Geology, alteration, and genesis of the Luis Lopez manganese district, New Mexico

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GEOLOGY, ALTERATION, AND GENESIS OF THE LUIS LOPEZ MANGANESE DISTRICT, NEW MEXICO

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INTRODUCTION

The Luis Lopez manganese district consists of a group of epithermal manganese deposits located in the northern Chupadera Mountains, southwest of Socorro, New Mexico (fig. 1). The district was one of the largest producers of manganese in New Mexico; as of 1957, total production in the district was 97,000 short tons of concentrate that averaged about 41 percent Mn and 18,000 short tons of crude ore that averaged 28 percent Mn (Farnham, 1961; Willard, 1973). Production continued until the early 1970's, but much of this later production has not been reported. The most productive mines in the district were the MCA, Tower, Nancy, and Black Canyon. The manganese was produced from both open pit and underground operations in fissure veins and breccia zones along steeply dipping faults. This paper reports the results of geochemical and stable isotope investigations of alteration associated with the manganese mineralization and stable isotope investigations of the vein material.

GEOLOGIC SETTING

The Luis Lopez manganese district is located in the northeast corner of the Mogollon-Datil volcanic field, a mid-Tertiary volcanic plateau consisting of lavas and ash-flow tuffs of mafic to felsic composition. Two cauldrons which produced major rhyolitic ash-flow tuff sheets are found within the manganese district. The Socorro cauldron (33 m.y.) is the source of the Hells Mesa Tuff and the Sawmill Canyon cauldron (--31 m.y.), which is nested within the Socorro cauldron, is the source of the La Jencia Tuff (Eggleston, 1982; Osburn and Chapin, 1983). The entire Luis Lopez manganese district is located within the eastern part of the Socorro cauldron. Within this area, the surface trace of the topographic margin of the younger Sawmill Canyon cauldron includes part of Black Canyon and an arcuate series of faults north of Black Canyon.

Though the manganese deposits have not been dated, structural evidence suggests that they formed between 7 and 3 m.y. ago (Chamberlin, 1980). The rhyolitic volcanism near Socorro Peak ended at about 7 m.y. ago and may have been responsible for the elevated heat flow necessary to form the deposits. Although no intrusives have been demonstrated to have a genetic relationship to the alteration and mineralization, a number of intrusives are spatially related (fig. 3-10.8a, Third Day road log, this guidebook).

South of Black Canyon, the only major manganese producer was the MCA mine which consists of three open pits along parallel structures. The structures are steeply dipping faults and shear zones that strike
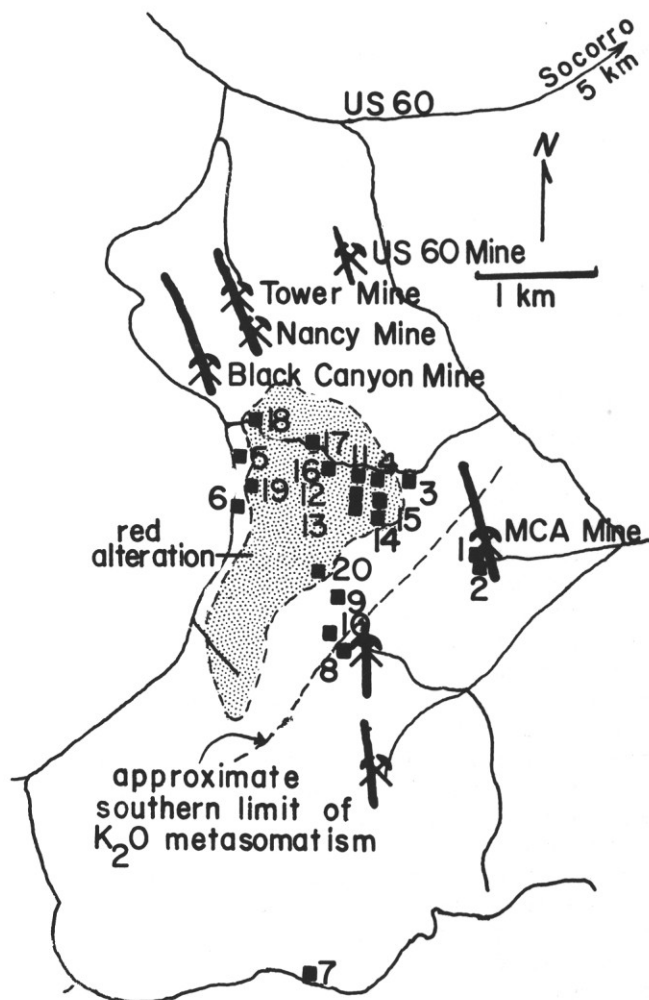

Figure 1. Location map showing the major manganese deposits and their relationship to the red alteration. See Figure 3-10.8a, Third Day road log (this guidebook), for the general geology of the region. Numbers are sample locations for the samples in Table 1. The trend of ore-hosting structures are shown as heavy lines; roads are shown as light, solid lines.

north to N 20° W. These structures cut cauldron-facies Hells Mesa Tuff with displacements believed to be only a few tens of meters (Willard, 1973; Eggleston, 1982). The ores at the MCA mine are breccia fillings and poorly developed veins of manganese oxides and calcite. Vein-related, wall-rock alteration is notably absent in all of the manganese deposits in the district. The MCA was the most important producer in the district, having produced about 67,000 short tons of concentrate averaging 40% Mn (Farnham, 1961).

North of Black Canyon, west of the topographic margin of the Sawmill Canyon cauldron, the Black Canyon and Tower-Nancy mines were important producers. Both mines are on steeply dipping, parallel structures that strike N 15° W to N 30° W. The host rocks in the upper workings are the two members of the Lemitar Tuff, a major ash-flow sheet which partially filled the moat of the Sawmill Canyon cauldron. At deeper levels, the ores are hosted by the moat-fill sedimentary and volcanic rocks in the Sawmill Canyon and Socorro cauldrons. The ores at the Black Canyon mine consist of a lenticular vein system filled with manganese oxides and minor calcite and quartz. Total production at the Black Canyon mine was about 18,000 tons of concentrate averaging about 44% Mn as of 1957 (Farnham, 1961). Production from 1957 to 1972 was significant, but has not been reported. The Tower-Nancy mine consists of an open pit (Tower mine) and underground workings (Nancy mine) on the same vein system. In this mine, the ores consist of narrow veins and large breccia zones which are filled with manganese oxides and minor calcite and quartz. Total production as of 1957 was about 12,000 tons of concentrate averaging 40% Mn (Farnham, 1961). The sporadic production since that time has not been reported.

Several small mines and prospects in the district have produced from veins and breccia zones similar to those in the major producers. North and east of the Tower-Nancy and Black Canyon mines, these small mines are hosted by the Luis Lopez Formation, the moat-filling sequence of the Socorro cauldron (Chamberlin, 1980). South of the MCA mine, the small mines and prospects are hosted by both the Luis Lopez Formation and by cauldron-facies Hells Mesa Tuff (Eggleston, 1982). The prospects between the MCA and Tower-Nancy mines are hosted by cauldron-facies Hells Mesa Tuff.

ALTERATION

Two periods of alteration have been recognized in the Luis Lopez manganese district. The older alteration is a regional potassium metasomatic event (Chapin and others, 1978; D' Andrea-Dinkelman and others, this guidebook). The younger alteration is overprinted on the potassium metasomatic event and is spatially related to the mineralization in the manganese district. Vein-related wall-rock alteration is absent near the manganese veins. D'Andrea (1981) and Lindley and others (1983) investigated the geochemical effects of potassium metasomatism on ash-flow tuffs of the Socorro-Magdalena area and reported that the metasomatism is characterized by increases in K_2O, Rb, and Ba and decreases in Na_2O, CaO, MgO, Sr, and Mn. K_2O can increase from normal values of 4 to 6 percent to as much as 12 percent; Na_2O drops from normal values of 3 to 5 percent to less than 1 percent in highly metasomatized rocks. The major alteration product is potassium feldspar with a composition of 90-100% Or and an intermediate structural state approximating that of orthoclase (Lindley and others, 1983). This alteration affects most silicic volcanic rocks of Tertiary age in the Magdalena, northern Chupadera, and Socorro-Lemitar Mountains. The southern boundary of this alteration is shown in Figures 1 and 4.

Overprinted on the regional potassium metasomatism is the red alteration around which the Luis Lopez manganese district is situated. Petrographically, the reddened rocks are characterized by alteration of ferromagnesian minerals (dominantly biotite with minor hornblende) to opaque oxides and sericite, partial alteration of plagioclase and sanidine to clays, and reddening of the groundmass by addition of hematite. The hematite may have been derived from oxidation of iron liberated during the destruction of the ferromagnesian minerals, since analyses do not show a significant increase in total iron content (fig. 3). These petrographic characteristics are consistent with Meyer and Hemley's (1967) definition of propylitic alteration. However, in this paper, we have refrained from attaching that name to the red alteration since the epidote, chlorite, and carbonate associated with propylitic alteration in the traditional sense are apparently absent.

Table 1 lists analyses from altered and unaltered Hells Mesa Tuff from in and near the red alteration; the samples were collected specifically to investigate the effects of the red alteration. Since the Hells Mesa Tuff contains abundant lithic material, it was necessary to remove the lithic fragments by hand picking prior to analysis. Major elements were determined by X-ray fluorescence spectrometry using the fusion-disk techniques of Norrish and Hutton (1969). Trace elements were determined by both X-ray fluorescence spectrometry and by atomic absorption spectrometry (see Table 1).

Since the red alteration is overprinted on regional potassium metasomatism, it was necessary to determine if all of the red altered samples were potassium metasomatized. Figure 2 is a ternary K_2O-Na_2O-CaO plot (see D'Andrea-Dinkelman and others, this guidebook) showing the general fields of metasomatized and fresh ash-flow tuffs from the Socorro-Magdalena areas as determined from the analytical work of D'Andrea (1981) and Lindley (1979). This plot shows that all of the red altered samples (triangles) fall within the metasomatized field. The two samples that fall outside either field are assumed to be fresh samples. Since all but three of the samples have been altered by regional potassium metasomatism, the data were placed in red altered and non-red altered groups, averaged, and enrichment factors calculated.

Figure 3 is a plot of enrichment factors calculated by means of the equation: enrichment factor = — ((average of unaltered samples/average of the altered samples) — 1). Using this equation, an unchanged sample
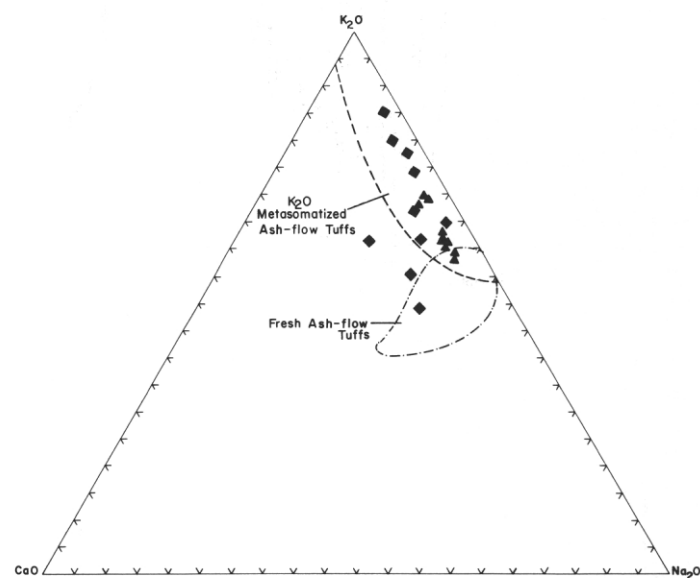
Figure 2. K_2O-CaO-Na_2O ternary plot of all the geochemical samples from the Luis Lopez district. Triangles are red altered samples, diamonds are samples outside the red alteration. Fields for fresh versus potassium-metasomatized ash-flow tuffs are based on 72 samples from five major ash-flow tuffs in the Socorro-Magdalena area analyzed by D'Andrea (1981) and Lindley (1979). Note that all of the red altered samples are within the K_2O-metasomatized field.

Table 1. Major and trace element geochemistry of the Hells Mesa Tuff in the Luis Lopez manganese district. Major elements are in percent, trace elements in ppm, and $\delta^{18}O$ in permil SMOW. (Y, Sr, Nb, Zr, U, Rb, and Th by XRF; Pb, Cu, Zn, Ba, and Ag by atomic absorption; na—not analyzed).

Sample Number					Non-Red Altered Samples					
Sample Number	1	2	3	4	5	6	7	8	9	10
Field	82-4-15	82-4-15	82-4-15	82-4-15	4-18-82	4-18-82	4-18-82	4-18-82	4-18-82	4-18-82
Number	-1	-2	-3	-5	-9	-10	-12	-14	-15	-17
SiO_2	72.87	69.71	73.17	74.48	69.3	71.81	72.54	69.96	71.93	71.88
TiO_2	0.23	0.27	0.26	0.23	0.29	0.25	0.23	0.27	0.23	0.23
Al_2O_3	13.31	13.95	13.40	12.79	14.79	13.28	13.32	14.18	13.53	14.18
Fe_2O_3	1.65	2.02	1.98	1.99	2.14	1.94	1.84	1.98	1.66	1.55
MnO	0.04	0.06	0.02	0.07	0.07	0.04	0.03	0.05	0.09	0.03
MgO	0.28	0.35	0.29	0.14	0.56	0.62	0.37	0.56	0.37	0.41
CaO	0.32	1.87	0.32	0.30	0.40	1.17	0.37	1.61	0.72	0.93
Na_2O	2.14	2.48	1.23	3.15	1.67	2.83	2.41	3.83	2.63	3.33
K_2O	8.21	6.88	8.45	6.29	8.07	4.89	7.90	5.24	6.6	6.84
P_2O_5	0.07	0.08	0.08	0.09	0.09	0.07	0.07	0.08	0.06	0.07
LOI	0.65	1.85	0.44	0.63	1.12	1.27	0.87	0.78	0.58	0.49
Total	99.77	99.53	99.65	100.11	98.5	98.17	99.94	98.53	98.4	99.93
Ag	0.4	0.8	0.4	0.4	0.3	−0.1	0.6	0.4	0.2	0.5
Ba	219	339	159	150	349	190	249	309	209	259
Cu	11	5	12	37	9	4	3	9	4	10
Nb	27	30	23	22	25	23	24	24	27	25
Pb	18	12	27	40	20	12	9	17	18	12
Rb	424	429	383	308	416	223	372	227	338	304
Sr	89	247	88	216	133	170	122	276	153	191
Th	38	34	29	30	30	30	26	26	35	29
U	6	5	4	3	3	5	3	6	6	5
Y	24	31	23	26	26	21	19	25	21	24
Zn	37	43	30	85	36	20	13	31	24	20
Zr	145	225	155	137	174	133	146	128	170	144
$\delta^{18}O$	na	9.26	na	na	na	na	na	9.37	10.38	9.68

Sample Number					Red Altered Samples					
Sample Number	11	12	13	14	15	16	17	18	19	20
Field	82-4-15	4-18-82	4-18-82	4-18-82	4-18-82	4-18-82	4-18-82	4-18-82	4-18-82	4-18-82
Number	-6	-1	-2	-3	-4	-5	-6	-8	-11	-16
SiO_2	72.09	74.96	72.05	71.79	72.1	73.88	72.33	71.96	70.83	72.65
TiO_2	0.34	0.18	0.32	0.37	0.29	0.33	0.34	0.3	0.31	0.33
Al_2O_3	13.14	12.74	14.1	13.78	13.53	13.28	13.23	13.61	13.81	13.76
Fe_2O_3	2.75	1.4	1.53	2.89	2.13	2.41	2.8	2.33	2.42	2.33
MnO	0.007	0.007	−0.001	0.006	0.009	0.004	0.002	0.001	0.005	0.005
MgO	0.34	0.3	0.31	0.43	0.33	0.23	0.27	0.24	0.33	0.2
CaO	0.51	0.38	0.67	0.54	0.42	0.38	0.47	0.43	0.5	0.53
Na_2O	3.35	2.6	2.84	3.38	3.48	2.18	3.2	2.98	3.16	3.85
K_2O	6.09	6.47	7.33	5.81	5.61	5.81	6.18	5.3	5.84	6.0
P_2O_5	0.12	0.05	0.12	0.15	0.1	0.12	0.13	0.1	0.1	0.12
LOI	0.63	0.27	0.38	0.44	0.73	1.02	0.69	0.84	—	0.53
Total	99.35	99.36	99.64	99.58	98.73	99.66	99.63	98.1	97.31	100.3
Ag	0.1	1.4	0.5	0.6	0.2	0.2	0.5	0.5	−0.1	na
Ba	155	409	185	185	184	140	160	140	170	na
Cu	8	18	12	10	22	9	14	7	9	na
Nb	23	26	23	22	24	22	23	24	24	17
Pb	26	25	23	30	31	30	49	16	16	na
Rb	317	335	292	298	366	301	323	255	272	304
Sr	214	177	260	224	217	137	217	142	168	330
Th	29	33	28	27	31	30	29	33	32	28
U	3	4	4	4	3	5	4	6	6	4
Y	23	17	22	22	22	24	24	23	23	18
Zn	113	93	10	173	125	143	75	50	78	na
Zr	143	112	136	145	142	140	144	148	145	129
$\delta^{18}O$	na	na	10.02	na	na	11.18	na	na	10.99	11.02

With the exception of Zn, the trace elements show little or no enrichment or depletion. Zn is enriched about 2 times in the red altered area. The significance of this enrichment, if any, is problematic. Silyel is stable in all samples with the exception of sample 12 which contains 1.4 ppm, about 3.4 times the concentration found in the unaltered samples.

STABLE ISOTOPE SYSTEMATICS

The oxygen isotopic composition of nine Hells Mesa Tuff samples and two vein calcite samples from the MCA mine has been determined (Table 1). The carbon isotopic composition of the vein calcite samples was also determined. Oxygen in the silicate samples was extracted and converted to carbon dioxide by the techniques of Clayton and Mayeda (1963). Carbon dioxide was extracted from the carbonates using 100 percent phosphoric acid (McCrea, 1950).

Eight of the Hells Mesa samples are from the Luis Lopez manganese district (fig. 4), a ninth sample is from west of Magdalena, New Mexico, and has been used as a control since it is a very fresh sample. These samples were expected to show a $\delta^{18}O$ depleted zone centered on the most intense portion of the red alteration, similar to the depleted zones described by Taylor (1974). The results, however, reveal an area of $\delta^{18}O$ enrichment centered on the red alteration. The fresh Hells Mesa Tuff (samples 2, 8, and the control sample) suggest that the Hells Mesa Tuff has a magmatic $\delta^{18}O$ composition of about 9.35 permil (SMOW). The potassium metasomatism (samples 9 and 10) enriched the whole rock $\delta^{18}O$ by 0.3 to 1.0 permil. The red alteration then enriched the Hells Mesa Tuff by an additional .8 to 1.5 permil to bring the $\delta^{18}O$ up
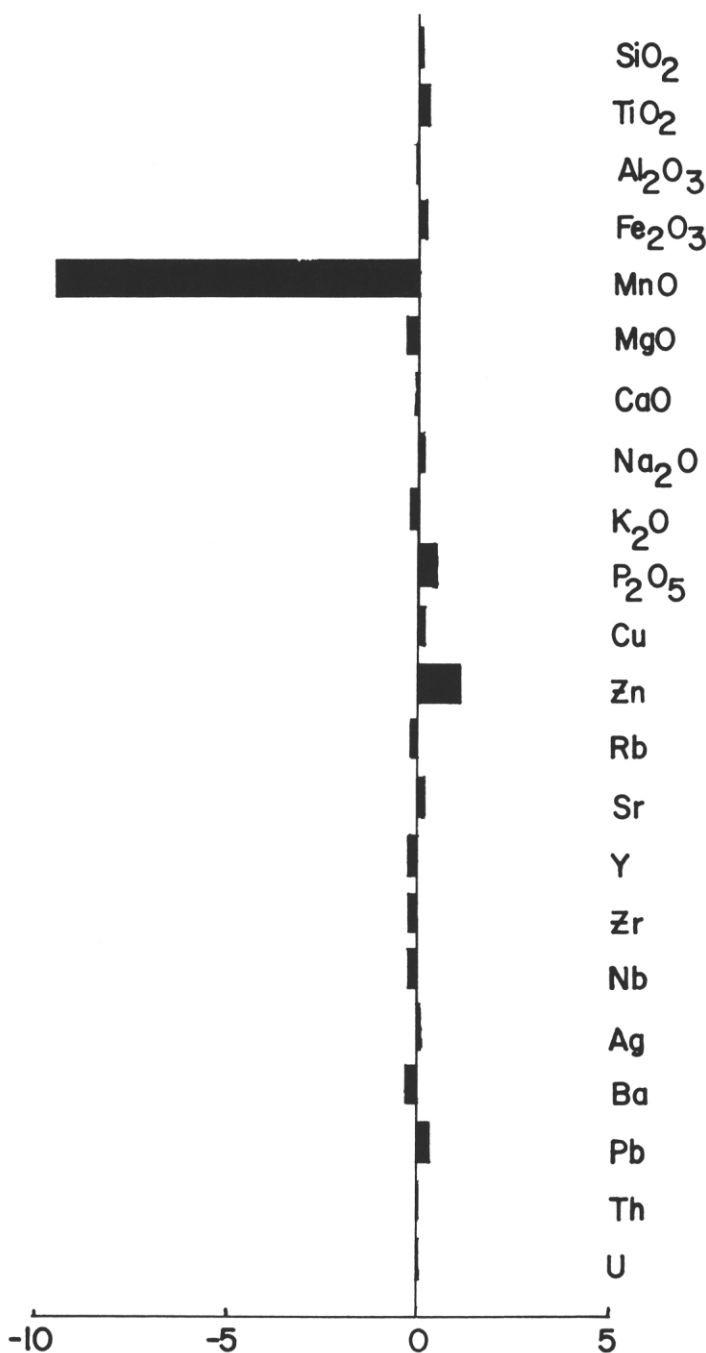

Figure 3. Enrichment factors for major and trace elements in the red alteration as compared to samples outside the red alteration. See text for method of calculation.

has an enrichment factor of 0, a positive value indicates enrichment, a negative value indicates depletion.

Of the major elements, only manganese shows a definite change during the red alteration. The MnO content of the rocks drops from an average of about .05 percent in the unaltered rocks to .005 percent in the altered rocks. This depletion is believed to be due to destruction of ferromagnesian minerals such as biotite and hornblende that survived the potassium metasomatism and to leaching of manganese from the groundmass and from interstitial iron and titanium oxides. This manganese is believed to have been transported short distances to the sites of the manganese veins and deposited from solution due to boiling of the fluids (Norman and others, this guidebook).
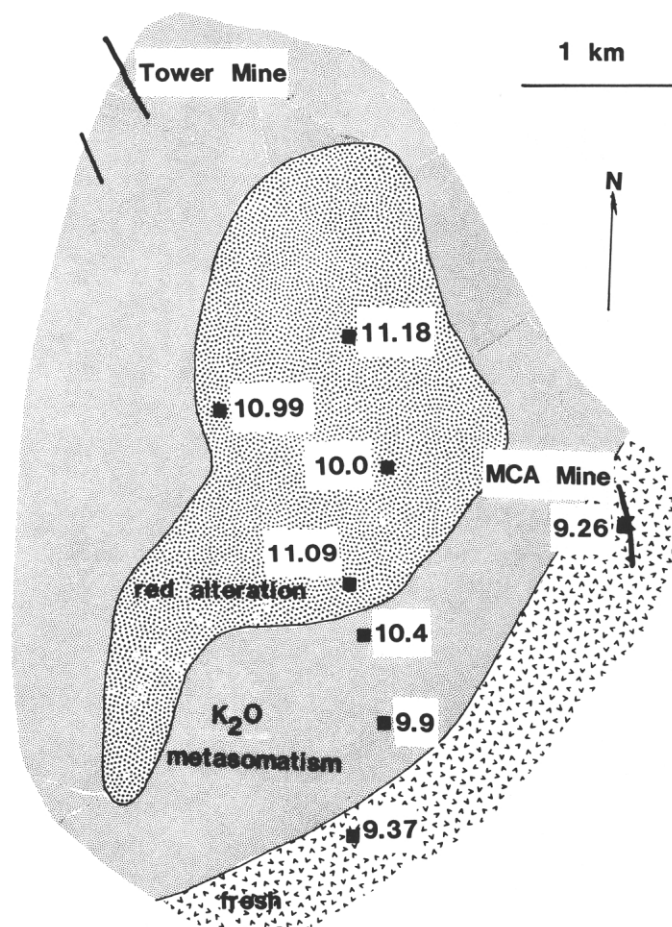

Figure 4. Location map for oxygen isotope analyses showing limits of both the red alteration and K₂O metasomatism. Oxygen values are in permil (SMOW).

to a maximum of 11.18 permit in the red alteration. The temperature of the mineralizing fluids in the manganese veins was found to be in the range of 150 to 350°C (Norman and others, this guidebook). We have hypothesized that the fluids that produced the vein mineralization and the fluids that produced the red alteration were the same; therefore, the temperature range for the mineralization is considered a minimum temperature for the alteration. At these temperatures, the calculated $8_{18}O$ of the altering fluid would be 5 to 7 permil if equilibrium between the rock and the fluid was attained (Friedman and O'Neil, 1977). These values fall within the realm of magmatic water, but the apparent volumes of water involved with the alteration and mineralization and the low salinities of the fluid inclusions (Norman and others, this volume) suggest that the fluid is probably an enriched meteoric water. Interaction of the fluid with sedimentary rock, especially carbonates which have $8_{18}O$ values in the range of 15 to 30 permit, will enrich the fluid by various amounts depending on the water-rock ratio, $8_{18}O$ composition of the sedimentary rock, rate of fluid flow, and temperature. Since there is no way of reasonably constraining the above variables, it is not possible to predict the amount of $8'_{8}O$ enrichment to be expected in the fluid. The same holds true if the fluid interacts with schists which may have a $8_{18}O$ of from 12 to 18 permil.

The two calcite samples have $8_{18}O$ compositions of 19.3 and 15.24 permil (SMOW). At 275°C, the fluids in equilibrium with these two samples will have a calculated $8_{18}O$ composition of about 12.9 and 8.85 permil, respectively (Friedman and O'Neil, 1977). These calculated compositions suggest that the mineralizing fluids were enriched in $8_{18}O$ after producing the red alteration and prior to deposition of the man-
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ganese ores. This apparent enrichment may be due to boiling of the fluids; destruction of minerals in the wallrock, such as biotite which concentrates 'SO; or deposition of minerals such as magnetite or possibly Mn oxides which concentrate '°O. The amount of enrichment due to these processes is difficult to quantify, but preliminary calculations suggest that they could not enrich the fluids by more than 1 to 3 permit. Another possibility is that the fluids were enriched to 10 to 14 permil by reaction of the fluid with heated Precambrian schists ($8_{18}O$ = 12-18 permil) and/or reaction with heated Paleozoic carbonates ($8_{78}O$ = 1530 permit; Brownlow, 1979). This enriched fluid then produced the red alteration but did not completely equilibrate with the rock during the red alteration. This incomplete reaction would have allowed the $8_{18}O$ of the fluid to remain high (9-12 permil) while enriching the rock by 1 or 2 permil. The vein calcite probably precipitated in equilibrium with the fluid and would therefore record the actual fluid composition. Carbon isotopic analyses yielded $8_{13}C$ values of —2.5 and —0.5 permit (PDB). These values are similar to those in other epithermal vein deposits (Ohmoto and Rye, 1979).

GENETIC MODEL

Integration of the geologic, geochemical, isotopic, and fluid inclusion data suggests that the manganese deposits in the Luis Lopez district formed from a circulating hydrothermal system dominated by meteoric water. Figure 5 is a schematic diagram depicting the proposed mode of origin of the manganese deposits. Meteoric water flows downward along permeable horizons and structures in Precambrian schist and gneiss, Paleozoic sedimentary rocks (dominantly carbonates), and Ter-
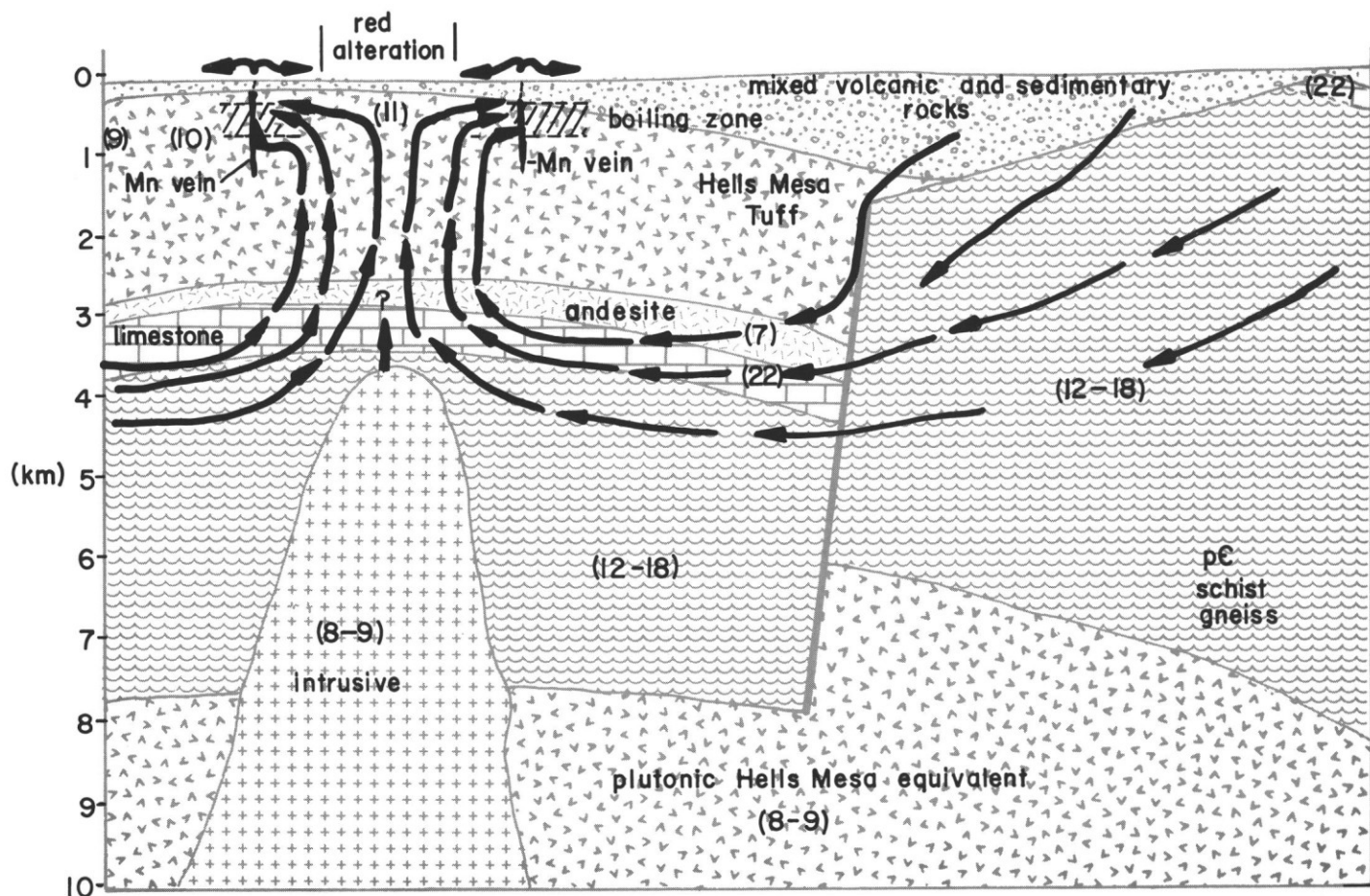

Figure 5. Model for the origin of the Luis Lopez manganese district within the Socorro cauldron. Heavy arrows show the projected direction of water flow; numbers in parentheses are possible isotopic compositions (in permil SMOW) for the various rock types. Vertical and horizontal scales are approximately the same.

tiary volcanic and volcaniclastic rocks. Since these deposits are within the Rio Grande rift, high heat flow is expected. Present-day gradients are on the order of 30 to 100°C per km with local gradients as high as 250°C per km (Reiter and Smith, 1977; Reiter and others, 1975). These high gradients could produce temperatures as high as 300 to 400°C at depths of 2 to 4 km. Isotopic equilibration of the water with the surrounding schists and carbonates at 400°C would shift the $\delta^{18}O$ composition by as much as 20 permil if equilibrium were complete and assuming low water-rock ratios. Total equilibration is unlikely, but enrichments due to partial equilibration could produce meteoric water with a PO composition of 10 to 14 permil. A focusing mechanism such as a buried intrusive or intersection of major structural features changed the direction of fluid flow from essentially horizontal to vertical. The $\delta^{18}O$-enriched water leached manganese from the Hells Mesa Tuff and the oxygen isotopes partially equilibrated producing modest enrichments in the Hells Mesa Tuff. The $\delta^{18}O$-enriched water, now carrying Mn in solution, flowed laterally along steeply dipping fractures. Precipitation of the manganese minerals was accomplished by boiling when the fluids had sufficiently low hydrostatic pressure, approximately 400 to 1400 m below the surface (Norman and others, this guidebook).

CONCLUSIONS

The geochemical, isotopic, and fluid inclusion data allow a number of important conclusions to be made. First, the volumes of water necessary and the low salinities of the fluids suggest that the water was meteoric in origin, although a magmatic component cannot be excluded. Second, the meteoric water was enriched in $\delta^{18}O$ by interaction of the water with Precambrian schists, Paleozoic carbonates, and possibly Tertiary volcaniclastic rocks. High heat flow in the region could supply the heat necessary to equilibrate the water and rock. Third, the source of the manganese in the vein deposits was the Hells Mesa Tuff which has undergone an order of magnitude depletion of manganese. Finally, boiling in high-angle fractures and breccia zones was responsible for deposition of the manganese minerals.

ACKNOWLEDGMENTS

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