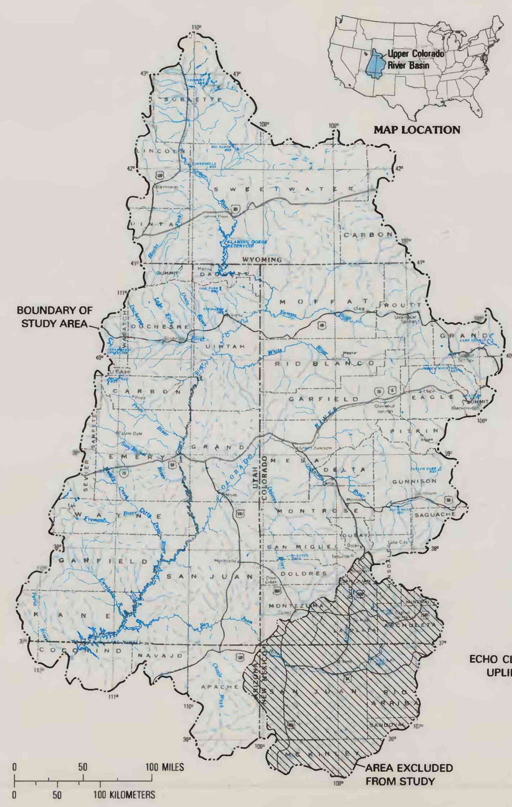


Figure 1.—Location of the Upper Colorado River Basin.

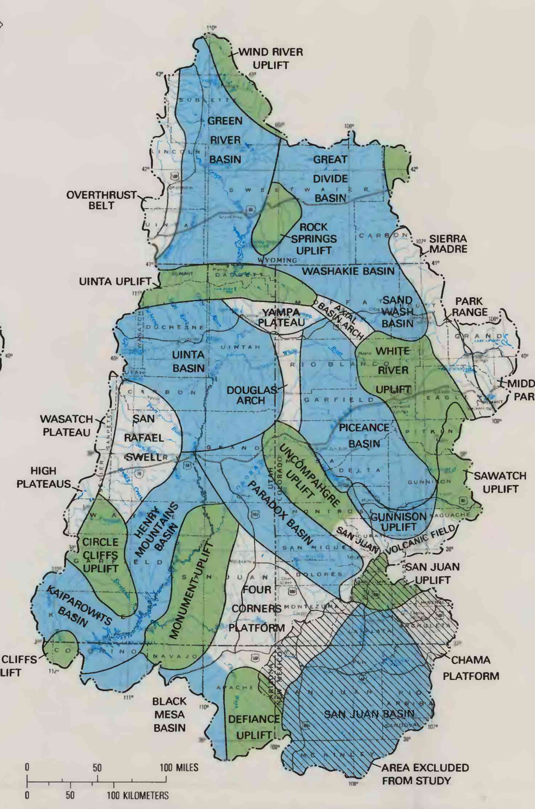


Figure 2.—Principal tectonic features of the Upper Colorado River Basin. [Modified from Rocky Mountain Association of Geologists, 1972]

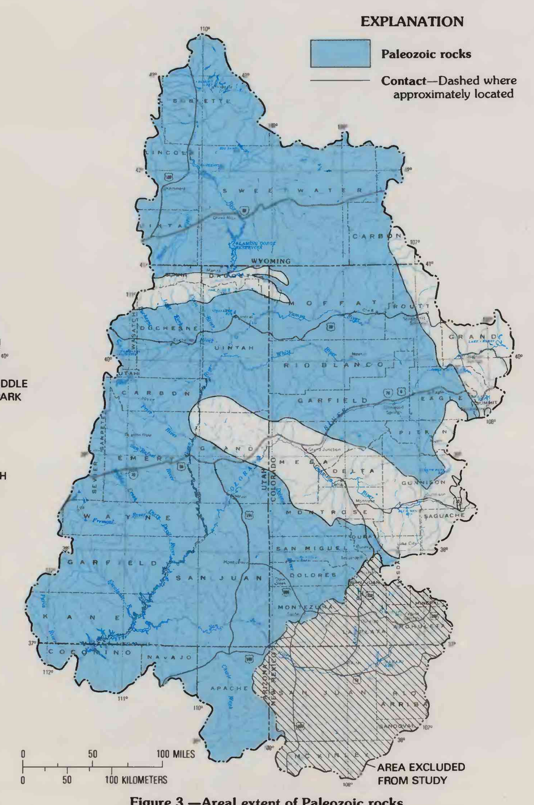


Figure 3.—Areal extent of Paleozoic rocks. [Modified from King and Beikman (1975) and Rocky Mountain Association of Geologists (1972)]

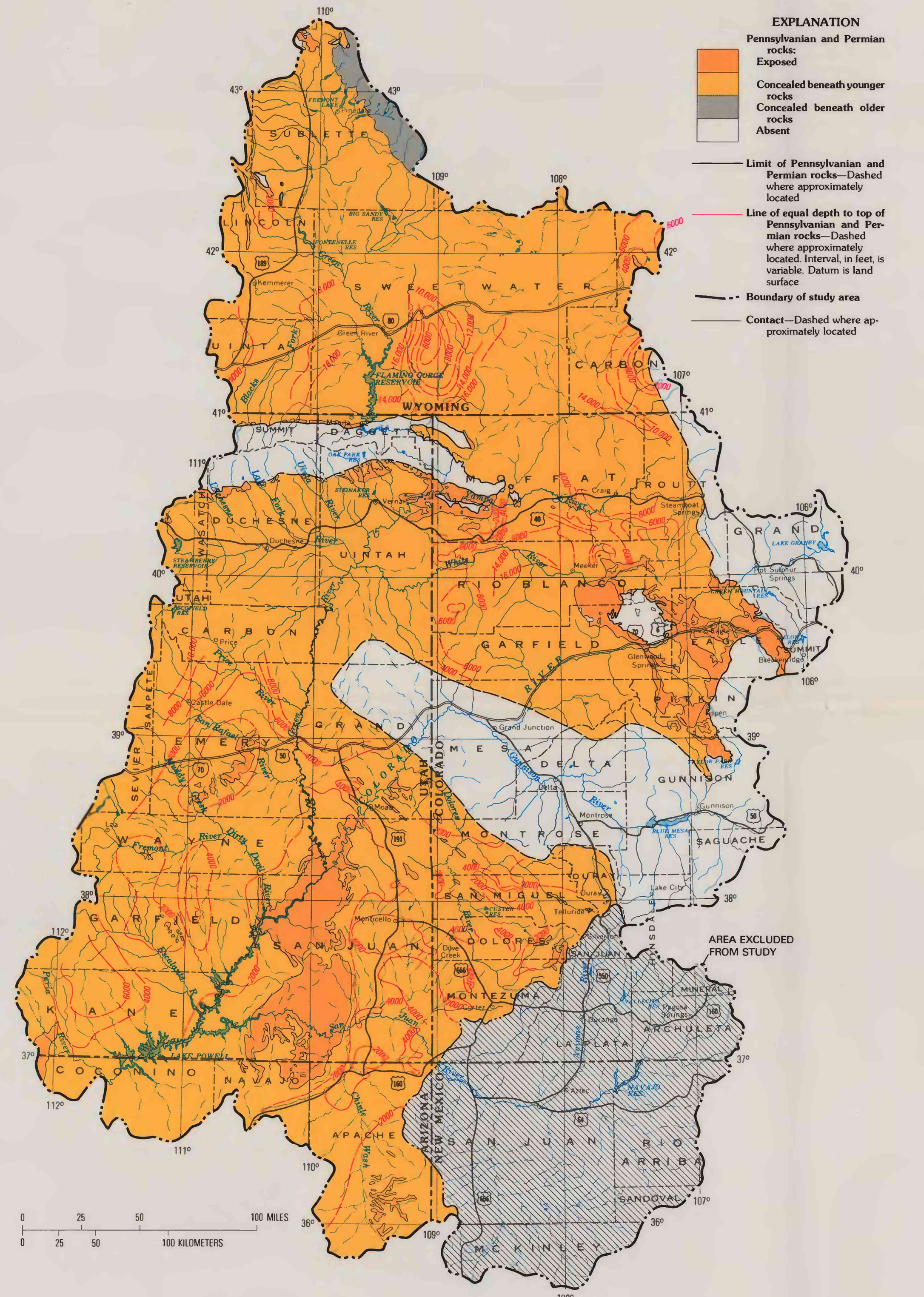


Figure 4.—Generalized depth to top of Pennsylvanian and Permian rocks.

INTRODUCTION

The Upper Colorado River Basin includes an area of about 113,500 mi² in parts of Colorado, Utah, Wyoming, Arizona and New Mexico. [illegible]

[illegible] uplift in the extreme northern part of the study area (Love, 1950).

DATA AVAILABILITY AND METHODS OF ANALYSIS

Most of the geologic and hydrologic analyses described in this report are based on data obtained from wells drilled by the oil and gas industry. The data include geologic and geophysical well logs, shut-in-pressure tests, and chemical analyses. In many instances, the quality of the data was extremely variable. Individual data points were not checked for accuracy; all the data points in an area were considered as a group to define potentiometric-surface and water-quality contours and probable direction of ground-water flow. Control points are not shown on the maps because their distribution could be misleading—the location of a particular contour is only known accurately when both the density of control points is great and their variability is small.

Shut-in-pressure data from drill-stem tests on oil and gas wells were the primary source of information for the potentiometric-surface maps. The information was supplemented by data published by Teller and Chafin (1984) and additional data provided by A.L. Geldon (U.S. Geological Survey, written commun., 1984). Altitudes of springs issuing from Mississippian aquifers (Teller and Welder, 1983) gave additional information about minimum heights of the potentiometric surface in the White River uplift area.

The effects of dissolved solids and temperature on water density had to be considered to convert shut-in-pressure data to equivalent freshwater head. A density of 61.8 lb/ft³ for water was used to calculate the freshwater heads (in feet) and to map the potentiometric surfaces. This density represents water with no dissolved solids and an average temperature of 112°F. However, dissolved-solids concentrations are greater than 100,000 mg/L in the middle Paleozoic aquifers in deep parts of the Paradox, Piceance, and Uinta basins. These large dissolved-solids concentrations could increase water density as much as 20 percent over the assumed value. Because of the density considerations, field measurements of head in some areas may be from 200 to 800 ft lower than the mapped potentiometric surface, which is based on equivalent freshwater head. Therefore, the maps presented in this report are suitable for analysis of recharge, movement, and discharge characteristics of the flow system; they are not suitable for detailed quantitative analysis of flow. In areas where water density varies greatly over a small distance, even direction of movement could be affected (E. J. Weiss, U.S. Geological Survey, written commun., 1985).

About 1,100 analyses were used to summarize the water chemistry of the Paleozoic aquifers and confining layers units. The data came from the WATSTORE files of the U.S. Geological Survey, the Brine File of Petroleum Data Services, and from published reports. Chemical analyses in the WATSTORE file are generally of water from wells or springs that have been developed from municipal, domestic, or livestock water supplies. Analyses in the Brine File are generally of water from exploratory holes sampled by petroleum companies primarily during drill-stem tests of oil wells. These two sources of data often represent opposite extremes of the water quality of the Paleozoic aquifers and confining layers. In the data summary that follows (table 1, sheet 2), data from each source have been combined only if statistical tests showed that the median values were not significantly different. For example, the data from the Brine File and from WATSTORE for the Kaibab Limestone are not significantly different, but the data from the two files for the Weber Sandstone are significantly different.

Geochemical data, such as dissolved-solids concentrations, often contain a few values that are much larger than most of the remaining data. Miesch (1967) suggested that the best estimate of a central value for geochemical data is given by a geometric mean, rather than an arithmetic mean; the arithmetic mean is too strongly influenced by extreme values. The data summaries in table 1 (sheet 2) were calculated from the data after transforming the values to logarithms because the values approximate a log-normal distribution. The antilog of the arithmetic mean of the log-transformed data is the geometric mean.

Several criteria were used to edit the data. If the ionic balance was not within 20 percent, the analysis was rejected. Many analyses included sodium that was calculated by ionic difference rather than being determined analytically. Although these samples would not be adequate for detailed geochemical analysis, they were considered sufficient to help establish contours for the dissolved-solids maps. If there was more than one analysis for a given interval in a single well and none of the analyses could be discarded because of a poor ionic balance or because the chemical composition indicated contamination by drilling fluids, then a geometric mean was used to represent the given interval. Therefore, the number of samples reported for a given major aquifer in table 1 may contain more than one sample for a given well but not more than one sample for a given interval at a single well.

The "box plots" in table 1 (sheet 2) show the distribution of the samples for each major aquifer if there are ten or more samples. The scale for the box plots is logarithmic. These plots are modeled after those suggested by Velleman and Hoaglin (1981). The median is shown by a plus (+). A confidence interval around the median, based on the range between the 25 and 75 percent quartiles and the number of samples, is indicated by notches on either side of the median (< >). The notches are calculated by the equation

$$\text{median} \pm 1.58 * (Q_{75}-Q_{25}) \;/\; \text{square root } (n),$$

where Q_{25} is the data value greater than 25 percent of the data, Q_{75} is the data value greater than 75 percent of the data, and n is the number of samples. If the areas within the notches of two groups do not overlap, there is about a 95 percent probability that they represent different populations.

The Q_{25} and Q_{75} are indicated by vertical bars, (I). Half of the data values are between these bars. Beyond these two bars there are three symbols that indicate if data values are inside, outside, or far outside areas defined by "fences." The fences are defined as:

$$\text{Lower outer fence} = Q_{25}-3.0 * (Q_{75}-Q_{25})$$
$$\text{Lower inner fence} = Q_{25}-1.5 * (Q_{75}-Q_{25})$$
$$\text{Upper inner fence} = Q_{75}-1.5 * (Q_{75}-Q_{25})$$
$$\text{Upper outer fence} = Q_{75}-3.0 * (Q_{75}-Q_{25})$$

The range of values that fall between the vertical bars at the quartiles and the inner fences is marked by a horizontal line (——) that extends from the bars to the smallest or largest value within the inner fences. Individual values that are between the inner and outer fences are marked by a star (*); they are called outside values. Values beyond the outer fences are marked by a circle (o), and are called far outside values. The box plot for the Madison Group uses each of these symbols. Both outside and far outside values were given special attention to be sure they did not result from input errors but, instead, that they represented real variations in the data. In many cases, it appeared that the variation was due to natural factors such as location within recharge areas versus basins. This simple set of rules allows the quick comparison of many groups of data in table 1 (sheet 2).

To construct the dissolved-solids maps, it was necessary to determine a representative value of dissolved-solids concentration for each individual well in a given map unit. In general, the geometric mean of dissolved solids at a well was used. However, if the range of values at a single well spanned more than one of the concentration intervals used on the dissolved-solids maps, the value that best fit the regional trend in that area was used.

HYDROGEOLOGIC UNITS

The consolidated sedimentary rocks of Paleozoic age in the study area were divided into four hydrogeologic units by Taylor and others (1984)—the basal Paleozoic aquifers unit, the lower Paleozoic aquifers and confining layers unit, the middle Paleozoic aquifers unit, and the upper Paleozoic aquifers and confining layers unit. Each hydrogeologic unit includes numerous formations of similar lithologic character and depositional environment. The grouping facilitated further investigation of the hydrologic characteristics of the formations; it would be impractical to map these characteristics on the scale of this atlas without doing such grouping. These units are described below and illustrated on the stratigraphic columns (fig. 5).

The geologic framework of the study area is described by structure-contour and thickness maps for each hydrogeologic unit. The maps are based on analysis of geologic logs of oil and gas wells and published geologic maps. Scarcity of deep well-log data reduced the scope of the description of the framework for the two lower hydrogeologic units. Geologic framework of the two upper units is described in more detail. Analysis was limited to the upper two units, essentially strata ranging in age from Devonian through Permian.

Structure-contour maps indicate the altitude of the top of the hydrogeologic unit; drilling depth to the top of the unit can be estimated at any site by subtracting the structure-contour altitude from the land-surface altitude. The maps showing the thickness of each unit can be used in conjunction with the structure-contour maps and land-surface altitudes to estimate drilling depth to the base of the unit. These maps indicate regions where the units are relatively thick. The included aquifers might be important local sources of water; the included confining layers may be important local aquicludes. The maps also indicate regions where the hydrogeologic units are thin or absent. However, they should be used with caution, because local variations may produce areas too small to be mapped that are thicker or thinner than indicated.

BASAL PALEOZOIC AQUIFERS UNIT AND LOWER PALEOZOIC AQUIFERS AND CONFINING LAYERS UNIT

The basal Paleozoic aquifers unit of Cambrian age consists mostly of sandstone and quartzite. Other rocks include shale, dolomite, and conglomerate. This hydrogeologic unit is areally extensive and is probably continuous.

Above the basal Paleozoic aquifers unit is the lower Paleozoic aquifers and confining layers unit of Cambrian and Ordovician age. This hydrogeologic unit consists mostly of limestone, dolomite, and shale, with minor beds of conglomerate and sandstone. Reported aquifers include the uplifted limestone and dolomite formations that contain solution openings. Confining layers include the shale and possibly the deeply buried limestone and dolomite.

Although a detailed analysis of the two lower hydrogeologic units was impossible, the limited data available indicate that basal Paleozoic aquifers and lower Paleozoic aquifers and confining layers units probably are absent in the Uncompahgre and Uinta uplifts, Sierra Madre, and Park Range. Both units are exposed on the southern edges of the Uinta uplift, in the San Juan volcanic field, and in the White River uplift. The depth to the top of the lower Paleozoic aquifers and confining layers unit is about 20,000 ft on the flanks of the Green River basin in Wyoming; the maximum depth is unknown. The combined basal and lower units thicken to the northwestern part of the study area and reach a thickness of approximately 1,600 ft in the Uinta basin.

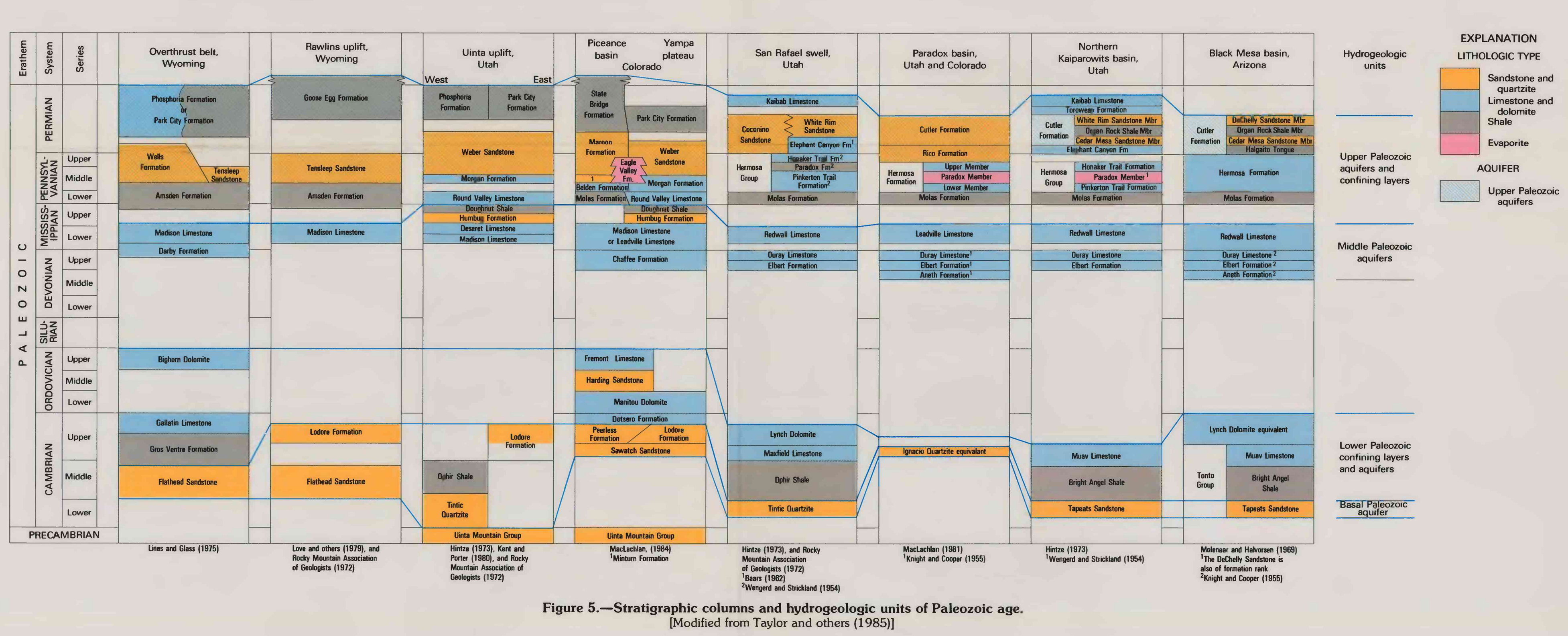


Figure 5.—Stratigraphic columns and hydrogeologic units of Paleozoic age. [Modified from Taylor and others (1985)]

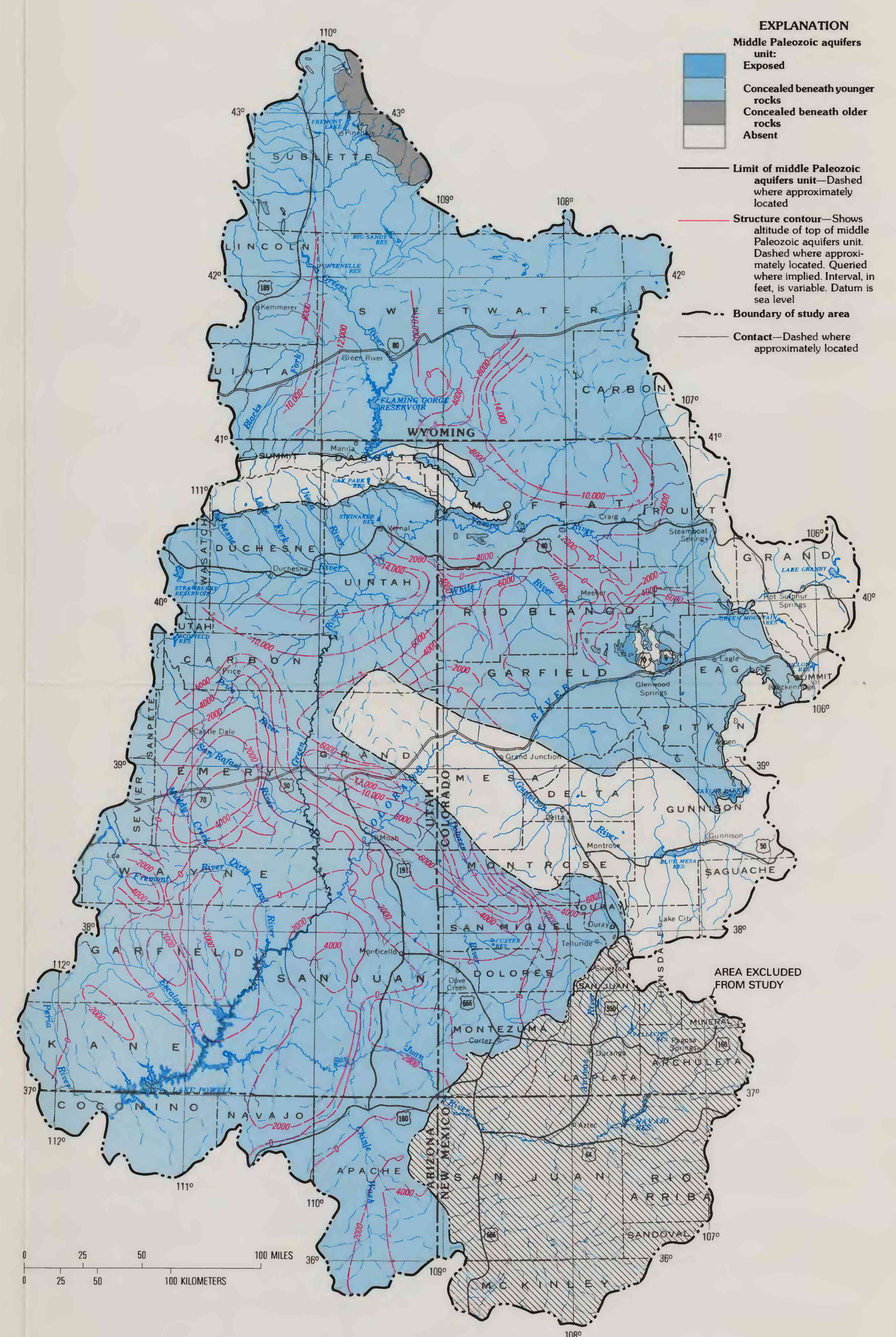


Figure 6.—Configuration of top of middle Paleozoic aquifers unit.

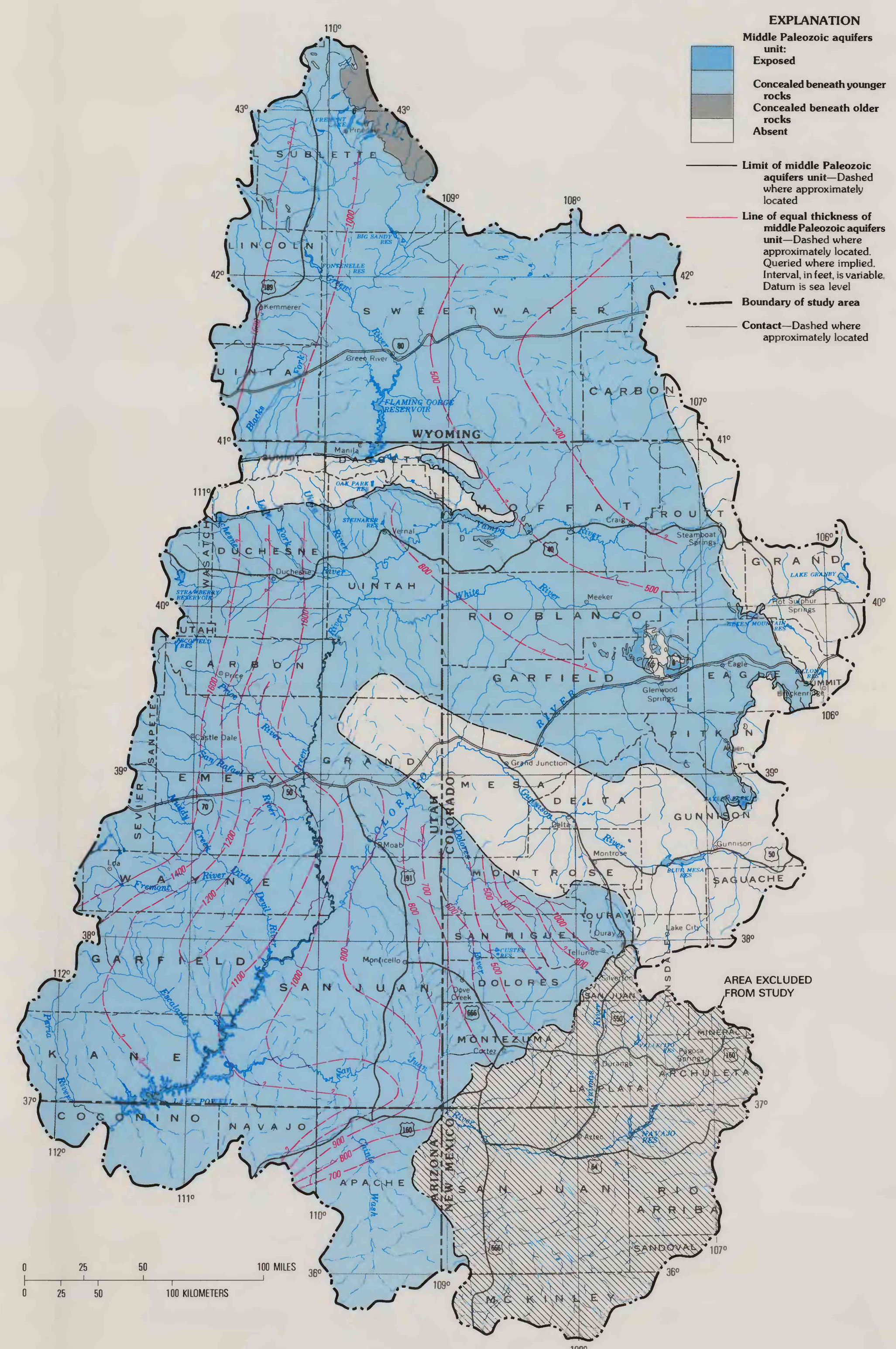


Figure 7.—Thickness of middle Paleozoic aquifers unit.

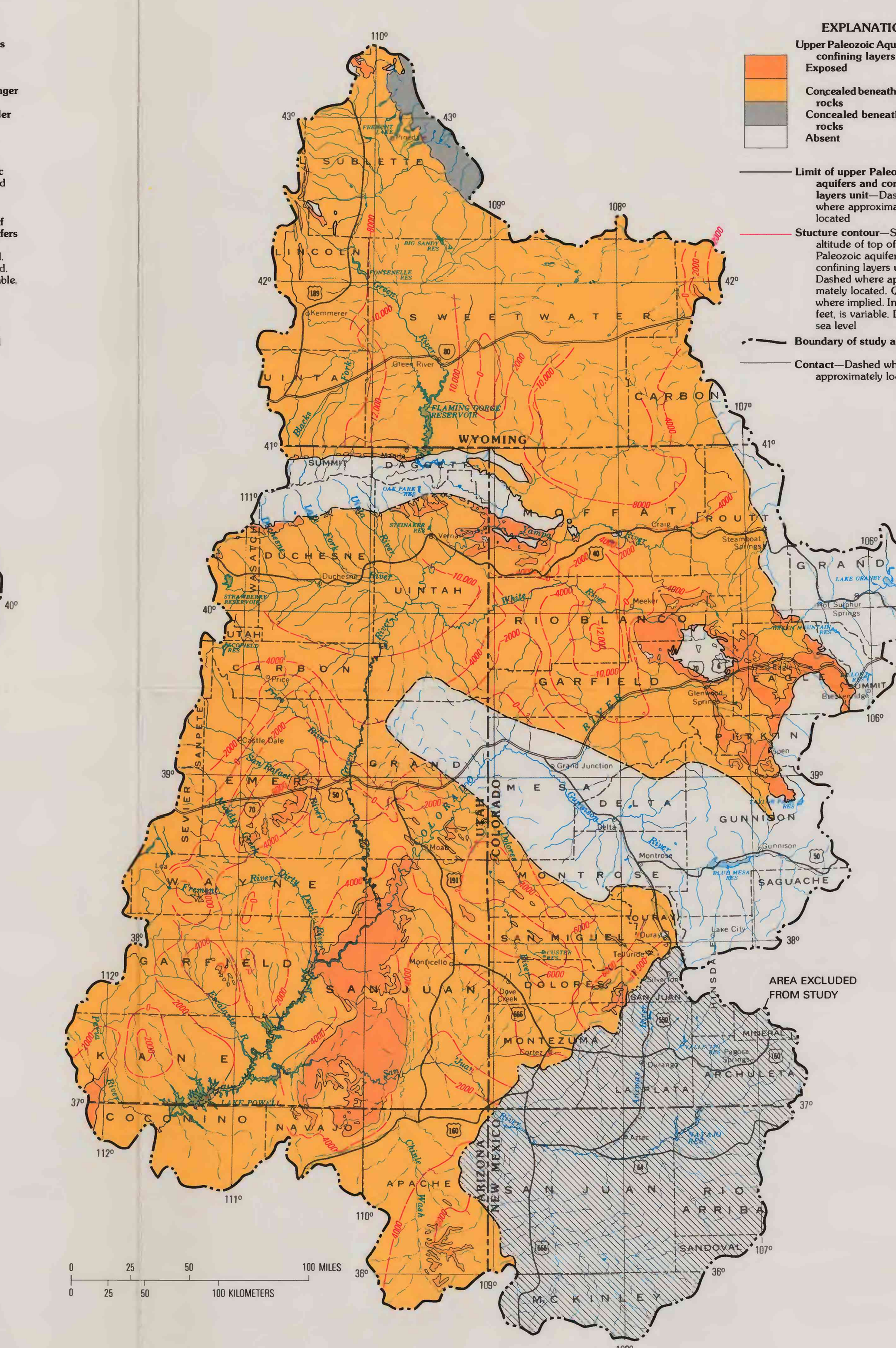


Figure 8.—Configuration of top of upper Paleozoic aquifers and confining layers unit.

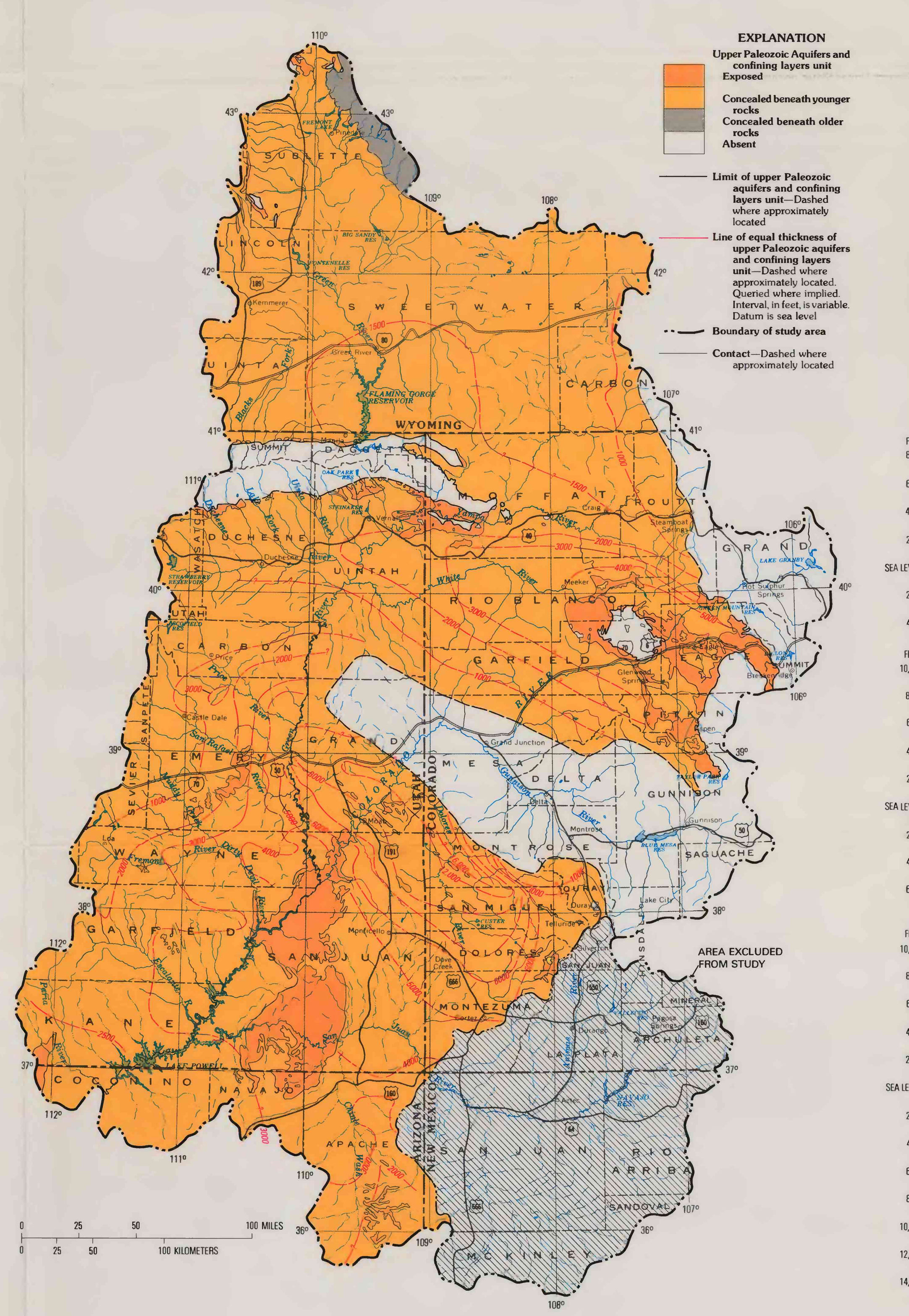


Figure 9.—Thickness of upper Paleozoic aquifers and confining layers unit.

MIDDLE PALEOZOIC AQUIFERS UNIT

[illegible]

UPPER PALEOZOIC AQUIFERS AND CONFINING LAYERS UNIT

[illegible]

Upper Paleozoic aquifers subunit

[illegible]

Upper Paleozoic confining layers subunit

[illegible]

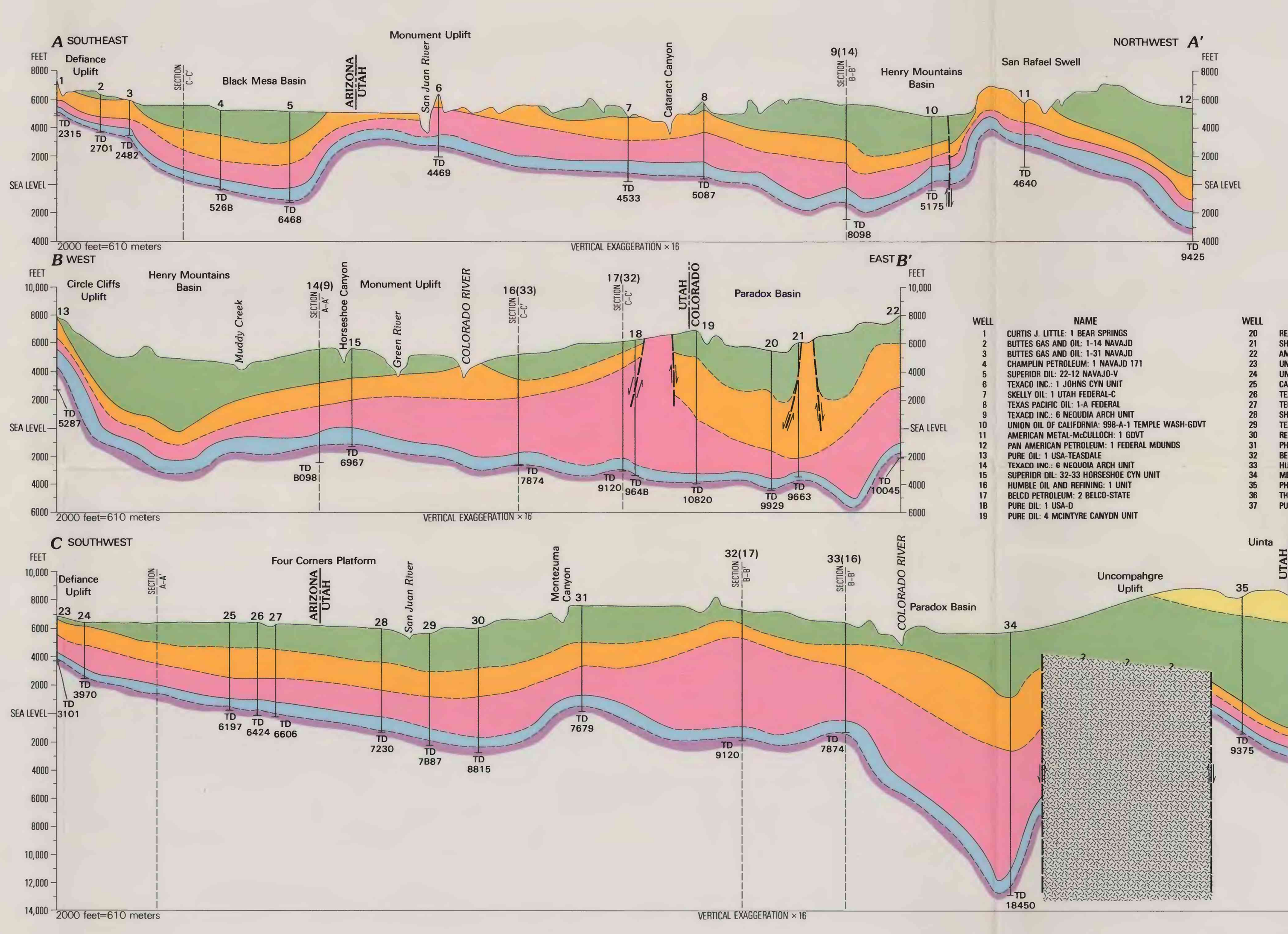
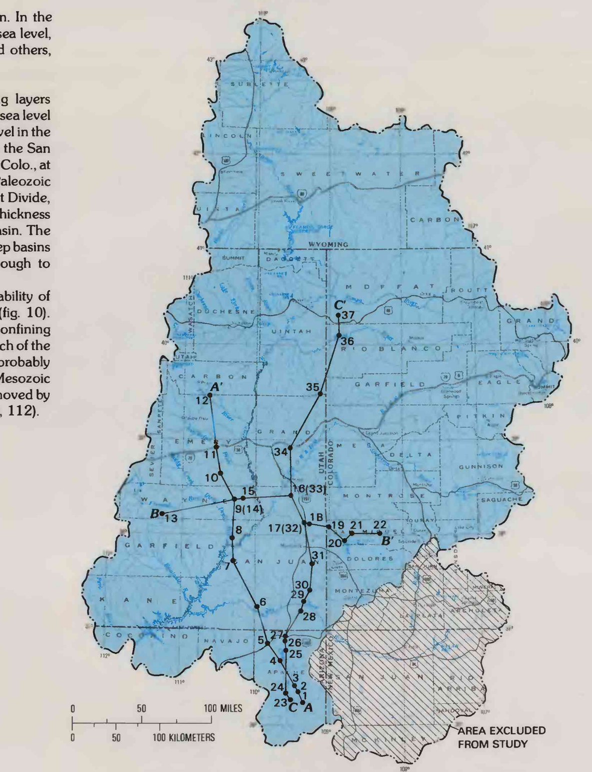


Figure 10.—Representative cross sections showing Paleozoic hydrogeologic units.



MAP SHOWING LINES OF SECTIONS A–A′, B–B′, AND C–C′

HYDROGEOLOGY OF AQUIFERS OF PALEOZOIC AGE, UPPER COLORADO RIVER BASIN—EXCLUDING THE SAN JUAN BASIN—IN COLORADO, UTAH, WYOMING, AND ARIZONA

By
Juli B. Lindner-Lunsford, Briant A. Kimball, D. T. Chafin,
and Christie G. Bryant

1989