INTRODUCTION

During 1978, the U.S. Geological Survey initiated a 5-year study of the High Plains regional aquifer to provide: (1) Hydrologic information needed to evaluate the effects of continued ground-water development; and (2) computer models to predict aquifer response to changes in ground-water development. The plan of study for the High Plains Regional Aquifer System Analysis was described by Weeks (1978). A map of the 1978 water table in the High Plains aquifer was presented by Gutentag and Weeks (1980). This report describes the bedrock units that underlie the High Plains aquifer and the saturated thickness of the aquifer. Geologic and saturated thickness maps presented herein were compiled from maps prepared by U.S. Geological Survey personnel in each of the eight States in the High Plains. Their work is an integral part of this investigation.

The High Plains aquifer underlies 177,000 square miles in eight States. Within this area, the aquifer is the principal source of water for irrigation as well as industrial, municipal, and domestic use. The economy of the High Plains is dependent upon irrigated farming. In recent years, declining water levels, decreasing water supplies, and increasing energy costs have caused the economics of irrigated agriculture to become marginal and, in some places, unprofitable. A thorough understanding of the geohydrology of the High Plains aquifer will be necessary to manage the remaining water resources in the most beneficial manner.

The geology of the High Plains aquifer was outlined by Gutentag and Weeks (1980). The aquifer consists mainly of Tertiary and Quaternary sediments which are briefly described in the accompanying table of geologic units. The bedrock units in contact with the High Plains aquifer are shown on the accompanying map and summarized in the table. This sheet describes the bedrock units and their relationship to the High Plains aquifer and the second sheet describes the distribution of saturated sediments in High Plains aquifer.

BEDROCK GEOLOGY

The oldest rocks in contact with the High Plains aquifer are of Permian age (240-290 million years ago). Permian rocks directly underlie 12 percent of the High Plains aquifer in Kansas, Oklahoma, and Texas.

Permian red beds and evaporites were deposited in extensive, shallow, brackish to saline seas subject to periodic influxes of marine water. Dissolution and removal of some of these evaporites by ground water within the Permian rocks has resulted in faulting of the overlying deposits (Gutentag and others, 1980). Bear Creek fault in southwestern Kansas and southeastern Colorado, and Crooked Creek fault in southwestern Kansas and northwestern Oklahoma, are the result of salt dissolution. Salt collapse basins and a broad zone of salt dissolution in northwestern Texas have been mapped by Seni (1980). Sink holes developed by salt solution subsequently were filled by younger materials which are part of the High Plains aquifer.

Permian rocks in contact with the High Plains aquifer contain water that is not suitable for irrigation use because of high concentrations of dissolved solids. Gutentag, Lobmeyer, and Slagle (1980, p. 53) reported 33,800 milligrams per liter dissolved solids in water from a well in Permian rocks in Seward County, Kansas. Mineralized water from Permian rock moves naturally through the High Plains aquifer to discharge along the Beaver, Cimarron, and Arkansas Rivers in Kansas and Oklahoma. Generally, Permian rocks have low permeability relative to the overlying High Plains aquifer. Where the High Plains aquifer is in hydraulic connection with Permian beds, water-level declines in the High Plains aquifer can cause movement of mineralized water from Permian beds into the aquifer.

Rocks of Triassic and Jurassic age (138-240 million years ago) directly underlie 16 percent of the High Plains aquifer in Colorado, Kansas, New Mexico, Oklahoma, and Texas. Although the Triassic and Jurassic are separate systems in the table showing the geologic section, they are combined on the geologic map because the rocks of both systems are predominately sandstones and shales and have similar hydrologic characteristics.

Lower and Middle Triassic and Lower Jurassic rocks are not present in the High Plains. The missing rocks indicate that continental erosion prevailed through Early and Middle Triassic time prior to deposition of the continental Upper Triassic rocks. Continental erosion again prevailed during Early Jurassic time prior to deposition of Middle and Upper Jurassic rocks.

Some sandstones of Triassic and Jurassic age have adequate permeability to yield large enough quantities of water for irrigation. Between the Arkansas and Canadian Rivers in parts of Colorado, Kansas, Oklahoma, New Mexico, and Texas, many irrigation wells withdraw water from both the High Plains aquifer and Triassic and Jurassic sandstones. In parts of Texas, north of the Canadian River, Triassic and Jurassic sandstones are in direct contact with overlying semiconsolidated sediments of Tertiary age. Locally, where the rocks of both systems are hydraulically connected and hydrologically similar, the High Plains aquifer includes Triassic and Jurassic sandstones in parts of Dallam, Hartley, Moore, and Sherman Counties, Texas.

Lower Cretaceous rocks directly underlie 12 percent of the High Plains aquifer in parts of Colorado, Kansas, Nebraska, New Mexico, Oklahoma, and Texas. Shallow seas covered the area intermittently throughout Early Cretaceous time (96-138 million years ago) when the Lower Cretaceous rocks were deposited. North of the Canadian River, Lower Cretaceous rocks were deposited near sea level or in adjoining lowlands and consist mostly of sandstones and shales. South of the Canadian River, Lower Cretaceous rocks were deposited in deeper water and consist mainly of shales that grade into limestones.

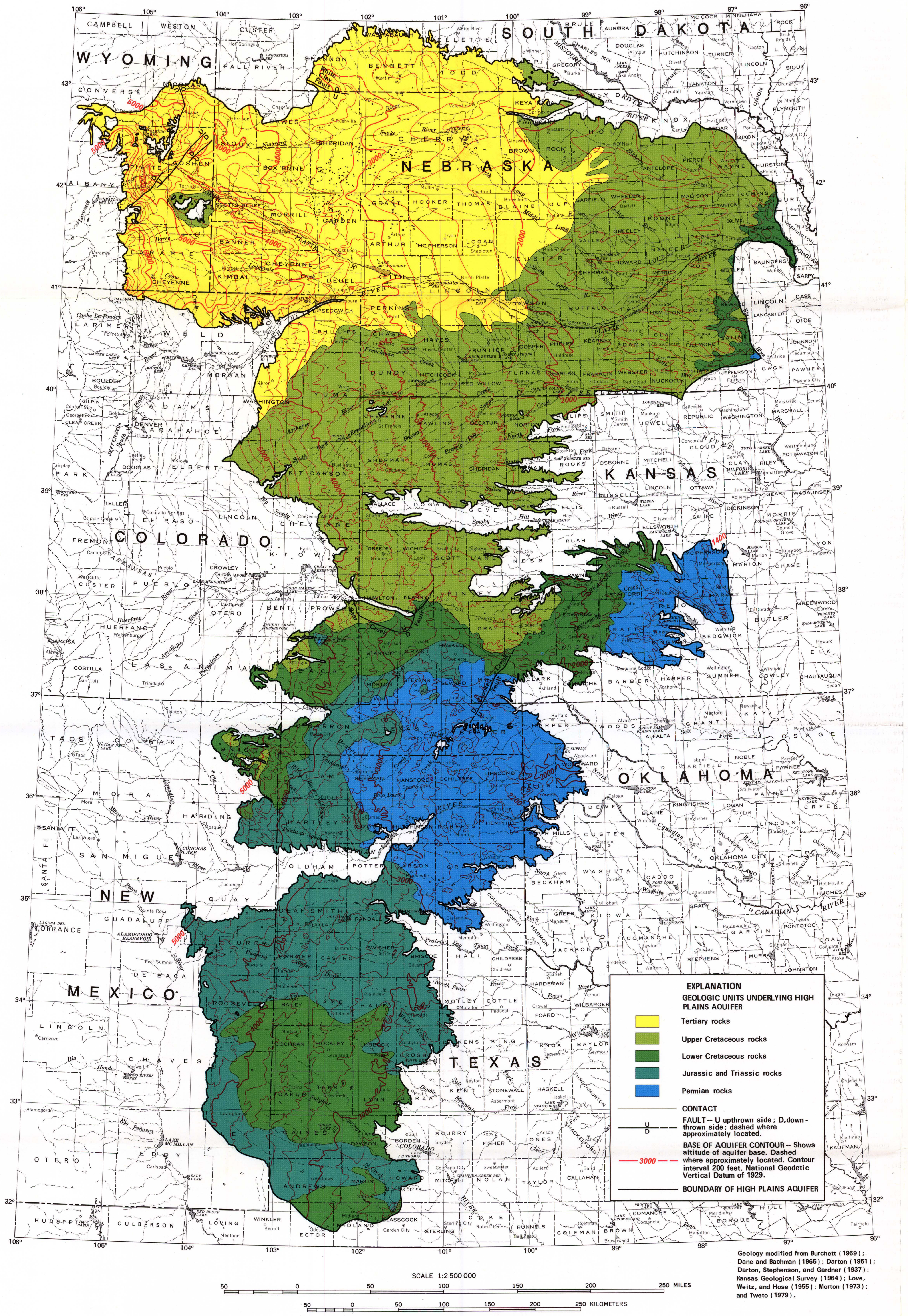
The sandstone beds within the Lower Cretaceous deposits are discontinuous and differ greatly in permeability both horizontally and vertically from one area to another. Where Lower Cretaceous sandstone beds are in contact with the overlying younger deposits in the High Plains aquifer, there is hydraulic connection between the two units. The sandstones and shales of the Lower Cretaceous generally contain water of suitable quality for irrigation use. However, these sandstones and shales typically have low permeability and storage relative to the High Plains aquifer and wells in Lower Cretaceous rocks experience large drawdowns and well interference over large areas.

Upper Cretaceous rocks directly underlie 32 percent of the High Plains aquifer in large areas in Colorado, Kansas, and Nebraska and small areas in New Mexico, South Dakota, and Wyoming. During Late Cretaceous time (63-96 million years ago), Upper Cretaceous shales, chalks, limestones, and sandstones were deposited in the broad Rocky Mountain trough which formed a vast seaway nearly 1,000 miles wide and about 3,000 miles long. As the sea retreated southward, the sea floor was transformed into a vast swampy lowland which was covered by thick non-marine sediments during the closing stages of Cretaceous time. The vegetation that accumulated in the swamps of this lowland formed the vast coal beds of Late Cretaceous age in the Rocky Mountain region from Canada to Mexico.

Within the Upper Cretaceous rocks, only the Niobrara Chalk is known to yield water to wells in quantities large enough for irrigation. The Niobrara Chalk underlies the High Plains in Colorado, Kansas, Nebraska, South Dakota, and Wyoming. Where fractures and solution openings have developed, large quantities of water of suitable quality for irrigation have been developed in Finney and Scott Counties, Kansas (Gutentag and Stullken, 1976, p. 11). The water in the Niobrara Chalk in Kansas is derived from the overlying High Plains aquifer. In Madison and Pierce Counties, Nebraska, the Niobrara Chalk yields water to domestic, stock, and municipal wells.

GENERALIZED SECTION OF GEOLOGIC UNITS IN THE HIGH PLAINS

System	Series	Geologic Unit	Thickness, in feet	Physical Character
QUATERNARY	Pleistocene and Holocene	Valley-fill deposits	0 to 60	Stream-lain deposits of gravel, sand, silt, and clay associated with the most recent cycle of erosion and deposition along present streams. Forms part of High Plains aquifer where hydraulically connected to underlying Quaternary and Tertiary deposits.
		Dune sand	0 to 300	Fine to medium sand with small amounts of clay, silt, and coarse sand formed into hills and ridges by the wind. Forms part of High Plains aquifer where saturated.
		Loess	0 to 250	Silt with lesser amounts of very fine sand and clay deposited as windblown dust.
	Pleistocene	Unconsolidated alluvial deposits	0 to 550	Stream-lain deposits of gravel, sand, silt, and clay locally cemented by calcium carbonate into caliche or mortar beds. Forms part of High Plains aquifer where hydraulically connected laterally or vertically to Tertiary deposits.
TERTIARY	Miocene	Ogallala Formation	0 to 700	Poorly sorted clay, silt, sand, and gravel generally unconsolidated; forms caliche layers or mortar beds when cemented by calcium carbonate. Includes units equivalent to the locally-used terms "Ash Hollow," "Kimball," "Sidney Gravel," and "Valentine" Members or Formations assigned to the Ogallala Formation or "Group," and Delmore and Laverne Formations. Ogallala comprises large part of High Plains aquifer where saturated.
		Arikaree Group	0 to 1000	Predominately massive very fine- to fine-grained sandstone with localized beds of volcanic ash, silty sand, siltstone, claystone, sandy clay, limestone, marl, and mortar beds. Includes units assigned to the Hemingford Group of Lugn (1938), Marsland Formation, Rosebud Formation used in South Dakota by Harksen and Macdonald (1969), and Sheep Creek Formation. Also includes units equivalent to Gering Formation, Harrison Sandstone, and Monroe Creek Sandstone. Forms part of the High Plains aquifer.
	Oligocene	White River Group	0 to 700	Upper unit, Brule Formation, predominately massive siltstone containing sandstone beds and channel deposits of sandstone with localized lenticular beds of volcanic ash, claystone, and fine sand. The Brule Formation is considered part of the High Plains aquifer only where it contains saturated sandstones or interconnected fractures. Lower unit, Chadron Formation, mainly consists of varicolored, bentonitic, loosely to moderately cemented clay and silt that contains channel deposits of sandstone and conglomerate.
CRETACEOUS	Upper Cretaceous	Undifferentiated rocks	0 to 8000	Shales, chalks, limestones, and sandstones. Upper part may contain lignite and coal beds. Unit includes Belle Fourche and Carlile Shales, Codell and Fox Hills Sandstones, Frontier Formation, Graneros Shale, Greenhorn Limestone, Lance Formation, Niobrara Chalk or Formation, and Pierre Shale.
	Lower Cretaceous	Undifferentiated rocks	0 to 700	Fine- to medium-grained, thin-bedded to massive cliff-forming sandstone interbedded with shale. Black and varicolored shale and thin- to thick-bedded limestone. Includes units equivalent to Fredericksburg and Washita Groups; Dakota and Purgatorie Formations; Antlers Sand of Hill (1894), Cheyenne, Fall River, Lakota, Mesa Rica, and Newcastle Sandstones; and Fuson, Kiowa, Mowry, Skull Creek, and Tucumcari Shales.
JURASSIC	Middle and Upper Jurassic	Undifferentiated rocks	0 to 600	Varicolored shale, fine- to very coarse-grained sandstone, limestone, dolomite, and conglomerate. Includes units equivalent to Entrada and Exeter Sandstones, and Morrison and Sundance Formations.
TRIASSIC	Upper Triassic	Dockum Group	0 to 2000	Upper unit, Trujillo Formation, varicolored siltstone, claystone, conglomerate, fine-grained sandstone, and limestone. Lower unit, Tecovas Formation, varicolored fine- to medium-grained sandstone with some claystone and interbedded shale. Include units equivalent to Chinle and Redondo Formations, and Santa Rosa Sandstone.
PERMIAN	Lower and Upper Permian	Undifferentiated rocks	300 to 3000	Interbedded predominately red-shale, siltstone, sandstone, gypsum, anhydrite, dolomite, bedded salt, and local limestone beds. Includes Artesia, Council Grove, Nippewalla, Quartermaster, and Whitehorse Groups.



Geology modified from Burchett (1969); Dane and Bachman (1965); Darton (1951); Darton, Stephenson, and Gardner (1937); Kansas Geological Survey (1964); Love, Weitz, and Hose (1955); Morton (1973); and Tweto (1979).

BEDROCK GEOLOGY AND ALTITUDE OF AQUIFER BASE

Oligocene rocks directly underlie 28 percent of the High Plains aquifer in Colorado, Nebraska, South Dakota, and Wyoming. The White River Group of Oligocene age represents the oldest Tertiary deposits present under the High Plains. Older Tertiary deposits, although present further west, do not underlie the High Plains. Oligocene time (24-38 million years ago) began with erosion and ended with deposition of alluvium by a system of streams that crossed the area from west to east.

The Chadron and Brule Formations make up the White River Group. The Chadron Formation is the lower unit and consists of consolidated beds of clay and silt deposited on ancient flood plains and stream channel fill deposits of sandstone and conglomerate. The Chadron is overlain by the Brule Formation which is predominately a massive siltstone containing consolidated beds of volcanic ash, clay, and fine sand.

The sediments comprising the Brule Formation were deposited in a large basin that contained freshwater lakes, mud flats, and meandering streams. The Brule Formation is considered an aquifer in areas where it contains sandstones or secondary permeability resulting from interconnected fractures. Areas where the upper part of the Brule Formation is included in the High Plains aquifer occur in northern Logan, Sedgwick, and Weld Counties, Colorado; Banner, Cheyenne, Kimball, and Scotts Bluff Counties, Nebraska; and Goshen and Laramie Counties, Wyoming.

BASE OF THE HIGH PLAINS AQUIFER

The surface depicted on the geologic map is an erosional surface cut in Permian, Triassic, Jurassic, Cretaceous, and Tertiary rocks. The configuration of this buried surface is illustrated by contours showing the altitude of the base of the High Plains aquifer. A knowledge of the configuration of the base of aquifer is useful in determining the thickness of the overlying deposits and in studying the ancestral drainage pattern and the mode of deposition of the materials that comprise the High Plains aquifer.

Data from lithologic and geophysical logs from thousands of water wells and test holes were used in constructing the contours showing the base of the High Plains aquifer. Published geologic and hydrologic maps were used where available. Because of the scale of the map, the contours showing the altitude of the base of aquifer are generalized and only illustrate the configuration of the surface upon which the High Plains aquifer was deposited.

In some areas, data are adequate to define the complex topographic surface of the rocks beneath the High Plains aquifer. In other areas, data are few and the contours are smooth. For example, the 2,600-foot contour from Sheridan County, Kansas, to Hayes County, Nebraska, shows complex topography because ample data are available to show detail. North of Hayes County, Nebraska, the 2,600-foot contour is smooth because the data are not adequate to detail the complex surface. Most likely a very intricately sculptured topographic surface would be revealed if the aquifer materials were stripped away and the surface underlying the aquifer was exposed.

Significant features shown by the altitude of the surface beneath the High Plains aquifer are: (1) Configuration of the base of aquifer; (2) several faults caused by tectonic forces or salt dissolution; and (3) many sinkholes and depressions caused by salt dissolution.

The configuration of the surface underlying the High Plains aquifer influences ground water flow through the aquifer. The contours on the base of aquifer shown here and the contours on the water-table map shown by Gutentag and Weeks (1980) generally parallel each other indicating that ground water flows in the direction of the slope of the aquifer base. The average slope of the bedrock surface is about 10 feet per mile from west to east. The slope of the water table averages 10 to 15 feet per mile in the same general direction.

Faulting has greatly affected the altitude of the aquifer base. In Wyoming, faulting has resulted in more than 1,000 feet of displacement in the aquifer base. Near the State line between South Dakota and Nebraska, the White Clay fault has caused about 500 feet of displacement in the aquifer base. Faults resulting from dissolution of evaporites in Permian deposits and collapse of the overlying rocks occur in Colorado, Kansas, and Oklahoma. Movement along these faults occurs over long periods of time as the edge of the dissolution zone is slowly dissolved by ground-water movement.

The Bear Creek fault crosses the Arkansas River twice in Colorado and Kansas. The Crooked Creek fault extends southward from Kansas into Oklahoma. Salt dissolution in the vicinity of Crooked Creek fault results in high concentrations of chloride in ground water discharging to the Cimarron and Beaver Rivers. The concentration of chloride increases from 220 to 650 milligrams per liter in a five-mile reach of the Cimarron River near Crooked Creek fault (Gutentag and others, 1980, p. 48). Collapse along these faults has caused about 200 feet of displacement in the altitude of the aquifer base.

Sinkholes, depressions, and other collapse structures resulting from salt dissolution occur in many places. Salt dissolution structures can be seen on the map as closed-contour depressions in southern Kansas, Oklahoma, and northern Texas. Many smaller depressions, that cannot be shown on the map, occur in the area where the aquifer is directly underlain by Permian deposits.

Faulting and collapse structures have formed since Permian time. Active sinkholes exist in the vicinity of Bear Creek and Crooked Creek faults. At land surface where unconsolidated materials are affected by collapse structures, concentric slump cracks and scarps outline areas of depression. Older collapse structures have been filled by younger material. For example, a collapse basin in Carson County, Texas, has been filled by several hundred feet of Ogallala Formation.

REFERENCES

Burchett, R. R., 1969, Geologic bedrock map of Nebraska: Conservation and Survey Division, University of Nebraska, scale 1:1,000,000.
Dane, C. H., and Bachman, G. O., 1965, Geologic map of New Mexico: U.S. Geological Survey, scale 1:500,000.
Darton, N. H., 1951, Geologic map of South Dakota, U.S. Geological Survey, scale 1:500,000.
Darton, N. H., Stephenson, L. W., and Gardner, J. A., 1937, Geologic map of Texas: U.S. Geological Survey, scale 1:500,000.
Dunham, R. J., 1961, Geology of uranium in Chadron area Nebraska and South Dakota: U.S. Geological Survey open-file report, plate 1, scale 1:48,000.
Gutentag, E. D., Lobmeyer, D. H., and Slagle, S. E., 1980, Geohydrology of southwestern Kansas: U.S. Geological Survey Open-File Report 80-218, 97 p.
Gutentag, E. D., and Stullken, L. E., 1976, Ground-water resources of Lane and Scott Counties, western Kansas: Kansas Geological Survey Irrigation Series, no. 1, 37 p.
Gutentag, E. D., and Weeks, J. B., 1980, Water table in the High Plains aquifer in 1978 in parts of Colorado, Kansas, Nebraska, New Mexico, Oklahoma, South Dakota, Texas, and Wyoming: U.S. Geological Survey Hydrologic Investigations Atlas 642.
Harksen, J. C. and Macdonald, J. R., 1969, Guidebook to the major Cenozoic deposits of southwestern South Dakota: South Dakota Geological Survey Guidebook No. 2, 103 p.
Hill, R. T., 1894, Geology of parts of Texas, Indian Territory and Arkansas adjacent to Red River region: Geological Society of America Bulletin, v. 5, p. 297-338.
Irwin, J. H., and Morton, R. B., 1969, Hydrogeologic information on the Glorieta Sandstone and the Ogallala Formation in the Oklahoma Panhandle and adjoining areas as related to underground waste material: U.S. Geological Survey Circular 630, 26 p.
Kansas Geological Survey, 1964, Geologic map of Kansas: Kansas Geological Survey Map M-1, scale 1:500,000.
Love, J. D., Weitz, J. L., and Hose, R. K., 1955, Geologic map of Wyoming, U.S. Geological Survey, scale 1:500,000.
Lugn, A. L., 1938, The Nebraska State Geological Survey and the "Valentine problem": American Journal of Science, 5th series, v. 36, no. 213, p. 220-227.
Morton, R. B., 1973, Preliminary investigations of the hydrogeology of the Permian to Tertiary rocks of the Oklahoma panhandle: U.S. Geological Survey Miscellaneous Geological Investigations Map I-738.
Seni, S. J., 1980, Sand-body geometry and depositional systems, Ogallala Formation, Texas: Texas Bureau of Economic Geology, Report of Investigation no. 105, 36 p.
Tweto, Ogden, 1979, Geologic map of Colorado: U.S. Geological Survey, scale 1:500,000.
Weeks, E. P., 1964, Hydrologic conditions in the Wheatland Flats area, Platte County, Wyoming: U.S. Geological Survey Water Supply Paper 1783, 79 p.
Weeks, J. B., 1978, Plan of study for the High Plains regional aquifer system analysis in parts of Colorado, Kansas, Nebraska, New Mexico, Oklahoma, South Dakota, Texas and Wyoming: U.S. Geological Survey Water-Resources Investigations 78-70, 28 p.

CONVERSION FACTORS

Multiply inch-pound units	*By*	*To obtain SI units*
foot	0.3048	meter
foot per mile	0.1894	meter per kilometer
mile	1.609	kilometer
acre-foot	1,233	cubic meter
square mile	2.590	square kilometer
gallon per minute	0.06309	liter per second

Base from U. S. Geological Survey
United States base map, 1972

INTERIOR—GEOLOGICAL SURVEY, RESTON, VA.—1981—W81176

BEDROCK GEOLOGY, ALTITUDE OF BASE, AND 1980 SATURATED THICKNESS OF THE HIGH PLAINS AQUIFER IN PARTS OF COLORADO, KANSAS, NEBRASKA, NEW MEXICO, OKLAHOMA, SOUTH DAKOTA, TEXAS, AND WYOMING

By
John B. Weeks and Edwin D. Gutentag
1981

For sale by Branch of Distribution, U.S. Geological Survey 1200 South Eads Street, Arlington, VA 22202 and Branch of Distribution, U.S. Geological Survey, Box 25286, Federal Center, Denver, CO 80225