

HYDROTHERMAL REGULARLY INTERSTRATIFIED CHLORITE-VERMICULITE AND TOBERMORITE IN ALTERATION ZONES AT GOLDFIELD, NEVADA

by

RICHARD D. HARVEY¹ AND CARL W. BECK

Department of Geology, Indiana University, Bloomington, Indiana

ABSTRACT

Hydrothermal alteration of andesitic and dacitic rocks in the Goldfield District, Nevada, has produced regularly interstratified chlorite-vermiculite and tobermorite. X-ray diffraction and oscillating-heating data indicate the regular interstratification of the chlorite-vermiculite. This mineral is found in the zone of least alteration and was formed by the alteration of hornblende phenocrysts. Penninite is an intermediate stage in this reaction. Increased intensity of alteration resulted in the disappearance of chlorite-vermiculite and the development of montmorillonite. Tobermorite, found only in the dacite, is associated with alunite as pseudomorphs after plagioclase phenocrysts in the most intense zone of alteration. The intermediate stage of hydration for tobermorite is indicated by the 11 Å spacing of the 002 diffraction peak. Oscillating-heating X-ray data at atmospheric pressure show that tobermorite decomposes thermally in two stages. The (00 l) planes collapse at approximately 520 °C and crystal planes having an 8 Å periodicity collapse at about 760 °C. Wollastonite develops from tobermorite above 700 °C under static heating conditions.

INTRODUCTION

During an intensive study of the hydrothermal alteration of the wall rocks adjacent to gold-bearing veins at Goldfield, Nevada, two minerals, regularly interstratified chlorite-vermiculite and tobermorite, were recognized that had not been described previously in the geologic literature on Goldfield. It is the purpose of this paper to report on these two minerals. This investigation was completed on unweathered samples collected from the surface of the ground because the mines were generally not safe to enter.

Mixed layer chlorite-vermiculite is found in the least-altered rocks and is therefore widespread in the district. Regular interstratified chlorite-vermiculite was found most abundantly in rocks about eight-tenths of a mile north of the former village of Diamondfield, in the north-central part of the district.

Tobermorite-bearing samples were collected immediately adjacent to a vein that is about four miles east of Goldfield, between Preble Mountain and Blackcap Mountain, and that strikes N. 45° W. The tobermorite occurs

¹ Present address: Illinois Geological Survey, Urbana, Illinois.

with alunite as a white, fine-grained, earthy material which has replaced the former plagioclase phenocrysts. Similar material was first reported by Heddle (1880) from three Scottish localities where it occurred in amygdules with thomsonite. Subsequently, similar material was reported by Eakle (1917) in the contact metamorphic limestones at Crestmore, California, and various Scottish occurrences are discussed by Claringbull and Hey (1952), McConnell (1954), and Gard and Taylor (1957). In each case tobermorite was of secondary origin and formed by hydration of other calcium silicates.

Field work in the Goldfield district was made possible by National Science Foundation Grant G-2933 under the direction of Professor Charles J. Vitaliano, Indiana University. Appreciation is expressed to Professor John B. Droste, Indiana University, and Dr. William F. Bradley, Illinois Geological Survey, for valuable suggestions and discussions.

GEOLOGIC SETTING

An early Tertiary volcanic sequence was altered accompanying gold mineralization in an epithermal environment. The gold was found within silicified veins which are thought to represent former fault zones. The veins are distributed in the shape of a U opening eastward. Major faults form the bend of the U and most of the ore was associated with these north-striking faults, which dip steeply eastward at the surface but shallow somewhat at depth (Searls, 1948).

The early Tertiary sequence overlies an alaskite-type granite which crops out in several small areas in the central part of the district. Small patches of black shale border the granite. According to Ransome (1909), the shales are Cambrian in age. The early Tertiary volcanics overlap the granite and shales.

The earliest Tertiary unit is a rhyolite which is overlain by a thick latite flow. Isolated rhyolites and tuffs are found on top of the latite and are overlain in turn by a series of andesite and dacite flows respectively. The entire sequence is never found in one section and the thickness of each is variable, but the maximum thickness is approximately 2000 ft. Each rock unit has been hydrothermally altered to varying degrees. The principal ore-bearing rocks are dacite, andesite and latite. The Esmeralda formation, a series of lacustrine deposits consisting of thin bedded, tuffaceous sandstones and conglomerates, overlies the ore-bearing rocks and in turn is overlain by a series of unaltered ignimbrites and capping basalt flows. Mineralization took place prior to the deposition of the lake beds (Searls, 1948). Because ore was found to a depth of approximately 1000 ft, the mineralization and alteration probably occurred at the earth's surface and extended downward about 1000 ft.

Regularly interstratified chlorite-vermiculite was found in the andesite and dacite flows, but tobermorite was found only in the dacite. The unaltered andesite is a dense, black rock having a porphyritic texture and an aphanitic groundmass. Zoned plagioclase crystals have an anorthite content of 45-50 percent. Along with the plagioclase crystals, subhedral phenocrysts of pyroxene and amphibole are embedded in a glassy groundmass. Optical data indicate that the composition of the pyroxene is between augite and pigeonite (Kerr, 1959, p. 309) and that the amphibole probably is an aluminum-bearing hornblende.

The dacite is a dark gray to black rock with a striking porphyritic texture. Light-gray phenocrysts of plagioclase (5-8 mm long), biotite, hornblende, and anhedral quartz grains that measure as much as 3 mm in diameter are embedded in a glassy groundmass. Euhedral plagioclase crystals have an anorthite content of 45-50 percent. The groundmass contains microlites which are more sodic than the plagioclase and aligned by the flow of the rock. Small weakly pleochroic (yellow to light green) amphibole anhedra are scattered throughout the rock. The amphibole in the dacite probably is an aluminum-bearing hornblende also. A detailed petrographic description of these and other rocks in the Goldfield District is given by Ransome (1909).

Detailed microscopic and X-ray analysis of the altered rocks showed a definite pattern of alteration. Three enveloping zones of alteration flank the veins. An innermost zone, consisting mainly of quartz and alunite with associated kaolinite, jarosite and tobermorite is bordered sharply by an argillic zone, which in turn grades into a propylitic zone. The clay minerals of the argillic zone are largely kaolinite and illite nearer the vein and montmorillonite farther away. The propylitic zone is the zone of least alteration and its presence or absence depends upon proximity to other veins. The propylitic zone is characterized by chlorite, chlorite-vermiculite, calcite and antigorite.

The width of the alunite-quartz zone ranges from a few inches to approximately 50 ft. The argillic zone is also variable in width and, furthermore, it does not vary directly with the observed width of the alunite-quartz zone. The argillic zone is always wider than the alunite-quartz zone and it may extend 200-225 ft on each side of an isolated alunite-quartz zone 50 ft in width. The propylitic zone is the widest zone and propylitically altered rocks grade imperceptibly into unaltered rocks.

REGULARLY INTERSTRATIFIED CHLORITE-VERMICULITE

A hand specimen from the propylitic zone containing regular mixed layer chlorite-vermiculite is shown in Plate I. The rock is slightly altered; plagioclase crystals are dull owing to incomplete alteration to calcite, and

hornblende phenocrysts are altered completely to brown chlorite-vermiculite. An X-ray trace of the -2μ fraction of a sample from the propylitic zone is shown in Fig. 1. The diffraction maximum between 2.5° and $3.0^\circ 2\theta$ is an indication of mixed layering. In thin section, this mixed-layer mineral is seen to be embedded in a dark-brown groundmass where it occurs as tiny birefringent, brown, micaceous material with a faint greenish pleochroism. Measured d_{00l} spacings are as follows:

$d_{(00l)}$ spacing in Å		
00l	Untreated	Glycolated
001	29.0	30.4
002	14.0	14.9
003	9.0	—
004	7.2	7.7
006	4.8	5.0
008	3.6	—

A regular periodicity of approximately 29 Å is indicated. The measured values are in agreement with calculated values for 1:1 interstratified chlorite-vermiculite (Bradley and Weaver, 1956).

Samples were heated under atmospheric pressure at a rate of 5°C per min and oscillating-heating X-ray diffraction patterns obtained by the technique of Weiss and Rowland (1956). The oscillating-heating pattern of the 002 peak of 1:1 chlorite-vermiculite (Fig. 2a) shows that dehydration starts at about 100°C and is accompanied by a shift in spacing from 14.0 Å to 12.35 Å. The loss of intensity is due to the loss of interlayer water in the vermiculite layers. Gradually increasing the temperature results in the decrease of the 002 spacing to 11.9 Å. At approximately 500°C , the intensity of the 002 increases and remains nearly constant until about 750°C , where the intensity falls off rapidly and the spacing shifts to 10.0 Å. Total collapse occurs at about 800°C . The increase in intensity at 500°C is characteristic of chlorites (Weiss and Rowland, 1956) and is due to the loss of hydroxyl ions from the interlayer "brucite" (Brindley and Ali, 1950).

Selected X-ray diffraction patterns of this material recorded over the range of about $2-10^\circ 2\theta$ with continuously increasing temperature are shown in Fig. 2(b). The shifting of d -spacings and increases and decreases in intensities discussed above are well shown here. In particular the increase in intensity of the 002 peak at about 500°C is accompanied by the appearance of the 001 peak at a d -spacing of 23.2 Å. The 001 and 002 peaks collapse at about 800°C .

A study of the rock farther away from the vein indicates the original hornblende was altered to the penninite (Mg-rich) variety of chlorite having the anomalous "berlin blue" interference color. Further alteration of the

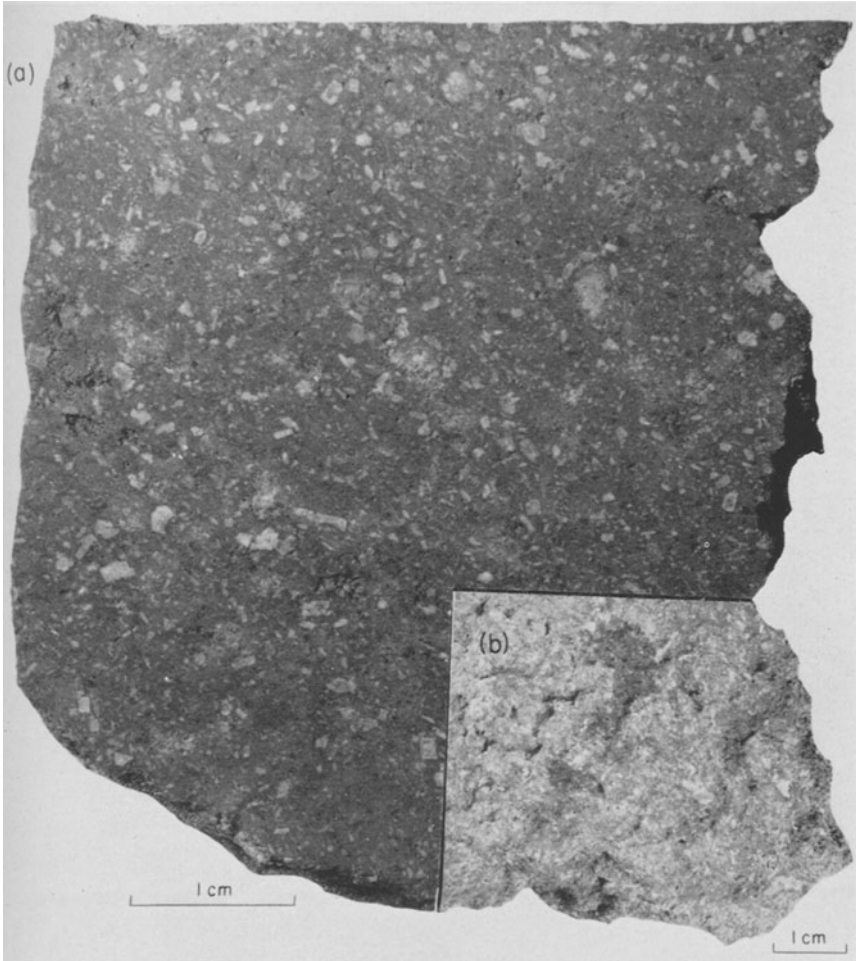


PLATE 1.—Photograph of a typical hand specimen from the propylitic zone containing regular mixed layer chlorite-vermiculite. (a) sawed surface; (b) fractured surface.

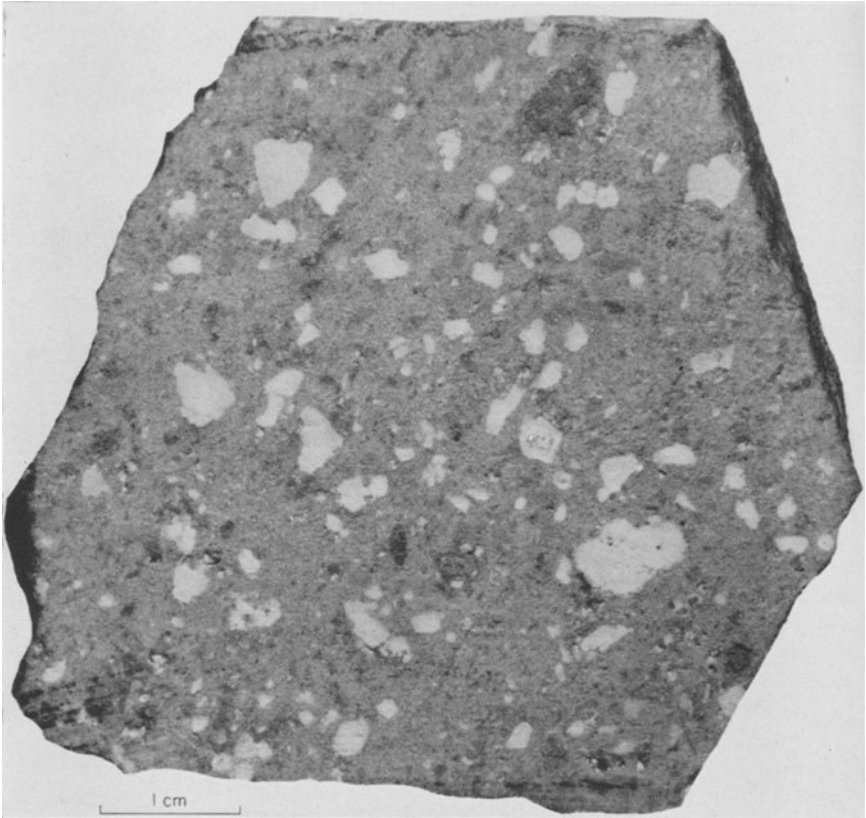


PLATE 2.—Photograph of a hand specimen of altered dacite from the alunite-quartz zone containing tobermorite and alunite.

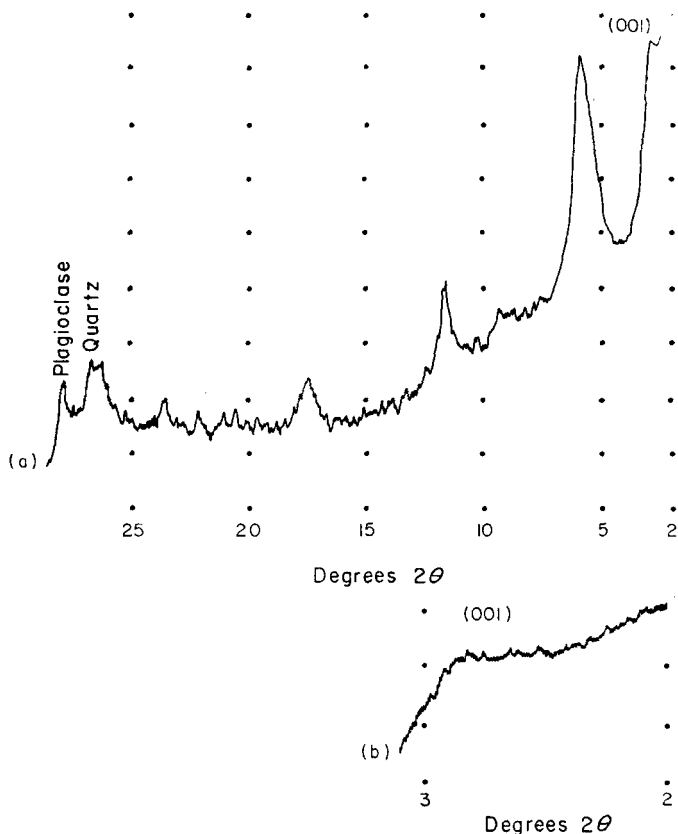


FIGURE 1.—X-ray diffraction patterns ($\text{Cu K}\alpha$) of glycolated 1:1 mixed layer chlorite-vermiculite. (a) normal scanning speed of 2° per min, (b) scanning speed of 0.2° per min.

penninite produced the regular mixed layer chlorite-vermiculite. This transition may have been accomplished simply by the addition of protons combining with the hydroxyl ions in every other brucite layer to form “bound” water layers. Rocks as much as 10 ft closer to the vein than the chlorite-vermiculite-bearing rocks have no detectable chlorite-vermiculite but do contain a montmorillonite-type clay mineral.

TOBERMORITE

A specimen of dacite from the alunite-quartz zone, from which tobermorite was recovered, is shown in Plate 2. The rock is medium gray in color with white, pseudomorphic tobermorite and alunite after plagioclase pheno-

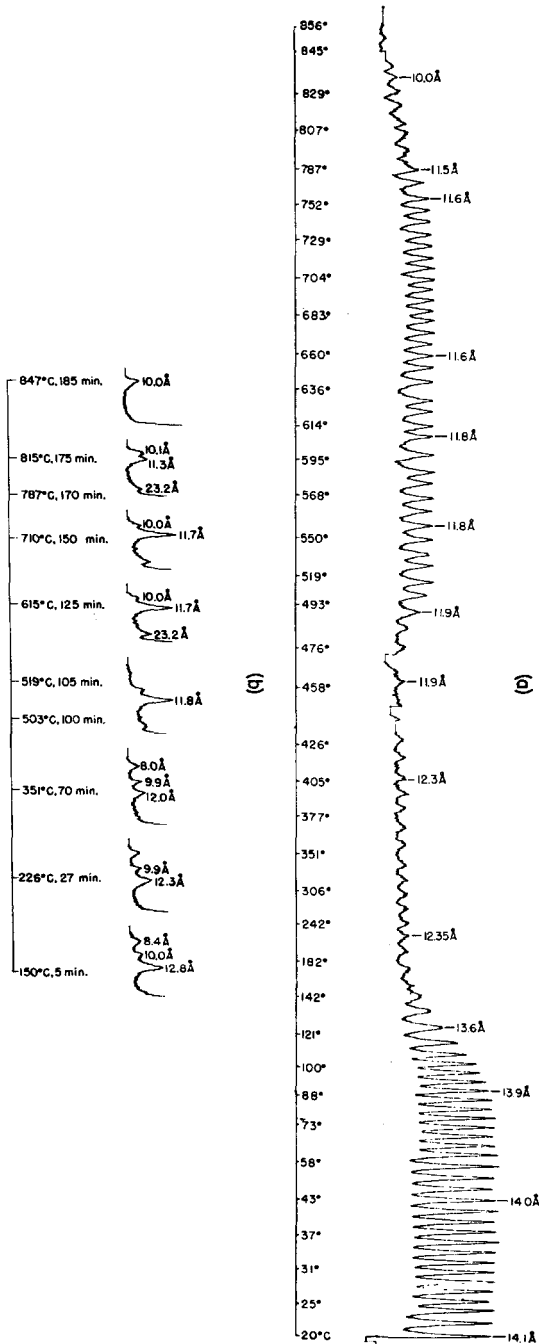


FIGURE 2.— (a) Oscillating-heating X-ray diffraction pattern of the 002 spacing, 1:1 chlorite-vermiculite. (b) Selected X-ray diffraction patterns ($Cu K_{\alpha}$) with continuously increasing temperature. The time in minutes is the elapsed time from the start of the experiment to the indicated temperature.

crysts. Megaw and Kelsey (1956) and Taylor and Howison (1956) show tobermorite to have a 2:1 layer-type structure similar to that of vermiculite. Taylor and Howison (1956) assign the formula $\text{Ca}_4(\text{Si}_6\text{O}_{18}\text{H}_2)\text{Ca} \cdot 4\text{H}_2\text{O}$ to tobermorite, and Taylor (1959) reports three hydration states characterized by the basal $d_{(002)}$ spacings of 14.0, 11.3, and 9.33 Å.

An X-ray trace of the alteration product of plagioclase phenocrysts from the dacite in the alunite zone shows the presence of alunite and tobermorite

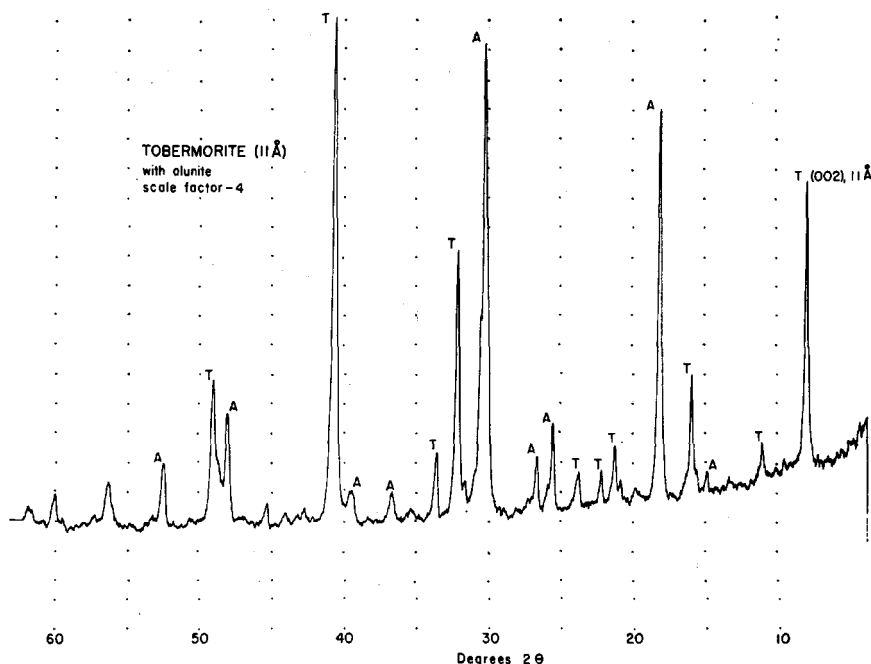


FIGURE 3.—X-ray diffraction trace of a mixture of tobermorite and alunite ($\text{CuK}\alpha$).

(Fig. 3). The 11 Å hydration state is indicated for this tobermorite. Intensities and d -spacings from two such traces are given in Table 1.

Oscillating-heating X-ray diffraction traces were made for five 00 l maxima: 002, 004, 008, 0010 and 0012. Experimental conditions were atmospheric pressure and temperature rises of 5 °C per min. Collapse started between 520 °C and 550 °C and was complete between 580 °C and 620 °C. The oscillating-heating trace on the 004 peak ($d = 5.6$ Å) is shown in (Fig. 4b). The sample was held at approximately 620 °C and a trace from 4° 2θ to 41° 2θ was made; the 00 l maxima had collapsed but the 8 Å maximum persisted (Fig. 4c). An oscillating-heating trace over the 8 Å maximum shows that collapse started at 760 °C and was complete by 790 °C (Fig. 4d).

Four stages of static heating are shown in Fig. 5. Fig. 5(a) is the unheated sample; Fig. 5(b) is a sample heated at 300 °C for 24 hr and shows a marked decrease in intensity of alunite maxima, whereas tobermorite maxima are unchanged; Fig. 5(c) is a sample heated at 500 °C for 12 hr and shows collapse of alunite maxima and 00 ℓ maxima of tobermorite and reduction in other tobermorite maxima; and Fig. 5(d) is a sample heated at 700 °C for 12 hr and shows complete collapse of tobermorite and development of weak wollastonite peaks. A random powder picture of this material confirmed the development of wollastonite at 700 °C.

A chemical analysis of the altered plagioclase phenocrysts is shown in Table 2. An approximate chemical composition of the tobermorite was

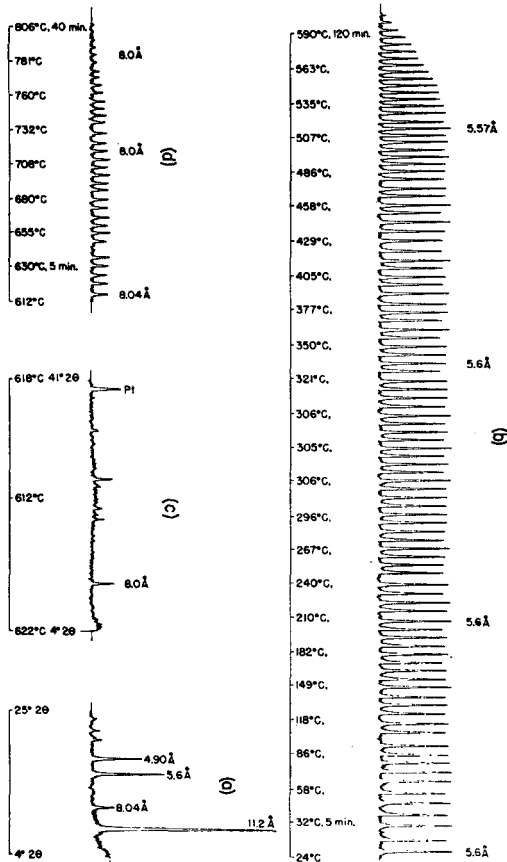


FIGURE 4.—(a) X-ray diffraction trace of tobermorite, — 2 μ . (b) Oscillating-heating X-ray diffraction trace of the 004 spacing of tobermorite. (c) X-ray diffraction trace of tobermorite at approximately 620 °C. Pt peak is due to platinum sample holder. (d) Oscillating-heating X-ray diffraction trace of the 8 Å maximum.

obtained from the analysis of the altered plagioclase phenocrysts by subtracting all SO_3 , Al_2O_3 , Fe_2O_3 , and enough H_2O (7.94 percent) to make theoretical alunite from the total. The reduced analysis is shown in Table 3. The $\text{CaO}:\text{SiO}_2$ ratio obtained by this method is approximately 1:1 instead of 5:6 as reported by Taylor and Howison (1956).

TABLE 1.—X-RAY DATA ON TOBERMORITE FROM GOLDFIELD, NEVADA (INTENSITIES MEASURED FROM DIFFRACTOMETER TRACES)

<i>d</i>	Intensity, Specimen 1	Intensity, Specimen 2
11.04	56	100
8.03	9	47
5.57	24	91
4.00	11	28
3.72	7	13
3.08	1	5
2.93	39	36
2.78	52	100
2.66	14	38
2.22	100	96
2.12	1	3
2.06	2	4
2.00	5	11
1.92	1	3
1.85	28	91
1.64	9	5
1.54	8	6

SUMMARY

Regularly interstratified chlorite-vermiculite and tobermorite were found in hydrothermally altered volcanic rocks at Goldfield, Nevada. Regular interstratified chlorite-vermiculite was found in the least intense zone of alteration as the alteration product of penninite. The order of the mixed layering is indicated by X-ray diffraction maximum between 2.5° and $3.0^\circ 2\theta$ and by its behavior when heated. The loss of interlayer water in the vermiculite layers occurs at approximately 100°C at atmospheric pressure; at about 800°C the 002 spacing becomes 10 \AA , and complete collapse occurs at approximately 850°C . Presumably the chlorite-vermiculite altered to montmorillonite; however, the environmental conditions and mechanism of this alteration remain in question. With the discovery of ordered chlorite-vermiculite mixed layers that give rise to low angle X-ray diffraction peaks reported in this paper the need for careful examination for ordered mixed-layer clay minerals from other hydrothermally altered deposits is emphasized.

TABLE 2.—CHEMICAL ANALYSIS OF ALTERED
PLAGIOCLASE PHENOCRYSTS FROM GOLDFIELD,
NEVADA

Constituent	Percent
SiO ₂	17.79
Fe ₂ O ₃	0.071
TiO ₂	0.032
Al ₂ O ₃	22.69
CaO	17.31
SO ₃	23.57
− H ₂ O	0.066
+ H ₂ O	11.80
K ₂ O	not determined
Total	93.329

Analyst, Maynard E. Collier, Indiana Geological Survey.

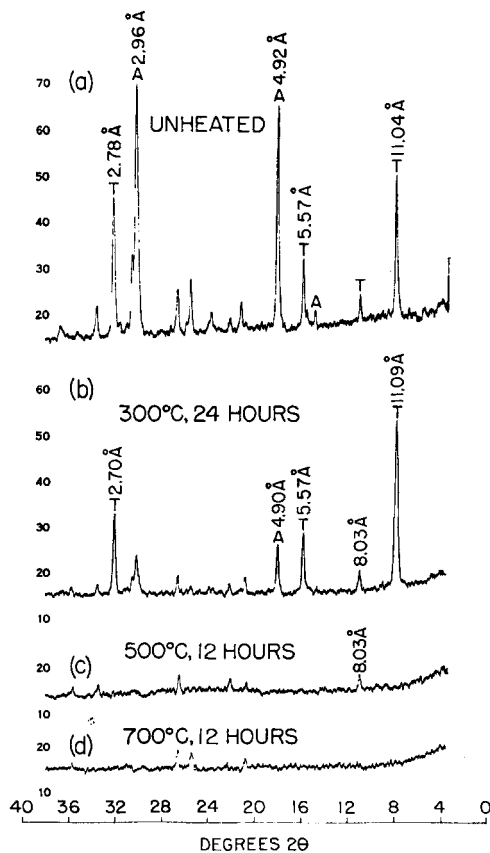


FIGURE 5.—X-ray diffraction traces of tobermorite after heat treatments.

TABLE 3.—CALCULATED CHEMICAL COMPOSITION OF TOBERMORITE FROM GOLDFIELD, NEVADA

	Percent	Computed to 100 percent	Molecular Weight	Molecular Proportion	Molecular Ratio
SiO ₂	17.79	45.66	60.1	0.7597	1.0000
CaO	17.31	44.43	56.1	0.7920	1.0425
H ₂ O	3.86	9.91	18.0	0.5506	0.7248
	38.96	100.00			

Analyst, Maynard E. Collier, Indiana Geological Survey.

The tobermorite is associated with alunite in the most intense zone of alteration. Tobermorite and alunite occur together as pseudomorphs after plagioclase phenocrysts in a dacite flow. This tobermorite corresponds to the 11 Å state (Taylor, 1955) and by heating at atmospheric pressure at the rate of 5 °C per min it apparently loses part of its structure, the (00 l) planes, between 520 °C and 620 °C. Other crystal planes having a periodic spacing of 8 Å break down between 760 °C and 790 °C. Wollastonite is the stable phase resulting from the destruction of tobermorite in this manner.

REFERENCES

- Bradley, W. F. and Weaver, C. E. (1956) A regularly interstratified chlorite-vermiculite clay mineral: *Amer. Min.*, v. 41, pp. 497-504.
- Brindley, G. W. and Ali, S. Z. (1950) X-ray study of thermal transformations in some magnesian chlorite minerals. *Acta Cryst.*, v. 3, pp. 25-30.
- Claringbull, G. F. and Hey, M. H. (1952) A re-examination of tobermorite: *Min. Mag.*, v. 29, pp. 960-962.
- Eakle, A. S. (1917) Minerals associated with the crystalline limestone at Crestmore, Riverside County, California: *Calif. Univ., Dept. of Geol. Bull.* 10, pp. 327-360.
- Gard, J. A. and Taylor, H. F. W. (1957) A further investigation of tobermorite from Loch Eynort, Scotland: *Min. Mag.*, v. 31, pp. 361-370.
- Heddle, M. F. (1880) Preliminary notice of substances which may prove to be new minerals: *Min. Mag.*, v. 4, pp. 117-123.
- Kerr, P. F. (1959) *Optical Mineralogy*: McGraw-Hill Book Co., Inc., New York, 3rd ed., 442 pp.
- McConnell, J. D. C. (1954) The hydrated calcium silicates riversideite, tobermorite and plombierite: *Min. Mag.*, v. 30, pp. 293-305.
- Megaw, H. D. and Kelsey, C. H. (1956) The crystal structure of tobermorite: *Nature*, v. 177, pp. 390-393.
- Ransome, F. L. (1909) The geology and ore deposits of Goldfield, Nevada: *U.S. Geol. Survey, Prof. Paper* 66, 258 pp.
- Searls, F. Jr. (1948) A contribution to the published information on the geology and ore deposits of Goldfield, Nevada: *Univ. Nevada Bull.* no. 5, v. 42, Geol. and Min. series no. 48, p. 24.

354 NINTH NATIONAL CONFERENCE ON CLAYS AND CLAY MINERALS

- Taylor, H. F. W. (1959) The dehydration of tobermorite: in *Clays and Clay Minerals*, Pergamon Press, New York, v. 6, pp. 101-109.
- Taylor, H. F. W. and Howison, J. W. (1956) Relationships between calcium silicates and clay minerals: *Clay Min. Bull.*, v. 3, pp. 98-111.
- Weiss, E. J. and Rowland, R. A. (1956) Oscillating-heating X-ray diffractometer studies of clay mineral dehydroxylation: *Amer. Min.*, v. 41, pp. 117-126.