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

Russell E. Clemons

CIRCULAR 203 New Mexico Bureau of Mines & Mineral Resources 1993

A DIVISION OF
NEW MEXICO INSTITUTE OF MINING & TECHNOLOGY

Circular 203

New Mexico Bureau of Mines & Mineral Resources

A DIVISION OF
NEW MEXICO INSTITUTE OF MINING & TECHNOLOGY

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

Russell E. Clemons

Department of Geological Sciences, New Mexico State University
Las Cruces, New Mexico 88003

SOCORRO 1993

Original Printing

Published by Authority of State of New Mexico, NMSA 1953 Sec. 63–1–4
Printed by University of New Mexico Printing Services, November 1993

Available from New Mexico Bureau of Mines & Mineral Resources, Socorro, NM 87801

Contents

Figures

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, skarn, hornfels, and felsites. The Cretaceous section is underlain by 1332 ft of fossiliferous shales, silty-lime mudstones, wackestones, packstones, and minor siltstones and sandstones correlative with the Lower Permian Hueco Formation.

Oligocene ash-flow tuffs and rhyolitic volcaniclastics, 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. Sun-land 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.

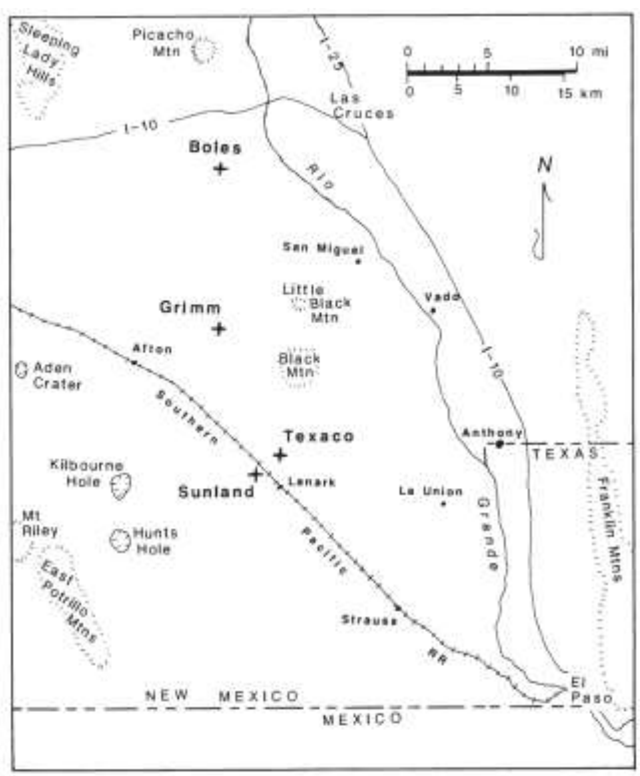

FIGURE 1—Index map of well locations in south-central Doña Ana County.

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-tilted fault block 18 mi east of the well sites; the East Potrillo Mountains are a southwest-tilted fault block 14-20 mi southwest of the well sites; the Robledo Mountains are a south-tilted 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

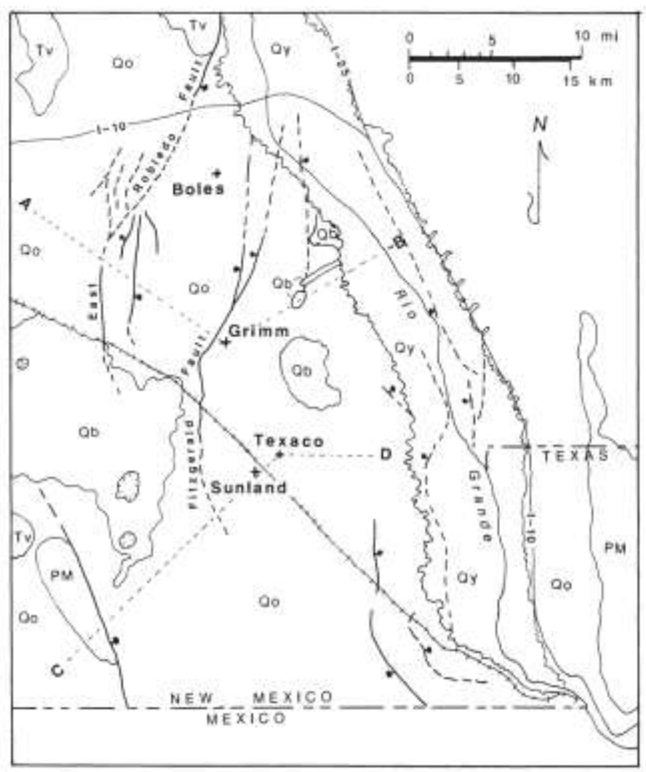

FIGURE 2—Generalized geologic map of south-central Doña Ana County. PM, Paleozoic–Mesozoic rocks; Tv, Tertiary volcanic rocks; Qb, Quaternary basalt; Qo, older Quaternary sediments; Qy, younger Quaternary sediments.

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 silty 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 silty 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 silty 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).

Petrography

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,

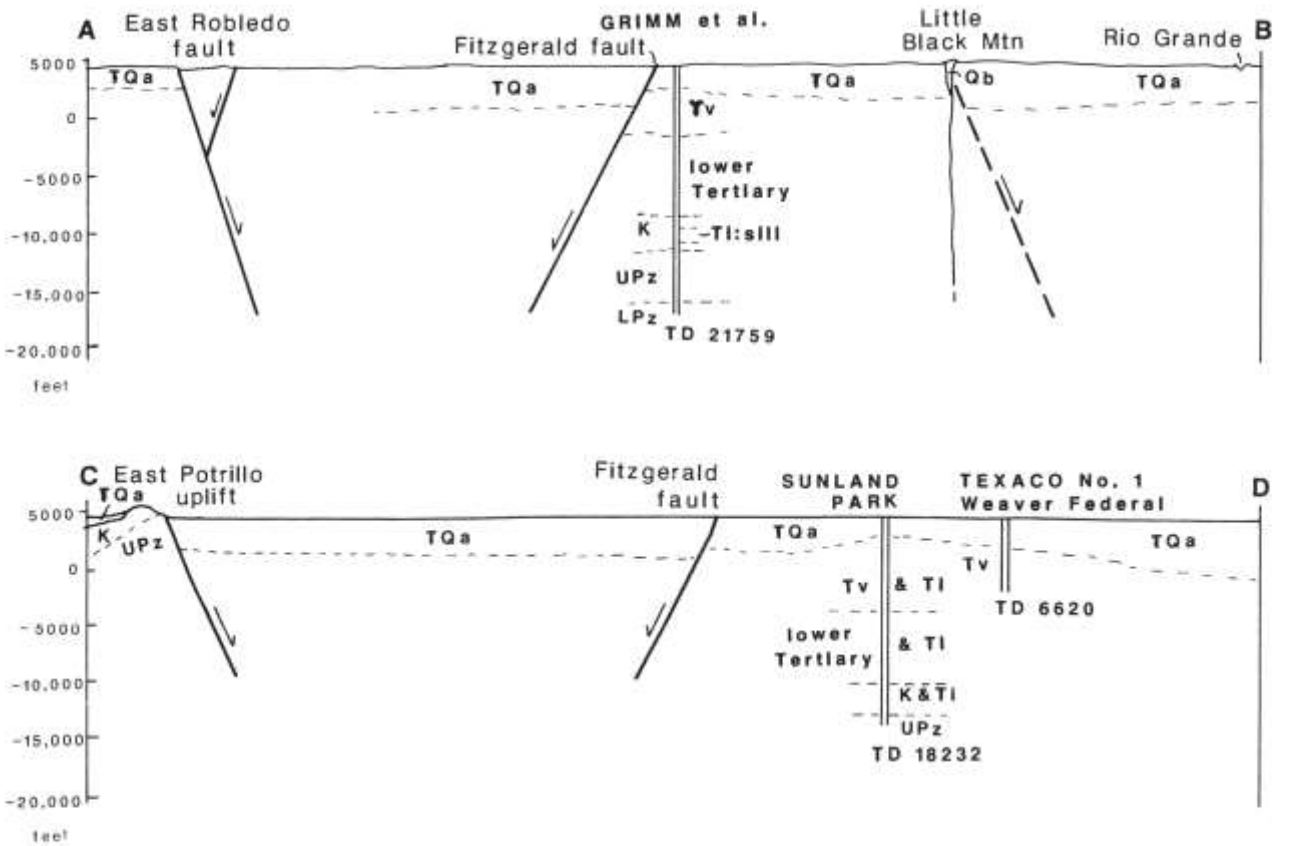

FIGURE 3—Locations of cross sections in the Potrillo basin shown in Fig. 2, showing relations of Grimm and Sunland Park wells. Modified from Seager et al. (1987).

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) increases 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 lime stones 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,

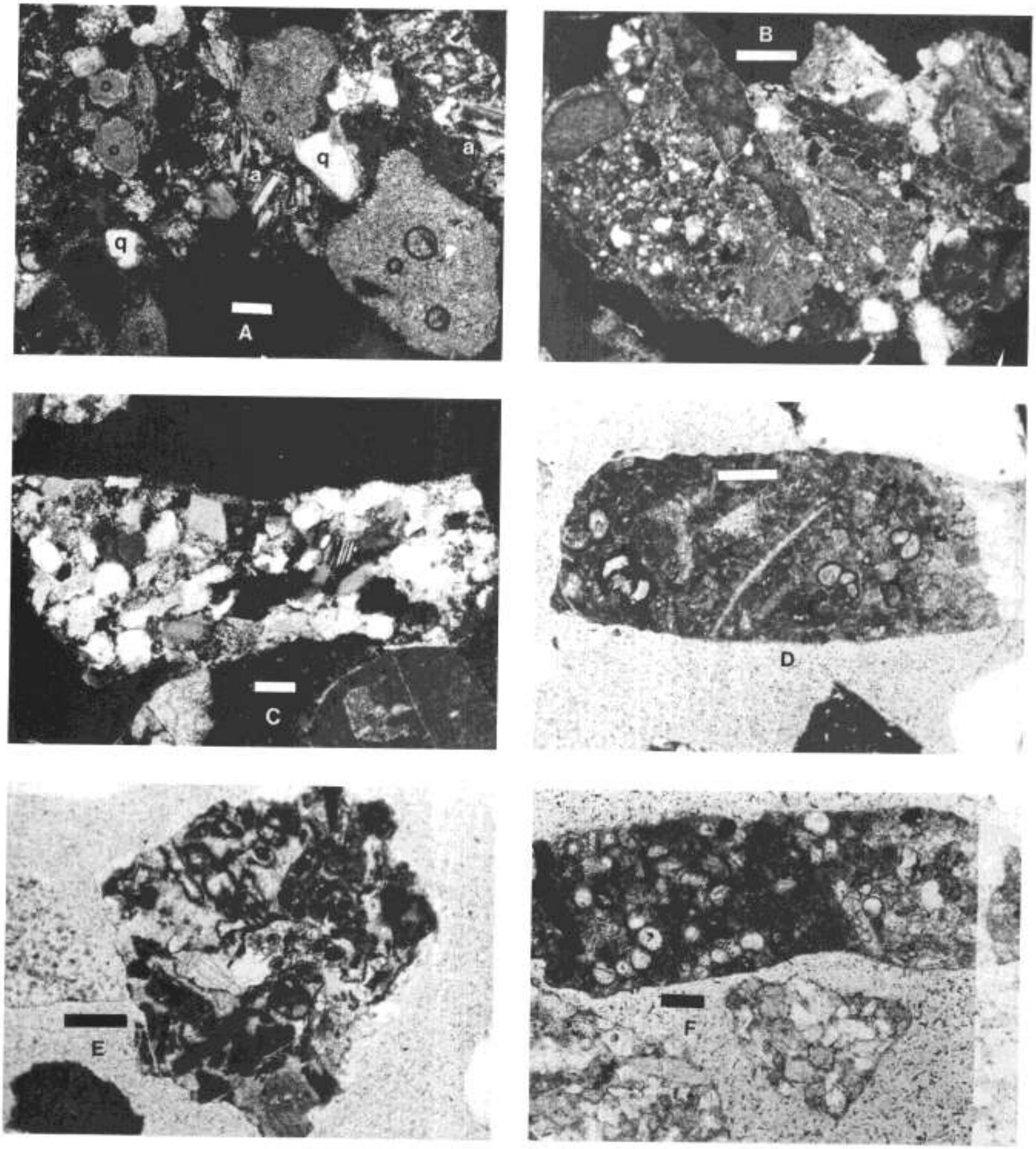

FIGURE 4—Photomicrographs of Grimm et al. well cuttings correlative with Love Ranch/Lobo Formations. **A**, Brown mudstone grains (under dark air bubbles), andesite (a) and quartz (q); 7600 ft; crossed nicols; bar = 0.1 mm. **B**, Elongate mudstone grains in silty mudstone matrix with quartz, chert, 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 foram 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.

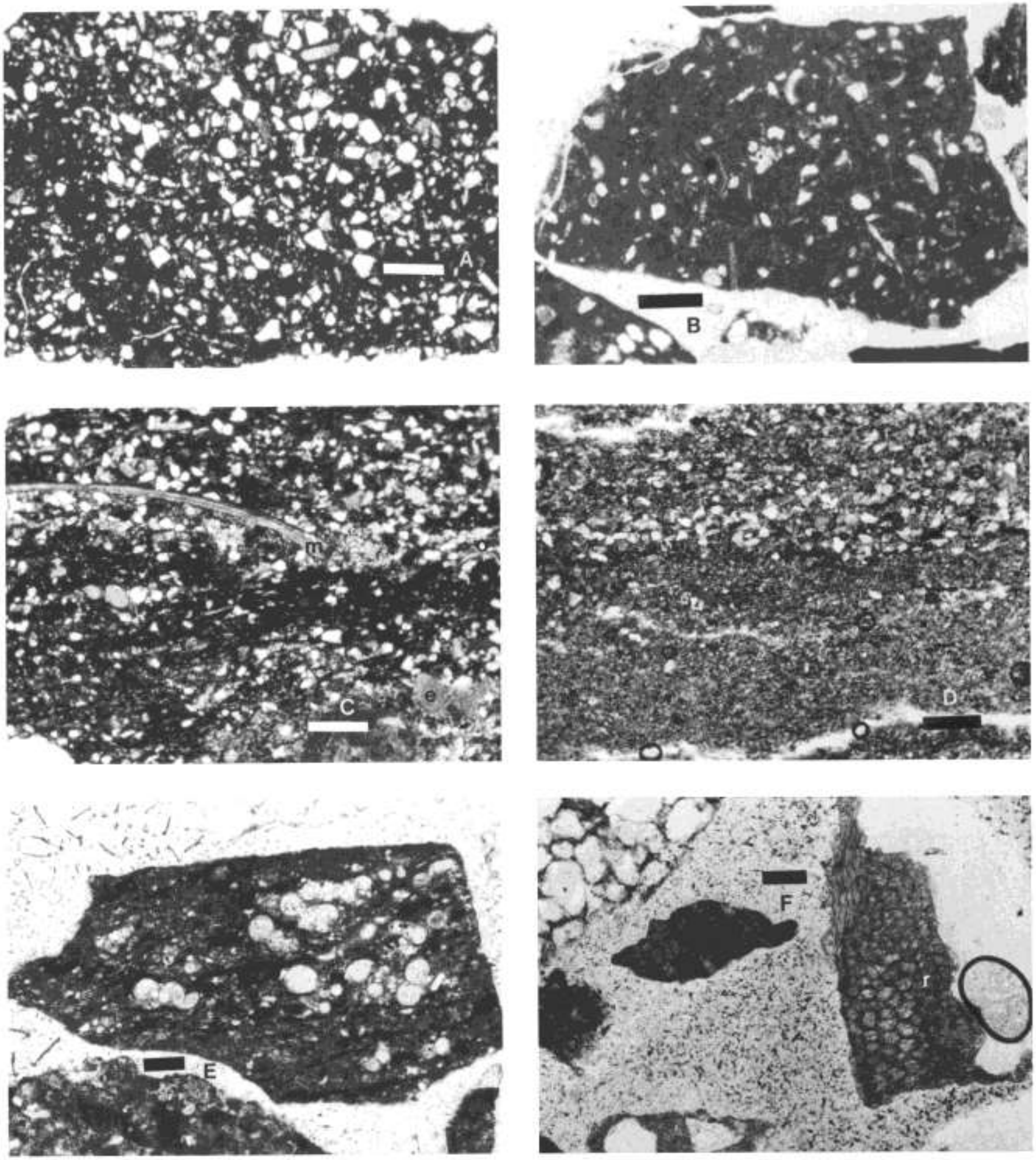

FIGURE 5—Photomicrographs of Grimm et al. well cuttings correlative with U-Bar and Hell-to-Finish Formations. **A**, Muddy, dark-brown, very fine-grained sandstone with well rounded to subangular quartz; 15,140 ft; plane polarized light; bar = 0.5 mm. **B**, Very fine sandy wackestone with neomorphosed 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 silty, 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; 14,060 ft; plane polarized light; bar = 0.1 mm.

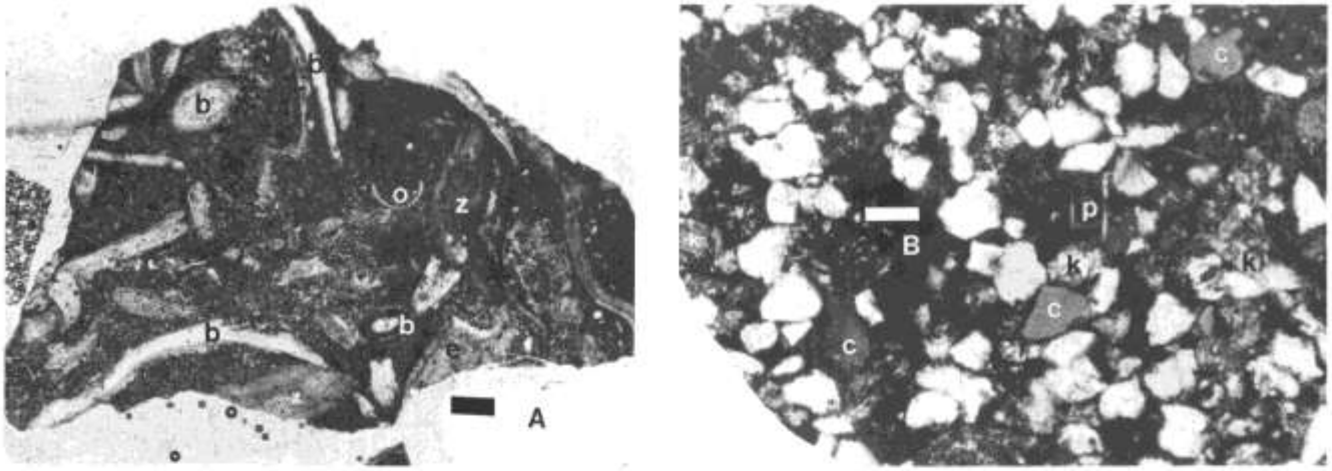

FIGURE 6—Photomicrographs of Grimm et al. well cuttings correlative with Hueco Formation. A, Neomorphosed packstone with brachiopod (b), echinoderm (e), ostracode (o), and bryozoan (z) fragments; 15,270 ft; plane polarized light; bar = 1 mm. B, Very fine-grained calcareous sandstone with quartz, plagioclase (p), K-feldspar (k), and carbonate-rock (c) fragments; 15,270 ft; crossed nicols; 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 ostracode 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 Bieber-man (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 basin-fill 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.

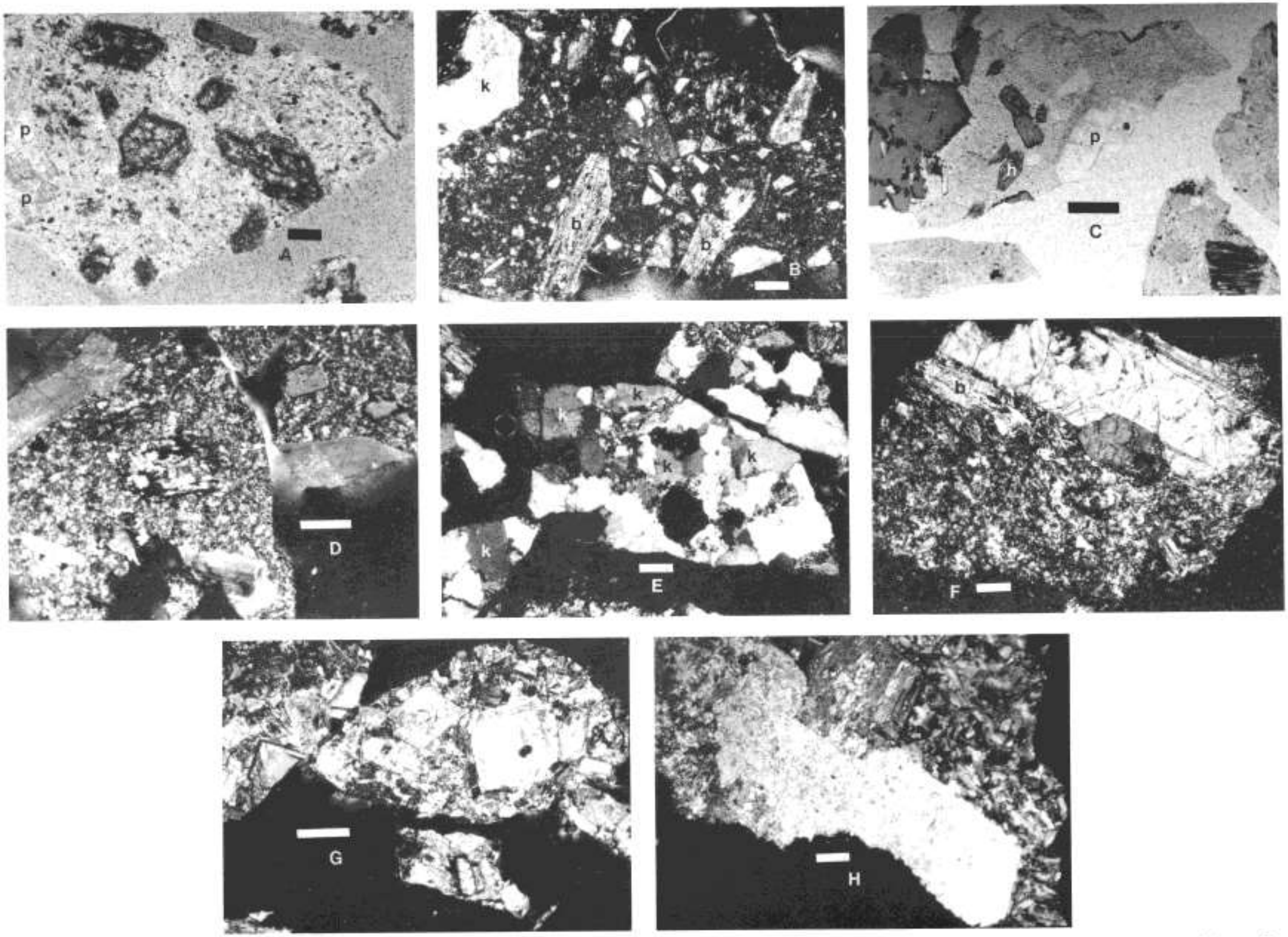

FIGURE 7—Photomicrographs of felsite cuttings from Sunland Park well. **A**, Altered hornblende–biotite–plagioclase (p) intrusive; 1810 ft; plane polarized light; bar = 0.1 mm. **B**, Sericitized and partly chloritized latite K-feldspar (k) and fresh biotite (b); 5470 ft; crossed nicols; bar = 0.1 mm. **C**, Biotite (oxidized rims), 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; 13,910 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.

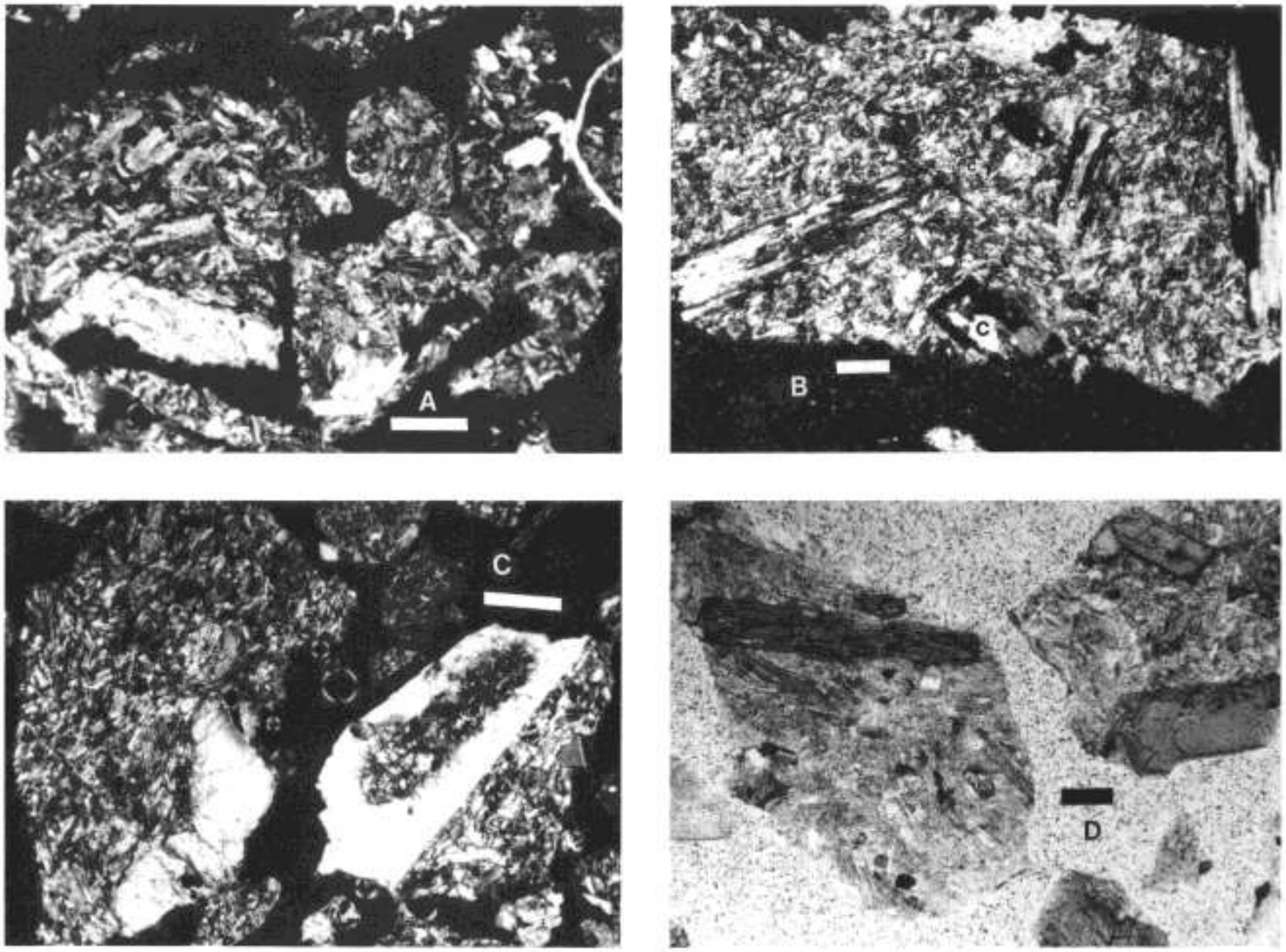

FIGURE 8—Photomicrographs of hornblende-andesite cuttings from Sunland Park well. **A**, Hornblende andesite; 8770 ft; crossed nicols; bar = 0.2 mm. **B**, Elongate chloritized biotite and carbonate-replaced hornblende microphenocrysts (c); 9200 ft; crossed nicols; bar = 0.1 mm. **C**, Altered hornblende inclusion in plagioclase phenocryst; 11,500 ft; crossed nicols; bar = 0.2 mm. **D**, Chloritized hornblende in left cutting and fresh hornblende in right cutting; 11,500 ft; plane polarized light; 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

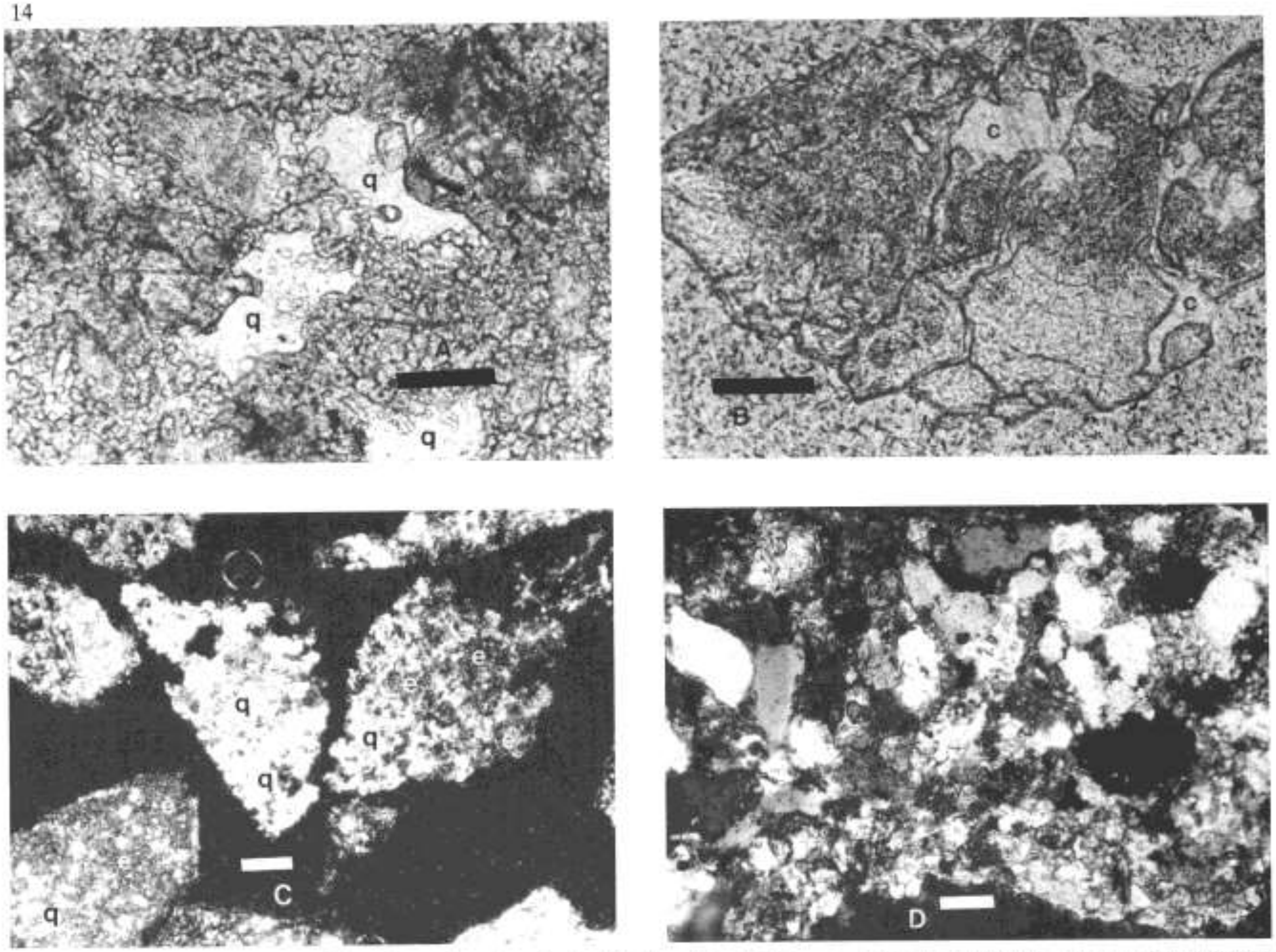

FIGURE 9—Photomicrographs of skarn in cuttings from Sunland Park well. **A**, Epidote–quartz (q) skarn; 8030 ft; plane polarized light; bar = 0.1 mm. **B**, Single cutting of garnet-carbonate (c) skarn; 9500 ft; plane polarized light; bar = 0.1 mm. **C**, Epidote (e) and quartz (q) skarn; originally 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.

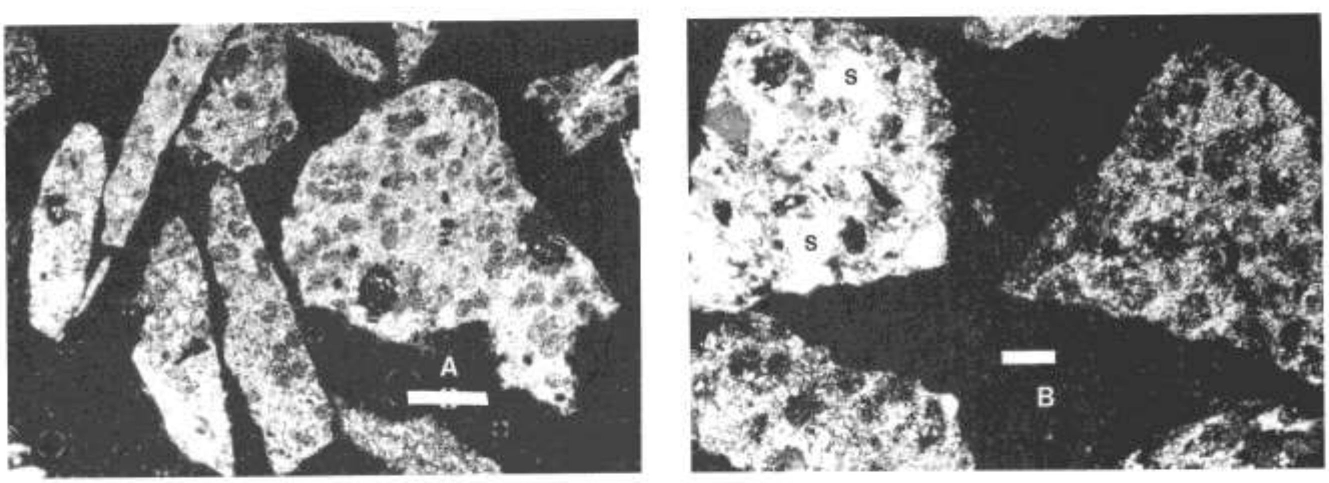

FIGURE 10—Photomicrographs of spotted hornfels in cuttings from Sunland Park well. **A**, Small, dark, circular areas are probably andalusite; 11,050 ft; crossed nicols; bar = 0.2 mm. **B**, Spotted hornfels and epidotized, calcareous, very fine-grained sandstone (s); 11,050 ft; crossed nicols; bar = 0.1 mm.

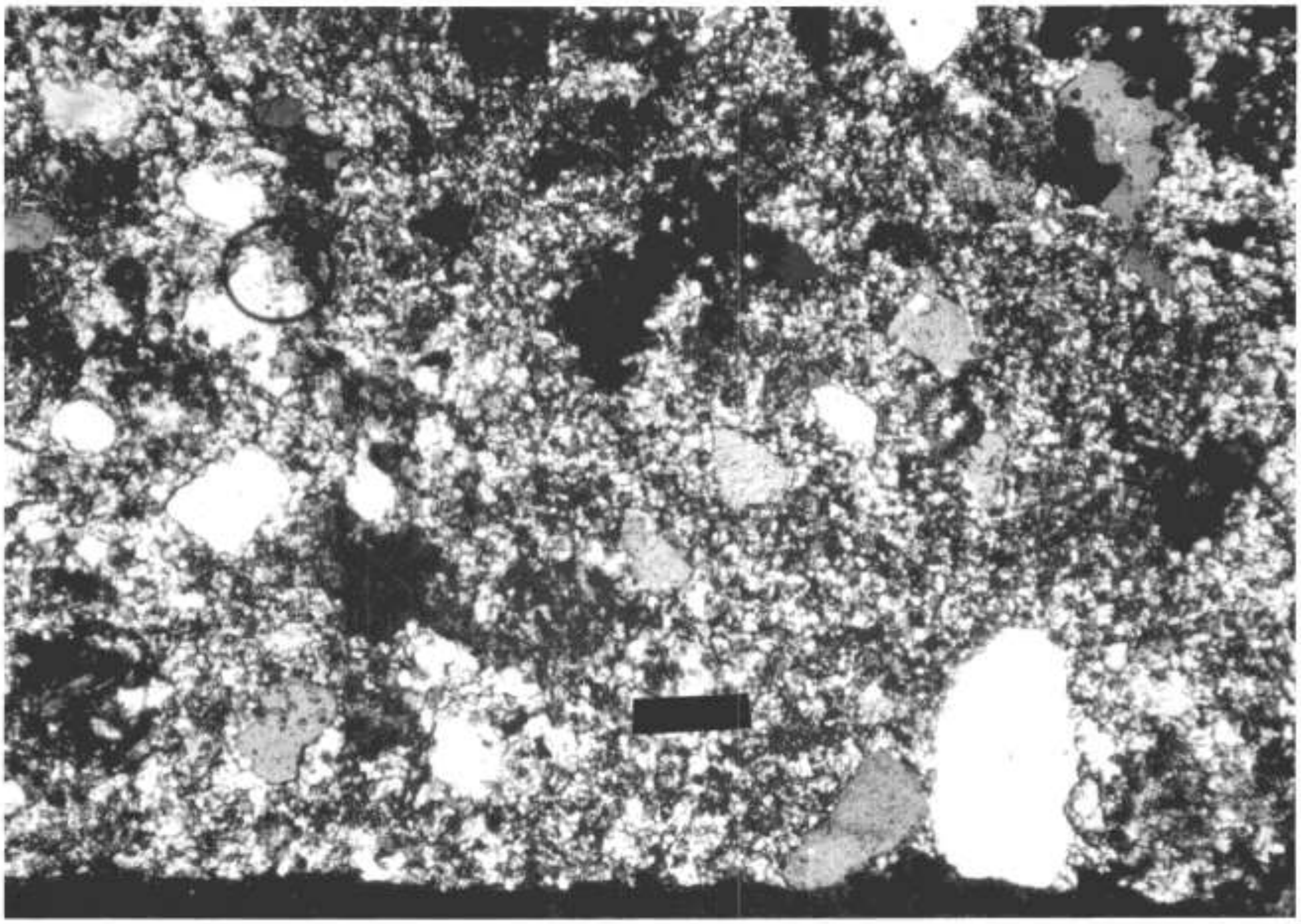

FIGURE 11—Photomicrograph of epidotized fine sandy calcareous mudstone in Sunland Park well. 8030 ft; crossed nicols; bar = 0.1 mm.

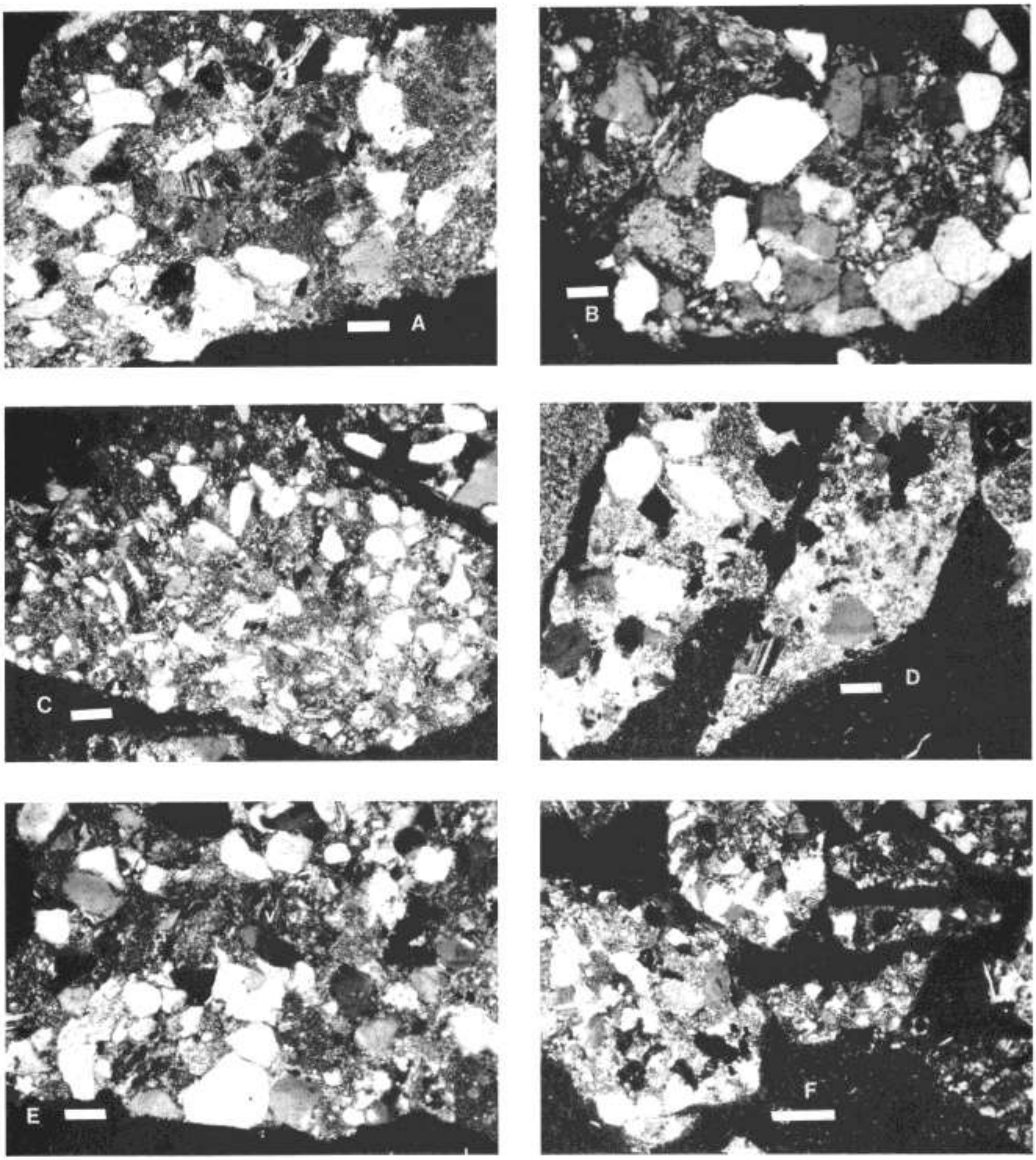

FIGURE 12—Photomicrographs of sandstones in Sunland Park well. **A**, Calcareous medium-grained arkosic sandstone with quartz, plagioclase, and K-feldspar grains; 13,070 ft; crossed nicols; bar = 0.1 mm. **B**, Siliceous medium-grained arkosic sandstone with quartz, plagioclase, chert, and K-feldspar 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 arkosic sandstone with quartz, plagioclase, chert and volcanic-rock (v) grains; 14,450 ft; crossed nicols; bar = 0.1 mm. **F**, Siliceous medium-grained arkosic sandstone; 14,720 ft; crossed nicols; bar = 0.2 mm.

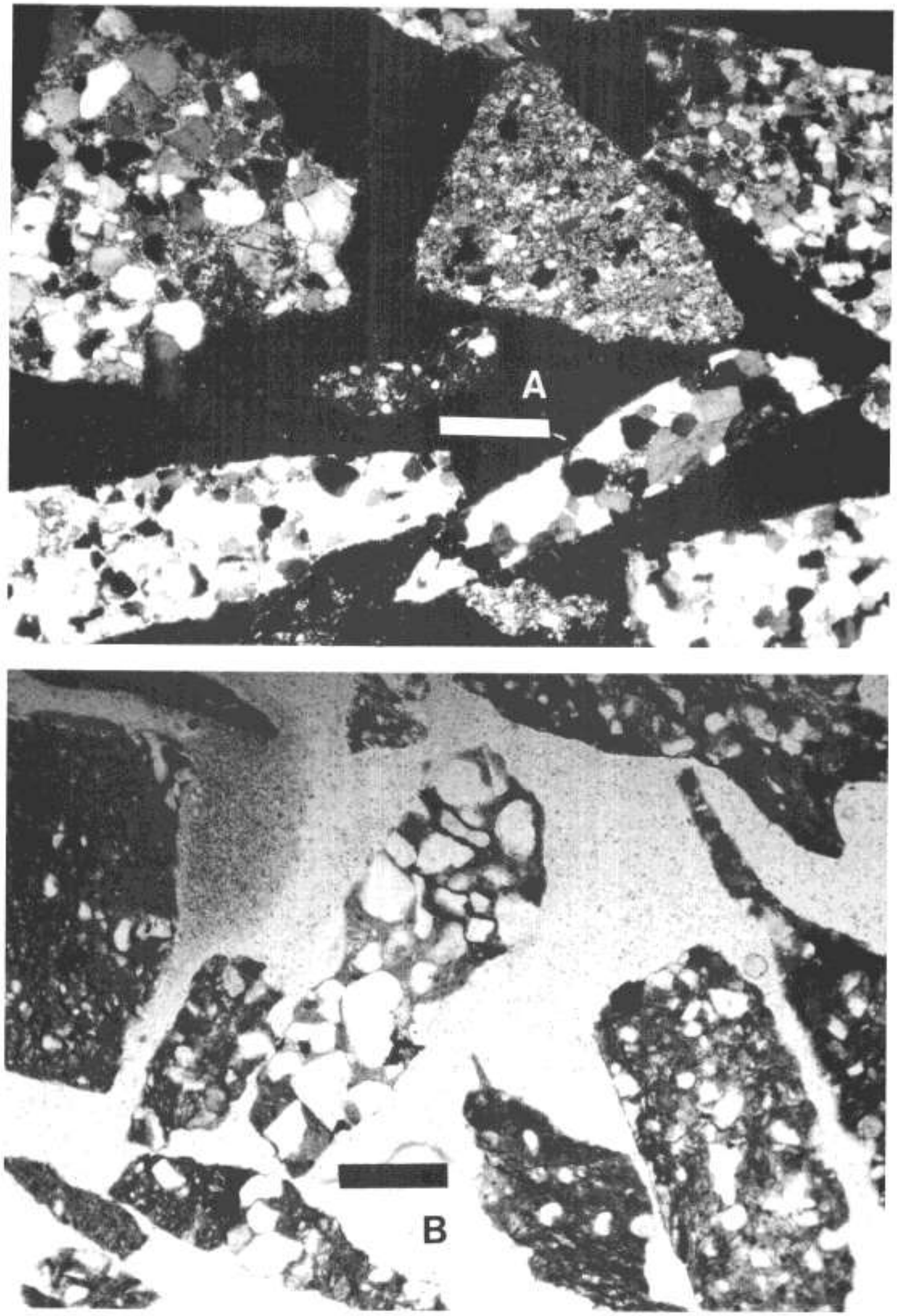

FIGURE 13—Photomicrographs of various sandstones, silty mudstones, and shales in Sunland Park well. **A**, 15,350 ft; crossed nicols; bar = 0.2 mm. **B**, 16,080 ft; plane polarized light; bar = 0.2 mm.

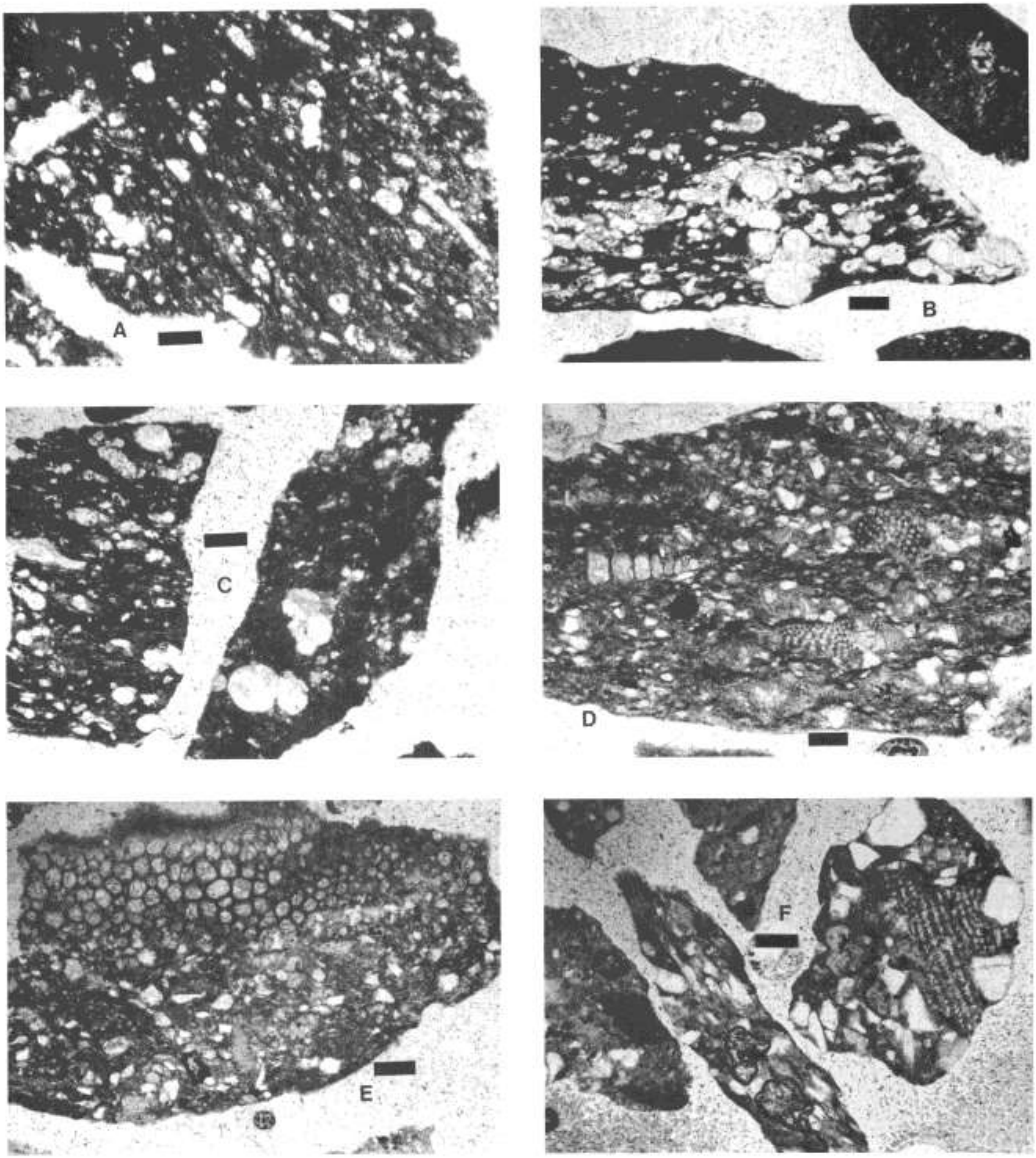

FIGURE 14—Photomicrographs of Cretaceous forams in shales and sandy mudstones in Sunland Park well. **A**, Globigerinid and biserial forams; 15,160 ft; plane polarized light; bar = 0.1 mm. **B** and **C**, Globigerinids; 15,290 ft; plane polarized light; bar = 0.1 mm. **D**, Various forams in silty shale; 15,980 ft; plane polarized light; bar = 0.1 mm. **E**, Unidentified bioclast in silty mudstone; 15,980 ft; plane polarized light; bar = 0.1 mm. **F**, Foram in sandy mudstone; 16,080 ft; plane polarized light; bar = 0.1 mm.

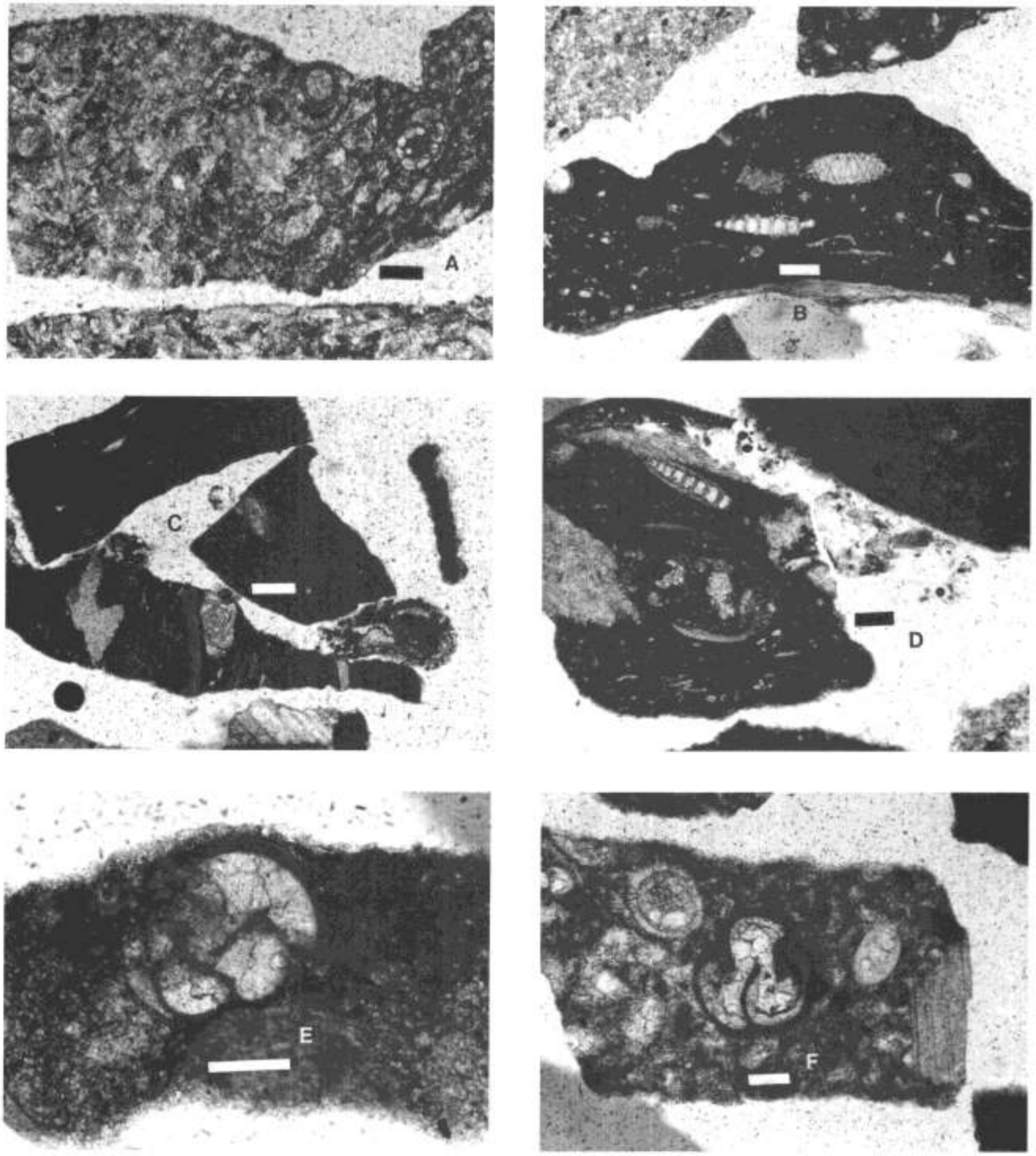

FIGURE 15—Photomicrographs of Permian forams in shales and mudstones from the Sunland Park well. **A**, 17,560 ft; plane polarized light; bar = 0.1 mm. **B**, 17,760 ft; plane polarized light; bar = 0.1 mm. **C**, 17,810 ft; plane polarized light; bar = 0.1 mm. **D**, 17,910 ft; plane polarized light; 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.

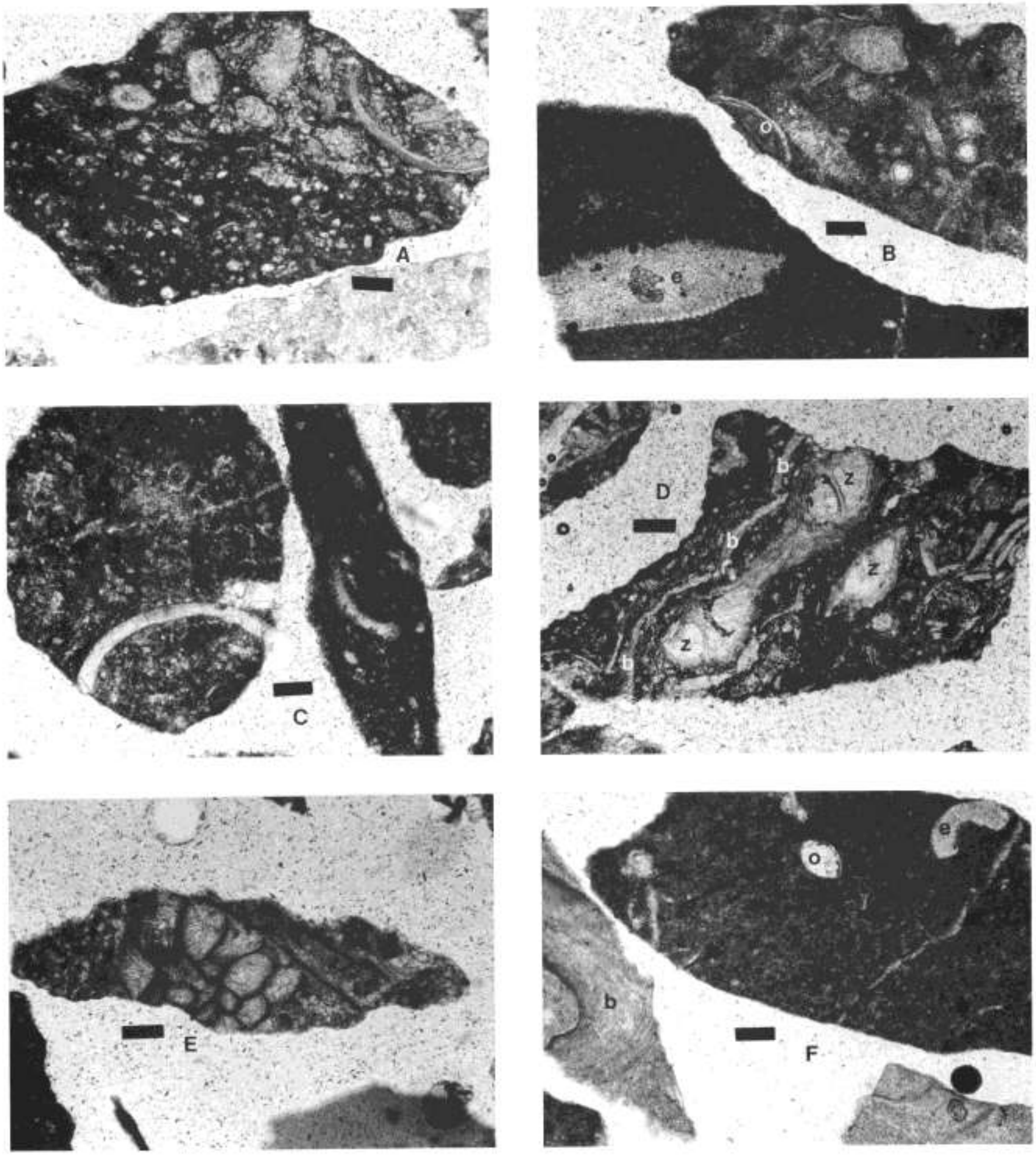

FIGURE 16—Photomicrographs of Permian bioclasts in Sunland Park well. **A**, Ostracode valve and neomorphosed bioclasts; 17,360 ft; plane polarized light; bar = 0.1 mm. **B**, Echinoderm fragment in lime mudstone (e), ostracode valve (o), and neomorphosed bioclasts in wackestone; 17,360 ft; plane polarized 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 (z) 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.

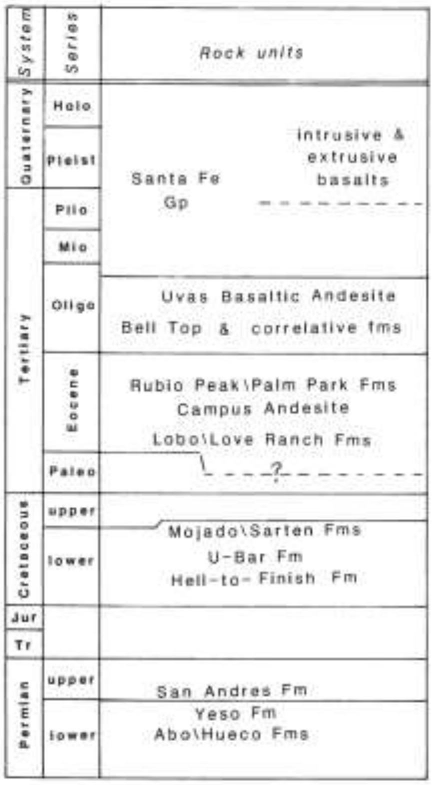

FIGURE 17—Stratigraphic chart of Cenozoic–Mesozoic–Permian rocks exposed in southern Doña Ana County.

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 volcaniclastics, 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 Potrillo Mountains by Seager and Mack (in press).

5. The 640 ft thick monzonite sill penetrated by the Grimm well is probably correlative 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 rocks overlie the Lower Permian Hueco Formation, similar to the Hueco exposed in East Potrillo, Franklin, and Robledo Mountains.

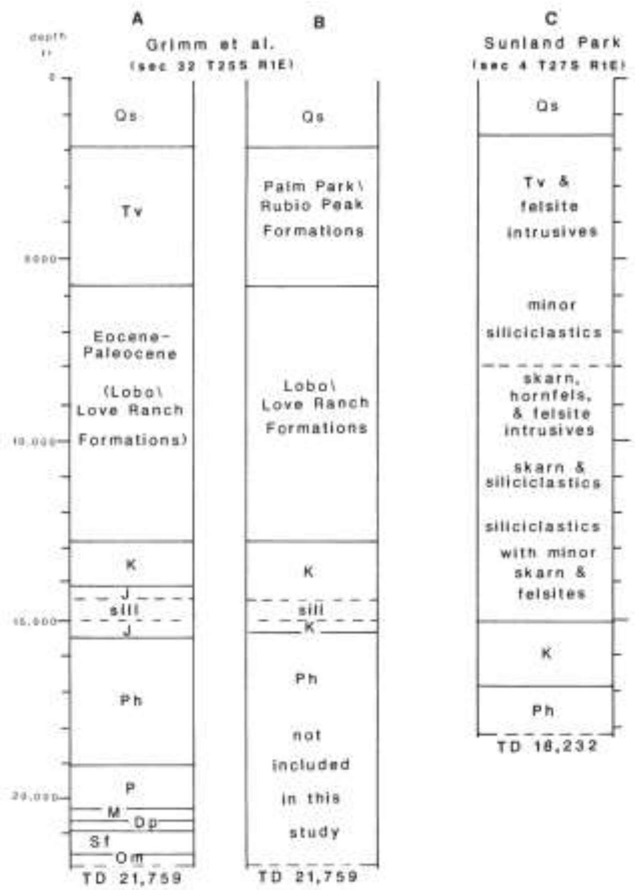

FIGURE 18—Correlation of rock units penetrated in the Grimm and Sunland Park wells with rock units mapped in Doña Ana County. Explanation: Om, Montoya Formation; Sf, Fusselman Dolomite; Dp, Percha Shale; M, Mississippian; P, Pennsylvanian; Ph, Hueco Formation; J, Jurassic; Ku, U-Bar/Hell-to-Finish Formations; Tv, Oligocene volcanics; Qs, basin-fill sediments. **A** is combined from Thompson and Bieberman (1975), Thompson (1982), and Uphoff (1978); **B** and **C** are interpretations of this study.

Acknowledgments

I thank Frank Kottlowski, Charles Chapin, and the New Mexico Bureau of Mines & Mineral Resources for financial support to do the petrographic analyses and for access to the well cuttings. I am also grateful to Phillips Petroleum Co. for providing the petrographic thin sections of cuttings from the Sunland Park well. Discussions with Sam Thompson aided in organizing and completing the project. Reviews by Steve Cather and Greg Mack substantially improved the manuscript.

References

Bordine, B. W., Robertson, E. B., and Young, C. R., 1986, Biostratigraphy and petroleum source-rock potential, Phillips Petroleum Co. No. 1 Sunland Park well, Doña Ana County, New Mexico: New Mexico Bureau of Mines & Mineral Resources, Open-File Report OF-327, 18 pp.

Chapin, C. E., and Seager, W. R., 1975, Evolution of the Rio Grande rift in the Socorro and Las Cruces areas: New Mexico Geological Society, Guidebook 26, pp. 297-321.

Clemons, R. E., 1976a, Sierra de las Uvas ash-flow field, south-central New Mexico; *in* Woodward, L. A., and Northrop, S. A. (eds.), Tectonics and Mineral Resources of Southwestern North America: New Mexico Geological Society, Special Publication 6, pp. 115-121.

Clemons, R. E., 1976b, Geology of east half Corralitos Ranch quadrangle, New Mexico: New Mexico Bureau of Mines & Mineral Resources, Geologic Map 36, scale 1:24,000.

Clemons, R. E., 1977, Geology of west half Corralitos Ranch quadrangle, New Mexico: New Mexico Bureau of Mines & Mineral Resources, Geologic Map 44, scale 1:24,000.

Clemons, R. E., 1979, Geology of Good Sight Mountains and Uvas Valley, southwest New Mexico: New Mexico Bureau of Mines & Mineral Resources, Circular 169, 32 pp.

Cordoba, D. A., 1969, Mesozoic stratigraphy of northeastern Chihuahua, Mexico: New Mexico Geological Society, Guidebook 20, pp. 91-96.

Dunham, K. C., 1935, The geology of the Organ Mountains: New Mexico Bureau of Mines & Mineral Resources, Bulletin 11, 272 pp.

Gile, L. H., 1987, A pedogenic chronology for Kilbourne Hole, southern New Mexico—II. Time of the explosions and soil events before the explosions: Soil Society of America Journal, v. 51, pp. 746-760.

Harbour, R. L., 1972, Geology of the northern Franklin Mountains, Texas and New Mexico: U.S. Geological Survey, Bulletin 1298, 129 pp.

Hawley, J. W., and Kottlowski, F. E., 1969, Quaternary geology of the south-central New Mexico border region; *in* Kottlowski, F. E., and LeMone, D. V. (eds.), Border Stratigraphy Symposium: New Mexico Bureau of Mines & Mineral Resources, Circular 104, pp. 89-115.

Hoffer, J. M., 1976, Geology of Potrillo basalt field, south-central New Mexico: New Mexico Bureau of Mines & Mineral Resources, Circular 149, 30 pp.

King, W. E., Hawley, J. W., Taylor, A. M., and Wilson, R. P., 1971, Geology and groundwater resources of central and western Doña Ana County, New Mexico: New Mexico Bureau of Mines & Mineral Resources, Hydrologic Report 1, 64 pp.

Kottlowski, F. E., 1960, Reconnaissance geologic map of Las Cruces thirty-minute quadrangle: New Mexico Bureau of Mines & Mineral Resources, Geologic Map 14, scale 1:126,720.

Kottlowski, F. E., Foster, R. W., and Wengerd, S. A., 1969, Key oil tests and stratigraphic sections in southwest New Mexico: New Mexico Geologic Society, Guidebook 20, pp. 186-196.

Lawton, T. F., McMillan, N. J., and Cameron K. L., 1993, Late Jurassic extension in the Bisbee Basin: Marine and volcanic strata of the Chiricahua Mountains, Arizona (abs.): Geological Society of America, Abstracts with Programs, v. 25, no. 5, p. 68.

Lucas, S. G., Basabilvazo, G., and Lawton, T. F., 1990, Late Cretaceous dinosaurs from the Ringbone Formation, southwestern New Mexico, U.S.A.: Cretaceous Research, v. II, pp. 343-349.

Mack, G. H., and Clemons, R. E., 1988, Structural and stratigraphic evidence for the Laramide (early Tertiary) Burro uplift in southwestern New Mexico: New Mexico Geological Society, Guidebook 39, pp. 59-66.

Mack, G. H., 1986, Lower Cretaceous stratigraphy and depositional environments in the East Potrillo Mountains and adjacent areas of southwestern New Mexico: El Paso Geological Society Guidebook, pp. 85-94.

Mack, G. H., and James, W. C., 1986, Cyclic sedimentation in the mixed siliciclastic–carbonate Abo–Hueco transitional zone (Lower Permian), southwestern New Mexico: Journal of Sedimentary Petrology, v. 56, pp. 635-647.

McIntosh, W. C., Kedzie, L. L., and Sutter, J. F., 1991, Paleomagnetism and $^{40}Ar/^{39}Ar$ ages of ignimbrites, Mogollon–Datil volcanic field, southwestern New Mexico: New Mexico Bureau of Mines & Mineral Resources, Bulletin 135, 79 pp.

New Mexico Geological Society, 1982, New Mexico highway geologic map: New Mexico Geological Society, scale 1:1,000,000.

Seager, W. R., 1975, Cenozoic tectonic evolution of the Las Cruces area, New Mexico: New Mexico Geological Society, Guidebook 26, pp. 241-250.

Seager, W. R., 1981, Geology of Organ Mountains and southern San Andres Mountains, New Mexico: New Mexico Bureau of Mines & Mineral Resources, Memoir 36, 97 pp.

Seager, W. R., 1987, Caldera-like collapse at Kilbourne Hole maar, New Mexico: New Mexico Geology, v. 9, pp. 69-73.

Seager, W. R., in press, Geology of southwest Las Cruces and northwest El Paso 1°x 2° sheets, New Mexico: New Mexico Bureau of Mines & Mineral Resources, Geologic Map 62, scale 1:125,000.

Seager, W. R., and Clemons, R. E., 1975, Middle to late Tertiary geology of Cedar Hills–Selden Hills area, New Mexico: New Mexico Bureau of Mines & Mineral Resources, Circular 133, 24 pp.

Seager, W. R., and Mack, G. H., 1986, Summary of geology of East Potrillo Mountains area: El Paso Geological Society Guidebook, pp. 158-159.

Seager, W. R., and Mack, G. H., 1987, Laramide paleotectonics of southern New Mexico: American Association of Petroleum Geologists, Memoir 44, pp. 669-685.

Seager, W. R., and Mack, G. H., in press, Geology of East Potrillo Mountains, and vicinity, Doña Ana County, New Mexico: New Mexico Bureau of Mines & Mineral Resources, Bulletin.

Seager, W. R., Hawley, J. W., Kottlowski, F. E., and Kelley, S. A., 1987, Geology of east half of Las Cruces and northeast El Paso 1°x 2° sheets, New Mexico; New Mexico Bureau of Mines & Mineral Resources, Geologic Map 57, scale 1:125,000.

Seager, W. R., Mack, G. H., Raimonde, M. S., and Ryan, R. G., 1986, Laramide basement-cored uplift and basins in south-central New Mexico: New Mexico Geological Society, Guidebook 37, pp. 123-130.

Seager, W. R., Shafiqullah, M., Hawley, J. W., and Marvin, R. F., 1984, New K–Ar dates from basalts and the evolution of the southern Rio Grande rift: Geological Society of America, Bulletin, v. 95, pp. 87-99.

Thompson, Sam, III, 1982, Oil and gas wells in southwestern New Mexico; *in* Drewes, H. (ed.), Cordilleran Overthrust Belt, Texas to Arizona Field Conference: Rocky Mountain Association of Geologists, pp. 137-153.

Thompson, Sam, III, and Bieberman, R. A., 1975, Oil and gas exploration wells in Doña Ana County, New Mexico: New Mexico Geological Society, Guidebook 26, pp. 171-174.

Uphoff, T. L., 1978, Subsurface stratigraphy and structure of the Mesilla and Hueco bolsons, El Paso region, Texas and New Mexico: unpublished M.S. thesis, University of Texas at El Paso, 66 pp.

Woods, T. F., 1987, Processing and interpretation of CDP, VSP and sonic log data acquired in the Rio Grande rift, Doña Ana County, New Mexico: unpublished M.S. thesis, University of Wyoming, Laramie, 236 pp.

Woodward, La. A., Callender, J. F., Gries, J., Seager, W. R., Chapin, C. E., Zilinski, R. E., and Shaffer, W. L., 1975, Tectonic map of Rio Grande region from New Mexico–Colorado border to Presidio, Texas: New Mexico Geological Society, Guidebook 26, p. 239.

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

2210 Fresh, strongly oscillatory zoned plag phenocrysts, biot, some oxidiz hbld, minor carb repl.
2500 Few like 2210; majority more altered w/abnt oxidiz hbld and less biot, w/zoned plag phenocrysts; equigran matrix and minor patchy carb.
3360 Plag–hbld–biot microphenocrysts; intersertal matrix; patchy carb repl; hbld relatively fresh except oxidiz rims.
4000 Same as 3360.
4660 Same as 3360, plus heavily oxidiz hbld and some alterat to chlorite.
4820 Oxidiz hbld–plag andesite w/minor biot; intersertal matrix and intergranular matrix (2 varieties); minor carb repl.
5010 Same as 4820 w/trace of fresh hbld andesite as above at 3360.
5080 Same as 5010.
5520 Similar to 5080 w/subequal (2:1) amount of volcanic arenite:calcareous fn–med ss; several varieties including muddy ss.

Clastics

5810 Calcareous muddy fn–med ss (plag, andesite VRF, biot, hbld, tr cht or felsite, tr CRF), VA–SA, poorly sorted. Minor silty mudstone and hbld–biot andesite.
6150 Mudstone and silty mdst; minor calcareous fn ss; similar to 5810.
6290 Mudstone and silty mdst, some w/anhydrite; calcareous fn ss (qz, CRF, cht, plag, tr VRF, hbld).
6610 Same as 6290.
6930 Same as 6290.
7210 Same as 6290.
7600 Calcareous fn–med muddy ss (qz, plag, CRF, mdst frag, VRF, minor hbld, biot, K-feld, cht, few qz w/abraded overgrowths), VA–SA; minor silty mdst.
7960 Mudstone w/minor calcareous muddy vfn ss (qz, plag, VRF, CRF, cht) 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 fragments are included in vfn ss, so actually is fn granule cgl; tr anhydrite.
8900 Same as 7960.
9300 Same as 8120 w/fn ss (qz, VRF, CRF, lm mdst, cht, minor plag).
9600 Same as 7960 and 8900.
9890 Same as 9300.
10200 /possible cgl/ Mdst, Silty mdst, vfn–fn ss as above, plus tr of siliceous med ss and calcareous fn ss w/SR–R qz; possible fossil ghosts in couple of lm mdst cuttings; probable globigerinids.
10600 Mdst, silty mdst, tr muddy crs siltst w/green pellets, silty lm mdst, calcar vfn ss.
10830 /possible cgl/ Mdst, silty mdst, lm mdst w/unident bioclasts; tr calcar fn ss, calcar/siliceous med ss (qz, cht, CRF, minor plag, K-feld, VRF); few qz w/overgrowths.
11120 /possible cgl/ Mdst, silty mdst, lm mdst, foram wackest, packst, grainst /ooids, cht, calcar med ss (qz, cht, CRF), calcar fn ss as above.
11320 /possible cgl/ Mdst, silty mdst, lm mdst, packst/grainst, dol, cht, minor calcar and siliceous fn ss (qz, CRF, tr plag), VRF.
11660 /possible cgl/ Abnt mdst, tr packst, calcar vfn ss (poorly sort; qz, CRF, silty mdst), siliceous fn ss (qz, cht, tr plag).
11790 /possible cgl/ Mdst, lm mdst, wackest (possible globigerinids), vfn, fn, med ss (qz, cht, CRF), A–SR qz; muddy dark ss.
12090 ((very small cuttings)) Mdst, lm mdst, dk muddy vfn ss, loose VA–WR qz, CRF, cht grains, minor plag grains, tr VRF.
12170 /possible cgl/ Lm mdst, cht, qz to 1 mm size, neomorphosed lm mdst, wackest, muddy fn ss, calcar vfn ss (qz, cht, CRF, tr plag), dk muddy vfn ss as above.
12270 /possible cgl/ Like 12170.
12650 Vfn-fn muddy ss (qz, cht, K-feld, plag—more abnt than in 12930), muddy matrix altered to chl; calcar vfn–fn ss; minor muddy vfn ss as above; minor lm mdst; tr coal(?).

Cretaceous

12930 Mdst, lm mdst, silty mdst; siliceous–calcar fn ss (qz, cht, plag—less abnt than in 12650, K-feld); WR qz, few to 0.6 mm; muddy vfn ss (qz, cht, CRF, plag); VA–SA qz and cht.
13040 Sh, lm mdst, silty sh, muddy crs siltst, muddy vfn ss (qz, cht, 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 Siliceous/calcar muddy fn ss (qz, plag, cht, K-feld); crs siltst and vfn ss like 12930–13200.
13380 ((very small cuttings)) Similar to 12930–13230 w/more lm mdst.
13560 Mdst, silty mdst, calcar muddy siltst, 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, siltst, muddy vfn ss (qz, plag).
14000 Similar to 13770–13950 w/more vfn–fn ss.
14060 Sh, silty sh, siltst, fn sandy lm mdst, crs siltst, probable rudist fragment (1 mm long); fn sandy neospar w/WR qz, calcar fn ss (qz), siliceous fn ss (qz).
14100 Similar to 14060; siliceous/calcar vfn ss (qz, cht).
14150 Calcar vfn ss (SR–WR qz), some silica overgrowths; poorly sorted fn sandy lm mdst and wackest, sml unident bioclasts; silty sh.
14200 Silty sh, vfn–fn ss (VA–SA qz, plag, cht, biot); crs siltst.
14310 Spar-filled foram (?) in calcar vfn ss (qz, plag, VRF); forams in silty mdst; neomorphosed lm mdst, wackest, silty sh and mdst w/foram(?); bioclast in ss.
14330 Brown silty mdst and lm mdst, muddy vfn–fn ss (qz, CRF); pyrite; wackest (ostracod, foram, mollusc, algae), few bioclasts also in vfn ss.
14420 Neomorph lm mdst, wackest (mollusc frags); silty and fn sandy lm mdst; calcar vfn ss (A–SR qz, plag, zircon, CRF); sh w/forams(?).

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.

Sill: approximately 600 ft thick
14490 Altered (chl) biot–hbld–feld intrusive:monzonite; minor brn muddy siltst, silty sh, calcar siltst, neomorph lm mdst.

15110 Silty sh w/bioclasts (ost, thin mollusc, ech), altered biot–hbld–feld intrusive, brn mdst w/globular forams, calcar 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, bryoz, ost, ech); brn silty sh and mdst; muddy fn ss (SA–R qz, plag, K-feld, 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

Basin fill

1530 --

Volcanics

1540 VRF (K-feld, hbld, biot, plag phenocrysts): biot ragged and fresh, hbld oxidized and repl w/carb; minor carb and chl alteration.

1630 Qz, plag (oligoclase), K-feld (microcline), VRF: all frags of crystals, few composites; qz, K-feld, and some plag appear plutonic; no volcanic qz; rhyolite and andesite VRF.

1700 50–60% VRF (calcar, oxidiz hbld andesite; porphyritic rhyolite (contain fresh biot, common carb alterat); qz, K-feld, mostly plutonic, angular xl 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, qz, sanidine xl frags. (latite?).

1810 VRF; pale med brn; oxidiz hbld and some fresh biot; abnt K-feld phenocrysts; few euhedral apatite (0.2 mm, hex); few plag phenocrysts; no qz. Common carb and chl alterat; carb patch as well as repl hbld. Some frags w/alined plag laths, most w/anhedral mosaic matrix.

2010 Same as 1810.

2130 Same as 1810, 2010: euh hbld repl w/carb and dk oxidiz rims; euh sanidine phenocrysts; euh–subhed plag; tr biot; no qz; 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 hbld phenos to 0.3 mm.

2230 Similar to 1810–2200. Hbld less abnt and chloritized; patch carb alterat as well as repl hbld and plag; chl repl biot.

3520 Similar to 1810–2230. Hbld and plag less common; minor interstitial qz; 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 qz 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 0.01–1.0 mm thick, 0.05–1.5 mm long; resembles tuff.

5500 Same as 5470: K-feld phenos and xl frags common; fresh biot books common; minor hbld(?) altered to chl; minor sml anh qz; minor oligoclase plag; anh microxln mosaic; sericite alterat pervasive; minor carb.

6310 More than 70% same as 5500: tr fn qz ss—intergrown anh xls; minor graphic intergrowth of qz/K-feld, minor hbld andesite, some fn xln rhyolite?; anh mosaic of qz, K-feld, biot; few frags w/K-feld and flow alined plag laths.

7150 Same as 5500: hbld altered to carb.

7280 VRF: fresh and altered hbld, some euh, some ragged; pyrite common; tr biot. Few frags of K-feld phenos. Anh mosaic of foliate laths, qz, unk mineral (thin tabular/foliate/ splintery, biax -, high biref, secondary? alterat mineral).

7670 Same as 7280: hbld altered to biot, epidote; minor patchy carb alterat.

7800 1) Anh, inequant sized qz mosaic w/hbld microlites;
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–subhed K-feld (highly altered), anh–subhed hbld altered to chl; minor interstitial qz 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 feldspathic ss (altered as granular epidote repl carb; skarn;
2) lm mdst altered to epid;
3) chloritized hbld andesite less abnt.

8210 Altered (chl) VRF; mostly plag laths w/minor biot and hbld; few plag phenos; tr vfn ss.

8400 1) Similar to 7280;
2) Altered felsic rock, mostly K-feld; epid granules; former mafic (hbld ?) altered to gypsum?—biax -, low biref, splintery;
3) Minor biot (pale) felsite (anh mosaic of qz and K-feld);
4) Anhydrite(?)—rectang C1, yel–rd–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) Latite?: plag laths, fresh hbld and plag microphenos, minor epid;
2) minor skarn;

8770 1) Same as 8700:
2) fresh euh hbld microphenos in plag lath matrix, minor pyrite; dusty sericite alterat on plag; no epid;
3) ragged, faded hbld w/plag laths; altered.

8890 Same as #3 in 8770, w/pyrite; minor epid granules.

8930 Same as 8890; 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 interstitial carb alterat;
3) vfn qz ss and fn arkosic ss: tr fresh euh hbld in plag lath matrix.

9200 1) Hbld andesite: hbld oxidiz and/or repl w/carb; fine subparal plag laths; few plag microphenos; chl alterat;
2) less abnt epid–qz skarn like 9100 (#3).

9250 Felsite: microphenos of K-feld, plag; minor qz, altered hbld in matrix of flow-alined plag laths; tr zircon; hbld chloritized, patchy carb alterat.

9300 Same as 9250; tr sphene; qz phenos rounded; feld phenos altered to sericite and carb.

9400 Same as 9250–9300.

9450 1) Same as 9250–9400 w/tr pyrite;
2) altered hbld–plag andesite similar 9200 (#1);
3) epid–qz skarn like 9100 (#2) and 9200 (#2).

9500 1) Same as 9250–9450;
2) calcar–qz skarn, garnet carb skarn, epid–qz skarn;
3) altered hbld–plag andesite?–latite?

9570 1) Felsite w/altered hbld in plag lath matrix w/carb alterat;
2) felsite w/altered hbld in inequant plag? matrix w/carb alterat;
3) less abnt qz–epid skarn; tr pyrite.

9620 1) Garnet–carb–qz–epid skarn;
2) hbld–plag felsite less abnt;
3) tr calcar fn ss; tr vfn metaqz.

9670 1) Felsite: altered hbld and K-feld microphenos in plag lath matrix w/carb patchy repl; minor interstitial qz; probably same as 9250;
3) less abnt garnet skarn.

9800 Same as 9670; some chl alterat of hbld; rnd fresh sanidine microphenos; also few plag (oligoclase) microphenos; minor skarn.

9880 1) Same as 9670–9800;
2) epid–qz skarn (met calcar ss?); epid–plag skarn;
3) less abnt fn xln andalusite?–garnet hornfels/skarn.

9930 Same as 9880.

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

10100 Same as 10010.

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

10260 Same as 10200; more fresh plag microphenos, some oscil zoned.

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

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

Skarn dominant with muddy siliciclastics

10500 1) Epid–qz skarn; some may be met poorly sorted fn ss;
2) less abnt felsite like 10010–10400.

10600 Epid–qz–garnet–carb skarn; some w/plag–epid.

10700 Epid–qz skarn and hornfels; met mdst, siltst, sandy mdst; few probably were originally calcar vfn arkosic ss; few qz grains to 0.2 mm.

10750 Same as 10700; less ss, more mdst.

10800 Epidotized silty 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 hbld felsite and epid marble.

10850 Same as 10800 w/incr fn–med ss; K-feld minor; tr plag grains; possible tr cht? grains; tr met ss w/carb and pyrite.

10890 Altered hbld felsite similar to those above (cf 9670); some rel fresh zoned plag microphenos (oligoclase); some same as 10800-10850.

10930 Skarn similar to 10800–10850; abnt epid silty mdst; common fn–med ss; tr altered hbld felsite.

11000 Same as 10930: mdst about 4 times as abnt as fn ss.

11030 Same as 11000: (5:1).

11050 Skarn/hornfels; spotted hornfels and vfn sandy hornfels similar to 9880; tr epid fn ss; epid skarn.

11080 1) Hbld felsite (sml microphenos in equixln matrix);
2) fn epid–qz ss; silty epid mdst; some sericite; tr spotted hornfels.

11090 Similar to 11080.

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

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

11140 Similar to 11130: spotted hornfels and hbld felsite more abnt.

Siliciclastic dominant with minor skarn and felsite

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

11350 Similar to 11250: more spotted hornfels, more epid alterat in ss; possible cht grains in ss; VA–SA qz and plag grains.

11450 Same as 11350 w/tr hbld latite.

11500 Hbld latite/andesite (fresh hbld and Na–plag microphenos in plag lath matrix; minor altered felsite.

11600 Similar to 11350.

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

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

11850 Similar to 11250–11800; muddy fn ss, vfn ss, silty mdst; VA–SA polyxln qz, minor plag, cht; epid 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 cht; minor spotted hornfels.

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

12250 Similar to 11850; minor med ss (qz, K-feld); epid alterat; VA–SR qz; minor cht grains.

12300 Varied lithologies: 1) abnt hbld–K-feld felsite w/feld lath matrix, some K-feld microphenos to 1 mm, large ones w/qz; extensive carb and epid alterat; 2) common ss and mdst as above; 3) minor metaqz and cht-appearing cuttings.

12400 Similar to 12300; less ss.

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

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

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

12570 Same as 12550 w/tr spotted hornfels.
12600 Same as 12550–12570; fresh biot, pale hbld to 1.5 mm; some feld and matrix sericitized.
12650 Mdst; silty mdst, muddy vfn–fn ss (VA–SR qz, plag, K-feld, cht?); common sericite.
12700 Same 12650; epid alterat of CRF in fn ss; minor carb alterat.
12750 1) Same as 12650–12700;
2) hbld felsite similar to 12550 w/sericite/carb alterat.
12800 Hbld–biot–plag felsite; same as 12750 w/abnt carb alterat.
12840 Same as 12800.
12900 1) Same as 12800 but more alterat;
2) mdst and silty mdst; some w/vein qz.
12990 Hbld–biot–plag felsite (pale hbld, some alterat to chl; sericite on Na-plag; anhed equant xl matrix; interstitial qz; minor carb alterat.
13040 Silty brn mdst; argillac fn ss (VA–SA qz, Na-plag, cht?) w/sericite alterat; tr hbld–biot felsite; tr spotted hornfels.
13070 Similar to 13040; less mdst, more muddy ss and med ss; more felsite.
13100 Muddy fn ss and silty mdst similar to 13040.
13140 1) Altered hbld–biot felsite;
2) mdst and silty mdst;
3) muddy vfn 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 abnt than in 13240); altered hbld felsite common.
13400 Similar to 13320 but vfn ss more abnt and hbld–biot–plag felsite fresher; ss grains are VA–SA qz, plag, cht?, VRF?.
13490 Fn–med siliceous ss (poorly sorted, VA–SR polyxln qz, plag, K-feld, PRF?, metaqz); pyrite.
13520 Similar to 13490; vfn–fn ss w/epid alterat and abnt pyrite.
13540 Similar to 13490–13520; fn–med ss plus silty and fn sandy mdst/sh; abnt pyrite.
13590 Similar to 13490–13540 except about 1/3 fresh hbld–biot–plag felsite w/abnt pyrite.
13650 Altered mdst/sh; minor silty mdst and vfn ss; spotted hornfels; common carb alterat; tr altered felsite.
13700 Similar to 13490–13590 except less felsite; abnt pyrite.
13750 Similar to 13700 but much more patchy carb alteration.
13800 Approx equal amts hbld–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 hbld–plag felsite; minor fn argillac–calcar arkosic ss (VA–SA qz, plag).
13960 Calcar–argillac vfn ss (VA–SA qz,); tr two felsites like 13910.
13990 Altered (chl, sericite) hbld–biot–plag felsite w/anh equant xln matrix; qz and calcite vein frags; calcar (epid) vfn ss; tr spotted hornfels.
14000 Calcar–argillac, poorly sorted, vfn ss; arkosic ss; spotted hornfels; tr hbld felsite; tr pyrite.
14080 Siliceous and calcar–argillac, poorly sorted, fn ss (VA–SR qz, plag, cht?); tr hbld felsite; pyrite.
14100 Mdst and muddy siltst; minor argillac–calcar vfn ss (VA–SA qz, plag, K-feld, cht?).
14140 Hbld–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, argillac vfn ss (VA–SR qz, plag, K-feld, cht?).
14450 Poorly sorted, argillac fn ss (SA–SR qz, abnt plag, K-feld, cht); few grains to 0.5 mm; muddy vfn ss and sandy mdst; minor skarn; rnd qz w/overgrowth grains.
14470 Calcar–argillac fn–med ss like 14450; poorly sorted SA–WR grains; subarkose–arkose; cht and WR qz (few w/overgrowths, indicate sed source; K-feld and plag indicate plutonic (and vol?) source.
14500 Mdst, silty mdst, muddy siltst; minor vfn–fn ss.
14540 /intrusive/ hbld–biot–plag felsite w/pyrite; sericitized feld, some chl; minor mdst and siltst like 14500.
14560 /intrusive/ similar to 14540 but fresher and coarser xln.
14680 /intrusive/ like 14540–14560.
14720 /intrusive/ qz–K-feld felsite like 13910; pyrite; tr hbld–biot–plag felsite.
14770 Argillac and calcar fn ss (VA–SA qz, plag, cht, K-feld): epid–chl alterat; pyrite.
14840 Varied lithologies: 1) like 14770; 2) mdst and muddy siltst; 3) hbld–biot–plag felsite.
14930 Similar to 14840 but #3 more abnt.
15000 Silty sh w/abnt pyrite; crs siltst w/pyrite (VA–A qz, plag); calcar fn ss w/epid alterat; tr skarn and felsites.
15100 Hbld–biot–plag–K-feld felsite w/chl, carb, sericite alterat; tr mdst and siltst.

Cretaceous

15160 Dk gray silty sh w/forams; tr felsite and calcar siltst (qz, plag, cht).
15240A Same as 15160.
15240B Calcar fn ss (abnt VA–SA plag); calcar siltst; silty sh; dk grey calcar sh; tr felsite.
15290 Dk gry calcar sh w/forams; dk gry silty sh.
15350A Siliceous, argillac, and slightly calcar vfn ss (SA–SR qz, tr cht); sandy mdst and lm mdst; tr dk gry fossil sh.
15350B Similar to 15350A plus silty and vfn sandy neosparite; ss mostly well sorted.
15370 Neospar, slightly silty and vfn sandy neospar (SA–WR qz); minor dk gry foram sh.
15400 Muddy vfn ss, sandy lm mdst, silty lm mdst w/epid alterat; silty neospar; tr dk gry foram sh.
15420 Same as 15400.
15430 Predominantly dk gry foram sh: silty and calcar.
15460 Mostly argillac and calcar vfn ss (qz, minor cht) as above; silty neospar; silty foram sh; silty black mdst.
15490 Similar to 15460 w/o sh and mdst.
15550 Mostly argillac, calcar and siliceous (qz overgrowths) vfn, fn and med ss (qz, minor cht), most well sorted; vfn and fn A–SR grains, med R–WR grains; minor silty calcar mdst; tr felsite.
15670 Hbld–biot–plag felsite (sericite and chl alterat); silty and vfn sandy mdst; minor calcar silty sh, calcar vfn ss.
15700 Similar to 15670: mostly felsite.
15750 Same as 15700; tr foram sh.
15790 Silty mdst and sh; muddy and calcar vfn ss w/pyrite.
15850 Hbld–biot–plag felsite w/chl and carb alterat.

15900 Silty sh, muddy vfn ss, argillac vfn ss (A–SR qz); tr foram sh; tr felsite.
15980 Silty sh, calcar crs siltst, foram sh, silty neospar.
16040 Poorly sorted, argillac, fn ss (SA–WR qz, cht); argillac–siliceous 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/tr plag grains.
16130 Calcar–argillac fn ss (SA–SR undulose extinct qz; tr cht; few WR); minor silty mdst and sh; tr plag in muddy crs siltst.
16140 Felsite like 15850; minor fn ss and silty mdst.
16190 Calcar–argillac vfn–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/carb 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 siltst.
16520 1) Silty neomorph wackest w/peloids and bioclasts; 2) calcar vfn ss (SA–SR qz, minor cht), poorly sorted; 3) siliceous fn ss (SA–R qz), moderate sorted.
16570 Crs silty neospar (VA–SR qz, tr cht); calcar siltst.
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 crs siltst (VA–SR qz, tr cht & CRF), poor sort; silty neospar; tr bioclasts; one cutting w/intraclasts and silt.
16730 Brn silty mdst; silty and vfn sandy neospar (one cutting w/med sand size siltst grains; few argillac crs siltst.
16780 Hbld–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.

Permian

16900 Calcar vfn ss; silty neospar; neomorph wackest (*Tuberitina* forams, ech, spines, bryoz, brach frags); silty sh.
16950 Felsite w/carb and chl alterat, like 16780; calcar vfn ss; silty calcar mdst; neospar.
16990 Neomorph lm mdst, wackest (foram, ech, spines, tril); minor silty lm mdst, cht.
17050 Same as 16900.
17110 Felsite w/carb and chl alterat; minor same as 16990–17050.
17150 Same as 17110; mostly felsite w/excel chl; 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 crs siltst, silty mdst and sh, neomorph silty lm mdst and wackest (*Tuberitina*, 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, forams, ech, bryoz): minor felsite but more than others below 17200.
17660 Similar to 17360–17610: but more neomorph lm mdst, less wacket.
17710 Similar to 17360–17610: some packst (forams, ech, bryoz, ost, brach spines).
17760 Similar to 17360–17710: bl sh more abnt; coral? frag.
17810 Similar but less neomorphism; 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 crs siltst.
18050 Similar to 17810–17960: w/minor siliceous fn ss and felsite (cave?).
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 packst, lm mdst, sh, silty lm mdst, calcar crs siltst; (forams, tril, ech, brach).
18210 Similar tp 18200: less silt.

Selected conversion factors*

TO CONVERT	MULTIPLY BY	TO OBTAIN
Length		
inches, in	2.540	centimeters, cm
feet, ft	3.048×10^{-1}	meters, m
yards, yds	9.144×10^{-1}	m
statute miles, mi	1.609	kilometers, km
fathoms	1.829	m
angstroms, Å	1.0×10^{-8}	cm
Å	1.0×10^{-4}	micrometers, μm
Area		
in^2	6.452	cm^2
ft^2	9.29×10^{-2}	m^2
yds^2	8.361×10^{-1}	m^2
mi^2	2.590	km^2
acres	4.047×10^{3}	m^2
acres	4.047×10^{-1}	hectares, ha
Volume (wet and dry)		
in^3	1.639×10^{1}	cm^3
ft^3	2.832×10^{-2}	m^3
yds^3	7.646×10^{-1}	m^3
fluid ounces	2.957×10^{-2}	liters, l *or* L
quarts	9.463×10^{-1}	l
U.S. gallons, gal	3.785	l
U.S. gal	3.785×10^{-3}	m^3
acre-ft	1.234×10^{3}	m^3
barrels (oil), bbl	1.589×10^{-1}	m^3
Weight, mass		
ounces avoirdupois, avdp	2.8349×10^{1}	grams, gr
troy ounces, oz	3.1103×10^{1}	gr
pounds, lb	4.536×10^{-1}	kilograms, kg
long tons	1.016	metric tons, mt
short tons	9.078×10^{-1}	mt
oz mt^{-1}	3.43×10^{1}	parts per million, ppm
Velocity		
ft sec^{-1} (= ft/sec)	3.048×10^{-1}	m sec^{-1} (= m/sec)
mi hr^{-1}	1.6093	km hr^{-1}
mi hr^{-1}	4.470×10^{-1}	m sec^{-1}

TO CONVERT	MULTIPLY BY	TO OBTAIN
Pressure, stress		
lb in^{-2} (= lb/in^2), psi	7.03×10^{-2}	kg cm^{-2} (= kg/cm^2)
lb in^{-2}	6.804×10^{-2}	atmospheres, atm
lb in^{-2}	6.895×10^{3}	newtons (N)/m^2, N m^{-2}
atm	1.0333	kg cm^{-2}
atm	7.6×10^{2}	mm of Hg (at 0° C)
inches of Hg (at 0° C)	3.453×10^{-2}	kg cm^{-2}
bars, b	1.020	kg cm^{-2}
b	1.0×10^{6}	dynes cm^{-2}
b	9.869×10^{-1}	atm
b	1.0×10^{-1}	megapascals, MPa
Density		
lb in^{-3} (= lb/in^3)	2.768×10^{1}	gr cm^{-3} (= gr/cm^3)
Viscosity		
poises	1.0	gr cm^{-1} sec^{-1} *or* dynes cm^{-2}
Discharge		
U.S. gal min^{-1}, gpm	6.308×10^{-2}	l sec^{-1}
gpm	6.308×10^{-5}	m^3 sec^{-1}
ft^3 sec^{-1}	2.832×10^{-2}	m^3 sec^{-1}
Hydraulic conductivity		
U.S. gal day^{-1} ft^{-2}	4.720×10^{-7}	m sec^{-1}
Permeability		
darcies	9.870×10^{-13}	m^2
Transmissivity		
U.S. gal day^{-1} ft^{-1}	1.438×10^{-7}	m^2 sec^{-1}
U.S. gal min^{-1} ft^{-1}	2.072×10^{-1}	l sec^{-1} m^{-1}
Magnetic field intensity		
gausses	1.0×10^{5}	gammas
Energy, heat		
British thermal units, BTU	2.52×10^{-1}	calories, cal
BTU	1.0758×10^{2}	kilogram-meters, kgm
BTU lb^{-1}	5.56×10^{-1}	cal kg^{-1}
Temperature		
°C + 273	1.0	°K (Kelvin)
°C + 17.78	1.8	°F (Fahrenheit)
°F − 32	5/9	°C (Celsius)

**Divide by* the factor number to reverse conversions.
Exponents: for example 4.047×10^{3} (see acres) = 4,047; 9.29×10^{-2} (see ft^2) = 0.0929.

Editor: Jiri Zidek
Composition: Lynne Hemenway
Typeface: Palatino
Presswork: Miehle Single Color Offset
Harris Single Color Offset
Binding: Saddlestitchedf with softbound cover
Paper: Cover on 12-pt. Kivar
Text on 70-lb White Matte
Ink: Cover—PMS 320
Text—Black
Quantity: 1000

Russell E. Clemons PETROGRAPHY OF WELL CUTTINGS New Mexico Bureau of Mines & Mineral Resources Circular 203