Exhibit 2

Movement of ground water in Permian Guadalupian aquifer systems, southeastern New Mexico and western Texas

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MOVEMENT OF GROUND WATER IN PERMIAN GUADALUPIAN AQUIFER SYSTEMS, SOUTHEASTERN NEW MEXICO AND WESTERN TEXAS

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AQUIFER SYSTEMS

Permian Guadalupian age strata can be divided into three aquifer systems Hiss (1975a p 132) described and named them the Capitan shelf and basin aquifers (fig 1) In most areas they are readily distinguished by differences in lithology geographic position stratigraphic relationships hydraulic characteristics and quality of the contained water (Hiss 1975b and c 1976a)

Capitan Aquifer

The Capitan aquifer is a lithosome that includes the Capitan and Goat Seep Limestones and most or all of the Carlsbad facies of Meissner (1972) Shelf margin carbonate banks or stratigraphic reefs in the upper part of the San Andres Limestone are included within the Capitan aquifer where they cannot be readily distinguished from the Goat Seep Limestone and Carlsbad facies (Silver and Todd 1969 figs 12 and 13)

Shelf Aquifers

Saturated strata yielding significant quantities of water from the San Andres Limestone and the Bernal and Chalk Bluff facies of Meissner (1972) constitute the shelf aquifers The lithologic contact between the Capitan and shelf aquifers is gradational and is difficult to discern with accuracy in some areas Observations of the geometry and lithologic relationships of the shelf margin rocks in the field suggest that the width of the Capitan Limestone (reef) is considerably less than is shown in many geologic reports (Dunham 1972 fig 1 1)

The present day ground water regimen is strongly influenced by the Pecos River in New Mexico As a result the hydraulic conductivity of the shelf aquifers west of the Pecos River has been greatly enhanced by the leaching of soluble beds from the Chalk Bluff facies (Meissner 1972 Motts 1968) Locally and west of the Pecos River valley between Carlsbad and Roswell the hydraulic conductivities of the shelf aquifers are quite large and may be similar to that of the Capitan aquifer The hydraulic conductivity of the shelf aquifers in the Carlsbad and Roswell underground water basins is several orders of magnitude higher than that generally encountered in the shelf aquifers east of the Pecos River at Carlsbad The water contained in the shelf aquifers is also much better in the shallow zones exploited in these basins than elsewhere in the same aquifers within the area studied East of the Pecos River near Carlsbad the hydraulic conductivity of the shelf aquifers is generally one to two orders of magnitude less than that of the Capitan aquifer

Basin Aquifers

Saturated strata yielding significant quantities of water from the Brushy Canyon Cherry Canyon and Bell Canyon Formations of the Delaware Mountain Group are referred to as the basin aquifers Although the Capitan aquifer abuts and overlies the Delaware Mountain Group along the margin of the Delaware Basin the lithologic and hydrologic characteristics of the basin and Capitan aquifers are quite different The average hydraulic conductivity of the basin aquifer ranges from one to two orders of magnitude less than that of the Capitan Therefore only a relatively small amount of water can be expected to move from the basin aquifers to the Capitan aquifer or vice versa The difference in quality of water contained in the two aquifers—relatively good in the Capitan bad in the basin—is also a distinguishing characteristic (Hiss 1975b)

CONSTRUCTION OF POTENTIOMETRIC SURFACES

Reliable pressure head and water level data were adjusted to freshwater heads to construct generalized potentiometric surfaces representative of two conditions in the three aquifer systems Figure 2 is a map representing conditions in the aquifer systems prior to both development of water supplies for irrigation and discovery and production of oil and gas and associated waste water Figure 3 is a similar map representing the shelf and basin aquifer for the period 1960 to 1969 and of the Capitan aquifer for the latter part of 1972

A potentiometric surface represents hydraulic head in an aquifer the general direction of ground water movement is inferred to be normal to the illustrated head contours Hiss (1975 p 220 255) discusses the computation of ground water head and the procedures followed in determining the heads used in these maps The potentiometric maps support the inferred movement of water shown in figure 4

MOVEMENT OF GROUND WATER

During the latter part of the Cenozoic Era the movement of ground water through the rocks of Permian Guadalupian age in southeastern New Mexico and western Texas has been controlled or influenced by the following (1) the regional and local tectonics (2) the evolution of the landscape (3) the relative transmissivities of the various aquifers (4) the amount of recharge and (5) the exploitation of the petroleum and ground water resources in the last five decades (fig 4)

Control by Regional Tectonics

The flow of ground water through the shelf basin and Capitan aquifers after the uplift of the Guadalupe and Glass Mountains but prior to the excavation of the Pecos River valley at Carlsbad is shown diagrammatically in figure 4A The three aquifer systems were recharged by water originating as rain or snowfall on the outcrops along the western margin of the Delaware Basin Evidence of major surface drainage within the Trans-Pecos area of southeastern New Mexico and western Texas has not been reported

Ground water moved generally eastward and southeastward through the shelf and basin aquifers under a gradient of probably only a few feet per mile toward natural discharge areas along

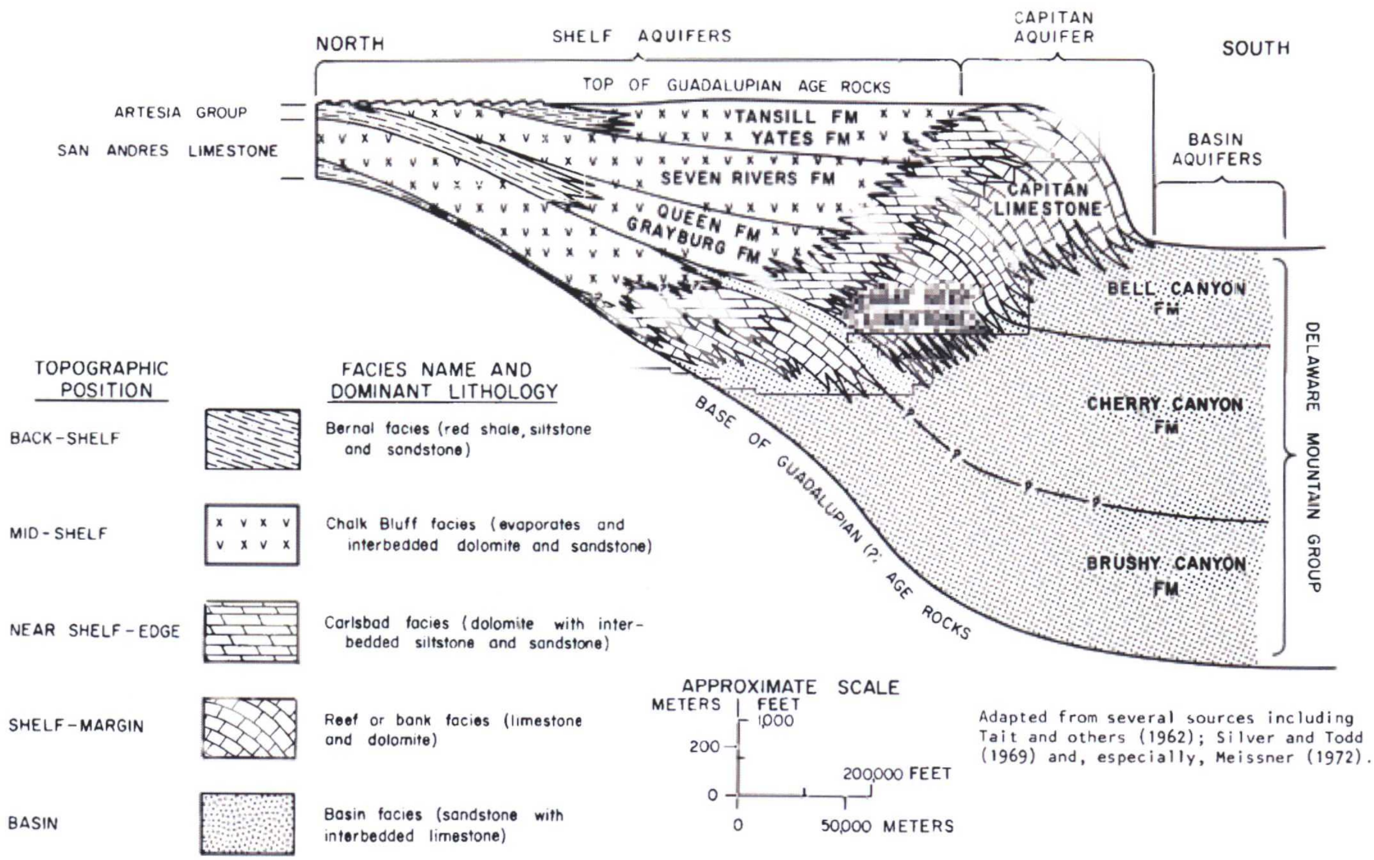

Figure 1. Highly diagrammatic north-south stratigraphic section showing the positions and relationships of the major lithofacies in the rocks of Guadalupian age, eastern New Mexico.

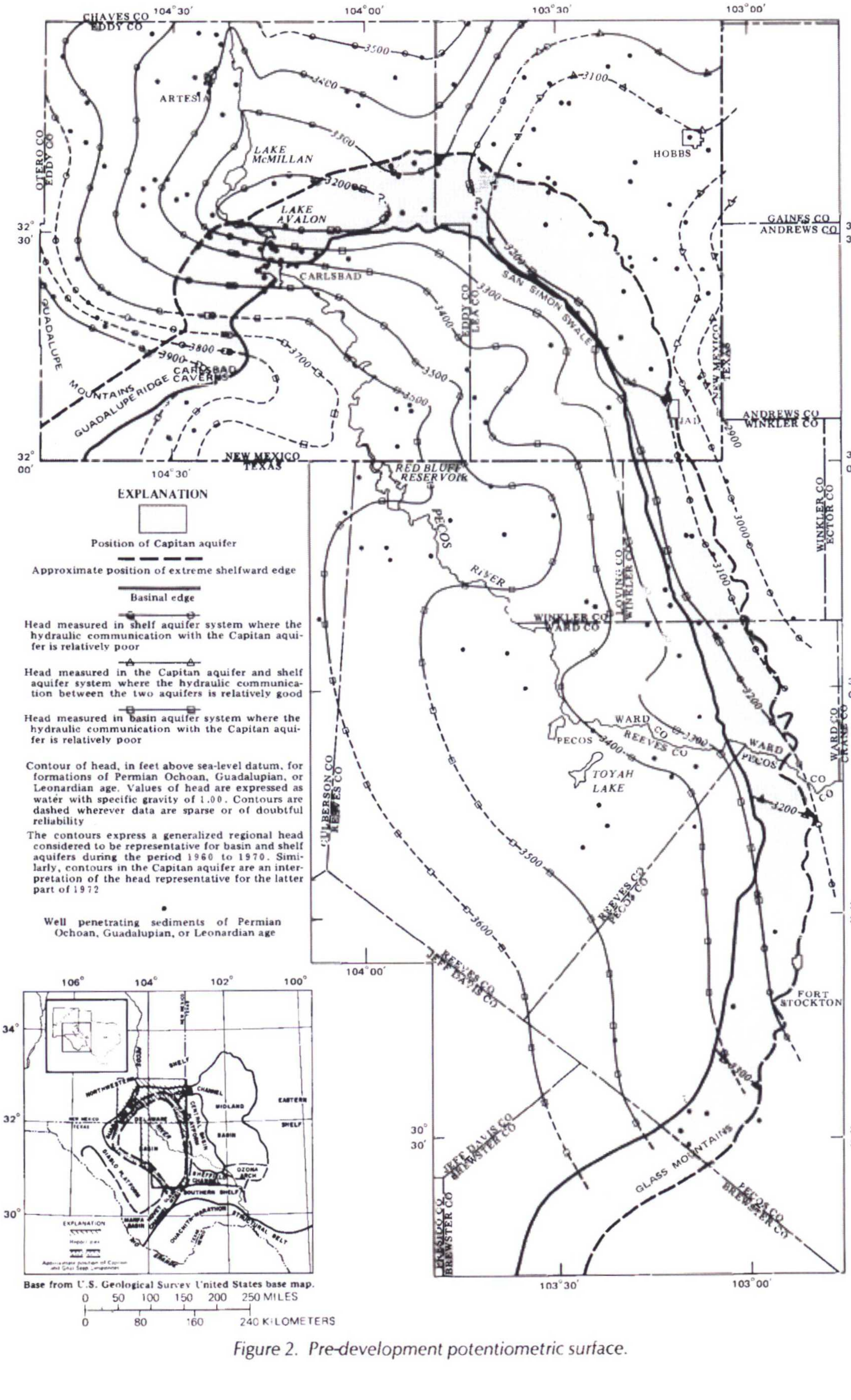

Figure 2. Pre-development potentiometric surface.

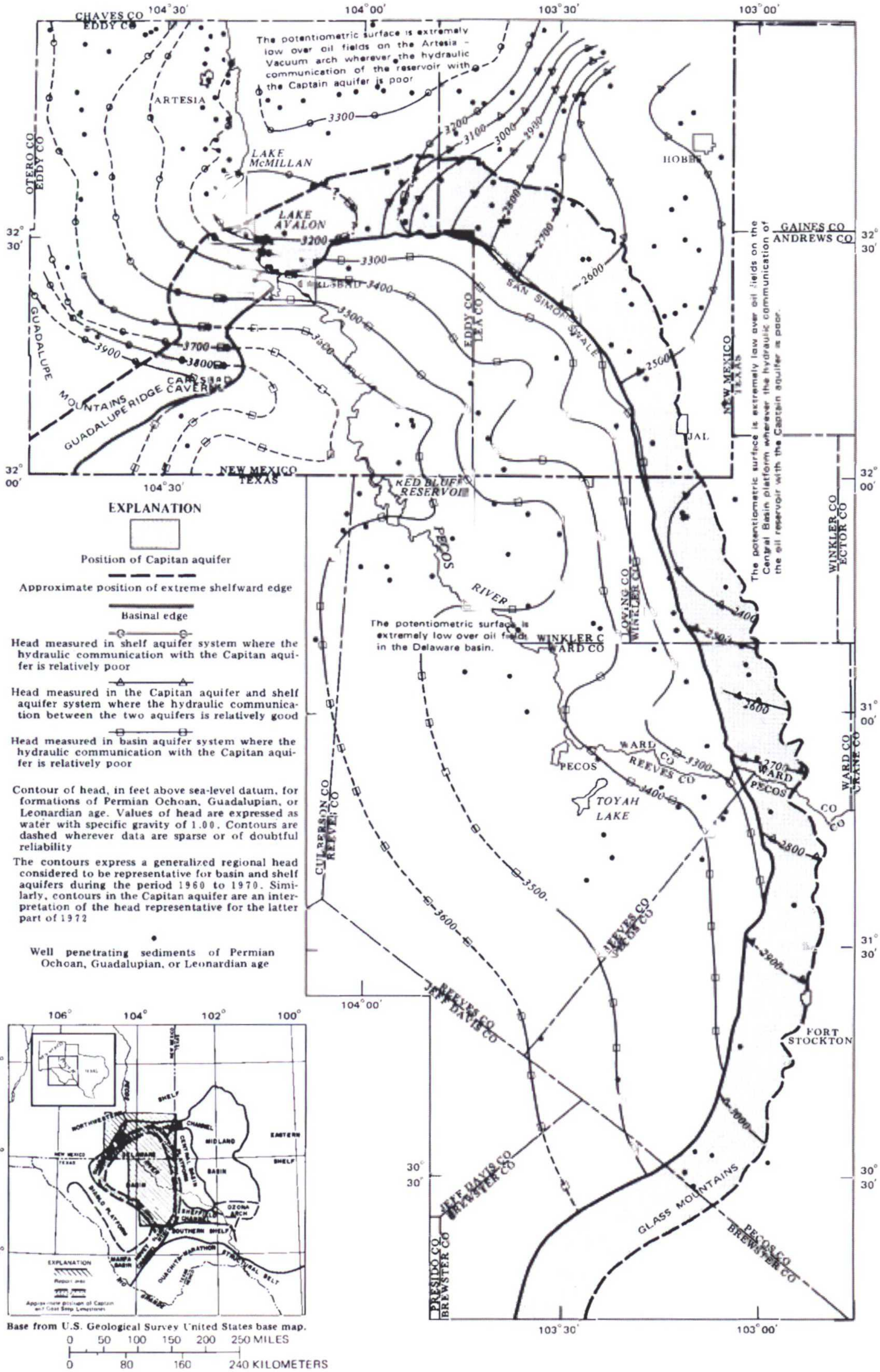

Figure 3. Post-development potentiometric surface.

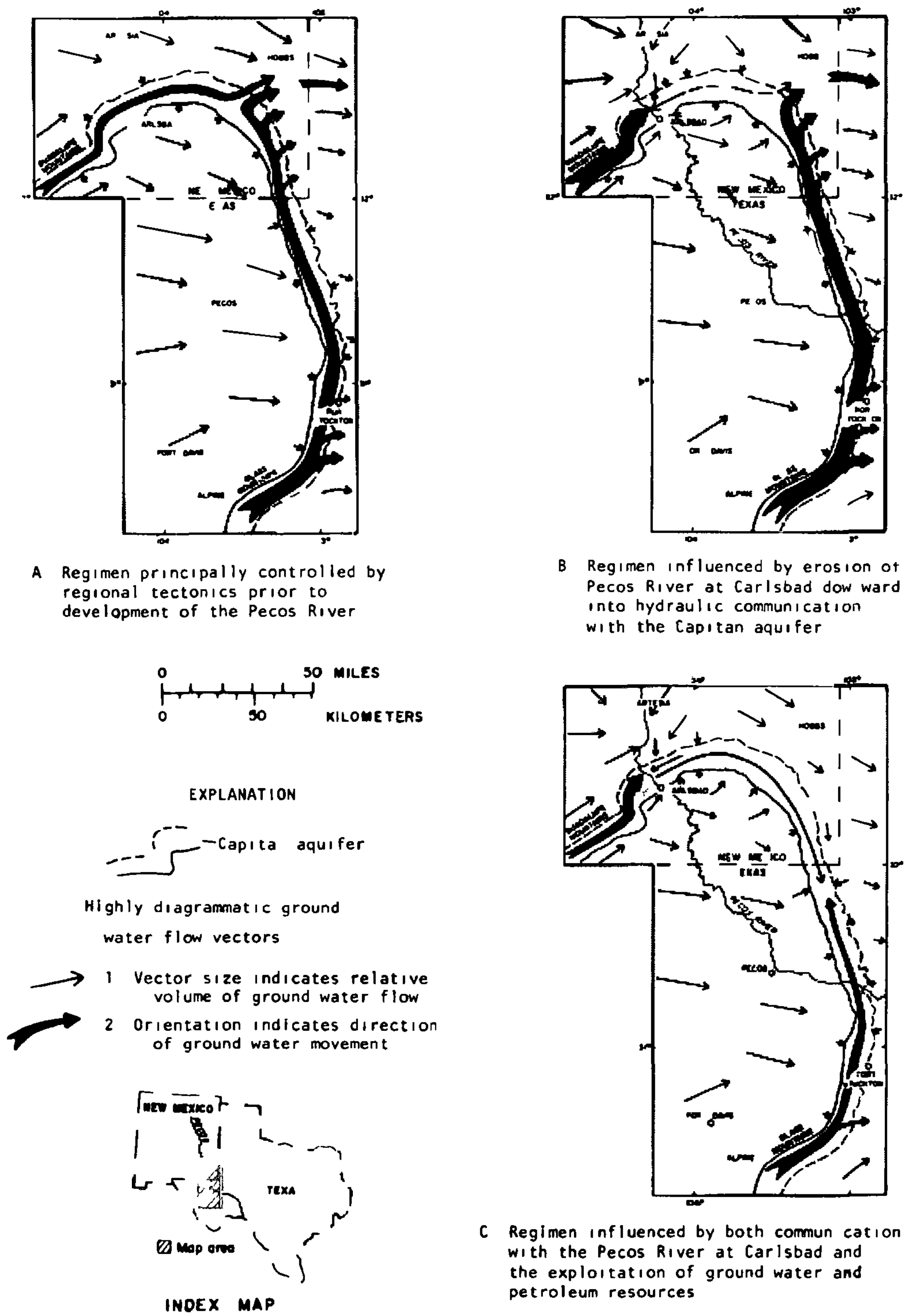

Figure 4 Diagrammatic maps depicting the evolution of ground water regimens in strata of Permian Guadalupian age in southeastern New Mexico and western Texas

streams draining to the ancestral Gulf of Mexico Water entering the Capitan aquifer in the Guadalupe Mountains moved slowly northeastward and then eastward along the northern margin of the Delaware Basin to a point southwest of present day Hobbs Here it joined and comingled with a relatively larger volume of ground water moving northward from the Glass Mountains along the eastern margin of the Delaware Basin From this confluence the ground water was discharged from the Capitan aquifer into the San Andres Limestone where it then moved eastward across the Central Basin Platform and Midland Basin eventually to discharge into streams draining to the Gulf of Mexico

Influence of Erosion of Pecos River at Carlsbad

Some time after deposition of the Ogallala Formation perhaps early in Pleistocene time the headward cutting Pecos River extended westward across the Delaware Basin to the exposed soluble Ochoan beds It then turned northward following this natural weakness in the sedimentary rocks to pirate the streams draining to the east from the Sacramento and Guadalupe Mountains (Plummer 1932 Bretz and Horberg 1949b Thornbury 1965) As the excavation of the Pecos River valley progressed the hydraulic communication with formations of Guadalupian age gradually increased until the Pecos River functioned as an upgradient drain Eventually the hydraulic gradients in the shelf basin and Capitan aquifer were reversed along the eastern side of the Pecos River valley and ground water that formerly flowed eastward was diverted westward as spring flow into the Pecos River (fig 4B) Water recharged to the same aquifers in the Guadalupe Mountains began to follow the shorter path to springs in the Pecos River Many of the solution features observed in the Guadalupian sedimentary rocks west of the Pecos River near Carlsbad probably were initiated during this period

Movement of water eastward toward Hobbs from the Guadalupe Mountains into the Capitan aquifer was decreased by the lowering of the hydraulic head along the Pecos River At the same time a trough in the potentiometric surface of the shelf and basin aquifers began to develop east of Carlsbad and water began to drain into the Capitan aquifer from the surrounding sedimentary rocks Meanwhile ground water continued to move northward from the Glass Mountains in the Capitan aquifer toward a point of discharge into the San Andres Limestone southwest of Hobbs This part of the aquifer was unaffected by the cutting of the Pecos River valley across the Delaware Basin and the Central Basin Platform

Influence of Exploitation of Ground Water and Petroleum Resources

Regionally the movement of ground water in the shelf and basin aquifers east of the Pecos River at Carlsbad has changed very little as a result of the exploitation of ground water and petroleum during a period of approximately 50 years (fig 4C) Locally however the movement of ground water within these same aquifers is controlled by the effects of the numerous producing oil fields

The shape of the regional potentiometric surface representative of the hydraulic head in the Capitan aquifer east of the Pecos River at Carlsbad has been changed significantly in response to withdrawal of both ground water and petroleum during the past 50 years The westward movement of saline water from the Capitan aquifer in Eddy County east of Carlsbad into the Pecos River has been greatly diminished or eliminated by a reduction in hydraulic head

Similarly the movement of water in the San Andres Limestone and Artesia Group eastward across the northern part of the Central Basin Platform from New Mexico into Texas has been decreased Eventually the movement of water probably will be reversed Water may be diverted from the San Andres Limestone and Artesia Group westward from Texas back toward Hobbs and then into the Capitan aquifer along the western margin of the Central Basin Platform The effects of exploitation of the ground water and petroleum resources will continue to be the dominant factor influencing the movement of ground water in the Capitan aquifer for many years into the future

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——— 1976a Structural position of the Capitan aquifer southeast New Mexico and West Texas New Mexico Bureau of Mines and Mineral Resources Resource Map 6

——— 1976b Structural position of the Rustler Formation southeast New Mexico and West Texas New Mexico Bureau of Mines and Mineral Resources Resource Map 7

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