this age may have been extruded are close to the area. One is Turner Peak, a neck about 6 miles northeast of Alpine and a few hundred feet across the New Mexico line; another is a hill that looks like an eroded cone about 1,500 feet north of the area and 3½ miles west of New Mexico. The most extensive basalt flow east of Stone Creek came from fissures on the flank of Turner Peak. A locality southeast of Nutrioso contains agglomerate and a thin flow thought to have issued from fissures in the immediate vicinity.

Within the area the thickness of the basalt probably does not exceed 200 feet and commonly is much less.

These basalts are believed to be Quaternary in age because they were deposited after the underlying deposits were deeply eroded and because locally the constructional surfaces they formed have not been greatly modified.

STRUCTURE

The structure of the Alpine-Nutrioso area is characterized by nearly horizontal strata and few faults and therefore is similar to much of the adjacent Colorado Plateaus. The Cenozoic rocks, which cover nearly the entire Alpine-Nutrioso area, are structurally simple; the exposed Paleozoic rocks, however, offer some structural enigmas.

The structure of the pre-Cenozoic rocks in the area is little known. In the vicinity of Springerville, and farther north, the bedrock is nearly flat lying Mesozoic strata, and, like the Tertiary rocks in the Alpine-Nutrioso area, they are structurally simple. Furthermore, Paleozoic and Mesozoic formations all along the northern and western edges of the White Mountains volcanic field are nearly horizontal and of simple structure (Darton, 1924); their distribution suggests that they probably occur with similar structural simplicity under Cenozoic deposits in the Alpine-Nutrioso area. The presence of rocks of Pennsylvanian or Permian age at much higher altitudes in the Alpine-Nutrioso area than would be expected from their position in the surrounding area, however, is not in accord with this suggestion.

On the northeast side of Escudilla Mountain, rocks of the Naco(?) group of Pennsylvanian or Permian age crop out at altitudes between 8,600 and 8,700 feet, more than 1,500 feet higher than the Mesozoic strata at Springerville, and possibly considerably more than 2,000 feet above the assumed base of the Permian at Springerville. The Pennsylvanian-Permian boundary reasonably could be expected at about the same altitude in the Alpine-Nutrioso area as at Springerville, yet the Naco(?), which was deposited close to that boundary, occurs many hundreds of feet higher. This suggests that faults with an aggregate throw of 2,000 feet or more could exist in the pre-Cenozoic bedrock between Escudilla Mountain and Springerville. The structure of the pre-Cenozoic rocks in the area is either more complicated than in areas around the northern and western edges of the White Mountains volcanic field, or the Naco(?) rocks that crop out northeast of Escudilla Mountain attained their present altitude in some way other than faulting.

Further indication that the outcrops of Naco(?) are structurally anomalous is their unusual position with respect to the base of the Cenozoic section. Along the edge of the volcanic field north of the Alpine-Nutrioso area the contact between the Tertiary and pre-Tertiary rocks is subplanar; at Springerville it is at an altitude of about 7,000 feet. If the Naco(?) northeast of Escudilla Mountain represents bedrock on which the Cenozoic formations were deposited, the depositional surface must have been of considerable relief. The relief in the Alpine-Nutrioso area would be at least 1,100 feet, the approximate exposed thickness of the Datil formation, and probably would be greater, for part of the Datil is buried. In the northeast corner of the area the relief would be at least 800 feet in 2 miles. Such relief is not impossible, but is improbable, for there is no other indication that the Cenozoic rocks were deposited on such irregular topography.

Alternately the Naco(?) occurrences can be interpreted as inclusions in the andesite member of the Datil formation. Although the two limestone areas shown on the map are each about 400 feet across, most outcrops within them are a few tens of feet in diameter or less and may not be connected; the largest is only 120 feet long. Even if the two areas represented discrete blocks, they are not large considering the thickness and extent of the surrounding andesite. The limestone is exposed over a possible vertical thickness of 40 feet; individual outcrops are much thinner, but the base of the section is not exposed. The andesite, in contrast, is 400 feet thick. The limestone is at the top of the andesite where it would be expected had it been extruded with and floated in the lava. Volcanic breccia and vertical layering in the andesite near the limestone suggests the presence of an eruptive vent from which the limestone could have been ejected. No evidence of metamorphism was found in the limestone, but this is not unusual: limestone cores in basaltic bombs near Williams, Ariz., contain recognizable fossils and are not metamorphosed (Brady and Webb, 1943, p. 403), and the same is true of some of the limestone ejecta at Mount Vesuvius (Johnston-Lavis, 1884, p. 79). An outcrop of Pennsylvanian limestone about 400 feet across, but partly covered by the upper sedimentary formation, is in New Mexico between Trout Creek and the Arizona line, 6½ miles southeast of the Naco(?) of the Alpine-Nutrioso area (Kottlowski, 1959, p. 59). This limestone has the same relation to the top of the andesite of the Datil as the Naco(?) described above, which suggests that the limestones may have had similar histories. Weber and Willard (1959) stated that the limestone near Trout Creek may have been rafted in andesite of the Datil. Proof that the limestone near Trout Creek and the Naco(?) of the Alpine-Nutrioso area are xenolithic inclusions in the andesite by no means has been established, but this possibility should be considered in evaluating their structural significance.

Although the Cenozoic rocks are nearly flat lying, some dip gently to the south. The porphyritic andesite of the Datil formation, the upper sedimentary formation, and the Tertiary or Quaternary basalt dip about 1° southward. Whether this dip is entirely original or is in part postdepositional is not known. Locally, on the east and west flanks of Escudilla Mountain and along the fault northeast of Luna Lake, the rocks dip in other directions. The southerly dip, whatever its origin, is regional: the Cenozoic rocks dip in that general direction for many miles south from the Alpine-Nutrioso area.

The Cenozoic formations described in this report lap northward onto the Colorado Plateaus; some of them, particularly the Tertiary or Quaternary basalt, and perhaps the underlying Tertiary deposits or their equivalents, extend south to the Basin and Range province. The distribution and stratigraphy of these rocks, however, are poorly known in Arizona outside the Alpine-Nutrioso area, and their structural history is not clear.

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