HYDROTHERMAL ARGILLIC ALTERATION ON THE HELEN CLAIM, EAST TINTIC DISTRICT, UTAH[1]

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ABSTRACT

On the Helen claim in Homansville Canyon, East Tintic district, a small deposit of kaolinic clay typical of argillic alteration, together with hematite and manganese, occurs at the intersection of a minor north–south fissure with a steep east-trending contact of Tertiary quartz latite lava and dolomitized Cambrian Herkimer limestone. The fissure ends at a small, completely argillized monzonite plug about 100 yd north.

Argillic alteration and other types of hydrothermal alteration are common near the ore deposits and many of the intrusive bodies that are scattered through the roots of the Eocene volcanic field in which the East Tintic and Tintic districts lie. In most areas of argillic alteration abundant pyrite or alunite and barite suggest that the alteration was caused largely or in part by sulfur acids, but in the Helen claim these minerals are virtually lacking and in contrast fluorite, hematite, and manganese and aluminum oxides are abundant.

A mineral zonation parallel to the lava–dolomite contact is conspicuous. The zones in the lava outward from the contact are: (L 1) a silicic zone 1–5 in. wide with some kaolinic clays, mixed-layer clay and micaceous minerals; (L 2) a strongly argillized zone about 3 ft wide having much montmorillonite and a moderate amount of kaolinic and micaceous minerals, but in which the kaolinic minerals decrease away from zone L 1; (L 3) transition zone 2–5 ft wide in which montmorillonite diminishes, micaceous minerals increase, and kaolinic minerals disappear as altered rock grades into normal country rock. The bulk density of the rock decreases with the intensity of argillic alteration and nearly all chemical constituents decrease in amount per unit volume; magnesium, water, manganese, and fluorine, however, increase conspicuously.

The zones in the altered dolomite away from the lava contact are (D 1) a hematite–quartz zone 5–8 ft wide, which contains some minor sericite and manganese oxides; (D 2) a manganiferous zone 1–2 ft thick containing abundant manganese oxides and hematite, and minor clay, quartz, and kaolinic minerals; (D 3) a discontinuous zone about 8 in. thick of halloysite and kaolinite; (D 4) a fluorite–kaolin zone with minor diaspore about 1 ft thick; (D 5) a diaspor–fluorite zone about $4\frac{1}{2}$ ft wide in which the kaolin minerals diminish away from zone D 4; (D 6) a diaspore–kaolinite zone about 1 ft wide with minor fluorite and mixed-layer clays; (D 7) a kaolin and mixed-layer clay zone about 3 in. thick with very minor manganese oxide, fluorite, and diaspore; (D 8) a "sanded dolomite" zone about 10 ft wide, consisting chiefly of weakly bonded granular dolomite with some kaolinite and mica; (D 9) hard fresh hydrothermal dolomite extending outward for several hundred feet. Zone D 8 grades imperceptibly into D 9.

The mineral zones suggest reaction of dolomite with hot halogen-rich acid emanations carrying halides of iron, aluminum, and silicon; the precipitation of the oxides of iron, manganese, silicon, and aluminum, and of fluorite, is appropriate to zonation responsive to the increasing pH caused by reaction with the carbonate wall rock.

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INTRODUCTION

The East Tintic district is about 60 miles south of Salt Lake City, Utah, and is dominantly a terrain of middle Eocene quartz latite lavas above which rise many islands of Paleozoic carbonate rocks. Small irregular intrusive masses of quartz monzonite or monzonite locally cut the lavas and sedimentary rocks. The area has attracted wide interest because of the many blind ore bodies found in the Paleozoic rocks beneath the lava blanket.

The lava has been extensively altered in many places. Some types of alteration seem closely related to ore in the underlying sedimentary rocks, whereas others are apparently unrelated to ore deposition as such (Lovering and others, 1949). Argillic alteration, typical of Lovering's mid-barren stage, is closely related to the intrusion of monzonite or quartz monzonite. In most places this stage was followed by other stages of alteration. On the Helen Claim, however, only argillic alteration is imposed on an early-barren stage chloritic and dolomitic alteration. The locality is thus unusually favorable for isolating the effects of argillic alteration. In most other areas of argillic alteration in the district, abundant pyrite or alunite and barite suggest that the alteration was caused largely or in part by sulfur acids, whereas in the Helen Claim these minerals are virtually lacking. In contrast fluorite, hematite, and manganese and aluminum oxides are abundant.

At a small prospect pit on the Helen Claim, about 50 ft above U.S. Highway 6 where it enters Homansville Canyon, the contact of the lavas with hydrothermally dolomitized Herkimer limestone is well exposed. It is essentially an erosional contact, which trends east–northeast, but it is unusually steep and some movement has probably taken place between the two formations. In addition to minor fracturing along this contact, some fractures in the underlying dolomite trend north–northeast to a completely argillized monzonite plug, which is well exposed about 300 ft northeast of the prospect pit.

ALTERATION

Mineral zones parallel to the lava–dolomite contact are conspicuous in both the lava and the dolomite. Outward from the contact, the lava is strongly argillized in a zone about 4 ft wide, and on the dolomite side the carbonates are completely replaced by various hydrothermal minerals through a distance of 15–18 ft. The highly altered rocks grade rather abruptly into normal country rock. As shown in Table 1, the bulk density of the rock decreases with the intensity of argillic alteration and nearly all the chief original chemical constituents decrease in amount per unit volume, but water, manganese, and fluorine increase conspicuously. The quartz latite lost notable amounts of CaO, Na_2O and K_2O per unit volume and some SiO_2, but gained appreciable amounts of MgO, H_2O, F, and MnO. The dolomite lost MgO, CaO, and CO_2 and gained SiO_2, Al_2O_3, Fe_2O_3, MnO, K_2O, H_2O and F. These changes in composition are reflected in the mineralogy.

TABLE 1.—CHEMICAL ANALYSES IN WEIGHT PERCENT OF ALTERED ROCKS, HELEN CLAIM, EAST TINTIC DISTRICT, UTAH[1]

| | Quartz Latite Vitrophyre | | | Altered Dolomite | | | | | |
| | Chl | IA | | QH | A | FKd | d \| K | S.D. | D |
	1	2	3	4	5	6	7	8	9
SiO_2	66.63	64.41	64.45	60.91	45.50	15.52	38.20	4.96	0.15
Al_2O_3	14.66	15.91	16.88	6.19	32.96	52.97	39.33	3.89	0.09
Fe_2O_3	2.15	2.50	2.55	22.58	2.07	0.17	0.54	0.88	0.28
FeO	0.45	0.00	0.00	0.00	0.00	0.07	0.02	0.00	0.02
MgO	0.98	2.47	2.46	0.86	1.00	0.09	1.01	17.48	21.09
CaO	2.57	1.58	1.01	0.69	1.07	13.39	3.89	29.08	31.01
Na_2O	1.86	1.17	0.48	0.12	0.17	0.11	0.28	0.06	0.02
K_2O	4.09	1.93	2.57	2.12	2.12	0.42	0.81	0.40	0.03
H_2O^-	2.29	3.47	2.55	0.42	1.75	0.22	1.35	0.14	0.03
H_2O^+	3.61	5.25	5.02	1.74	10.25	11.69	12.02	1.16	0.09
TiO_2	0.39	0.42	0.45	0.29	0.05	0.04	0.05	0.04	0.01
CO_2	0.04	0.10	0.15	0.04	0.24	0.22	0.12	41.18	47.13
P_2O_5	0.09	0.12	0.13	0.34	0.34	0.17	0.71	0.04	0.00 (tr)
SO_3	0.01	0.02	0.07	0.08	0.01	0.01	0.13	0.00	0.00
Cl	0.02	0.05	0.02	0.00	0.00	0.00	0.05	0.06	0.04
F^-	0.07	0.29	0.30	0.16	0.40	8.75	2.26	0.20	0.01
S	0.00	0.01	0.02	0.03	0.02	0.01	0.10	0.02	0.01
MnO	0.06	0.26	0.57	2.69	1.81	0.01	0.04	0.45	0.16
BaO	0.17	0.12	0.32	0.48	0.10	0.00	0.04	0.02	0.01
	100.14	100.08	100.00	99.74	99.86	103.86	100.95	100.04	100.18
Less O	0.03	0.13	0.14	0.08	0.18	3.68	1.01	0.10	0.01
TOTAL	100.11	99.95	99.86	99.66	99.68	100.18	99.94	99.94	100.17
Bulk density	2.18	1.77	1.95	2.19	2.24	2.64	2.32	2.42	2.74
Powder density	2.40	2.39	2.52	3.04	2.63	3.02	2.69	2.81	2.82
Spec									
BaO	0.20	0.10	0.30	0.30	0.10	0.004	0.05	0.02	0.002
SrO	0.05	0.01	0.01	0.01	0.01	0.005	0.05	0.02	0.01

[1] Analyst, L. N. Tarrant, U.S. Geological Survey, Denver, Colorado.

Key

All samples are channel samples; see Fig. 1 for location of samples relative to contact of quartz latite vitrophyre with altered dolomite.

Abbreviations above the sample numbers show position of samples with respect to zones.

Zones: Chl—chloritic; IA—intensely argillized; QH—quartz–hematite; A—kaolin; FKd—fluorite–kaolin–diaspore; d—diaspore–kaolin–fluorite; K—kaolin–diaspore–fluorite; S.D.—sanded dolomite; D—dolomitized limestone.
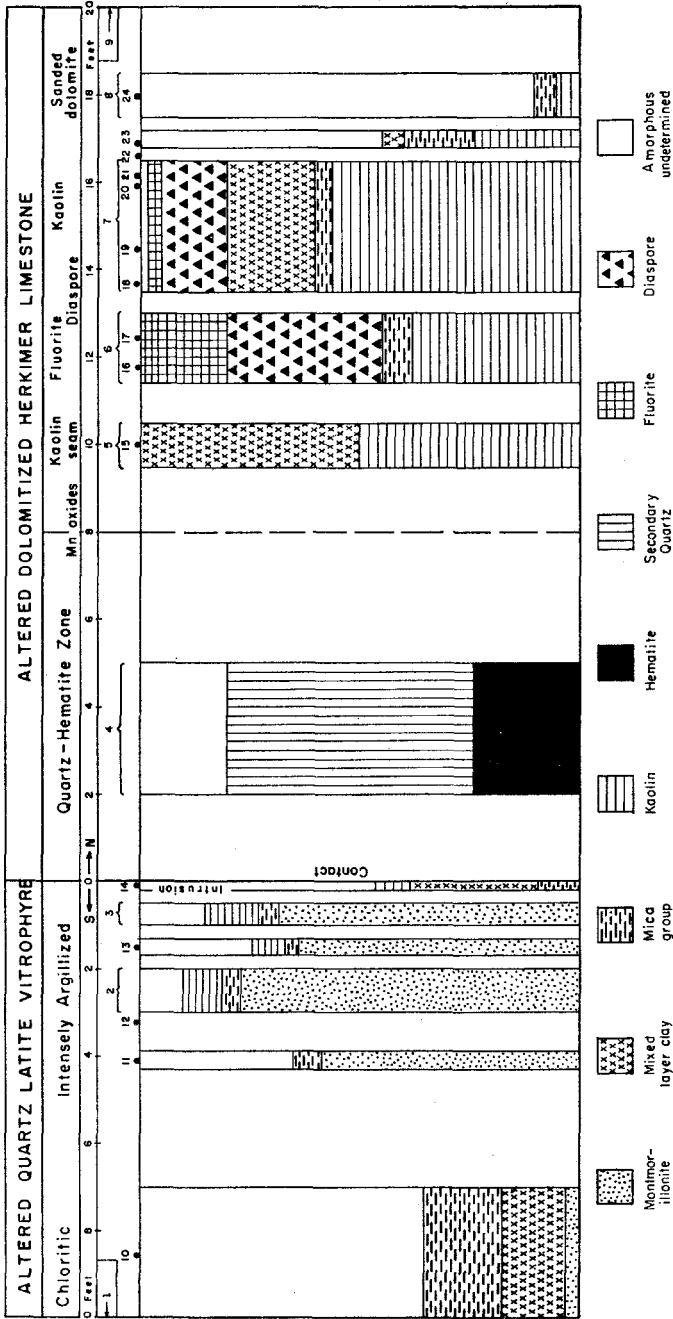
FIGURE 1.—Relative position of samples in relation to alteration zones. Bar diagram: mineralogical composition of channel samples estimated from x-ray analysis. Widths of bars are proportional to widths of zones sampled. This diagram should be compared with results of more detailed sampling (grab samples 10–24 marked by solid circles under sample numbers) summarized in Tables 2 and 3. Note especially the relations of samples 15 to 5, 16 and 17 to 6, and 18 and 19 to 7. Note: Sample 1 for chemical analysis was taken 21 feet north of contact.

The mineralogical composition of the altered latite and dolomite as estimated from x-ray analysis is illustrated graphically in Fig. 1, which shows strikingly the contrast in clay mineralogy between the two formations: the lava has altered to montmorillonite and carries only minor kaolinite near the contact whereas in the altered dolomite kaolin minerals are the dominant clays. The results shown were obtained from the channel samples for which chemical analyses are reported in Table 1. The quantitative estimates of the clay minerals are based mainly on the method of Schultz (1960). With the exception of diaspore and fluorite, only the clay minerals are plotted. The term kaolin includes kaolinite and halloysite, the latter identified only by electron micrographs; the x-ray curves showed only the sharp peaks of well crystallized kaolinite. Minerals that give a basal spacing of about 10 Å are reported as mica group minerals. In the partially altered lava primary biotite is the principal mineral that gives this reflection, whereas in the fully altered lava and in the altered dolomite the mica group minerals are secondary.

The lava shows a simpler and more uniform gradation in mineral alteration than the dolomite. Samples taken in the slightly altered lava, in a narrow transition zone, and in the zone of intense alteration showed respectively about 15, 60, and 80 percent clay. In the chloritic zone minor chlorite is distinguishable under the microscope but only a trace is evident in the x-ray curve. In this zone most of the expanding-lattice clay has been interpreted as a mixed-layer montmorillonite–mica because of the comparatively low 17 Å peak obtained on glycolation, as compared with the increase of the 10 Å peak after collapse. This is the only indication of mixed-layer clay in the altered quartz latite. The mica in the chloritic zone is trioctahedral, judged by the 060 reflection, and persists into the transition zone (sample 11) but disappears in the zone of intense argillic alteration, presumably reflecting the complete alteration of the primary biotite. A zeolite that is not destroyed on heating to 500° occurs in the chloritic zone and persists into the outer edge of the zone of intense argillic alteration. Cristobalite is present throughout the altered latite.

In the intensely argillized lava beginning approximately $3\frac{1}{2}$ ft from the contact kaolinite makes up about 10 percent of the clay and persists to the contact. The decrease in the mica group minerals in the zone of intense argillic alteration suggests that mica did not all alter to a mineral with a 10 Å spacing. A narrow seam of intrusion breccia occurs between the altered latite and quartz hematite zone but is unrelated to the latite and has a totally different clay composition: its principal clay mineral is a random mixed-layer mica–montmorillonite, predominantly mica. There is a minor amount of kaolinite and a mica group mineral but no montmorillonite. The alteration minerals suggest a late intrusion of fragments of rock altered at depth by late barren-stage solutions.

The dolomite at its contact with the lava has been replaced by hematite and quartz in a zone 5–8 ft wide, which merges on the far side with a manganiferous zone 1–3 ft thick containing abundant quartz, pyrolusite, and

hematite, minor manganapatite, and kaolin minerals, chiefly kaolinite and halloysite—formed by dehydration of endellite from $Al_2SiO_5 \cdot 4H_2O$ to $Al_2SiO_5 \cdot 2H_2O$. Farther from the contact, a fluorite–kaolin–diaspore zone, a diaspore–kaolin–fluorite zone, a kaolin–diaspore–fluorite zone, and a thin kaolin–mica zone appear successively. All these zones show many alternating generations of the chief minerals, most zones have minor amounts of mica group minerals and the two zones closest to the dolomite have mixed-layer chlorite–montmorillonite clay. Fluellite and zunyite were noted under the microscope, and boehmite is suggested by x-ray studies of sample 17. The edge of the dolomite is leached and altered through a zone about 5 ft wide, where the rock consists chiefly of weakly bonded granular dolomite—a distinctive altered rock that is called " sanded dolomite." Some kaolin and mica and minor calcite, fluorite, chlorite, goethite, and manganese oxide are present in the sanded dolomite. Beyond this zone hard fresh hydrothermal dolomite extends outward for several hundred feet.

Abrupt local variations in composition of the altered dolomite apparently have resulted from the guidance of solution by the many minor fractures. These variations are shown by the grab samples (Tables 2 and 3) but are averaged out in the channel samples (Fig. 1), e.g., the mixed-layer mica–montmorillonite of sample 5 is apparently localized on the contact side of this sample, as only a trace is present in grab sample 15 taken near the center of channel sample 5; samples 16 and 17 within channel sample 6 show successive fluorite and diaspore maxima; the mixed-layer mont-morillonite–chlorite in channel sample 7 apparently is concentrated close to the sanded dolomite, as samples 18 and 19 show no mixed-layer clay. There is also an abrupt decrease in clay in sample 19, marking this point as beyond the kaolin–diaspore–fluorite zone.

The relative abundance of the chief minerals changes notably from the dolomite toward the contact with the argillized lava. As shown by x-ray studies, kaolinite first rises to a maximum, then diaspore, and then fluorite which reaches its maximum close to the quartz–hematite–manganese oxide zone (Table 3). The slightly sanded dolomite next to the thin kaolin–mica transition zone carries approximately 10 percent clay minerals, and they rise to 45 percent in the kaolin–mica transition zone and to 75 percent in the kaolin–diaspore–fluorite zone. Sample 19, however, 7–8 ft from the contact with the dolomite shows an abrupt drop to 10 percent with a concomitant rise in diaspore and fluorite. The chlorite component of the mixed-layer clay is high in the kaolin–mica transition zone and decreases to approximately half in the kaolin–diaspore–fluorite zone. The mixed-layer clay is limited to these zones.

A late kaolin seam about 6 in. wide (sample 15, Fig. 1), which separates the fluorite-rich zone from the manganese-rich edge of the quartz–hematite–manganese oxide zone, consists largely of kaolinite and halloysite—identified by its tubular structure in electron micrographs. A mixed-layer 1 : 1 mica–montmorillonite clay of moderately high birefringence is locally abundant in

TALBE 2.—APPROXIMATE ABUNDANCE OF MINERALS IN THE ALTERED QUARTZ LATITE VITROPHYRE: ESTIMATES BASED ON X-RAY DIFFRACTION DATA

Zone	Sample No.	Distance in Feet from Contact of IA with Q-H	Percent of Sample						Clay Minerals in Decils of Total Clay				
			Total Clay Minerals	Quartz	Sanidine	Plagioclase	Beta Cristobalite	Zeolite	Micas	Mont.	Kaol.	Mixed-layer Mica–Mont.	Chl.
Chloritic	10	7–10	35	< 5	10	10	10	5	5.0	1.0	—	4.0	tr.
Transition Chloritic to Argillic	11	1.2	65	< 1	5	6	15	5	1.0	9.0	—	—	—
Intensely Argillized	12	3.3	80	< 1	4	2	10	5	0.5	8.5	1.0	—	—
	13	1.5	75	< 3	1	—	< 15	—	0.5	8.5	1.0	—	—
Intrusive Breccia	14	0–0.3	45	30	7	—	—	—	2.0	—	1.5	6.5	—

TABLE 3.—APPROXIMATE ABUNDANCE OF MINERALS IN THE ALTERED HERKIMER LIMESTONE: ESTIMATES BASED ON X-RAY DIFFRACTION DATA

| Zone | Sample No. | Distance in Feet from Contact of IA with Q–H | Percent of sample | | | | | Clay Minerals in Decils of Total Clay[1] | | | Mixed-Layer Ratio |
			Fluorite	Dia-spore	Clay Minerals	Dolo-mite	Other Minerals	Kaolin	Micas	Mixed-Layer	Mont.: Chl.
Hydrothermal Dolomite	9	40	—	—	—	99	—	8.5	0.8	0.2	—
Sanded Dolomite	24	18	—	—	10	72	goethite calcite (15)	5.0	4.0	1.0	?
Kaolin–Mica	23	16.9	22	—	45	5	goethite	5.0	3.5	1.5	20 : 80
Kaolin–	22	16.7	6	8	85	—	—	8.0	0.5	1.5	45 : 55
Diaspore–	21	16.1	20	2	75	—	boehmite ?	7.0	0.5	2.5	60 : 40
Fluorite	20	16	10	17	75	—	tr. chlorite ?	7.5	0.5	2.0	50 : 50
Diaspore	19	14.5	35	60	10	—	—	5.0	5.0	—	—
Kaolin–	18	13.7	35	45	25	—	—	9.0	1.0	—	—
Fluorite	17	12.3	13	62	30	—	—	7.5	2.5	—	—
Fluorite– Kaolin– Diaspore	16	11.8	58	8	35	—	—	9.5	tr.	tr.	—
Kaolin Seam	15	10–10.5	—	—	100	—	—	9.5	?	tr.	—
Quartz– Hematite	4	2–5	—	—	—	—	quartz (30–50) hematite (30)				

[1] Estimation of proportion of clay minerals based on < 5 μ fraction except for nos. 20–23 for which < 2 μ fractions were taken.

the kaolinite–halloysite matrix and is oriented in a crisscross pattern; the matrix is cut by a few cross-fiber veinlets of coarser (about 50μ) mixed-layer clay intergrown with sericite. The macro- and micro-veins in the altered argillized dolomite exemplified in this seam suggest—but do not prove—a period of alteration to be measured in many years rather than one of short duration.

TEMPERATURE OF FORMATION

Quartz and hematite from the center of the quartz–hematite zone were studied in the laboratories of the California Institute of Technology by Engel and his associates. Engel reports (letter of May 14, 1956, to H. T. Morris) that the ratio of oxygen isotopes in the two minerals suggests " temperatures well above 200°C, possibly above 300°C." At temperatures near 300°C, the diaspore field, as shown by Kennedy (1959), would require a pressure of only 100 to 200 bars of water vapor; higher temperatures would result in corundum unless the vapor pressure of water were increased greatly. Lower temperatures—especially if less than 200°C—would tend to produce meta-stable boehmite, a mineral found only in the sample taken 2 ft from the sanded dolomite.

According to Roy and Osborne (1952) and Bates (1952) endellite is unstable above a temperature of 175°C even at steam pressures of 1000 bars. Endellite was presumably an early " fringe zone " alteration mineral in the cooler part of the reaction zone and was replaced by halloysite, kaolinite or diaspore at higher temperatures. The six-inch halloysite–kaolinite seam between the fluorite–diaspore–kaolinite zone and the quartz–hematite–manganese oxide zone is thermally incompatible with its walls and suggests a later origin from cooler solutions.

CONCLUSIONS

The mineralogy and the paragenesis of the argillized lava and dolomite indicate that the alteration was accomplished by halogen-acid solutions low in sulfur and rich in fluorine. The dolomite was largely removed but a sub-stantial amount of calcium was fixed as fluorite. The hot acid fluorine-bearing solutions carried a substantial amount of silica, iron, and aluminum which were precipitated zonally in various minerals as the solutions reacted with the dolomite. The comparatively sharp contact between the quartz–hema-tite–manganese oxide zone and the fluorite–diaspore–kaolin zone is believed to reflect an increase in the pH of the solutions, and the hydrolysis of the iron, manganese, and aluminum successively with decreasing acidity of the hydrothermal solutions. The sharp increase in mixed-layer clays and hydro-mica, and of the chlorite component of the mixed-layer clays immediately adjacent to the sanded dolomite presumably is due to both the change in pH and the increased concentration of magnesia in the solution at this place.

The controlling factor in the formation of kaolinite rather than mont-morillonite in the dolomite seems to have been the silica–alumina ratio of

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the solutions and the host rock rather than the magnesium present, as both magnesium and calcium must have been dissolved in large quantities from the dolomite. In contrast, the altered lava (adjacent to the dolomite) contains abundant montmorillonite but little kaolinite. Only minor amounts of magnesium and other bases are present in the montmorillonite zone, but silica makes up two-thirds of the rock by weight.

No veinlets of quartz and hematite were found cutting the fluorite–diaspore–kaolinite zones at a distance, as would be expected if the quartz–hematite alteration were late. On the other hand, vugs in the quartz–hematite–manganese oxide zone contained halloysite and kaolinite, suggesting that late-stage solutions belonging to the argillic alteration stage were still active in this area after the quartz–hematite alteration had ceased. Moreover, the halloysite clay seam between the quartz–hematite and fluorite–diaspore–kaolinite zones clearly established the lateness of some of the argillizing solutions. It is believed that the evidence now available favors the interpretation that the quartz and hematite belong to an early high-temperature stage of an alteration episode that was characterized by the precipitation of endellite in outer zones throughout its duration, and that endellite was therefore deposited at a late stage in zones that formerly had been above its decomposition temperature. The change from endellite to halloysite is in part recent—a near-surface dehydration caused by the semiarid climate— but it is probable that the endellite that formed in the outward moving fringe zone of alteration during the period of hydrothermal activity was also changed to halloysite where it was overtaken by zones of more intense alteration and higher temperatures, which were also expanding. Endellite seems to be absent at the surface, as all the x-ray curves lack its distinctive pattern.

The hydrothermal solutions must have been changed by reaction with wall rocks at depth, both gaining and losing various constituents. Much of the silica, alumina, iron, and manganese introduced into the dolomite could have been displaced from monzonitic intrusions at depth during argillic alteration, which nearly everywhere caused a marked loss in these constituents when measured in weight per unit volume (Lovering and others, 1949, pp. 46, 50). The halogen anions, however, can only be of magmatic origin.

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