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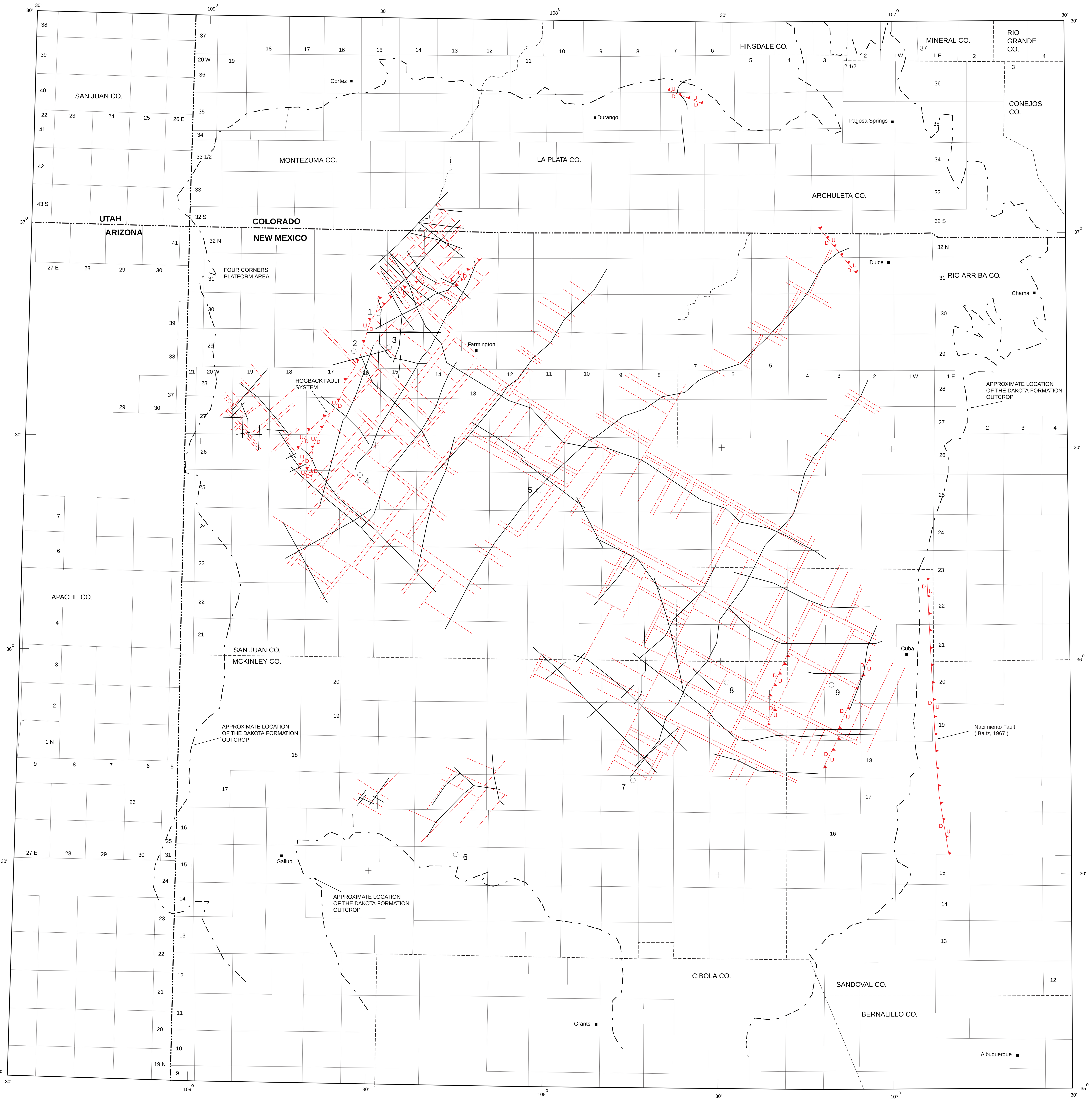

Base compiled from U.S. Geological Survey 1:250,000 Albuquerque (1963), Aztec (1961), Cortez (1969), Durango (1945), Gallup (1970), Shiprock (1969)

Land grid compiled from U.S. Geological Survey State Maps at 1:1,000,000 scale for Arizona (1974), Colorado (1969), New Mexico (1985), Utah (1976).

Transverse Mercator Projection

Scale 1:500,000

10 0 10 20 30 Miles

10 0 10 20 30 40 Kilometers

Outline of the Dakota Formation from Huffman (1987).
Manuscript approved for publication April 9, 1998

EXPLANATION

- Fault — Approximately located
- Fault — Inferred
- Thrust fault — Mapped; D, downthrown side; U, upthrown side
- Thrust fault — Approximately located; D, downthrown side; U, upthrown side
- Seismic line
- 9 Referenced deep well
- State boundary
- County boundary

GEOLOGIC SUMMARY

INTRODUCTION

Interpretation of more than 1,100 mi (1,750 km) of seismic reflection data in the San Juan Basin and vicinity allowed us to map a large number of faults that have measurable offset at the top of the Proterozoic crystalline basement. Predominant fault trends are N. 60º–70º W. and N. 30º–40º E. with a typical spacing of 4–10 mi (6–16 km). The orthogonal pattern was established in the Precambrian, but episodic movements in the late Paleozoic, Mesozoic, and Cenozoic have been measured by the authors on a number of the faults. Periods of significant movement correspond to recognized orogenic events, particularly the Pennsylvanian to Permian Ancestral Rocky Mountain orogeny and the early Tertiary Laramide orogeny.

The seismic data set available to the authors is composed of long regional lines and shorter lines used for oil and gas prospect evaluation. All lines of the data were shot conventionally as two-dimensional surveys between 1969 and 1983, most utilizing dynamite as the source. Data were purchased from Bass Enterprises Production Co., Dome Petroleum Co., El Paso Natural Gas Co., Northwest Exploration Co., and Tenneco Oil Co. and were borrowed from Amoco Production Co., Maxus Exploration Co., Meridian Oil Co., and the Ute Mountain Ute Tribe (Wintershall Oil Co.). In addition, two small seismic surveys were shot by the U.S. Geological Survey over uranium deposits in the southwestern part of the study area. With the exception of the USGS data, all lines and shot points are proprietary.

METHODS

Generally, data quality was adequate to resolve subsurface structure on a coarse regional scale but not on a smaller detailed exploration-oriented scale. Digital field data were obtained for a limited number of lines, allowing for some reprocessing using newer and more advanced techniques. This resulted in better definition of the faults with more detail, but little or no change in the overall pattern or interpretation. The basement reflector was identified by generating synthetic seismograms from a number of key wells (located on the map and described below) that penetrated basement rocks. Where available, sonic and formation density logs were used, but because these logs were not run on many of the wells, some of the synthetic seismograms were generated from pseudo sonic logs derived from resistivity logs. For a description of this technique see Peterson and others (1955).

In order to construct the map, fault intercepts at the basement reflector were plotted on a basin shot-point map. Each of the faults was annotated as to style and direction of motion as observed at the basement level. Only those faults having observable seismic time offset are shown on the map, and all faults were plotted as straight line segments. These ground rules were adopted in order to provide a manageable framework for the almost limitless number of possible interpretations

Geologic mapping around the basin margins (for example, Goddard, 1966; Baltz, 1967; Santos, 1970; Thaden and Zech, 1984; Condon, 1990; Thaden, 1990) indicates that the predominant fault directions throughout the section are northeast and northwest with some north-south and east-west. We began our interpretation and correlations in the areas of greatest data density with this general pattern in mind but also tried a number of other orientations. The data fit the northwest-southeast and northeast-southwest pattern better than any other. The blocks defined by the orthorhombic fault pattern are similar in size and orientation to those mapped on the Four Corners platform by Stevenson and Baars (1986), and the density of faulting is comparable to that around the margins of the basin compiled by Thaden and Zech (1984).

DISCUSSION

Several aspects of the fault pattern and density should be noted: (1) there is an apparent clockwise rotation of fault trends from east to west across the basin (for example from about N. 28º E. near Cuba to about N. 38º E. west of Farmington), which continues beyond the hogback fault into the Paradox Basin to the west and may be partly explained by Laramide rotation of the Colorado Plateau (Hamilton, 1988); (2) in the southeast part of the basin more of the predominant through-going faults appear to be northwest-trending whereas in the northwest the northeast-trending set appears to be more common; and (3) there is an apparent increase in the density of faulting west of the Hogback fault system. None of these observations is unambiguous, since the quality and density of data vary significantly across the area, but taken together they suggest that the Precambrian basement of the San Juan Basin might be divided into several structural domains.

Proterozoic reconstructions of southwestern North America indicate that the boundary between the Yavapai (1.75–1.70 Ga) and Mazatsal (1.66–1.60 Ga) Provinces trends northeastward across the San Juan Basin (Bowring and Karlstrom, 1990; Condie, 1992; Karlstrom and Daniel, 1993). Baars and Stevenson (1982) proposed a north-south principle stress, dated at 1.60 Ga by Baars and Ellingson (1984), to produce the observed fault pattern of the San Juan Basin. This would correspond generally with the Mazatsal orogeny (Karlstrom and Daniel, 1993). Northwest of the boundary (northwestern San Juan Basin and Paradox Basin) the fracture pattern would probably have originated in the Yavapai orogeny (1.74–1.69 Ga) under a slightly different stress regime.

During the Phanerozoic the large number of blocks in the San Juan Basin may have moved individually relative to each other, as discussed by Stevenson and Baars (1977) and Baars and Stevenson (1982); together as larger blocks as documented by Baltz (1967); or as some combination of the two as suggested by Huffman and Condon (1993). Fault activity related primarily to either uplift or extension would result in mostly normal faulting and vertical movement of the blocks, with or without tilting, relative to each other. Compression would likely produce mostly reverse faulting and some amount of rotation of the blocks, particularly if the compressive stress was oblique to the bounding faults. Any shear stress associated with extension or compression would increase the likelihood of block rotation. Because the basin has been subjected to a wide variety of stress fields since the Precambrian, it is likely that the blocks would have moved a number of times in a variety of directions relative to each other. The movement on any one fault at a particular time is determined by its orientation in the stress field of the time so that the present pattern is a result of many periods of movement and care must be taken in interpreting it.

DEEP WELLS USED

The following deep wells were used to generate synthetic seismograms. The numbers on the map correspond to the numbered wells listed.

1. Stanolind Oil Co.
   Hover No. 1
   Total Depth 10,800 ft
   Sec. 23, T. 30 N., R. 16 W.

2. Stanolind Oil Co.
   USG No. 13
   Total Depth 7,440 ft
   Sec. 19, T. 29 N., R. 16 W.

3. Pure Oil Co.
   Navajo No. 1
   Total Depth 11,148 ft
   Sec. 18, T. 29 N., R. 15 W.

4. Pan American Oil Co.
   No. 1 Gulf Navajo
   Total Depth 10,108 ft
   Sec. 4, T. 25 N., R. 16 W.

5. Shell Oil Co.
   No. 113-17 “Carson Unit”
   Total Depth 11,445 ft
   Sec. 17, T. 25 N., R. 11 W.

6. Tidewater
   Mariano Dome
   Total Depth 4,708 ft
   Sec. 8, T. 15 N., R. 13 W.

7. Great Western Drilling
   No. 1 Hospah
   Total Depth 7,852 ft
   Sec. 1, T. 17 N., R. 9 W.

8. Sun Oil Co.
   New Mexico State No. 1
   Total Depth 10,572 ft
   Sec. 16, T. 20 N., R. 6 W.

9. Pan American Oil Co.
   “C” USA No. 1
   Total Depth 10,428 ft
   Sec. 17, T. 20 N., R. 3 W.

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MAP SHOWING INFERRED AND MAPPED BASEMENT FAULTS, SAN JUAN BASIN AND VICINITY, NEW MEXICO AND COLORADO

By
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