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Cover: Virgin anticline near St. George, Washington County, Utah.

Lower Mesozoic and Upper Paleozoic Petroleum Potential of the Hingeline Area, Central Utah*

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ABSTRACT.—A late Pennsylvanian uplift in central Utah experienced extensive erosion which removed Pennsylvanian and most Mississippian rocks. The segment of this ancient arch where Pennsylvanian sediments are missing has been named the Emery uplift. The western part of the uplift was affected by a north-south trending Middle Jurassic depression herein named the Sanpete-Sevier rift. The eastern growth fault defining this depression is herein named the ancient Ephraim fault. More than 8,000 feet of Jurassic Carmel-Arapien marine shale and evaporites filled this rift. The Sanpete-Sevier rift has been partly defined by extensive seismograph surveys.

Recent wildcat drilling has encountered 2,038 feet of salt in the Jurassic Carmel-Arapien sequence, and limits of these salt deposits can now be postulated.

The west part of the Emery uplift, still covered by the thick Jurassic evaporite sediments, has excellent oil and gas potential in the Lower Mesozoic and Upper Paleozoic rocks.

INTRODUCTION

The hingeline area of central Utah, located along the western margin of the Colorado Plateau Province, has long been a puzzle to exploration geologists. Until late Pennsylvanian time this area was the hingeline along which most Lower Paleozoic formations thicken westward into the Cordilleran geosyncline. Late Pennsylvanian uplift and erosion exposed the Mississippian rocks, which later were buried by onlapping Permian sediments.

The complexity of the surface structure is due in part to compression-forming thrusts with later relaxation which caused some down-drop faulting typical of the Basin and Range Province to the west. Additional complexity caused by diapirism involving Jurassic salt and shale, now evident on the surface, has made the area unique.

Some resolution of the puzzle is now possible with the accumulation of data from exploratory wells and from extensive seismograph surveys carried out in recent years. Systemic and formation isopach maps, together with panel cross sections, help to define the best places to anticipate commercial oil and gas fields in central Utah.

Figure 1 shows the area of study, situated along the western part of the Colorado Plateau Province, adjacent to discontinuous, eastwardly directed thrust segments which mark the eastern limit of the Basin and Range Province. These thrusts are mapped as the southern extension of the Thrust Belt Province of northern Utah, western Wyoming, and southeastern Idaho. The Pavant Range and Mount Nebo thrusts are within the study area. The axis of the Sevier Orogenic Belt lies west of the area but is referred to later in the discussion of Jurassic sediments.

The ancient Ephraim fault (fig. 1), located on the eastern side of a deep depression which formed in Early Jurassic time, is buried, with no direct surface expression. The Sevier and Paunsaugunt faults, surface faults south of the study area, may have some genetic relationship to the ancient Ephraim fault.

SEDIMENTARY AND TECTONIC HISTORY

The sedimentary and tectonic history of the Mississippian through Jurassic systems are summarized below. Figure 2 shows the stratigraphic nomenclature and the position of the isopach maps and panel cross sections in the order in which they are discussed.

Mississippian

Figure 3 is an isopach map of the preserved Mississippian sediments (not including the Manning Canyon Formation). The area of thin Mississippian rocks represents the highest part of the northwest trending uplift. It was exposed during a late Pennsylvanian uplift and erosion cycle (fig. 2).

Mississippian carbonates are generally porous because of solution during late Pennsylvanian erosion. They constitute a major potential oil and gas reservoir. Oil staining and some gas shows have been observed in many wells.

The Manning Canyon Formation includes shale, carbonate, and thin sandstone. It is Late Mississippian to

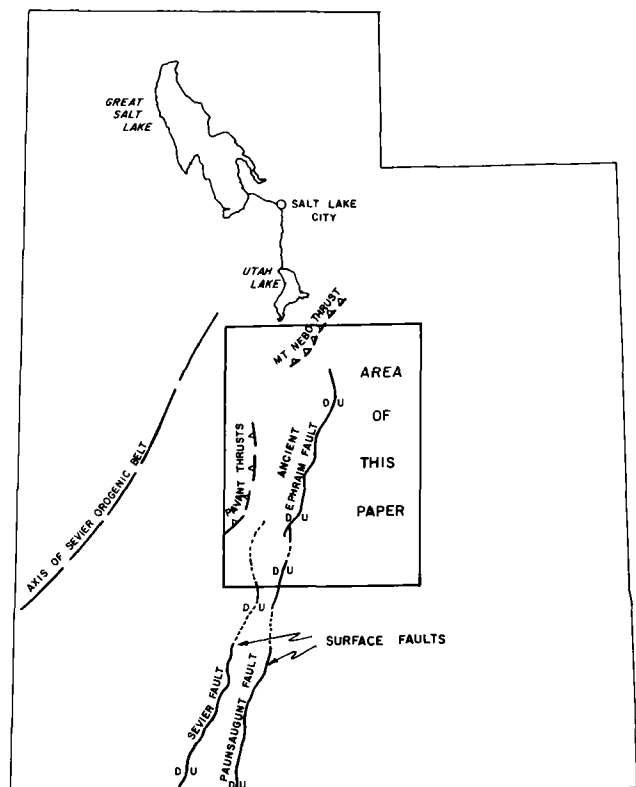


FIGURE 1.—Index map with major faults.

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WYOMING	UTAH					SYSTEM	ERA
SOUTHWEST WYOMING	NORTHWEST	SOUTHWEST	CENTER OF EMERY HIGH	NORTHEAST	SOUTHEAST		
GANNETT	GANNETT	CURTIS ENTRADA	SUMMERVILLE CURTIS ENTRADA	MORRISON SUMMERVILLE CURTIS ENTRADA	MORRISON SUMMERVILLE CURTIS ENTRADA	14	MESOZOIC
STUMP PREUSS	STUMP PREUSS	CARMEL-ARAPIEN	CARMEL-ARAPIEN	CARMEL NAVAJO	CARMEL NAVAJO	11	
TWIN CREEK NUGGET	TWIN CREEK NUGGET	NAVAJO	NAVAJO	KAYENTA	KAYENTA	10	
ANKAREH THAYNES WOODSIDE	ANKAREH THAYNES WOODSIDE	KAYENTA WINGATE CHINLE MOENKOPI	KAYENTA WINGATE CHINLE MOENKOPI	KAYENTA WINGATE CHINLE MOENKOPI	KAYENTA WINGATE CHINLE MOENKOPI	9	
PHOSPHORIA	PARK CITY	KAIBAB	KAIBAB	KAIBAB TOROWEAP CEDAR MESA ELEPHANT CANYON	KAIBAB TOROWEAP CEDAR MESA ELEPHANT CANYON	8	PALEOZOIC
WEBER	DIAMOND CREEK KIRKMAN OQUIRH	CEDAR MESA PAKOON CALLVILLE		HERMOSA	HERMOSA	7	
MORGAN				MANNING CANYON GREAT BLUE HUMBUG DESERET LEADVILLE	MANNING CANYON GREAT BLUE HUMBUG DESERET LEADVILLE	6	
BRAZER	MANNING CANYON GREAT BLUE HUMBUG DESERET MADISON	REDWALL	LEADVILLE			5	
MADISON						4	
						3	

FIGURE 2.—Generalized correlation chart. Circles indicate positions of figs. 3-18.

Early Pennsylvanian in age. The northeast part of figure 4 shows what previously was named the "Manning Canyon Embayment." It should not be called an embayment since the isopachs represent only the preserved thickness of the Manning Canyon, which was deposited over a much larger area, probably with an east-west depositional trend, and was subsequently reduced to its present extent by late Pennsylvanian erosion.

The southern part of the map shows the preserved Molas shale sequence. Originally the Molas may have covered a much larger area, but the formation was removed from part of the area by late Pennsylvanian erosion.

The shaded area on figure 4 represents the area of the exposed Mississippian carbonates.

Oil staining and gas shows have been recorded in the Manning Canyon sandstone within the study area.

Pennsylvanian

The thickness of the Pennsylvanian carbonate and shale sequence is shown in figure 5. This map shows the Pennsylvanian deposits that were preserved after the late Pennsylvanian uplift and erosion of the Emery uplift. All the shaded area represents the exposed Mississippian carbonates.

Pennsylvanian rocks have not had significant oil and gas shows within the study area.

Permian

The Permian rests unconformably on older rocks (fig. 6), except possibly in the extreme northeast part of the

area, where it is believed to be conformable on Pennsylvanian. The Permian consists of carbonates, evaporites, sandstone, and shale.

The Permian isopach thin (fig. 7) defines the highest part of the ancient Emery uplift. The northwest trend is again obvious and may represent uplift during Permian sedimentation.

Permian carbonates are porous and contain good live oil shows in many wells on and near the high part of the Emery uplift. Permian reservoirs constitute a major objective throughout most of the area. In the southeast corner of the area, however, they are exposed at the surface. Upper Valley oil field, located in Garfield County south of the map area, has produced more than twelve million barrels of oil from the Kaibab limestone and dolomites.

Triassic

Early Triassic marine shale and thin carbonates were deposited over the Emery uplift with no significant reflection of the old high. The late Triassic rocks are dominantly continental and thicken to the west and southwest. As shown in figure 8, the regional thickening to the west followed the early Paleozoic pattern.

The Navajo Sandstone, a major objective reservoir, is present across the buried Emery uplift. It thickens from 400 feet on the north to more than 1100 feet (estimated) on the south (fig. 9).

The early Triassic Sinbad carbonates have yielded live oil shows and combustible gas. South Last Chance (T. 26 S., R. 7 E.) is a shut-in gas field capable of producing from the Sinbad. The Navajo Sandstone is stained in some places and contains live oil shows in a few wells.

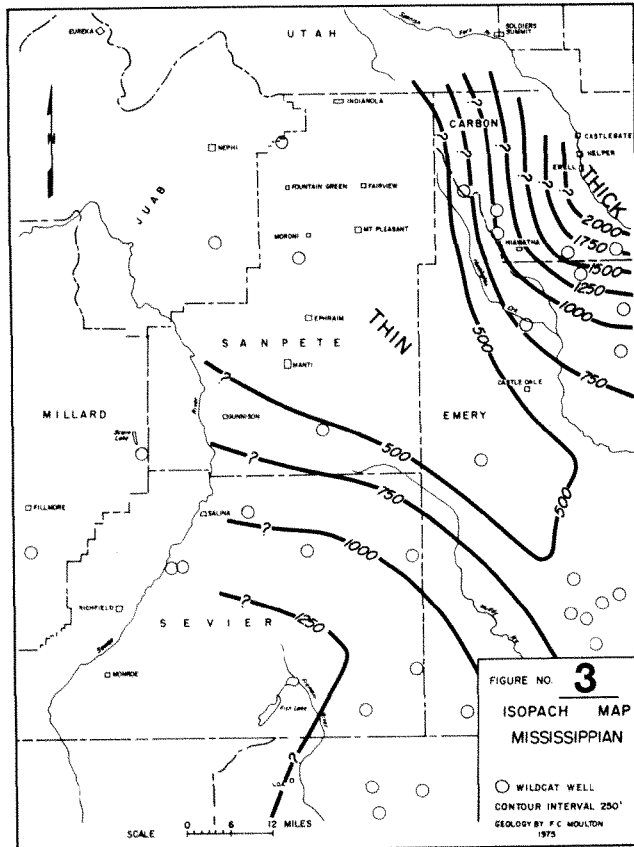


FIGURE 3.—Isopach map of preserved Mississippian sediments.

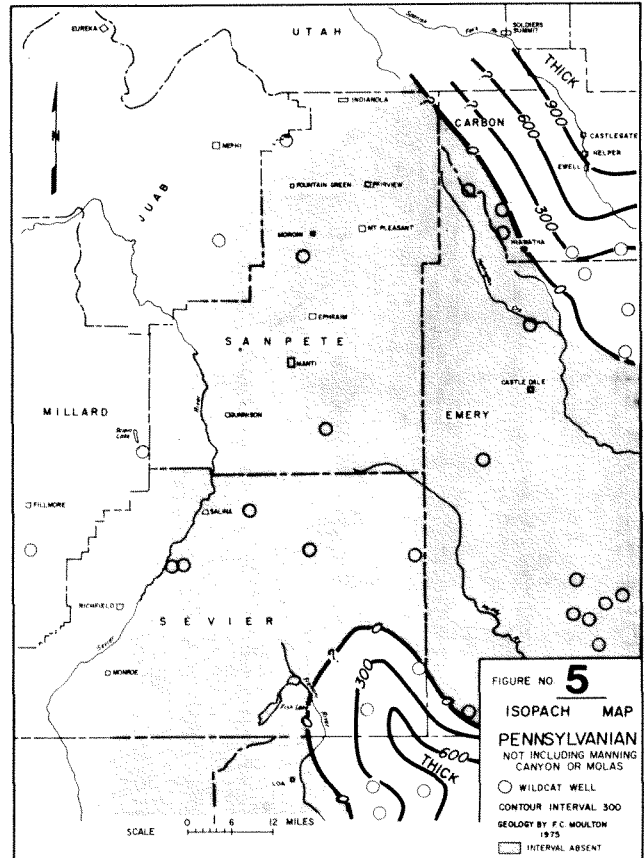


FIGURE 5.—Isopach map of preserved Pennsylvanian deposits.

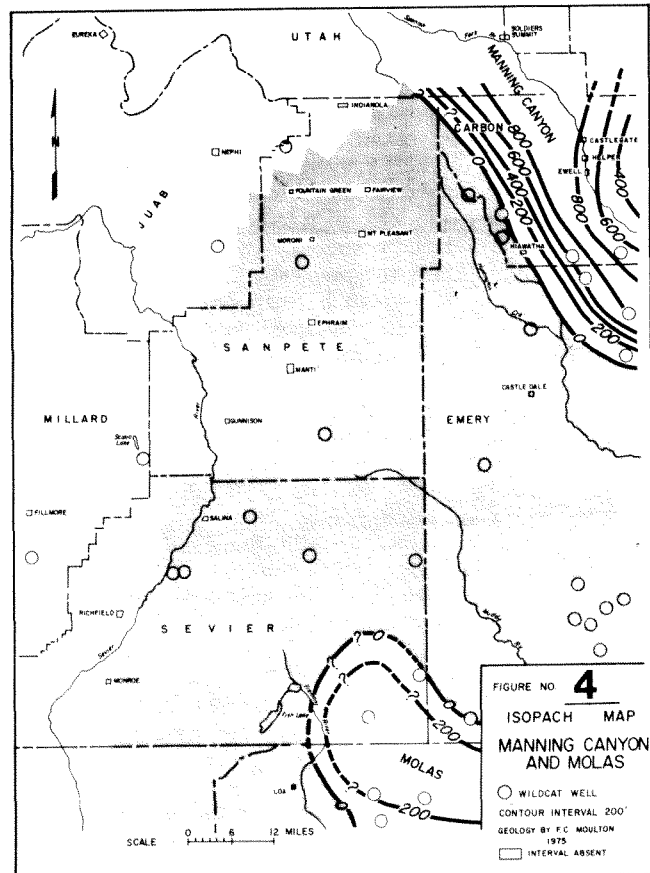


FIGURE 4.—Isopach map of Manning Canyon and Molas.

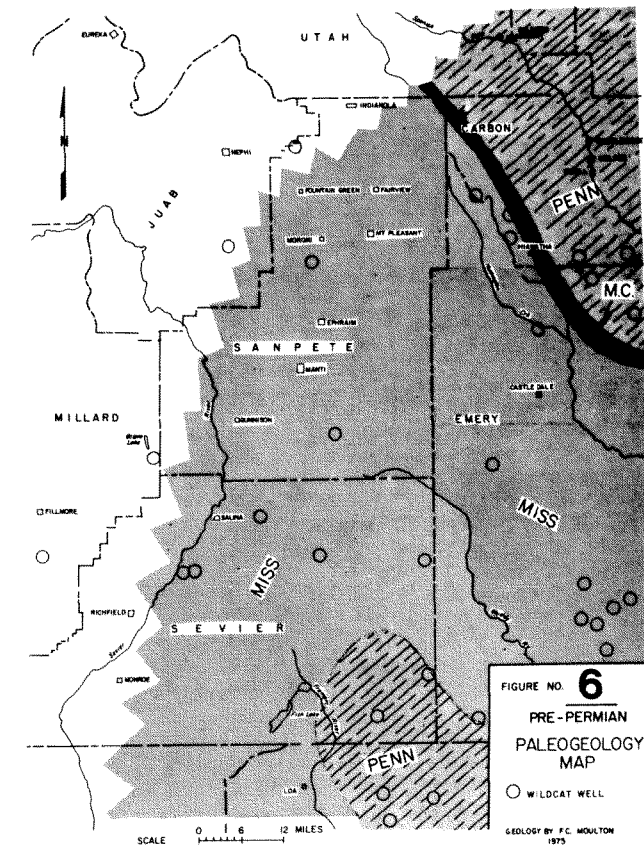


FIGURE 6.—Paleogeology map of the pre-Permian.

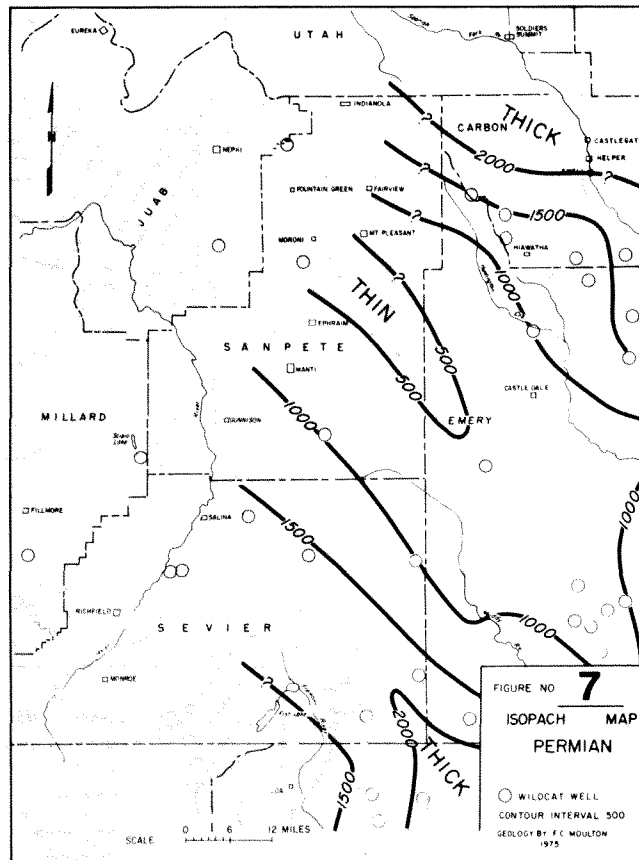


FIGURE 7.—Isopach map of the Permian.

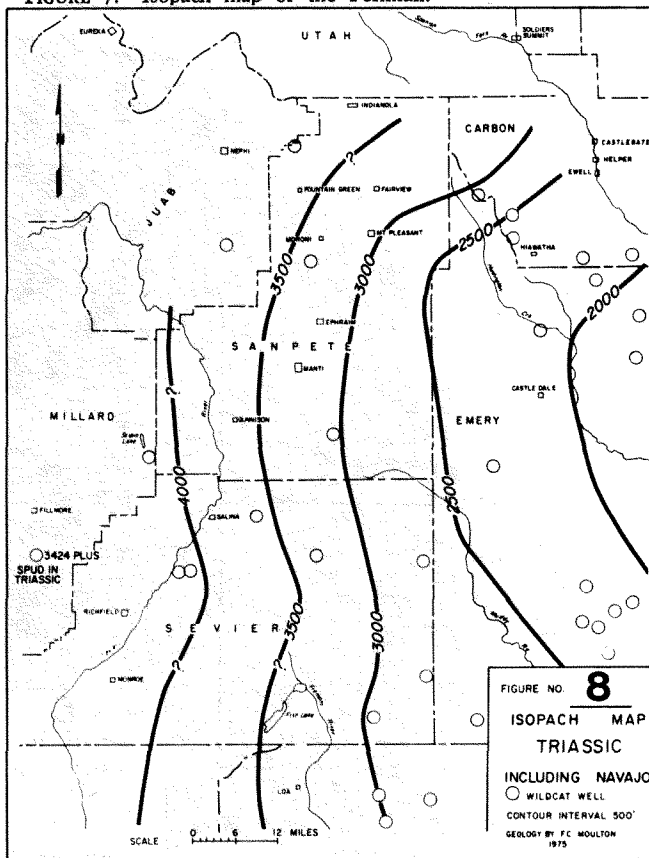


FIGURE 8.—Isopach map of the Triassic, including Navajo.

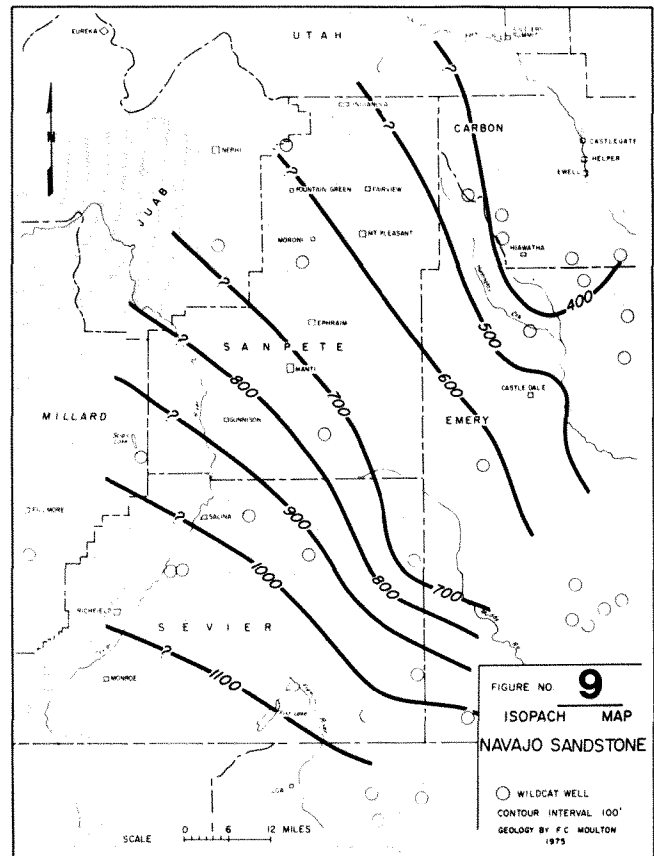


FIGURE 9.—Isopach map of Navajo Sandstone.

Jurassic

The general configuration of the Emery high at the end of Navajo Sandstone deposition is shown in figure 10. This panel cross section depicts the broad Emery uplift. At the center of the Emery high, a thin Permian sequence rests unconformably on thin Mississippian rocks. As will be shown later, the western side of the uplift was severely faulted and modified during the Jurassic.

Figure 11 shows the preserved thickness of all Jurassic sediments where they can be mapped on the east side of the study area. In the Sanpete-Sevier rift (shaded), the Jurassic thickness values are posted on the map for reference.

The lowest Jurassic sediments of the Sanpete-Sevier rift area are thin carbonates which seem to correlate with thin carbonates on the shelf to the east. They may represent a shallow marine invasion from the northwest during an early stable period before the deep rift was formed. Subsequently, in about middle Jurassic time, the Sevier uplift in western Utah was elevated as a broad arch (see fig. 1). The position of the present Sanpete-Sevier rift was downwarped and filled with evaporites, carbonates, shale, and thin sandstones called the Carmel-Arapien.

The Sanpete-Sevier rift area is bounded by growth faults with displacements up to 4,000 feet or more along its east side. The ancient Ephraim fault system, along the east side of the Sanpete-Sevier rift, may be genetically related to faults of similar trend both north and south of the map area. To the south the Paunsaugunt and Sevier surface faults (fig. 1) may have a similar middle Jurassic history of movement. These two surface faults have moved

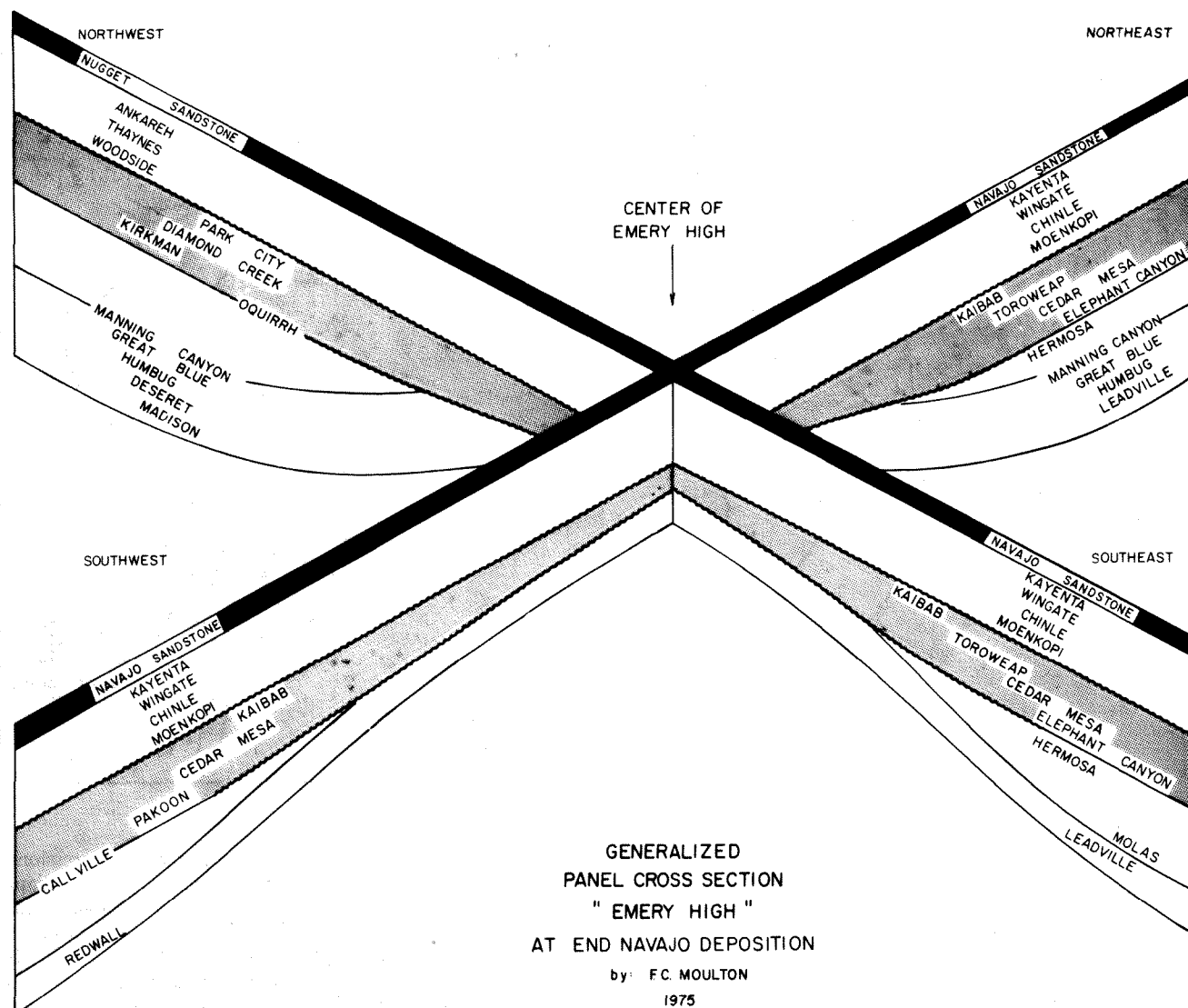


FIGURE 10.—Generalized panel cross section of the Emery high at the end of Navajo deposition.

in recent history, but the ancient Ephraim fault has been relatively inactive since middle Jurassic time.

Within the Sanpete-Sevier rift deep structures, both related and unrelated to the ancient faulting, are now buried under Jurassic salt, evaporites, and shale which locally exceed 11,000 feet in thickness. Excessive thickness of salt and evaporites could be a result of flowage of salt, evaporite, and shale into "salt cells" or broad diapirs.

The Phillips Petroleum Company No. 1 Price "N" wildcat well, (sec. 29, T. 15 S., R. 3 E.), in Sanpete County south of the town of Moroni, was drilled to a total depth of 12,332 feet. Salt 2,038 feet thick was penetrated from 9,072 to 11,110 feet; 1,222 feet of Jurassic shale was drilled below the salt. A total of 5,832 feet of Jurassic sediments was drilled.

The Jurassic Carmel-Arapien isopach map (fig. 12) is based on direct correlation of typical Carmel shale and thin carbonate beds in the eastern part of the map area with most of the Arapien as defined in central Utah by

previous writers. These original investigations had only the surface outcrops to study and assigned much of the Arapien shales and evaporites to a younger age.

Within the thick Sanpete-Sevier rift belt, most of the San Rafael Group (Carmel, Entrada, Curtis, and Summerville formations) can be distinguished in recently drilled wells. This new information proves that most of the Arapien strata in the rift belt correlates with the Carmel. It is significant to future exploration to note here that in the Phillips No. 1 Price "N" a 16-foot salt bed was encountered at 6,897 feet in the Summerville. Some surface outcrops containing salt are Summerville and not Carmel as mapped by some surface geologists.

Recent exploration work and deep drilling indicate that the Carmel-Arapien is more than 8,000 feet thick in some local areas. These thick shale and salt sequences may be due in part to flowage into broad, thick diapiric masses and smaller salt cells. Thrust faults have moved Paleozoic rocks eastward over Mesozoic rocks more than ten miles

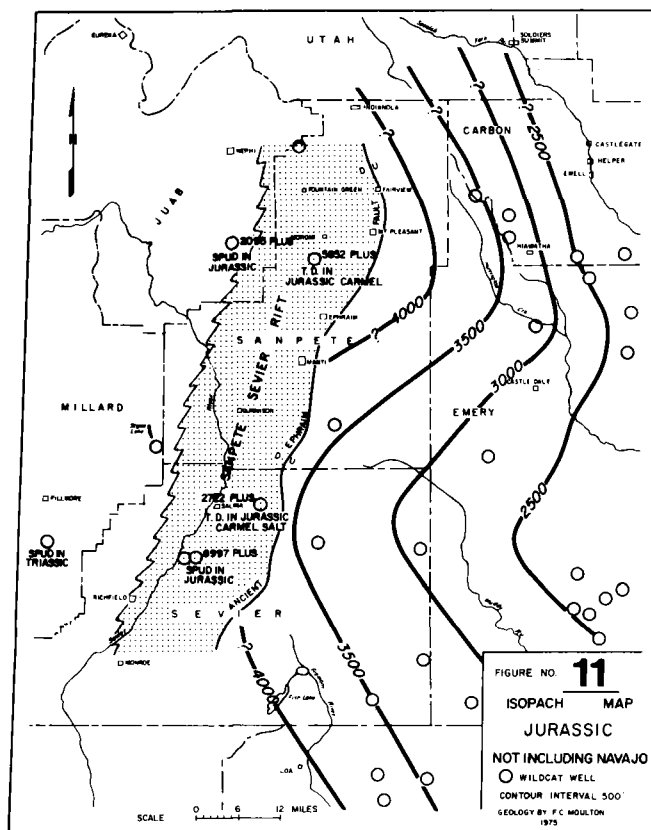


FIGURE 11.—Isopach map of the Jurassic (not including Navajo).

along the west sector of the study area. Compressive forces affected the low density salt, evaporites, and shale sequences of the Jurassic, locally forming excessive thicknesses in front of these thrusts.

The possible limits of the Carmel salts are shown in figure 13. The eastern limits are generally defined by data from wells, but the western limits are more speculative. All wells that encountered Carmel salt are noted. The Phillips No. 1 Price "N" is labeled with a salt interval of 2,038 feet.

The thick rift belt of probable maximum salt thickness is the shaded area on the map. Within the shaded area is a Jurassic surface outcrop belt which has been named the Sanpete-Sevier Valley anticline and which may define the area of maximum thickness of the Jurassic and also the Carmel salt.

The Sanpete-Sevier Valley anticline is confined within the rift belt and is probably a result of vertical diapir movement of Jurassic sediments only. The Triassic Navajo Formation probably served as the floor. The Navajo Formation was folded and faulted to some extent below the Jurassic sediments but was not included in the vertical diapir mass.

Overtaken beds on the surface have been interpreted as being formed from large scale overthrusts in some areas along the Sanpete-Sevier Valley anticline. However, the same evidence also can be explained as erosional remnants of recumbent or mushroom-shaped folds formed by diapiric movement.

The vertical diapir movement can also be explained

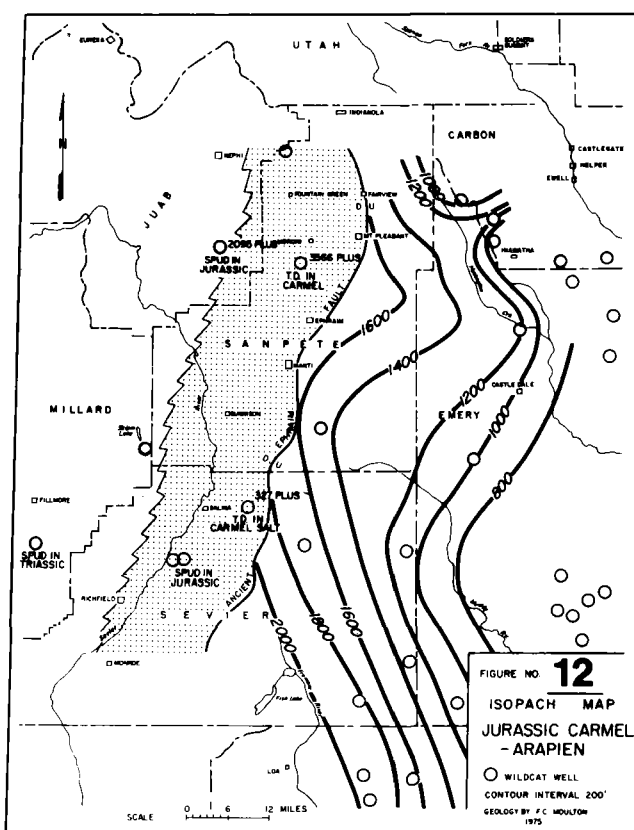


FIGURE 12.—Isopach map of Jurassic Carmel-Arapien.

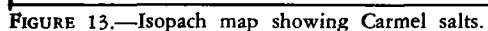
by differential sediment loading along early compressional folds formed within the Jurassic sequence. Vertical diapir growth during Tertiary time is documented in some areas.

Algal reefs are associated with evaporite deposits in many basins. A logical place to expect these reefs in the Carmel-Arapien would be within and along the edges of the Sanpete-Sevier rift belt. Future drilling will help to define the depressed areas where the salt and evaporites were concentrated as well as the optimum shelf localities for algal reef growth near normal marine water. Some dark to black shale sequences in the Carmel are believed to be excellent source beds of hydrocarbon because they have very high contents of kerogen.

The panel cross section (fig. 14) shows the thick Carmel-Arapien trough formed during the major fault movements. This depression, or rift, developed as the Sevier Orogenic Belt was elevated in western Utah and southeastern Nevada. The tectonic instability which caused this elongate rift occurred mostly during the Jurassic Carmel-Arapien sedimentary cycle. The presence of salt and anhydrite within a dominantly marine shale sequence indicates that downwarping of the depressed area exceeded the supply of available clastics.

As shown in this panel cross section, the Entrada was not significantly affected by the previous depression.

Some faults, including the ancient Ephraim fault, have not had any significant movement since Middle Jurassic time. Structural traps, fault traps, and facies traps could be preserved below and within the Carmel-Arapien sediments.



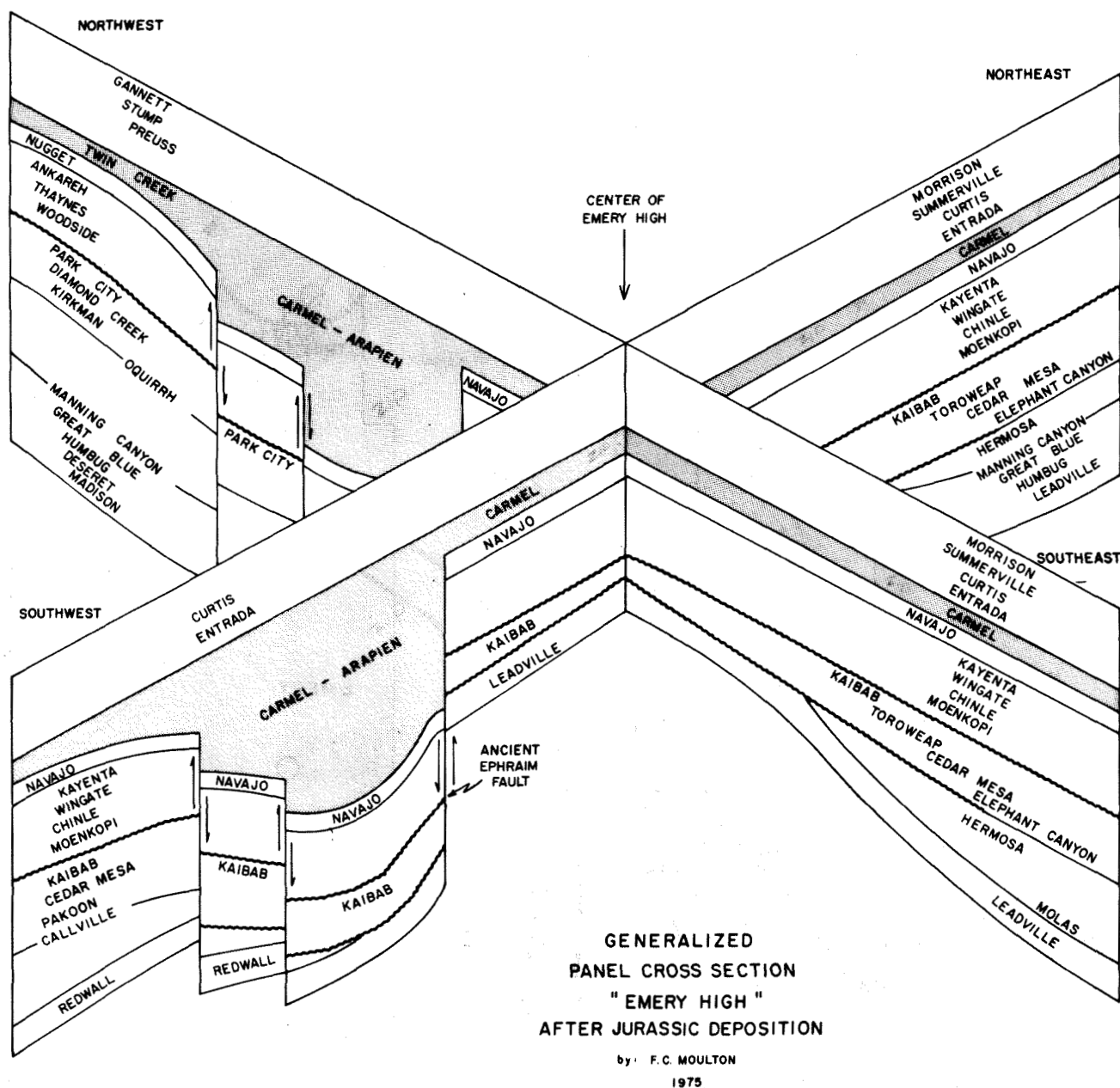


FIGURE 14.—Generalized panel cross section of the Emery high after Jurassic deposition.

Figures 15, 16, 17, and 18 show the relationship of the Jurassic evaporite basin to the older formations on the Emery uplift. The northwest portion of the uplift is covered by thick evaporites, which have provided an impervious seal over pre-Jurassic sedimentary rocks.

The Carmel carbonates are oil stained and have had gas shows in some wells in the Sanpete-Sevier rift belt. Thick oolitic limestone sequences in the Carmel have scattered oil staining and could be important objectives in some areas.

STRUCTURE

The present structural relationship of the eastern part of the study area is shown by a schematic cross section (fig.

19). The location of this cross section is shown in figure 13. The location of the Phillips Petroleum Company No. 1 U.S. "D" is shown on a structural fault trap. On the west end of this cross section the ancient Ephraim fault can be seen with the Jurassic Carmel sediments down-thrown against the Lower Mesozoic and Upper Paleozoic rocks.

OIL AND GAS POSSIBILITIES

The central Utah area covered by thick Jurassic strata has excellent oil and gas possibilities in Lower Mesozoic and Paleozoic formations. Source sediments and reservoir rocks are present in the Jurassic, Triassic, Permian, Pennsylvanian, and Mississippian within the study area. The

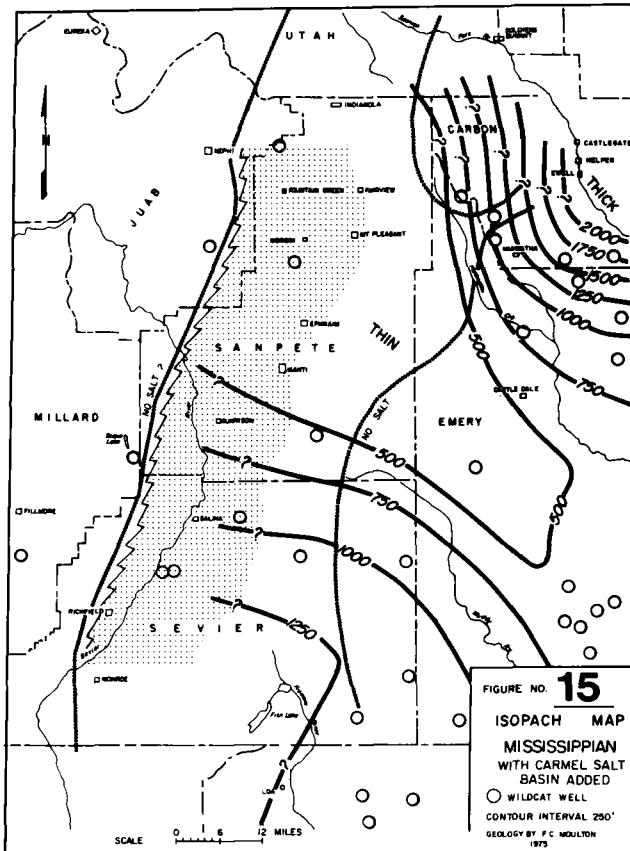


FIGURE 15.—Mississippian isopach map with Carmel salt basin added.

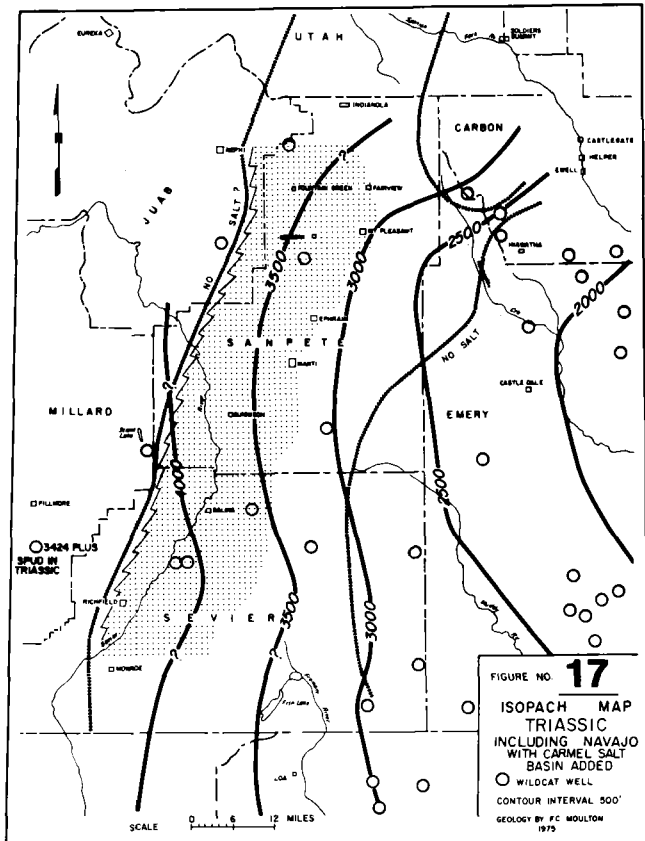


FIGURE 17.—Triassic isopach map, including Navajo with Carmel salt basin added.

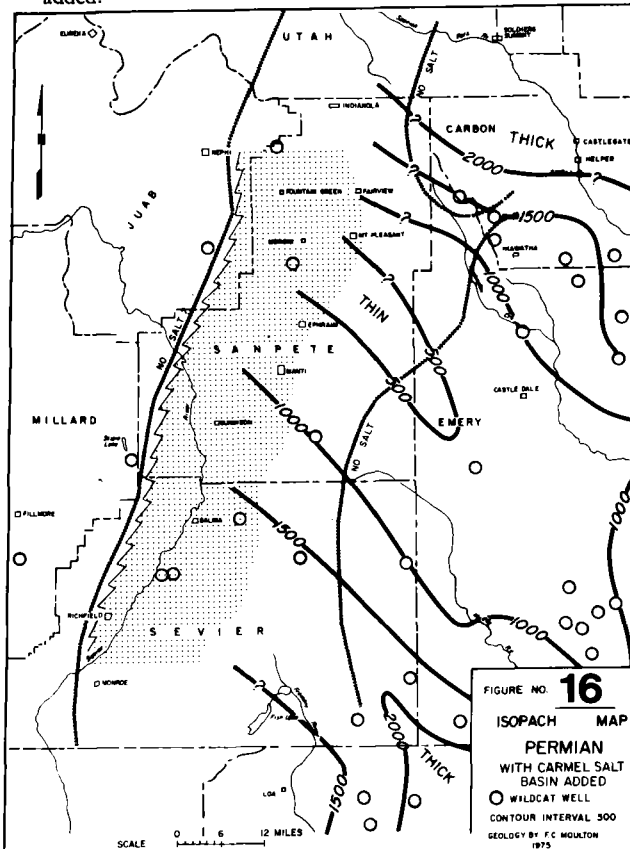


FIGURE 16.—Permian isopach map with Carmel salt basin added.

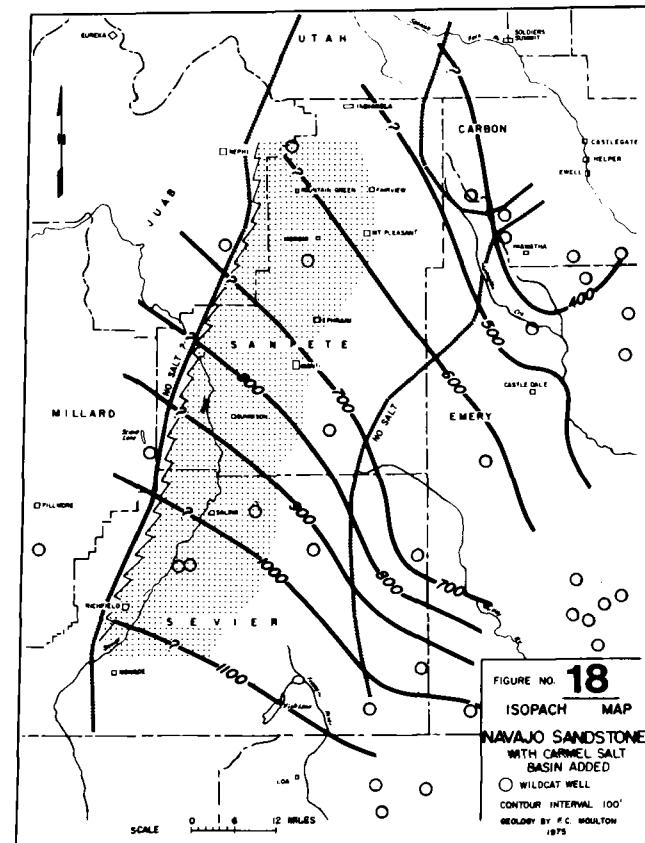


FIGURE 18.—Navajo Sandstone isopach map with Carmel salt basin added.

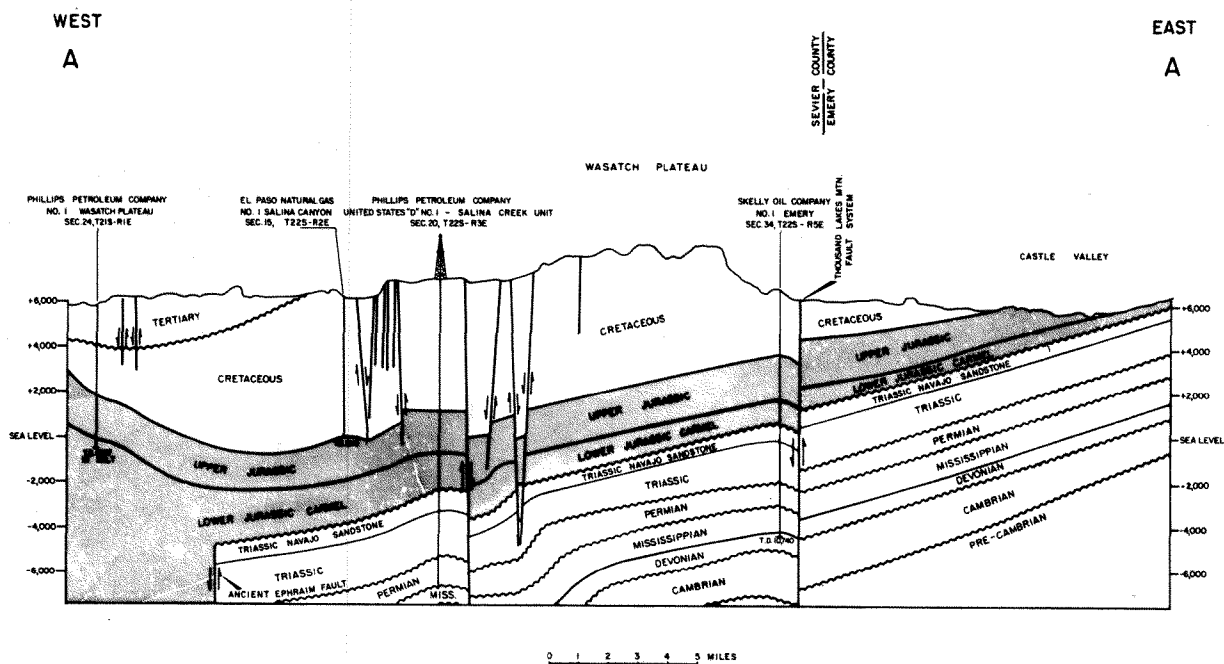


FIGURE 19.—Schematic cross section of eastern part of study area. See figure 13 for location.

older Paleozoic formations also could have oil and gas possibilities because they are in fault contact with all sediments up to and including the Jurassic.

Good oil and gas shows and some production are found in all formations discussed in this paper. Shows of live oil and gas have been found in the Carmel carbonates, the Navajo Sandstone, and the Sinbad Timpoweap. Producing gas occurs in the Sinbad at South Last Chance field (shut-in). The Sinbad had an excellent oil and gas show in the Phillips Petroleum Company No. 1 U.S. "E" (sec. 27, T. 19 S., R. 3 E.), Sanpete County. As previously discussed, the Permian Kaibab carbonates have produced more than 12 million barrels of oil at the Upper Valley oil field south of the study area. Other Permian formations which have had oil stains in exploratory wells are Cedar Mesa, White Rim, Toroweap, and Elephant Canyon. The Lower Pennsylvanian and Upper Mississippian Manning Canyon is oil stained in some wells, and subcommercial gas production was found in one well. Some exploratory wells have found live oil shows in the Madison limestones.

Bissell (1970) has presented a detailed discussion of oil and gas shows and production to the south.

CONCLUSIONS

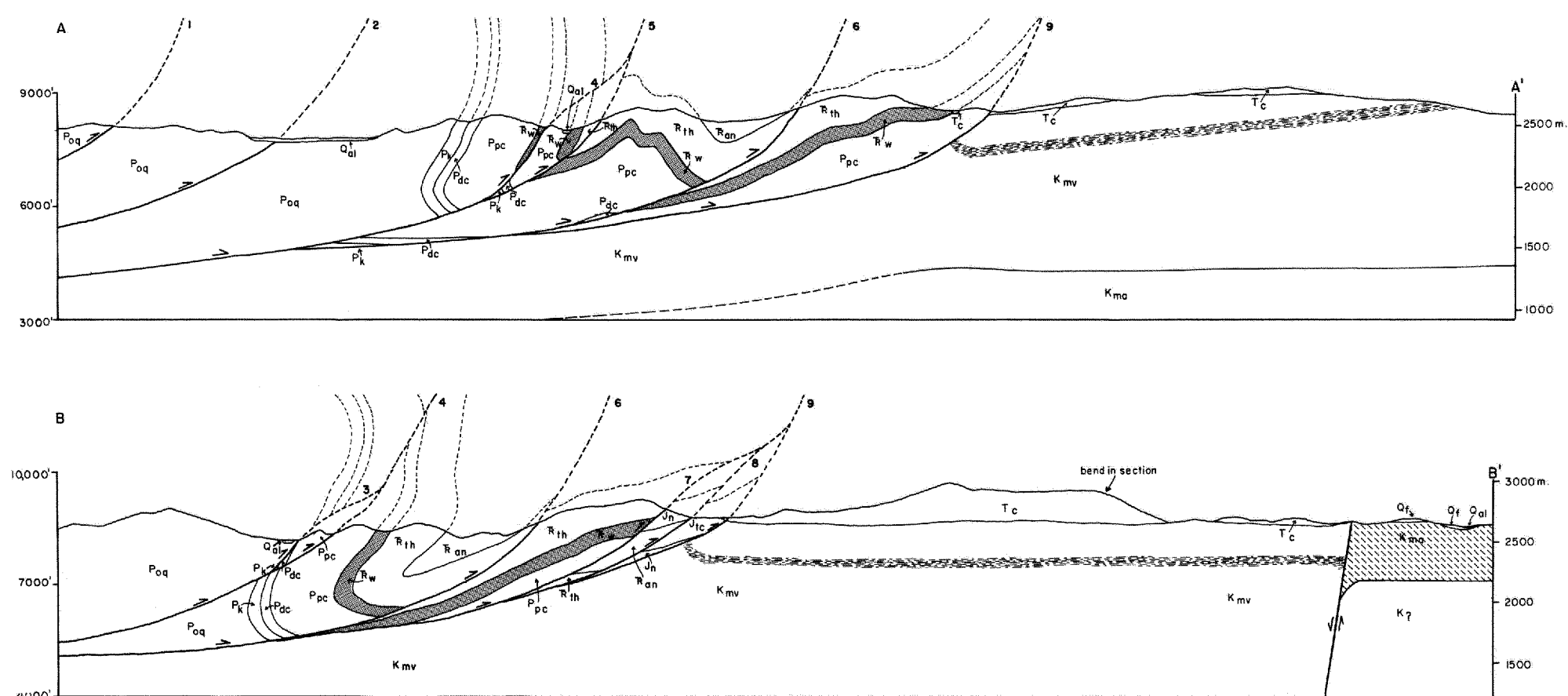
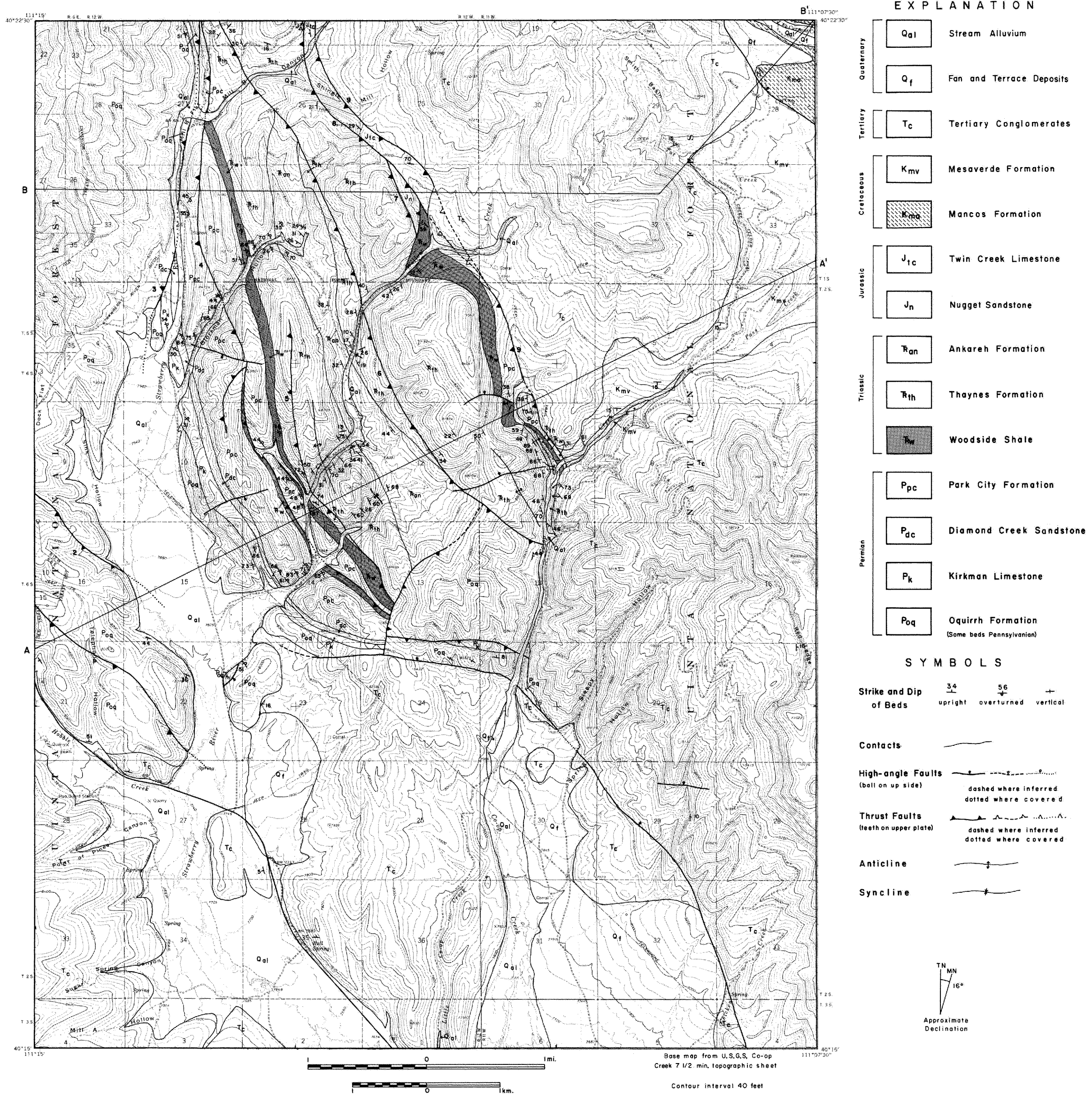
Recent seismic surveys and exploratory drilling have provided better definition of the Paleozoic Emery uplift. Some ancient structures with repeated growth are associated with this old high. The Upper Paleozoic and Lower Mesozoic sequences include many good reservoirs. Source beds of hydrocarbons also have been identified; portions of the Jurassic are especially important. Thick evaporite and shale deposits of Early Jurassic age provide impervious seals which should have prevented the escape of hydrocarbons from deeper structures and stratigraphic traps and from algal mounds or reefoid carbonates within the Jurassic sequence.

The geologic history of the area covered by thick Jurassic evaporites indicates that a large segment of central Utah should be highly prospective for oil and gas. Numerous shows, including some production, appear to confirm this conclusion. The Lower Paleozoic formations, which have not been considered in this report, also have potential in this deep drilling frontier. It is the writer's opinion that very large oil and gas reserves will be found in the central Utah hingeline area.

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GEOLOGIC MAP AND CROSS-SECTIONS, CO-OP CREEK QUADRANGLE
 by
 Gary K. Astin
 1976