

## HALLOYSITE DEPOSITS IN THE TERRACED HILLS WASHOE COUNTY, NEVADA\*

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**Abstract**—Large hydrothermal deposits of halloysite clay occur in the Terraced Hills, Washoe County, Nevada and similar bodies probably are present elsewhere in the Basin and Range province. The host rock, an andesitic tuff, is underlain and overlain by volcanic flows; all these rocks are late Miocene to Pliocene in age. The clay bodies are composed mostly of halloysite with some iron oxides, variable amounts of feldspar and quartz, and locally some montmorillonite. Commonly all the pyroclastic unit is altered to halloysite material. In one locality, however, the halloysite body is restricted to the upper part and it is in sharp contact with underlying, partly montmorillonitized tuff. The contact of a clay body with the overlying basalt is distinct. Generally some halloysite is present in the lower part of the basalt and montmorillonite occurs in both materials near their contact. The solutions that altered the tuff were generated during volcanism, rose along high-angle faults, and were restricted to the permeable and otherwise favorable vitric tuff by the capping of relatively impermeable basalt.

### INTRODUCTION

ALTHOUGH halloysite formed by hydrothermal processes is rather common, the occurrence of this clay mineral in large relatively pure bodies has seldom been reported. This paper describes large deposits of halloysite, formed by the hydrothermal alteration of volcanic rock, that occur in the Terraced Hills, Washoe County, Nevada (Fig. 1). One of the bodies is being exploited (Fig. 2) by the Nevada Cement Co. as a source of clay for portland cement. Geologic conditions such as those responsible for the Terraced Hills deposits are common in the Basin and Range province, and similar clay bodies probably are present elsewhere in the province.

### GEOLOGIC SETTING

A series of andesitic to basaltic flows separated by a pyroclastic unit are exposed in the mapped area (Fig. 3); all these rocks are late Miocene to Pliocene in age. The host rock of the clay is a pale red to moderate brown devitrified andesitic tuff that commonly contains fragments of pumice and other volcanic rocks. In some places arkose or conglomeratic arkose is present in the upper part of the pyroclastic unit in beds 3–10 ft thick.

The rocks underlying the tuff are gray andesitic to basaltic flows with vesicular or, less commonly, porphyritic textures. The overlying rocks are of

basaltic composition. A dense, often vesicular, dark gray basalt in the lower 30–40 ft of this sequence has been differentiated on the geologic map (Fig. 3) in some areas. This basalt is overlain by a relatively great thickness of flows that are more variable in color and texture. Typically these are grayish red, fine-grained rocks; some have a coarse, vesicular texture.

The extrusive rocks are broken into a number of structural blocks by northwestward- and northeastward-trending high-angle faults. The dip of the rocks ranges from horizontal to 45 degrees.

### HALLOYSITE DEPOSITS

The halloysite bodies were formed by hydrothermal alteration of the tuff. Their present attitudes are due to displacement of the tuff by high-angle faults; probably most of the displacement occurred before the development of the clay. A few similar but more widely separated deposits occur within several miles east and southeast of the mapped area.

Commonly all the pyroclastic rock is altered to clay but in one area complete argillization is restricted to the upper part of the unit. Where arkose or conglomeratic arkose beds are present in the pyroclastic unit, they were partly replaced by halloysite and montmorillonite or by lesser amounts of montmorillonite only.

The most extensive exposure of the tuff-arkose-clay unit is near the north border of Section 13, T. 27 N., R. 19 E., where the unit is nearly continuous for half a mile. Near the west end the rocks dip

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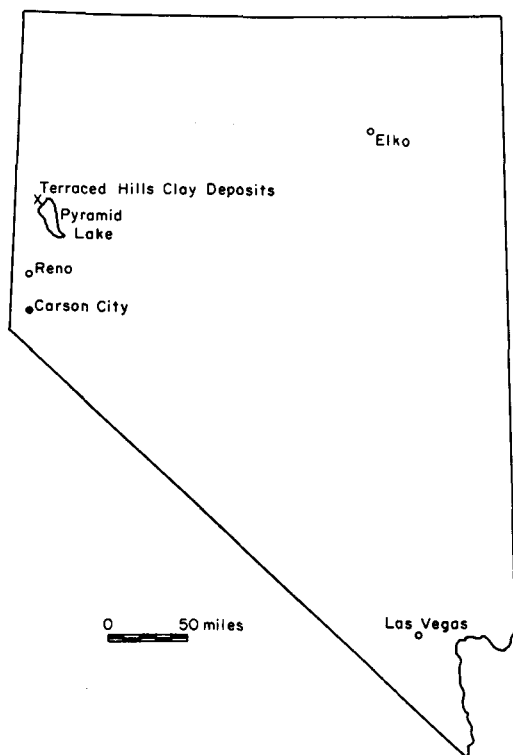


Fig. 1. Index map of Nevada showing location of Terraced Hills halloysite deposits.

northward at low angles and the underlying and overlying volcanic flows are exposed within a few feet of the contacts. The halloysite body has a stratigraphic thickness of about 60 ft and it is overlain by about 10 ft of arkose that contains some thin halloysite beds.

In the eastern part of the nearly continuous exposure, however, the arkosic rocks are absent. Here the halloysite body becomes thinner and is restricted to the upper part of the pyroclastic unit, immediately beneath the dense basalt. At the extreme eastern end, the halloysite has a thickness of about 10 ft. The contact of the halloysite and the underlying andesitic tuff is sharp, and there is a pronounced color change. The tuff is completely devitrified and part of the matrix is altered to montmorillonite.

The contact of the underlying volcanic rocks with the clay or tuff is not exposed in the mapped area but almost fresh volcanic rock is present in several outcrops two or three feet stratigraphically below the clay. The contact between halloysite and the overlying basalt, a disconformity with slight undulations, is well exposed in a few places (Fig. 4).

The upper several feet of the clay is highly colored by iron oxides but the original pyroclastic texture is still evident. The lower two feet of the basalt commonly is altered to a softer material that retains the vesicular texture and, usually, the dark color. Irregular masses and veinlets of clay material are present locally in the basalt near the contact. The alteration products in the basalt are montmorillonite and variable, but lesser, amounts of halloysite.

Most of the halloysite clay is grayish orange to light brown. Much of the remainder is very light gray; this color is more common in the upper half of a clay body. Usually the color variations are approximately parallel to the original crude stratification of the rock. Hydrated iron oxides are the principal coloring material in the clay. Hydrated iron oxides also are present in fractures and veinlets; these are especially abundant in the darker-colored clays.

Coarse pyroclastic fragments were common in the tuff and are still visible in the clay. Most are less than an inch in diameter but the observed maximum is 18 in. Usually the fragments retain their shape, texture, and color, even when they have been almost completely converted to halloysite (Fig. 5). Some of the larger or denser fragments have been only partly replaced.

#### Mineralogy

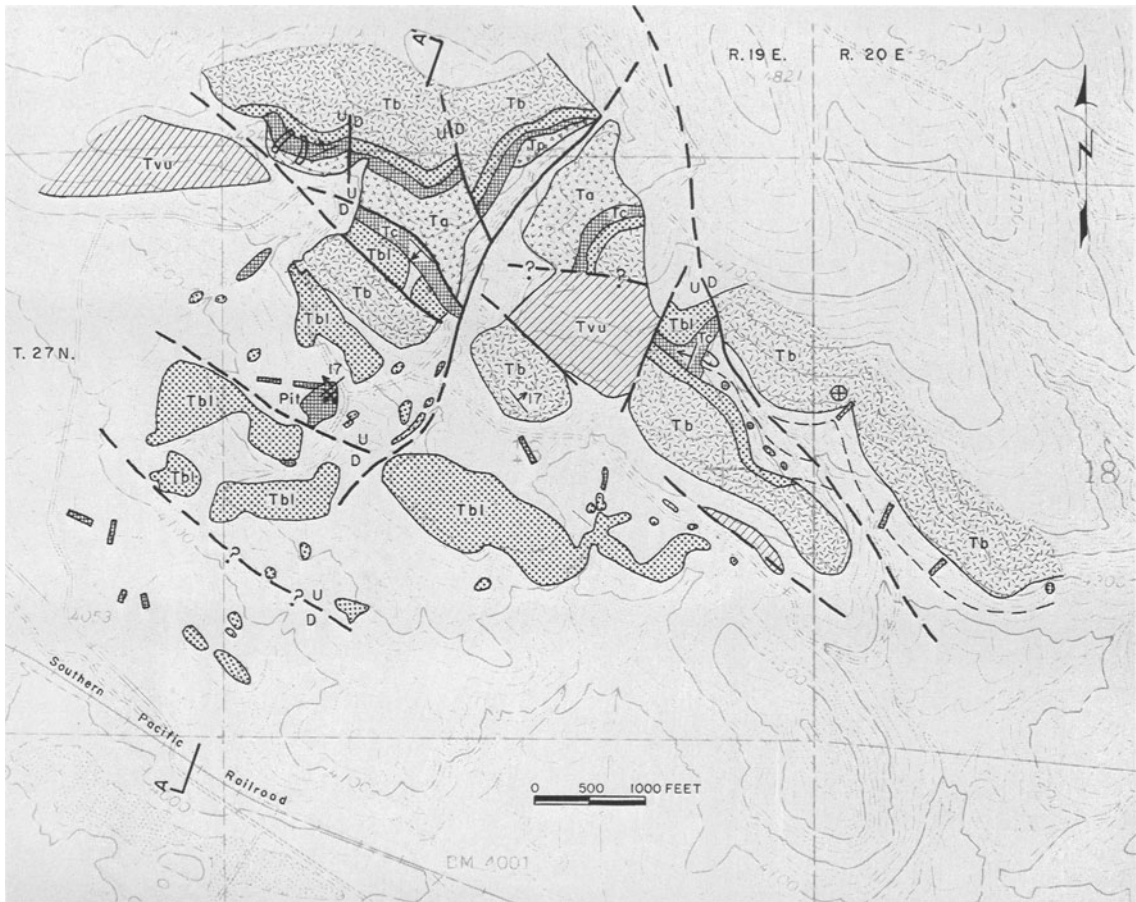
The clay bodies are composed of compact, brittle material with a dull to slightly waxy luster that slakes rapidly in water to form granules or small curved chips. Study of numerous samples by X-ray diffraction, differential thermal analysis and the optical microscope showed that the clay is composed principally of halloysite, hydrated iron oxides, and variable amounts of residual feldspar and residual or introduced quartz. About 1 per cent magnetite is present in small disseminated grains. Montmorillonite was detected in a few samples.

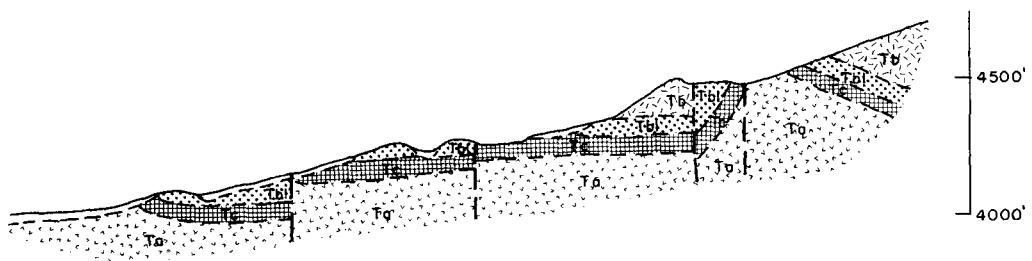
Most of the samples were cut from within 1 ft of an exposed face. The samples were stored in airtight containers, except while being pulverized in a mortar and pestle, to prevent any change of hydration state. X-ray diffraction studies showed that all samples were mixtures of the fully-hydrated and dehydrated forms of halloysite. Portions of some samples were dried in air for 48 hr and examined again by X-ray. These contained a much higher percentage of the dehydrated form than did the original material. It is probable that the fully-hydrated form is the only type present in deeper, unexposed portions of the deposits. Figure 6 shows typical X-ray diffraction and differential thermal patterns of the halloysite.

In the area where the halloysite body is underlain



Fig. 2. View, looking north, of a clay pit in the Terraced Hills.





CROSS SECTION A-A'  
 VIEW LOOKING NORTHWEST  
 VERTICAL EXAGGERATION 2X

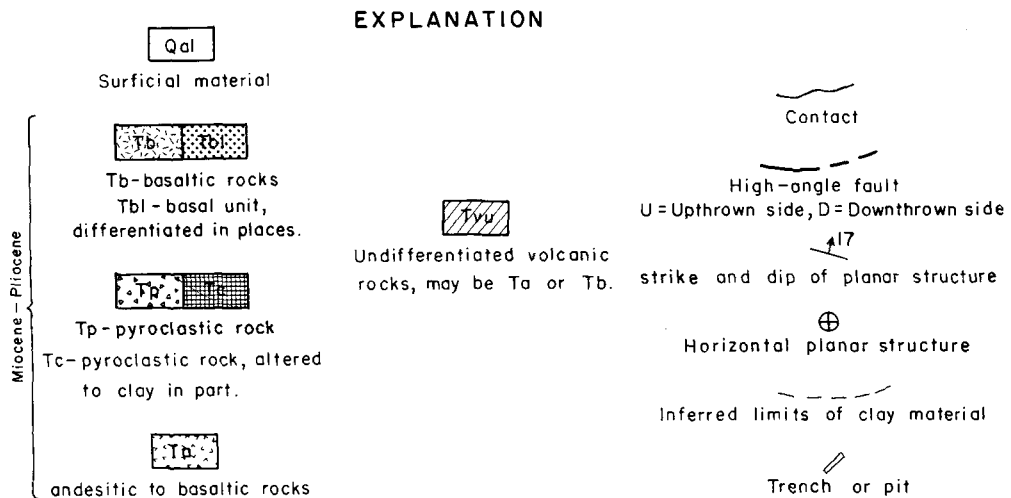


Fig. 3. Geologic map and cross section of the western part of the Terraced Hills.





Fig. 4. Contact between halloysite body and overlying basalt.



Fig. 5. Halloysite clay, showing pyroclastic fragments that have been almost completely converted to halloysite.

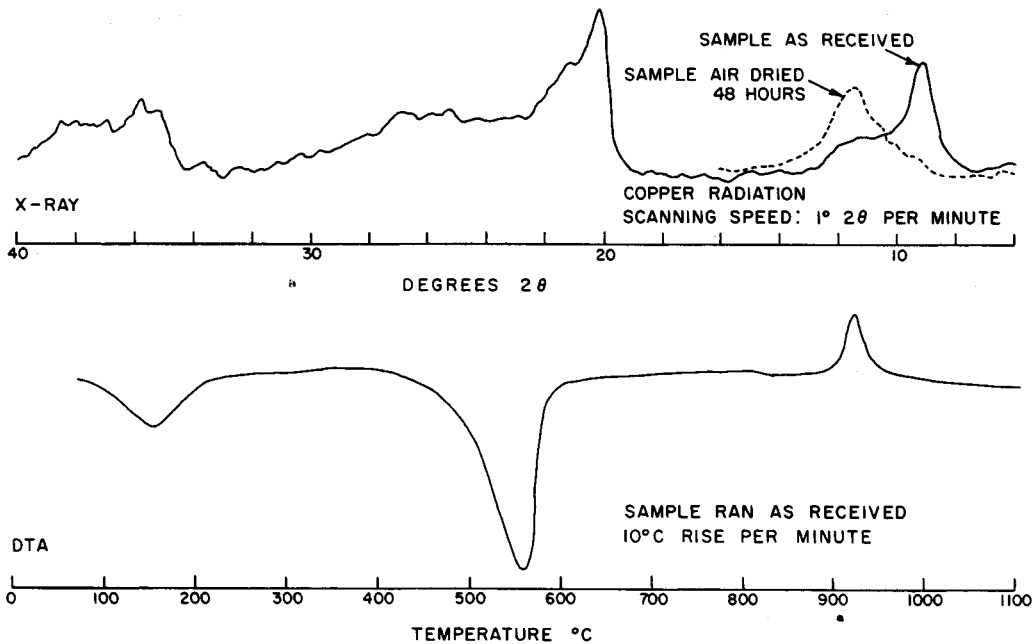


Fig. 6. Typical X-ray diffraction and differential thermal patterns of the halloysite.

by tuff, halloysite was not detected in the six samples of tuff examined. The mineral montmorillonite is abundant in the tuff and in the lower several feet of the clay body. The presence of montmorillonite was confirmed by X-ray examination of powder packs and oriented slides made from the  $-2\mu$  fraction; these were tested in air-dried state, after solvation with ethylene glycol, and by the  $\text{Li}^+$  method of Greene-Kelly (1953). Gypsum occurs in both the tuff and clay near the contact.

At one place samples were taken at 6 in. intervals on both sides of the halloysite-basalt contact and examined by X-ray diffraction methods. Montmorillonite was first detected in the basalt 2 ft above the contact. The amount of montmorillonite increased steadily from that point to a maximum in the halloysite body one foot below the contact, and then decreased to the limit of detection about 5 ft below the contact. In the samples of basalt, halloysite was either present in minor amounts or was not detected.

#### Genesis

Geologic mapping and laboratory studies furnished convincing evidence that the halloysite deposits were formed by hydrothermal alteration of the pyroclastic rock beneath a relatively impermeable basalt flow. The most definitive points of evidence are; (1) the lack of gradational contact between the clay and underlying rock such as

might be expected in a residual deposit, (2) the presence of some halloysite in the lower part of the overlying basalt, and (3) the crosscutting relationship of the clay body with its restriction locally to the upper part of the pyroclastic unit.

The solutions that formed the halloysite are believed to have risen along high-angle faults and spread out into the permeable and chemically favorable horizon. The tuffaceous rocks sandwiched between volcanic flows formed a natural channelway for solutions fed into the area by crosscutting faults, and the solutions tended to be channeled into the upper part of this permeable rock. Adjacent to major fault channelways, all of the pyroclastic beds were replaced but farther away only the upper beds were replaced. The alteration probably was accomplished by moderately acid solutions generated during volcanism. The north-westward-trending faults in the Terraced Hills can be projected southeastward to an active thermal area on the north shore of Pyramid Lake 8 miles away.

The hydrothermal alteration was selective and the fine-grained, glassy material was more completely argillized than the fragments of crystalline rock. During the hydrolytic process that converted the andesitic rock to clays, silicon, calcium, magnesium, sodium, potassium, and possibly some iron were removed and water was added. The overlying rocks are not silicified such as they are in some of

the Mexican hydrothermal clay deposits (Keller and Hanson, 1969). The mineralogical zoning, with halloysite predominant in the clay bodies and montmorillonite present near the edges and in the adjacent rocks, probably was completed during a single period of hydrothermal activity.

Glassy igneous rocks are especially susceptible to alteration, but in only a few cases has hydrothermal alteration to halloysite been reported. Deposits formed by hydrothermal alteration of glassy rocks have been described in the state of Jalisco, Mexico (Keller, 1963) and Iki Island, Japan (Minato and Utada, 1969).

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**Résumé**—De grands dépôts hydrothermaux d'halloysite se rencontrent dans les Terraced Hills, Washoe County, Nevada, et il est probable qu'il en existe d'autres, ailleurs, dans la province de Basin and Range. La roche mère, un tuf andésitique repose sur des coulées volcaniques, et en est aussi recouverte; toutes ces roches datent de l'époque miocène supérieur à pliocène. Les masses argileuses contiennent essentiellement de l'halloysite, avec en plus des oxydes de fer, des quantités variables de feldspath et de quartz, et localement de la montmorillonite. D'une façon générale toute l'unité pyroclastique est altérée en matériel halloysitique. Dans une localité cependant, la masse d'halloysite est limitée à la partie supérieure et se trouve, d'une façon nettement tranchée, au contact du tuf sous jacent, partiellement montmorillonitisé. La limite entre la masse argileuse et le basalte qui la recouvre est nette. En général, on trouve de l'halloysite dans la partie inférieure du basalte, et de la montmorillonite dans les deux matériaux, au voisinage de leur zone de contact. Les solutions qui ont altéré le tuf ont pris naissance pendant la période de volcanisme et sont montées le long de failles à pente élevée; leur action a été limitée au tuf vitreux parce qu'il était perméable, et que de toute manière, il était disposé favorablement à cause de son revêtement par du basalte relativement imperméable.

**Kurzreferat**—Grosse hydrothermische Ablagerungen von Halloysit Ton kommen in den Terraced Hills, Washoe County, Nevada vor und ähnliche Vorkommnisse existieren vermutlich in der Basin und Range Provinz. Das Wirtsgestein, ein andesitischer Tuff, ist mit vulkanischen Fließgesteinen unterlegt und überdeckt, wobei all diese Gesteine von spät-miozänischem bis pliozänischem Alter sind. Die Tongesteine bestehen hauptsächlich aus Halloysit mit etwas Eisenoxiden, veränderlichen Mengen von Feldspat und Quarz, sowie örtlich etwas Montmorillonit. Im allgemeinen wird der gesamte pyroklastische Stein in Halloysitmaterial verändert. An einer Stelle bleibt jedoch das Halloysitgestein auf den Oberteil beschränkt und steht in scharfem Gegensatz zu dem darunter befindlichen montmorillonisierten Tuff. Die Berührungstelle eines Tongesteins mit dem darüberliegenden Basalt ist deutlich. Im allgemeinen ist etwas Halloysit im unteren Teil des Basalts gegenwärtig und Montmorillonit kommt in beiden Materialien in der Nähe der Berührungstelle vor. Die den Tuff verändernden Lösungen sind im Vulkanismus entstanden, stiegen an steilen Verwerfungen empor, und blieben zufolge der Bedeckung durch verhältnismässig impermeablen Basalt auf den permeablen und auch sonst günstigen glasartigen Tuff beschränkt.

**Резюме**— На Террасовых холмах (Вэшоу Каунти, Невада) имеются большие гидротермальные месторождения галлуазитовой глины; вероятно, аналогичные скопления галлуазита имеются в некоторых районах провинций Бэйсин и Рэйндж. Вмещающая порода (андезитовый тuff) подстилается и покрывается лавовыми потоками; возраст всех этих пород от позднего миоцена до плиоцена. Залежь глины состоит, главным образом, из галлуазита с небольшим количеством окислов железа; в различных количествах наблюдается полевой шпат и кварц, местами в глине отмечается немного монтмориллонита. Обычно весь пирокластический материал превращен в галлуазитоподобное вещество. На одном участке, однако, галлуазитовое тело приурочено к верхней части месторождения; оно имеет четкий контакт с нижележащим, частично монтмориллонитизированным туфом. Контакт глинистого тела с лежащим сверху базальтом также является четким. Обычно некоторое количество галлуазита обнаруживается в нижней части базальтового тела; у контакта в базальте и галлуазитовой глине наблюдается монтмориллонит. Растворы, изменившие тuff, генерировались при процессах вулканизма, поднимались вдоль крутопадающих складок и циркулировали только в проницаемом стекловидном туфе под покровом относительно непроницаемого базальта.