Department of the Interior
United States Geological Survey

Open-File Map 80-730
(Water-Resources Investigations)

EXPLANATION

This map is one of a series of preliminary hydrogeologic maps of selected Paleozoic rock units in the Northern Great Plains of Montana, North and South Dakota, and Wyoming. The maps were prepared as part of a study to determine the water-resources potential of the Mississippian Madison Limestone and associated rocks. These maps help describe the basic hydrologic conditions in the rocks, which can be used to develop predictive models of the geohydrologic and geochemical flow systems.

The map shows the altitudes of freshwater heads that were determined from shut-in pressures of drill-stem tests according to the procedure outlined by Miller (1976, p. 17). The following equation was used:

$$h = (FSIP \times C) - PRD + LSD, \qquad (1)$$

where h is the altitude of the water surface, in feet above sea level; $FSIP$ is the final bottom-hole shut-in pressure, in pounds per square inch, measured by the pressure-recording device; C is a factor to convert $FSIP$ to equivalent feet of water; PRD is the depth of the pressure-recording device, in feet below the measuring point; and LSD is the altitude of the measuring point, in feet above sea level. The factor C for this map equals 2.307 feet of water per pressure increment of 1 lb/in^2 (pound per square inch). It assumes pure water at a temperature of 39.2°F (4°C) having a density of 1.00 g/cm^3 (gram per cubic centimeter). The resultant map indicates the altitude at which water levels would stand in tightly cased wells penetrating the Red River Formation, Bighorn Dolomite, or equivalent rocks of Ordovician age if the water in the well had a density of 1.00 g/cm^3. Gradients of freshwater head in a variable-density ground-water system are not always proportional to the magnitude of flow nor do they always indicate the actual direction of flow.

To show the altitude to which water would actually rise in a tightly cased well, the heads would have to be corrected for density variations due to increases in temperature and dissolved-solids concentration. Equation 1 can be modified to reflect density corrections as:

$$h = (2.307 + C_T - C_S)FSIP - PRD + LSD, \qquad (2)$$

where C_T is the temperature correction, C_S is the dissolved-solids correction, and the other symbols are as given in equation 1. The temperature correction, C_T, is positive and in the inch-pound system ranges from 0.0001 foot/(lb/in^2) for each 1°F change at 50°F to 0.0011 foot/(lb/in^2) for each 1°F change at 250°F.

The dissolved-solids correction, C_S, is negative and is 0.007 foot/(lb/in^2) for each 5,000 mg/L (milligrams per liter) change in dissolved solids, assuming sodium and chloride are the major constituents.

The net result of correcting the data for density would be a map similar to the one shown, but the surface on the west side of the area would be elevated because temperature in the aquifer increases faster than the dissolved-solids concentration, and the surface to the northeast would be depressed because the dissolved-solids concentration increases more rapidly than the temperature. The resultant map could be used to indicate actual water-level altitudes or depths to water in wells but would not show the true hydraulic gradient.

Most of the data are from drill-stem tests of exploration and development wells drilled by the petroleum industry from 1946 to 1978. Some data are from bottom-hole pressure measurements in cased oil wells. The locations of all known drill-stem tests have been plotted on the map to show the relative control in the area. The numerical data have not been plotted.

The drill-stem-test data can be divided into seven categories of reliability, based on the probability that the shut-in pressures are close to the original formation pressure. They are, from most to least reliable:

1. Tests with charts that can be extrapolated to an apparent original formation pressure or tests that flowed at land surface with charts indicating that the shut-in pressures had stabilized.

2. Tests that flowed at land surface or had large fluid recovery from the drill pipe and that had reported initial and final shut-in pressures that were nearly equal.

3. Tests that flowed at land surface but had only one flow and one shut-in period.

4. Tests that flowed at land surface or that had relatively large fluid recovery from the drill pipe and that had a reported initial shut-in pressure greater than or equal to the reported final shut-in pressure.

5. Tests with relatively large fluid recovery from the drill pipe but had only one flow and one shut-in period.

6. Tests with poor to moderate fluid recovery from the drill pipe and with the reported initial shut-in pressure greater than or equal to the reported final shut-in pressure.

7. Tests that do not fit the above categories. These tests are probably unreliable, but factors such as length of flow and shut-in periods and the type and amount of fluid recovery from the drill pipe can be used to evaluate the utility of the data as a guide to contouring.

This preliminary map was contoured using all data except those from categories 6 and 7 and those obviously in error due to packer failure. The map was contoured using present-day geologic-structure maps (D. L. Brown, USGS, written commun., 1979; Carlson, 1969; Darton, 1951; Love and others, 1955; Ross and others, 1955; Stone, 1969, 1974; Thomas, 1974; and U.S. Geological Survey and American Association of Petroleum Geologists, 1962) and porosity-distribution maps (Quentin Query, American Stratigraphic Company, written commun., 1979; J. A. Peterson, USGS, written commun., 1979) as guides but independent of paleostructure and lithofacies maps. Data points that create apparently anomalous highs and lows without an obvious relation to known recharge and discharge areas were assumed to be valid and were used in contouring. The resulting freshwater-head map shows a series of linear highs and lows that are similar to linear trends evident on paleostructure and lithofacies maps.

The number of anomalies and the tortuosity and complexity of the contours are obviously related to the amount of control. Other factors that can affect the anomalies and the contour complexity and tortuosity are:

1. The occurrence of producing oil fields and subsequent depletion or repressurization.

2. The magnitude of the possible error due to both instrumentation and shut-in pressure extrapolation approaching or exceeding that of the contour interval.

3. The effect of density differentials between fluids within the system, such as brines, fresher water, and hydrocarbons.

4. The effect of temperature and depth of burial on the compaction of argillaceous material and the subsequent expulsion of fluids (water and hydrocarbons). The mechanism is probably a combination of abnormal geothermal gradients, geochemical reactions, reduction in porosity, and expulsion of water by compaction or conversion of montmorillonite to illite, differential osmotic pressure across semipermeable membranes, and the generation of hydrocarbons.

5. The effect of areally extensive evaporites and low-permeability shales which impede the movement of fluids and, in essence, act as seals in a dynamic system.

6. The effect of facies changes and the related changes in porosity and the effect of heterogeneous and anisotropic permeability distribution.

7. The effect of paleostructure and present-day structure and whether fracturing has enhanced the permeability or has created barriers to fluid movement.

Most of these factors have been described in the literature by American Association of Petroleum Geologists (1974), Bradley (1975), Houston Geological Society (1971), and Meissner (1978).

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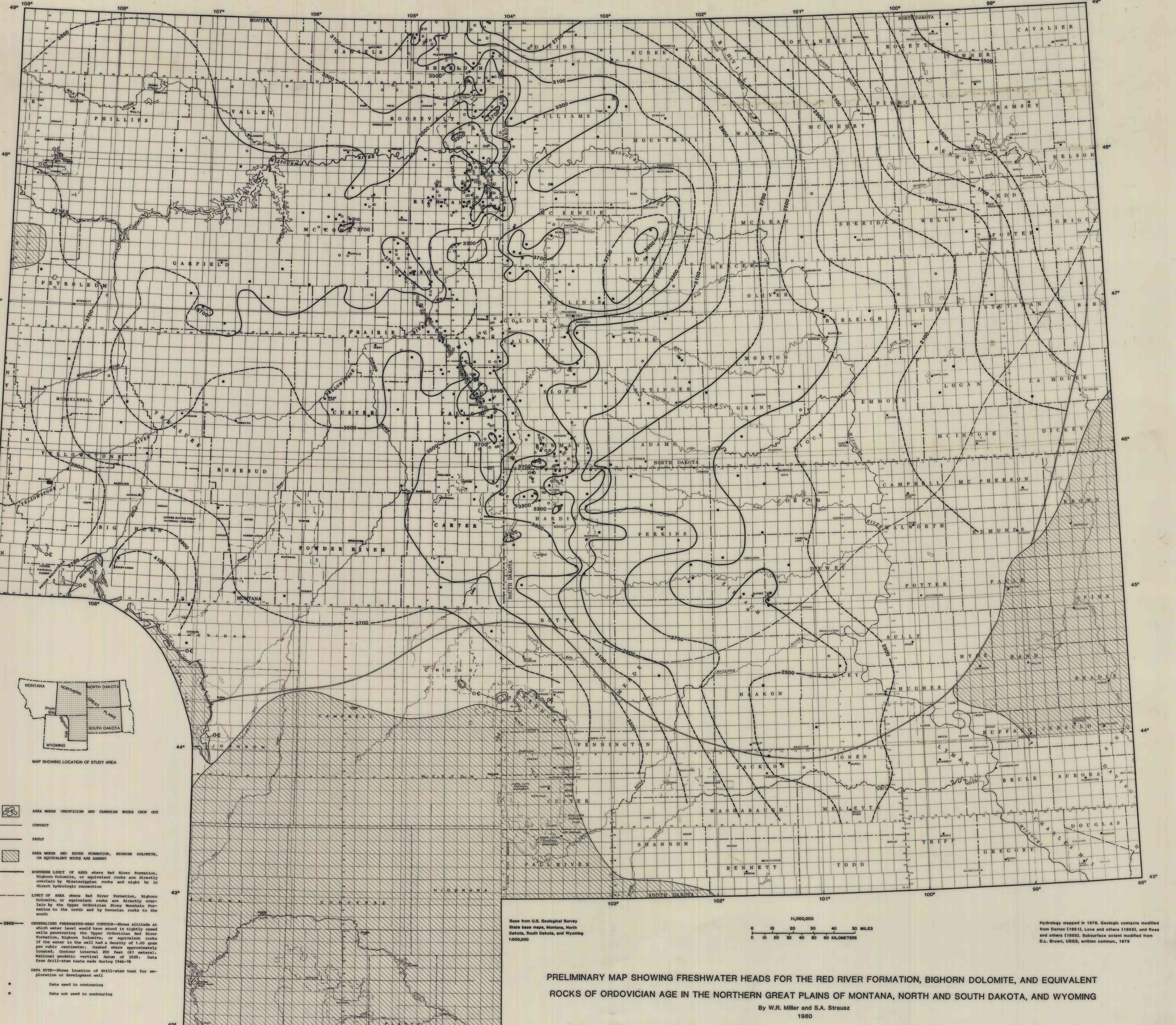

PRELIMINARY MAP SHOWING FRESHWATER HEADS FOR THE RED RIVER FORMATION, BIGHORN DOLOMITE, AND EQUIVALENT ROCKS OF ORDOVICIAN AGE IN THE NORTHERN GREAT PLAINS OF MONTANA, NORTH AND SOUTH DAKOTA, AND WYOMING

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