Petrographic analysis of Cenozoic—Mesozoic—Permian well cuttings from two exploration wells in south-central New Mexico

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Contents

INTRODUCTION 5
REGIONAL GEOLOGY 6
PETROGRAPHY 7 Grimm
well 7
Sunland Park well 11
SUMMARY 21
ACKNOWLEDGMENTS 22
REFERENCES 22
APPENDIX A 23
APPENDIX B 25

Figures

FIGURE 1—Index map of well locations in south-central Dona Ana County. 5
FIGURE 2—Generalized geologic map of south-central Doña Ma County. 6
FIGURE 3—Location of cross sections in the Potrillo basin. 8
FIGURE 4—Photomicrographs of Grimm et al. well cuttings correlative with Love Ranch/Lobo Formations. 9
FIGURE 5—Photomicrographs of Grimm et al. well cuttings correlative with U-Bar and Hell-to-Finish Formations. 10
FIGURE 6—Photomicrographs of Grimm et al. well cuttings correlative with Hueco Formation. 11
FIGURE 7—Photomicrographs of felsite cuttings from Sunland Park well. 12
FIGURE 8—Photomicrographs of homblende-andesite cuttings from Sunland Park well. 13
FIGURE 9—Photomicrographs of skarn in cuttings from Sunland Park well. 14
FIGURE 10—Photomicrographs of spotted homfels in cuttings from Sunland Park well. 14
FIGURE 11—Photomicrograph of epitomized fine sandy calcareous mudstone in Sunland Park well. 15
FIGURE 12—Photomicrographs of sandstones in Sunland Park well. 16
FIGURE 13—Photomicrographs of various sandstones, silty mudstones, and shales in Sunland Park well. 17
FIGURE 14—Photomicrographs of Cretaceous forams in shales and sandy mudstones in Sunland Park well. 18
FIGURE 15—Photomicrographs of Permian forams in shales and mudstones from the Sunland Park well. 19
FIGURE 16—Photomicrographs of Permian bioclasts in Sunland Park well. 20
FIGURE 17—Stratigraphic chart of Cenozoic–Mesozoic–Permian rocks exposed in southern Dona Ma County. 21
FIGURE 18—Correlation of rock units penetrated in the Grimm and Sunland Park wells with rock units mapped in Doña Ma County. 21
Abstract

The Grimm, Hunt, Brown and Am. Arctic Ltd. No. 1 Mobil well (TD 21,759 ft) and Sunland Park Unit No. 1 well (TD 18,232 ft) were drilled in southern Doña Ana County in 1972-73 and 1985, respectively. This study involved scanning cuttings from the two wells and petrographic analysis of 265 thin sections made from the cuttings. The study provides data essential for interpretation of stratigraphy and structure between fault-block ranges in south-central New Mexico. The Grimm well penetrated 1920 ft of basin-fill sediments; 3880 ft of andesitic and volcaniclastic rocks, probably correlative with the upper Eocene Palm Park and Rubio Peak Formations; 7000 ft of muddy volcanic arenites with minor conglomerates, correlative with lower Eocene—Paleocene Love Ranch and Eocene Lobo Formations; 2400 ft (including a 640 ft monzonite sill near the base) of fossiliferous shales, siltstones, sandstones, lime mudstones, and wackestones, believed correlative with the Lower Cretaceous U-Bar and Hell-to-Finish Formations. About 5360 ft of Permian—Pennsylvanian rocks and 1200 ft of Mississippian—Lower Ordovician rocks underlie the Cretaceous.

The upper 200 ft of Permian rocks are shales, mudstones, sandstones, wackestones, and packstones, probably correlative with the Lower Permian Hueco Formation. The Sunland Park well penetrated 1530 ft of basin-fill sediments overlying Tertiary volcanic and volcaniclastic rocks. Distinctive characteristics of stratigraphic units in this well are mostly obscured by alteration and contact metamorphism adjacent to felsite intrusions encountered frequently between 1530 and 17,150 ft depths. Eighteen hundred ft of Cretaceous section, composed of fossiliferous shales, lime mudstones, wackestones, siltstones, and sandstones, was penetrated at 15,100 ft. Actual top of the Cretaceous is probably within the immediately overlying 4000 ft of muddy siltstones, sandstones, wackestones, packstones, and minor silstones and sandstones correlative with the Lower Permian Hueco Formation.

Oligocene ash-flow tuffs and rhyolitic volcanics, abundant north of the well sites, are not in the subsurface where these two wells were drilled. No evidence of earlier reported early Tertiary marine rocks or Jurassic rocks was found in either well during this study.

Introduction

Two deep oil and gas exploration wells were drilled in southern Doña Ana County in 1972-1973 and 1985. The Grimm, Hunt, Brown and Am. Arctic Ltd. No. 1 Mobil 32 is in sec. 32, T25S, R1E, 1315 FNL, 1315 FWL (Fig. 1). It was spudded October 2, 1972, drilled to total depth of 21,759 ft; was dry and abandoned October 12, 1973. The Phillips Petroleum Corp. Sunland Park Unit No. 1 is in sec. 4, T27S, R1E, 600 FNL, 1980 FWL, about 7 mi south of the Grimm et al. well. It was spudded February 7, 1985, drilled to total depth of 18,232 ft; was dry and abandoned September 19, 1985. Reported formation tops differ significantly between the two wells, especially from the surface down to the base of the Cretaceous. The reported post-Cretaceous section is about 5200 ft thicker in the Phillips well. Previously reported marine(?) Eocene—Paleocene rocks in the Phillips well and Jurassic(?) marine rocks in the Grimm well (Bordine et al., 1986; Thompson, 1982; Thompson and Bieberman, 1975; Uphoff, 1978; Woods, 1987) were not substantiated by this study.

Purposes of this petrographic study are to: (1) provide more detailed data on subsurface lithologies in southern Dona Ma County; (2) provide information to support or negate the presence of Jurassic and early Tertiary marine rocks; (3) compare lithology of the well cuttings with correlative strata exposed in the nearby mountains; (4) determine if subsurface structures in the Potrillo basin (Seager and Mack, 1987; Seager et al., 1986) are necessary to explain different depths of reported stratigraphic tops in the two wells; and (5) provide additional information on lithology and thickness of Cretaceous rocks along the northern edge of the Chihuahua trough.

FIGURE 1—Index map of well locations in south-central Doña Ana County.
Cuttings of both wells, collected at 10 ft intervals, are on file with the New Mexico Bureau of Mines & Mineral Resources. Cuttings were scanned under a binocular microscope. All depths cited in this report are indicated as the bottom of each 10 ft interval.

Phillips Petroleum Corp. kindly loaned 200 thin sections for petrographic analysis made from cuttings of the Sunland Park well. Selected intervals for preparing 65 thin sections of cuttings, from the Grimm et al. well depended on bracketing distinctive changes in lithologies and whether or not cuttings were available. Some intervals apparently had been extensively used in previous studies.

Thin sections were prepared as follows: (1) cut a "blank" of marble about 0.5 inch thick and size of standard petrographic thin sections; (2) apply thin coat of epoxy on smooth surface of "blank"; (3) sprinkle clean cuttings onto epoxy surface; (4) place blank on heat-plate until epoxy hardens; (5) lap smooth surface on the exposed cuttings; (6) clean, dry, and apply glass slide to lapped surface of cuttings with epoxy; (7) after epoxy is hardened, cut marble blank from cuttings and lap thin section of cuttings to desired thickness. Petrographic analyses of the thin sections included identification of minerals, detrital rock grains, rock types, bioclasts, and cements. Some exceptionally small cuttings from the Sunland Park well prevented detailed identification of rock types and bioclasts. Most of these cuttings were 0.1-0.5 mm; a few were larger than 1.0 mm.

**Regional geology**

South-central New Mexico lies in the Basin and Range physiographic province and present topography is dominated by north-trending fault-block mountains and intervening basins of late Cenozoic age. The Franklin Mountains are a west-titled fault block 18 mi east of the well sites; the East Potrillo Mountains are a southwest-titled fault block 14-20 mi southwest of the well sites; the Robledo Mountains are a south-titled horst, just north of Picacho Mountain, about 27 mi north of the well sites (Fig. 1). Geologic maps (Dunham 1935; Harbour, 1972; Kottlowski, 1969; New Mexico Geological Society, 1982; Seager et al., 1987; Woodward et al., 1975) show the ratio of bedrock exposures to basin fill/alluvium to be about 1:3. Regional geologic descriptions and interpretations are based chiefly on bedrock outcrops. Exploration wells drilled in the intervening basins provide much useful and essential data for interpretation of pre-Laramide, Laramide, and middle Tertiary stratigraphy and structure. Three major tectonic stages in the evolution of the region are: Laramide uplifts, late Eocene—Oligocene volcanism, and Miocene—Holocene volcanism and rifting (Chapin and Seager, 1975; Seager, 1975; Seager and Mack, 1987).

Precambrian igneous and metamorphic rocks that form the basement of south-central New Mexico are exposed in the Franklin and Organ Mountains (Fig. 2). The lower Paleozoic section contains about 2800 ft of sandstones, shales, and carbonates that crop out in the Franklin and northern Robledo Mountains. The upper Paleozoic is represented by 5600 ft of limestone, shale, and minor sandstone well exposed in the Franklin Mountains. Extensive Pennsylvanian and Permian sections crop out in the Robledo Mountains, and the upper part of the Permian section is exposed in the East Potrillo Mountains. These Pennsylvanian and Permian marine strata were deposited along the southwestern side of the Orogrande basin and thin to the west and northwest. Lower Permian rocks in south-central New Mexico contain a facies change from red, nonmarine siliciclastic rocks (Abo Formation) in the north to marine limestone (Hueco Formation) in the south (Mack and James, 1987). This facies change is well exposed as intertonguing units in the Robledo Mountains; the Abo is not exposed, and probably is not present, south of the Robledo Mountains. Lower Permian rocks exposed in the East Potrillo Mountains consist of about 1000 ft of limestone, dolomitic limestone, and minor siltstone/sandstone believed correlative to Yeso and San Andres Formations (Seager and Mack, 1986, in press; Seager et al., 1987). Part of the upper unit of Hueco Formation mapped in the Franklin Mountains by Harbour (1972) may be correlative to these rocks in the East Potrillo Mountains.

Triassic and Jurassic rocks are not exposed in southern New Mexico. The only reported occurrence is marine black mudstone, dark limestone, and sandstone in the Grimm well (Thompson and Bieberman, 1975; Thompson, 1982; Uphoff, 1978). About 400-500 ft of marine Upper Jurassic shale, sandstone, and calcareous
rocks have been described in Chihuahua and about 60 mi south of El Paso (Cordoba, 1969), and recently 5900 ft of Upper Jurassic marine limestone, shale, and basalt were reported in the northeastern Chiricahua Mountains about 150 mi west of El Paso. Unconformably overlying Permian rocks in the East Potrillo Mountains are about 1900 ft of Lower Cretaceous limestone, siltstone, sandstone, and conglomerate (Mack, 1986). These are correlative with the Hell-to-Finish and U-Bar Formations of southwestern New Mexico. The lower conglomerate member of the Hell-to-Finish Formation in the northern East Potrillo Mountains is 128 ft thick. It contains clasts of Permian(? ) limestone, dolostone, and minor chert in a medium- to coarse-grained sandstone matrix. The upper siltstone/sandstone member of the Hell-to-Finish Formation is 551 ft thick in the northern East Potrillo Mountains. It consists of very fine- and fine-grained sandstone, calcareous siltstone, minor thin conglomerate and granular coarse-grained sandstone beds, dark gray shale, and siltly lime mud-stone. The sandstones are quartzarenites, chert arenites, and subarkoses (Seager and Mack, in press).

The U-Bar Formation, that has been informally divided into six map units by Seager and Mack (in press), conformably overlies the Hell-to-Finish Formation in the East Potrillo Mountains. In ascending order these units are the lower limestone, sandstone, rudistid limestone, siltstone—limestone, massive limestone, and upper siltstone members. The lower limestone member ranges in thickness from 43 ft in the southern East Potrillos to 98 ft in the northern part of the range. It consists of wackestones, packstones, and grainstones, with minor silt and sand grains. Allochems are forams, pelecypods, gastropods, peloids, ooids, and intraclasts. The sandstone member is 216 ft thick at the northern end of the range and thins southward to 82 ft. This member contains granular—pebbly sandstone, very fine-to medium-grained arkoses and subarkoses, and minor pelecypod-shell debris and siltly lime mudstone. The rudistid limestone member varies in thickness from 43 ft in the north to 20 ft in the south. The lower half of this member is a rudistid boundstone with minor intraclasts, ooids, and forams (including Orbitolina). The upper part is gastropod and pelecypod wackestones. The siltstone—limestone member contains about 295 ft of calcareous siltstone, very fine- to fine-grained sandstone, and minor limestone and shale. The limestone is mostly slightly gastropod—pelecypod wackestone and packstone and minor grainstone. The massive limestone member, 436 ft thick, is exposed only in the southern East Potrillo Mountains. The basal part of this member is mostly silty gastropod—pelecypod wackestone; the remainder is neomorphosed to the extent of destroying all original allochems and textures. The upper siltstone member, 49 ft thick, is also exposed only in the southern East Potrillo Mountains (Mack, 1986; Seager and Mack, in press).

A cumulative thickness of 700 ft of Upper Cretaceous and/or lower Tertiary sedimentary rocks around Mt. Riley (Fig. 1) has been mapped and described by Seager and Mack (in press). The basal 130 ft consist of pink mudstone overlain by about 130 ft of limestone pebble—cobble conglomerate, tan to olive sandstone and siltstone, and red shale. These strata may be correlative to part of the Love Ranch Formation exposed about 16 mi northeast of Las Cruces. About 440 ft of strata, believed to be stratigraphically above the conglomerate—sandstone—siltstone—shale beds, consist of varicolored sandstone, shale, siltstone, and thin conglomerate units. Some of the elastics are derived from intermediate-composition volcanic or intrusive rocks (Seager and Mack, in press) and may be correlative with the Eocene Palm Park/Rubio Peak Formations. The Palm Park crops out extensively around Picacho Mountain (Seager et al., 1987) and to the north and northeast, where it consists of 2000-3500 ft of chiefly intermediate-composition volcaniclastic rocks (Clemons, 1976b, 1977, 1979; Seager and Clemons, 1975). Numerous intermediate-composition intrusive rocks in the region, including the Campus Andesite at El Paso, one near Vado (Fig. 1), and Mt. Riley are about 47 m.y. old (Hoffer, 1976) and coeval to the Palm Park.

Rhyolitic intrusives, ash-flow tuffs, and silicic volcaniclastic rocks are voluminous in the Organ Mountains (Seager, 1981), Sleeping Lady Hills (Fig. 1), and to the west and northwest (Clemons, 1976a, 1976b, 1977, 1979; Seager and Clemons, 1975). The six Bell Top Formation ash-flow tuffs, extensively exposed in the Sleeping Lady Hills and Sierra de las Uvas, possess very distinctive petrographic characteristics. Each tuff is readily distinguished from the others by its shard content, phenocryst compositions, percentage of crystals, and lithic fragments. The Bell Top ash-flow tuffs and the Organ Mountain tuffs are early Oligocene age (Clemons, 1976a; McIntosh et al., 1991; Seager, 1981).

Basin-fill deposits in south-central New Mexico belong to the Santa Fe Group and range in age from late Oligocene to middle Pleistocene. The Santa Fe contains calcareous gravels, sands, silt, and clay deposited as alluvial fans and fluvial facies of the Rio Grande. Thicknesses of the Santa Fe basin-fill deposits in southern Doña Ana County range from a few hundred to 2000 ft (King et al., 1971).

Basaltic plugs, dikes, cinder cones, and flows intrude and overlie the Santa Fe Group. More than 150 cinder cones, maars, and shield volcanoes, including Aden Crater, Little Black Mountain, and Black Mountain (Fig. 1), have been mapped in southwestern Data Ana County (Hoffer, 1976; Seager, in press). The basalts have yielded radiometric dates from 0.5 to 0.1 m.y. (Seager et al., 1984; Hoffer, 1976; Hawley and Kottlowski, 1969). Kilbourne Hole, a maar about 8 mi west of the Sunland Park well (Fig. 1), is as young as 180,000 years or possibly 24,000 years (Seager, 1987; Gile, 1987).

**Grimm well**

The Grimm well penetrated about 3880 ft of andesitic and volcaniclastic rocks beneath 1920 ft of basin-fill sediment (Fig. 3). Relatively fresh hornblende andesites contain strongly oscillatory zoned plagioclase.
biotite, and oxidized hornblende phenocrysts in intersertal and intergranular matrices. Some of the andesites contain patchy carbonate replacement and chloritized hornblende. Interbedded volcanic arenites are calcareous, fine- to medium-grained sandstones and muddy sandstones. These volcanic rocks are probably correlative with the upper Eocene Palm Park and Rubio Peak Formations to the north and northwest, respectively.

At about 5800 ft depth, lithology of cuttings changes to predominantly calcareous, muddy, fine- to medium-grained sandstones, siltstones, and mudstones. These are mostly volcanic arenites containing very angular to subangular grains of plagioclase, biotite, hornblende, andesitic-rock fragments, and minor chert and carbonate-rock fragments. Below 6280 ft, quartz becomes a common constituent and a few quartz grains contain abraded overgrowths indicative of recycled sandstones. Grain content of carbonate- and mudstone-rock fragments (Fig. 4A, B) decreases downward as plagioclase, biotite, hornblende, and volcanic-rock-fragment content decreases. Traces of anhydrite are intermittently present in the cuttings. The interval between 10,200 and 12,800 ft depths contains probable interbedded conglomerates. Cuttings contain varied lithologies (Fig. 4C, D, E) including mudstones, siltstones, siliceous and calcareous sandstones, lime mudstones, wackestones, packstones, grainstones, dolostones, and chert. Most of the limestones are neomorphosed with unidentifiable bioclasts, but ooids and probable globigerinids (Fig. 4F) are present. The muddy matrix of sandstones below 12,500 ft is chloritized. This 7000 ft section, between 5800 and 12,800 ft depths, is correlative, at least in part, with the lower Eocene—Paleocene Love Ranch and Eocene Lobo Formations to the north and west, respectively (Seager and Mack, 1987; Mack and Clemons, 1988).

Rocks believed correlative to the U-Bar and Hellto-Finish(?) Formations were penetrated between 12,800 and 15,200 ft depths. This 2400 ft interval includes a 640 ft thick monzonite sill between 14,480 and 15,120 ft depths. Interbedded medium- to dark-gray shales, siltstones, sandstones, silty lime mudstones, and wackestones comprise most of the section. Brown and reddish-brown silty and sandy shale intervals are present throughout the section but are more common in the basal 900 ft above and below the sill. The calcareous and calcareous/siliceous, muddy, very fine-to fine-grained, poorly sorted sandstones contain well rounded to subangular grains in the upper part of the section (Fig. 5A) and subrounded to angular grains in the lower part of the section. Quartz is the dominant grain component with common chert, carbonate rock fragments, plagioclase, and traces of K-feldspar and volcanic-rock fragments. Wackestones (Fig. 5B) and fossiliferous, calcareous shales and siltstones (Fig. 5C, 5D, 5E) are present.
FIGURE 4—Photomicrographs of Grimm et al. well cuttings correlative with Love Ranch/Lobo Formations. A, Brown mudstone grains (under dark air bubbles), andesite (a) and quartz (q); 7600 ft; crossed nicols; bar = 0.1 mm. B, Elongate mudstone grains in silty mudstone matrix with quartz, chert, and plagioclase grains; 8490 ft; plane polarized light; bar = 0.5 mm. C, Calcareous fine sandstone with quartz, plagioclase, biotite, and carbonate-rock fragment; 10,200 ft; crossed nicols; bar = 0.1 mm. D, Neomorphosed foraminifer wackestone; 11,120 ft; plane polarized light; bar = 0.5 mm. E, Neomorphosed algal grainstone; 11,120 ft; plane polarized light; bar = 0.5 mm. F, Calcareous globigerinid shale and two coarse siltstone cuttings; 10,200 ft; plane polarized light; bar = 0.1 mm.
FIGURE 5—Photomicrographs of Grimm et al. well cuttings correlative with U-Bar and Hell-to-Finish Formations. A, Muddy, dark-brown, very fine-grained sandstone with well rounded to subangular quartz; 15,140 ft; plane polarized light; bar = 0.5 mm. B, Very fine sandy wackestone with neomorphosed bioclasts; 13,770 ft; plane polarized light; bar = 0.5 mm. C, Fossiliferous very fine sandy shale; with thin mollusc valve (m), ostracode valve (o), and echinoderm fragment (e); 15,110 ft; plane polarized light; bar = 0.5 mm. D, Laminated mudstone and silty mudstone, 15,150 ft; plane polarized light; bar = 0.5 mm. E, Globular forams (globigerinids?) in slightly silted, organic-rich shale; 13,700 ft; plane polarized light; bar = 0.1 mm. F, Rudist fragment (r), brown mudstone (center and left center) and fine-grained sandstones; 14,080 ft; plane polarized light; bar = 0.1 mm.
D) are more abundant below 13,700 ft. Bioclasts include globigerinid-like forams (Figs. 4F, 5E), rudists (Fig. 5F), and echinoderm, mollusc (Fig. 5C), and oyster fragments. This 2400 ft section, excluding 640 ft of sill, contains 1760 ft of interbedded clastic and carbonate rocks which are comparable to about 1800 ft of U-Bar and Hell-to-Finish Formations in the East Potrillo Mountains (Seager and Mack, in press) 16 mi southwest of the Grimm well. Missing in the Grimm well cuttings are varied lithologies matching the conglomerate at the base of the Hell-to-Finish in the East Potrillo Mountains. This is not surprising, however, considering the conglomerate ranges in thickness from 3 to 128 ft in the East Potrillo Mountains (Seager and Mack, in press).

Beneath the Cretaceous section, about 5360 ft of Permian—Pennsylvanian rocks were penetrated at depths of 15,200 to 20,560 ft. These rocks have been briefly described by Thompson (1982), Thompson and Bieberman (1975), and Uphoff (1978). The upper 200 ft of Permian rocks examined in this study are interbedded brown, silty mudstone and shale, dark-gray silty and fine-grained sandy mudstone, muddy fine-grained sandstone, wackestones, and packstones (Fig. 6A). The sandstone contains predominantly rounded to subangular quartz with minor plagioclase, K-feldspar, and carbonate bryozoans, brachiopods, echinoderms, ostracodes, and unidentified, neomorphosed bioclasts. These rocks are correlative to the upper part of the Hueco Formation.

**Sunland Park well**

The Sunland Park well penetrated 1530 ft of basinfill sediment (Thompson, written comm. 1991; Woods, 1987) overlying Tertiary volcanic rocks. Distinctive petrographic characteristics of stratigraphic units in the Sunland Park well are mostly obscured by alteration and contact metamorphism adjacent to felsite intrusions (Fig. 7) encountered frequently between 1530 and 17,150 ft depths. The felsite cuttings above 8000 ft are chiefly microporphyritic latite. Subequal amounts of K-feldspar (sanidine?) and sodic-plagioclase microphenocrysts, with lesser hornblende and biotite, occur in an anhedral equant microcrystalline to cryptocrystalline matrix. Traces of euhedral apatite, zircon, and sphene are present in a few cuttings. The feldspars are pervasively sericitized, hornblende typically has oxidized rims and chlorite and carbonate replacement, and biotite is mostly fresh-appearing, but at some depths it has been chloritized (Fig. 7D). Similar felsite occurs to about 17,000 ft; a few of these latite cuttings also contain traces of interstitial quartz. A second felsite, hornblende andesite, is the dominant type between 8000 and 17,150 ft. It contains euhedral hornblende and minor biotite and plagioclase microphenocrysts in a plagioclase-lath matrix (Fig. 8). Some of the hornblende is fresh, but typically it has oxidized rims and extensive chlorite and carbonate replacement.

It is not possible to pick the exact top of the Eocene volcanic/volcaniclastic section (Palm Park Formation), Eocene—Paleocene Lobo/Love Ranch Formation, and Cretaceous section solely on petrographic criteria obtained from the cuttings. Cuttings between 1530 and 8000 ft are composed dominantly of volcanic-rock fragments and felsite intrusive, but traces of quartz siltstone and calcareous very fine-grained sandstone occur as high as 6310 and 7670-7800 ft. Very fine-grained clastic and metaclastic rocks are dominant between 10,500 and 11,200 ft. Skarn, composed of epidote, carbonate, chlorite, garnet, and pyrite (Fig. 9), was intercepted below 7600 ft, masking most of the original lithology. Hornfels and spotted hornfels (with andalusite?) cuttings (Fig. 10) cut intermittently between 9800 and 12,600 ft probably represent original interbedded calcareous shale/mudstone sequences. Felsite, skarn, and hornfels prevail between 8000 and 11,200 ft. Very fine- to medium-grained sandstone, muddy sandstone, siltstone, and mudstone are the dominant lithologies between 11,200 and 15,100 ft.
FIGURE 7—Photomicrographs of felsite cuttings from Sunland Park well. A, Altered hornblende-biotite-plagioclase (p) intrusive; 1810 ft; plane polarized light; bar = 0.1 mm. B, Sericitized and partly chloritized latite K-feldspar (k) and fresh biotite (b); 5470 ft; crossed nicols; bar = 0.1 mm. C, Biotite (oxidized rim), plagioclase (p), felsite, small euhedral hornblende (h); 7150 ft; plane polarized light; bar = 0.2 mm. D, Chloritized and sericitized hornblende-biotite-plagioclase felsite; 7150 ft; crossed nicols; bar = 0.2 mm. E, Quartz-K-feldspar (k) felsite; 13910 ft; crossed nicols; bar = 0.1 mm. F, Plagioclase and biotite (b) in hornblende andesite; 14,140 ft; crossed nicols; bar = 0.1 mm. G, Slightly altered felsite; 14,560 ft; crossed nicols; bar = 0.2 mm. H, Sericite and carbonate replacing plagioclase in felsite; 17,110 ft; crossed nicols; bar = 0.1 mm.
Felsite intrusive is common and traces of hornfels and skarn occur at 13,400, 13,650, 14,000, 14,450, and 15,000 ft.

The upper part of the elastic sequence, down to 11,000 ft, is dominantly muddy, calcareous, and very fine- to fine-grained, poorly sorted sandstones. Contact metamorphism makes it difficult (or impossible) to determine original composition of most of the non-quartz grains and matrix material (Fig. 11). Traces of angular to subangular plagioclase and chert grains are present. Most of the quartz is subangular to subrounded, but a few grains are rounded with overgrowths. The lower 4000 ft of the elastic sequence, to 15,100 ft, contains quite a few felsite intrusive intervals, but skarn and hornfels are much less abundant than in the upper part. The cuttings represent interbedded silty mudstones and muddy, calcareous and siliceous, very fine- to medium-grained sandstones (Fig. 12). Sand grains are predominantly very angular to subangular quartz, with minor plagioclase, chert, and traces of K-feldspar.

An 1800 ft thick section, between 15,100 and 16,900 ft, consists of interbedded calcareous, fossiliferous shales, lime mudstones, neomorphosed wackestones, siltstones, and calcareous and siliceous, muddy, very fine- to medium-grained, poorly sorted sandstones (Fig. 13). Sand grains are chiefly subangular to rounded quartz (some with overgrowths) and minor chert; angular plagioclase grains are abundant at 15,240 ft. Five or six felsite intrusives were encountered in this interval, but skarn and hornfels were not seen in the cuttings. The shales and limestones (Fig. 14) contain Globigerinelloides, Hedbergella, Heterohelix?, Praeglobotruncana?, and radiolarians indicating a late Aptian to late Albian age (C. L. McNulty, written comm. 1989). Other allochems include molluscs, echinoderms, and peloids.

The section from 16,900 to TD 18,232 ft is predominantly silty lime mudstones and wackestones with minor packstones, shales, and calcareous siltstones. Several calcareous, very fine-grained sandstones and coarse siltstones are interbedded, and felsite intrusive was cut at 16,950 and 17,110-17,150 ft. The top of the Paleozoic is put at 16,900 ft on the basis of Geinitzina, Tuberitina, and Apterinella? forams identified by Merlynd.
FIGURE 9—Photomicrographs of skarn in cuttings from Sunland Park well. A, Epidote-quartz (q) skarn; 8030 ft; plane polarized light; bar = 0.1 mm. B, Single cutting of garnet-carbonate (c) skarn; 9500 ft; plane polarized light, bar = 0.1 mm. C, Epidote (e) and quartz (q) skarn; originally calcareous siltstone (?); 9880 ft; crossed nicols; bar = 0.1 mm. D, Epidotized calcareous fine-grained sandstone; dark grains are K-feldspar, chert, and carbonate rock fragments; 14,450 ft; crossed nicols; bar = 0.2 mm.

FIGURE 10—Photomicrographs of spotted hornfels in cuttings from Sunland Park well. A, Small, dark, circular areas are probably andalusite; 11,050 ft; crossed nicols; bar = 0.2 mm. B, Spotted hornfels and epidotized, calcareous, very fine-grained sandstone (s); 11,050 ft; crossed nicols; bar = 0.1 mm.
FIGURE 11—Photomicrograph of epidotized fine sandy calcareous mudstone in Sunland Park well. 8630 ft; crossed nicols; bar = 0.1 mm.
FIGURE 12—Photomicrographs of sandstones in Sunland Park well. A, Calcareous medium-grained arkose sandstone with quartz, plagioclase, and K-feldspar grains; 13,070 ft; crossed nicols; bar = 0.1 mm. B, Siliceous medium-grained arkose sandstone with quartz, plagioclase, chert, and K-feldspar grains; 13,490 ft; crossed nicols; bar = 0.1 mm. C, Argillaceous fine-grained sandstone; 13,540 ft; crossed nicols; bar = 0.1 mm. D, Calcareous fine-grained sandstone with quartz, plagioclase, and chert grains; 14,080 ft; crossed nicols; bar = 0.1 mm. E, Calcareous fine-grained arkose sandstone with quartz, plagioclase, chert and volcanic-rock (v) grains; 14,450 ft; crossed nicols; bar = 0.1 mm. F, Siliceous medium-grained arkose sandstone; 14,720 ft; crossed nicols; bar = 0.2 mm.
FIGURE 13—Photomicrographs of various sandstones, silty mudstones, and shales in Sunland Park well. A, 15,350 ft; crossed nicols; bar = 0.2 mm. B, 16,080 ft; plane polarized light; bar = 0.2 mm.
FIGURE 14—Photomicrographs of Cretaceous forams in shales and sandy mudstones in Sunland Park well. A, Globigerinid and biserial forams; 15,160 ft, plane polarized light; bar = 0.1 mm. B and C, Globigerinids; 15,290 ft, plane polarized light; bar = 0.1 mm. D, Various forams in silty shale; 15,980 ft, plane polarized light; bar = 0.1 mm. E, Unidentified bioclast in silty mudstone; 15,080 ft, plane polarized light; bar = 0.1 mm. F, Foram in sandy mudstone; 15,080 ft, plane polarized light; bar = 0.1 mm.
FIGURE 15—Photomicrographs of Permian foram in shales and mudstones from the Sunland Park well. A, 17,560 ft; plane polarized light; bar = 0.1 mm. B, 17,760 ft; plane polarized light; bar = 0.1 mm. C, 17,810 ft; plane polarized light; bar = 0.1 mm. D, 17,910 ft; plane polarized light; bar = 0.1 mm. E, 17,910 ft; plane polarized light; bar = 0.1 mm. F, 17,910 ft; plane polarized light; bar = 0.1 mm.
FIGURE 16—Photomicrographs of Permian bioclasts in Sunland Park well. A, Ostracode valve and neomorphosed bioclasts; 17,360 ft; plane polarized light; bar = 0.1 mm. B, Echinoderm fragment in lime mudstone (e), ostracode valve (o), and neomorphosed bioclasts in wackestone; 17,360 ft; plane polarized light; bar = 0.1 mm. C, Ostracode (?) or trilobite fragment in neomorphosed lime mudstone; 17,420 ft; plane polarized light; bar = 0.1 mm. D, Bryozoan (e) and brachiopod (b) fragments in lime mudstone; 17,560 ft; plane polarized light; bar = 0.1 mm. E, Coral (?) fragment in wackestone; 17,760 ft; plane polarized light; bar = 0.1 mm. F, Brachiopod (b), ostracode (o), and echinoderm (e) fragments; 17,810 ft; plane polarized light; bar = 0.1 mm.
Nestell (C. L. McNulty, written comm. 1989). Other forams identified in cuttings to a depth of 18,210 ft by Nestell include Globivalvulina, Agathammina, Nodosinella, and encrusting forams, including Tubiphytes (Fig. 15) indicating a Permian age for these rocks. Other bioclasts (Fig. 16) include echinoderm, brachiopod, bryozoan, trilobite, ostracode, mollusc, algal, and coral? fragments.

Summary

Petrographic study of cuttings from the Grimm et al. and Sunland Park wells provides data to support the following conclusions and interpretations. Unfortunately, contact metamorphism of rocks penetrated by the Sunland Park well prevents picking of formation tops within the Tertiary section. Fig. 17 shows the rock units exposed in adjacent areas.

1. Late Cenozoic basin-fill sediments are about 400 ft thicker in the Grimm well than in the Sunland Park well (Fig. 18).

2. Oligocene ash-flow tuffs and rhyolitic volcanioclastics, so abundant east and west of Las Cruces, are not in the subsurface where these two wells were drilled.

3. Earlier reports of early Tertiary marine rocks probably resulted from drilling mud or other type of contamination in analyses (Lucas et al., 1990). The Tertiary sequence of Eocene Palm Park/Rubio Peak Formations overlying Eocene—Paleocene Lobo/Love Ranch Formations mapped to the north and northwest correlates well with lithology of cuttings in the wells. This sequence is 10,880 ft thick in the Grimm well and 13,570 ft thick in the Sunland Park well, 7 mi to the south (Fig. 18). The difference in thickness may be due to: (a) abundance of felsite intrusions, (b) unrecognized subsurface structure, (c) relief on post-Cretaceous surface, or (d) not recognizing the correct Cretaceous top due to contact-metamorphic effects.

4. The Cretaceous section is about 1800 ft thick in each well, is Aptian—Albian in age, and correlates well with the U-Bar and Hell-to-Finish Formations mapped in the East Poetillo Mountains by Seager and Mack (in press).

5. The 640 ft thick monzonite sill penetrated by the Grimm well is probably correlatable with the abundant latite intrusions in the Sunland Park well.

6. No evidence of Jurassic age rocks in either well was found in this study.

7. It appears that Cretaceous-age rocks overlie the Lower Permian Hueco Formation, similar to the Hueco exposed in East Poetillo, Franklin, and Robledo Mountains.

FIGURE 18—Correlation of rock units penetrated in the Grimm and Sunland Park wells with rock units mapped in Doña Ana County. Explanation: Om, Montoya Formation; Sf, Fuscalman Dolomite; Dp, Perch Shale; M, Mississippian; P, Pennsylvanian; Ph, Hueco Formation; J, Jurassic; Ku, U-Bar/Hell-to-Finish Formations; Tv, Oligocene volcanics; Qs, basin-fill sediments. A is combined from Thompson and Biebezen (1975), Thompson (1982), and Uphoff (1978). B and C are interpretations of this study.
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Appendix A
Petrographic descriptions of thin sections,
Grimm, Hunt, Brown, Am. Arctic No. 1 Mobil 32 Well,
sec. 32, T25S, R1E, Doña Ana County, New Mexico

Basin fill
1920
Volcanics
Fresh, strongly oscillatory toned plagiophyric, biot, some oxidiz blbd, minor carlb repl.
2500 Few like 2210; majority more altered w/abt oxidit blbd and less biot, w/toned plagiophyric; equigran matrix and minor patchy blrd.
3360 Plag-blbd+biot microphenocrysts; interstitial matrix; patchy carlb repl; blbd relatively fresh except oxidix rim.
4000 Same as 3360.
4660 Same as 3360, plus heavily oxidiz blbd and some alterat to chlorite.
4820 Oxidiz blbd-plag asesite w/minor biot; interstitial matrix and intergranular matrix (2 varieties); minor carlb repl.
5010 Same as 4820 w/trace of fresh blbd andesite as above; 3360.
5980 Same as 5010.
5520 Similar to 5080 w/trace equl (2-1) amount of volcanic arenite:calcareous fn mad ss; several varieties including muddy ss.

Clastics
5810 Calcareous muddy fn mad ss (plag, andesite VRF, biot, hbl, tcr or felsite, tcr CRF), VA-SA, poorly sorted. Minor silty mudstone and blbd-biot andesite.
6150 Mudstone and silty mdst; minor calcarenite fn ss, similar to 5810.
6290 Mudstone and silty mdst, some w/anhdrite, calcarenite fn ss (qz, CRF, tch, plag, tr VRF, blbd).
6610 Same as 6320.
6930 Same as 6290.
7210 Same as 6290.
7600 Calcareous fn mad muddy ss (qz, plag, CRF, mdst frag, VRF, minor hbl, biot, K-feld, fch, low qz w/abraded overgrowths), VA-SA; minor silty mdst.
7960 Mudstone w/minor calcarenite muddy vfn ss (qz, plag, VRF, CRF, tch) and some silty mdst.
8120 Similar to 7960 w/slightly more vfn ss.
8490 Similar to 7960 and 8120; more vfn ss and distinctive that many mdst fragmens are included in vfn ss, so actually is fn granule crl; tr anhdyrite.
8900 Same as 7960.
9300 Same as 8120 w/fn ss (qz, VRF, CRF, lm mdst, tch, minor plag).
9900 Same as 7960 and 9900.
9890 Same as 9300.
10200 Possible vfn Mdls, Silty mdst, vfn-fn ss as above, plus tr of silicose med ss and calcarenite fn ss w/SR–R qz; possible fossil lipids in coup of lm mdst cuttings; probable globigerinids.
10600 Mdst, silty mdst, tr muddy crs slst w/green pellets, silty lm mdst, calcar vfn ss.
10830 Possible vfn Mdls, Mdst, fn mad w/unident bioclasts; tr calcar fss, calcar/silicose med ss (qz, tch, CRF, minor plag, K-feld, VRF), few qz w/overgrowths.
11200 Possible vfn Mdls, Silty mdst, lm mdst, foram wackest, packst, grainst/oids, chl, calcar med ss (qz, tch, CRF), calcar fn ss as above.
11320 Possible vfn Mdls, Silty mdst, lm mdst, packst/grainst, dol, tch, minor calcar and silicose fn ss (qz, CRF, tr packst). VRF.
11660 Possible vfn Abnt mdst, tr packst, calcar vfn ss (poorly sort, qz, CRF, silty mdst), silicose fn ss (qz, tch, tr packst).
11790 Possible vfn Mdls, lm mdst, wackest (possible globigerinids), vfn, fn, med ss (qz, tch, CRF). A–SR qz; muddy dark ss.
12090 (very small cuttings) Mdls, lm mdst, dk muddy vfn ss, loose VA–WR qz, CRF, tch grains, minor plag grains, tr VRF.
12710 Possible vfn. Lm mdst, tch, qz to 1 mm aze, neomorphised lm mdst, wackest, muddy fn ss, calcar vfn ss (qz, tch, CRF, tr packst), dk muddy vfn ss as above.
12270 Possible vnf Like 12170.
12650 Vfn-fn muddy ss (qz, tch, K-feld, plag—more abat than in 12930), muddy matrix altered to tch; calcar vfn-fn ss; minor muddy fn ss as above; minor lm mdst, tr coal (1%).

Cretaceous
12930 Mdst, lm mdst, silty mdst; silicose–calcar fn ss (qz, tch, plag—less abat than in 12650, K-feld); WR qz, few to 0.6 mm; muddy fn ss (qz, tch, CRF, plag); VA–SA qz and tch.
13040 Sh, lm mdst, silty sh, muddy crs slst, muddy vfn ss (qz, tch, plag, minor CRF), VA–SA grains.
13100 Same as 13040 and 12930.
13200 Similar to 12930–13100 w/biot flakes and tr VRF in vfn and fn ss.
13230 Silicose/calcar muddy fn ss (qz, plag, chl, K-feld); crs slst and vfn ss like 12930–13200.
13380 (very small cuttings) Similar to 12930–13230 w/more lm mdst.
13560 Mdst, silty mdst, calcareous sandy slst, minor vfn ss: red-brown.
13700 Similar to 13560 w/more sh, darker brown; abnt globigerinid-like forams.
13770 Lm mdst, wackest, sandy wackest, calcar fn ss (qz), SA–WR; unident bioclasts.
13950 Silty sh, slsts, muddy vfn ss (qz, plag).
14000 Similar to 13770–13950 w/more vfn–fn ss.
14060 Sh, silty sh, slst, fn sandy lm mdst, crs slst, probable rudist fragment (1 mm long); fn sandy neospa w/WR qz, calcar fn ss (qz), silicose fn (qz).
14100 Similar to 14060; silicose/calcar vfn ss (qz, chl).
14150 Calcar vfn ss (SR–WR qz), some silica overgrowths; poorly sorted fn sandy lm mdst and wackest, smn unident bioclasts; silty sh.
14200 Silty sh, vfn–fn ss (VA–SA qz, plag, chl, biot); crs slst.
14310 Spar-filled foram (?) in calcar vfn ss (qz, plag, VRF); forams in silty mdst; neomorphosed lm mdst, wackest, silty sh and mdst w/format (2); bioclasts in ss.
14330 Brown silty mdst and lm mdst, muddy vfn–fn ss (qz, CRF); pyrite; wackest (ostracod, foram, molluse, algae), few bioclasts also in vfn ss.
14420 Neomorph lmr mdst, wackest (molluse frags); silty and fn sandy lm mdst; calcar vfn ss (A–SR qz, plag, zircon, CRF); sh w/formats(?).
14430 Calcar vfn–fn ss (A–SR qz, CRF); dk brn silty sh; neomorph sandy lm mdst w/tr bioclasts, foram, peloids; pyrite.
14460 Similar to 14420 except no foram sh.

Silt: approximately 600 ft thick.

14490 Altered (chl) biot–hbl–feld intrusive: monzonite; minor brn muddy siltst, silty sh, calcare siltst, neomorph lm mdst.

15110 Silty sh w/bioclasts (ost, thin mollusc, ech), altered biot–hbl–feld intrusive, brn mdst w/globular forams, calcare siltst, wackest w/unident spar-mold bioclasts and tr forams.
15120 Altered intrusive; calcar fn ss; argillac vfn ss (SA–SR qz, plag, K-feld, tr VRF); brn fn sandy sh.
15130 Similar to 15110; silty brn sh w/forams (globigerinids?).
15140 Silty mdst and sh, dk muddy ss (A–SR qz, CRF); silty brn sh w/globigerinids? like 15130; tr intrusive; crs siltst.
15150 Silty sh w/globigerinid? like 15130; only one cutting as in 15140; lt brn silty sh and muddy siltst; some intrusive.

Permian

15200 Lt brn silty mdst and sh; dk gray silty and fn sandy mdst, muddy siltst; tr wackest w/bryozoa and unident bioclasts.
15270 Packst (brach, bryox, ost, cc); brn silty sh and mdst; muddy fn ss (SA–R qz, plag, K-fel, CRF).
15370 Similar to 15270 w/neomorph wackest (ost, bryoz, ech and unident bioclasts).
Appendix B
Petrographic descriptions of thin sections,
Phillips Petroleum Co. #1 Sunland Park Well,
sec. 4, T27S, R1E, Dona Ana County, New Mexico

1530
Basin fill

Voenies
1540 VRF (K-feld, hbl, biot, plag phenocrysts); biot ragged and fresh, hbl oxidized and repl w/ carb; minor carb and chl alteration.
1630 Qt, plag (oligoclase), K-feld (microcline), VRF: all frags of crystals, few composites; Qt, K-feld, and some plag appear plutonic; no veoaeic Qt, rhyolite and andesite VRF.
1700 50-60% VRF (calcar, oxidiz hbd andesite; porphyritic rhyolite (contain fresh biot, common carb alterat); Qt, K-feld,mostly plutions, angular xk frags; minor plag; few rnd grains.
1730 50-60% VRF, pale med brn w/carb like 1700; w/fresh biot; subeq amts of rnd and ang K-feld, Qt, sanidine xk frags. (latite?).
1810 VRF; pale med brn; oxidiz hbd and some fresh biot; abnt K-feld phenocrysts; few euhedral apatite (0.2 mm, hex); few plag phenocrysts; no Qt. Common carb and chl alterat; carb patch as well as repl hbd. Some frags w/aligned plag laths, most w/anhedral mosaic matrix.
2010 Same as 1810.
2130 Same as 1810, 2010: euh hbd repl w/carb and dk oxidiz rims; euh sanidine phenocrysts; euh-subuhed plag; tr biot; no Qt; some euh pyrite; tr zircon.
2200 Same as 1810–2130: carb and chl alterat; tr zircon, K-feld phenos to 1 mm, clusters to 4 mm; repl hbd phenos to 0.3 mm.
2230 Similar to 1810–2200. Hbld less abnt and chloritized; patch carb alterat as well as repl hbdl and plag; chl repl biot.
3520 Similar to 1810–2230. Hbld and plag less common; minor intesial Qt; pyrite common; some fresh biot.
3620 Similar to 1810–3520. More altered; abnt carb and pyrite; only 1 or 2 frags w/plag lath matrix.
4210 Same as 3620, interstitial Qt common.
4250 Same as 3620–4210.
4710 Similar to 3620–4250 but most frags have seriate feld xls; some fresh biot altered to chl.
5220 Same as 3620–4250.
5470 Similar to 3610–5220 but much more fresh biot; some partly altered to chl, much less carb alterat; magnetite, no pyrite. Random orient biot flakes and thin books 0.01–10 mm thick, 0.05–1.5 mm long; resembles tuff.
5500 Same as 5470: K-feld phenos and xk frags common; fresh biot books common; minor hbd (?) altered to chl; minor sml anh Qt; minor olgoelase plag; anh microxln mosaic; sericie alterat pervasive; minor carb.
6310 More than 70% same as 5500: tr fn Qt ss—intergrown anh xls; minor graphic intergrowth of Qt-Kfeld, minor hbd andesite, some fn xk rhyolite?; anh mosaic of Qt, K-feld, biot; few frags w/K-feld and flow alined plag laths.
7150 Same as 5500: hbdl altered to carb.
7280 VRF: fresh and altered hbdl; some euh, some ragged; pyrite common; tr biot. Few frags of K-feld phenos. Anh mosaic of foliate laths, Qt, unk mineral (thin tabular/foliate/splintery, biax-, high biref, secondary? alterat mineral).
7670 Same as 7280: hbdl altered to biot, epidote; minor patchy carb alterat.
7800 1) Anh, inequat sized Qt mosaic w/hbdl microites;
2) same as 7280 and 7670;
3) K-feld and biot phenos in chl carb—epid altered matrix; some pyrite and garnet.
7950 1) Anh-subuhed K-feld (highly altered), anh-subuhed hbdl altered to chl; minor interstitatial Qt in matrix of foliate and lath alined chl? and plag; also tr of ragged biot books; few carb alterat patches;
2) Same as #1 in 7800, common but less abnt.

Predominantly skarn, hornfels and felsite intrusions
8030 1) Calcar feldsparitic as (altered as granular epidote repl carb; skarn;
2) Im mdz altered to epid;
3) chloritized hbdl andesite less abnt.
8210 Altered (chl) VRF; mostly plag laths w/miner biot and hbdl; few plag phenos; tr vfn ss.
8400 1) Similar to 7280; 2) Altered felsic rock, mostly K-feld; epid granules; former mafic (hbd (?) altered to gypsum?—biax-, low biref, splintery;
3) Minor biot (pale) felsite (anh mosaic of Qt and K-feld);
4) Anhydrite (?)—rectang C1, yel–red–blu biref.
8600 1) Skarn similar to 8030;
2) Epidotized VRF, plag laths and pyrox or epid;
3) tr of felsite w/qz, K-feld;
4) tr of garnet, marble, metaqz.
8700 1) Latitite?: plag laths, fresh hbdl and plag microphenos, minor epid;
2) minor skarn;
8770 1) Same as 8700; 2) fresh euh hbdl microphenos in plag lath matrix, minor pyrite; dusty sericie alterat on plag, no epid;
3) ragged, faded hbdl w/plag laths; altered.
8800 Same as #3 in 8770, w/pyrite; minor epid granules.
8930 Same as 8800, tr epid and pyrite.
9000 Same as 8890; smaller cuttings; pyrite and more epid.
9050 Same as 8890–9000; sml (0.5 mm) cuttings here and below; much alterat.
9100 1) Same as 8890–9050;
2) epid–qz skarn, tr garnet, tr interstitatial carb alterat;
3) vfn qz ss and fn arkosic ss: tr fresh euh hbd in plag lath matrix.
9200 1) Hbdl andesite: hbd oxidiz and/or repl w/carb; fine subpar plag laths; few plag microphenos; chl alterat;
2) less abnt epid–qz skars like 9100 (#3).
9250 Felsite: microphenos of K-feld, plag; minor qz, altered hbdl in matrix of flow-alined plag laths; tr zircon; hbdl chloritized, patchy carb
alterat.

9300  Same as 9250; tr sphene; qz phenocrysts rounded; lidded phenocrysts altered to sericite and carb.

9400  Same as 9250-9300.

9450  1) Same as 9250-9400 w/tr pyrite;
      2) altered bld-plag andesite similar to 9200 (#1);
      3) epd-qtz skarn like 9100 (#2) and 9200 (#2).

9500  1) Same as 9250-9450;
      2) calcar-qtz skarn, garnet carb skarn, epd-qtz skarn;
      3) altered bld-plag andesite?–latite?

9570  1) Felsite w/ altered bbl in plag lath matrix w/carb alterat;
      2) felsite w/ altered bbl in inequigr. plag matrix w/carb alterat;
      3) less abt qz–epd skarn; tr pyrite.

9620  1) Garnet-carb–qtz–epd skarn;
      2) bld-plag felsite less abt;  
      3) tr calc+ fn ss; tr tr fns tactite.

9670  1) Felsite; altered bbl and K-feld microphenocrysts in plag lath matrix w/carb patchy repl; minor interstitial qz; probably same as 9250;
      3) less abt garnet skarn.
9800  Same as 9670; some chl alterat of bbl; rnd fresh sanidine microphenocrysts; also few plag (oligoclase) microphenocrysts; minor skarn.

9880  1) Same as 9670–9800;
      2) epd–qtz skarn (met calcar ss?); epd-plag skarn;
      3) less abt fn xtn andalusite?–garnet hornfels/karn.

9930  Same as 9880.

10010 Same as #1 and #2 in 9880–9930. Some fresh bbl as well as altered; patchy carb in skarns and felsite; tr fn arkosic ss.

10100 Same as 10100.

10200 Similar to 10100: skarn less abt; more patch carb in bld–K-feld felsite w/flow alianged plag laths; tr biot. Still small cuttings.

10260 Same as 10260; more fresh plag microphenocrysts, some oscil zoned.

10300 Same as 10200–10260; tr skarn; less carb patches.

10400 Same as 10200–10300; mostly fresh, pale brn bbl microphenocrysts; plag microphenocrysts rel fresh; K-feld microphenocrysts altered; flow aliaged plag lath matrix; tr interstitial qz.

Skarn dominant with muddy silticlastics

10500  1) Epd–qtz skarn; same as met poorly sorted fn ss;
      2) less abt felsite like 10010–10400.

10600  Epd–qtz–garnet–carb skarn; some w/plag–epd.

10700  Epd–qtz skarn and hornfels; met mdst, slst, sandy mdst; few probably were originally calc+ vfn arkosic ss; few qz grains to 0.2 mm.

10750  Same as 10700; less ss, more mdst.

10800  Epidotized silti mdst; vfn muddy ss and fn arkosic ss; few grains to 0.4 mm; K-feld minor, mostly SA–A qz grains but few appear rnd w/overgrowths; angularity probably due to met; poorly sorted; tr altered bbl felsite and epd mbl.

10850  Same as 10800 w/fn mdst ss; K-feld minor; tr plag grains; possible tr chl? grains; tr met ss w/carb and pyrite.

10890  Altered bld felsite similar to those above (cf 9670); some rel fresh zoned plag microphenocrysts (oligoclase); some same as 10800–10850.

10930  Skarn similar to 10800–10850; abt epd silty mdst; common fn–med ss; tr altered bbl felsite.

11000  Same as 10930; mdst about 4 times as abt as fn ss.

11030  Same as 11000: (5.1).

11080  Skarn/hornfels; spotted hornfels and vfn sandy hornfels similar to 9880; tr epd fn ss; epd skarn.

11080  1) Bld bbl felsite (sml microphenocrysts in equigr. matrix);
      2) fn epd–qtz ss; silty epd mdst; some sericite; tr spotted hornfels.

11090  Similar to 11080.

11100  Similar 11080–11090; equigr. felsite w/carb alterat; spotted hornfels; sericite? sh; minor epd silty mdst.

11130  Varied clastic lithologies: muddy vfn ss, epd silty mdst, fn ss (qz, plag, chit? grains); sericite–epd alterat; tr silty spotted hornfels; tr bbl felsite.

11140  Similar to 11130; spotted hornfels and bbl felsite more abt.

Silticlastic dominant with minor skarn and felsite

11250  Muddy fn ss, vfn ss (VA qz, plag grains); silty mdst; minor epd skarn; bbl bbl felsite.

11350  Similar to 11250: more spotted hornfels, more epd alerat in ss; possible chit grains in ss; VA–SA qz and plag grains.

11450  Same as 11350 w/tr bbl latite.

11500  Bld bbl and Na–plag microphenocrysts in plag lath matrix; minor altered felsite.

11600  Similar to 11350.

11700  Similar to 11250 w/o skarn and felsite; less alerat than 11350 and 11600 but sericite common in matrix.

11800  Same as 11700: VA–SA qz, plag, possible chit grains; minor spotted hornfels.

11850  Similar to 11250–11800; muddy fn ss, vfn ss, silty mdst; VA–SA polyxln qz, minor plag, chit; epd and sericite alterat common; some carb and pyrite.

11890  Same as 11850.

12000  Same as 11850.

12050  Similar to 11850; less ss, more mdst and silty mdst; pyrite.

12100  Same as 11850.

12150  Similar to 11850; muddy ss and mdst about equal; VA–SA polyxln qz w/undul extinct, minor chit; minor spotted hornfels.

12190  Similar to 11850; fresh SR qz w/undul extinct; pyrite, sericite and carb common.

12250  Similar to 11850; minor md st ss (qz, K-feld); epd alerat; VA–SR qz, minor chit grains.

12300  Varied lithologies: 1) abt bbl–K-feld microphenocrysts in feld lath matrix; some K-feld microphenocrysts to 1 mm, large ones w/qz; extensive carb and epd alerat; 2) common ss and mdst as above; 3) minor metaqz and chit appearing cuttings.

12400  Similar to 12300; less ss.

12450  Similar to 11850–12250; silty mdst and vfn ss most abat; tr spotted hornfels.

12520  Similar to but mostly spotted hornfels and silty mdst; tr fresh plag.

12550  Bbl–biot–plag felsite; sml microphenocrysts in plag lath matrix; carb–sericite alterat of feld phenos; minor silty mdst.
27

12570 Same as 12550 w/tr spotted hornfels.
12600 Same as 12550-12570; fresh biot, pale bbl/d to 1.5 mm; some feld and matrix sericitized.
12620 Mdst; silty mdst, muddy fvn-ht ss (VA-SR qz, plag, K-feld, chs?); common sericite.
12650 Same as 12650; epid alter of CRF in fns; minor carb alterat.
12750 1) Same as 12650-12700; 
2) bbl/d felsite similar to 12550 w/sericite/carb alterat.
12800 Hblbd-biot-plag felsite; same as 12750 w/abtn carb alterat.
12840 Same as 12800.
12900 1) Same as 12800 but more alterat;
2) mdst and silty mdst; some wvein qz.
12930 Hblbd-biot-plag felsite (pale bbl/d, some alterat to chl; sericite on Na-plag; anhed equant xln matrix; interstitial qz; minor carb alterat.
13040 Silty brn mdst; argillae fn ss (VA-SA qz, Na-plag, chs?) w/sericite alterat; tr bbl/d-biot felsite; tr spotted hornfels.
13070 Similar to 13040; less mdst, more muddy ss and ndy ss; more felsite.
13100 Muddy fn ss and silty mdst similar to 13040.
13140 1) Altered bbl/d-biot felsite; 
2) mdst and silty mdst;
3) muddy fn ss.
13200 Same as 13140 (#1) but not all as altered.
13240 Mdst, silty mdst, lm mdst, muddy calcar fn ss.
13320 Silty mdst, lm mdst, calcar fn ss (more abtn than in 13240); altered bbl/d felsite common.
13400 Similar to 13320 but vfn ss more abtn and bbl/d-biot-plag felsite fresher; ss grains are VA-SA qz, plag, chs?, VRF?.
13490 Fm-med siliceous ss (poorly sorted, VA-SR polyln qz, plag, K-feld, PRF?, metaqz); pyrite.
13520 Similar to 13490; vfn-ss w/epid alterat and abtn pyrite.
13540 Similar to 13490-13520; fevmed ss plus silty and fn sandy mdst/ah; abtn pyrite.
13590 Similar to 13490-13540 except about 1/3 fresh bbl/d-biot-plag felsite w/abtn pyrite.
13650 Altered mdst/ah; minor silty mdst and vfn ss; spotted hornfels; common carb alterat; tr altered felsite.
13700 Similar to 13490-13590 except less felsite; abtn pyrite.
13750 Similar to 13700 but much more patchy carb alteration.
13800 Approx eqal amts bbl/d-biot-plag felsite and fn calcar ss (VA-SA qz, plag, K-feld); pyrite.
13880 Mostly felsite like 13800; minor ss.
13910 Qz-K-feld felsite; minor bbl/d-plag felsite; minor fn argillae-calar arcokis ss (VA-SA qz, plag).
13960 Calar-argillae fn ss (VA-SA qz), tr two felsites like 13910.
13970 Altered (chl, sericite) bbl/d-biot-plag felsite w/an equant xln matrix; qz and calcite vein frgs; calcite (epid) vfn ss; tr spotted hornfels.
14000 Calar-argillae, poorly sorted, fn ss; arcokis ss; spotted hornfels; tr bbl/d felsite; tr pyrite.
14080 Siliceous and calcar-argillae, poorly sorted, fn ss (VA-SA qz, plag, chs?); tr bbl/d felsite; pyrite.
14100 Mdst and muddy silst; minor argillae-calar fn ss (VA-SA qz, plag, K-feld, chs?).
14140 Hblbd-biot-plag felsite (fresh and some chl alterat and some sericite); tr mdst w/mollusc frag; tr silty mdst.
14190 Mdst; spotted mdst; minor silty mdst; minor carb-qz vein material; sericite and chl alterat.
14240 Similar to 14190 w/o spotted mdst.
14350 Similar: mdst, silty mdst, argillae fn ss (VA-SA qz, plag, K-feld, chs?).
14450 Poorly sorted, argillae fn ss (SA-SR qz, abtn plag, K-feld, chs); few grains to 0.5 mm; muddy vfn ss and sandy mdst; imnr skar; rnd qz w/overgrowthm grants.
14470 Calar-argillae fn-med ss like 14450; poorly sorted SA-WR grains; subarkose-arkose; chl and WR qz (few w/overgrowths, indicate sed source; K-feld and plag indicate plutonic (and vol?) source.
14500 Mdst, silty mdst, muddy silst; minor vfn ss.
14540 /intrusive/ bbl/d-biot-plag felsite w/pyrite; sericitized feld. some chl; minor mdst and silst like 14500.
14560 /intrusive/ similar to 14540 but fresher and coarser fn.
14680 /intrusive/ like 14540-14560.
14720 /intrusive/ qz-K-feld felsite like 13910; pyrite; tr bbl/d-biot-plag felsite.
14840 Varied lithologies: 1) like 14770; 2) mdst and muddy silst; 3) bbl/d-biot-plag felsite.
14930 Similar to 14840 but #3 more abtn.
15000 Silty sh w/abtn pyrite; crs silst w/pyrite (VA-A qz, plag). calcar fn ss w/epid alterat; tr skarn and felsites.
15100 Hblbd-biot-plag-K-feld felsite w/chl, carb, sericite alterat; tr mdst and silst.

Cretaceous

15160 Dk gray silty sh w/forams; tr felsite and calcar silst (qz, plag, chs).
15240 Same as 15160.
15240B Calcarr fn ss (abtn VA-SA plag); calcar silst; silty sh; dk gray calcar sh; tr felsite.
15290 Dk gray calcar sh w/forams: dk gry silty sh.
15350A Siliceous, argillae, and slightly calcar vfn ss (SA-SA-SR qz, tr ch); sandy mdst and lm mdst; tr dk gry fossil sh.
15350B Similar to 15350A plus silty and vfn sandy neospar; ss mostly well strfed.
15370 Neospar, slightly silty and vfn sandy neospar (SA-WR qz); minor dk gry forams sh.
15400 Muddy fn ss, sandy lm mdst, silty lm mdst w/epid alterat; silty neospar; tr dk gry forams sh.
15420 Same as 15400.
15430 Predominantly dk gry forams sh: silty and calcar.
15460 Mostly argillae and calcar fn ss (qz, minor chs) as above; silty neospar; silty forams sh; silty black mdst.
15490 Similar to 15460 w/o sh and mdst.
15550 Mostly argillae, calcar and siliceous (qz overgrowths) vfn, fn and med ss (qz, minor chs), most well sorted; vfn and fn A-SR grains, med K-WR grains; minor silty calcar mdst; tr felsite.
15670 Hblbd-biot-plag felsite (sericite and chl alterat); silty and vfn sandy mdst; minor calcar sils, calcar fn ss.
15700 Similar to 15670: mostly felsite.
15750 Same as 15700; tr forams sh.
15790 Silty mdst and sh; muddy and calcar fn ss w/pyrite.
15850 Hblbd-biot-plag felsite w/chl and carb alterat.
28

15900 Silty sh, muddy vfn ss, argillac vfa ss (A-SR qz); tr foram sh; tr felsite.
15980 Silty sh, calcar crrs silsit, foram sh, silty neospar.
16040 Poorly sorted, argillac, fn ss (SA-WR qz, cht); argillac-silicious fn ss; silty sh, silty neospar, tr foram sh, tr neospar w/bioclast ghosts.
16080 Similar to 16040: fossil sh more abnt and calcar fn ss w/tring plag grains.
16130 Calcar-argillac: fn ss (SA-SR unciulose extinct qz; tr cht; few WR); minor silty mdst and sh; tr plag in muddy crrs silsit.
16140 Felsite like 15850; minor fn ss and silty mdst.
16190 Calcar-argillac vfa-fn ss (SA-SR und ext qz, few WR); minor silty mdst, sh, and neospar; pyrite.
16320 Similar to 16190; silty neospar more abnt.
16350 Similar to 16190; about 1/3 to 1/2 felsite w/carc alterat.
16390 Neomorph wackest w/bioclast ghosts incl ech, mollusc; minor calcar vfn ss, sandy neospar and sandy mdst and sh.
16450 Similar to 16390; (foram, ech, mollusc); dk gry-Black sandy mdst and sh w/ech and foram frags.
16500 1) Dk gry vfn sandy mdst w/bioclasts; 2) neomorph wackest similar to 16390-16450, incl peloids; 3) lens of muddy calcar silsit.
16520 1) Silty neomorph wackest w/peloids and bioclasts; 2) calcar vfn ss (SA-SR qz, minor cht), poorly sorted; 3) silicious fn ss (SA-R qz), moderate sorted.
16570 Crrs silty neospar (VA-SR qz, tr cht); calcar silsit.
16600 Same as 16570; tr of bioclasts.
16660 Similar to 16570-16600 w/about 1/3 calcar vfn ss (VA-SR qz, tr cht), poorly sorted.
16700 Calcar dk brn crrs silsit (VA-SR qz, tr cht & CRF), poor sort; silty neospar; tr bioclass; one cutting w/intradasts and silt.
16730 Bra silty mdst; silty and vfn sandy neospar (one cutting w/med sand size silsit grains; few argilac crrs silsit.
16780 Hblrd-biot-K-feld felsite (sericitized K-feld, fresh biot); few cuttings like 16730.
16810 Felsite like 16780 and silty mdst and neospar like 16730, approx equal amts.
16840 Similar to 16730.

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Permian

16900 Calcar vfn ss; silty neospar; neomorph wackest (Tubitina forans, ech, spines, bryoz, brach frags); silty sh.
16950 Felesite w/carr and ech alterat, like 16780; calcar vfn ss; silty calcar mdst; neospar.
16990 Neomorph lm mdst, wackest (foram, ech, spines, tril); minor silty lm rdst, cht.
17050 Same as 16900.
17110 Felesite w/carr and ech alterat; minor same as 16990-17050.
17150 Same as 17110; mostly felesite w/excel cht, tr neomorph wackest (bryoz, ech, brach, foram).
17200 Neomorph lm mdst and wackest like tr in 17150; minor cht repl of carb; tr dk gry fossil sh; tr felsite.
17250 Calcar crrs silsit, silty mdst and sh, neomorph silty lm mdst and wackest (Tubitina, foram, ech).
17310 Neomorph lm mdst and minor wackest (foram frags).
17360 Med dk gry neomorph wackest (forams, ost, ech, brach, spines, bryoz); lm mdst; tr bl sh.
17420 Similar to 17360.
17460 Similar to 17360-17420.
17510 Similar to 17360-17460.
17560 Similar to 17360-17510: (bryoz, endothyrid).
17610 Similar to 17360-17560: (ost, foram, ech, bryoz): minor felesite but more than others below 17200.
17660 Similar to 17360-17610: more neomorph lm mdst, less wacket.
17710 Similar to 17360-17710: more bryoz, ech, bryoz, ost, brach spines).
17760 Similar to 17360-17710: bi sh more abnt, coral frag.
17810 Similar to 17360-17810: more dk gry-bl lm mdst and sh w/bioclasts (forams, ech, ost, brach spines & valve frags).
17860 Similar to 17810.
17910 Similar to 17810-17860.
17960 Similar to 17810-17910: mostly dk gry-bl lm mdst and sh (forams, bryoz, brach, mollusc, ech, ost).
18000 Similar to 17810-17960: w/silty sh and calcar crrs silsit.
18050 Similar to 17810-17960: w/minor silicious fn ss and felesite (case?).
18100 Similar to 17810-17960: probable phylloid algae.
18150 Similar w/packet more common (abnt various forams, ech); silty lm mdst.
18200 Similar to 18150: dk gry packet, lm mdst, sh, silty lm mdst, calcar crrs silsit; (forams, tril, ech, brach).
18210 Similar tp 18200: less silt.
### Selected conversion factors*

<table>
<thead>
<tr>
<th>TO CONVERT</th>
<th>MULTIPLY BY</th>
<th>TO OBTAIN</th>
<th>TO CONVERT</th>
<th>MULTIPLY BY</th>
<th>TO OBTAIN</th>
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*Divide by the factor number to reverse conversions.
Exponents: for example $4.047 \times 10^7$ (see acres) = 4,047; $9.29 \times 10^{-2}$ (see ft$^3$) = 0.0929.