MAP I-1543

UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

PETROLEUM POTENTIAL OF WILDERNESS LANDS, NEW MEXICO

By Robert T. Ryder

RYDER—PETROLEUM POTENTIAL OF WILDERNESS LANDS, NEW MEXICO   1:1,000,000   MAP I-1543

Petroleum Potential of Wilderness Lands in New Mexico

By Robert T. Ryder

PETROLEUM POTENTIAL OF WILDERNESS LANDS IN THE
WESTERN UNITED STATES

GEOLOGICAL SURVEY CIRCULAR 902-I

*This chapter on the petroleum
geology and resource potential of
Wilderness Lands in New Mexico
is also provided as an accompany-
ing pamphlet for Miscellaneous
Investigations Series Map I-1543*

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ILLUSTRATIONS

Petroleum Potential of Wilderness Lands in New Mexico

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ABSTRACT

On the basis of in-depth geologic framework and petroleum geology studies, the oil and gas potential of Wilderness Lands in New Mexico is rated qualitatively on a scale from high to zero. A high rating is assigned to Wilderness Lands that are located near or along the projected trend of hydrocarbon production and that have all the geologic attributes of the producing area. A medium rating is assigned to Wilderness Lands that have all the attributes, including shows, of an oil and gas producing area but presently lack commercial production. In contrast, low, low to zero,.and zero ratings are assigned to Wilderness Lands that have few or no attributes of an oil and gas producing area. Usually a zero rating is reserved for regions having autochthonous igneous and metamorphic rocks at or near the surfaĉe.

The Wilderness Lands in New Mexico are grouped into 18 clusters, each containing one or more tracts that have the same or similar geologic characteristics and the same hydrocarbon potential. Of the 2,676,856 acres of Wilderness Lands in New Mexico the potential acreage can be summarized as follows: high potential, 96.6 thousand acres; medium potential, 115.3 thousand acres; low potential, 1,237.3 thousand acres; low to zero potential, 158 thousand acres; and zero potential, 1,069.6 thousand acres.

INTRODUCTION

New Mexico is among the leading producers of oil and gas in the Uriîted States and has the potential for yielding significant undiscovered oil and gas resources (Dolton and others, 1981). Much of New Mexico is still a frontier area in terms of oil and gas exploration. Future oil and gas dis-

coveries in the sedimentary basins of New Mexico will likely depend on imaginative, but geologically sound, interpretations of the complex structural, depositional, and magmatic history of the State and on the testing of these interpretations with reflection seismic profiles and deep drilling. To date, drilling outside the regions of known production has been disappointing. The purpose of this investigations is to provide qualitative estimates—complete with written documentation—of the future oil and gas potential of the 2,676,856 acres of Wilderness Lands in New Mexico. These estimates are based largely on data derived from current published literature. Future estimates may vary as new data and concepts become available.

This report is divided into three parts. The first part, the geologic framework section, is intended to acquaint the reader with the physiographic and geologic provinces of New Mexico and the complex tectonic and magmatic history that shaped the provinces and ultimately helped control the distribution of oil and gas. The second part, the petroleum geology section, consists of a general treatment of several key elements related to the generation and entrapment of oil and gas in New Mexico. The third and final part, the petroleum potential of Wilderness Lands, contains the qualitative estimates of the oil and gas potential of the Wilderness Lands in New Mexico.

GEOLOGIC FRAMEWORK

PHYSIOGRAPHIC PROVINCES

New Mexico is divided into four major physiographic provinces: the Colorado Plateau, the Basin and Range, the Southern Rocky Mountain, and the Great Plains (fig. 1A)(Fenneman, 1931). The Great Plains and Colorado Plateau provinces occupy the eastern half and northwest quarter of the State, respectively, and are separated by the northward-tapering, wedge-shaped Basin and Range province (fig. 1A). A transitional zone between the Colorado Plateau and Basin and Range provinces is situated in southwest New Mexico. The Southern Rocky Mountain province is restricted to two lobes which flank the northern extremity of the Basin and Range province.

WILDERNESS LANDS

The 2,676,856 acres of Wilderness Lands in New Mexico are distributed over the four physiographic provinces (fig. 1A). Two-thirds of the Wilderness Lands is located in the Basin and Range province (31 percent) and the transitional zone (34 percent); the remainder of the Wilderness Lands is distributed mainly between the Colorado Plateau (18 percent) and the Southern Rocky Mountain provinces (15 percent). Only 2 percent of the Wilderness Lands is in the Great Plains province.

TECTONIC PROVINCES AND TECTONIC HISTORY

The physiographic provinces, and to a large extent the hydrocarbon accumulations within them, are controlled by the tectonic framework of the underlying rocks. The major tectonic features which shaped New Mexico's physiographic provinces are identified and discussed in the following sections.

COLORADO PLATEAU AND GREAT PLAINS PHYSIOGRAPHIC PROVINCES

The Colorado Plateau and Great Plains provinces represent a part of the North American craton which has been relatively stable since the late Precambrian. Structural features in the Colorado Plateau province are characterized by broad basins flanked by monoclines. Depending on the magnitude of the uplift involved, the structurally high blocks of the monoclines are manifested at

the surface as either structural terraces capped by gently dipping strata or mountain ranges with a core of granitic basement rocks. First-order structural features in the Colorado Plateau province are the San Juan Basin, Defiance uplift, Zuni uplift, Four Corners platform, Chama basin, Zuni basin, Acoma basin, and Lucero uplift of probable Laramide age (Woodward, 1974; Davis, 1978), the Paradox basin of Pennsylvanian age, and a Pennsylvanian precursor to the Defiance and Zuni uplifts (Peterson and Ohlen, 1963; Kottlowski, 1971) (figs. 1A, 2, 3). The San Juan Basin has a combined thickness of 9,000 to 10,000 feet of Cretaceous and Tertiary rocks and 3,000 feet of Pennsylvanian rocks (Peterson and others, 1965; Molenaar, 1977) (fig. 2). Many of the first-order structural features have been controlled by an underlying basement block mosaic which probably developed in Precambrian time and was reactivated by later episodes of structural instability (Kelley, 1955; Davis, 1978). In the vicinity of the Four Corners platform and the Paradox basin, several episodes of early Paleozoic block faulting

SOUTHERN ROCKY MOUNTAIN
PROVINCE

108° 106° 104°

DALHART BASIN OF EARLY PERMIAN AND PENNSYLVANIAN AGE

PARADOX BASIN OF PENNSYLVANIAN AGE

CHAMA BASIN

BRAZOS UPLIFT

SAN LUIS BASIN

SANGRE DE CRISTO UPLIFT

RATON BASIN

FOUR CORNERS PLATFORM

S A N

ESPANOLA BASIN

36°

COLORADO PLATEAU PROVINCE

J U A N

B A S N

NACIMIENTO UPLIFT

JEMEZ VOLCANIC PROVINCE

LAS VEGAS BASIN

SIERRA GRANDE UPLIFT OF EARLY PERMIAN AND PENNSYLVANIAN AGE

DEFIANCE UPLIFT

Santa Fe

Las Vegas

ZUNI UPLIFT

Grants

ACOMA BASIN

ALBUQUERQUE BASIN

TUCUMCARI BASIN OF EARLY PERMIAN AND PENNSYLVANIAN AGE

Tucumcari

LUCERO UPLIFT

ESTANCIA BASIN

Albuquerque

ZUNI BASIN

PEDERNAL UPLIFT OF EARLY PERMIAN AND PENNSYLVANIAN AGE

GREAT PLAINS

34°

Socorro

SAN AUGUSTIN BASIN

MUERTO BASIN

PROVINCE

ROOSEVELT UPLIFT OF PENNSYLVANIAN AGE

DATIL-MOGOLLON VOLCANIC FIELD

JORNADA DEL MUERTO

SAN ANDRES MTNS UPLIFT

SIERRA BLANCA BASIN

BASIN AND RANGE PROVINCE

Roswell

NORTHWEST SHELF OF PERMIAN AND PENNSYLVANIAN AGE

TRANSITIONAL ZONE

CABALLO MTNS UPLIFT

SACRAMENTO MTNS UPLIFT

CENTRAL BASIN PLATFORM

Silver City

TULAROSA BASIN

GUADALUPE MOUNTAIN UPLIFT

RIFT BASINS OF EARLY CRETACEOUS AGE

GOODSIGHT-CEDAR HILLS DEPRESSION

Las Cruces

SALT BASIN

Carlsbad

DELAWARE BASIN OF PERMIAN AND PENNSYLVANIAN AGE

32°

MESILLA BASIN

OROGRANDE BASIN OF EARLY PERMIAN AND PENNSYLVANIAN AGE

BROKEOFF HILLS UPLIFT

PEDREGOSA BASIN OF EARLY PERMIAN AND PENNSYLVANIAN AGE

RIO GRANDE RIFT

0   50   100 MILES

0   50   100   150 KILOMETERS

FIGURE 1A.—Physiographic and tectonic provinces. Outline and tectonic features of the Rio Grande Rift are from Woodward and others (1975).

I3
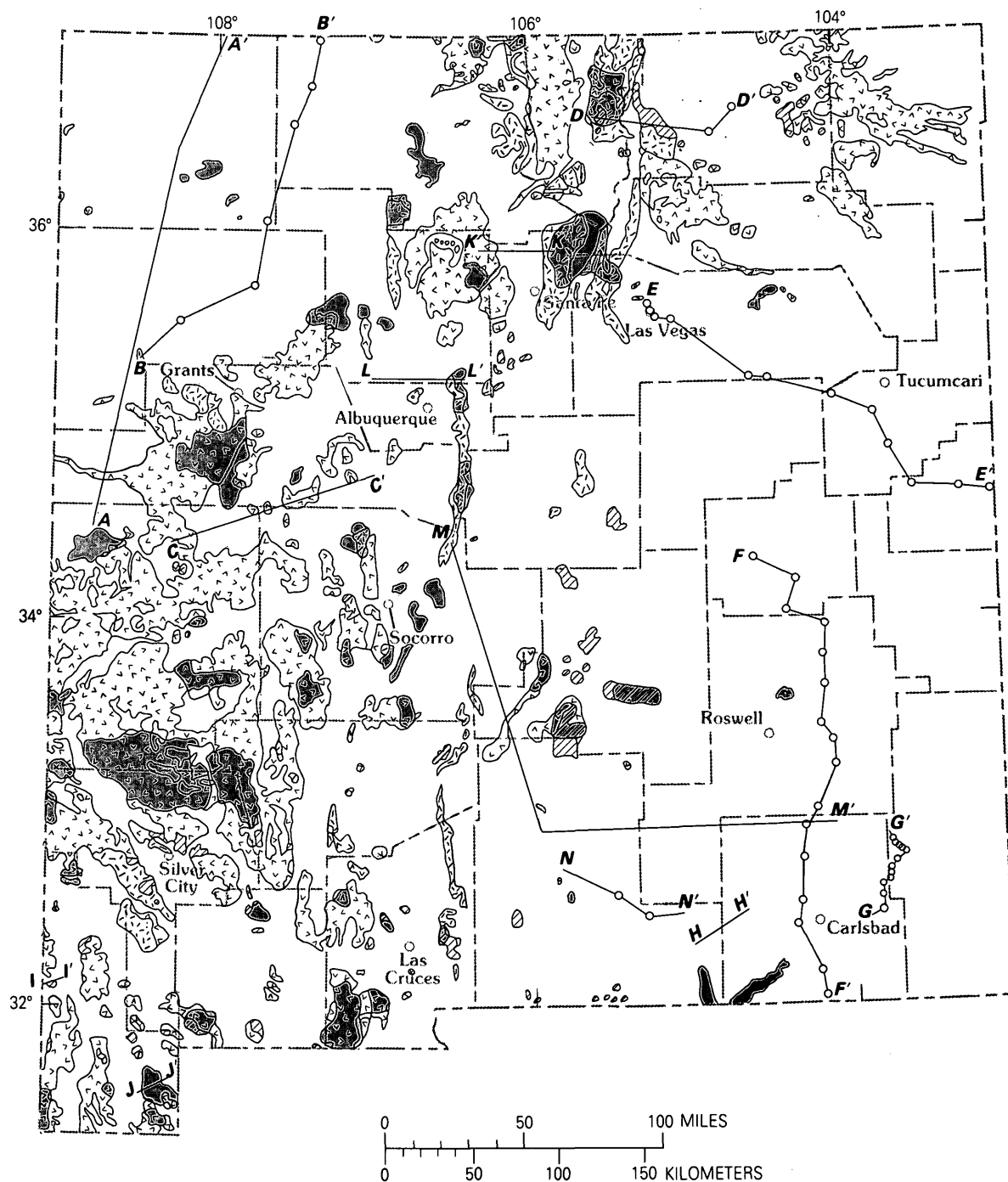
FIGURE 1B.—Major outcrops of igneous and metamorphic rocks and lines of cross sections. Distribution of igneous and metamorphic rocks are based on the geologic map of New Mexico (Dane and Bachman, 1965).

I4
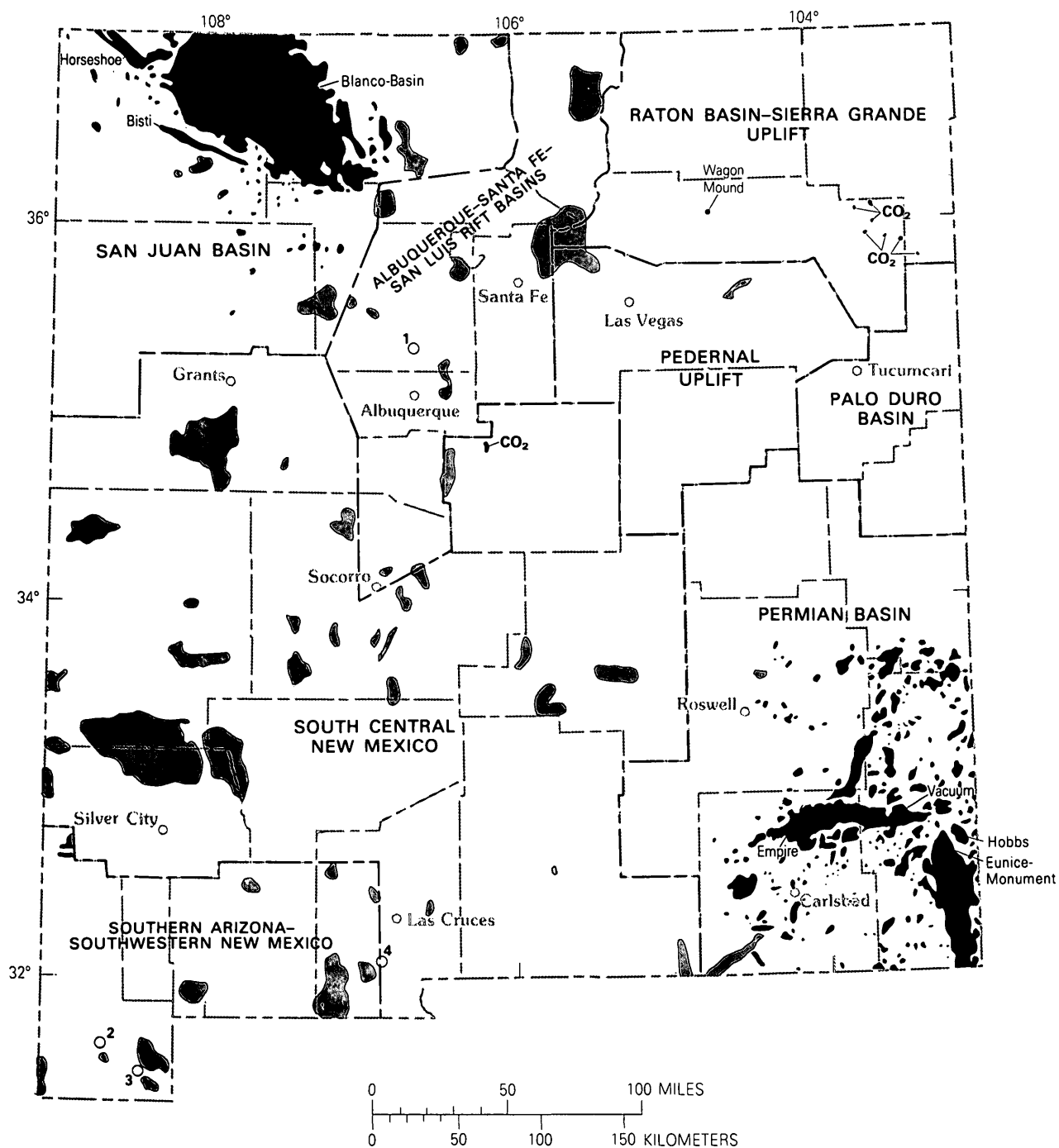
FIGURE 1C.—Oil and gas field data and petroleum provinces (Dolton and others, 1981). Oil and gas fields are from Bieberman and Weber (1969) and David (1977).

I5

A ZUNI BASIN | ZUNI UPLIFT | SAN JUAN BASIN A'
BISTI FIELD | BLANCO GAS FIELD

MAES-TRICHTIAN

CAMPANIAN

SAN-TONIAN

CONI-ACIAN

TURONIAN

CENOMANIAN

EXPLANATION
Marine shale
Marine and coastal barrier sandstone
Nonmarine deposits
Limestone or very calcareous shale
Section removed by pre-mid-Tertiary erosion
Section removed by late Tertiary-Holocene erosion

0   20   40 MILES

Kirtland Shale - Fruitland Formation
Pictured Cliffs Sandstone
Lewis Shale
Cliff House Sandstone
Menefree Formation 2000 feet
Point Lookout Sandstone
Upper Mancos Shale 1000 feet
Tocito Sandstone Lentil
Dalton Sandstone
Gallup Sandstone
Lower Mancos Shale 950 feet
Greenhorn Limestone
(Dakota "A")
Graneros Shale
(Dakota "B")
Dakota Sandstone
POSSIBLY INTERMITTENT DEPOSITION

B ZUNI UPLIFT SAN JUAN BASIN B'
FEET
8000
4000
SEA LEVEL
4000
8000

EXPLANATION
Tertiary sedimentary rocks
Cretaceous sedimentary rocks
Jurassic sedimentary rocks
Triassic sedimentary rocks
Permian sedimentary rocks
Pennsylvanian sedimentary rocks
Pre-Pennsylvanian sedimentary rocks
Precambrian basement rocks

0   10   20 MILES

FIGURE 2.—Upper Cretaceous time-stratigraphic section A–A' from the Zuni basin through the San Juan Basin (top) and geologic cross section B–B' (bottom) through the San Juan Basin. Lines of section are shown on figure 1B. Cross section A–A' is from Molenaar (1977) and section B–B' is from Peterson and others (1965).

FIGURE 3.—Geologic cross section C–C' through the Acoma basin and Lucero uplift. Line of section is shown in figure 1B. Cross section is from Wengerd (1959).

are well documented (Stevenson and Baars, 1977).

First-order structural features in the Great Plains province are the Raton and Las Vegas basins of Laramide age (Baltz, 1965) and the Delaware basin, Tucumcari basin, Dalhart basin, Roosevelt uplift, Northwest shelf, Central basin platform, Sierra Grande uplift, and Pedernal uplift of Early Permian and Pennsylvanian age (Bachman, 1975) (figs. 4, 5, 6, 7, 8). Many of these structures are controlled by fault blocks in the Precambrian basement (Kelley, 1971; Woodward and Snyder, 1976; Roberts and others, 1976). For example, major faults of primarily Early Permian and Pennsylvanian age border the west side of the Central basin platform and the east side of the Guadalupe Mountains uplift (fig. 8), along which Precambrian basement rocks have been uplifted at least 5,000 feet with respect to the adjacent Delaware basin. The precursor to the Raton and Las Vegas basins of Laramide age was the Rowe-Mora basin of Permian and Pennsylvanian age (Read and Wood, 1947). Approximately 5,000 feet of Pennsylvanian and Lower Permian (Wolfcampian) rocks were deposited in the Delaware basin

(Meyer, 1966) (fig. 6); the total Permian-Pennsylvanian section in the Delaware basin totals 18,000 feet (Silver and Todd, 1969; Hartman and Woodard, 1971) (fig. 7).

SOUTHERN ROCKY MOUNTAIN PHYSIOGRAPHIC PROVINCE

The Brazos, Nacimiento, and Sangre de Cristo uplifts of the Southern Rocky Mountain province are fault-bounded blocks of Precambrian granitic basement that have 10,000 to 20,000 feet of structural relief with respect to the Precambrian basement in the adjacent basins (Baltz and others, 1959; Baltz, 1965, 1967; Woodward and others, 1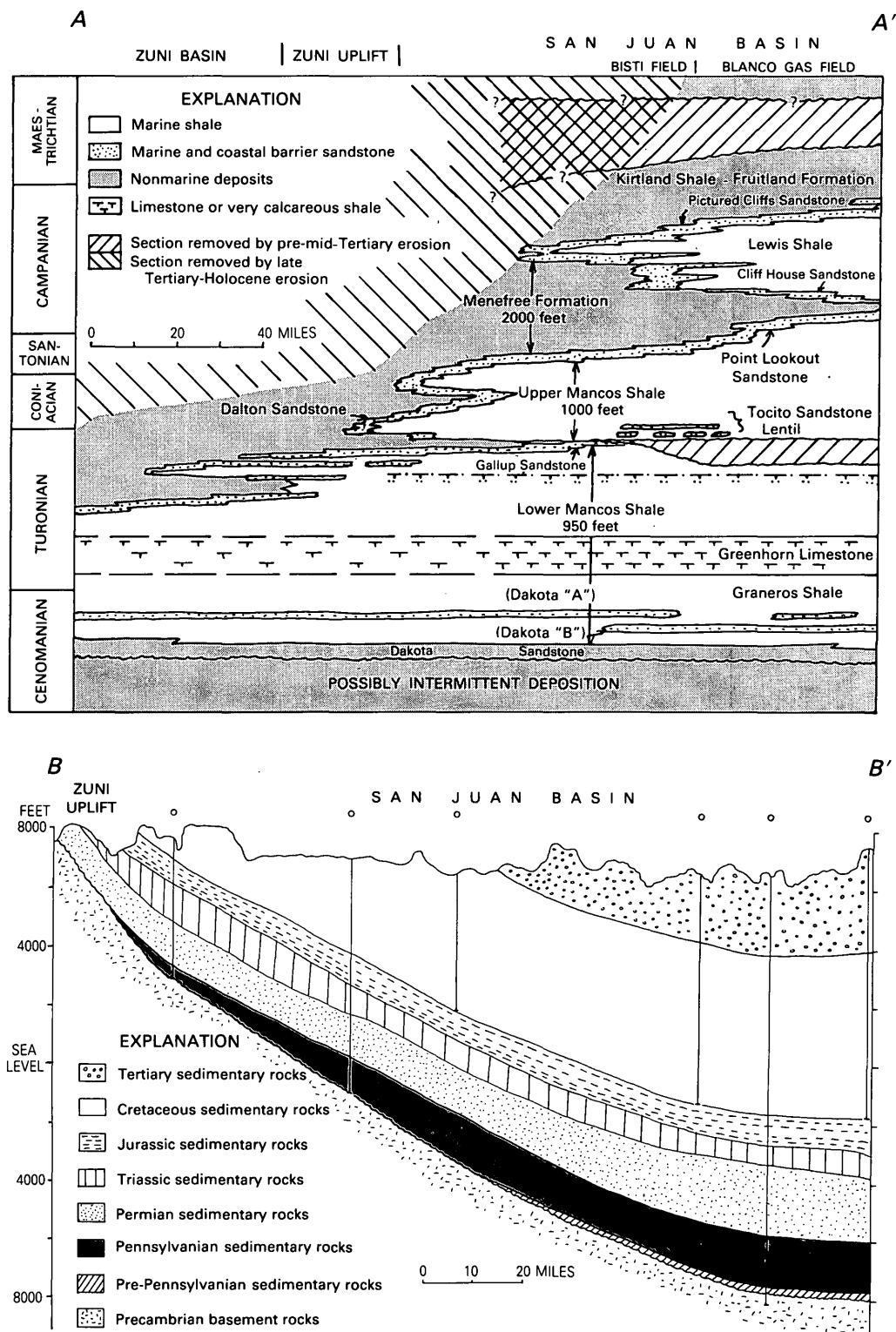972; Woodward, 1974) (figs. 1A, 4). These uplifts in the Southern Rocky Mountain province have resulted from intense episodes of compressional deformation in the late Paleozoic (Early Permian and Pennsylvanian) and again in Laramide time (Late Cretaceous and early Tertiary) (Chapin and Seager, 1975). Post-Laramide block faulting controlled the present topographic expression of the uplifts (Epis and Chapin, 1975). The Jemez volcanic province (figs. 1A-1B), contain-

I7

D   D′

SANGRE DE CRISTO UPLIFT   RATON   BASIN

FEET
10,000

5000

SEA
LEVEL
3000

0   10   20 MILES

EXPLANATION

o   [diagram]   [diagram]   [diagram]   [diagram]   [diagram]   [diagram]   [diagram]

Drill hole   Tertiary   Tertiary   Cretaceous   Jurassic and   Permian   Pennsylvanian   Precambrian
            sedimentary   intrusive   sedimentary   Triassic   sedimentary   sedimentary   basement
              rocks   rocks   rocks   sedimentary   rocks   rocks   rocks
                                                            rocks

FIGURE 4.—Geologic cross section D–D′ through the Sangre de Cristo Uplift and the Raton basin. Line of section is shown in
figure 1B. Cross section is from Baltz and others (1959).

E
LAS VEGAS
  BASIN   SIERRA GRANDE UPLIFT

FEET   o   o   o   o   o   o   o

5000

SEA
LEVEL

5000

EXPLANATION

DOMINANT ENVIRONMENT

[diagram] [diagram] [diagram] [diagram]   o   [diagram]   [diagram]   [diagram]

Conti- Nearshore Open   Basinal   Drill   Tertiary   Pre-   Precambrian
nental   marine   shelf   hole   sedimentary   Pennsylvanian   basement
                                                 rocks   sedimentary   rocks
                                                                rocks

TUCUMCARI BASIN

o   o   o   o   o   E′

FEET
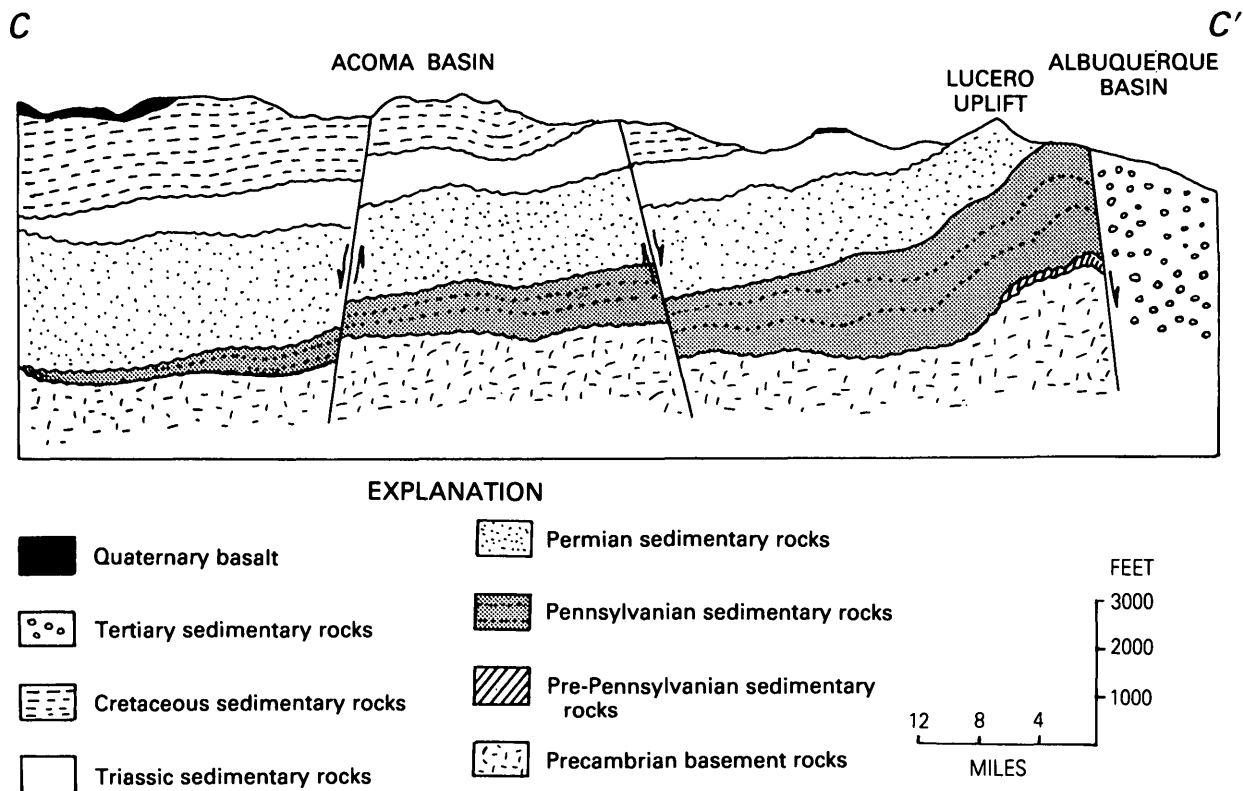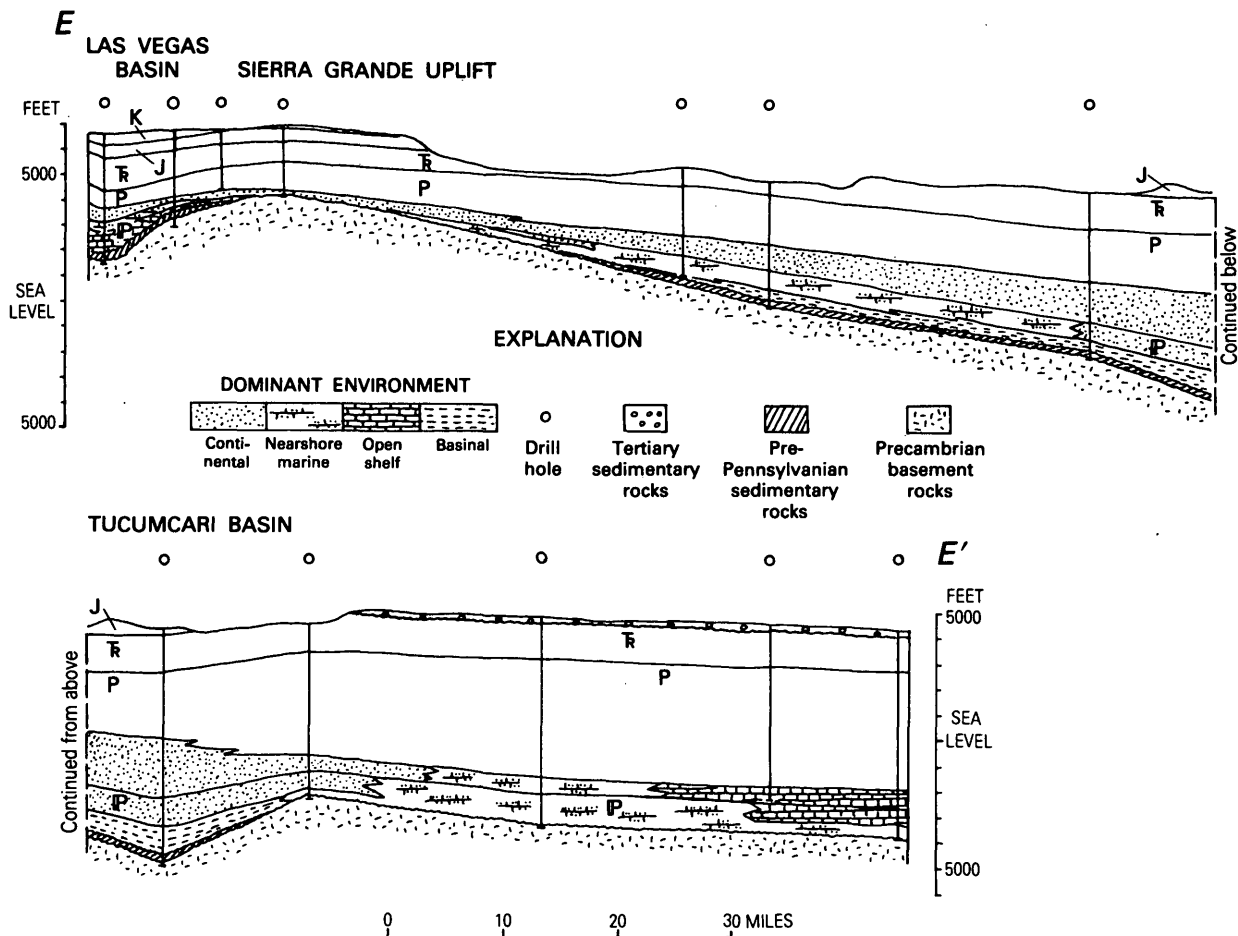5000

SEA
LEVEL

5000

0   10   20   30 MILES

FIGURE 5.—Geologic cross section E–E″ through the Tucumcari basin and Sierra Grande uplift. Line of section is shown in
figure 1B. Cross section is from Roberts and others (1976).

I8

ing a ·thick sequence of late Cenozoic volcanic rocks (Bailey and others, 1969), is included with the Southern Rocky Mountain province.

BASIN AND RANGE PHYSIOGRAPHIC PROVINCE

The Basin and Range province, with its complex history of crustal extension, plutonism, and volcanism, represents a far more mobile sector of the North American craton than the Colorado Plateau and the Great Plains provinces. Major crustal instability appeared in the Basin and Range province in Early Permian and Pennsylvanian time and resulted in the development of the Pedregosa basin in southwesternmost New Mexico, the Orogrande basin centered over the Tularosa and Jornada del Muerto basins of late Tertiary age, and the Uncompahgre–San Luis and Nacimiento uplifts centered, respectively, over the Brazos and Nacimiento uplifts of Laramide age (Tweto, 1975; Chapin and Seager, 1975; Greenwood and others, 1977) (fig. 1A). The Pedregosa basin trends northwestward from its depocenter in north-central Chihuahua, Mexico, through southwesternmost New Mexico, into southeasternmost Arizona (Greenwood and others, 1977). Pennsylvanian and Lower Permian marine carbonate rocks have a combined thickness of 5,000 feet in the New Mexico part of the Pedregosa basin (Ross, 1973) and 3,000 to 4,000 feet in the Orogrande basin (Greenwood and others, 1977).

In Mesozoic time, the crust in the Basin and Range physiographic province of southwestern New Mexico was deformed by a Late Cretaceous (through early Tertiary) magmatic arc (Thorman and Drewes, 1978; Dickinson, 1981), Early Cretaceous rifting (Bilodeau, 1982), Laramide compression (Drewes, 1978; Corbitt and Woodward, 1973), and Laramide extension (Hamilton, 1978). Many of the geologic complexities that resulted from these tectonic and magmatic events are illustrated in figure 9.

Early Cretaceous rift basins were superimposed on the Pedregosa basin by an aulacogen which extended into southwest New Mexico and southeast Arizona from the Chihuahua trough in Mexico (Bilodeau, 1982) (fig. 1A). Lower Cretaceous rocks in these basins are collectively known as the Bisbee Group (Hayes, 1970) or locally in New Mexico by names such as the Mojado (top), U-Bar, and Hell-to-Finish (base) Formations (Zeller, 1965). The nonmarine and marine deposits of the rift basins are between 10,000 and 15,000 feet

thick (Hayes, 1970; Kottlowski, 1971; Greenwood and others, 1977).

Corbitt and Woodward (1973), Woodward (1974), and Drewes (1978) believe that many of the thrust faults and folds in southwest New Mexico represent a structural link between the Cordilleran fold and thrust belt of southern Nevada and southeast California and the Chihuahua fold and thrust belt of northern Mexico. Hamilton (1978), Davis (1979), Dickinson (1981), and Matthews (1982) disagree with such a linkage on the grounds that neither the stratigraphic facies nor the structural features are present. The leading edge of the Cordilleran fold and thrust belt as defined by Corbitt and Woodward (1973) is shown in figure 1A.

According to Hamilton (1978), the Laramide basement uplifts in New Mexico occurred along the eastern border of the northward-moving, clockwise-rotating Colorado Plateau crustal plate. Laramide crustal extension originated along the southern trailing edge of the Colorado Plateau crustal plate (Hamilton, 1978).

Rifting began in what is today the Basin and Range province of New Mexico with the opening of the Rio Grande rift (fig. 1A) about 29 to 30 m.y. ago (late Oligocene) (Chapin and Seager, 1975; Eaton, 1979). A second major episode of rifting began in the late Miocene and (or) early Pliocene (3–8 m.y. ago) and lasted into the late Pliocene and Holocene (2 m.y. ago to present) (Chapin and Seager, 1975; Seager and Morgan 1979). The eruption of basaltic andesites about 20 to 26 m.y. ago and basalts about 5 m.y. ago in the Rio Grande rift seems to have been a direct consequence of the major rifting episodes, but lagged behind the rifting by 3 to 5 m.y. (Chapin and Seager, 1975).

The Rio Grande rift cuts across major centers of Oligocene calc-alkaline volcanism (30 to 38 m.y ago; Elston, 1976), such as in the Datil-Mogollon volcanic province (figs. 1A, B), subparallel to north-trending zones of crustal weakness inherited from late Paleozoic and Laramide uplifts (Chapin and Seager, 1975; Eaton, 1979; Kelley, 1979). Structural basins in the rift are grabens and half grabens, which, from north to south, include the San Luis basin, Espanola basin, Albuquerque basin, Estancia basin, Jornada del Muerto basin, Tularosa Basin, and the Mesilla basin (figs. 1A–1B, 10). Through a system of relay faults, ramps, and benches, the Albuquerque, Espanola, and San

NORTHWEST SHELF

PERMIAN SYSTEM (PART)

~ LEONARDIAN ~ SERIES ~ (PART) ~

PENNSYLVANIAN SYSTEM

WOLFCAMPIAN SERIES

VIRGILIAN SERIES

MISSOURIAN SERIES

DESMOINESIAN SERIES

ATOKAN SERIES

PRECAMBRIAN

PRECAMBRIAN ROCKS

MISSISSIPPIAN ROCKS

EXPLANATION

Brown anhydritic dolomite

Red beds

Quartzose sandstone

Light-colored fossiliferous limestone and variegated shale

Dark brown and black limestone

Dark gray, brown and black shale and siltstone

○ Drill hole

FEET

800

400

0

0   6   12

MILES

FIGURE 6.—Restored stratigraphic cross section *F–F''* of the Pennsylvanian System and Lower Permian Series through the Northwest shelf and the Delaware basin. Line of section is shown in figure 1*B*. Restored section is from Meyer (1968).

I10

F′

YESO FORMATION

DELAWARE BASIN

LEONARDIAN SERIES (PART)

ABO FOR- MATION

BONE SPRING FORMATION

WOLFCAMPIAN SERIES

VIRGILIAN SERIES

MISSOURIAN SERIES

DESMOINESIAN SERIES

ATOKAN SERIES

MORROWAN SERIES

MISSISSIPPIAN ROCKS

PERMIAN SYSTEM (PART)

PENNSYLVANIAN SYSTEM

PRE-PENN- SYLVANIAN
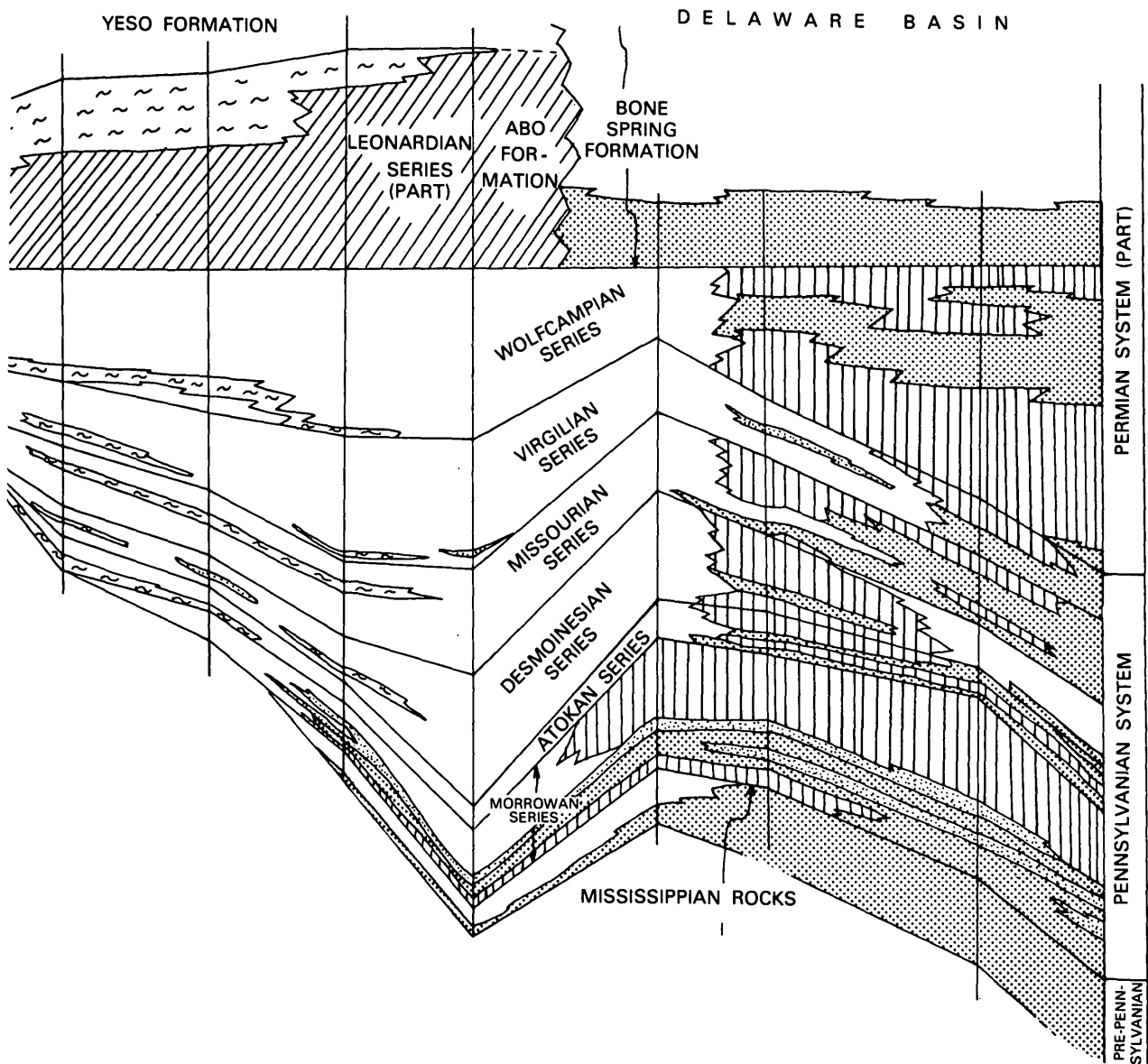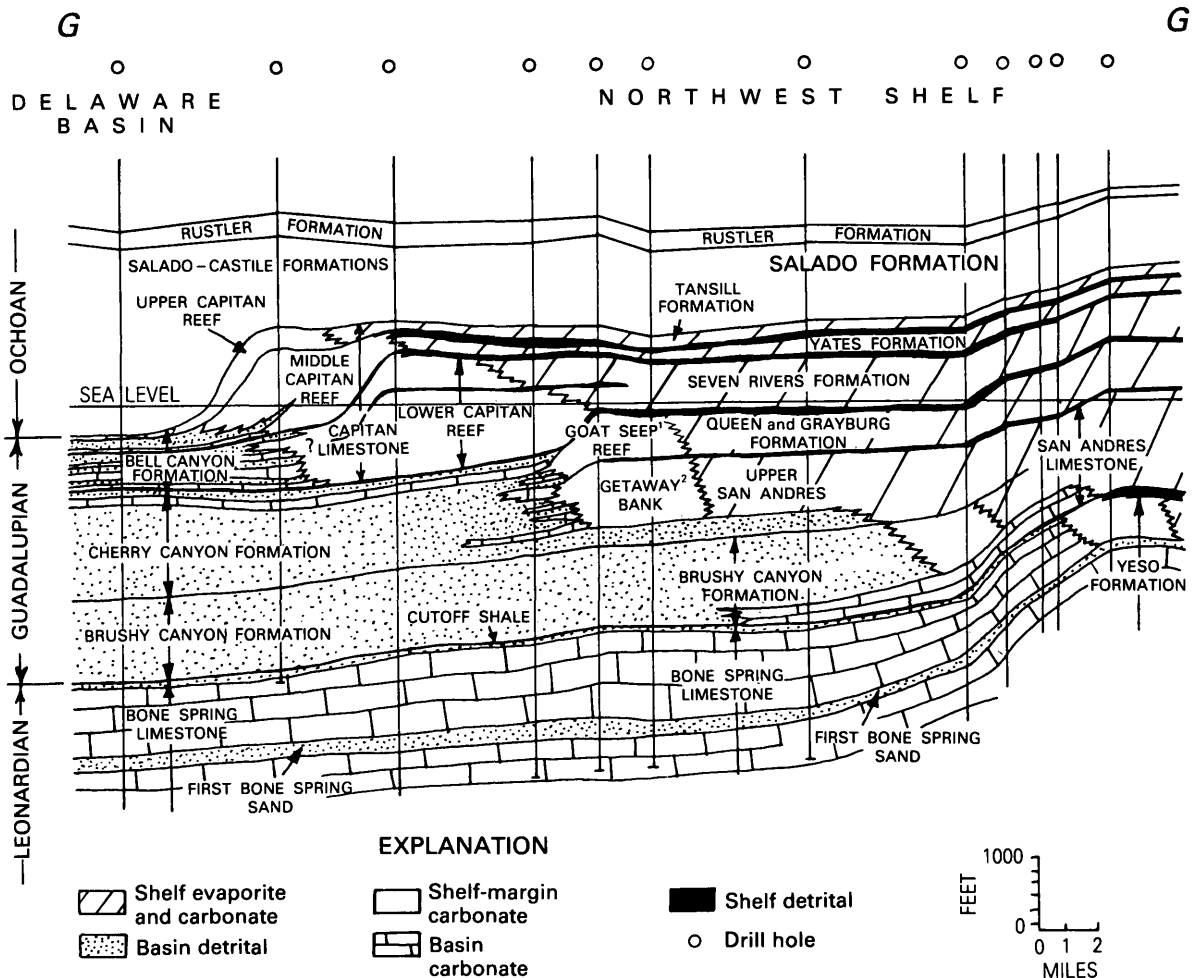
I11

FIGURE 7.—Restored stratigraphic cross section G–G' of the Leonardian (part), Guadalupian, and Ochoan Series of the Permian System through the Northwest shelf and the Delaware basin. Line of section is shown in figure 1B. Restored section is from Silver and Todd (1969).

Luis basins have been set in a right en-echelon pattern (Kelley, 1979) (fig. 1A–1B). The 10,000 feet-thick Santa Fe Group in the Espanola basin is the most complete outcrop section of the rift-forming deposits (Galusha and Blick, 1971; Kelley, 1979). In the Albuquerque basin, only about a fourth of the 12,000 to 13,000 feet of rift-filling nonmarine strata are exposed (Kelley, 1979).

Major horsts and tilted fault blocks adjacent to and within the Rio Grande rift include the San Andres Mountains uplift, Sacramento Mountains uplift, and Caballo Mountains uplift (figs. 1A, 10, 11). Basins and uplifts outside the Rio Grande rift proper, but tectonically akin to the rift, include the Guadalupe Mountains uplift, Brokeoff

Hills uplift, and the Salt basin of southeast New Mexico (figs. 1A, 8, 11).

The Basin and Range province in southwest New Mexico and adjacent southeast Arizona had a different history than the Rio Grande rift. First, crustal extension began in southwest New Mexico about 30 to 29 m.y. ago, but—rather than being expressed as rifting—the extension was confined to plastic stretching of the lower crust of the kind which produced the metamorphic core complexes in southern Arizona (Coney, 1978; Eaton, 1979). Secondly, rifting in southwest New Mexico began later (20 m.y. ago; Elston and others, 1973; Deal and others, 1978) and ended earlier (10 m.y. ago; Eaton, 1979) than rifting in the Rio Grande rift.
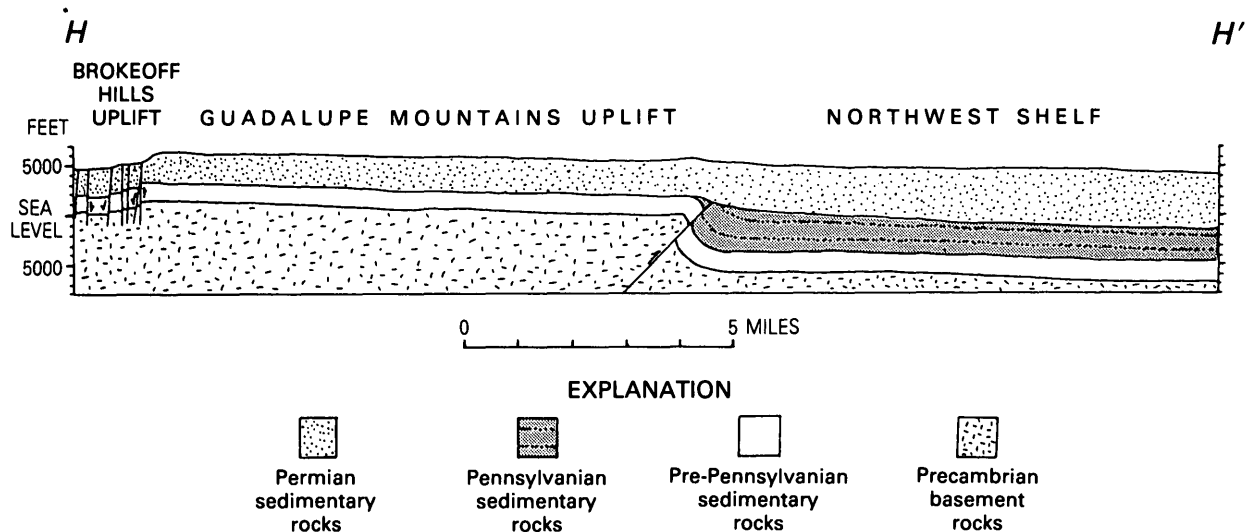
FIGURE 8.—Geologic cross section *H–H'* through the Guadalupe Mountains uplift. Line of section is shown in figure 1B. Cross section is from Hayes (1964).

FIGURE 9.—Geologic cross sections *I–I'* and *J–J'* through parts of the Pedregosa basin and the superimposed Early Cretaceous rift basins. Lines of sections are shown in figure 1B. Cross section *I–I'* is from Drewes and Thorman (1980) and cross section *J–J'* is from Zeller (1975). Place names used in this figure do not appear on figures 1A, 1B, and 1C.

I13
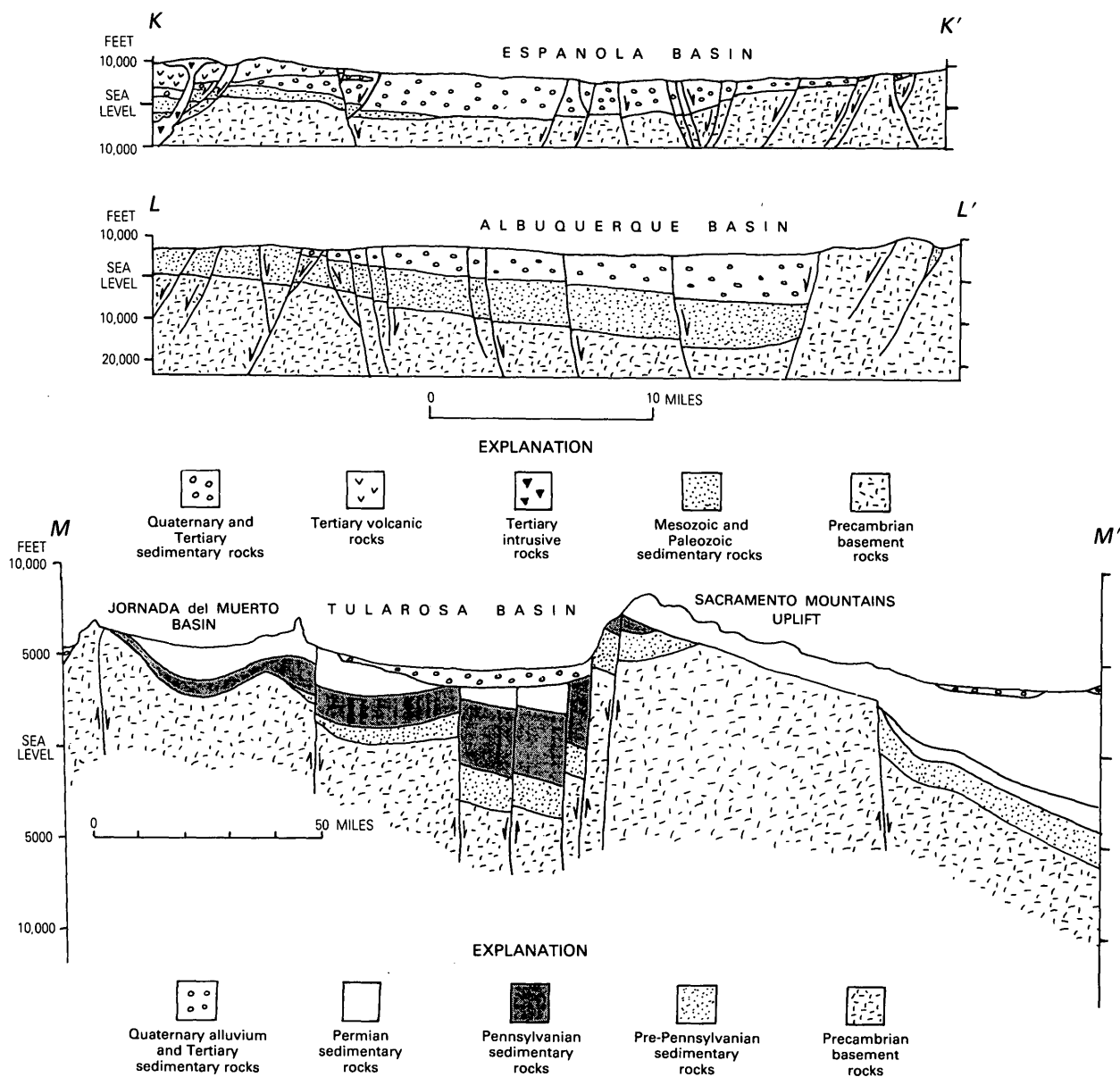
FIGURE 10.—Geologic cross sections through the Espanola basin (*K–K'*), Albuquerque basin (*L–L'*), and Tularosa basin and Sacramento Mountains uplift (*M–M'*). Lines of section are shown in figure 1B. Cross sections *K–K'* and *L–L'* are from Kelley (1979) and cross section *M–M''* is from Oetking and others (1967).

In adjacent southeast Arizona, major rifting may have lasted only between 13 and 10 m.y. ago (Eberly and Stanley, 1978). Finally, the rift basins in southwest New Mexico are generally much shallower than the rift basins in the Rio Grande rift (Seager and Morgan, 1979), a difference that could be attributed to either the longer duration or a greater intensity of rifting in the Rio Grande rift.

TRANSITIONAL ZONE

The transitional zone between the Colorado Plateau and the Basin and Range physiographic provinces (fig. 1A) is an eastward extension of the transitional zone in Arizona (Wilson and Moore, 1959) and the central Arizona transition zone of Lucchitta (1978), who suggests that this zone—with its extensive volcanism, orogeny, deep erosion, and mineralization—may mark a former plate boundary.

I14

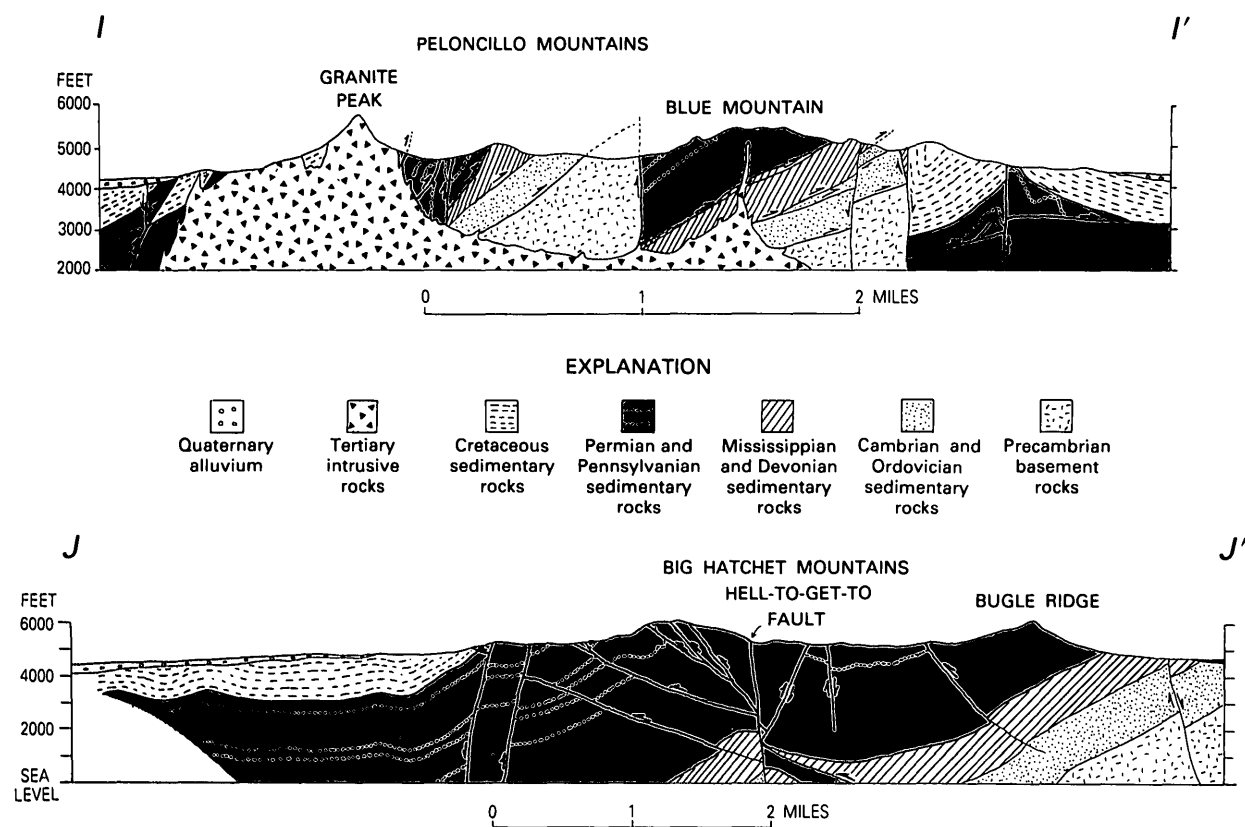FIGURE 11.—Geologic cross section N–N' through the Sacramento Mountains and part of the Guadalupe Mountains uplift. Line of section is shown in figure 1B. Cross section is from Black (1975).

PETROLEUM GEOLOGY

USGS PETROLEUM PROVINCE BOUNDARIES

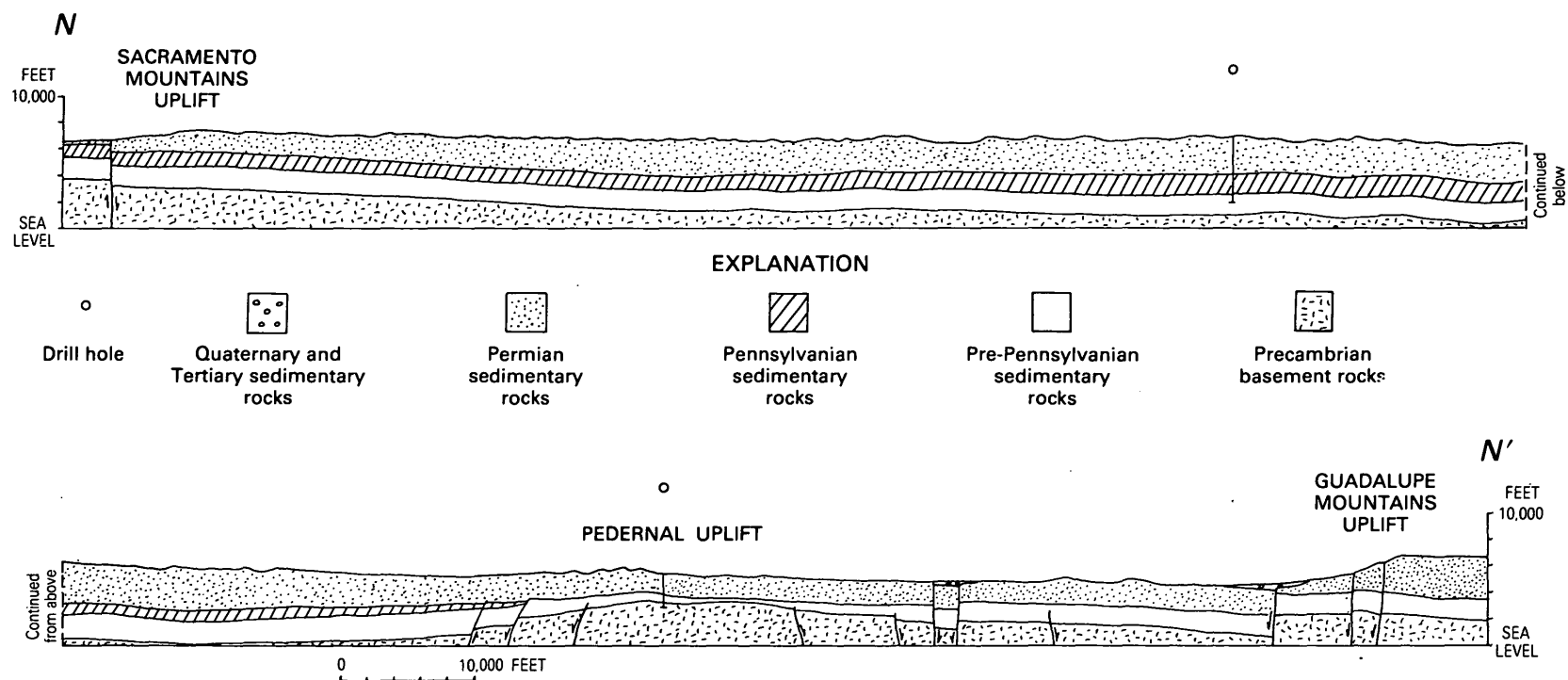The State of New Mexico is subdivided into seven petroleum provinces by the U.S. Geological Survey for which oil and gas resource estimates have been prepared (Dolton and others, 1981). The petroleum province boundaries do not perfectly match the physiographic and tectonic province boundaries because the USGS petroleum provinces often follow county lines to simplify the tabulation of oil and gas data (figs. 1A, C).

OIL AND GAS FIELDS

New Mexico is among the leading producers of oil and gas in the United States. In 1980, New Mexico ranked fourth and seventh in the nation, respectively, for gas and oil production (Broadhead, 1982). Oil and gas fields are confined to the San Juan Basin and the adjacent Four Corners platform in the northwest corner of the State and to the Delaware basin, Northwest shelf, and Central Basin platform in the southeast corner of the State (fig. 1C). Both the northwest and southeast producing provinces have been in existence since the early 1920's (Arnold and others, 1981). The ultimate recovery (cumulative production plus reserves) for the northwest province is estimated to be 178 million barrels of oil (Foster and others, 1978) and 23 trillion cubic feet of gas (Pritchard, 1972). For the southeast province, the ultimate recovery is estimated to be nearly 5 billion barrels of oil (Foster and others, 1978) and 22.5 trillion cubic feet of gas (American Petroleum Institute and American Gas Association, 1980). Gas in northwest New Mexico is predominantly nonassociated, whereas in southeast New Mexico 75 percent of the gas is associated.

Oil in the San Juan Basin and adjacent Four Corners platform comes largely from stratigraphic traps in the Upper Cretaceous Tocito Sandstone Lentil (Molenaar, 1977, 1983) (fig. 2). The largest fields in this trend are Bisti and Horseshoe, both of which are shallow-marine bar complexes and have an ultimate recovery of about 40 million barrels of oil (Sabins, 1963, 1978; McCubbin, 1969; Pritchard, 1972; McEachin and Royce, 1978). Oil fields of lesser importance in the San Juan Basin and adjacent Four Corners platform produce from structural and stratigraphic traps in the Pennsylvanian Paradox Formation (Spencer, 1978), Juras-

sic Entrada Sandstone (Vincelette and Chittum, 1981), Upper Cretaceous Dakota Sandstone (Black, 1978; Luce, 1978), and Upper Cretaceous Mancos Shale (Mallory, 1977).

Most of the gas in the San Juan Basin is produced from the giant, hydrodynamically controlled Blanco Basin gas field located along and adjacent to the axis of the basin (Pritchard, 1972; Molenaar, 1977) (figs. 1C, 2). Major producing horizons in the Blanco Basin field are the Upper Cretaceous Dakota Sandstone (Deischl, 1973; Hoppe, 1978), Point Lookout Sandstone (Pritchard, 1973, 1978), Cliff House Sandstone (Pritchard, 1973, 1978), and the Pictured Cliffs Sandstone (Brown, 1973; 1978) (figs. 1C, 2). Except for the lower part of the Dakota Sandstone which is nonmarine in origin, all the above sandstone units are shallow marine in origin (Molenaar, 1977) (fig. 2).

Major oil-bearing horizons in southeast New Mexico are the Lower Ordovician Ellenburger Group (Symposium Committee, 1956; Sharp, 1956), Middle Ordovician Simpson Group (Hill, 1971), Upper Ordovician Montoya Dolomite (Hill, 1971), Lower and Middle Silurian Fusselman Dolomite (Hill, 1971), unnamed dolomite units of the Devonian System (Bender, 1956; Lewis, 1956), limestone from the Missourian and Virgilian Provincial Series (Upper Pennsylvanian) (Stipp and others, 1956; Meyer, 1966; Hartman and Woodard, 1971) (fig. 6), and dolomite, limestone, and sandstone from the Wolfcampian, Leonardian, and Guadalupian Provincial Series of the Permian System (Stipp and others, 1956; Meyer, 1966; Hartman and Woodard, 1971) (figs. 6, 7).

Oil in Permian-aged rocks of southeast New Mexico is widely distributed in stratigraphic and structural traps across the Northwest shelf and the Central Basin platform. The fields are strongly controlled by depositional facies. Rocks in the back reef and shelf facies are the dominant habitat for oil in the Permian System, as exemplified by the giant Hobbs (McPeters and Kelly, 1956), Eunice-Monument (Babcock, 1956), and Vacuum (Milks, 1956) anticlinal fields where production is from dolomites and sandstones of the San Andres Limestone and Grayburg Formation (figs. 1C, 7). Permian rocks represented by basinal facies yield some oil in the Delaware basin, but the production is generally limited to thin sandstone units (Leonardian-Guadalupian) interbedded with dark carbonate rocks (Symposium

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Committee, 1960; Nottingham, 1960; Broadhead, 1982, 1983) (figs. 1C, 7). Guadalupian shelf-margin reefs are poor reservoirs and produce very little oil (fig. 7). In contrast, the dolomitized shelf-margin reefs of the Abo trend (Leonardian) are responsible for large oil accumulations such as the Empire field (Le May, 1960; Wilson, 1960).

Oil fields in the Ellenburger Group, Simpson Group, Montoya Dolomite, and Fusselman Dolomite are confined to structural traps on the Central Basin platform whereas oil fields in the Devonian dolomites are located in structural traps on the Central Basin platform and the Northwest shelf (Stipp and others, 1956). Missourian and Virgilian limestones yield oil from stratigraphic and structural traps on the Northwest shelf (Stipp and others, 1956; Meyer, 1966) (fig. 6).

At the end of 1979, over three-fourths of the ultimate recoverable gas in southeast New Mexico was estimated to come from gas associated with the oil fields (American Petroleum Institute and National Gas Association, 1980). However, new discoveries have added significantly to the nonassociated gas reserves, probably to the point where the ultimate recoverable gas is divided about equally between associated and nonassociated gas. For example, sandstone interbedded with gray to black shale of Morrowan and Atokan age contains abundant nonassociated gas in southeast New Mexico (Meyer, 1966; David, 1977; Anderson, 1977) (fig. 6). This gas comes from stratigraphic and structural traps in the Delaware basin and Northwest shelf. Wheatley (1981a) reports that the Morrowan sandstone trend alone may contain reserves of 10 trillion cubic feet of gas. The Abo Formation (Wolfcampian) (Meyer, 1966) with interbedded sandstone and red shale units is a relatively new producer of nonassociated gas in the Northwest shelf and it has been estimated to have reserves of 3 trillion cubic feet of gas (Wheatley, 1981b). Other stratigraphic horizons with significant quantities of nonassociated gas in southeast New Mexico are the Ellenburger Group, Fusselman Dolomite, unnamed dolomites in the Devonian System, and Desmoinesian, Missourian, and Virgilian Series of the Pennsylvanian System (Galley, 1971; Hill, 1971; Hartman and Woodard, 1971; David, 1977).

The only commercial oil and gas production from other than northwest and southeast New Mexico is from the Wagon Mound gas field in the Las Vegas basin (fig. 1C). This field produces from the Cretaceous Dakota sandstone and the Upper Jurassic Morrison Formation along the crest of a southeast-trending anticline (Arnold and others, 1978). Carbon dioxide is produced from the Tubb sandstone (Leonardian), an economic unit, in the northeast part of the State adjacent to the Sierra Grande uplift (Broadhead, 1982) (fig. 1C). Several now-abandoned carbon dioxide gas fields on the west flank of the Estancia basin produced from Permian and (or) Pennsylvanian rocks (Beaumont, 1961) (fig. 1C).

THICKNESS AND ORIGIN OF SEDIMENTARY ROCKS

The combined thickness of Paleozoic, Mesozoic, and Tertiary sedimentary rocks is 10,000 feet or greater in (1) the San Juan Basin, (2) the Delaware basin and adjacent Northwest shelf and Central Basin platform, (3) Pedregosa basin and superimposed Lower Cretaceous rift basins, (4) Raton and Las Vegas basins, and (5) at least six Tertiary basins in the Rio Grande rift (Foster and Grant, 1974).

SAN JUAN BASIN

Paleozoic sedimentary rocks in the San Juan Basin range in thickness from about 2,500 to 5,000 feet (Momper, 1957; Peterson and others, 1965). Strata of the Cambrian, Devonian, and Mississippian System are relatively thin or absent and, where present, generally have a combined thickness of less than 500 feet (Loleit, 1963; Parker and Roberts, 1963). Pennsylvanian rocks in the San Juan Basin—composed of marine carbonate rocks, black shale, and evaporite in the center and on the southwest flank of the Paradox basin and equivalent nonmarine arkose and red shale on the northeast flank of the Paradox basin—attain a maximum thickness of about 3,000 feet (Peterson and others, 1965). Permian rocks in the San Juan Basin are largely nonmarine in origin and have a maximum thickness of about 2,100 feet (Peterson and others, 1965).

Mesozoic and Tertiary rocks in the San Juan Basin have a maximum combined thickness between 11,000 and 12,000 feet. The Triassic and Jurassic rocks are largely nonmarine in origin and have a combined thickness ranging from slightly less than 2,000 feet to 3,000 feet (Peterson and others, 1965). As much as 6,500 feet of Cretaceous rocks are present in the San Juan Basin owing largely to the deposition of offshore marine shale,

nearshore marine sandstone, paludal shale, sandstone, and coal, and alluvial plain sandstone and shale at or near a northeastward prograding shoreline (Molenaar, 1977, 1983). Tertiary rocks in the basin are nonmarine and attain a maximum thickness of about 3,500 feet (Peterson and others, 1965; Fassett and Hinds, 1971).

DELAWARE BASIN, NORTHWEST SHELF, AND CENTRAL BASIN PLATFORM

In southeast New Mexico, Paleozoic sedimentary rocks attain a combined thickness of between 9,000 and 23,000 feet (Meyer, 1966; Oriel and others, 1967; Hill, 1971; Hartman and Woodard, 1971; Bachman, 1975). The Paleozoic rocks generally thicken from the Northwest shelf and Central Basin platform into the Delaware basin. A relatively thin section of Triassic and Tertiary rocks, with a combined thickness of 2,000 feet or less, overlies the Paleozoic section throughout most of southeast New Mexico (Stratigraphic Research Committee, 1956).

The Cambrian through Mississippian strata in southeast New Mexico have a combined thickness between 1,000 and 5,000 feet and primarily consist of shelf carbonates with minor amounts of sandstone and black shale (Hill, 1971; Wright, 1979). These strata were removed from the northern extremity of the Northwest shelf by pre-Pennsylvanian and pre-Permian erosion (Stratigraphic Studies Committee, 1953; Stratigraphic Research Committee, 1956). Pennsylvanian rocks thicken from about 1,000 feet on the Northwest shelf to a maximum of about 3,000 feet in the Delaware basin (Meyer, 1966; Bachman, 1975). The Pennsylvanian rocks consist of shelf carbonate rocks and minor intercalated red shale on the Northwest shelf and basinal sandstone and gray to black shale and limestone in the Delaware basin (Meyer, 1966; 1968) (fig. 6). Permian strata thicken from about 7,000 feet on the Northwest shelf to a maximum of about 14,000 feet in the Delaware basin (Oriel and others, 1967; Hartman and Woodard, 1971). Shelf, shelf-margin, and basinal carbonate facies are well defined in the Permian rocks, particularly in the rocks of the Guadalupian Series (Stratigraphic Studies Committee, 1953; Meyer, 1966; Silver and Todd, 1969) (figs. 6, 7).

PEDREGOSA BASIN

Southwest New Mexico has as much as 7,500 feet of Pennsylvanian and Permian rocks in the Pedregosa basin and as much as 15,000 feet of Lower Cretaceous rocks in the superimposed rift basins (Greenwood and others, 1977). More than 5,000 feet of Pennsylvanian and Lower Permian (Wolfcampian) shelf carbonate rocks, shelf-margin carbonate rocks, and basinal black shale and carbonate rocks were deposited in the Pedregosa basin (Ross, 1973). The remaining 2,500 feet of Permian rocks is represented largely by shelf carbonates of the Leonardian Stage (Greenwood and others, 1970). Deposits of the Early Cretaceous rift basins began with conglomerate of alluvial fan origin, but eventually evolved into shallow marine limestone, shale, and sandstone (Hayes, 1970). Cambrian through Mississippian rocks with a maximum combined thickness of as much as 4,000 feet (Kottlowski, 1971; Greenwood and others, 1977) and Tertiary sedimentary and volcanic rocks locally as much as 6,000 feet thick (Thompson and others, 1978) further contribute to the already thick sedimentary section in southwest New Mexico. Because of the complex history of uplift, erosion, and plutonism, the above-mentioned rock units are not uniformly distributed throughout the area (fig. 9). Nonetheless, the overall thickness of this depocenter is impressive.

RATON AND LAS VEGAS BASINS

Sedimentary rocks reach a maximum combined thickness of between 14,000 and 20,000 feet in the Raton basin (Baltz, 1965; Roberts and others, 1976) and 12,700 feet in the Las Vegas basin (Baltz, 1965). The sedimentary section in these basins is largely comprised of Pennsylvanian (about 5,500 feet maximum, Baltz, 1965; Roberts and others, 1976), Permian (about 2,000 feet maximum, Dixon, 1967; Roberts and others, 1976), Cretaceous (4,100 feet maximum, Molenaar, 1983), and Tertiary (5,000 feet maximum, Speer, 1976) rocks. The Pennsylvanian and Lower Permian rocks in the Rowe-Mora basin consist of dark basinal shale in the lower part of the Pennsylvanian System (Morrowan, Atokan, lower Desmoinesian) which are flanked on the west by nonmarine arkosic sandstones and on the east by shelf carbonate rocks (Roberts and others, 1976; Casey, 1980) whereas the upper part of the Pennsylvanian System and the lower part of the Permian System (Wolfcampian) are represented by nearshore carbonate rocks flanked on the north, west, and east by arkosic sandstone and conglomerate (Roberts and others, 1976). Most of the arkosic

rocks· were derived from the adjacent Sierra Grande and Uncompahgre–San Luis uplifts (Roberts and others, 1976). Nearshore marine sandstone and shelf carbonate rocks dominate the upper part of the Permian System (Leonardian and Guadalupian) (Roberts and others, 1976).

A nearly complete section of Cretaceous and Tertiary rocks is preserved in the Raton basin, but in the Las Vegas basin only the lower part of the Cretaceous section is present. The majority of the Cretaceous rocks in both basins are shale and sandstone deposited in offshore marine, nearshore marine, paludal, and alluvial plain environments, along or near an easterly prograding shoreline (Speer, 1976).

BASINS IN THE RIO GRANDE RIFT

Sedimentary rocks attain a thickness of 10,000 feet or more· in the Albuquerque, Espanola, Jornado del Muerto, Mesilla, Tularosa, and San Luis basins (fig. 1A).

Approximately 7,300 feet of Pennsylvanian through Cretaceous strata underlie the 10,000 to 12,000-foot-thick rift-filling Tertiary deposits of the Albuquerque basin (Black and Hiss, 1974). The pre-rift rocks encountered in the Shell Santa Fe No. 1 (fig. 1C) are as follows: 600 feet of Pennsylvanian sandstone, fossiliferous limestone, and black, gray, and reddish brown shale of largely marine origin; 1,400 feet of Permian reddish brown sandstone and mudstone of nonmarine origin and nearshore marine limestone; 2,000 feet of Triassic and Jurassic nonmarine sandtone, variegated mudstone, and local gypsum and dark gray limestone; and 3,300 feet of Cretaceous sandstone and gray shale of offshore marine, nearshore marine, and paludal origin (Black and Hiss, 1974). The Pennsylvanian section in the Albuquerque basin probably thickens southward and westward against the adjacent Lucero uplift (Wengerd, 1959) (fig. 3).

Pre-rift rocks beneath the 10,000-foot-thick rift-filling Tertiary deposits of the Espanola basin probably have about the same thickness and lithologic characteristics as the pre-rift rocks in the Albuquerque basin (Black, 1979a; Ingersoll and Kelley, 1979). However, Permian and Pennsylvanian rocks may be thinner in the Espanola basin than in the Albuquerque basin and contain a greater proportion of nonmarine rocks.

In the San Luis basin the Pennsylvanian and Permian section thins to a zero edge over the Un-compahgre–San Luis uplift, except possibly along the east side of the basin where several thousand feet of proximal Pennsylvanian rocks may have been preserved (Baltz, 1965; Rascoe and Baars, 1972; Mallory, 1972). Triassic, Jurassic, and probable Cretaceous rocks also thin from south to north across the San Luis basin (Baltz, 1965). Lipman and Mehnert (1979) suggest in a diagrammatic cross section through the San Luis basin that at least 9,000 feet of Tertiary rift deposits fill the deepest part of the basin.

The Jornadá del Muerto (about 6,700 feet maximum), Mesilla (about 10,100 feet maximum), and Tularosa (about 8,800 feet maximum) basins have a slightly greater thickness of pre-rift rocks than the northern rift basins (Greenwood and others, 1977). Moreover, the pre-rift rocks of the Jornada del Muerto, Mesilla, and Tularosa basins are nearly all Paleozoic in age. Cambrian through Mississippian rocks in the southern rift basins are largely shelf carbonate rocks with secondary sandstone and black shale (Kottlowski, 1971; Greenwood and others, 1977). The thickness of these rocks ranges between zero and 2,800 feet in the Jornado del Muerto and Tularosa basins and between 2,500 and 3,600 feet in the Mesilla basin (Greenwood and others, 1977). Most of the Paleozoic rocks are absent in the northern part of the Jornada del Muerto and Tularosa basins (Greenwood and others, 1977).

The Tularosa Basin is situated over the center of the Pennsylvanian-Permian Orogrande basin, whereas the Jornada del Muerto and Mesilla basins are located on the flanks of the Orogrande basin (Meyer, 1966; Greenwood and others, 1977). Pennsylvanian rocks attain a maximum thickness of about 3,500 feet in the center of the Tularosa Basin and thin to about 2,000 feet or less in the Jornada del Muerto and Mesilla basins (Greenwood and others, 1977). Shelf carbonate rocks, sandstone, and variegated shale of marine and nonmarine origin are the dominant rock types in the Orogrande basin (Meyer, 1966); however at times, particularly in the Virgilian, basinal, shelf margin, and shelf facies developed in the Orogrande basin. Locally, dark gray basinal shale and shelf-margin bioherms are present (Pray, 1961; Kottlowski, 1971).

Permian rocks in the Orogrande basin are similar to the Pennsylvanian rocks except that the Permian section contains more sandstone, red shale, and evaporite. Shelf-margin carbonate

rocks and basinal dark shale and carbonate rocks are present in the Wolfcampian (Meyer, 1966; Kottlowski, 1971). The maximum thickness of the Permian rocks is about 2,000 feet in the Jornada del Muerto basin and about 3,000 feet in the Mesilla and Tularosa basins (Greenwood and others, 1977).

Approximately 1,000 feet of Lower Cretaceous rocks are present in the southern basins of the Rio Grande rift and about 700 feet of marine Jurassic rocks are present in the Mesilla basin (Thompson and Bieberman, 1975; Greenwood and others, 1977). The combined thickness of the pre-rift and rift-filling Tertiary rocks is about 3,000 feet in the Jornada del Muerto basin (Sanford, 1968), about 6,000 feet in the Tularosa Basin (McLean, 1970), and 12,000 feet in the Mesilla basin (Thompson and Bieberman, 1975).

SOURCE ROCKS, HYDROCARBON SHOWS, AND THERMAL MATURITY

Organic-rich rocks, which have generated or are capable of generating significant quantities of oil and gas in New Mexico, are Pennsylvanian and Permian black marine limestone and shale, Upper Cretaceous offshore marine shale, Upper Cretaceous paludal carbonaceous shale and coal, Upper Devonian marine black shale, and Middle Jurassic lacustrine(?) black limestone. Depending upon burial history, regional geothermal gradient, and proximity to magmatic activity, these rocks have attained a variety of maturation levels—with respect to hydrocarbon generation—ranging from immature to overmature.

PENNSYLVANIAN AND PERMIAN BLACK LIMESTONE AND SHALE

Pennsylvanian and Permian black shale and limestone are unquestionably the source for the numerous oil and gas accumulations in Pennsylvanian and Permian reservoirs of the Northwest shelf, Central Basin platform, and Delaware basin (Jones and Smith, 1965; Meyer, 1966). Moreover, oil and gas fields in Pennsylvanian rocks of the Four Corners platform were probably supplied by Pennsylvanian black shale beds. The weight percent organic carbon of the Pennsylvanian black shales in that area ranges from less than 1 to about 1.5 (Ross, 1980).

Black shale and limestone units of Pennsylvanian and (or) Permian age are present in many deep and thermally mature, but presently nonpro-

ducing, basins such as the Albuquerque basin, Jornada del Muerto basin, Las Vegas basin, Mesilla basin, Pedregosa basin, Raton basin, and Tularosa Basin. Oil and gas shows in Paleozoic rocks of these basins probably originated from Pennsylvanian and (or) Permian black shales (Petroleum Information Well History Control System (WHCS) files);(Northrop and others, 1946; McCaslin, 1974; Foster and Grant, 1974; Thompson and Bieberman, 1975; Thompson and others, 1978). A positive correlation between oil and gas shows in Paleozoic rocks and the presence of Pennsylvanian and (or) Permian black shale is also evident in marginally mature basins and uplifts such as the Estancia basin, Tucumcari basin, and Lucero uplift (Beaumont, 1961; Kottlowski, 1971; Reese, 1975; McCaslin, 1982, 1983).

Detailed geochemical studies of samples from the KCM No. 1 Forest Federal drill hole (fig. 1C), Humble No. 1 State BA (fig. 1C) drill hole, and nearby outcrops suggest that the Pennsylvanian and (or) Permian black shales and limestones in the Pedregosa basin have a maximum weight percent organic carbon value of slightly less than 1 and have kerogen types which are gas prone (Cernock, 1977; Cernock and Bayliss, 1977; Thompson, 1980). A Conodont Alteration Index (CAI) of 5 in the KCM No. 1 Forest Federal drill hole indicates that the Paleozoic rocks in this well have been heated above the limit of dry gas generation (Behnken, 1977; Harris and others, 1978). However, this CAI value is strongly influenced by a quartz monzonite pluton encountered in the drill hole at a depth of 4,116 feet (Thompson, 1977) and thus may not be indicative of the regional paleotemperature. B. R. Wardlow and A. G. Harris (unpub. data) have shown, in the Pedregosa basin of Arizona, that once the excessively high CAI values near plutons have been removed the CAI values range between 3 and 4. If the Pennsylvanian and Permian rocks in the New Mexico part of the Pedregosa basin have similar CAI values, the implied burial history would be favorable for the generation of gas.

UPPER CRETACEOUS SHALE AND COAL

The Upper Cretaceous Mancos Shale, with weight percent organic carbon values up to 2, is the probable source for most of the oil fields in Cretaceous rocks in the San Juan Basin (Ross, 1980). In contrast, most of the gas in the San Juan Basin was probably generated from thick se-

quences of carbonaceous shale and coal of paludal origin (Buckner, 1976; Rice and Threlkeld, 1983). Gas in the Wagon Mound field was probably generated from carbonaceous shale units in the Dakota, but in light of the thin Cretaceous and Tertiary overburden in the Las Vegas basin, the gas may be biogenic rather than thermal in origin. Thick, thermally mature sequences of Upper Cretaceous gray marine shale, carbonaceous shale, and coal are present in the Albuquerque basin and undoubtedly these rocks have been the source of oil and gas shows reported in the Cretaceous section (Black, 1979a). Oil and gas shows in Cretaceous rocks of the Espanola (Black, 1979b) and Raton (Speer, 1976) basins were probably generated from gray offshore marine shale and paludal carbonaceous shale beds.

DEVONIAN BLACK SHALE

An Upper Devonian marine black shale, between 100 and 400 feet thick, extends across most of southern New Mexico (Greenwood and others, 1977; Wright, 1979). In southeast New Mexico this black shale unit is known by some geologists as the Woodford Shale and is commonly thought to have been the source of much of the pre-Pennsylvanian oil and gas on the Northwest shelf and Central Basin platform (Greenwood and others, 1977; Wright, 1979). In south-central and southwest New Mexico this black shale unit is called the Percha Shale, but the source-rock characteristics remain the same. The Percha Shale may have been the source for the oil and gas shows in the pre-Pennsylvanian rocks of the Pedregosa (Thompson and others, 1978) and Mesilla (Thompson and Bieberman, 1975) basins.

MIDDLE JURASSIC LIMESTONE

The black limestone member of the Middle Jurassic Todilto Formation is the probable source of the oil fields in the Jurassic Entrada Sandstone of the San Juan Basin (Ross, 1980; Vincelette and Chittum, 1981). In the San Juan Basin this limestone unit is thermally mature, yields up to 24 gallons of oil per ton, and has a maximum weight percent organic carbon value of about 1 (Ross, 1980; Vincelette and Chittum, 1981). Tanner (1974) suggests that the Todilto Formation may be lacustrine in origin. The organic-rich limestone unit in the Todilto Formation extends as far east as the Albuquerque basin where it is the probable source of oil shows in the Entrada Sandstone (Black, 1979a).

Thompson and Bieberman (1975) suggest that an organic-rich, marine Jurassic unit (limestone?) in the Mesilla basin has the potential for being a petroleum source rock. However, the areal extent of this unit in New Mexico seems to be rather limited (Greenwood and others, 1977).

RESERVOIRS AND TRAPS

Major reservoir characteristics and trapping conditions have already been discussed for the hydrocarbon fields of the San Juan Basin, Northwest shelf, Central Basin platform, and Delaware basin. The following discussion will mention briefly those stratigraphic units where hydrocarbons would most likely reside in presently unproductive basins of New Mexico and what the mode of entrapment might be.

The Epitaph Dolomite (Permian), Concha Limestone (Permian), and the shelf-margin dolomite units of the Horquilla Limestone (Pennsylvanian-Permian) seem to be the most prospective reservoir units in the Pedregosa basin (Greenwood and others, 1977; Thompson, 1980). Reservoirs of secondary importance in the vicinity of the Pedregosa basin include local rudistid reefs in the U-Bar Formation (Lower Cretaceous), shallow marine sandstone in the Mojado Formation (Lower Cretaceous), and shelf carbonates and dolomites in the El Paso Limestone (Ordovician), Montoya Dolomite (Ordovician), and Fusselman Dolomite (Silurian) (Thompson and others, 1978). A wide variety of structures, some in combination with stratigraphic variations suitable for hydrocarbon traps, are present in the Pedregosa basin.

Pennsylvanian and Lower Permian shelf carbonate rocks with local sandstone and shelf-margin carbonate rocks (Magdalena Group) and dolomite in the Permian San Andres Limestone seem to be the most important potential reservoir units in the Jornada del Muerto and Tularosa basins (Greenwood and others, 1977; Thompson and others, 1978). Both structural and stratigraphic traps are available. The El Paso Limestone, Montoya Dolomite, and Fusselman Dolomite may also be important reservoirs in the Jornada del Muerto and Tularosa basins, particularly in areas where truncation traps are available (Kottlowski, 1971; Foster and Grant, 1974). The favorable reservoirs in the Jornada del Muerto and Tularosa basins also are present in the Mesilla basin; in addition, Lower Cretaceous sandstone units are possible reservoirs in the latter (Foster and Grant, 1974).

Potential traps in the Mesilla basin are largely of the structural variety (Foster and Grant, 1974).

The primary stratigraphic units with reservoir potential in the Albuquerque basin, and probably the Espanola basin, are Upper Cretaceous shallow marine sandstones such as the Dakota, Gallup, and Point Lookout Sandstones, the Middle Jurassic Entrada Sandstone, and shelf carbonates in the Pennsylvanian Madera Limestone. Faults and drape folds associated with individual fault blocks provide a trapping mechanism, in addition to the southward pinch out (truncation) of the Entrada Sandstone across the southern part of the Albuquerque basin and facies variations and pinch outs in the Cretaceous sandstones (Black, 1979a; Kelley, 1979).

Shallow marine sandstone units in the Upper Cretaceous Trinidad Sandstone and the Lower and Upper Cretaceous Dakota Sandstones have the best potential as petroleum reservoirs in the Raton and Las Vegas basins (Baltz, 1965; Speer, 1976). Shelf carbonates of the Pennsylvanian Madera Limestone and nearshore marine conglomeratic sandstones of the Sandia Formation may also be good reservoir units in the Las Vegas basin (Baltz, 1965; Foster and Grant, 1974). Both anticlinal and stratigraphic traps are present in the Raton and Las Vegas basins. Other traps may be formed by the updip truncation of the Madera Limestone and Sandia Formation in the northern part of the Las Vegas basin beneath the Permian-Pennsylvanian Sangre de Cristo Formation (Baltz, 1965; Foster and Grant, 1974).

SUMMARY STATEMENT

Aside from the San Juan Basin, Delaware basin, Northwest shelf, and Central Basin platform, much of New Mexico is a frontier area in terms of oil and gas exploration. However, given the complex tectonic and magmatic history and the susceptibility of many of the potential reservoir rocks to flushing by freshwater, the hydrocarbon potential in these frontier areas is considered by the author to be low to moderate. One of the major problems that may have precluded large hydrocarbon accumulations from forming in the present frontier areas of the State is that the oil and gas may have been redistributed from primary traps to secondary and tertiary traps as various generations of faults evolved in a given rift system. Commonly, these redistributed hydrocarbons escaped

to the atmosphere. Another problem is that many hydrocarbons or hydrocarbon source rocks may have been destroyed by high thermal regimes associated with plutonism and volcanism.

The Pedregosa basin—with good source rocks, good reservoirs, and local hydrocarbon shows— seems to be one of the more promising frontier areas in New Mexico for oil and gas exploration. Unfortunately, most of the oil and gas in the area probably was generated during or shortly after a thick section of sedimentary rocks was deposited in the superimposed Early Cretaceous rift basins; thus oil and gas accumulations were subject to redistribution or destruction by Laramide, middle Tertiary, and late Tertiary tectonic and magmatic episodes that followed.

The question of whether or not the Cordilleran fold and thrust belt extends across southwest New Mexico and adjacent Arizona is still unresolved. However, the results of the Phillips Arizona State No. A–1 drill hole (Reif and Robinson, 1981) strongly suggest that if the thrust belt does extend through southwest New Mexico, it is not expressed as a major allochthon of crystalline rocks that overlies a thick, previously unknown and unexplored section of Paleozoic and Mesozoic sedimentary rocks (Hansen and others, 1980). Therefore, this unanswered question concerning the presence or absence of the thrust belt probably does not significantly affect the overall assessment of the oil and gas potential of southwest New Mexico.

Rift basins in the southern part of the Rio Grande rift, such as the Jornada del Muerto, Mesilla, and Tularosa basins, also are promising areas for oil and gas exploration because of good source rocks, good reservoir rocks, and local hydrocarbon shows. However, these basins are plagued by the same problems that exist in the Pedregosa basin and superimposed Early Cretaceous rift basins, namely, repeated episodes of extensional tectonism, magmatism, and volcanism.

The better opportunities for finding oil and gas in the Pedregosa basin and the basins in the southern Rio Grande rift probably exist in the deep parts of the basins where initially trapped hydrocarbons were least affected by repeated extensional tectonism and flushing by freshwater. Known centers of plutonism and volcanism should be avoided for petroleum exploration. Tertiary strata near the flanks of the basins may also have trapped hydrocarbons which were redistributed

from preexisting oil and (or) gas accumulations in pre-rift rocks.

Commercial oil and gas accumulations may also be found in the Albuquerque basin, but deep drilling here has proven disappointing to date. Only one major gas show has been reported (Broadhead, 1983). A major difficulty could be the recognition of a trap that is well sealed and predates the migration of hydrocarbons. Despite these economic failures, the recent deep drilling by the oil industry in the Albuquerque basin exemplifies the type of action that must be taken if commercial hydrocarbons are to be found in the Rio Grande rift.

The Espanola and San Luis basins are not as attractive for hydrocarbon exploration as the Albuquerque basin but, nonetheless, may have some potential. The best exploration objectives are Cretaceous rocks in the Espanola and San Luis basins, supplemented by Pennsylvanian rocks in the Espanola basin. Major drawbacks to exploration in these basins, in addition to multiple phases of extensional tectonics and the recognition of a suitable trap, may be the proximity of the Jemez volcanic province to the Espanola basin and the probable lack of Pennsylvanian reservoir and source rocks in the San Luis basin.

Other basins and uplifts along the Rio Grande rift that may yield commercial hydrocarbons include the Salt basin and the Guadalupe Mountains uplift (fig. 1A). Basins and uplifts such as the Estancia basin, Caballo Mountains uplift, Sacramento Mountains uplift, and San Andres Mountains uplift are less desirable because many of the reservoir objectives are exposed and are susceptible to flushing by freshwater.

Of the basins outside the Rio Grande rift and the southwestern part of the Basin and Range province, the Las Vegas basin, Raton basin, and possibly the Tucumcari basin have the best potential for yielding commercial hydrocarbons. Basins and uplifts such as the Acoma basin, Chama basin, Lucero uplift, Sierra Grande uplift, and Zuni basin are not as favorable for oil and gas accumulations because of their thin sedimentary cover and their susceptibility to flushing by freshwater.

PETROLEUM POTENTIAL OF WILDERNESS LANDS

On the basis of the geologic framework and petroleum geology outlined in the previous sections,

the hydrocarbon potential of the Wilderness Lands in New Mexico is rated qualitatively on a scale from high to zero. A high rating is assigned to Wilderness Lands that are located near or along the projected trend of hydrocarbon production and have all the geologic attributes of the producing area. A medium rating is assigned to Wilderness Lands that have all the attributes, including shows, of a future petroleum producing area, but lack commercial production. In contrast, low and zero ratings are assigned, respectively, to Wilderness Lands that have few or no attributes of a future petroleum producing area. Usually a zero rating is reserved for regions characterized by autochthonous igneous and metamorphic rocks.

For ease of discussion, the Wilderness Lands in New Mexico are grouped into 18 clusters (fig. 12), each containing one or more tracts that have the same or similar geologic characteristics and the same hydrocarbon potential.

Cluster 1

Cluster 1 is comprised of a single tract of Wilderness Land along the west flank of the Mesilla basin in south-central New Mexico near the Mexico and Texas border (figs. 1A, 12). Quaternary basalt is exposed throughout the tract (Dane and Bachman, 1965). Judging from the sedimentary rocks in the nearby Grimm et al No. 1 Mobil-32 drill hole, the author believes a thick section of Paleozoic rocks probably exists beneath the basalts (Thompson and Bieberman, 1975) (fig. 1C). Oil and (or) gas shows were reported in the Grimm No. 1 drill hole from Tertiary rocks, Lower Cretaceous rocks, Pennsylvanian rocks, and the Ordovician Montoya Dolomite (Thompson and Bieberman, 1975). Because of the hydrocarbon shows and the thick section of sedimentary rocks in the Grimm No. 1, the hydrocarbon potential of the tract in cluster 1 is rated medium. Units having the best reservoir potential are Lower Cretaceous rocks, Pennsylvanian and Permian rocks, the Fusselman Dolomite, the Montoya Dolomite, and the El Paso Limestone. Units having the best source rock characteristics in the cluster are the Devonian Percha Shale, Permian black shale, and Jurassic marine rocks (Thompson and Bieberman, 1975). Anticlines, faulted anticlines, and tilted fault blocks are the most probable traps. Negative aspects of cluster 1 in terms of oil and gas exploration are adjacent centers of volcanism and complex faulting associated with the development of the Rio Grande rift.
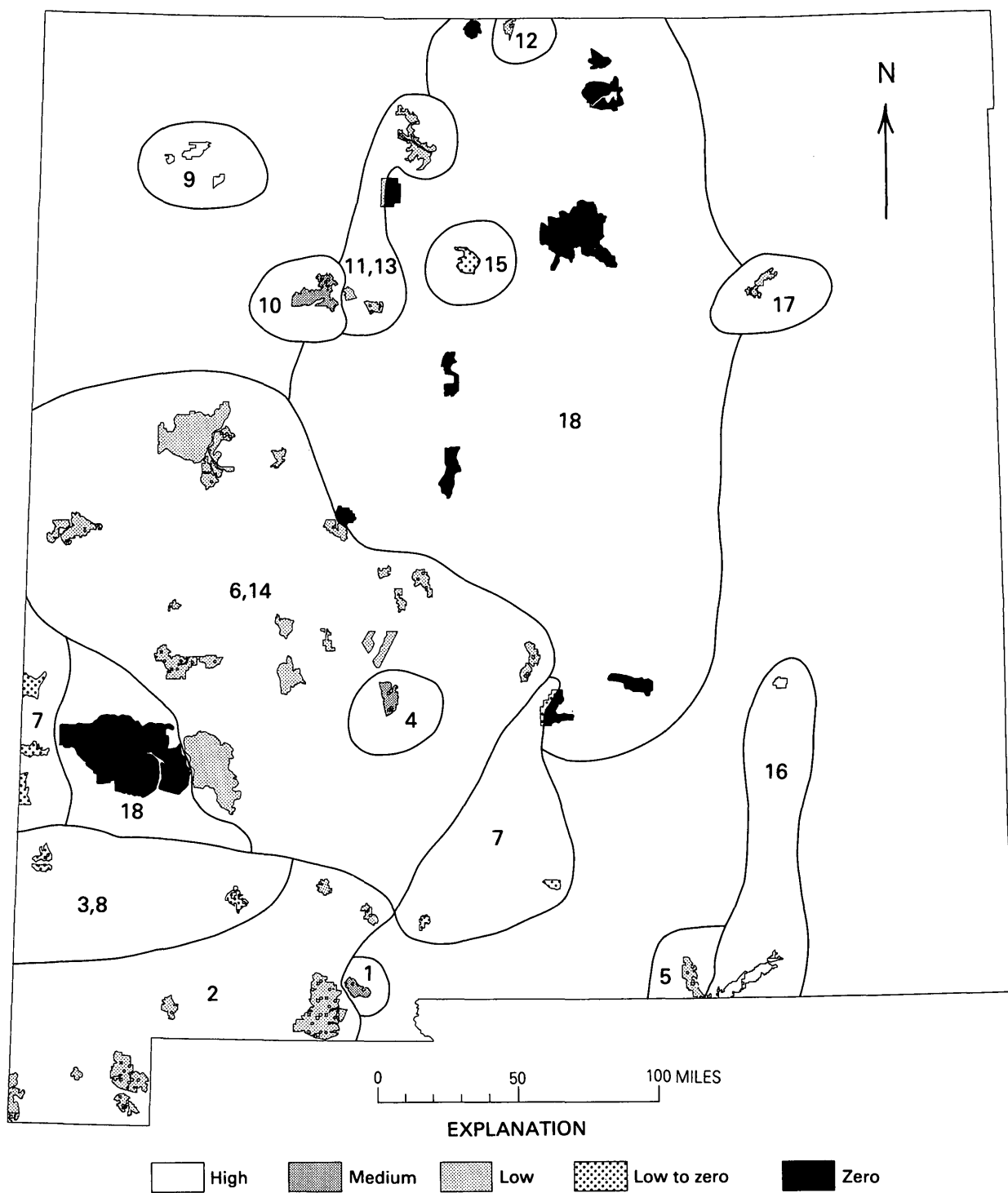
FIGURE 12.—Map showing the qualitative estimate of petroleum potential for Wilderness Lands in New Mexico. The heavy lines and associated numbers define clusters of Wilderness Lands that have the same or similar geologic characteristics and the same hydrocarbon potential.

Cluster 2 contains 12 tracts of Wilderness Lands in southwesternmost New Mexico that are distributed across the Pedregosa basin, Early Cretaceous rift basins, and the southern part of the Rio Grande rift (figs. 1*A*, 12). The hydrocarbon potential of these tracts is rated low.

The tracts in the Pedregosa basin and superimposed Early Cretaceous basins have a thick section of Paleozoic and Lower Cretaceous rocks. Some of these rocks are allochthonous (fig. 9, section *J–J'*). Source rocks, reservoir rocks, structural traps, and thermal history are at least locally favorable for the generation and entrapment of hydrocarbons. By analogy to the thermal history of the Pedregosa basin in Arizona (B. R. Wardlaw and A. G. Harris, unpub. data), the thermal history of the Pedregosa basin in New Mexico probably favors the generation of gas over oil. Kerogen types in the Pennsylvanian black shale and limestone also favor the generation of gas over oil (Thompson, 1980). Both oil and gas shows have been reported from drill holes near the tracts (Thompson and others, 1978). However, hydrocarbons generated in these tracts are very prone to leakage and destruction owing to the presence of several generations of faults and plutons, many of which postdate the major phase of oil and gas generation and migration. Elston (1976) estimates that as much as a third of southeast New Mexico may be underlain by plutons such as the one encountered in the KCM No. 1 Forest Federal drill hole (Thompson, 1977). The location of the tracts along structurally high fault blocks, which permit the entry of freshwater, further reduce their hydrocarbon potential.

The easternmost tract in the cluster is located on an intrarift horst block between the Goodsight–Cedar Hills depression and the Jornada del Muerto basin (fig. 1*A*). Pennsylvanian and Permian sedimentary rocks intruded by thick rhyolite sills crop out at the surface and are very susceptible to flushing by freshwater. No shows were reported in a nearby drill hole that reached Precambrian basement rocks (Thompson and Bieberman, 1975). A small piece of this tract is grouped with cluster 6 for the quantitative petroleum assessment because it falls across the south-central petroleum province boundary, but for this discussion it will be included in cluster 2.

The tracts in the easternmost part of cluster 2 are in or adjacent to the Goodsight–Cedar Hills

depression, a large cauldron filled with up to 2,000 feet of ash-flow tuff and lava flows (fig. 1*A,B*). Two nearby drill holes indicate that about 3,500 feet of Paleozoic rocks are present beneath the cover of volcanic rocks (Thompson and Bieberman, 1975; Thompson and others, 1980). One of the drill holes is about 5 miles southeast of the northernmost tract in the depression. This drill hole yielded no oil and gas shows and the reservoirs have probably been flushed by freshwater (Thompson and Bieberman, 1975). The second drill hole is in the southwest corner of the large tract south of the Goodsight–Cedar Hills depression. Gas shows were reported in this well from the El Paso Limestone (Thompson and others, 1980). The hydrocarbon potential of the large tract south of the Goodsight–Cedar Hills depression is rated lower than the adjacent tract in the Mesilla basin (cluster 1) because the sedimentary section in the tract near the Goodsight–Cedar Hills depression is thinner and is cut by more dikes, sills, and volcanic pipes than the tracts in the Mesilla basin.

Clusters 3 and 8 consist of three small tracts of Wilderness Lands that are in or adjacent to the transitional zone between the Basin and Range and Colorado Plateau physiographic provinces (figs. 1*A*, 12). The hydrocarbon potential of these clusters is rated low to zero. The eastern tract in these clusters has Paleozoic and Cretaceous strata at the surface intruded by a Cretaceous and (or) Tertiary pluton. The western tracts probably contain no Paleozoic rocks and only a thin section of Cretaceous rocks (Dane and Bachman, 1965); Precambrian rocks crop out a few miles northwest of both groups of tracts.

Cluster 4 is comprised of a single tract of Wilderness Land in the northern part of the Jornada del Muerto basin (figs. 1*A*, 12). Quaternary basalt is exposed throughout the tract (Dane and Bachman, 1965) (fig. 1*B*). The hydrocarbon potential of this tract is rated medium because of the location of the tract near the axis of the basin and because 5,000 to 6,000 feet of Pennsylvanian, Permian, and Upper Cretaceous rocks are present beneath the cover of volcanic rocks. Some pre-Pennsylvanian sedimentary rocks may also be present. Also, oil and gas shows have been reported from several drill holes in the deep part of the Jor-

nada del Muerto basin about 25 miles south of cluster 4. Strata in cluster 4 are probably thermally immature because of their thin overburden, so for hydrocarbons to be present they had to migrate there from the south. Pennsylvanian rocks and the Ordovician El Paso Limestone are the most likely exploration objectives. Tilted fault blocks and (or) associated anticlines are the most probable traps, although traps involving the northward truncation of the El Paso Limestone are possible. Perhaps the most negative aspect of the tract, in terms of oil and gas exploration, is that freshwater could easily enter the basin through outcrops of Paleozoic rocks along the west flank of the basin reducing the potential for petroleum.

Cluster 5

Cluster 5 is represented by a single tract of Wilderness Land in the Brokeoff Hills uplift of southeast New Mexico, a highly faulted subblock of the Guadalupe Mountains uplift (figs. 1A, 12). The wilderness tract is about 20 miles west of the nearest gas field on the Northwest shelf (fig. 1C). Permian rocks of the Guadalupian Stage are exposed throughout the tract (Dane and Bachman, 1965). The numerous northwest trending faults that transect the wilderness tract were probably formed during the late Tertiary phase of rifting in the Basin and Range province and, thus, postdated the major late Paleozoic phase of oil and gas generation and migration in the Delaware basin and Northwest shelf. Most likely, any hydrocarbons trapped in the Brokeoff Hills area as a result of the late Paleozoic phase of generation and migration would have been severely dislocated by the extensional faulting and escaped to the atmosphere. Drill holes near the wilderness tract have not yielded oil and gas shows. The hydrocarbon potential of cluster 5 is rated low.

Clusters 6 and 14

Clusters 6 and 14 consist of numerous tracts of Wilderness Lands spread across the southern part of the Colorado Plateau province, the eastern part of the transitional zone, and the southern part of the Rio Grande rift (figs. 1A, 12). The hydrocarbon potential in these tracts is rated low.

The tracts in the Colorado Plateau province occupy parts of the Zuni basin, Zuni uplift, Acoma basin, Lucero uplift, and the northern flank of the San Augustin basin (figs. 1A, 12). Quaternary and Tertiary basalts, Upper Cretaceous marine and nonmarine rocks, and Triassic nonmarine rocks are the most commonly exposed rocks in these tracts and the total sedimentary section is less than 5,000 feet thick. It is doubtful if the strata of source rock quality in these tracts have been buried deeply enough to generate oil and gas. Only one of a half dozen or more drill holes in or near the tracts has yielded hydrocarbon shows.

Rocks of the Datil-Mogollon volcanic field are exposed throughout the tracts of the transition zone. The interior parts of the volcanic field, such as clusters 7 (part) and 18, are most likely underlain by a large pluton or complex of plutons (Elston and others, 1976). However, around the fringes of the volcanic field, where tracts in clusters 6 and 14 are located, Paleozoic rocks and possibly Cretaceous rocks with adequate source and reservoir characteristics may underlie the cover of volcanic rocks.

All but one of the remaining tracts in clusters 6 and 14 are astride intrarift horst blocks in the Rio Grande rift between the San Augustin and Jornada del Muerto basins. The exception is a tract on the northwest flank of the Sierra Blanca basin, a northern extension of the Tularosa Basin (figs. 1A, 12). Many of the intrarift horst blocks are comprised of 3,000- to 4,000-foot-thick sections of Pennsylvanian, Permian, and Upper Cretaceous rocks. Commonly, these tracts are capped by volcanic rocks of the Datil-Mogollon volcanic field and by Tertiary rift-filling deposits. The rocks in the horst blocks are probably thermally immature, and even if hydrocarbons had been generated they would have been very susceptible to flushing by freshwater. The most probable sites for hydrocarbon accumulations in these tracts are in the Tertiary rift basins that adjoin several of the intrarift horst blocks. Of the half dozen or so drill holes adjacent to these tracts, only one (about 18 miles south of Socorro) has a hydrocarbon (gas) show.

The single tract on the northwest flank of the Sierra Blanca basin is comprised of about 1,800 to 2,000 feet of Pennsylvanian rocks (Meyer, 1966), about 5,000 to 6,000 feet of Permian rocks (Meyer, 1966; Petroleum Information WHCS file), and a cover of Quaternary basalt. The sedimentary section is thicker by about 500 to 1,000 feet if the Mesozoic rocks along the eastern margin of the tract are included. A large northeast trending anticline, which has been tested without shows to as deep as the Precambrian basement, extends

through the northern part of the tract (Woodward and others, 1975). Oil and gas shows have been reported from Permian rocks in several drill holes less than two miles northeast of the tract. The hydrocarbon potential of this tract is not rated higher because part of the section has been intruded by Cretaceous and (or) Tertiary plutons (Dane and Bachman, 1965) and many of the units having reservoir potential are susceptible to flushing by freshwater.

Cluster 7

Cluster 7 contains tracts in the western part of the transitional zone, along the flanks of the Jornada del Muerto and Tularosa basins, and near the center of the Sierra Blanca basin (figs. 1A, 12). The hydrocarbon potential of these tracts is rated low to zero.

The three westernmost tracts in cluster 7 have volcanic rocks of the Datil-Mogollon volcanic field at the surface. These tracts are rated low to zero because Paleozoic rocks are probably absent (Greenwood and others, 1977) and those sedimentary rocks that are present have probably been intruded by major plutons (Elston and others, 1976).

The tract on the east flank of the Jornada del Muerto basin, south of the San Andres Mountains uplift, is dominated by a large Cretaceous and (or) Tertiary pluton which has pervasively intruded adjacent Paleozoic rocks. Hydrocarbons, if present at all in the area, would be located beneath the Tertiary rift deposits adjoining the westernmost part of the tract.

The tract in the Sierra Blanca basin has also been intruded by a large Cretaceous and (or) Tertiary pluton. Sedimentary rocks beneath the pluton (in cluster 18) have probably been severely altered. In contrast, sedimentary rocks along the northwest fringe of the pluton (in cluster 7) may have escaped destruction and might be adequate reservoir units. One good gas show was reported from Pennsylvanian rocks about 10 miles southwest of the tract (McCaslin, 1974).

The tract on the Sacramento Mountains uplift has Pennsylvanian and Permian rocks at the surface which seem to be free of igneous intrusions. However, the tract is given a low to zero rating because freshwater would have easy access to all the possible reservoir units.

Cluster 9

Cluster 9 consists of three tracts along the southwest flank of the San Juan Basin (figs. 1A, 12). The hydrocarbon potential of this cluster is rated high because the cluster is located along several major producing trends in the basin. Several producing oil wells, probably drilled as step-out wells to the Bisti field, are present in the northernmost tract, and numerous subsurface oil and gas shows have been reported from Upper Cretaceous rocks in and around the other two tracts in the cluster. Oil fields in the Jurassic Entrada Sandstone are located within 5 or 6 miles of the southernmost tract. The most probable exploration objectives in cluster 9 are stratigraphically trapped oil and gas accumulations in Upper Cretaceous nearshore-marine sandstones and in the Jurassic Entrada Sandstone.

Cluster 10

A single tract of Wilderness Land along the southern flank of the San Juan Basin comprises cluster 10 (figs. 1A, 12). Several Upper Cretaceous sandstone and shale units and local Tertiary basalts crop out in the tract (Dane and Bachman, 1965). On the basis of the presence of Jurassic and Upper Cretaceous oil fields about 10 miles to the north, oil shows in nearby drill holes, and favorable reservoir and stratigraphic traps in Upper Cretaceous nearshore marine sandstones and the Jurassic Entrada Sandstone, the hydrocarbon potential of cluster 10 is rated medium. The hydrocarbon potential is not rated high because numerous small Cretaceous and (or) Tertiary plutons are scattered about the tract and freshwater is accessible to the rocks beneath the tract from outcrops flanking the Nacimiento and Zuni uplifts. Also, one unsuccessful test has been drilled to the Precambrian basement in this tract.

Clusters 11 and 13

Clusters 11 and 13 are comprised of 6 tracts of Wilderness Lands which extend from the southern part of the Chama basin, across the western margin of the Nacimiento uplift, to the southeast corner of the San Juan Basin (figs. 1A, 12). Despite the nearby oil fields and oil and gas shows, the hydrocarbon potential of these tracts is rated low.

A low rating is assigned to the tracts in the southern Chama basin because the Upper Cretaceous reservoir units have been removed by erosion and the Pennsylvanian reservoir units are very susceptible to flushing by freshwater.

Upper Cretaceous, Jurassic, and Pennsylvanian rocks are possible exploration objectives beneath the western margin of the allochthonous Precambrian basement rocks of the Nacimiento uplift. However, the units with reservoir potential are steeply dipping and would require very efficient traps to retain hydrocarbons.

The two tracts in the southeastern San Juan Basin are rated low because the westernmost tract is intruded by a small Cretaceous and (or) Tertiary pluton and the easternmost tract has been tested without success to the Precambrian basement. The strata with reservoir potential in these tracts are closer to the Nacimiento uplift than the strata in cluster 10 and thus are more susceptible to flushing by freshwater.

Cluster 12

Cluster 12 consists of a single tract of Wilderness Land along the west flank of the San Luis basin (figs. 1A, 12). Basalts of Tertiary and (or) Quaternary age crop out throughout the tract (Dane and Bachman, 1965). The hydrocarbon potential of the tract is rated low because the sedimentary section here is probably limited to a thin section of Upper Cretaceous and Tertiary rocks.

Cluster 15

Cluster 15 is represented by a single tract of Wilderness Land on the eastern fringe of the Jemez volcanic province (figs. 1A, 12). A thick section of volcanic rocks is present at the surface, and it is very likely that intrusive rocks associated with these volcanic rocks have disrupted the underlying sedimentary rocks of Late Cretaceous, Jurassic, and Pennsylvanian age and any hydrocarbons trapped within. The hydrocarbon potential of cluster 15 is rated low to zero.

Cluster 16

Cluster 16 consists of several tracts of Wilderness Lands along the rim of the Delaware basin and one tract of Wilderness Land on the Northwest shelf (figs. 1A, 12). Shelf-margin carbonates of the Guadalupian crop out across the southern tracts whereas shelf carbonates of the Guadalupian crop out across the northern tract (Dane and Bachman, 1965). Oil and gas fields extend to the borders of both groups of tracts, and for this reason the hydrocarbon potential of these tracts is rated high.

Gas in Morrowan sandstones and pre-Pennsylvanian carbonates, in either stratigraphic or structural traps, is the most likely exploration objective in the southern tracts. Some oil may be present in the dark basinal carbonate rocks of the Permian System (Broadhead, 1983).

In the northern tract, the main exploration objective is gas in shelf carbonates and intercalated sandstones of the Wolfcampian and Leonardian. Stratigraphically trapped hydrocarbons would be the most likely type of accumulation.

Cluster 17

Cluster 17 has a single tract of Wilderness Land on the Sierra Grande uplift of Permian and Pennsylvanian age (figs. 1A, 12). Jurassic and Triassic rocks that crop out throughout the tract cover a sequence of Permian and Pennsylvanian rocks less than 3,500 feet thick (Dane and Bachman, 1965; Roberts and others, 1976). The hydrocarbon potential of the tract is rated low because suitable reservoirs in the Pennsylvanian and Permian rocks are generally absent and because no hydrocarbon shows have been recorded from nearby drill holes.

Cluster 18

Cluster 18 consists of numerous tracts in north-central and central New Mexico having autochthonous Precambrian crystalline basement rocks or Cretaceous and (or) Tertiary intrusive rocks at, or near, the surface (figs. 1A, B, 12). The hydrocarbon potential of these tracts is rated zero. Any sedimentary rocks in the tracts that rest on Precambrian rocks are very thin and have been highly dissected by modern drainage. Those sedimentary rocks that may exist beneath laccolith-type plutons of Cretaceous and (or) Tertiary age are probably very thin and pervasively intruded by satellite intrusions. The large tract in southwest New Mexico has volcanic rocks of the Datil-Mogollon province at the surface and a large pluton or complex of plutons at depth (Elston and others, 1976).

SUMMARY

Of the 2,676,856 acres of Wilderness Lands in New Mexico the potential acreage can be summarized as follows: high potential, 96.6 thousand acres; medium potential, 115.3 thousand acres; low potential, 1,237.3 thousand acres; low to zero potential, 158 thousand acres; and zero potential, 1,069.6 thousand acres. The petroleum potential

by acreage of all Wilderness Land categories in the Western United States is shown in this circular by B. M. Miller in table 1, chapter P.

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