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ALPINE 1/FEDERAL COREHOLE — SUBSURFACE STRATIGRAPHY OF THE EASTERN WHITE MOUNTAINS, APACHE COUNTY, ARIZONA

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Abstract—The Alpine 1/Federal corehole provides the first observations of Permian, Upper Cretaceous, and lower Tertiary rocks in the eastern White Mountains of Arizona. Due to erosion beneath a pre-Late Cretaceous unconformity, no Triassic to Lower Cretaceous rocks exist. Only 74 ft of Permian San Andres Formation is preserved. The Permian Glorieta Sandstone, 203 ft thick, is intruded by basaltic rocks that also truncate the top of the underlying Corduroy Member of the Supai Formation. An additional basaltic intrusion separates the Corduroy Member, 515 ft thick, from the underlying Fort Apache Limestone, 48 ft thick. Only 49 ft of Big A Butte Member was cored before encountering another basaltic intrusion. Permian carbonate units represent restricted marine and coastal sabkha environments and hydrocarbon shows indicate source potential. Carbonaceous Upper Cretaceous Dakota (?) sandstone, 116 ft thick, is preserved beneath a Laramide unconformity. Homoclinal downwarping, less than one degree of dip to the south and with possible faults, has formed a basin with at least 1600 ft of structural relief on the Laramide erosional surface. An unnamed early (?) Laramide unit, 107 ft thick, unconformably rests on reddened Cretaceous sandstone and underlies the basal conglomerate of the Eocene Eagar Formation, 1087 ft thick. Volcaniclastic rocks of the Eocene to Oligocene Spears Group, 2032 ft thick, conformably overlie the Eagar Formation. The only distinct volcanic flow that was cored is a 20-ft-thick Datil (?) Group rhyolite ash-flow tuff. Composite thickness of the Tertiary sediments in the corehole is 3226 ft. Basaltic intrusions in Paleozoic rocks may range in age from mid-Tertiary to Quaternary and could represent several magmatic events.

INTRODUCTION

The primary mission of the Alpine 1/Federal drilling project was to assess the hot dry rock (HDR) geothermal energy potential of the eastern White Mountains region. However, the purpose of this paper is to present an overview of field geologic logs of core for the Alpine 1/Federal hole at Alpine Divide. Our discussion attempts to correlate units within a regional stratigraphic framework. Also, special attention is given to the details of stratigraphy and depositional environments of the Permian Supai units because of potential oil and gas implications.

No definite pre-Tertiary stratigraphic information exists for the eastern White Mountains area. There are a lack of outcrops as well as deep borehole data beneath Tertiary volcanic and sedimentary rocks in the region for at least 40 to 70 mi to the east, south and west, and 20 to 40 mi to the northwest, north and northeast. Alpine Divide is located on the Colorado Plateau adjacent to the boundary with the transition zone of the Basin and Range province, near the southwest margin of the Paleozoic Defiance-Zuni positive area, and along the Jemez volcanic zone or lineament (Fig. 1). All of these features are related to regional crustal structures that have had a major influence on the nature of Paleozoic through Tertiary deposition and erosion. As a result, projection of regional Paleozoic isopachs, structure, and facies into the subsurface of the area, based on the nearest well and outcrop control to the northwest, north and northeast, has been uncertain. The Alpine 1/Federal corehole provides the first observations of the lower Tertiary, Upper Cretaceous and Permian rocks beneath the eastern White Mountains region.

LOCATION AND CORE

The Tonto Alpine 1/Federal (state permit 878) is located 15 mi from the New Mexico border in Arizona in the SW1/4 sec. 23 T6N R30E, 1153 ft FWL and 2122 ft FSL, at an elevation of 8556 ft at Alpine Divide on the east side of U. S. Highway 180/190/666. Alpine Divide is in the Apache-Sitgreaves National Forest, 5 mi north of Alpine, in Apache County in the eastern White Mountains area (Fig. 1).

Core recovery was over 99% for the two sizes of core that were obtained. The HQ (2.50 in. diameter) core from 500 to 3265.5 ft, which comprises the Tertiary stratigraphic section, is stored at the New Mexico Bureau of Mines and Mineral Resources, in Socorro, New Mexico. The HQ and NQ (1.875 in. diameter) core from 3265.5 to 4505 ft, which comprises the Mesozoic and Paleozoic stratigraphic section, is stored at the Arizona Geological Survey, in Tucson, Arizona. Table 1 summarizes formation footages.

STRATIGRAPHY

Previous studies

Reconnaissance geologic studies are the only available information specific to the Alpine region (Sirrine, 1956; Weber and Willard, 1959; Wrucke, 1961). Weber and Willard (1959) and Wrucke (1961) mapped Pennsylvanian carbonate rocks in isolated outcrops on the northeast side of Escudilla Mountain and just across the New Mexico-Arizona border. Sirrine (1956) and Wrucke (1961) described the lower Tertiary Eagar Formation and the middle Tertiary Datil Formation (now Spears Group) rocks in the area. Gerrard (1966) and Winters (1963) described Supai Formation stratigraphy in the eastern Mogollon Rim region; Foster (1964) discussed the stratigraphy of deep oil and gas tests; Ratte et al. (1969) and Ratte (1989) mapped the Tertiary geology of areas south and southeast of Alpine Divide; and Merrill and Pewe (1977) covered the late Cenozoic volcanism in the White Mountains.

Permian Supai Formation

Nomenclature

Sandstones, evaporites and carbonate rocks below the Permian Coconino and Glorieta sandstones are the subject of debate over regional correlation and use of nomenclature. Eastward in New Mexico, rocks below the Glorieta Sandstone are assigned to the Yeso Formation. West of the Alpine Divide site, these rocks are assigned to the Schenebly Hill Formation (Blakey, 1980), the Supai Formation (Winters, 1963), and Supai Group (Peirce, 1989). The nomenclature of Peirce (1989) and Blakey (1980) is formulated upon regional interpretations of stratigraphy far removed from the Alpine area. The measured sections used by Winters (1963) are within 50 to 70 mi of Alpine Divide and contain a limestone unit, the Fort Apache Limestone Member of the Supai Formation, that is easily recognized in the Alpine 1/Federal. From top to bottom, the Winters nomenclature for Supai units are the Corduroy Member, Fort Apache Limestone Member, Big A Butte Member, and Amos Wash Member.

Gerrard (1966) redefined the Fort Apache Limestone Member of Winters (1963) as the Fort Apache Member by including all contiguous limestone, dolomite and evaporites at the base of the Corduroy Member. This redefinition correlates subsurface well data in the Holbrook basin with the Mogollon Rim outcrops of Winters (1963). Gerrard's (1966) correlations assume that the lowest and thickest dolomite/evaporite sequence in the Corduroy Member is the same

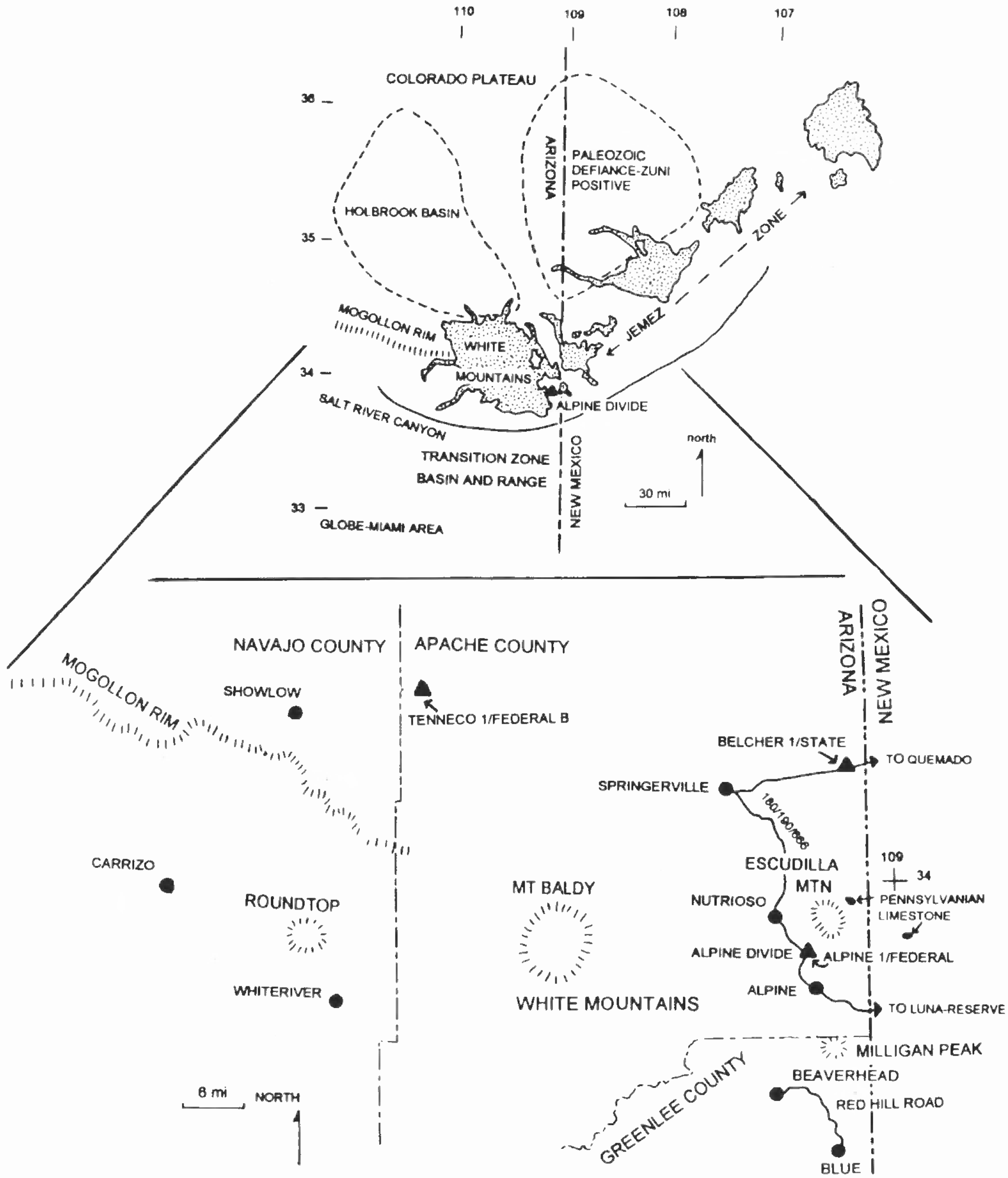

FIGURE 1. Location maps for the Alpine 1/Federal corehole. Stippled areas are Cenozoic (<15 Ma) volcanic rocks of the Jemez zone.

laterally continuous unit as the Fort Apache Limestone in outcrop.

Blakey (1980) retained Gerrard's (1966) Corduroy and Fort Apache Member designations in his Schenebly Hill Formation, whereas Peirce (1989) upgraded Winters' (1963) Corduroy Member to formation status in the Supai Group. Peirce's (1989) Corduroy Formation includes the Fort Apache Limestone as a member. Because of potential differences in depositional environment implied by the dolomite/evaporite (intertidal-to-supratidal coastal sabkha) and the limestone (possible restricted shallow marine), we choose to use Winters' (1963) nomenclature.

Big A Butte Member

The base of the cored 49-ft-thick section of the Big A Butte Member, representing only the upper part of the unit, has an intrusive contact with basaltic rocks at 4454 ft (Fig. 2). The majority of the Big A Butte Member from 4405 to 4454 ft is a brown, very fine-grained sandstone and siltstone. Between 4421 and 4428 ft a fine-to-medium crystalline, nodular-to-mosaic anhydrite interval overlies 1 ft of gray dolomite with black shale laminations.

Fort Apache Limestone

The Fort Apache Limestone Member, a dark gray to black, fetid, fossiliferous micrite and biomicrite with vuggy and moldic porosity, is identified between 4322 and 4327 ft and 4362 and 4405 ft (Fig. 2). Hydrocarbon films and staining occurs between 4399 and 4402 ft. The Fort Apache Limestone is conformable with the Big A Butte Member. A basaltic dike or sill intrudes the Fort Apache Limestone from 4327 to 4362 ft. If the basalt is a sill, the Fort Apache Limestone is thinned to about 50 ft in the Alpine subsurface compared to a thickness of about 95 to 120 ft in the region around Whiteriver, west of the borehole (Winters, 1963). However, if the basalt is a dike, the Fort Apache at Alpine Divide has similar thickness to outcrops around Whiteriver.

Corduroy Member

Basaltic rocks intrude the contact between the Corduroy Member and the Fort Apache Limestone from 4260 to 4422 ft. For descriptive purposes, the Corduroy Member is divided into six major subdivisions (Fig. 2). Mostly brown microcrystalline dolomite and dolomitic limestone, with interbedded nodular and mosaic blue-gray anhydrite, forms the basal unit 1, from 4226 to 4260 ft. Some of the dolomite horizons in this interval are fetid and have wavy laminations and black shale laminae, whereas other dolomite layers exhibit scattered blue-gray anhydrite grains and nodules.

From 4158 to 4226 ft, unit 2 forms a sandy section of light brown to dark brown, dolomitic, fine-grained sandstone and muddy siltstone with wavy laminations, some cross laminations, bioturbation and minor anhydrite at 4203 ft.

A mostly carbonate section, unit 3, is observed from 4038 to 4158 ft. Lost circulation occurred while coring unit 3. Finely crystalline dolomite, silty and sandy dolomite, and dolomitic limestone are interbedded with minor, fetid and fossiliferous, laminated limestone. Gray-brown and brown colors predominate and wavy laminations and black shale laminae are common. A few dolomite horizons have small (less than 1.0 in.) blue-gray anhydrite nodules. From 4128 to 4145 ft, numerous calcite-filled fractures occur.

The carbonate strata in unit 4, between 3906 and 4038 ft, are essentially the same as in unit 3, except more sandy and silty dolomite is present. Unit 4 also has two interbeds of 10-to-12 ft-thick, brown to red brown siltstone and fine-grained sandstone with flaser, wavy laminations, scour and rip-up clasts. Two 8 to 10 ft intervals of anhydrite were

TABLE 1. Summary of formation footages.

lower Oligocene (?) upper Spears Group	0 to 854 ft	thickness 854 ft
upper Eocene (?) andesite breccia (possible clastic unit associated with andesite of Dry Leggett Canyon)	854 to 942 ft	thickness 88 ft
upper Eocene (?) middle Spears Group - conglomerate and sandstone (volcanic-clast conglomerate and sandstone)	942 to 1018 ft	thickness 76 ft
upper Eocene (?) Datil Group ignimbrite (possibly the tuff of Bishop Peak)	1018 to 1038 ft	thickness 20 ft
upper Eocene (?) middle Spears Group - conglomerate and sandstone (volcanic-clast conglomerate and mixed-clast conglomerate with volcanic and Precambrian granite and Paleozoic limestone clasts)	1038 to 1358 ft	thickness 320 ft
upper Eocene (?) middle Spears Group - pumiceous sandstone	1358 to 1574 ft	thickness 216 ft
upper Eocene lower Spears Group - andesitic sandstone	1574 to 2052 ft	thickness 478 ft
Eocene Eagar Formation	2052 to 3139 ft	thickness 1087 ft
Upper Cretaceous(?)/ Paleocene (?) /lower Eocene (?) unnamed beds	3139 to 3246 ft	thickness 107 ft
Cretaceous Dakota (?) Sandstone	3246 to 3362 ft	thickness 116 ft
Permian San Andres Formation	3362 to 3436 ft	thickness 74 ft
Permian Glorieta Sandstone	3436 to 3639 ft	thickness 203 ft
Tertiary (?)/Quaternary(?) basaltic intrusion	3639 to 3751 ft	thickness 112 ft
Permian Corduroy Member Supai Formation	3751 to 4266 ft	thickness 515 ft
Tertiary (?)/Quaternary(?) basaltic intrusion	4260 to 4322 ft	thickness 62 ft
Permian Fort Apache Limestone Member Supai Formation	4322 to 4327 ft	thickness 5 ft
Tertiary (?)/Quaternary(?) basaltic intrusion	4327 to 4362 ft	thickness 35 ft
Permian Fort Apache Limestone Member Supai Formation	4362 to 4405 ft	thickness 43 ft
Permian Big A Butte Member Supai Formation	4405 to 4454 ft	thickness 49 ft
Tertiary (?)/Quaternary(?) basaltic intrusion	4454 to 4505 ft	thickness 51 ft

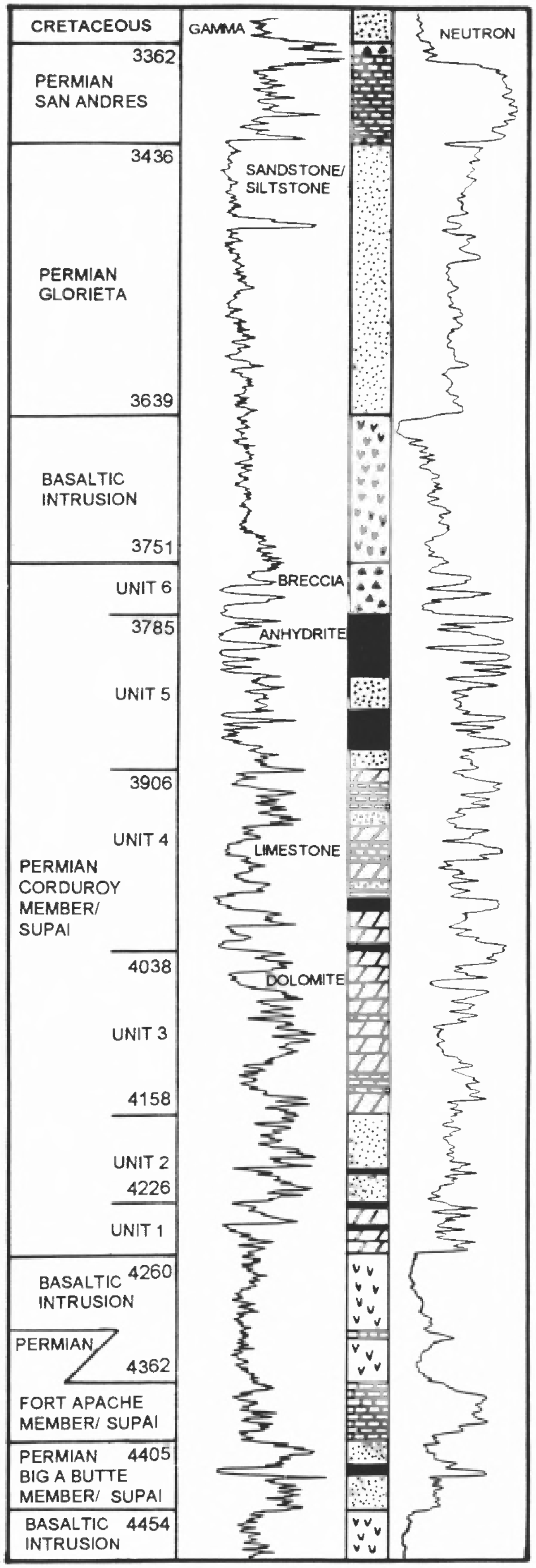

FIGURE 2. Summary stratigraphic column of the Paleozoic rocks cored in the Alpine 1/Federal hole.

also encountered in the lower one-third of unit 4. Rauzi (1994) observed hydrocarbon stains and leakage from around vertical fractures in a fetid limestone from 4027 to 4031 ft after the core had been placed in storage in Tucson.

Unit 5, from 3906 to 3785 ft, consists of interbedded light gray to gray anhydrite and mostly brown to gray-brown siltstone and fine sandstone. The anhydrite intervals ranged in thickness from 20 to 5 ft. Mosaic textures predominate. The anhydrite intervals are generally subdivided into several 1-to-3-ft thick beds separated by scour, very thin siltstone beds, sandy dolomite or black wavy shale laminae. The sandstone and siltstone beds contain scour, rip-up clasts, soft-sediment deformation, and anhydrite nodules.

The upper 35 ft, unit 6, of the Corduroy Member is characterized by a probable solution-collapse of rubble breccia. This zone was characterized by major lost circulation during drilling. The lower breccia, starting at 3785 ft, is vuggy sucrosic dolomite that contains "saddle" dolomite crystals. Dolomite breccia at the top of the zone is black with abundant microfractures. Scattered anhydrite in the breccia shows mosaic textures. Basaltic rocks intruded the top of the Corduroy Member breccia unit at 3751 ft.

Discussion and interpretation of Supai rocks

A restricted, shallow marine or subtidal lagoon depositional environment is interpreted for the Fort Apache Limestone. Overall, a coastal sabkha depositional environment is indicated for the Big A Butte Member and Corduroy Members. A supratidal facies apparently dominates unit 5 of the Corduroy. Units 3 and 4 of the Corduroy probably indicate a range of sabkha facies from subtidal, intertidal to supratidal. Unit 2 may also represent a supratidal environment with abundant terrestrial clastic influx. A detailed study is required to delineate sequence stratigraphy and define the depositional environments in detail. Also, source terrains and provenance studies of the clastic units in the Corduroy and Big A Butte Member may significantly augment regional stratigraphic correlations and paleogeographic interpretations.

A total of 515 ft of the Corduroy Member was cored in the Alpine 1/Federal. If basalt intrusions at the base and top of the Corduroy are dikes, the Corduroy Member beneath Alpine Divide may have a thickness approaching 680 ft. Winters (1963) reported approximatetly 330 ft of the Corduroy Member west of Whiteriver. The Corduroy Member in the Alpine area also contains considerably more carbonates and evaporites than measured sections to the west near Whiteriver.

Permian Glorieta Sandstone

The Glorieta is a fluvial equivalent of the Coconino eolian sandstones to the west (Peirce, 1989). Contact between the Glorieta Sandstone and the underlying Corduroy Member is obscured by a basalt intrusion (Fig. 2). The Glorieta Sandstone, from 3436 to 3639 ft, consists of medium- to fine-grained, well-sorted, light-gray and white sandstone with wavy and parallel laminations, ripple cross-laminations, cross laminations, and cross bedding. Calcite, quartz and dolomite (?) cement is present. Isolated zones, generally less than 0.5 in. diameter, contain marcasite or pyrite and carbonaceous material and represent local reducing conditions ("reduction spots"). Marcasite or pyrite and black carbonaceous material is common along wavy laminations. Healed and open high-angle fractures are present. Open fractures contain calcite crystals and contributed to major lost circulation during drilling, especially between 3450 and 3520 ft. Intergranular porosity is indicated by drill mud sieving (mud buildups) on outer core surfaces, except on darker gray "reduction spots." A total of 203 ft of Glorieta Sandstone was cored.

Permian San Andres Formation

The Permian San Andres Formation is distinguished from equivalent strata (Kaibab Formation) to the west by a more restricted marine depositional environment (Peirce, 1989). The lower 3 ft of the San Andres Formation, just above the Glorieta Sandstone, is a probable solution-collapse breccia with a black shale and dark micrite matrix, possibly rich in carbonaceous material (Fig. 2). The San Andres limestone, between 3362 and 3436 ft, is fetid, finely crystalline, medium to dark gray, and brown. The San Andres micrites and biomicrites have black shale laminae and black, parallel and wavy laminations. Dark sutured stylolites are common. Hydrocarbon films are present along stylolite and fracture surfaces. Vertical fractures and minor small-scale vugs, partially filled with calcite crystals, are common. Several fractures probably contributed to lost circulation during coring.

The top of the San Andres Formation was picked at a silicified and brecciated zone at 3362 ft. Only 74 ft of San Andres is preserved. The silicified zone represents a post-Triassic to pre- Late Cretaceous regional unconformity.

Cretaceous Dakota (?) Formation

Unconformably above the San Andres Formation is a carbonaceous, medium- to coarse-grained sandstone with calcite cement. This unit is tentatively correlated with the Cretaceous Dakota Formation (Nations, 1989). In the Alpine 1/Federal, the Dakota Formation is cross laminated and has abundant ripple cross-laminated zones with much carbonaceous laminae. This unit is a light gray, dark gray and black, moderately well-sorted sandstone. Marcasite or pyrite is abundant, especially in association with carbonaceous zones. Where carbonate cements are lacking in ripple troughs or in high-porosity coarse-sand laminae, the carbonaceous material appears to be diagenetic. A 4 in. bentonite bed was observed at 3309 ft, together with laminated coal and carbonaceous shale at 3339 feet depth. The upper 10 ft, from 3246 to 3256 ft, of the Cretaceous sandstone is yellow to orange brown, but shows the same depositional structures and textures as underlying dark-gray sandstone (Fig. 3). We interpret this upper 10 ft zone to be oxidized by weathering.

The depositional environment of the Cretaceous sandstone is uncertain. A marine barrier island system, delta, or terrestrial fluvial environment are all possible, but further study of this unit is needed.

Cretaceous or Tertiary unnamed beds

An unnamed stratigraphic unit, from 3139 to 3246 ft, was encountered unconformably above the Cretaceous sandstone in the Alpine 1/Federal corehole (Fig. 3). A limestone-pebble conglomerate marks the base of the unit. These beds, 107 ft thick, are orange-red and orange, mostly siltstone and fine- to medium-grained silty sandstone with calcite cement. A similar orange and orange-red unit of limited lateral extent, beneath the Eocene Mogollon Rim basal conglomerate, unconformably overlies Cretaceous sediments near Round Top, about 55 mi to the west of Alpine Divide (Potochnik, 1989). The depositional setting of this unit is different than the overlying Eagar Formation and minor granule-to-cobble conglomerate beds suggest a different provenance. Clasts are predominantly limestone, with minor intermediate volcanic clasts, in contrast with gravels in the overlying Eagar Formation that are rich in Precambrian plutonic and metamorphic

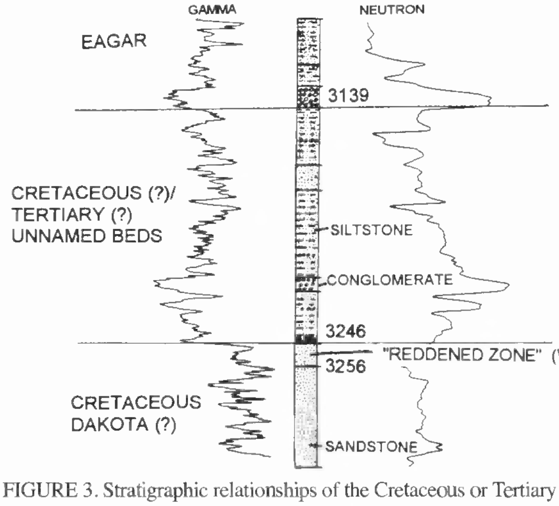

FIGURE 3. Stratigraphic relationships of the Cretaceous or Tertiary unnamed beds.

clasts. The beds show both parallel and cross laminations and some ripple cross-laminated zones. The occurrence of intermediate volcanic clasts may indicate a Late Cretaceous to early Tertiary (early Laramide) age. It is possible that the unit is a southern Colorado Plateau/transition zone equivalent to early Laramide units, namely, the Fort Crittenden and Ringbone formations of the Basin and Range of southeastern Arizona and southwestern New Mexico (Dickinson et al., 1989; Lawton et al., 1993). Alternatively, the beds may record the initial deposition of the overlying Eagar Formation. The depositional structures and the fine-grained and regionally discontinuous nature of the unit suggests low-energy fluvial deposits that filled isolated, low-relief valleys cut into the Cretaceous sandstones.

Tertiary Eagar Formation

Unconformably overlying the unnamed Cretaceous or Tertiary unit at 3139 ft are conglomerate beds containing abundant plutonic and metamorphic clasts with Precambrian affinity. Lower Tertiary sediments that have Precambrian basement and Paleozoic provenance are variously designated in the region as the Baca Formation (Cather and Johnson, 1984), Eagar Formation (Sirrine, 1956), Mogollon Rim Formation (Potochnik, 1989), and Rim Gravels (Cooley and Davidson, 1963). Potochnik's (1989) and Sirrine's (1956) sections also contain intermediate volcanic clasts in the basal conglomerate, which is not a characteristic of the Baca Formation to the east in New Mexico. Precambrian-clast conglomerate strata in the Alpine 1/Federal also contain andesite at the base, and are therefore, correlated more closely with the Eagar and Mogollon Rim formations. The Baca, Eagar and Mogollon Rim formations are Eocene age (Cather and Johnson, 1984; Potochnik, 1989). Ash-fall tuffs, 125 and 220 ft below the top of the Mogollon Rim Formation, range from 37.6 to 37.5 Ma, respectively (Potochnik, 1989). Peirce et al. (1979) reported that three volcanic clasts in the Mogollon Rim conglomerate range in age from 54.6 to 66.7 Ma.

The Eagar Formation at Alpine Divide is divided into two major units. The lower unit, from 2580 to 3139 ft, is composed of matrix-supported conglomerate and red-brown mudstone (Fig. 4). Clasts within the conglomerate beds are composed mostly of Precambrian lithologies, ranging from granite and metamorphic rocks to younger Precambrian limestone and sandstone of the Apache Group. The conglomerate beds also contain intermediate volcanic porphyry clasts, possibly derived from the Globe-Miami area of Arizona (Potochnik, 1989). Matrix in the conglomerate beds consists of poorly consolidated, sandy silt and clay. This interval presented drilling problems due to washouts, caving and maintenance of proper drilling mud properties. The gravels rich in Precambrian lithologies at the base of the Eagar and Mogollon Rim formations represent the uplift and unroofing of basement-cored uplifts, associated with the later phases of the Laramide Orogeny in the Salt River Canyon region of east-central Arizona (Potochnik, 1989).

From 2052 to 2574 ft, the Eagar Formation consists of mostly siltstone and fine- to medium-grained sandstone with minor interbedded conglomerate and red-brown mudstone. The upper unit of the Eagar Formation is predominantly a brown and brown-gray arkosic litharenite, showing bioturbation, parallel laminations, ripple cross-lamination, flaser, soft-sediment deformation, very thin to medium bedding, weak pedogenic calcite, and root casts.

A detailed study of the core is required to correlate the Alpine Divide section with facies of the Mogollon Rim Formation (Potochnik, 1989) and the Baca Formation (Cather and Johnson, 1984). However, the depositional environment of the Eagar Formation in the Alpine 1/Federal appears to be dominated by fluvial channel deposits in the lower unit and floodplain deposits in the upper unit.

Cather and Johnson (1984) defined the top of the Baca Formation at a level where volcanic debris, characteristic of the overlying Spears Formation (now Spears Group), becomes abundant. Potochnik (1989) defined the top of the Mogollon Rim Formation at the horizon where volcanic clasts roughly equal Paleozoic and Precambrian clasts. With Potochnik's (1989) criteria, the top of the Eagar Formation is approximately 2052 depth in the Alpine Divide corehole. This top occurs where coarse, quartz-rich sandstones of the Eagar Formation give way to fine- to medium-grained, quartz-poor, andesitic sandstones of the lower Spears Group (S. M. Cather, personal commun., 1994).

Tertiary stratigraphic nomenclature

Outcrops of Tertiary volcaniclastic sedimentary rocks and volcanic rocks in the Alpine area have been designated as the Tertiary Datil Formation or Tertiary Datil Group in most previous studies in the area. However, Osburn and Chapin (1983) restricted the use of Datil nomenclature in its type locality in the eastern Mogollon-Datil region in New Mexico to volcanic rocks and related sediments beneath the 32 Ma Hells Mesa Tuff. The Hells Mesa Tuff is not known to extend into the Alpine region or into much of the western Mogollon-Datil region of New Mexico and Arizona (Marvin et al., 1987; Ratte, 1989).

In the Alpine area, the 900 ft of basaltic lavas that cap Escudilla Mountain may represent the Bearwallow Mountain Andesite (R. M. Chamberlin, personal commun., 1994). Marvin et al. (1987) bracketed the Bearwallow Mountain andesite at 23 to 27 Ma. Also, a sanidine-rich ash-flow tuff crops out a short distance below the Escudilla Mountain basaltic rocks and near the top of the Tertiary volcaniclastic sedimentary section (Wrucke, 1961). This ash-flow tuff may correlate with the regionally extensive Bloodgood Canyon Tuff that McIntosh et al. (1991) showed is 28.1 Ma. Volcaniclastic and minor volcanic rocks in the Alpine area overlie the Eagar Formation and lie below the

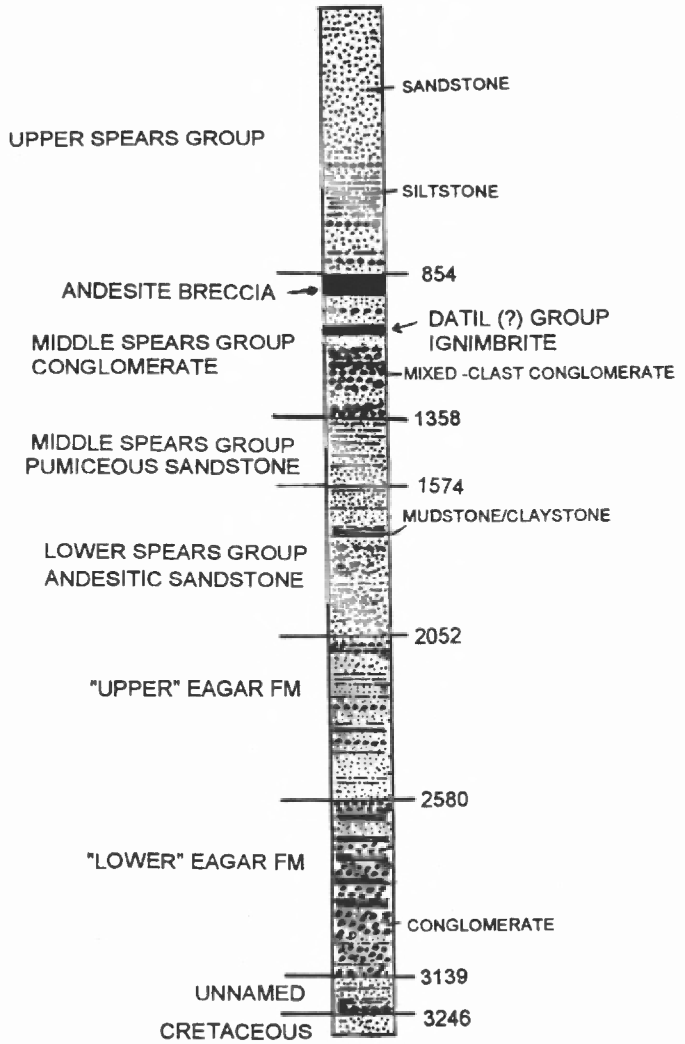

FIGURE 4. Summary stratigraphic column of the Tertiary rocks in the Alpine 1/Federal hole.

presumed Bearwallow Mountain Andesite. Therefore, volcaniclastic rocks in the Alpine area may be younger, at least in part, than the Hells Mesa Tuff; especially, the 650 ft of Tertiary sediments exposed on the surface at Alpine Divide upward to the base of basaltic rocks on Escudilla Mountain.

Cather et al. (1994, this volume) redefine Tertiary nomenclature in the Mogollon-Datil volcanic field of western New Mexico and eastern Arizona. Volcanic rocks older than 31.4 Ma are assigned to the Datil Group, whereas younger Oligocene volcanic rocks are placed in the Mogollon Group. More importantly to this paper, all sedimentary rocks above the Baca Formation (Eagar Formation) and below the Santa Fe Group (Gila Group), but interbedded with the Mogollon and Datil Group volcanic sequences, are referred to as the Spears Group. Since nearly all of the post-Eagar Formation rocks in the Alpine Divide corehole are volcaniclastic sedimentary rocks, the Spears Group nomenclature is most appropriate.

Lower Spears Group - andesite sandstone unit

The lower Spears Group, from 2052 to 1574 ft, grades downward into the Eagar Formation. Generally, both units have similar depositional structures and lithology except that the lower Spears contains more andesite volcanic detritus, less quartz, and fewer beds of red-brown mudstone, and it coarsens upward. This unit is mostly gray, clayey siltstone and clayey, fine- to medium-grained, andesitic sandstone that shows possible bioturbation, parallel laminations, ripple cross-lamination, flaser, soft-sediment deformation and very thin to medium bedding. The lower Spears Group sediments probably represent fluvial plain deposits and distal alluvial apron deposits of andesitic volcanoes to the south and southeast.

Middle Spears Group - pumiceous sandstone unit

Light gray, gray-green, and pink muddy sandstone and mudstone with abundant felsic pumice lapilli occur from 1358 to 1574 ft. This unit is assigned to the middle Spears Group because it may record the initiation of silicic pyroclastic volcanism in the Mogollon-Datil volcanic field to the south and east of Alpine Divide. At 1438 ft, a 2-to-3-in.-thick, ash-fall tuff was encountered. An isotopic-age determination of the tuff may assist to constrain the volcanotectonic transition from Laramide compression to mid-Tertiary extension at about 35 to 37 Ma (Cather, 1989; Cather and Chapin, 1989). This pumiceous middle Spears unit was deposited on an alluvial apron, spreading outward from volcanoes to the southeast and south.

Middle Spears Group - conglomerate unit

A middle Spears Group conglomerate unit in the Alpine 1/Federal is separated into two major lithologic types, mixed-clast conglomerate beds and mostly volcanic-clast sandstone and conglomerate beds (Fig. 4). The first distinctive mixed-clast conglomerate bed was observed at 1093 ft. This conglomerate unit from 1093 to 1266 ft, contains the first down-hole occurrence of red granite (Precambrian). The unit is a sandy, granule-to-cobble conglomerate, interbedded with coarse- to medium-grained sandstone and pebbly sandstone. The mixed-clast conglomerate beds are moderately indurated, matrix-supported, and contain well rounded to subrounded clasts of silicic and intermediate volcanics, limestone and red granite. From 1266 to 1325 ft, the middle Spears Group consists of siltstone that coarsens downward into fine- to medium-grained sandstone and pebbly sandstone and pumiceous sandstone. Between 1325 and 1358 ft, the middle Spears Group again consists of interbedded, mixed-clast matrix-supported granule-to-cobble conglomerate and medium- to coarse-grained sandstone.

Between 854 and 942 ft, a dark blue-green to gray-green andesite porphyry breccia is present in the middle Spears Group sequence. This unit may be a toe-breccia that is peripheral to an andesite flow. The andesite flow mapped at the surface along the northern and southeastern flanks of Escudilla Mountain is about 500 to 600 ft higher in elevation than the andesite in the corehole (Wrucke, 1961). Wrucke's (1961) flow, a medium-crystalline andesite porphyry lava with seriate texture, is tentatively correlated with the andesite of Dry Leggett Canyon of Ratté (1989) (S. M. Cather, personal commun., 1994). Further study is needed to determine the relationship, if any, of the cored andesite breccia and the andesite lavas mapped in the area.

Datil Group (?) ignimbrite

A partially- to densely-welded, orange-brown to pale red rhyolite ash-flow tuff between 1018 and 1038 ft is the only distinctly volcanic unit intercalated in the Spears Group. This moderately crystal-rich unit contains brown and white pumice fragments and medium-grained phenocrysts of clear sanidine and black biotite, but little or no quartz. This ash-flow tuff is tentatively correlated with the tuff of Bishop Peak, one of the Datil Group ignimbrites. McIntosh et al. (1991) gave a $^{40}Ar/^{39}Ar$ age of 34.7 Ma for the tuff of Bishop Peak and an apparently equivalent unit, the tuff of Lebya Well, in the Horse Springs, New Mexico area about 65 mi east of Alpine Divide. If this tentative correlation is correct, this ignimbrite out-flow sheet probably originated from a New Mexico source to the east.

Discussion of mixed-clast conglomerate beds in middle Spears Group

Ratté (1989) mapped a conglomerate with limestone, granite, gneiss and volcanic clasts near the base (?) of the Pueblo Creek Formation (middle Spears Group) and stratigraphically below the tuff of Bishop Peak in the San Francisco Mountains about 30 mi southeast of Alpine Divide.

Ratté et al. (1969) and Landis et al. (1971) described other mixed-clast conglomerate beds near the base of the exposed Tertiary volcanic and volcaniclastic section (Spears Group and Datil (?) Group) along the Red Hill Road between Beaverhead and Blue about 20 mi south of Alpine and at Milligan Peak, 5 mi northeast of the Red Hill Road. Many conglomerate strata in the Red Hill Road section have over seventy percent non-volcanic clast composition. Landis et al. (1971) indicated that virtually all of the fossiliferous limestone clasts are of Middle and Late Pennsylvanian age and may be derived from strata correlative with the Horquilla Limestone of southeastern Arizona. They discussed the evidence for a source within 10 mi or less of the Red Hill Road section. Limestone boulders, 2 ft in length, provide the most compelling evidence for a possible nearby Eocene uplift.

In the Nutrioso area, about 5 mi north of the Alpine Divide, Wrucke (1961) described additional gravels with volcanic, granite and limestone clasts. Mixed-clast conglomerate beds intercalated in the Spears Group are clearly not localized to the Alpine 1/Federal corehole and appear to have regional extent and importance. It is not clear whether the conglomerates observed in these widely separated localities represent the same unit or several discontinous conglomerate lenses with similar stratigraphic position.

The mixed-clast conglomerate beds in the middle Spears Group (1093 to 1358 ft) may indicate drainage incision into pre-Tertiary rocks due to regional thermal uplift associated with Tertiary magmatism, an episode of very late-stage Laramide uplift of basement-involved structures, or reworking of lower Eagar and Mogollon Rim gravel units. If late-stage Laramide compressional uplift to the south and west in Arizona was concurrent with volcanism in the Mogollon-Datil volcanic field to the east and southeast, these conglomerate beds may represent southwesterly-derived upper tongues of the Eagar Formation that are intercalated with southerly- and southeasterly-derived volcaniclastic sediments of the Spears Group. Further study is needed to detail provenance, timing, and tectonic setting of the mixed-composition conglomerate.

Upper Spears Group

The upper Spears Group was encountered from the surface to 854 ft depth. The cored portion of this unit consists mostly of light brown and brown fluvial and alluvial volcanic arenites and conglomerates. These sediments were deposited on the alluvial aprons of volcanic complexes to the south and southeast. Surface outcrops in the vicinity of Alpine Divide also contain white and light cream-colored cross-bedded and moderately well-sorted eolian (?) volcaniclastic sandstones.

TERTIARY-QUATERNARY BASALTIC INTRUSIONS

Several basaltic intrusions were cored. Age of the magmatism is unknown, but a range from mid-Tertiary to Quaternary is reasonable. Whether the intrusions represent dike or sill geometry is unknown, but the two upper intrusions are between formation contacts, suggesting concordance (sills).

The first intrusion, a porphyritic basalt or basaltic andesite, separates the Glorieta Sandstone and the Corduroy Member of the Supai Formation and is 112 ft thick. The upper 35 ft of the Corduroy Member is a solution-collapse breccia, which would allow ingress of magma.

The second intrusion at 4260 to 4322 ft is between the Corduroy Member and the Fort Apache Limestone and is 62 ft thick. A third intrusion, 5 ft below the second, in the Fort Apache Limestone is 35 ft thick. The second and third intrusions are both aphanitic olivine basalts with a composite thickness of 97 ft.

A fourth intrusion, a pyroxene basalt with minor olivine, intrudes the Big A Butte Member at 4454 ft. Because the hole reached total depth at 4505 ft in this intrusion, its total thickness is unknown.

Three different intrusive events may be indicated and each intrusion may have cooled to ambient temperature before the next intrusive event. Modeling of transient thermal fronts associated with the intrusions may constrain the role the intrusions play in hydrocarbon maturation of source rocks in the Permian section.

STRUCTURAL IMPLICATIONS

Winters (1963) reported that the Big A Butte and Amos Wash Members of the Supai Formation total about 805 ft thickness in the White River region. Therefore, the bottom of the Alpine 1/Federal corehole may be at least 750 ft above Precambrian basement. If Pennsylvanian and older rocks are present, the remaining depth would approach 2,000 ft. The Tenneco 1/Federal B well, 45 mi northwest of Alpine Divide, has 1167 ft of Pennsylvanian and older rocks (Peirce et al., 1977) On the other hand, the Belcher 1/State well, 20 mi northeast of the Alpine drill site, has 1670 ft of section between Precambrian basement and the Coconino/Glorieta Sandstone (Foster, 1964). The Fort Apache Limestone is not present in the Belcher well. The difference in the cored Supai thickness at Alpine Divide and pre-Glorieta rocks in the Belcher well suggests that the Alpine 1/Federal bottom is about 800 ft above Precambrian basement.

Weber and Willard (1959) and Wrucke (1961) mapped allochthonous (?) outcrops of Pennsylvanian carbonate rocks in Tertiary andesitic rocks on the northeast side of Escudilla Mountain and just across the New Mexico-Arizona border east of the Alpine drill site (Fig. 1). Harrison (1989) described similar allochthonous Pennsylvanian rocks in andesitic Tertiary rocks in New Mexico more than 100 mi southeast of the Alpine area. Harrison (1989) postulated that the Pennsylvanian limestone outcrops are gravity-slide deposits associated with wrench faulting. Individual slide blocks may be tens of miles from their origin as a result of wrench faulting and slide detachment. Also, Cather and Chapin (1989) described additional allochthonous Paleozoic limestone blocks in Tertiary volcaniclastic rocks about 70 mi east of the Alpine area. Major strike-slip faulting in the region east and south of Alpine was hypothesized by Chamberlin and Anderson (1989). Confirmation of the occurrence of Pennsylvanian and older rocks in the subsurface of the Alpine area will require deeper drilling.

An inferred and unknown thickness of Jurassic rocks, all of the Triassic Chinle Formation, and most of the Permian San Andres Formation, were removed by erosion beneath a sub- Late Cretaceous unconformity and most of the Cretaceous Dakota Sandstone was removed by erosion beneath a Laramide unconformity. Both unconformities resulted from upwarp along the southern margin of the Colorado Plateau (Fig. 5). The Laramide unconformity is approximately 1600 ft lower in elevation in the Alpine 1/Federal than in the Belcher 1/State. Up to 1600 ft of structural displacement, down to the south, has occurred since erosion of the low-relief Laramide surface that bevels the Dakota Sandstone. Determination of the exact location and nature of major subsurface structure between Alpine Divide and Springerville requires detailed geologic mapping. However, several structural geometries are possible. One or more buried and unmapped early Tertiary faults may create a basin. On the other hand, a gently-dipping homoclinal slope with less than one degree of dip to the south is all that is required to displace the Laramide surface. Wrucke (1961)

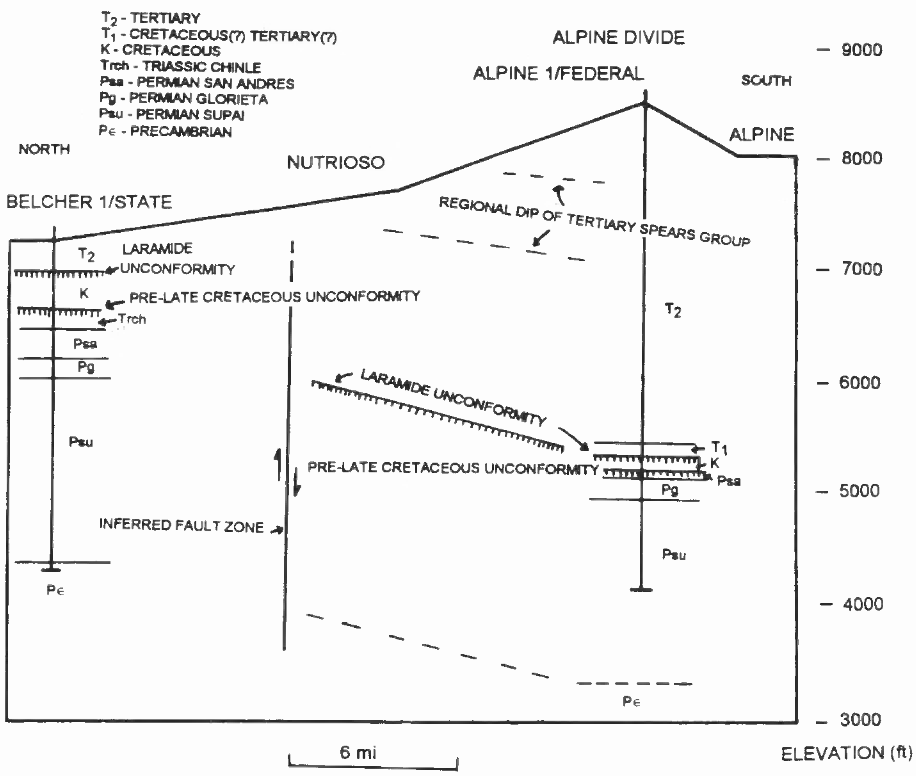

FIGURE 5. Diagrammatic structure cross section between the Alpine 1/Federal and the Belcher 1/State boreholes.

indicated that Tertiary sediments in the area have a gentle southerly dip. In conclusion, the subsurface of the eastern White Mountains is typical of the Mogollon Slope to the east in New Mexico. Subsurface structure in the New Mexico segment of the Mogollon Slope shows a post- Late Cretaceous south-facing downwarp toward the southern Colorado Plateau margin. The subsurface in the region north of the Mogollon Rim, to the west in Arizona, generally rises upward toward the southern Colorado Plateau margin.

SUMMARY

The Alpine 1/Federal drilling provides valuable new information on the geology of the region. The eastern White Mountains region of Arizona is tectonically situated over a south-facing downwarp of the Mogollon Slope on the southern Colorado Plateau. Unnamed Upper Cretaceous or lower Tertiary beds were cored. Several basalt sills or dikes of unknown age intrude the Paleozoic section. Cretaceous rocks rest unconformably on the Permian San Andres Formation. The Corduroy Member of the Supai Formation is thicker and has a greater percentage of carbonate and evaporite rocks than in sections east of Springerville and around Whiteriver.

Minimum depth to the Precambrian is estimated to be 5300 ft at Alpine Divide. If Pennsylvanian or older rocks are present, the estimated depth to Precambrian will approach 6500 ft.

The organic-rich Dakota Sandstone and fetid and petroliferous dolomites and limestones in the San Andres Formation, and the Corduroy and Fort Apache Limestone Members of the Supai indicate potential as source rocks for petroleum maturation. Detailed petrographic analysis and facies studies of core, hydrocarbon maturation studies, delineation of the burial and thermal history of the Cretaceous and Permian rocks, assessment of the hydrodynamic history of the area, and analysis of potential structural and stratigraphic traps and potential reservoir rocks is required to detail the oil and gas potential of the area. The Alpine 1/Federal core and logs provide key information for such an assessment.

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