Ground water in the Navajo sandstone in the Black Mesa area, Arizona

E. H. McGavock and Gary W. Levings

1973, pp. 150-155. https://doi.org/10.56577/FFC-24.150

in:

Monument Valley (Arizona, Utah and New Mexico), James, H. L.; [ed.], New Mexico Geological Society 24 th Annual Fall Field Conference Guidebook, 232 p. https://doi.org/10.56577/FFC-24

This page is intentionally left blank to maintain order of facing pages.

GROUND WATER IN THE NAVAJO SANDSTONE IN THE BLACK MESA AREA, ARIZONA*

by

E. H. McGAVOCK and GARY W. LEVINGS
U.S. Geological Survey
Flagstaff, Arizona

INTRODUCTION

Black Mesa is in northeastern Arizona near the center of the Navajo Indian Reservation (fig. 1). The Navajo Sandstone, of Triassic(?) and Jurassic age, is the main aquifer in the area and supplies water to domestic, stock and community wells along the periphery of Black Mesa. Industrial wells that have been drilled on the mesa completely penetrate the aquifer at depths of about 3,200 feet. The Navajo Sandstone contains water of good chemical quality and is the only aquifer in the area that is capable of yielding more than 100 gpm (gallons per minute) of water to wells.

GEOHYDROLOGIC SETTING

Black Mesa is a prominent topographic high that stands from 500 to 1,000 feet above the surrounding area; the mesa occupies the structural center of Black Mesa basin (fig. 1). Triassic and Jurassic rocks dip gently toward the mesa except along the west side, where several monoclines plunge 5° to 30° beneath the mesa. The Navajo Sandstone crops out along the periphery of the mesa and is buried as much as 3,000 feet below Upper Cretaceous rocks that crop out on the mesa. (Cooley and others, 1969)

In the Black Mesa area the Navajo Sandstone has a remarkably uniform lithology. The formation is composed of very fine to medium subrounded quartz grains bonded with a weak calcareous cement. Large-scale, high-angle eolian cross-beds are the most conspicuous feature of the formation. The Navajo Sandstone thins progressively from the northwest to the southeast. The sandstone is about 950 feet thick near Tonalea and pinches out along a line that extends from near Keams Canyon to about 10 miles southeast of Rough Rock. The area of pinchout probably represents the original limit of deposition of the Navajo (Harshbarger and others, 1957, p. 21).

In the northern part of the area the Navajo Sandstone combines hydraulically with the underlying Triassic(?) Kayenta Formation and Triassic Wingate Sandstone to form a continuous aquifer system. In the southern part of the area the Kayenta is primarily a siltstone, which separates the water in the Navajo from that in the Wingate Sandstone. The Navajo Sandstone is unconformably overlain by the Jurassic Carmel Formation, which is predominantly a siltstone near Black Mesa. The Carmel acts as a confining bed and creates artesian conditions in the Navajo Sandstone beneath Black Mesa.

GROUND WATER IN THE NAVAJO SANDSTONE

Ground water in the Navajo Sandstone is under confined or artesian conditions in most of the Black Mesa area (fig. 2). The amount of artesian head ranges from zero in the areas of outcrop to about 2,000 feet near the Peabody well field. The area where unconfined or water-table conditions prevail coincides approximately with the area of outcrop of the aquifer.

Recharge to the artesian part of the aquifer takes place only in the area between Black Mesa and Shonto (fig. 3), where the aquifer crops out at altitudes of between 6,000 and 7,000 feet above mean sea level. The outcrop area comprises about 100 square miles and provides the only direct recharge to the Navajo Sandstone in the approximately 3,000 square miles underlying Black Mesa.

Ground water moves southeastward from the recharge area toward the center of the mesa; there, the flow path diverges toward both the southwest and northeast, where the Navajo Sandstone crops out at an altitude of less than 5,500 feet. Ground-water movement toward the southeast is retarded by the pinchout of the aquifer. Although some water may move downward through the sandy facies of the Kayenta Formation into the Wingate Sandstone along the line of pinchout, the contours of the potentiometric surface indicate that the pinchout acts as a ground-water dam and retards ground-water movement toward the southeast (fig. 3).

Near Black Mesa, natural discharge from the Navajo Sandstone is primarily in the form of seeps and small springs along the contact of the Navajo Sandstone with the Kayenta Formation or as evapotranspiration in the area of outcrop. Near Kayenta, discharge from the Navajo Sandstone may maintain the flow in several short perennial reaches of Laguna Creek.

The amount of water recharged to the Navajo Sandstone is unknown, but the rate of ground-water movement is too slow for recharge to balance the withdrawal in the artesian part of the aquifer. The rate of ground-water movement in the recharge area is calculated to be from 2 to 4 feet per year; these rates are supported by an age of about 15,500 years for water withdrawn from the aquifer about 40,000 feet down-gradient from the recharge area (William Back, U.S. Geological Survey, written commun., 1972).

The feasible rates and amounts of ground-water withdrawal from an aquifer are dependent on the aquifer characteristics, such as transm issivity, saturated thickness, haydrau l ic conductivity and storage coefficient. Transmissivity is the rate at which water is transmitted through a unit width of the aquifer under a unit hydraulic gradient and is the product of the saturated thickness and the hydraulic conductivity. Hydraulic conductivity is the volume of water that will move in unit time under a unit hydraulic gradient through a unit area of the aquifer at right angles to the direction of flow. The storage coefficient is dimensionless and is defined as the

*Publication authorized by the Director, U.S. Geological Survey.

volume of water an aquifer releases from or takes into storage per unit surface area of the aquifer per unit change in head.

The transmissivity of the Navajo Sandstone was calculated using aquifer-test data from 12 wells around Black Mesa, and the values range from 75 to 350 feet squared per day (fig. 4). The transmissivity is governed primarily by the saturated thickness of the aquifer; in the Black Mesa area the maximum saturated thickness and transmissivity of the Navajo Sandstone are near Tonalea. The hydraulic conductivity was calculated for the same wells by dividing the transmissivity by the saturated thickness of the aquifer. The hydraulic conductivity ranges from about 0.40 foot per day on the northeast side of Black Mesa to about 0.70 foot per day in the southwestern part of the area near the Hopi villages. Although there is considerable variation in the computed hydraulic conductivity values, the values tend to increase from northeast to southwest.

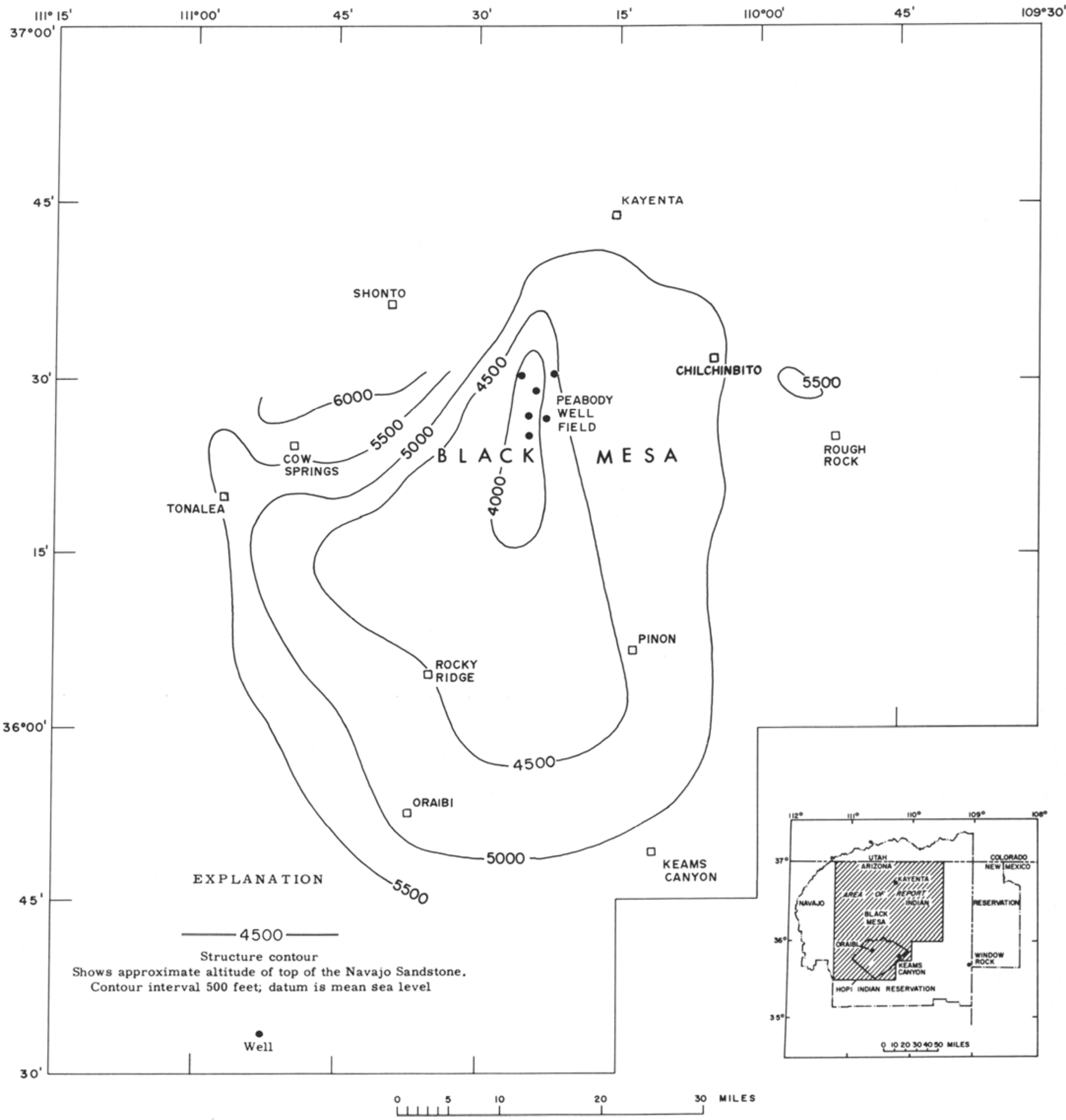

Figure 1.

Approximate altitude of the top of the Navajo Sandstone, Black Mesa area, Arizona.

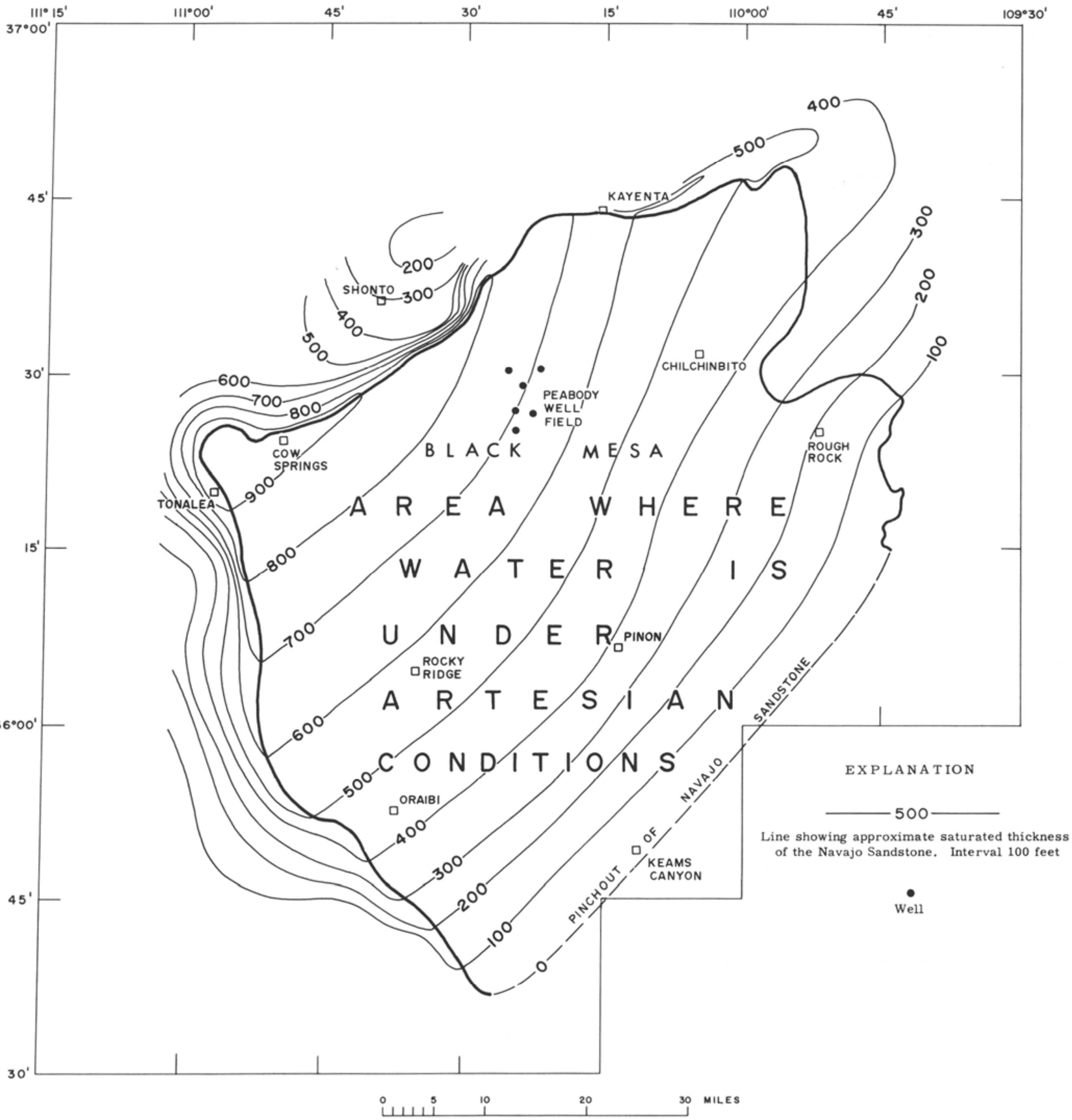

Figure 2.

Approximated saturated thickness of the Navajo Sandstone, Black Mesa area, Arizona.

The storage coefficient for the Navajo Sandstone has not been determined, but data from aquifer tests near Rough Rock and the performance of the Peabody well field on Black Mesa indicate that the storage coefficient for the artesian part of the aquifer probably ranges from about 10^{-3} to 10^{-4}. The storage coefficient in the unconfined part of the aquifer is virtually equal to the specific yield and is estimated to be between 0.10 and 0.15.

GROUND WATER DEVELOPMENT

The feasibility of developing ground water in the Navajo Sandstone is affected by several economic and physical factors, such as well depth, depth to water, well yield and the amount of available drawdown from the static water level to the base of the aquifer. Along the periphery of Black Mesa, the well depth required to penetrate the entire thickness of the Navajo Sandstone ranges from about 500 to 1,000 feet below the land surface; on the mesa, the required depth ranges from about 2,500 to 4,000 feet below the land surface. The estimated required well depth at a site may be calculated using the data shown in Figures 1 and 2.

Along the periphery of Black Mesa, the static water levels in most wells that penetrate the Navajo Sandstone range from 250 to 750 feet below the land surface; on the mesa, static

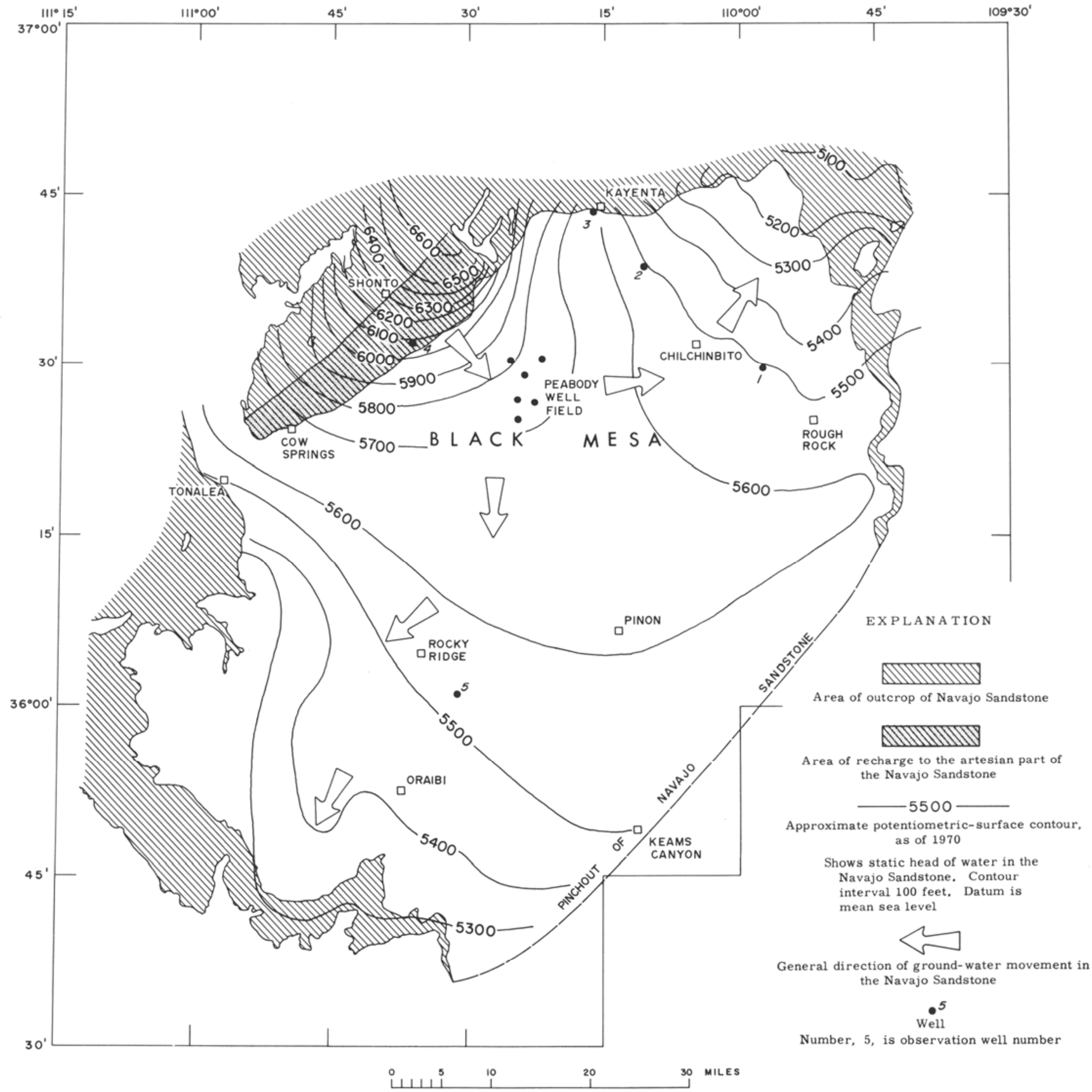

Figure 3.

Approximate altitude of the potentiometric surface of the water contained in the Navajo Sandstone, Black Mesa area, Arizona.

water levels generally range from 500 to 1,500 feet below the land surface. The depth to the static water level can be estimated by subtracting the altitude of the potentiometric surface (fig. 3) from the altitude of the land surface. The amount of artesian head can be estimated by subtracting the altitude of the top of the Navajo Sandstone (fig. 1) from the altitude of the potentiometric surface (fig. 3).

Yields from community and industrial wells that penetrate the Navajo Sandstone range from about 30 gpm at Rough Rock to about 500 gpm in the Peabody well field on Black Mesa. Although potential well yields may be larger, most community wells are pumped at less than 100 gpm because this amount is sufficient to meet the present demand.

At the present time (1973), the Navajo Sandstone is a relatively undeveloped aquifer. In 1972 about 4,700 acre-feet of water was pumped from the formation—about 3,700 acre-feet of which was withdrawn from the Peabody well field; the largest withdrawal for public supply was about 200 acre-feet at Kayenta. Although present withdrawals seem small compared to the extent of the aquifer, an artesian aquifer is a

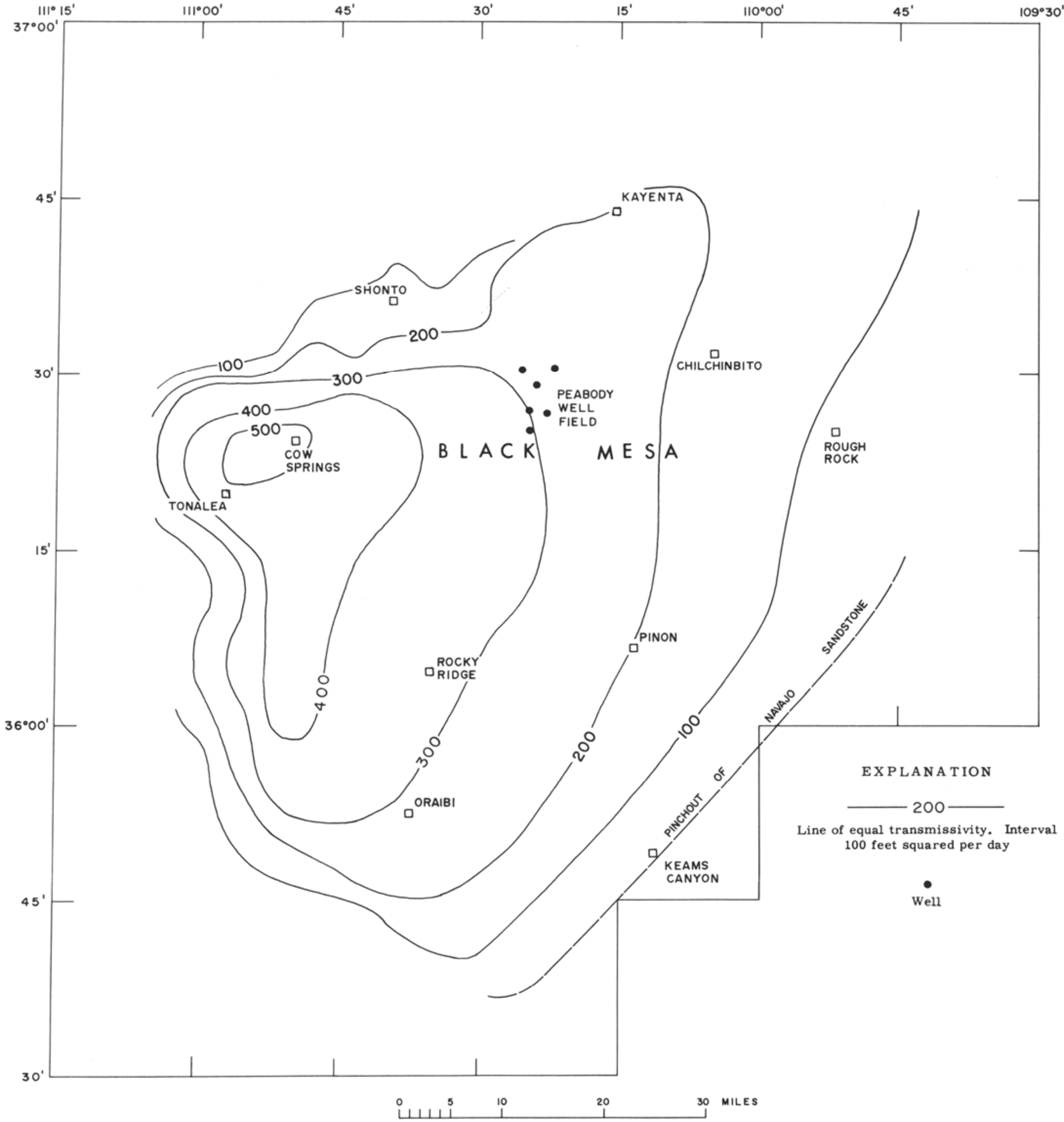

Figure 4.
Generalized transmissivity of the Navajo Sandstone, Black Mesa area, Arizona.

pressure system and any significant withdrawal will reduce the artesian pressure over a wide area.

In April, 1972, five wells (fig. 3) along the periphery of the mesa were equipped with continuous water-level recorders in order to monitor any effects of the industrial pumpage on the water levels in the community wells. The water levels have not declined in any of the observation wells during the year of monitoring; however, at Kayenta the water level in well 3 (fig. 3) fluctuates as much as 5 feet in response to local pumping. During the last 20 years, periodic water-level measurements have been made in several windmill wells, and no permanent water-level declines have been detected.

In a large part of the Black Mesa area the potential well yields from the Navajo Sandstone are more than 500 gpm (fig. 5). The area of greatest potential well yield appears to be northeast of Tonalea, where the transmissivity is estimated to

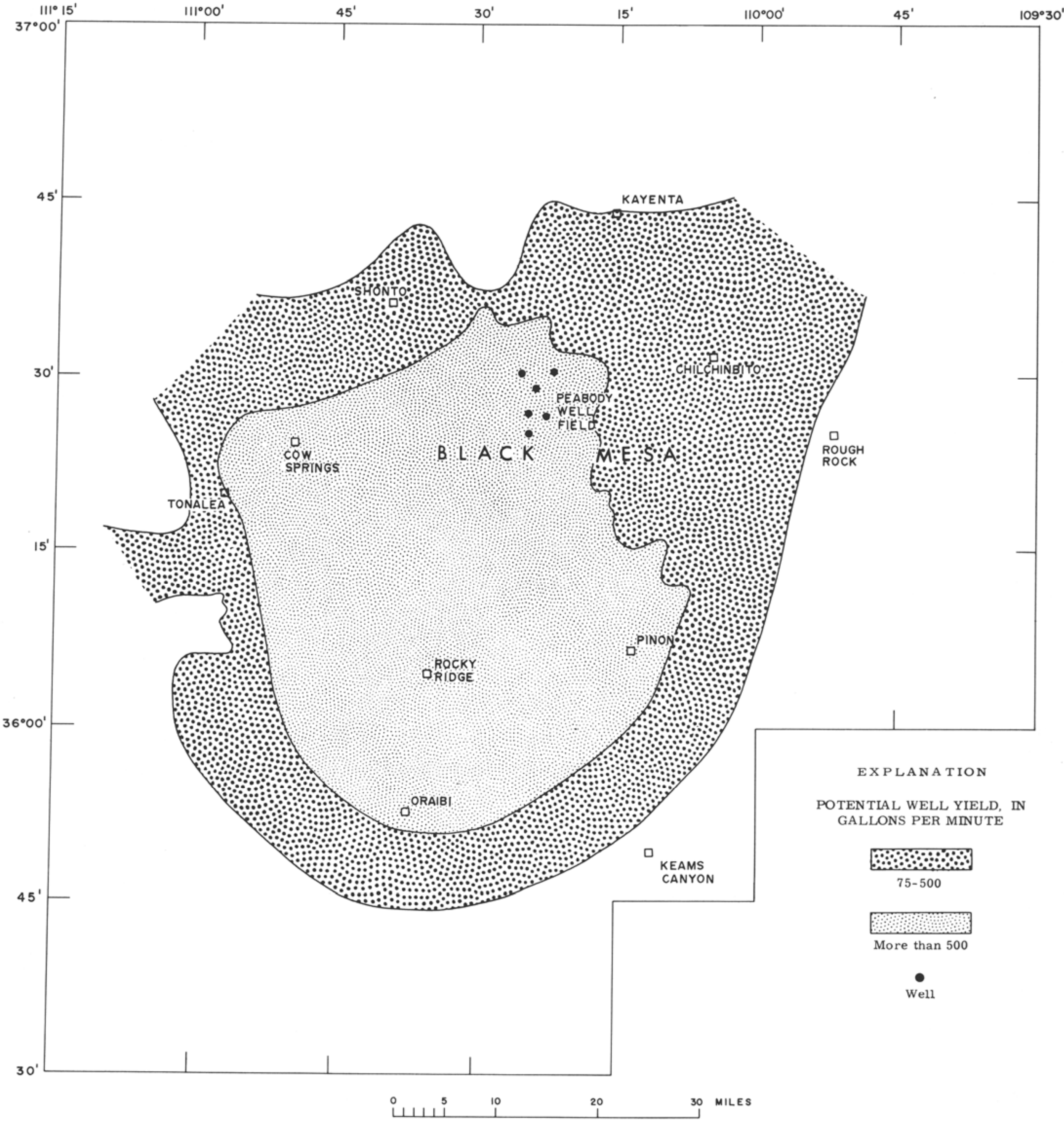

Figure 5.
Potential well yields from the Navajo Sandstone, Black Mesa area, Arizona.

be more than 500 feet squared per day (fig. 4). It should be stressed, however, that development of the water supply will result in interference between wells or well fields, especially in the artesian parts of the aquifer. The Navajo Sandstone is the principal fresh-water aquifer in the Black Mesa area; therefore, future development should be evaluated carefully with respect to the effects on the existing water supplies.

REFERENCES

Cooley, M. E., Harshbarger, J. W., Akers, J. P., and Hardt, W. F., 1969, Regional hydrogeology of the Navajo and Hopi Indian reservations, Arizona, New Mexico, and Utah, with a section on vegetation, by 0. N. Hicks: U.S. Geol. Survey Prof. Paper 521-A, 61 p.

Harshbarger, J. W., Repenning, C. A., and Irwin, J. H., 1957, Stratigraphy of the uppermost Triassic and the Jurassic rocks of the Navajo country: U.S. Geol. Survey Prof. Paper 291,74 p.