

PRELIMINARY INVESTIGATION OF THE HYDROLOGIC
PROPERTIES OF DIATREMES IN THE HOPI BUTTES, ARIZONA

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ABSTRACT

Diatremes of Late Pliocene age in the Hopi Buttes area of Arizona are becoming increasingly important sources of groundwater to the Indian nations. These volcanic vent structures are prime sources of groundwater because sedimentary formations in the Hopi Buttes area yield only limited amounts of water or yield poor quality water. Diatremes act as traps for groundwater and some have yielded moderate amounts of good quality water to wells.

Surface geologic investigations and analysis of drillers' logs indicate that structural relationships and diatreme lithology provide a means to project the hydrologic properties of the vent. Diatremes most suitable for groundwater development should have a diameter greater than one half mile, should contain volcanic tuff and breccia at its center, and should be fractured from collapse. Lava flows covering diatremes reduce recharge from sheet wash or from ephemeral stream flow.

Data from geomagnetic and gravity surveys will be analyzed to determine its suitability for predicting subsurface size, shape, and lithology of the diatreme. The integration of geophysical and surface geologic data will reveal the total geometry of the structure enabling the most accurate appraisal of the hydrologic properties of the diatreme.

INTRODUCTION

The Hopi Buttes are located in northeastern Arizona and occur throughout an area of approximately 800 square miles on the Hopi and Navajo Indian Reservations. The Hopi Buttes area is arid, receiving an average of only ten inches of rainfall per year. The land is used for grazing of livestock and for limited dry farming. Potential for further development of the area is limited because water supplies are

inadequate. Groundwater in the Paleozoic sedimentary rocks is saline; surface water is ephemeral and meager. Groundwater of acceptable quality has been encountered in several explosive volcanic crater structures, which were termed diatremes (Hack, 1942) in the Hopi Buttes area. These diatremes appear to offer the best potential for future short-range sources of groundwater.

GEOLOGIC SETTING

SEDIMENTARY ROCKS

The Paleozoic sedimentary rock sequence in the Hopi Buttes area is correlative to the classical Paleozoic section in the Grand Canyon. Mesozoic sediments dip gently to the north and in the Cedar Springs area consist in ascending order of the Moenkopi Formation, the Chinle Formation, and the Wingate Sandstone. The Moenkopi Formation is about 300 feet thick and comprises gypsiferous siltstone, mudstone, and sandstone. The Chinle is approximately 1400 feet thick and consists of siltstone, mudstone, limestone and conglomerate. The Wingate is 930 feet thick and consists of silty sandstone and fine-grained quartz sandstone. The Mesozoic sediments are unconformably overlain by the Bidahochi Formation of Pliocene age. The Bidahochi is divided into three members. The upper and lower members are sedimentary and comprise mudstone and argillaceous fine-grained sandstone. Volcanic rocks, including diatremes, comprise the middle member.

VOLCANIC ROCKS

Studies of the Hopi Buttes (Williams, 1936; Hack, 1942) indicate a complex volcanic history and a variety of volcanic structures. These structures comprise volcanic necks, flows, dikes, and several hundred diatremes. Volcanic structures trend northwest which parallels a regional joint trend in the Colorado Plateau.

DIATREME FORMATION

The history of individual and groups of diatremes is diverse; few diatremes show the same sequence of volcanic, structural, and sedimentary events. A general cycle of diatreme formation includes the following events:

1. Intrusion of magma along fractures.
2. Explosive crater formation resulting from the contact of magma with near-surface sediments saturated with groundwater. (Shoemaker (1962) suggests an alternate theory for explosive crater formation.)
3. Upwelling of magma, filling the diatreme crater.

4. Collapse of diatreme crater, resulting in a large bowl-shaped depression.
5. Infilling of the collapsed depression with sediments.
6. Further collapse, which fractures lithified sedimentary rocks in the diatreme.

Figure 1 is a schematic diagram of the cross section of a diatreme which has undergone several cycles of formation. The cycle of formation may be reinitiated at any point with a single diatreme undergoing several cycles or subcycles of formation. Lithologies produced in the cycle are as varied as the formational histories. Volcanic rocks associated with diatremes comprise agglomerate; tuff; breccia; and dark, dense lava flows. Sedimentary rocks filling the diatreme depression include fine-grained calcareous sandstone, siltstone, and travertine. Subsidence or collapse occurs throughout the cycle of formation. Subsidence increases the diversity of rock types in the diatreme; slump blocks of country rock are broken and mixed with the volcanics. Fracturing is usually concentrated in the peripheral areas of the diatreme and may produce a high secondary porosity and permeability in the diatreme.

HYDROLOGIC FEATURES

Groundwater occurs in several rock units in the Hopi Buttes-Tees Toh area. (1) The Coconino Sandstone lies at a depth of 2000 feet and is saturated with saline water which requires desalination prior to use for stock or domestic purposes. (2) Small springs issue from interflow zones in volcanic rocks. Several wells have been drilled into these zones and produce small quantities of good quality water. (3) Alluvium in dry washes contains good quality water in small quantities. Water from alluvial aquifers is not dependable because groundwater storage varies with precipitation amounts. (4) Several diatremes in the Hopi Buttes supply large quantities of acceptable quality water.

Diatremes appear to be the best potential source of groundwater in the Hopi Buttes. Diatremes are surrounded by fine-grained sedimentary rocks of low permeability which retards the loss of groundwater stored in the diatreme. Fracturing produced during explosive crater formation and the subsequent collapse produces secondary porosity and permeability of material filling the diatreme. Large portions of most diatremes are filled with porous volcanic tuff.

Groundwater was discovered in diatremes in the early 1950's when these structures were drilled in search of uranium deposits. Subsequently more than 25 diatremes have been drilled in search of groundwater. Results of exploration drilling in diatremes indicates:

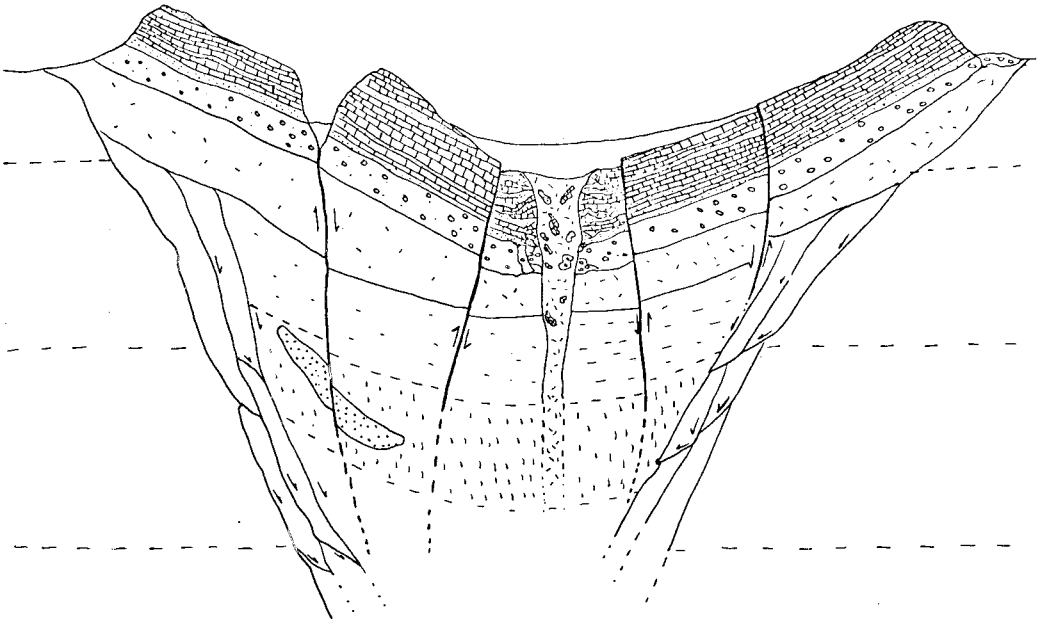


Figure 1. Schematic diagram of a diatreme after the vent has collapsed, been filled with sediments, collapsed again, and undergone erosion. Sediments filling the diatreme consist of fine-grained sandstone and siltstone interbedded with volcanic tuff. Alluvium and soil fill the uppermost portion of the vent. Inner portions of the vent are filled with volcanic tuff, breccias, and agglomerates. A collapse ring, steeply dipping beds, and outwardly dipping faults are produced from collapse of the vent.

1. Most diatremes contain groundwater.
2. Chemical quality of groundwater in diatremes ranges from 262 to 1564 mg/l dissolved solids.
3. Chemical quality of groundwater in diatremes becomes poorer with depth below the water table.

Three wells were drilled into the Dilkon School diatreme. The first and second wells were drilled to a depth of 197 and 202 feet respectively, yielding good quality water with dissolved solids of 462 mg/l. A third well was drilled to a depth of 362 feet to increase production from the diatreme and prolong the life of the structure by pumping from greater depths. The water from the third well contained 1564 mg/l of dissolved solids as compared to 462 mg/l of dissolved solids. These quality of water relations suggest that water in the Dilkon School diatreme is density stratified.

ANALYSIS

Until recently diatremes were drilled on a random basis without first analyzing the geologic and hydrologic relations in the area of the structure. Analysis of a diatreme's size, surface lithology, structure, and location can significantly aid in evaluating the groundwater potential of the diatreme before it is drilled. Diatremes which contain groundwater commonly display the following characteristics:

1. Size. Diatremes with a diameter of one-half mile or larger have a sufficient surface area to obtain significant quantities of recharge from limited precipitation. A diameter of this magnitude usually indicates the presence of a diatreme large enough to contain useful quantities of groundwater.
2. Dip of strata. Outcrops of diatreme strata which dip at 30 degrees or more indicate that substantial collapse or subsidence has occurred in the structure causing fractures and producing secondary porosity and permeability.
3. Surface lithologies. Outcrops of thick beds of volcanic tuff indicate that the subsurface lithologies may comprise large quantities of volcanic tuff. Volcanic tuff units interbedded with sedimentary rocks indicate the diatreme has undergone several sub-cycles during formation, producing large amounts of fracturing within the rock units. Large quantities of dark, dense lavas exposed at the surface of the diatreme indicate subsurface lithologies may consist of non-porous, poorly permeable volcanic rocks.
4. Location. Diatremes traversed by a wash offer the maximum opportunity for recharge in an area where precipitation is minimal.

WATER MINING

Pumping groundwater from a diatreme is a water mining operation--once the water is removed there is little chance for recharge because the quantity of water available for recharge from precipitation and ephemeral streamflow is small. A diatreme is at best a temporary source of water.

NEED FOR FURTHER WORK

Further work is needed to more accurately appraise the hydrologic properties of diatremes. The principal author is engaged in a geophysical study of several diatremes in the Tees Toh-Cedar Springs area. The study includes both gravity and magnetic surveys of diatremes with producing wells together with surveys of diatremes penetrated by non-producing wells. Interpretation of the geophysical data will be used to develop a method which can be used to analyze the water-bearing potential of diatremes. A geophysical method to estimate subsurface size and shape of the structure will also be developed so the total amount of water that might be withdrawn from diatremes can be estimated.

CONCLUSIONS

Initial investigation of the hydrologic properties of diatremes in the Hopi Buttes suggests the following conclusions:

1. Diatremes most likely to contain groundwater have a diameter greater than one-half mile, strata dipping at 30 degrees or greater, surface lithologies composed of volcanic tuff, and are transected by a wash.
2. Diatremes with only hard, dense lavas outcropping at the surface offer the least chance of containing groundwater.
3. The stratification of water may greatly limit the amount of useable water which can be withdrawn from a diatreme.
4. Pumping water from a diatreme is a water mining operation because the quantity of water available for recharge is small.
5. Analysis of a diatreme's size, surface lithology, structure and location can significantly aid in evaluating the groundwater potential of the diatreme before it is drilled.

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