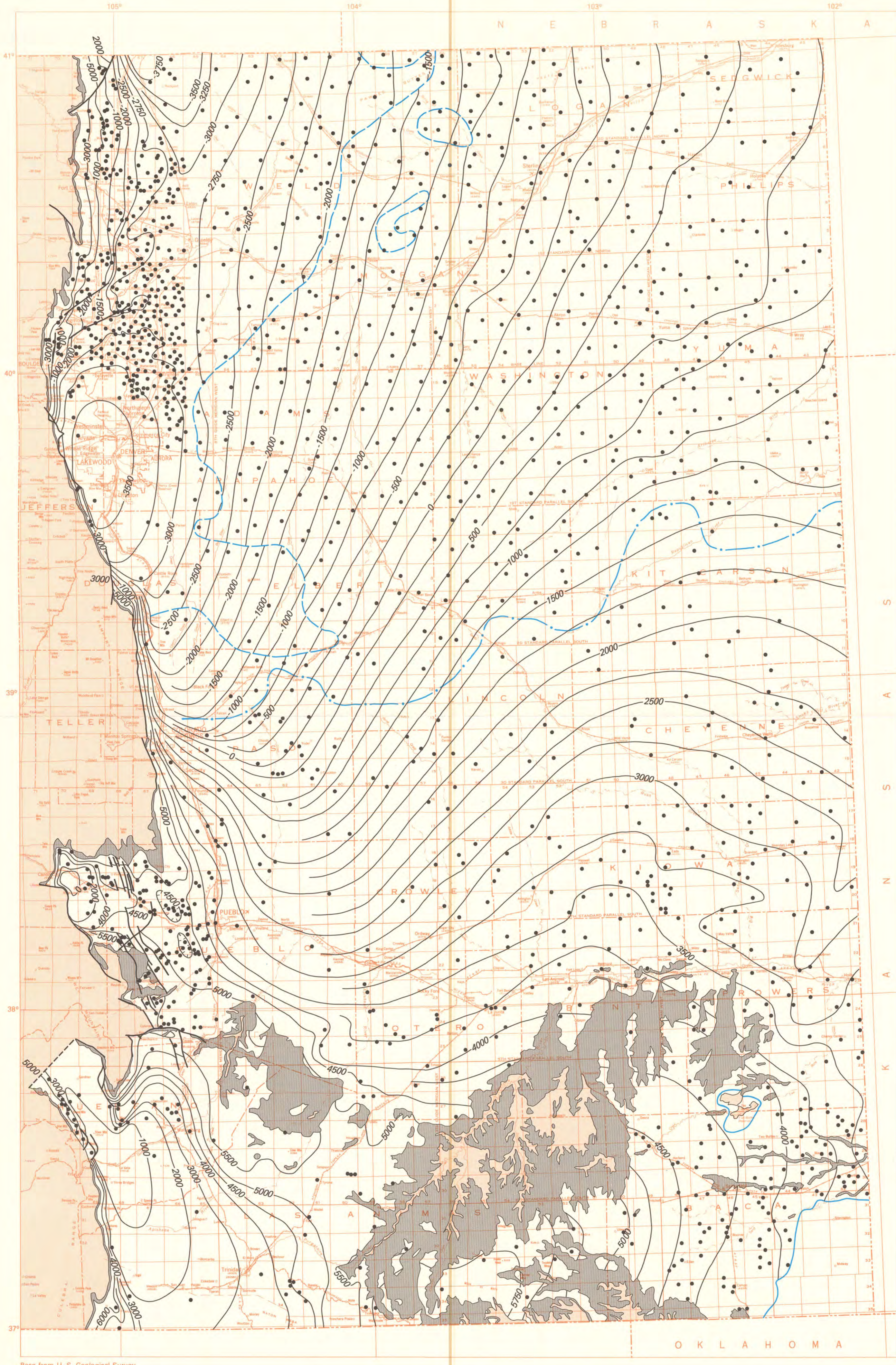


Base from U. S. Geological Survey Colorado State base map, 1969

0 20 40 60 MILES
0 20 40 60 KILOMETERS

EXPLANATION

OUTCROP OF PRE-CRETACEOUS ROCKS

OUTCROP OF DAKOTA SANDSTONE AND PURGATOIRE FORMATION

—1000— STRUCTURE CONTOUR—Shows altitude of the top of the Dakota-Cheyenne aquifer. Contour interval, in feet, is variable. Datum is sea level

FAULT

LIMIT OF THE DAKOTA-CHEYENNE AQUIFER IN SUBSURFACE

SOUTHERN LIMIT OF HUNTSMAN SHALE

WESTERN LIMIT OF "D" SANDSTONE

• DATA POINT

Figure 14.—Altitude and configuration of the top of the Dakota-Cheyenne aquifer in eastern Colorado.

FORT HAYS-CODELL AQUIFER

Geology

The Cretaceous Codell Sandstone Member of the Carlile Shale and the overlying Fort Hays Limestone Member of the Niobrara Formation (fig. 2) are used as a source of water to a limited extent in southeastern Colorado. The Fort Hays-Codell aquifer in Colorado is part of the Great Plains confining system (fig. 2). The Codell Sandstone Member is thin, ranging in thickness from about 3 to 34 ft, and usually consists of pale orange, yellowish-gray, or rusty-brown, calcareous sandstone and sandy siltstone that was deposited in a shallow marine environment (Dane and others, 1936; McLaughlin, 1954; Voegeli and Hershey, 1965; Weist, 1965; Krutak, 1970). The Fort Hays Limestone Member ranges in thickness from about 50 to 65 ft and typically consists of white to cream-colored, chalky limestone containing thin beds of gray, calcareous shale (Dane and others, 1936) deposited in a marine environment (Berman and others, 1980). These two units form the Fort Hays-Codell aquifer. The top of the Fort Hays-Codell aquifer lies about 400 to 570 ft above the top of the Dakota Sandstone. The aquifer is overlain by the Smoky Hill Shale Member of the Niobrara Formation and is underlain by the Blue Hill Shale Member of the Carlile Shale.

Hydrology

Voegeli and Hershey (1965) report that in Prowers County recharge to the Fort Hays-Codell aquifer occurs through fractures and solution channels in the Fort Hays Limestone and Smoky Hill Marl Members of the Niobrara Formation. The recharge process presumably occurs similarly elsewhere, because the lithologies of these rocks are fairly uniform over a large area.

In the vicinity of the Arkansas River, water recharges the Fort Hays-Codell aquifer in the outcrop area and flows toward the river. In northeastern Huerfano County, water recharged in the outcrop flows toward the Huerfano River and its tributaries. The potentiometric surface for the Fort Hays-Codell aquifer generally is 50 to 300 ft higher than that in the Dakota-Cheyenne aquifer. However, in the north side of the Canon City embayment, the potentiometric surfaces for the two aquifers are approximately equal.

Reports (Voegeli and Hershey, 1965; Weist, 1965) state that water in the Codell Sandstone Member and the Fort Hays Limestone Member occurs in fractures, solution channels, and joints. In places, however, the Codell Sandstone Member is a soft, friable sandstone and may contain water in intergranular pores. Wells completed in the Fort Hays-Codell aquifer reportedly yield as much as 300 gal/min (Voegeli and Hershey, 1965).

The water contained in the Fort Hays-Codell aquifer generally is unfit for domestic use but is of suitable to marginal quality for stock or irrigation use. The dissolved-solids concentration of the water in most places ranges from 1,000 to more than 6,000 mg/L, although a small number of wells and springs near recharge areas produce water containing less than 500 mg/L of dissolved solids.

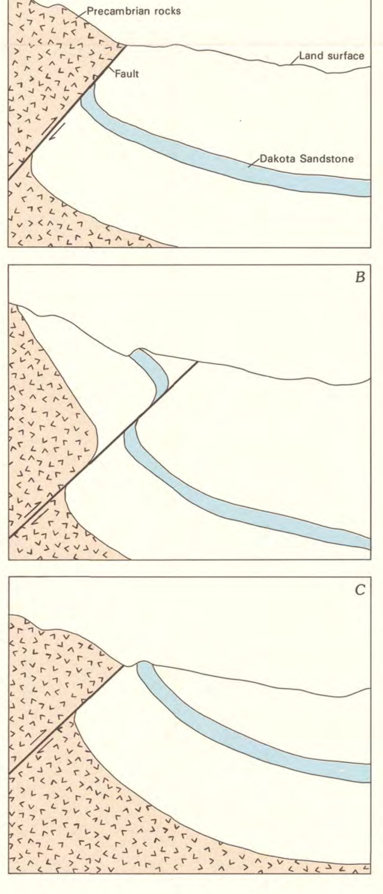


Figure 15.—Conceptualized geologic sections across western margin of study area.

DAKOTA-CHEYENNE AQUIFER

Geology

The Dakota-Cheyenne aquifer of eastern Colorado (Great Plains aquifer system) consists of the water-yielding, clastic sedimentary rocks of the Dakota Sandstone and the underlying Cheyenne Sandstone Member of the Purgatoire Formation (fig. 2). In southeastern Colorado, these formations have been developed as water supplies, and the stratigraphic terminology applied in numerous hydrologic and geologic studies in this area (McLaughlin, 1954, 1966; Weist, 1963, 1965; Voegeli and Hershey, 1965; Scott, 1968; Hershey and Hampton, 1974) is used in this report to apply to the water-yielding materials situated between the base of the Cretaceous Graneros Shale and the top of the Jurassic Morrison Formation. The Dakota-Cheyenne aquifer is the most extensive water-yielding unit in eastern Colorado; it extends from outcrops along the Front Range and the Apishapa Arch to depths of as much as 9,500 ft on the axis of the Denver Basin to correlative rock units in Wyoming, Nebraska, Kansas, Oklahoma, and New Mexico (Leonard and others, 1983). The aquifer occurs at depths of less than 1,000 ft in extensive areas near the Arkansas River and Apishapa Arch and commonly supplies water of better chemical quality than that found in local shallow alluvial aquifers. Along the Apishapa Arch, downcutting by the Arkansas River system has created extensive exposures of the Dakota Sandstone and Cheyenne Sandstone Member, and in a few areas, the downcutting has removed the Cretaceous section, exposing Jurassic and older rocks.

The lithology of the Dakota-Cheyenne aquifer may be characterized as a sequence of sandstones interbedded with localized, relatively thin shale beds, partitioned by two relatively thick shale beds. The two thick shale beds separate the sandstone and thin shale into upper, middle, and lower units. The Kiowa Shale Member of the Purgatoire Formation is the thicker and more extensive of the two shale beds and is located between the underlying Cheyenne Sandstone Member and the overlying Dakota Sandstone. The second thick shale bed, known locally as the Huntsman shale (Mossel, 1978), occurs only in the northern part of the area and separates two units of the Dakota Sandstone known locally as the "J" sandstone and the "D" sandstone (Mossel, 1978).

The Cheyenne Sandstone Member consists of massive to crossbedded, white to yellow-gray, fine- to coarse-grained, quartzose sandstone that is generally friable and irregularly interbedded with gray to green shale and claystone and occasional beds of conglomerate. The Cheyenne is a westward-thinning fluvial channel deposit in which individual beds vary in width from a few hundred feet to a few thousand feet. In local areas, the sandstone grades to silty sandstone and claystone. The underlying Morrison Formation is composed mostly of fine clastic and carbonate sedimentary rocks. The contact between the Cheyenne Sandstone Member and the Morrison Formation is indistinct in some areas (Haun, 1959, 1963; Weist, 1965; Berman and others, 1980); however, in this study, the base of the Dakota-Cheyenne aquifer is chosen to be the base of this predominantly sandstone sequence without regard for exact formational contacts.

The Kiowa Shale Member of the Purgatoire Formation is a gray to black, platey, calcareous, clayey shale with some thin beds of sandstone. In some areas the shale is sandy, has the appearance of soft yellow-brown sandstone or siltstone (Weist, 1965), and may be partly included here with either the overlying Dakota or the underlying Cheyenne Sandstone Member.

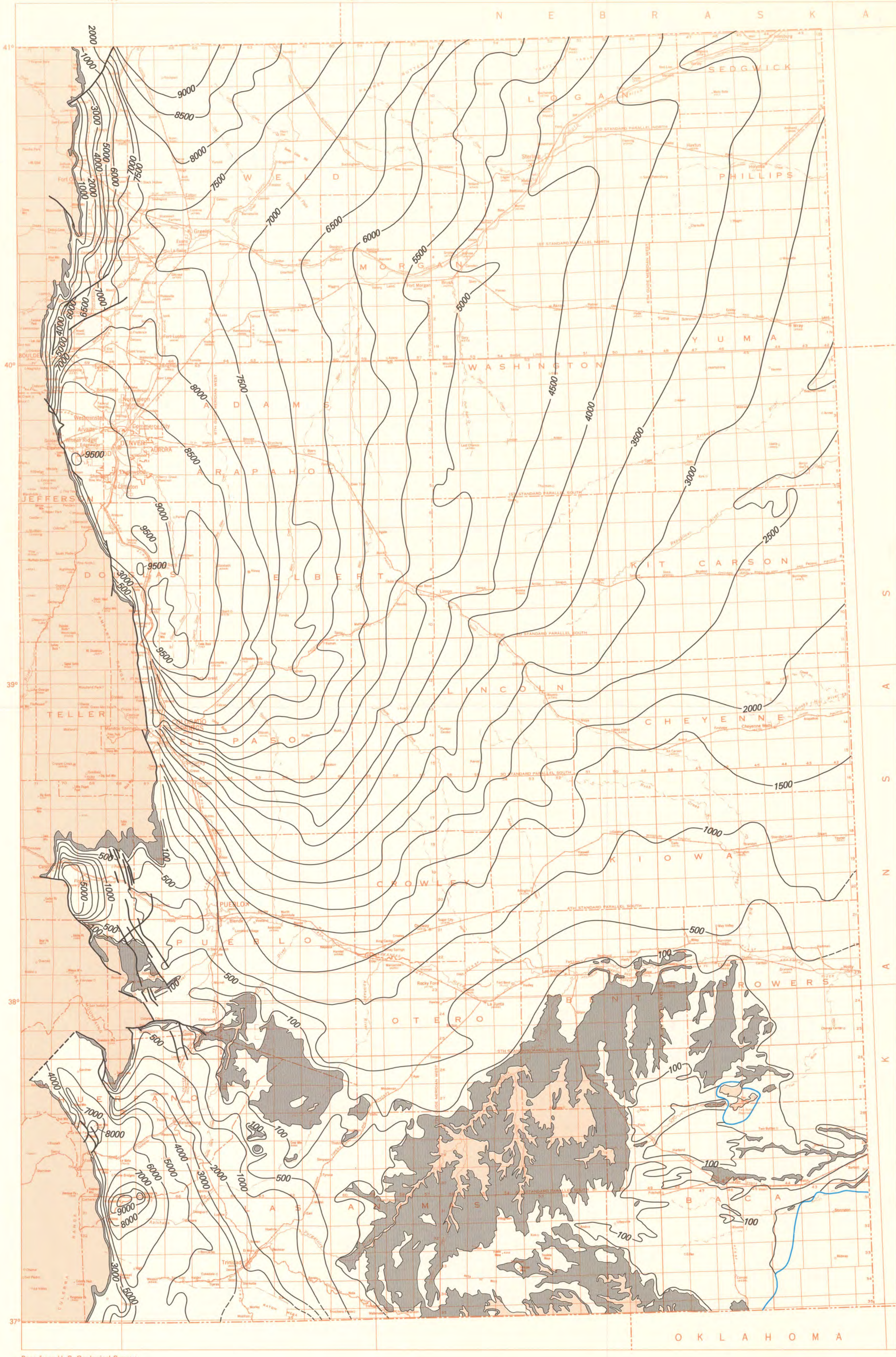
The Dakota Sandstone is the most intensively studied bedrock formation in eastern Colorado because of the interest in this formation as an oil and gas reservoir in the Denver Basin and as an aquifer in the southern part of the State. The sandstone generally is classified as a fine- to medium-grained, thin-bedded to massive, or locally crossbedded and ripple-marked quartzose sandstone ranging from white to dark brown. Although soft and friable in some areas, the sandstone generally is more consolidated than that of the underlying Cheyenne Sandstone Member of the Purgatoire Formation and commonly weathers to form ledges, cliffs, or hogbacks. The sandstone contains carbonaceous or lignitic materials and is interbedded with claystone locally grading, both laterally and vertically, to siltstone or to marine shale. Detailed stratigraphic studies (Land and Weimer, 1978; Mossel, 1978; Peterson and Janes, 1978) indicate that the "D" and "J" sandstone members of the Dakota Sandstone consist of a complex interconnection of active through abandoned channel-fill deposits, marine bay, freshwater-lake and swamp sediments, and splay-delta deposits accumulated during transgressive and regressive phases of deposition. Significant hydrocarbon reserves are contained in stratigraphically trapped reservoirs on the eastern flank of the Denver Basin and, more commonly, in structural traps on the western flank of the basin. Trapping mechanisms include classical accumulation on anticlinal noses, or in sandstone lenses that pinch out updip into impermeable fine clastics, or the more complex traps associated with interchannel areas where porous and permeable point bars pinch out. Hydrodynamic flow may affect hydrocarbon accumulation in some traps (Miller, 1963). In the northwestern part of the study area, the lithology of the "D" and "J" sandstones is strongly affected by the discontinuous and lenticular stratigraphy of the channel-fill and deltaic deposits.

The Huntsman shale separates the Dakota Sandstone in the northern part of the study area into the "D" and "J" sandstones and generally forms a leaky confining layer between them. The unit consists of black to gray or buff, clayey siltstone and fissile shale interbedded with sandstone and siltstone. The Graneros Shale overlies the Dakota-Cheyenne aquifer and consists of dark gray to black, fissile, noncalcareous shale containing thin-bedded limestone and interlayered sandstone in the lower part. The upper limit of the Dakota-Cheyenne aquifer is at the top of the predominantly sandstone sequence; locally it may include some adjacent sandstone beds associated with the lower part of the Graneros Shale.

The altitude of the top of the Dakota Sandstone ranges from more than 6,000 ft above sea level on the hogback outcrops along the western margin of the Denver and Raton Basins to more than 3,500 ft below sea level in the trough of the Denver Basin (fig. 14). The eastern and southern flanks of this asymmetrical structure dip gently to the west, northwest or north from the Las Animas and Apishapa Arches. Along the western flanks of the Denver and Raton Basins, the Dakota Sandstone generally dips eastward at 40° to 60° and is locally overturned as a result of Late Cretaceous and early Tertiary faulting and folding associated with elevation of the Rocky Mountains. This structural configuration is the result of a complex and poorly understood combination of low-angle thrust or moderate- to high-angle reverse faulting in the Precambrian rocks and drape folding of sedimentary rocks over the differentially uplifted Precambrian fault blocks (Matthews, 1976). These faults may truncate the water-yielding formations (fig. 15*A*) or offset the formations (fig. 15*B*), both of which effectively isolate the deeper parts of the aquifer from the surface. Such fault configurations are common in the interval from Golden to about 10 mi south of Colorado Springs. North and south of this interval, the principal form of deformation is either folding or faulting in rocks underlying the Dakota sandstone (fig. 15*C*), and the Dakota Sandstone is usually nearly continuous from outcrop to depth with only relatively minor displacements across some local faults (Banta, 1983).

Because of the large variation in altitude of the top of the Dakota Sandstone, the depth to the top of the Dakota-Cheyenne aquifer exceeds 9,000 ft in the axis of the Denver and Raton Basins and exceeds 5,000 ft in the Canon City embayment west of Pueblo (fig. 16). The depth is less than 2,000 ft only along the narrow band of outcrop on the western margin of the aquifer and in the southern part of Colorado on the crests and flanks of the Apishapa and Las Animas Arches.

The total thickness of the Dakota Sandstone and Purgatoire Formation generally ranges from about 100 to 500 ft, and rocks in this interval consist of interlayered sandstone and shale. The aggregate sandstone thickness for the Cheyenne Sandstone Member ranges from zero in the southeastern corner of the State to about 200 ft in a few scattered areas. The most consistently thick interval occurs in the northern half of the study area (fig. 17) where 100 to 200 ft of sandstone is common. The aggregate shale thickness for the Kiowa Shale Member ranges from 0 to 50 ft in much of the southwestern part of the area and increases to more than 150 ft in the northern part of the area (fig. 17). The aggregate sandstone thickness map for the Dakota Sandstone (fig. 18) includes the thickness of both the "D" and "J" sandstones of the unit. Sandstone thickness decreases to zero in southeastern Colorado but more commonly ranges from 100 to 200 ft over the eastern part of the area. The Huntsman shale separates the "D" and "J" sandstones in the northern part of the area and ranges in thickness from a southerly pinch out to more than 80 ft in the north-central part of the area.



Base from U. S. Geological Survey Colorado State base map, 1969

0 20 40 60 MILES
0 20 40 60 KILOMETERS

EXPLANATION

OUTCROP OF PRE-CRETACEOUS ROCKS

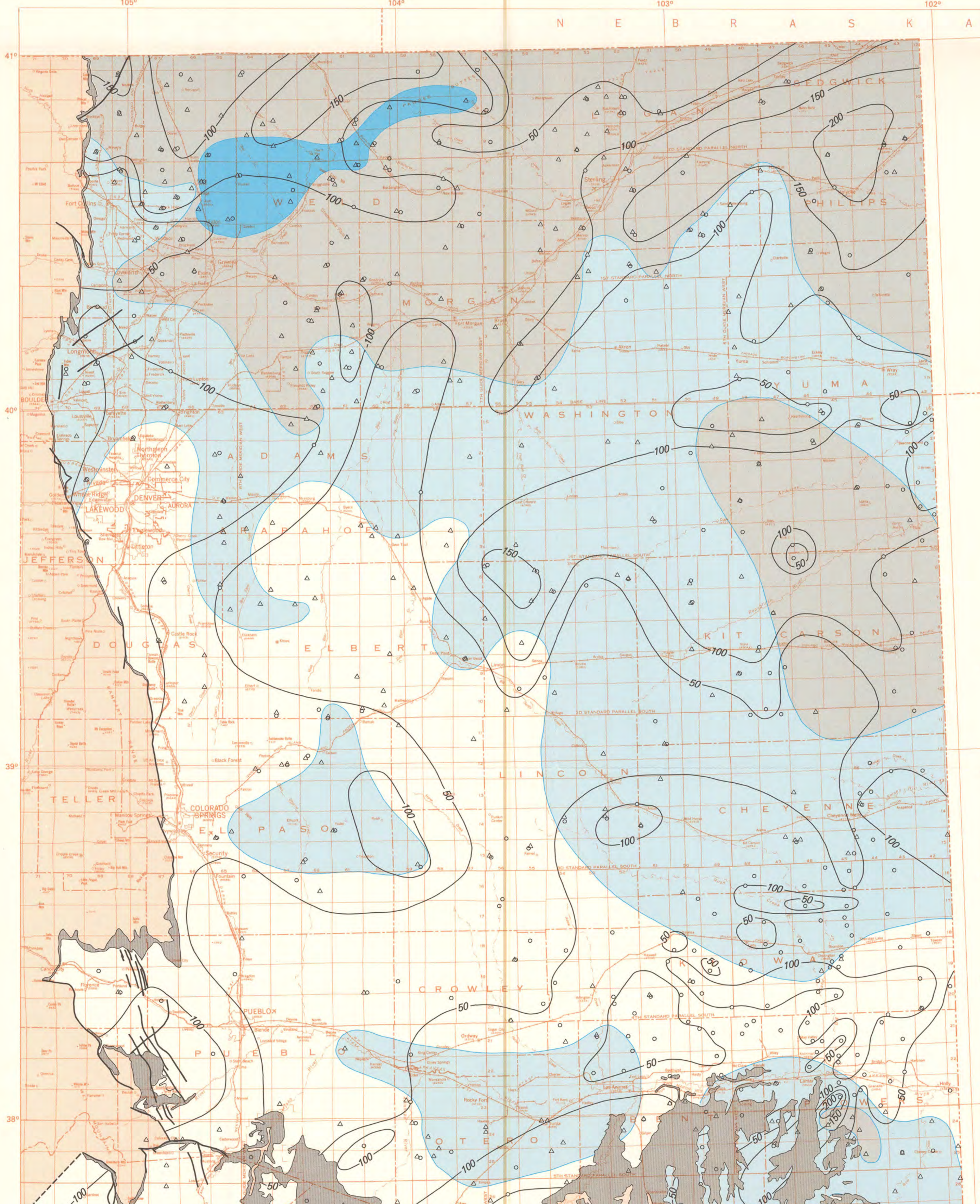
OUTCROP OF DAKOTA SANDSTONE AND PURGATOIRE FORMATION

—1000— LINE OF EQUAL DEPTH TO THE TOP OF THE DAKOTA-CHEYENNE AQUIFER

FAULT

LIMIT OF DAKOTA-CHEYENNE AQUIFER IN SUBSURFACE

Figure 16.—Depth to the top of the Dakota-Cheyenne aquifer in eastern Colorado.



Base from U. S. Geological Survey Colorado State base map, 1969

0 20 40 60 MILES
0 20 40 60 KILOMETERS

EXPLANATION

AGGREGATE SHALE THICKNESS FOR THE KIOWA SHALE MEMBER OF THE PURGATIORE FORMATION—In feet

0
50
100
150
200

OUTCROP OF PRE-CRETACEOUS ROCKS

OUTCROP OF THE DAKOTA SANDSTONE AND PURGATIORE FORMATION

—100— LINE OF EQUAL AGGREGATE SANDSTONE THICKNESS IN THE CHEYENNE SANDSTONE MEMBER OF THE PURGATIORE FORMATION—Interval 50 feet

FAULT

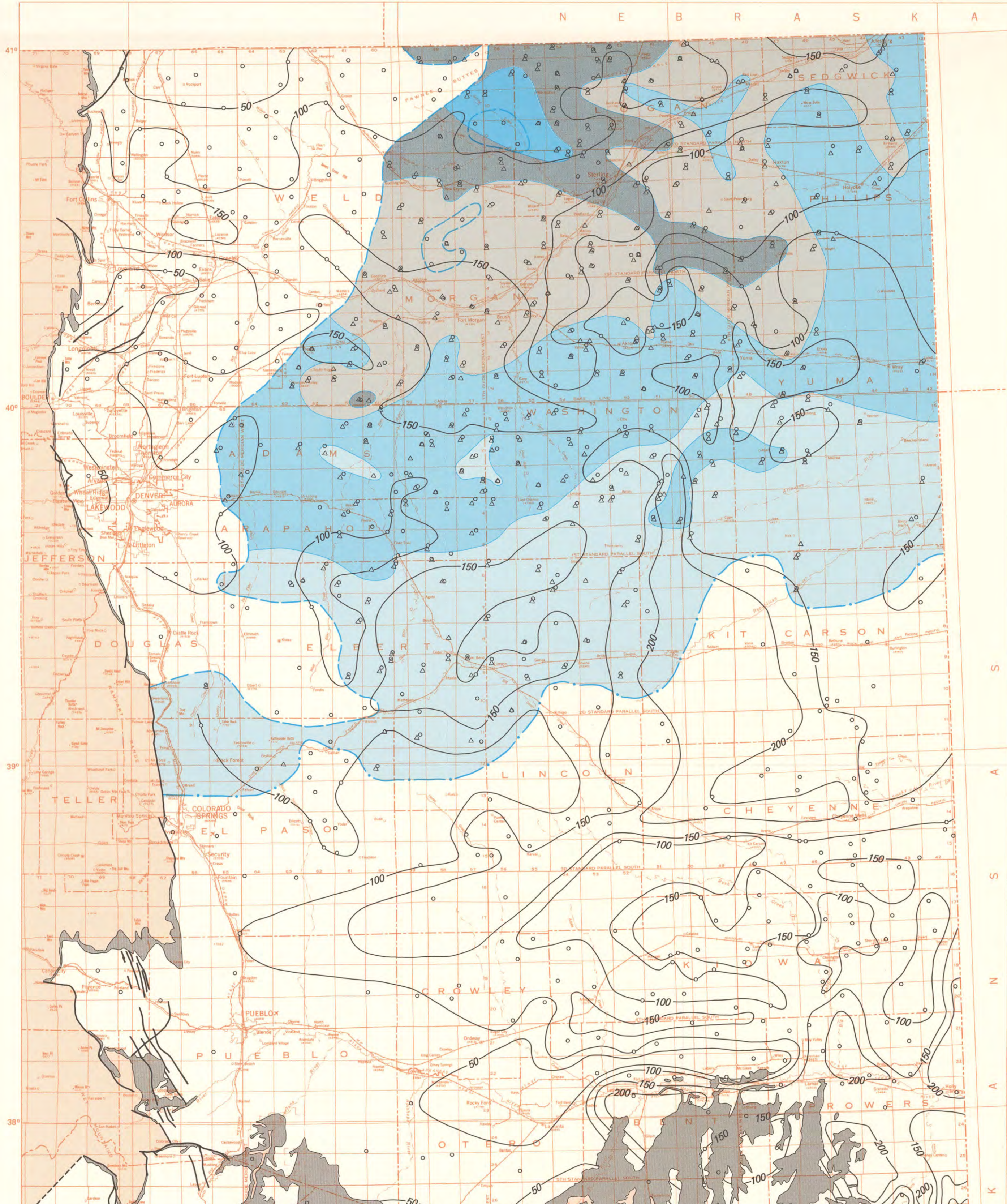
LIMIT OF THE DAKOTA-CHEYENNE AQUIFER IN SUBSURFACE

DATA POINTS

△ Control point for Kiowa Shale Member

○ Control point for Cheyenne Sandstone Member

Figure 17.—Aggregate sandstone thickness for the Cheyenne Sandstone Member and aggregate shale thickness for the Kiowa Shale Member of the Purgatoire Formation in eastern Colorado.



Base from U. S. Geological Survey Colorado State base map, 1969

0 20 40 60 MILES
0 20 40 60 KILOMETERS

EXPLANATION

AGGREGATE SHALE THICKNESS FOR THE HUNTSMAN SHALE—In feet

0
20
40
60
80
100

OUTCROP OF PRE-CRETACEOUS ROCKS

OUTCROP OF THE DAKOTA SANDSTONE AND PURGATIORE FORMATION

—100— LINE OF EQUAL AGGREGATE SANDSTONE THICKNESS IN THE DAKOTA SANDSTONE—Interval 50 feet

FAULT

LIMIT OF THE DAKOTA-CHEYENNE AQUIFER IN SUBSURFACE

SOUTHERN LIMIT OF HUNTSMAN SHALE

WESTERN LIMIT OF "D" SANDSTONE

DATA POINTS

△ Control point for Huntsman Shale

○ Control point for Dakota Sandstone

Figure 18.—Aggregate sandstone thickness for the Dakota Sandstone and aggregate shale thickness for the Huntsman shale in eastern Colorado.

GEOLOGY AND HYDROLOGY OF THE DEEP BEDROCK AQUIFERS IN EASTERN COLORADO

By
S. G. Robson and E. R. Banta

1987