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GEOLOGICAL SURVEY

GEOLOGIC SUMMARY OF THE SAN JUAN BASIN, NEW MEXICO, WITH REFERENCE TO DISPOSAL OF LIQUID RADIOACTIVE WASTE *

By

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Trace Elements Investigations Report 603

This report is preliminary and has not been edited for conformity with Geological Survey format and nomenclature.

*This report concerns work done on behalf of the Division of Reactor Development of the U. S. Atomic Energy Commission.

CONTENTS

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ILLUSTRATIONS

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ABSTRACT

The San Juan Basin occupies about 20,000 square miles of northwestern New Mexico and adjacent parts of Colorado. Parts of the area contain over 13,000 feet of sedimentary rocks, of which a little less than half is of Paleozoic age. The Paleozoic rocks are approximately 55 percent siltstone, 30 percent limestone, and 14 percent sandstone with some evaporite deposits. They are largely of Pennsylvanian and Permian age, although Cambrian, Devonian, and Mississippian rocks are present.

In contrast to the Paleozoic rocks, the Mesozoic rocks of the San Juan Basin are about half sandstone and half siltstone and claystone. Limestone and evaporites form a relatively insignificant part of the section. More than half of the Mesozoic rocks are of Cretaceous age and are of both marine and continental origin. Jurassic rocks contain proportionally greater amounts of continental deposits and the Triassic rocks include no known marine beds. The Cretaceous and Jurassic marine beds are primarily impervious claystone, siltstone, and sandy siltstone. The continental beds consist of intercalated sandstone and shale lenses.

Prediction of the lithology of most continental sequences at any specific point is virtually impossible without local field study. On the other hand the uniformity of marine lithologies is such that it may be predicted for any locality with a fair degree of certainty. Intermediate deposits, deposited in environments which may be grouped under the term "marginal marine," and including the most prominent sandstone units are of intermediate predictability as to their lithology at any specific point.

Tertiary rocks in the San Juan Basin are exclusively continental. For the most part these rocks are lithologically comparable to the Mesozoic continental beds and are composed of intercalated sandstone and shale lenses.

Structurally, the San Juan Basin resembles a northward tilted floor with steep walls along its north, east, and west sides. Maximum relief along these walls occurs in the northern part of the area and decreases southward along the west and east sides. The southern side of the basin is not sharply defined. The basin structure was developed in Late Cretaceous and early Tertiary time and is divisible into several structural elements. Most oil and gas production is from the structural element referred to as the "Central basin," which is the deepest part of the area. Most of the minor structures are concentrated in the structural element referred to as the area of "Intermediate structures."

Four types of reservoirs in the San Juan Basin appear to deserve consideration for possible storage of high-level liquid radioactive waste. These are in gypsum, limestone, shale, and sandstone. Gypsum appears more useful for the storage of sintered waste. Storage of liquid waste in limestone is possible but it is uncertain whether the stored waste could be controlled. The construction of artificial reservoirs in shale units by hydraulic fracturing or deep-seated explosion has several advantages, the most significant of which is the relative certainty of confinement. Storage in permeable sandstone units is more favorable from the standpoint of heat control.

INTRODUCTION

This summary report on the geology of the San Juan Basin, New Mexico, and adjoining parts of Colorado was prepared as part of the Radioactive Waste Disposal Program being carried on by the Geological Survey on behalf of the Division of Reactor Development of the Atomic Energy Commission. It is the first of a proposed series of reports covering sedimentary basin areas or other large regional units underlain by sedimentary rocks in the United States. The purpose of these reports is to describe the geology of the areas so that the possibilities for the disposal of high-level radioactive fluid waste in deep wells can be ascertained. These studies look ahead to the time when there will be extensive commercial production of atomic power, with the attendant creation of liquid radioactive waste from the processing of radioactive fuel elements. The disposal of liquid waste in deep wells is only one of several possibilities to be considered in the general problem.

The geologic environment of deep-well disposal is discussed in this report. In the larger view of the problem there are many other factors to be taken into account, such as certainty of containment for the duration of hazardous radioactivity, monitoring requirements, regional and local hydrology, engineering problems, and cost. These factors, however, can be evaluated more adequately when a specific disposal site is considered. This report does not provide sufficient detail for specific site selection. It should serve, however, as a guide to the more favorable areas.

This report presents the stratigraphy of the rocks in the San Juan Basin, beginning with the oldest formations, with most attention being given to their general lithologic features. This is followed by a description of the general structural features of the area. The radioactive waste disposal possibilities are then considered, in terms of the rock formations in which the liquid waste might be placed through deep wells, and the general structural attitude of those beds which may or may not favor confinement.

STRATIGRAPHY

The San Juan Basin is a structural basin occupying approximately 20,000 square miles in northwestern New Mexico and adjacent Colorado (fig. 1). Prior to Late Cretaceous time this area was not a discrete depositional basin but was at many times a pronounced low trough-like area with a northwest orientation. It may have been connected with basins on the northwest, or southeast, or both, and was bounded by highlands on the northeast and southwest. The pattern had exceptions, however. For example, during Late Triassic time no highland area seems to have existed to the southwest, but in Jurassic time this area was uplifted. In Cretaceous time the highland to the northeast was reduced to obscurity. Thus, although the San Juan Basin was not a discrete basin throughout all of geologic time, more than 14,000 feet of sediments were deposited over parts of the area by mid-Tertiary time. Most of these deposits are of Mesozoic and Paleozoic age.

The present structure of the San Juan Basin is largely the result of very Late Cretaceous and early Tertiary orogeny, and only rocks deposited in the basin during this time appear to be entirely unrelated to the deposits beyond the limits of the basin. The older rocks represent extensive deposition in areas beyond the limits of this discussion. More than two dozen stratigraphic formations are recognized in the surface and subsurface sections of the basin. These formations overlie the Precambrian complex of igneous and metamorphic rocks. Most of the formations recognized are shown on figures 2 and 7. This report does not include a detailed description of each of the formations, so the following is presented largely by rock groups, rather than by individual formations.

The rocks which crop out in the large central area of the San Juan Basin are largely of Tertiary and Cretaceous age (fig. 1). Older sedimentary rocks crop out along the margins of the structural basin, and Precambrian rocks form the core of most of the highlands surrounding the basin (figs. 1 and 14). The thickness of sediments overlying the largely igneous and metamorphic Precambrian rocks locally exceeds 14,000 feet.

Paleozoic Rocks

A maximum thickness of between 5,000 and 6,000 feet of Paleozoic rocks is known in the San Juan Basin. Of this thickness about 5,000 feet are of Pennsylvanian and Permian age; the remaining rocks, totaling less than 1,000 feet, are of Cambrian, Devonian, and Mississippian ages. No Ordovician or Silurian rocks have been recognized in the area (fig. 2). Although the rock types vary throughout the area, the total Paleozoic section is composed of about 55 percent siltstone and silty sandstone of low hydraulic permeability, 30 percent limestone and dolomite of variable and somewhat unpredictable permeability, 14 percent sandstone of moderate permeability, and perhaps 1 percent evaporite deposits.

Cambrian rocks

Cambrian rocks are present only in the northwestern part of the area (fig. 3). They are not exposed except along the flanks of the San Juan uplift near Durango, Colorado, where the Ignacio quartzite crops out. The Cambrian rocks are as much as 260 feet thick, and are composed of well-cemented sandstone, limestone, and dolomite. Throughout most of the area, these rocks are from 7,000 to 8,000 feet below the present land surface. They have a relatively limited distribution and generally have low permeability.

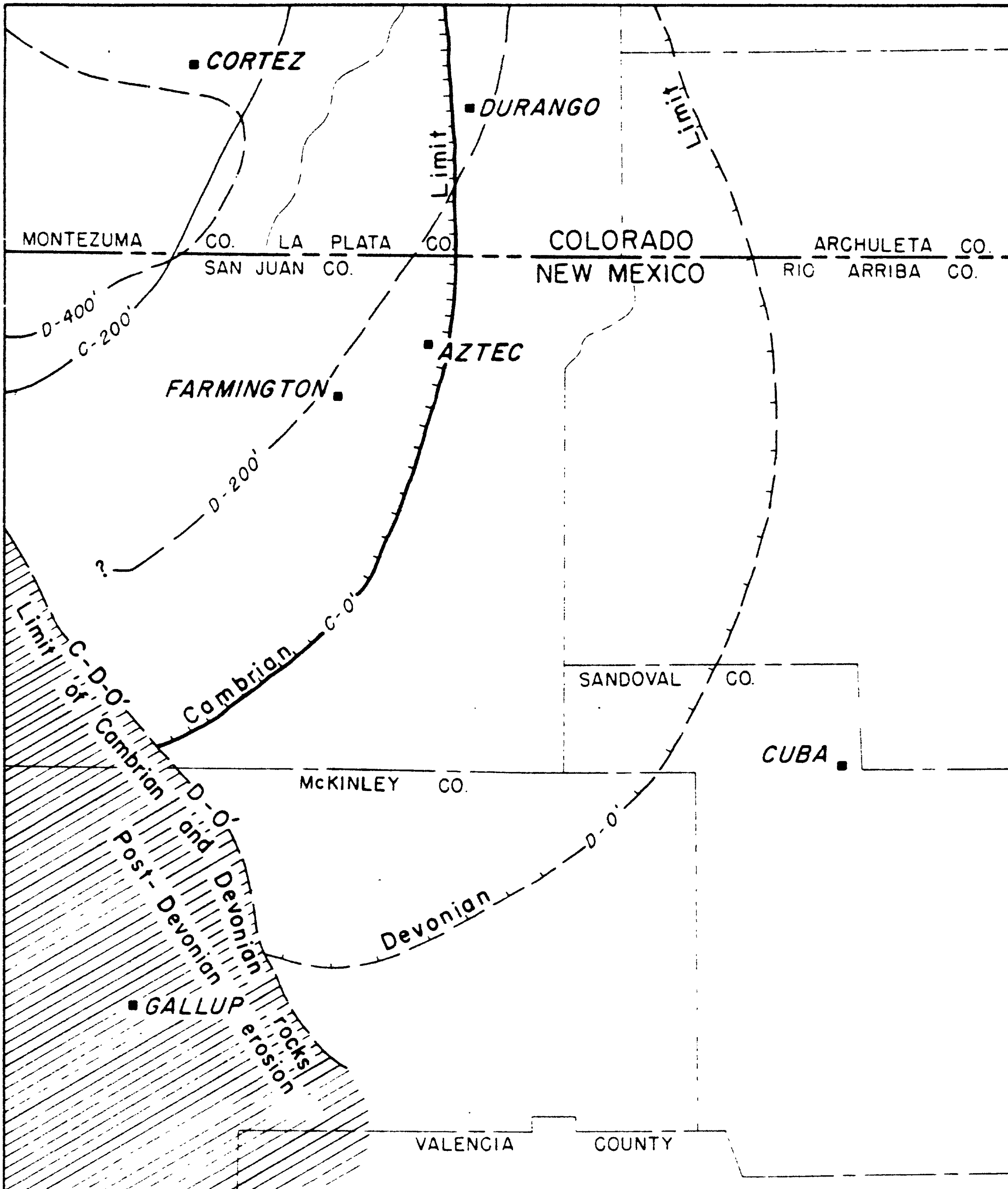

FIGURE 3. -- ISOPACH MAP OF THE
CAMBRIAN AND DEVONIAN ROCKS,
SAN JUAN BASIN

D-200' — DEVONIAN ISOPACH.
C-200' — CAMBRIAN ISOPACH

FROM MOMPER, J. A., 1957,
COOPER, J. C., 1955

0 5 0 30 50 80 00 MILES

Devonian rocks

Devonian rocks include the Elbert formation, which is generally similar to the Cambrian rocks in both rock type and distribution. Its lower part is poorly sorted glauconitic sandstone and the upper part is largely saccharoidal, sandy dolomite with green and red shale interbeds.

The overlying Devonian Ouray limestone has a distribution similar to that of the Elbert, but is similar in lithology to the Mississippian Leadville limestone and is frequently grouped with that formation in discussions of the subsurface stratigraphy. The Ouray is composed of dense and argillaceous massive limestone that contains some green waxy claystone interbeds. The total thickness of Devonian rocks in the San Juan Basin (fig. 3) is about 500 feet in the northwestern part of the area and is thicker farther to the northwest. However, the average thickness of Devonian rocks in the area under consideration is only about 200 feet.

Mississippian rocks

Carbonate rocks of Mississippian age are present in approximately the central two-thirds of the San Juan Basin (fig. 4). These limestone and dolomite units are permeable to some extent and in the northwestern part of the area contain helium-bearing natural gas. In addition, the Mississippian Leadville limestone was extensively caverned prior to the deposition of the overlying Pennsylvanian Molas formation, which was deposited on a karst topography. In many areas the Molas would form an efficient seal for liquids moving through the Mississippian rocks. The Leadville limestone, and the approximately equivalent Arroyo Peñasco formation in the eastern part of the area, is nearly 200 feet thick along the northwestern and northern margins of the area; it is locally absent or of irregular thickness, generally less than 100 feet, in the eastern part of the area. The Mississippian rocks lie between 4,000 and 9,700 feet beneath the present land surface in most of the area where they are present.

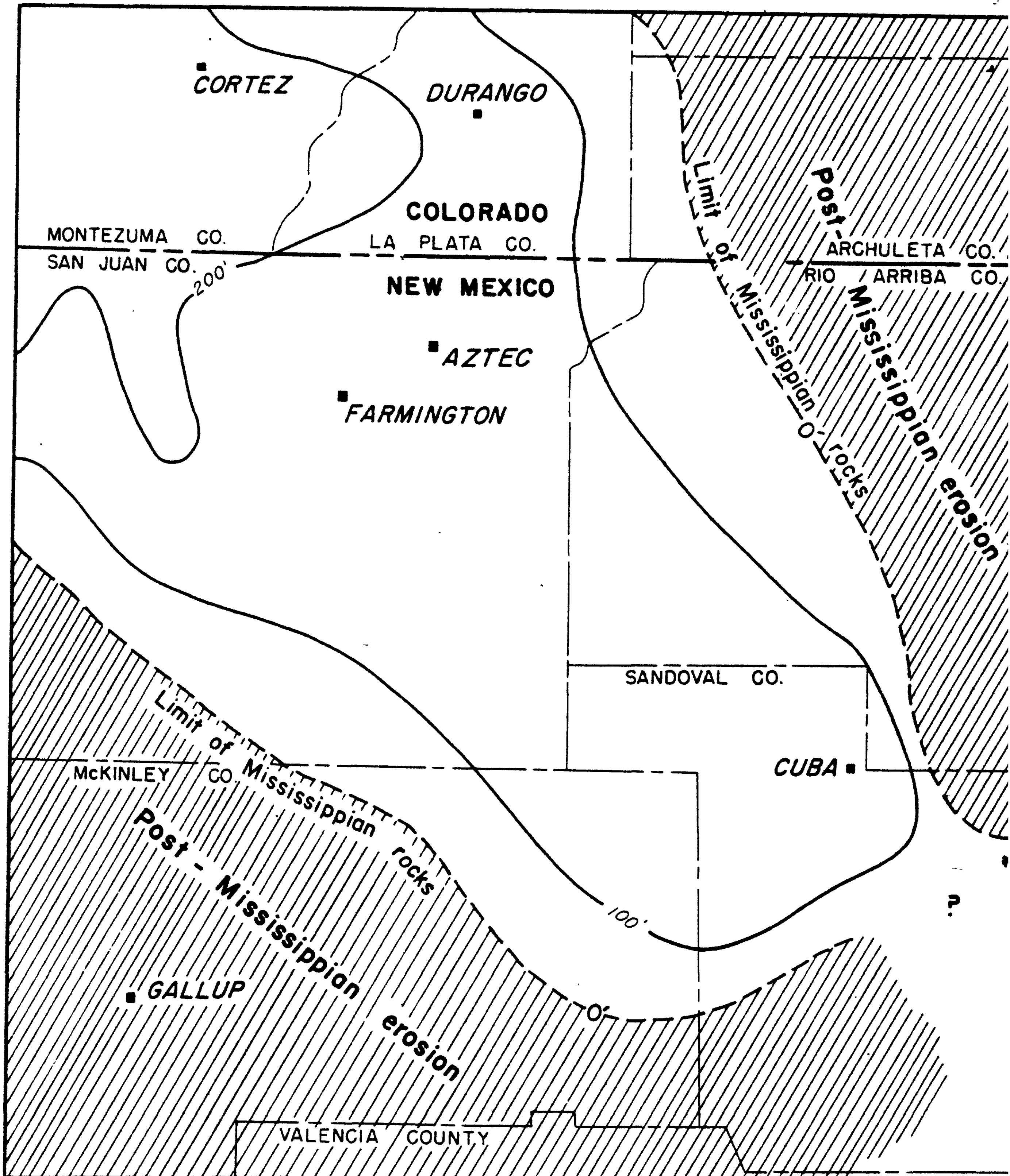

FIGURE 4.-- ISOPACH MAP OF THE

MISSISSIPPIAN ROCKS,

SAN JUAN BASIN

0 5 10 30 50 80 100 MILES

IN PART FROM COOPER, F. C., 1955

Pennsylvanian rocks

Pennsylvanian rocks make up most of the Paleozoic section in most of the San Juan Basin (fig. 5). Near Shiprock, in the northwestern part of the area, they comprise as much as 1,500 feet of thick-bedded limestone, evaporites, and red siltstone beds. North and northwest of Shiprock they thicken rapidly by the addition of the salt beds of the Paradox member. About 2,000 feet of the Hermosa and Molas formations are present in the Durango area on the northern side of the basin and about 1,000 feet of the Madera and Sandia formations crop out on the eastern side in the vicinity of Cuba. The Pennsylvanian section thins to around 800 feet in the central part of the basin where red siltstone is predominant, and thins more rapidly in a southwesterly direction; no Pennsylvanian rocks are exposed on the Defiance upwarp, northwest of Gallup, and a maximum of 125 feet is known to crop out in the Zuni upwarp area, south of Gallup.

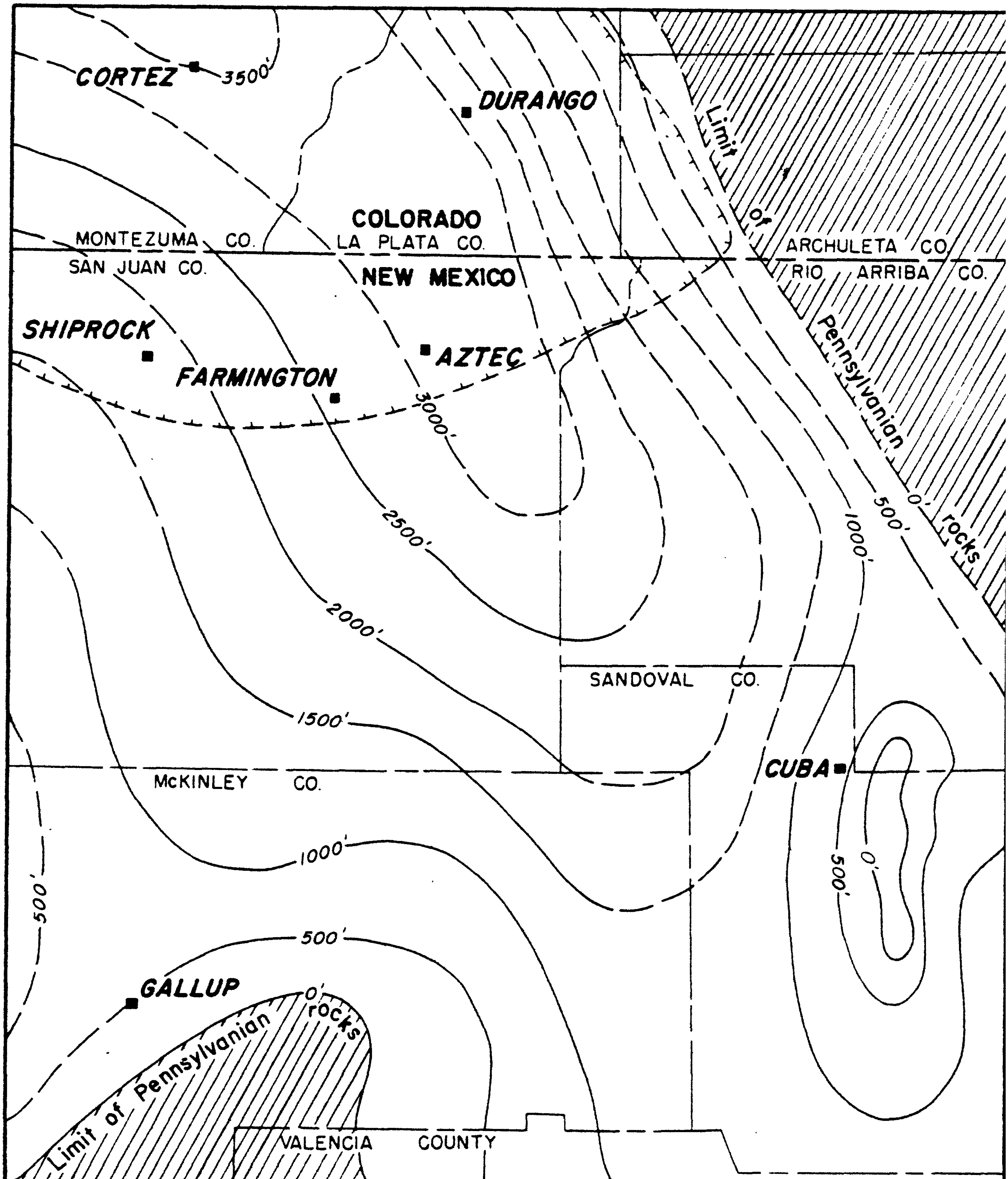

FIGURE 5.--ISOPACH MAP OF THE
PENNSYLVANIAN ROCKS,
SAN JUAN BASIN

0 5 10 30 50 80 100 MILES

—+—+— SOUTHEASTWARD EXTENT OF PARADOX FACIES

FROM BRADISH, B. B., AND MILLS, N. K., 1950

The oldest Pennsylvanian unit, the Molas formation in the northern part and the Sandia formation in the eastern part of the basin, is widespread but quite thin, averaging about 100 feet in thickness. It consists largely of varicolored shale with some limestone; in part it may be an ancient regolith overlying the Mississippian limestone, for in many areas it fills karst depressions in this limestone. The Pennsylvanian sequence overlying the Molas and Sandia formations is called the Hermosa formation throughout most of the area, but the Madera limestone to the southeast. This unit is composed of limestone with varying amounts of sandstone and shale. It produces oil and gas in some areas.

The name Rico formation, which is typically applied to units of Permian age, is also applied in a facies sense to strata equivalent to the Hermosa, notably in the central part of the basin, where red beds replace limestone to a large extent. In the southeastern part of the area this facies is largely included in the upper arkosic part of the Madera limestone. Throughout the area, therefore, the characteristic Pennsylvanian limestone grades upward into red beds characteristic of the Permian Rico, Abo, and Cutler formations.

Permian rocks

Permian rocks of the San Juan Basin are composed principally of red fine-grained sandstone or siltstone. They are locally more than 2,000 feet thick (fig. 6) and represent deposition marginal to basins both southeast and west of the area. The lower part of the Permian section is almost entirely of this silty lithology and is assigned to the Rico, Cutler, Abo, Yeso, and Supai formations. The upper part of the section is increasingly sandy to the south and west. In the south-eastern part of the area it is overlain by the thin limestone unit of the San Andres formation. The sandy parts of the Permian section include the DeChelly and Glorieta sandstones, which have fair to good porosity.

DeChelly and Glorieta sandstones.--Although the DeChelly sandstone of the western side of the basin seems to be continuous with the Glorieta sandstone on the south and east side of the basin, the two units may represent somewhat different types of deposition. The Glorieta is generally more coarsely grained and has less silt than the DeChelly and as a result it is likely to be more permeable. Toward the northern part of the basin both units grade into the poorly sorted, arkosic, silty to coarse-grained sandstone of the Cutler formation. In most areas these units are confined between relatively impermeable strata: the Chinle formation of Triassic age above and silty red beds of the Cutler, Yeso, or Supai formations below.

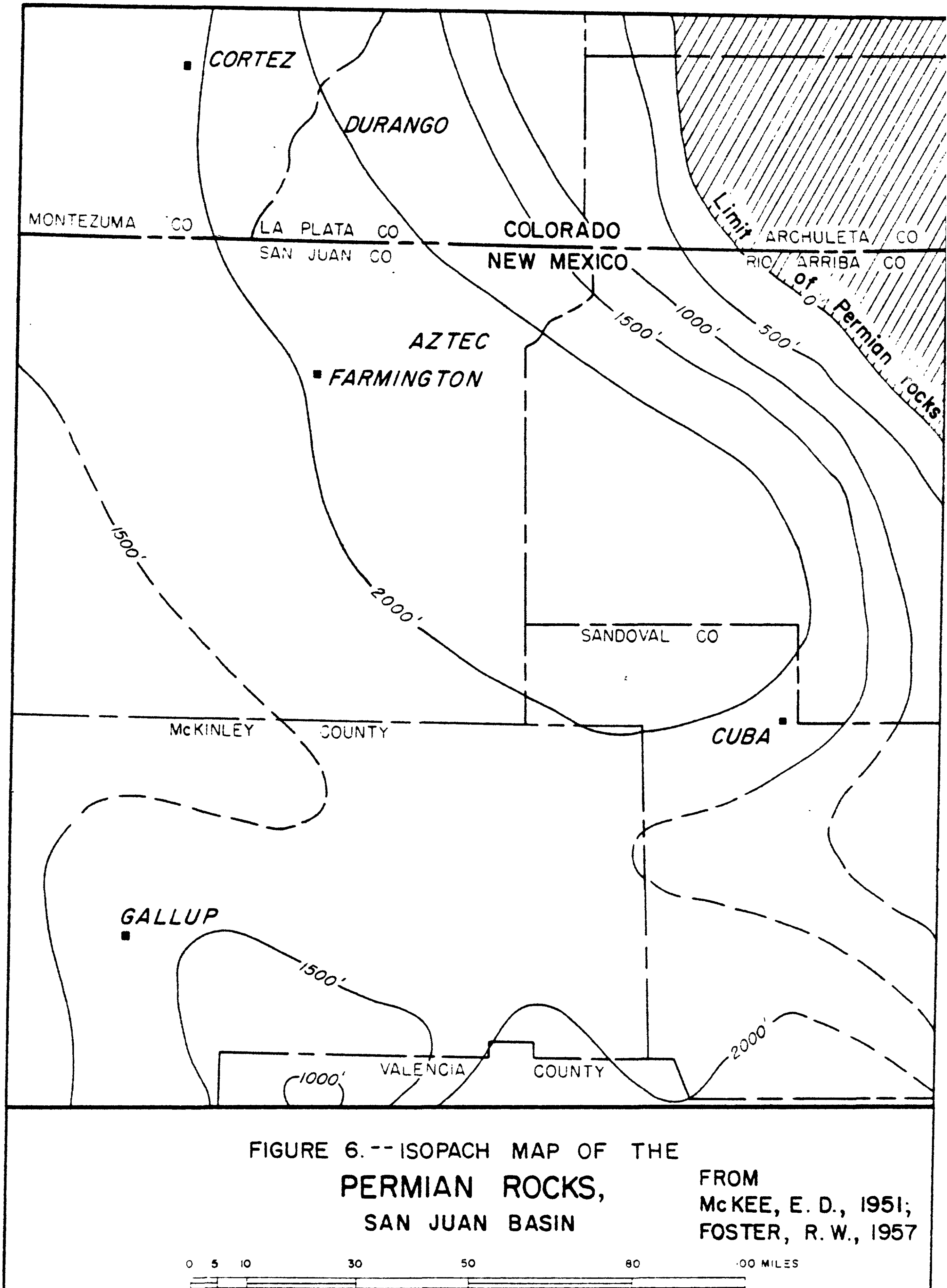

FIGURE 6.--ISOPACH MAP OF THE

PERMIAN ROCKS,

SAN JUAN BASIN

FROM
McKEE, E. D., 1951;
FOSTER, R. W., 1957

The DeChelly sandstone along the west side of the basin is reddish orange and is composed of fairly well sorted, subangular to subrounded, fine- to medium-grained quartz, and some feldspar. It becomes progressively finer grained and silty toward the north and northeast, and is less well sorted. The induration of the DeChelly sandstone varies from poorly to very well cemented, and as a result its permeability varies from place to place. The cement is primarily calcium carbonate, locally with some ferruginous cement.

The DeChelly sandstone is very thick bedded, with beds four feet and more in thickness, but it is more thinly bedded eastward toward the center of the basin. Sandstone beds are usually separated by partings or thin beds of siltstone which thicken eastward with the result that much of the unit grades basinward into red beds of the Abo-Yeso-Cutler group.

Along the Defiance upwarp outcrops of the DeChelly sandstone are as much as 750 feet thick. However, it thins rapidly eastward and is about 200 feet thick along the New Mexico State line. It is about 100 feet thick throughout most of the southern half of the basin.

In the Zuni upwarp area the Glorieta sandstone is a very pure well-sorted, coarse-grained quartz sandstone. However, in other areas about the southeastern and eastern sides of the San Juan Basin it is a medium- to fine-grained buff to white sandstone. It is quite firmly cemented with calcium carbonate, which reduces the permeability otherwise characteristic of medium-grained, well-sorted sandstone.

The Glorieta sandstone is about 100 feet thick in the southern part of the basin. In the subsurface it seems to be the lateral equivalent of the DeChelly sandstone, and the application of nomenclature to the unit is arbitrary. As a unit, however, the DeChelly-Glorieta sandstone has better sorting and somewhat greater average grain size in the southeastern part of the San Juan Basin.

Along the south and east sides of the basin the Glorieta sandstone is overlain by the limestone of the San Andres formation which is locally cavernous due to solution while exposed during Early Triassic time prior to deposition of the Chinle formation. The San Andres includes red beds and gypsiferous sandstone as well as limestone.

Although the limestone of the San Andres locally may be quite permeable, the thick shale of the overlying Triassic rocks would effectively confine upward migration of fluids within the Glorieta sandstone. Downward migration of fluids would be greatly retarded because the Glorieta sandstone, like the DeChelly sandstone, overlies and intertongues with very silty and relatively impermeable red beds.

Mesozoic rocks

Between 7, 000 and 8, 000 feet of Mesozoic rocks are present in the San Juan Basin. More than half of this thickness is made up of rocks of Cretaceous age; rocks of Triassic age have a maximum thickness of somewhat more than 1, 700 feet and rocks of Jurassic age vary in thickness from 1, 000 to 1, 200 feet over most of the area. These rocks represent primarily Late Triassic, Late Jurassic, and Late Cretaceous deposition; rocks of Early and Middle Triassic, Early and Middle Jurassic, and Early Cretaceous ages are thin or absent.

The Mesozoic rocks of the San Juan Basin represent continental, marine, and marginal marine deposition. They are primarily detrital rocks and very little limestone or evaporite is present. Approximately half of the rocks are sandstone. The relations between the various rock units are very complex and to some extent this is reflected in the complexity of the nomenclature shown on figure 7.

Triassic rocks

Lower Triassic rocks do not seem to be present in the San Juan Basin, except near Gallup and possibly in the subsurface near Shiprock. Rocks of Late Triassic age are represented by the Chinle and Wingate formations, both of continental origin. They are as much as 1,750 feet thick in the southwestern part of the area (fig. 8) and thin to the east and northeast.

Chinle formation.-- The Chinle formation is composed largely of mudstone and argillaceous sandstone, all of fluvial origin. In most areas a conglomeratic sandstone is at the base; this unit is called the Shinarump member in the western and southern parts of the area. Conglomeratic sandstone beds are also present in other parts of the Chinle. Locally all of these beds are quite permeable. In the Gallup area the El Paso Natural Gas Company is using sandstone units in the middle of the Chinle for underground storage of natural gas. These conglomeratic sandstone units, however, are variable in permeability and in distribution and do not contain discrete beds of sandstone greater than 20 feet thick, but rather comprise a series of overlapping sandstone lenses more or less isolated from each other by interbedded shale. For this reason the thickness and permeability of these sandstone units in any specific area, as well as of similar beds in the Jurassic Morrison formation and continental deposits of the Cretaceous Mesaverde group, can be ascertained only by detailed studies.

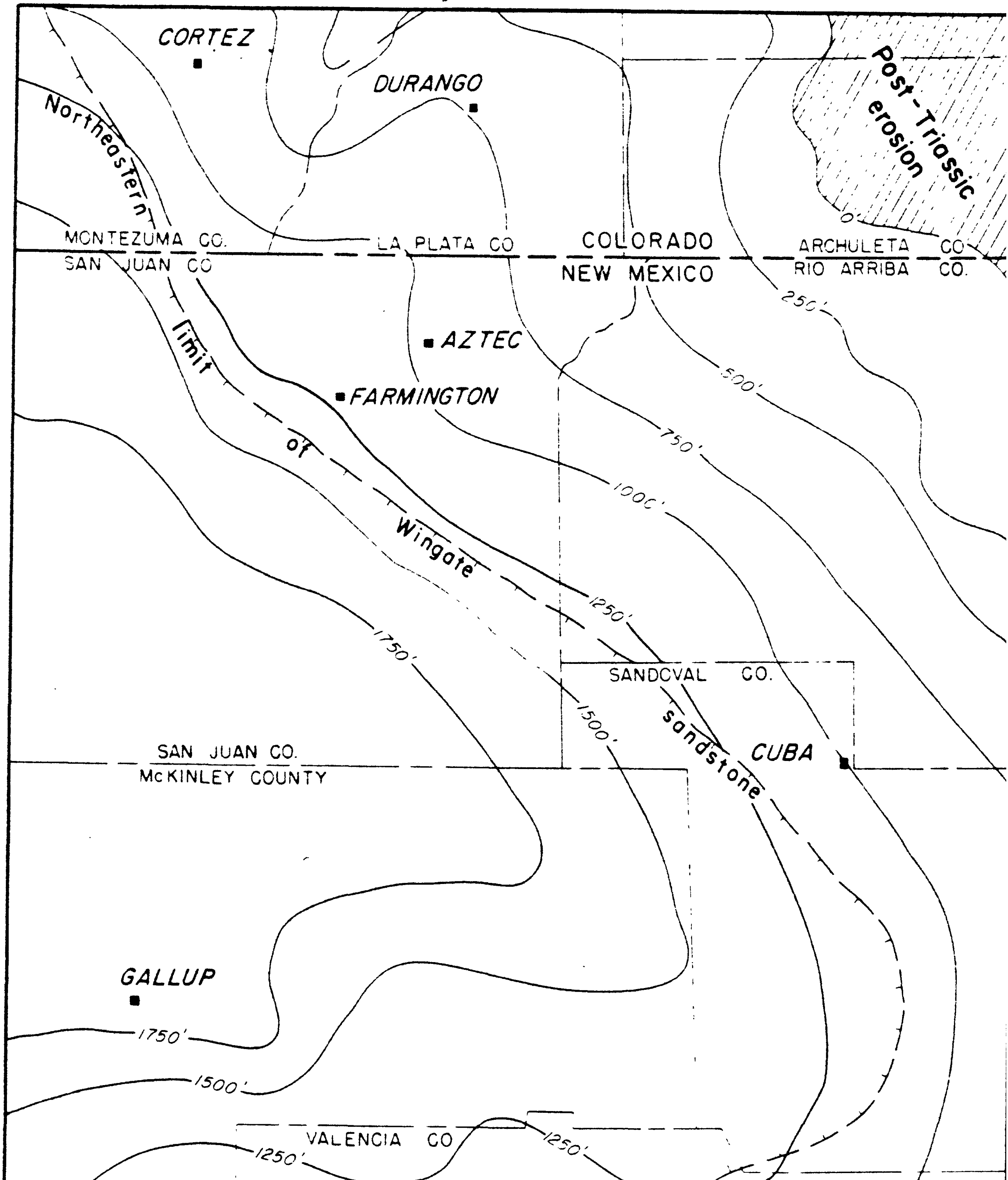

FIGURE 8.-- ISOPACH MAP OF THE

TRIASSIC ROCKS,

SAN JUAN BASIN

0 5 10 30 50 80 100 MILES

LIMIT OF THE WINGATE SANDSTONE

MODIFIED FROM WENGERD, 1950

The Chinle formation is thickest in an east-west belt across the southern edge of the San Juan Basin. In this area it is approximately 1,500 feet thick. It thins in a northerly direction, ranging from 0 to 500 feet thick in the northeastern part of the area and from 500 to 1,000 feet thick in the northwestern part. The basal conglomeratic sandstone zone ranges in thickness from a few feet to as much as 100 feet in the Gallup area. Both the basal conglomeratic sandstone zone and higher zones of conglomeratic sandstone are extremely variable and are absent locally.

Wingate sandstone.--The Wingate sandstone is present across the southwestern half of the San Juan Basin. It is composed predominantly of eolian and lacustrine deposits but locally includes prominent stream deposits. Within the San Juan Basin the Wingate sandstone is uniform in composition. It is a fine- to very fine-grained silty sandstone. The unit aggregates over 600 feet in the western part of the area, but thins rapidly to the east and northeast. It has a relatively low permeability because of its fine-grained nature.

Jurassic rocks

Units of Jurassic age in the San Juan Basin are similar to the underlying Triassic beds in that they are also largely continental in origin, although some of the units seem to be of marginal marine origin, at least in part. The total Jurassic section ranges in thickness from around 800 to about 1,200 feet in the basin, the thicker sections being in the central part (fig. 9). The oldest Jurassic unit, the Entrada sandstone, is lithologically similar to the Wingate sandstone. However, the Entrada is more extensive and thicker than the Wingate throughout the basin and may be somewhat more permeable due to slightly greater average grain size and better sorting.

Entrada sandstone.--The Entrada sandstone is present throughout the San Juan Basin and, except at a few places, is of uniform lithology. The formation unconformably overlies the Wingate sandstone in much of the basin and is overlain by a limestone bed and in some areas also by a thick bed of gypsum. These overlying units are the Todilto limestone. The Todilto is an efficient confining layer for vertical fluid movement in that in a few areas it serves as a reservoir cap to oil accumulation within the Entrada.

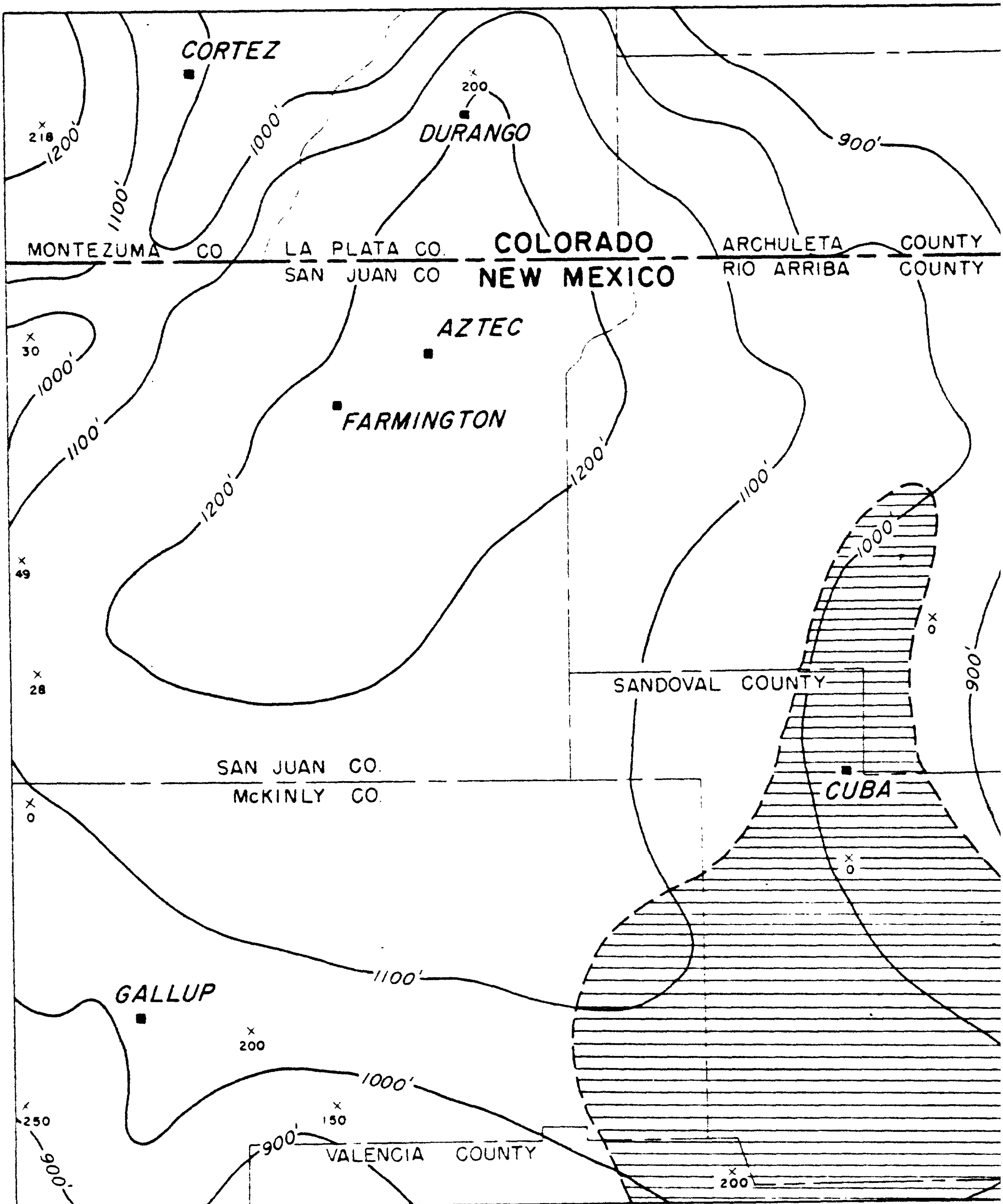

FIGURE 9. -- ISOPACH MAP OF THE
JURASSIC ROCKS,
SAN JUAN BASIN

APPROXIMATE EXTENT OF GYPSUM IN THE TODILTO LIMESTONE

× 20 THICKNESS OF BLUFF - COW SPRINGS SANDSTONE UNIT

0 5 10 30 50 80 100 MILES

The Entrada sandstone is an orange-pink, medium- to fine-grained somewhat silty sandstone. It is moderately to poorly sorted and is weakly to moderately cemented by calcareous material. Locally, however, it is firmly cemented by limonitic cement. The unit has an average of 4.7 percent carbonate minerals as cement. Of the insoluble remainder, quartz makes up about 95 percent and feldspar as much as 4 percent. The bedding ranges in thickness from 1/2 to over 4 feet.

The Entrada is thickest in the southwestern part of the basin, where it is over 250 feet thick. In other areas it is between 100 and 200 feet thick.

The Todilto limestone is present throughout the San Juan Basin and ranges in thickness from 25 to around 100 feet. As much as 100 feet of massive gypsum are included in the unit in the southeastern part of the area (fig. 9).

The Summerville formation or its equivalent is present throughout the San Juan Basin. It has a fairly uniform thickness of about 150 feet and is composed of fine-grained silty sandstone with poor sorting and a firm calcareous cement. It is usually a brownish color and interbedded with claystone. Along the southern and northern margins of the basin it grades laterally and upward into a nonmarine sandstone unit of a light greenish white color that is medium to fine grained and is well sorted. This better sorted unit is referred to the Cow Springs, Bluff, or Junction Creek sandstones.

Bluff, Cow Springs, and Junction Creek sandstones.--These names are more or less synonymous and refer either to the same sandstone unit in the same or nearby areas or to lithologically, genetically, and temporally similar units in different areas. They are applied variously by different geologists. In general they represent two sandstone facies of the Summerville formation which was deposited in the central part of the San Juan Basin area. The names Bluff and Junction Creek are generally and typically applied to the facies on the northwest side of the area, whereas the name Cow Springs has been applied to the facies on the south, although the southern sandstone also has often been called Bluff. This sandstone facies of the Summerville is largely the result of eolian deposition about the northern and southern margins of the marine embayment in which the Summerville was deposited. No sandstone facies is present on the east side of the San Juan Basin. The Summerville formation has low permeability but the marginal Bluff-Cow Springs sandstone facies is much more permeable.

The lithology of the Bluff, Junction Creek, and Cow Springs sandstones is basically the same and for convenience they are described together. The Cow Springs and its equivalent are greenish-white to gray well-sorted sandstone. They are composed of medium- to fine-grained, firmly cemented quartz sand with minor amounts of feldspar and black accessory minerals. Quartz grains, averaging 95 to 98 percent of the rock, range in size from 0.50 to 0.06 millimeter. About 5 percent are angular, 30 percent subangular, 45 percent subrounded, and 20 percent rounded. Feldspar makes up 2 to 4 percent of the rock; 1 to 2 percent is the grayish-green calcium carbonate cement; and less than one half of one percent is miscellaneous unidentified minerals.

The Bluff and the Cow Springs sandstones intertongue with the overlying Morrison formation and form a homogeneous unit within which the Summerville-Morrison contact has not been recognized. This is particularly true along the southern side of the San Juan Basin. Throughout most of this area the equivalence of the Cow Springs to either Morrison or to the Summerville formations can be stated only in approximate terms.

In the southern area the Cow Springs sandstone ranges in thickness from about 200 feet to locally nearly 500 feet. The Bluff sandstone is around 200 feet thick in most of the northern area. Both units thin and become interbedded with finer grained beds of both the Summerville and the Morrison formations toward the center of the San Juan Basin and along its eastern edge.

Morrison formation.--The Morrison formation is the youngest Jurassic unit in the San Juan Basin. It ranges in thickness from about 300 to 900 feet and is composed of fluvial sandstone and shale. For the most part the sandstone units are of relatively low permeability and are of a lenticular nature; however, along the southern and western edges of the area the sandstone units in the lower part of the formations increase in abundance, extent, and permeability and in the southwestern part of the area much of the formation is inseparable from the Cow Springs sandstone.

Three members are recognized in the area. They are, in ascending order, the Recapture member, the Westwater Canyon member, and the Brushy Basin member. The Recapture member is composed of intercalated silty sandstone and mudstone. It is conspicuously sandier in the area of the Zuni and the Defiance upwarps. The Westwater Canyon member contains a higher percentage of sandstone than does the Recapture, and it also becomes more sandy to the southwest. The Brushy Basin member consists largely of claystone and siltstone. It thins to the southwest and is not represented in stratigraphic sections near the Zuni and Defiance upwarps.

Except in the above gross trends, the lithology of the members of the Morrison formation is difficult to predict for specific areas because of the extreme lenticularity and lithologic variability of these deposits.

Cretaceous rocks

Lower Cretaceous rocks are present in parts of the San Juan Basin but are not described in most published reports on the area. In the northwestern part of the area rocks of Early Cretaceous age are composed primarily of shale and are called the Burro Canyon formation. In other parts of the area rocks of this age are sandy and are similar to the overlying Dakota sandstone of Late Cretaceous age. For this reason they are usually grouped with the Dakota in stratigraphic discussion and will be treated so here.

The Upper Cretaceous rocks of the San Juan Basin range in thickness from about 2,000 feet along the southern margin to almost 6,000 feet along the northern margin. They form the principal outcrops within the basin and are exposed in about three-fourths of the area. The thickness of Cretaceous rocks, therefore, is controlled to a great extent by Recent erosion. The Cretaceous rocks are the major source of oil and gas in the basin. As a result, more information is available for this group of strata than for any other.

The Cretaceous strata include marine, marginal marine, and continental deposits. The marine rocks are largely impermeable shale and those of marginal marine or continental origin are of several lithologies with great local variation. The continental deposits are essentially continuous with the overlying Tertiary continental deposits.

Cretaceous deposition in the San Juan Basin records two major marine transgressions extending into the area from the northeast. The first transgression deposited the basal Dakota sandstone and the Mancos shale. Its withdrawal left a thick series of intertonguing marine shale of the Mancos and marginal marine and continental sandstone of the lower part of the Mesaverde group. The second transgression deposited marginal marine and continental sandstone units of the upper part of the Mesaverde group which intertongue with and are overlain by the marine Lewis shale. Its withdrawal was more rapid than the first and is recorded by a relatively thin sequence of intertonguing marine Lewis shale and marginal marine to continental Pictured Cliffs sandstone. The overlying continental beds of the Fruitland and Kirtland formations and younger Cretaceous and Tertiary units, including the Nacimiento and San Jose formations, record no return of marine waters.

An attempt to discuss the Cretaceous formations individually in this summary would result in redundancy, for the rock types of these several transgressive and regressive units are basically uniform for the environment represented. It seems more reasonable, therefore, to describe here the several lithologic types and then to list those formations which have these basic compositional and textural characteristics.

Marine units.--The purely marine units of the Cretaceous rocks in the San Juan Basin are largely dark-gray to yellowish-gray claystone and siltstone with some sandy units. Near areas of the intertonguing with marginal units they become more sandy. The composition is quite uniform and the units are of extremely low permeability. Thin but very widespread beds of bentonitic clay are present at several horizons and a few zones are marked by thinly bedded silty sandstone. These sandstone units were deposited by turbid water, containing much fine-grained sand, which was introduced relatively suddenly into the sea and which spread laterally along the floor for distances as great as 100 miles. The fine-grained sand they carried thus was deposited within the otherwise normal claystone sequence. Although very thin and poorly sorted, these units have somewhat greater permeability than the enclosing shale. The bentonite beds and the turbid-water sandstone beds are of considerable use as stratigraphic controls in an otherwise extremely homogeneous marine shale.

The Mancos and Lewis shales are the two formations in the basin representing this marine lithology. Many tongues of these formations, particularly the Mancos, extend southwestward into the marginal marine deposits. Similarly, many tongues and isolated lenses of marginal marine sandstone extend northeastward into the main body of marine shale (see fig. 10).

Marginal marine units.--The Cretaceous marginal marine deposits in the San Juan Basin are largely sandstone, but have considerable variation in rock types. These deposits represent offshore bars and spits, foreshore sands, backshore sands, and lagoonal deposits, frequently with coal. The sandstone of the marginal marine units is thick bedded, yellowish brown to buff, and fine to medium grained. Sorting is usually fair but becomes increasingly poor toward marine intertongues. In general the grain size is coarsest to the southwest and locally the units are coarse grained. The calcareous cement varies from moderate to weak. The percentage of carbonate minerals, principally as cementing material, seems to increase to the northeast, seaward.

The bedding, for the most part from 2 to 4 feet thick, is lenticular and individual lentils may vary considerably in physical properties because of intricate changes in varied environments during deposition. The units are, however, quite permeable. Their relations to the impermeable marine shale units are such that many possibilities are present throughout the San Juan Basin for essentially positive hydrostatic confinement. These varied relations are diagrammatically shown by the many tongues and isolated lenses of sandstone within the marine shale units in figure 10. In this figure the marginal marine sandstone units are shaded. The most abundant intertonguing occurs in the Dakota and Mesaverde sandstone beds. Figure 11 shows the variation of the Gallup sandstone of the Mesaverde group which is typical of the marginal marine units. The Dakota, Gallup, Dalton, Point Lookout, Cliff House, and Pictured Cliffs sandstones, as well as several smaller units, are of marginal marine origin. The Gallup, Dalton, Point Lookout, and Cliff House sandstones are included in the Mesaverde group, the thickness of which is shown in figure 12.

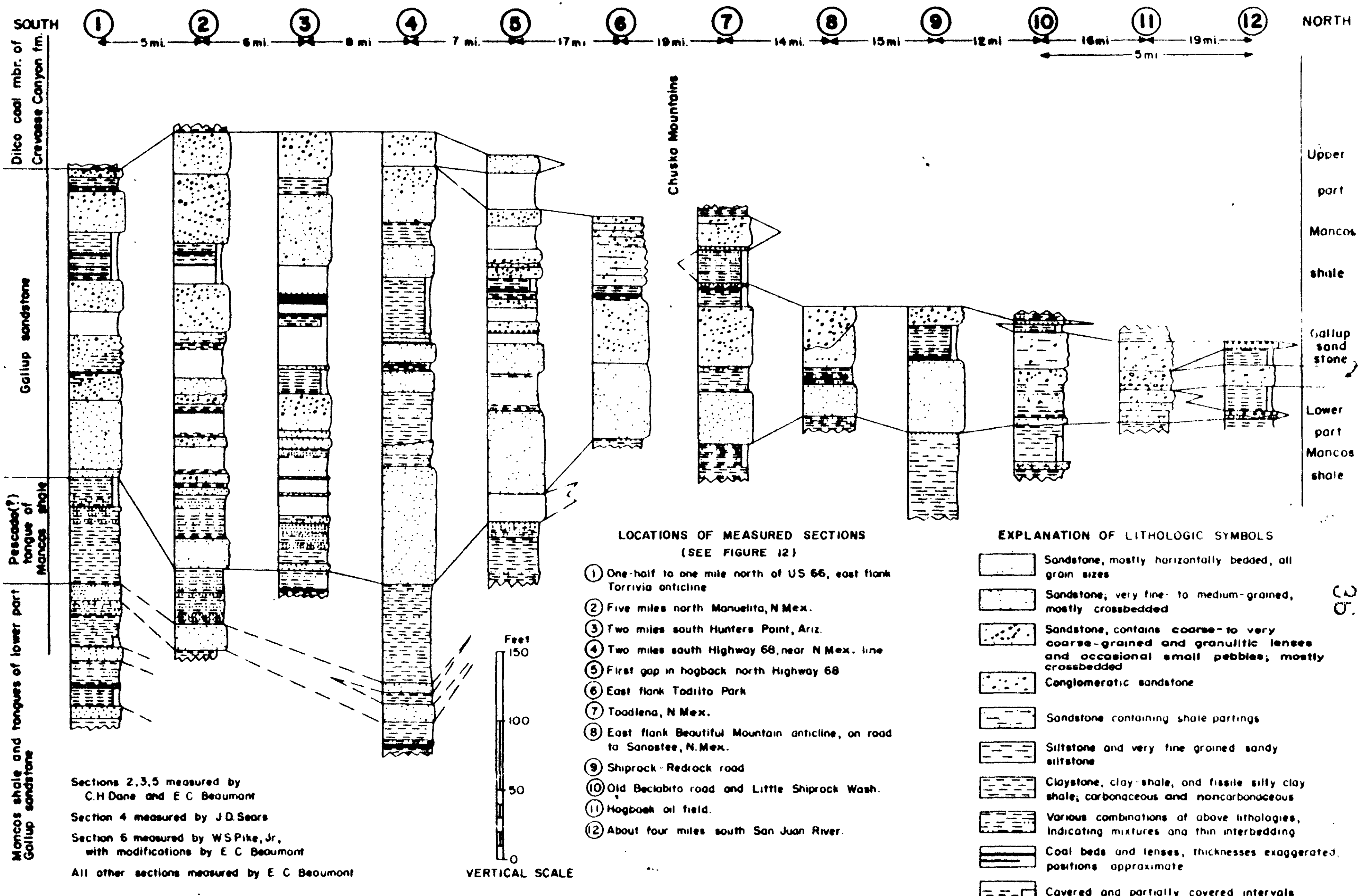

Figure 11. Stratigraphic sections of the Gallup sandstone and associated rocks between U.S. Highway 66 and the San Juan River, New Mexico and Arizona.

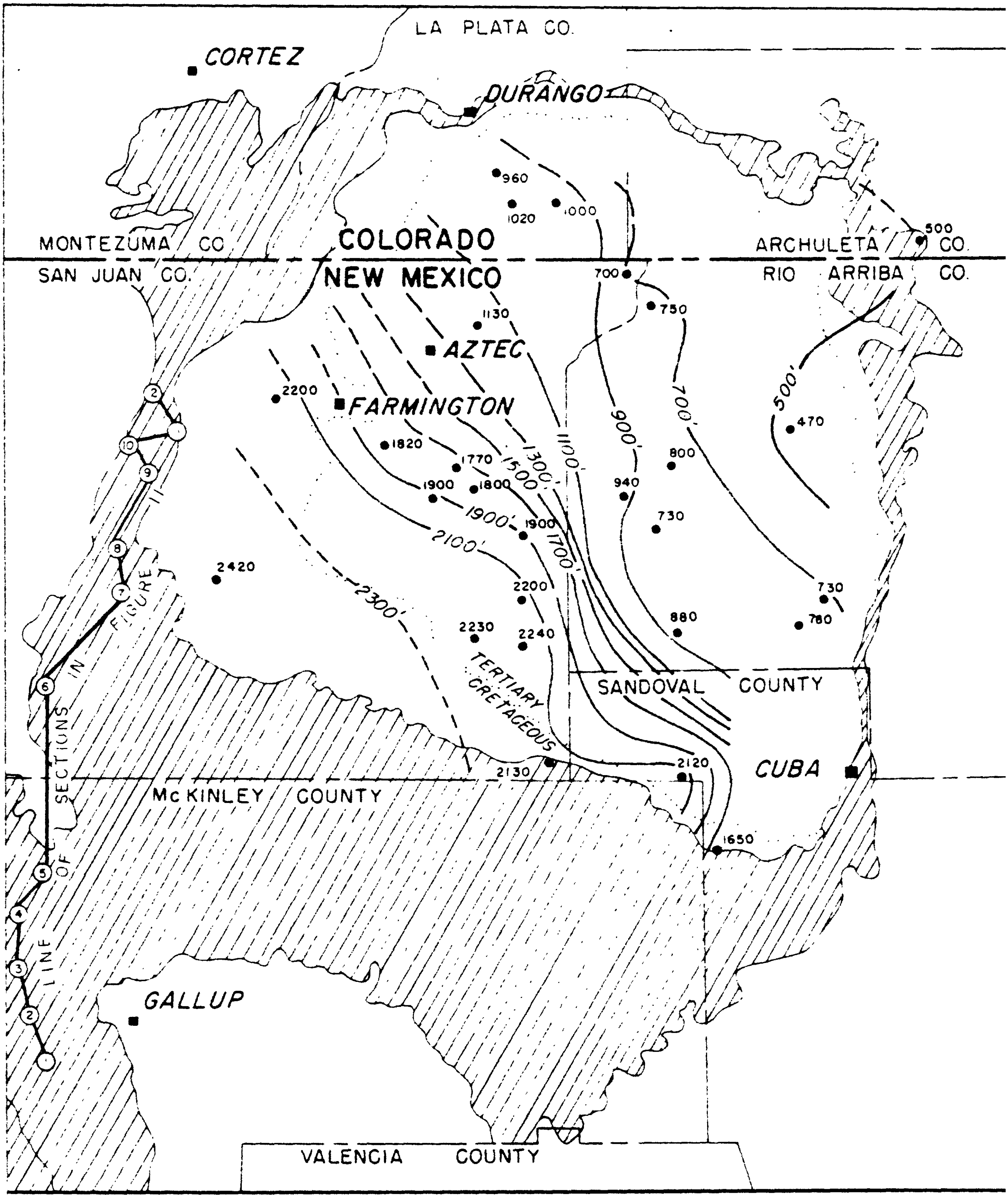

FIGURE 12.-- ISOPACH MAP OF THE MESAVERDE GROUP, SAN JUAN BASIN

CLIFF HOUSE
MENEFEE — ISOPACH INTERVAL
POINT LOOKOUT

MESAVERDE OUTCROP

FROM BOZANIC, 1955

0 5 10 30 50 80 100 MILES

Continental units.--Landward (toward the southwest) the coastal deposits are intercalated with backshore silty and coaly lagoon deposits and lenticular silty sandstone and mudstone of fluvial origin. The siltstone and mudstone units range from dark olive gray to medium light gray and are carbonaceous in many places. They contain sandy zones and sandstone lenses. The bedding is usually flat and laminated to very thin, although some crossbedding is present.

The fluvial sandstone units are crossbedded and generally yellowish gray. They vary from weakly cemented, very argillaceous units, to firmly cemented relatively clean units as much as 40 feet thick. The sandstone is poorly sorted in most places and contains quartz grains that range from very coarse to fine. They are relatively rich in detrital feldspar and mica. Some are conglomeratic and the proportion of conglomerate increases to the southwest.

Coal beds and associated lagoonal deposits are very common in the area of intertonguing with marginal marine sandstone units, but not elsewhere. The lenticular nature of these fluvial deposits is such that except in gross terms their lithology is unpredictable at any particular spot without local detailed study. Parts of these units are quite permeable and others are not.

The Crevasse Canyon, Menefee, Fruitland, Kirtland, and Animas formations are units of the continental lithology. The Crevasse Canyon and Menefee have several members defined on the basis of their coal content. These formations are best developed toward the southwestern part of the area and extend northeastward (seaward) varying distances, the younger units being the most extensive. The thickness of the Kirtland and Fruitland formations is shown in figure 13.

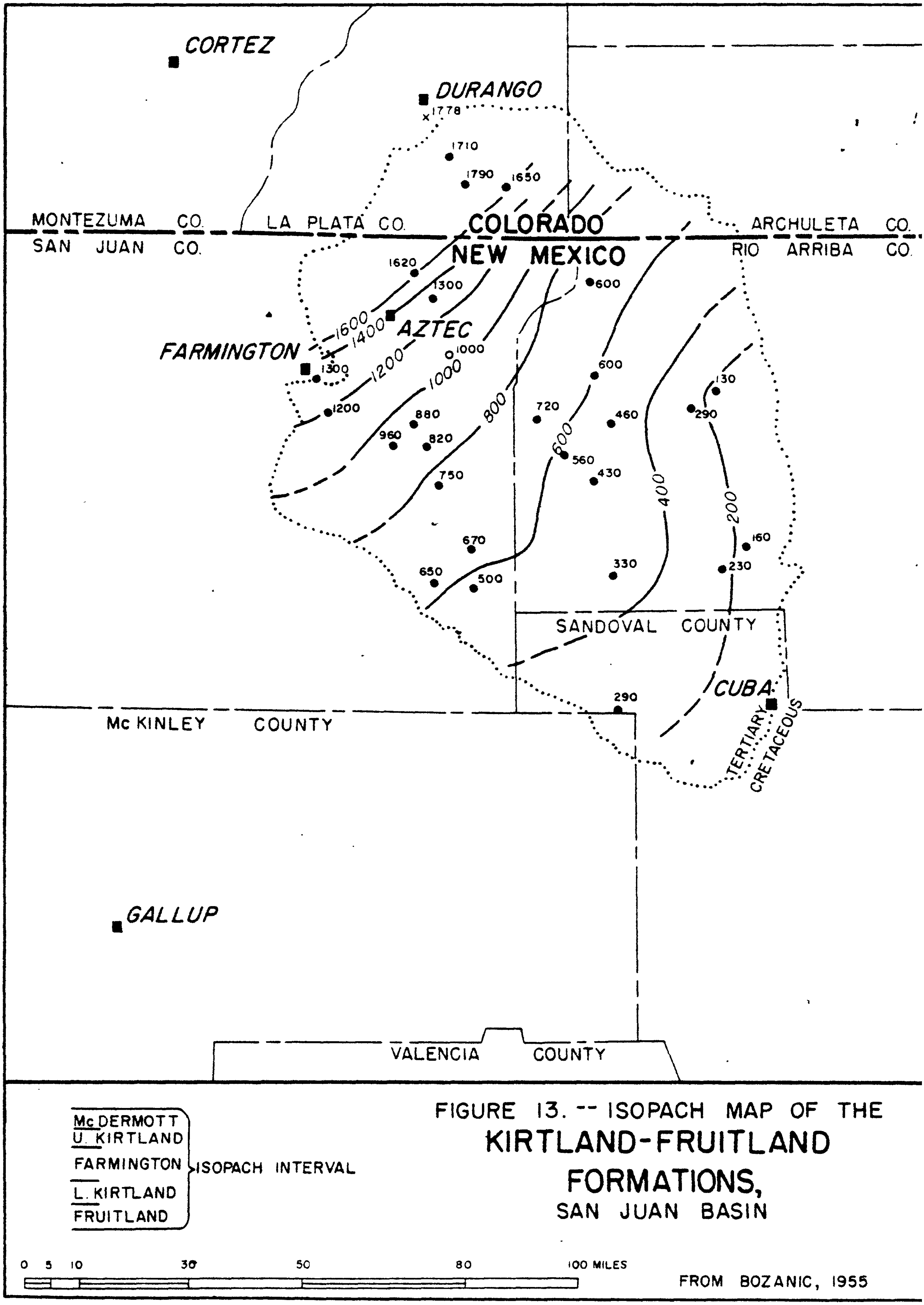

FIGURE 13. -- ISOPACH MAP OF THE KIRTLAND-FRUITLAND FORMATIONS, SAN JUAN BASIN

FROM BOZANIC, 1955

Cenozoic rocks

The Tertiary rocks of the San Juan Basin are Paleocene and Eocene in age and are entirely continental in origin. Except for the Chuska sandstone of Pliocene(?) age along the western edge of the area, no sediments younger than Eocene have been recognized within the San Juan Basin.

Paleocene rocks are included in the Nacimiento formation and are composed largely of gray, yellow, and some rose-gray claystone and mudstone, containing a few sandy beds. The Nacimiento formation ranges in thickness from 400 to 800 feet.

Eocene rocks are included in the San Jose formation and are more coarse grained than the Nacimiento formation, particularly in eastern exposures. Mudstone and some claystone also are prominent in the Eocene section. The San Jose formation, previously known as the Wasatch formation, is locally as much as 2,000 feet thick in the northeastern part of the San Juan Basin; however, it generally is around 1,000 feet.

The Nacimiento contains few permeable beds but the San Jose, in the area between Cuba and the Colorado State line, contains many permeable beds. The permeability of the continental Tertiary beds at any particular location, like the continental beds of the Cretaceous, Morrison, and Chinle formations, cannot be adequately evaluated without local detailed study.

STRUCTURE

The San Juan Basin has a more or less flat floor that is gently inclined northward from the Zuni upwarp (fig. 14). The southern side of the basin has a uniform northward slope, which Kelley (1951) has called the Chaco slope. The east, west, and north sides, however, are marked by abrupt flexures in the strata which increase in structural relief northward (fig. 14). He has grouped the structural features of the basin into four major elements (fig. 15):

I --Uplifts, which are present on all sides of the basin.

II --Intermediate structures, as slopes, embayments, and platforms.

III --Monoclines, essentially lineal features formed by abrupt warping into the deeper parts of the basin.

IV --Central basin, the deep part of the basin which appears to be distinct from other categories on the basis of gross nature.

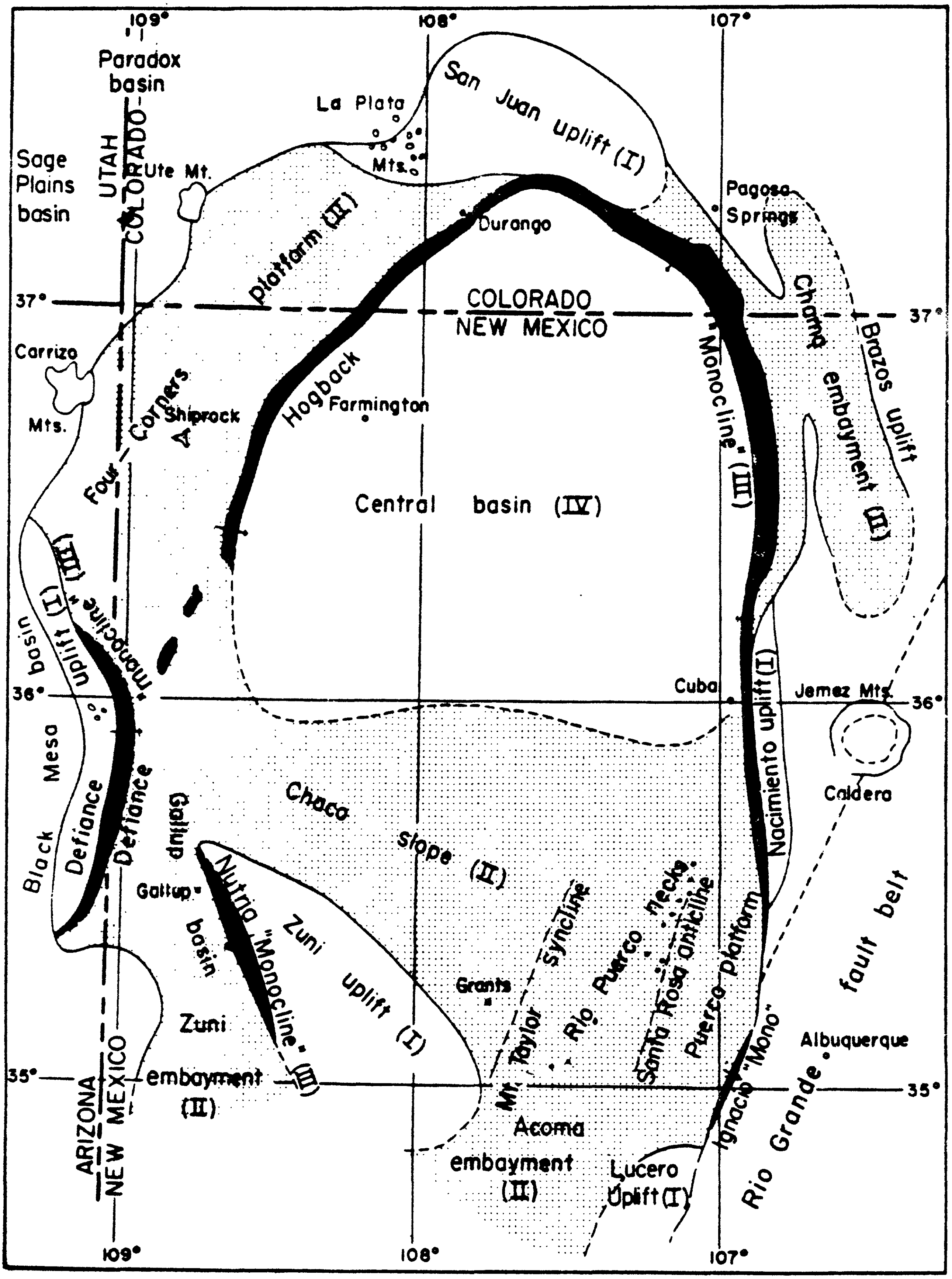

FIGURE 15.--STRUCTURAL ELEMENTS OF THE SAN JUAN BASIN FROM KELLEY, 1951

Insofar as surface evidence indicates, most uplifts about the margins of the San Juan Basin are products of warping. However, the Nacimiento uplift, along the eastern margin of the basin, is separated from the basin by a high-angle reverse fault and some workers have suggested that this relation may exist in depth beneath some of the other uplifted margins, perhaps marked at the surface by the monoclines.

The intermediate elements, group II, include the Chaco slope, three embayments, and two platforms. The embayments are structurally low areas tributary, in a sense, to the main basin, and the platforms are intermediately high areas that bridge the basin margin between major upwarps and separate the San Juan Basin from adjacent structurally low areas. These features, shaded on figure 15, form a belt that essentially surrounds the Central basin. This belt contains the majority of the minor structures of the San Juan Basin (fig. 16).

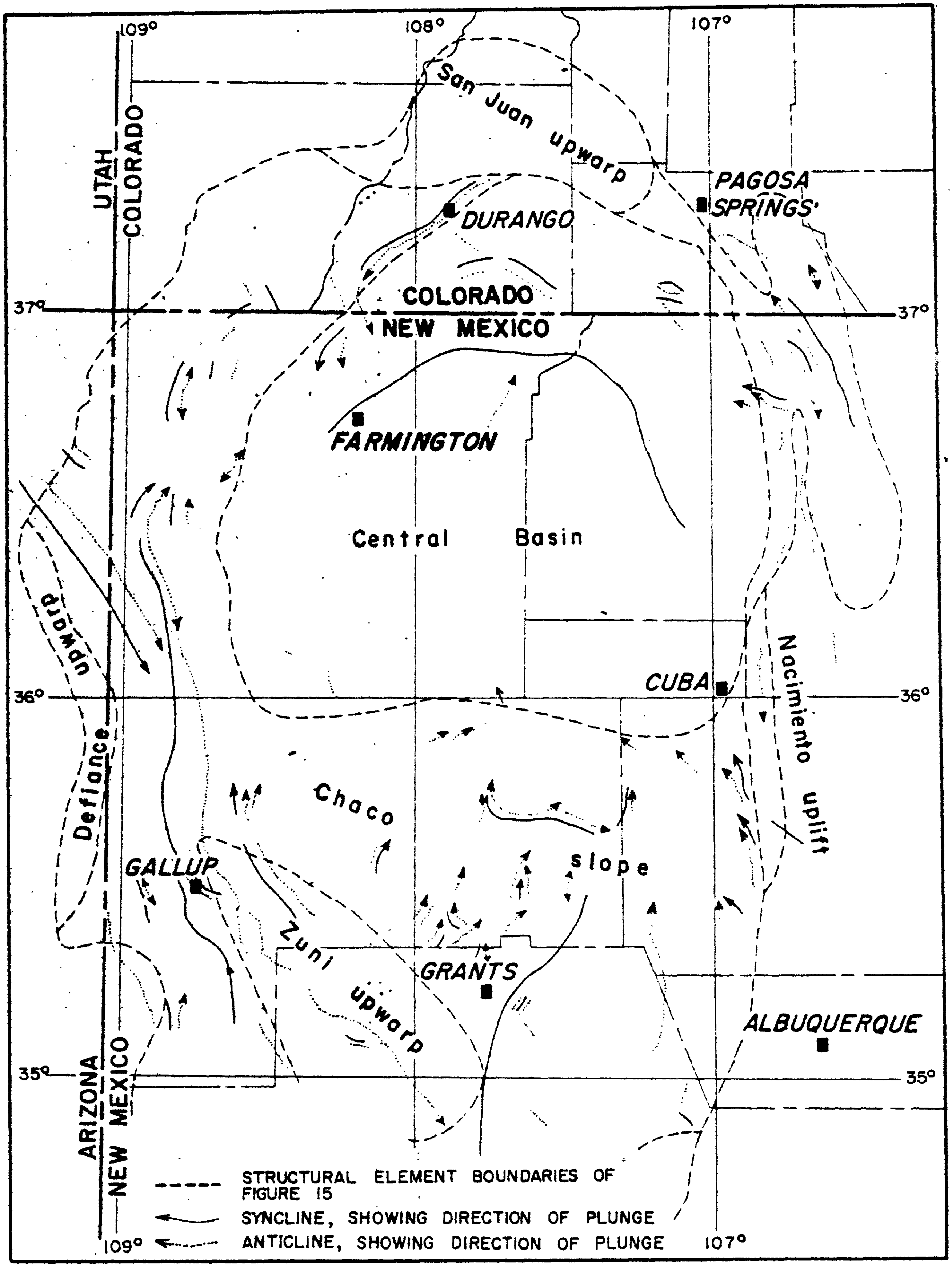

FIGURE 16.-- STRUCTURES OF THE SAN JUAN BASIN FROM KELLEY, 1957

The monoclines, group III, are the prominent structural features of the basin and they ring it on the east, north, and west sides. These steeply dipping structures are of limited areal extent and are hydrostatically the most unstable.

The Central basin, structural type IV, is a completely enclosed basin with perhaps 5,000 feet of closure for the DeChelly sandstone. Most of the oil and gas produced in the San Juan Basin comes from the Central basin (fig. 17); however, this structural element has far fewer minor structures than does the area of intermediate structure.

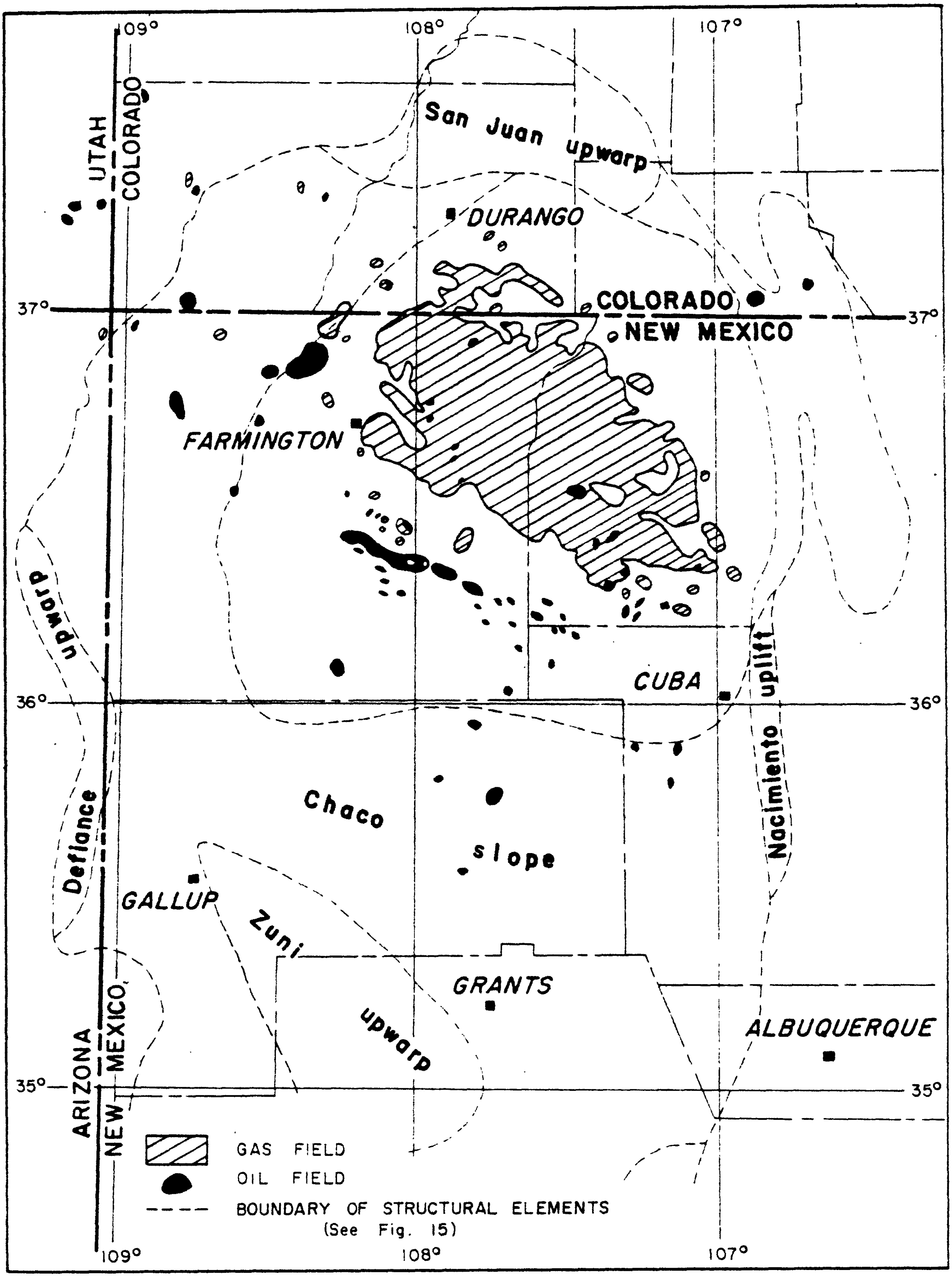

FIGURE 17. -- OIL AND GAS FIELDS OF THE SAN JUAN BASIN

FROM THE PETROLEUM ENGINEER, DEC. 1957

WASTE DISPOSAL POSSIBILITIES

The San Juan Basin contains four types of reservoir rocks that seem to deserve consideration for liquid waste disposal by injection through deep wells. These, named in order of increasing apparent suitability, are gypsum, limestone, shale, and sandstone. Gypsum seems to be more suitable for storage of solid waste in underground excavations than for injected liquid waste. Therefore, it will not be considered further in this report.

Storage of liquid waste in limestone units, such as the Ouray, Leadville, and Hermosa-Madera formations, seems to have some possibility. However, the prevalence, in limestone, of open fractures, solution channels, and other voids greatly complicates the problems of containment.

By hydraulic fracturing or by underground explosion, reservoirs may be made in impermeable shale. This type of reservoir might be suitable for radioactive waste disposal because the fractured zone would be completely enclosed by essentially impermeable rock and confinement probably would be more complete than in most other types of reservoirs. Moreover, some radioactive isotopes react with clay minerals and this natural fixation would be an added safeguard.

Reservoirs created by hydraulic fracturing possibly, by inducing fluid injection along thin sandstone interbeds and producing a wedge-shaped fluid front, can be formed as somewhat tabular or sill-like bodies. Such a reservoir shape would probably be more suitable for the distribution and dissipation of radiogenic heat to the country rock than would a spherical reservoir created by explosion.

The units best suited for fractured-reservoir storage in the San Juan Basin are the Mancos and Lewis shales. The few sandstone interbeds in these units might favorably influence the shape of the reservoir produced by hydraulic fracturing.

Sandstone units occur in many stratigraphic and structural "traps" in the San Juan Basin. Some of these traps might provide effective confinement for stored liquid waste. Thermal problems would probably be less formidable in sandstone than in shale because waste would disperse more readily in the sandstone and because sandstone has about twice the heat conductance of shale (Birch, 1954, p. 651). Plugging of the sandstone by chemical reaction and precipitation of solids might offer a serious difficulty. Perhaps precipitation could be minimized by pre-treatment of the reservoir and the waste before injection. Hydraulic fracturing of the sandstone might be a means of restoring permeability through a clogged zone immediately adjacent to a well.

At any given site, the problem of down-dip migration of denser waste seems more easily predictable than the problems of up-dip migration. A definite hazard from heavy-liquid radioactive waste stored in sandstone reservoirs might be up-dip diffusion of the waste in the natural liquids of the sandstone reservoir and the up-dip migration of the diluted waste by convection currents resulting from the generation of heat by radioactivity of the liquid waste. The extent of contamination from these processes probably could be fully evaluated only by extensive field tests, but if the hazard is real, it lessens the importance, for waste disposal, of structural traps, of widespread sandstone units, and of structural basins. Rather, isolated sandstone bodies that are completely surrounded by impermeable shale, such as Upper Cretaceous offshore bar deposits in the San Juan Basin, would merit special attention.

From the standpoint of permeability, hydrostatic confinement within stratigraphic traps, and areal distribution within the San Juan Basin, the Cretaceous marginal-marine sandstone formations seem to be the most practical host rocks for waste storage. Throughout the area these sandstone units lie at depths generally less than 5,000 feet.

Although along the northern and southern sides of the basin the Bluff and Cow Springs sandstones may be potential disposal media, they are not widely distributed and dip steeply basinward, reaching depths in excess of 5,000 feet. The Entrada sandstone is present throughout the basin, but it probably would be of interest for waste disposal only near the basin margin. Elsewhere, the depth is considerably greater. The DeChelly and Glorieta sandstones seemingly would be suitable only locally because they are suitably permeable only along the southern margin of the area. In nearly all other areas they lie at depths in excess of 5,000 feet.

From the standpoint of localization of storage, relatively shallow depth of storage, minimum hydrostatic head, and possible contamination of existing or potential petroleum sources, the area of structural group II seems most desirable for further study. The approximate number of minor structures which might provide local confinement of stored liquid waste is shown by figure 16. Each structure contains several beds whose lithology and relations to other beds seem to be favorable for waste storage.

The most favorable combination of structure and stratigraphy seems to be within the Chaco slope. There the DeChelly-Glorieta sandstone is present, the Cow Springs sandstone is thickest and most permeable, and a great variety of Upper Cretaceous marginal marine sandstone units intertongue with impermeable marine shale. Also, the Chaco slope is not an oil and gas producing area (fig. 17).

The possibility of contamination of oil, gas, or economically significant water by migrant waste liquids needs further careful study. This study necessarily would concern the detailed characteristics of specific sites within the basin as a whole. A summary of oil- and gas-producing zones is given in figure 18. In all aquifers in the San Juan Basin the salt content in the water increases down-dip toward the center of the basin. At depths exceeding 2,000 feet, the ground water is unsuitable for present-day use.

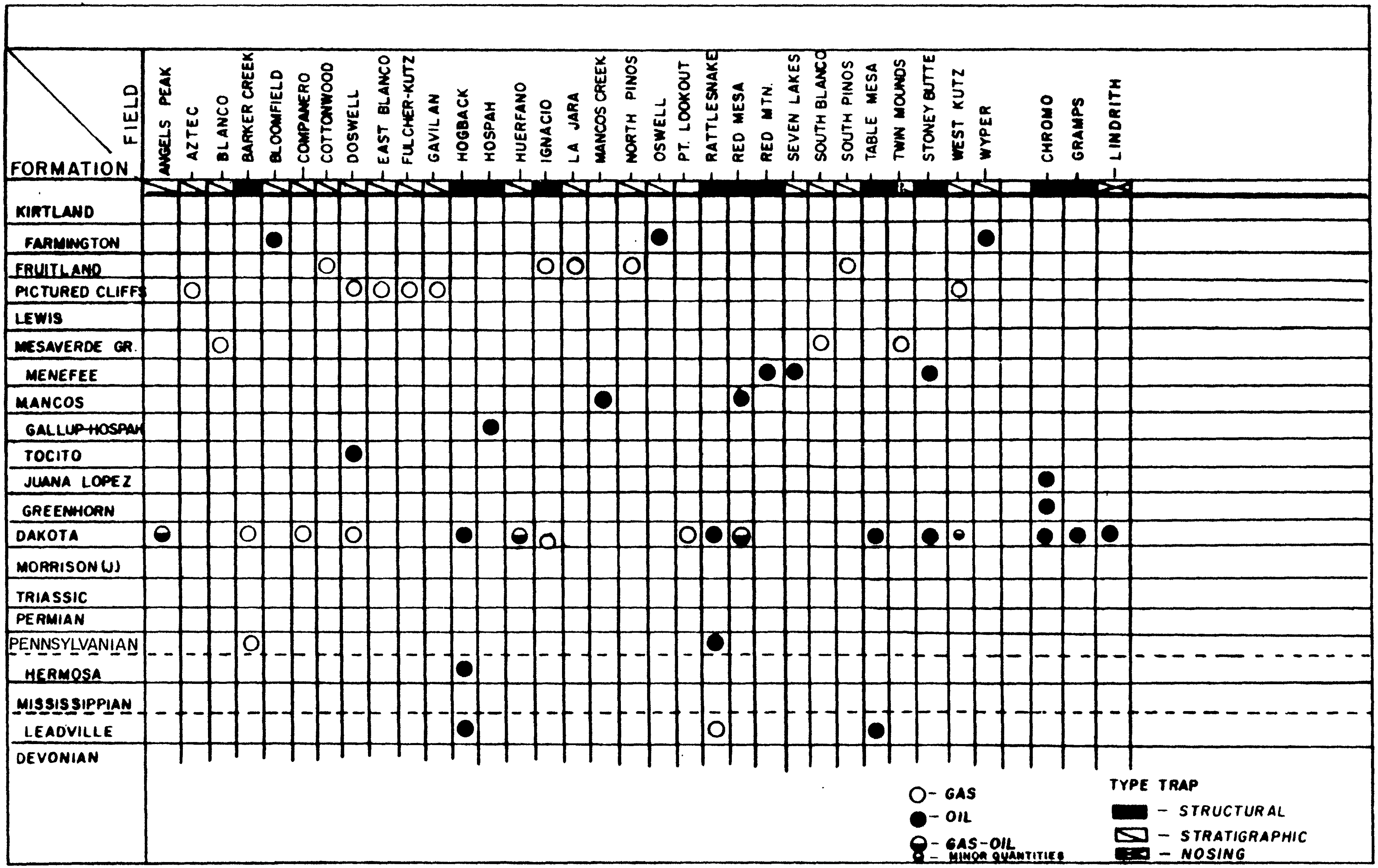

FIGURE 18. -- SAN JUAN BASIN PRODUCTION CHART FROM BOZANIC, 1955.

Because it is structurally low, the Central basin of the San Juan Basin appears, at first glance, to be ideal for storage of heavy-liquid radioactive waste. However, the possibility of up-dip diffusion of the waste and actual up-dip convectional migration could reduce the apparent advantages of structurally low areas. In addition, the fact that most of the oil and gas production is from this area, the relative scarcity of minor structures for use in localization of waste, the very considerable depth of all potentially useful stratigraphic units except the youngest of the Cretaceous rocks, and the maximum hydrostatic head in all units makes the Central basin seem rather unfavorable for consideration as an area of waste disposal. It seems to be much less favorable than the area of the Chaco slope.

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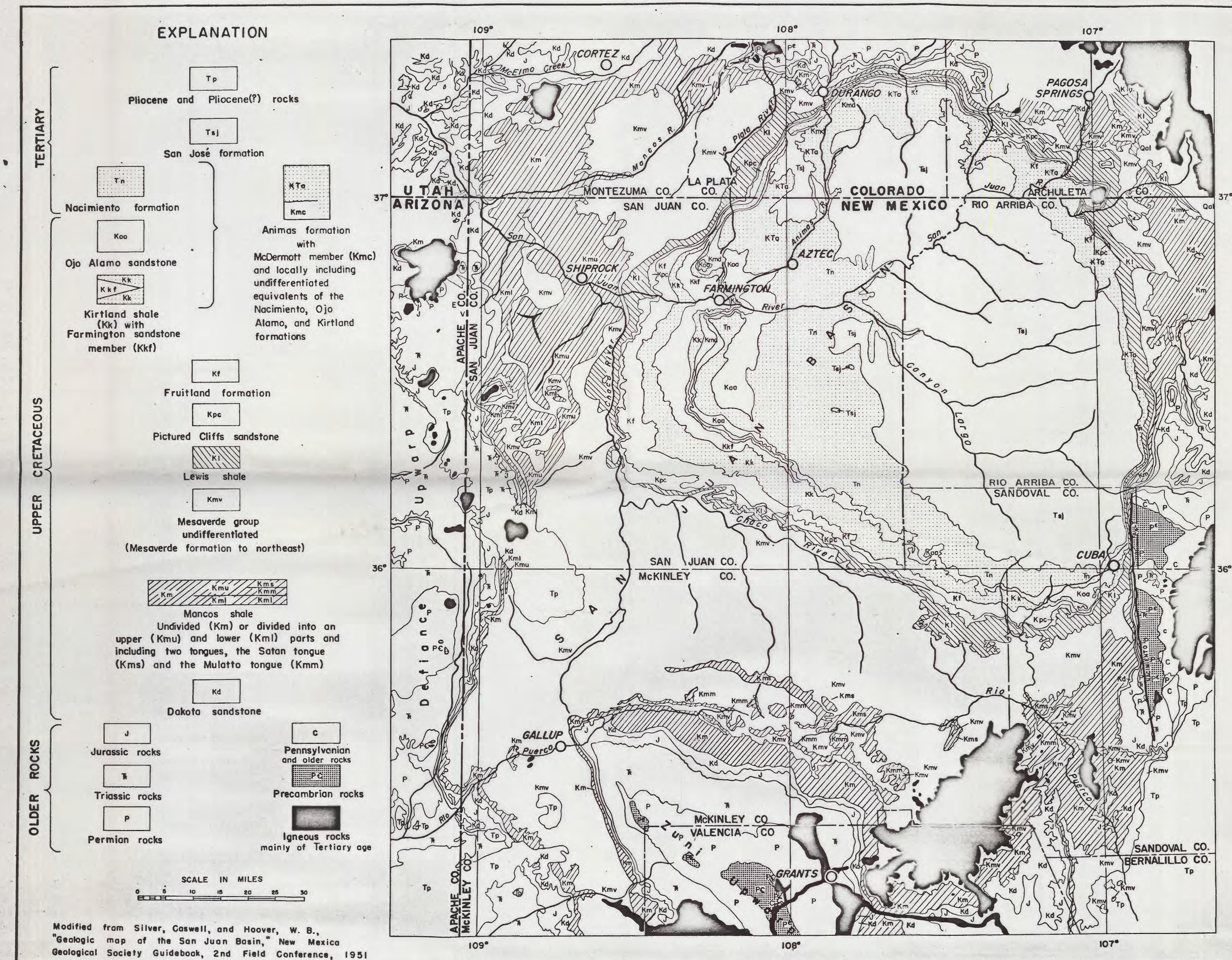

This map is preliminary and has not been edited for conformity with Geological Survey format and nomenclature

FIGURE 1. --GENERALIZED GEOLOGIC MAP OF THE SAN JUAN BASIN

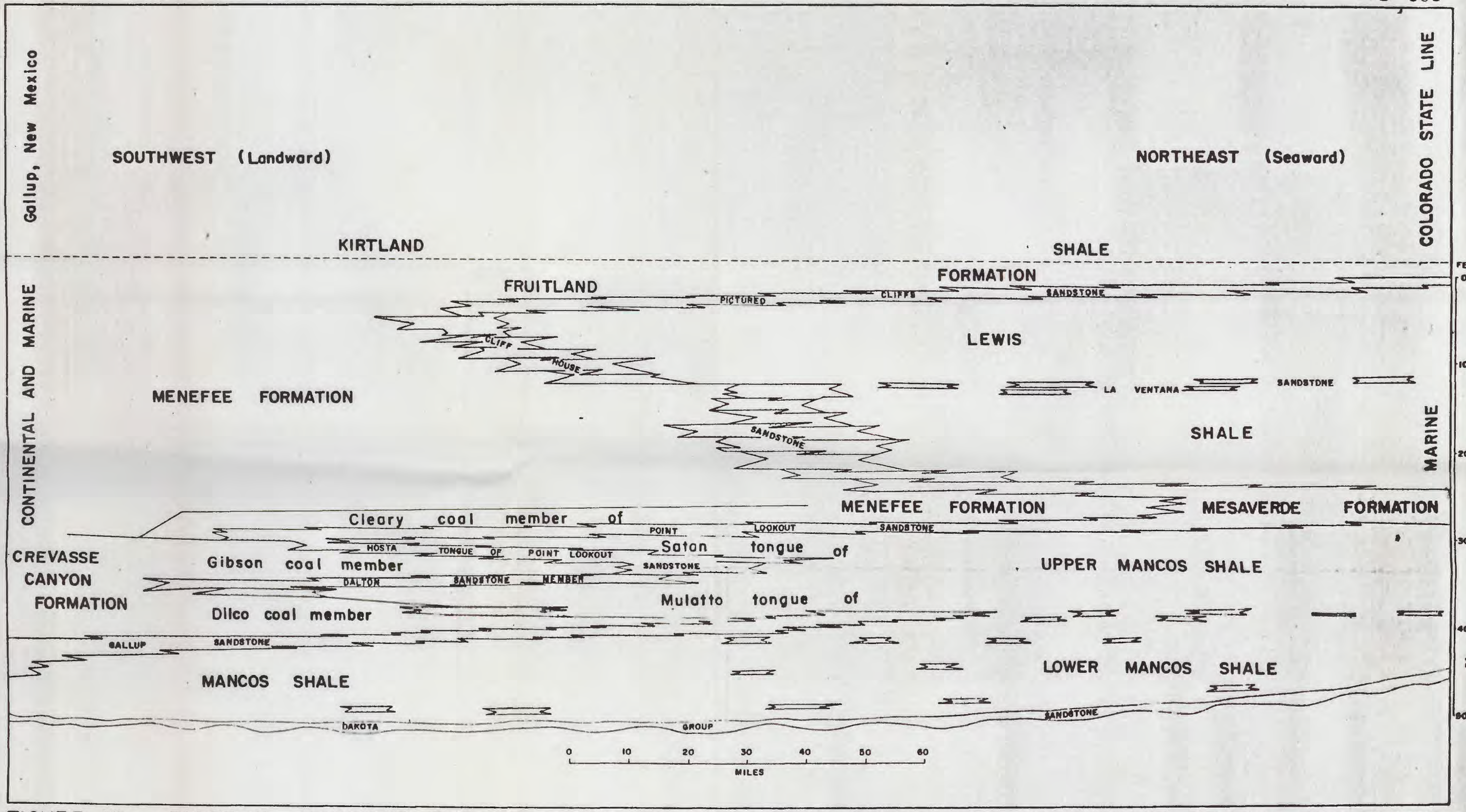

FIGURE 10.--DIAGRAM SHOWING THE RELATION OF THE UPPER CRETACEOUS FORMATIONS OF THE SAN JUAN BASIN, NEW MEXICO AND COLORADO. FROM SILVER, 1957.

This map is preliminary and has not been edited for conformity with Geological Survey format and nomenclature

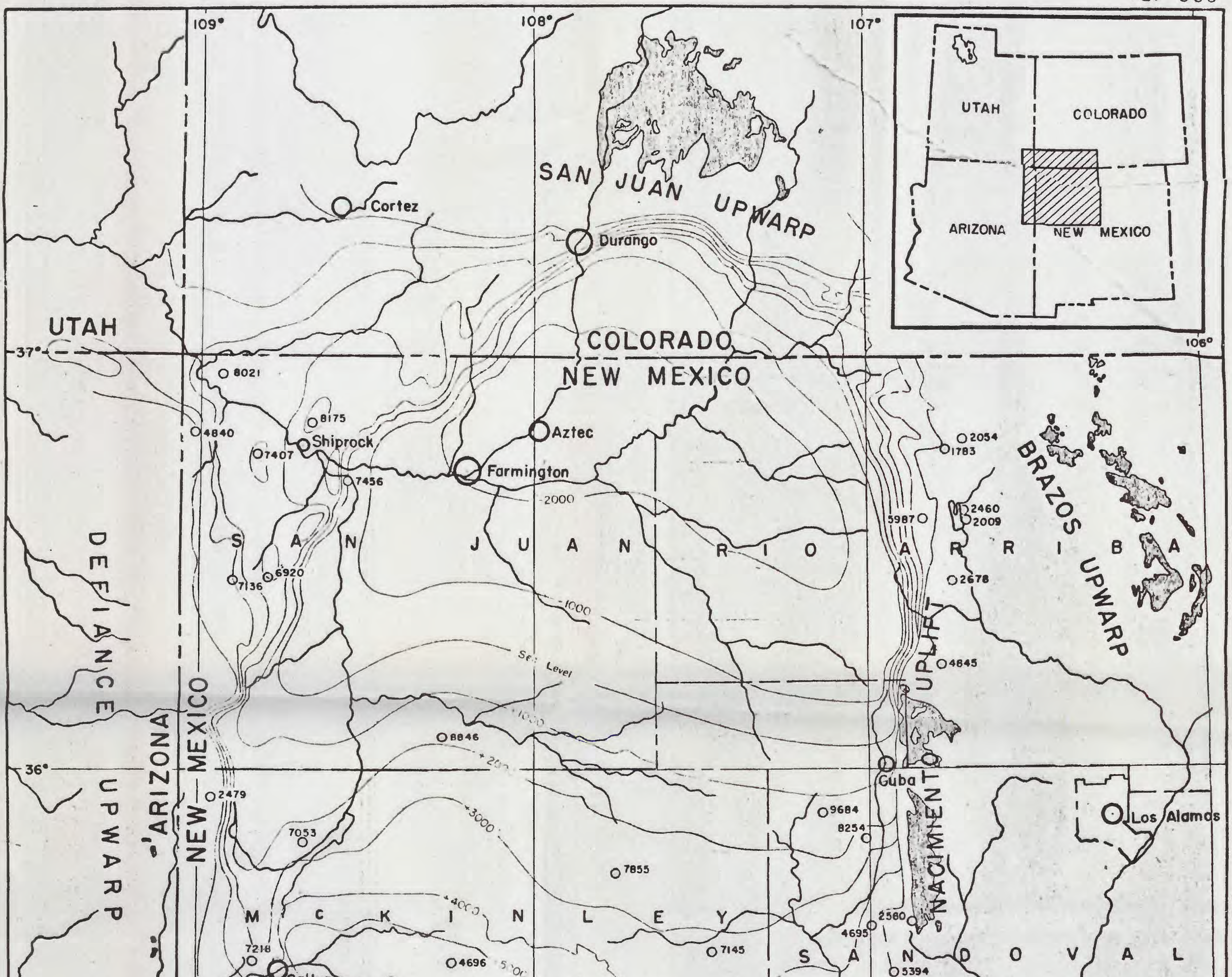

FIGURE 14. -- STRUCTURE OF THE SAN JUAN BASIN

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Survey format and nomenclature

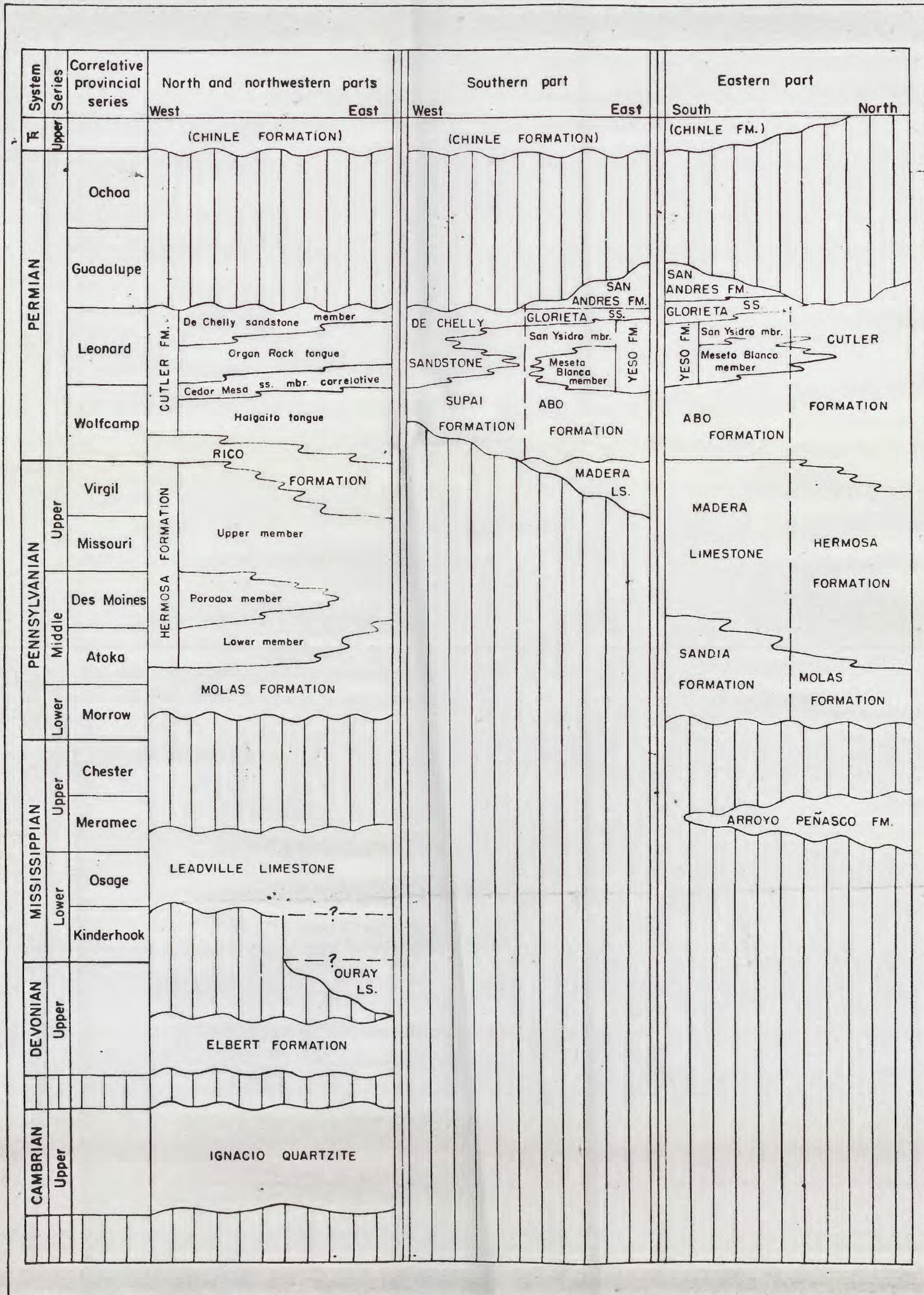

FIGURE 2.--PALEOZOIC FORMATIONS OF THE SAN JUAN BASIN.

This map is preliminary and has not been edited for conformity with Geological Survey format and nomenclature

This map is preliminary and has not been edited for conformity with Geological Survey format and nomenclature

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FIGURE 7. -- MESOZOIC AND CENOZOIC FORMATIONS OF THE SAN JUAN BASIN.