



THE DESERT VIEW MINE

SAN BERNARDINO MOUNTAINS, CALIFORNIA: A POSSIBLE INTERMEDIATE BETWEEN LÅNGBAN, SWEDEN AND FRANKLIN, NEW JERSEY

Peter B. Leavens

Department of Geology
Penny Hall
University of Delaware
Newark, Delaware 19716

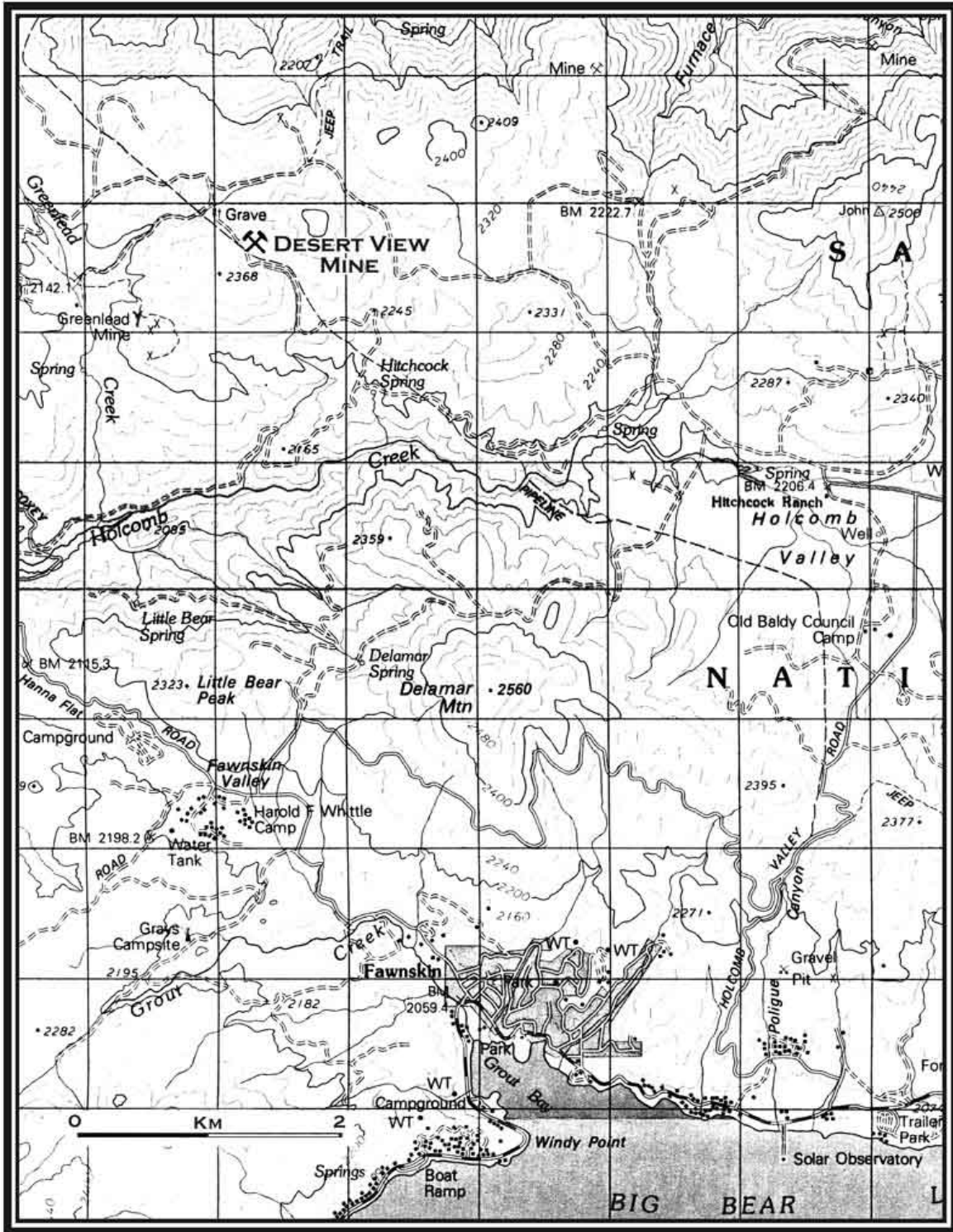
Jimmie D. Patton

Department of Geology
University of Delaware
Newark, Delaware 19716

The Desert View mine deposit bears chemical, mineralogical and genetic similarities to those at Franklin-Sterling Hill, New Jersey (including the presence of franklinite, willemite and zincite) and Långban, Sweden. Although the suite of species is far more limited and display-quality crystal specimens have not been found there, the area has been heavily collected for fluorescent minerals.

INTRODUCTION

The Desert View mine is a small prospect in Paleozoic marble in the San Bernardino Mountains, northwest of Fawnskin, California. Paul (1986) noted that the rocks of the mine include the minerals franklinite (ideally $ZnFe_2O_4$), hetaerolite ($ZnMn_2O_4$), willemite (Zn_2SiO_4), and zincite (ZnO), a suite usually considered unique to the famous Fe-Mn-Zn deposits at Franklin and Sterling Hill, New Jersey.



**Figure 1. USGS topographic map of the area.
The mine is shown near the top left.**

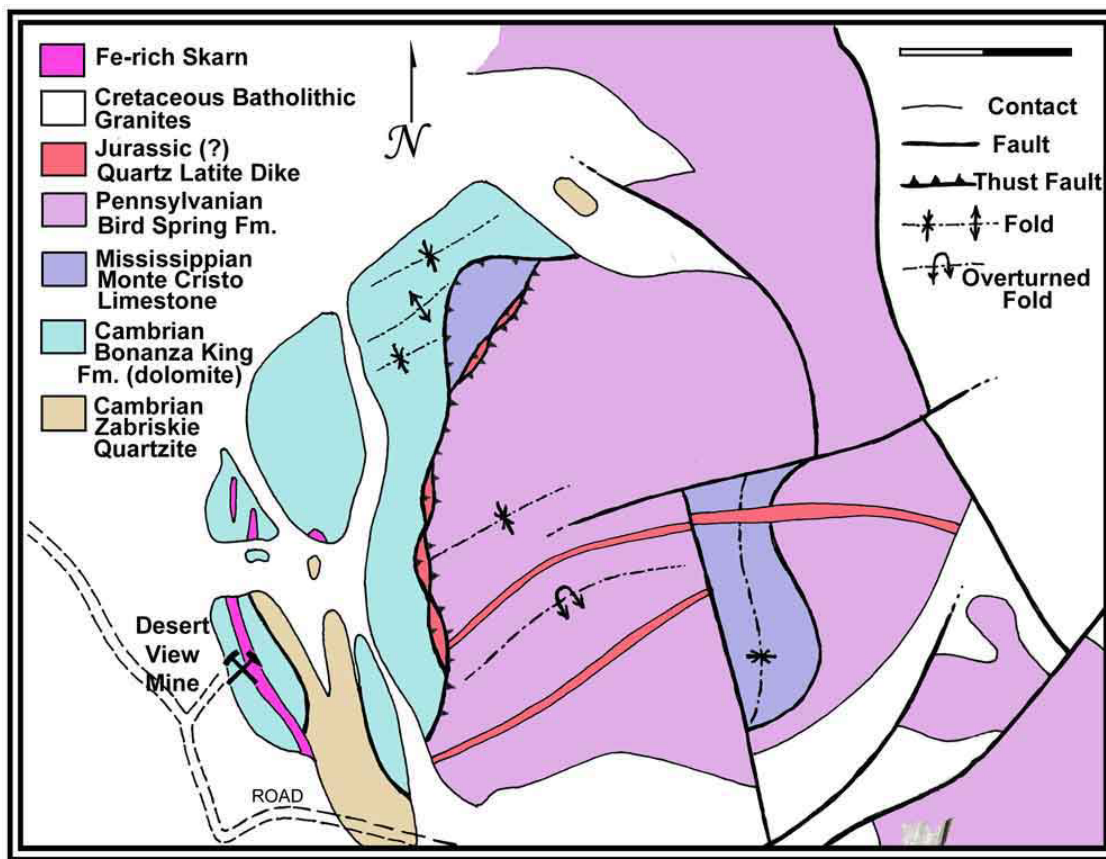


Figure 2. Sketch map of the geology around the Desert View mine (H.J. Brown, unpublished).

Hematite and magnetite-rich rocks are associated with the deposit at the Desert View mine, and are more abundant there than at Franklin-Sterling Hill (Leavens and Patton, 2000.) Although it has not been studied in any detail, the deposit appears to be exhalative—intermediate chemically, structurally, and probably genetically between the Franklin and Sterling Hill deposits of the New Jersey Highlands, on the one hand, and the Fe-Mn deposits at Långban and elsewhere in the Bergslagen district of Sweden, on the other. This article is an expansion of a preliminary article published seven years ago (Leavens and Patton, 2000).

GEOLOGY

The Desert View mine is situated in the San Bernardino Mountains of southern California, about 150 kilometers (90 miles) east of Los Angeles, at lat. 34° 18' 50" N, long. 116° 57' 55" W, in the Fawnskin 7.5" quadrangle, about 5 km (3 miles) northwest of the town of Fawnskin, California. It is within the boundaries of the San Bernardino National Forest, in steep, brushy desert, at an elevation of about 2300 meters (7600 feet), near the crest of the mountains. It is accessible by steep, narrow, unpaved roads passable by four-wheel-drive vehicles. A number of small prospects and mines dot the terrain. The northeastern slope of the mountain range is being quarried extensively for lime. Much of the area was burned over in the early 2000's, after the field work for this report was done; we don't know the current conditions in the immediately vicinity of the mine.

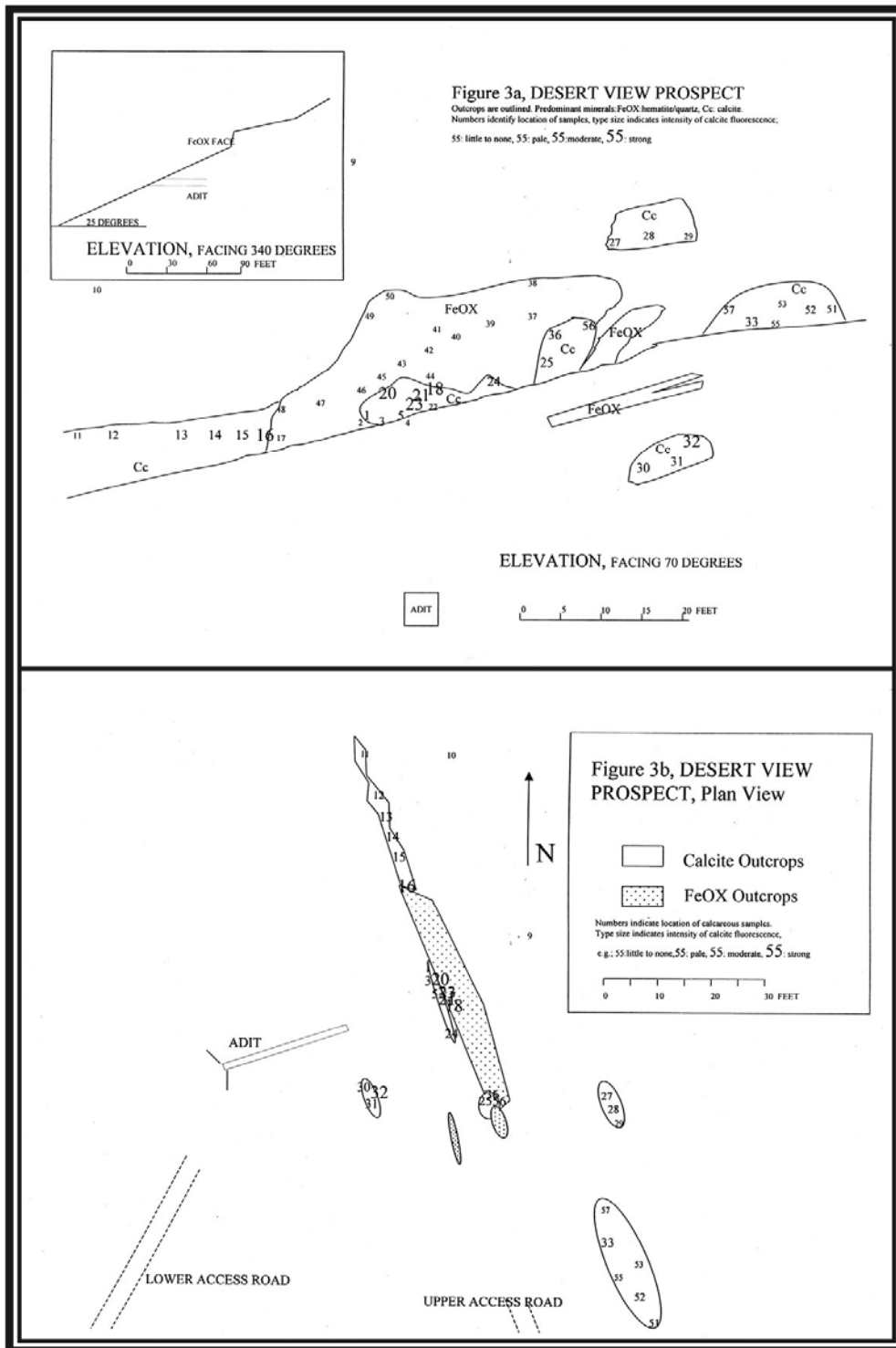


Figure 3. Desert View mine area.

The Fawnskin quadrangle was mapped by Miller *et al.* (1998); the major rocks of the area are intrusive Mesozoic granodiorites of the Southern California batholith. Contact-metamorphosed sedimentary rocks occupy roof pendants in the intrusions; these rocks can be correlated with Paleozoic cratonic to miogeosynclinal sedimentary rocks of the Mojave Desert to the east (Miller *et al.*, 1998; Brown, 1986).

The metasedimentary rocks are complexly folded and faulted. Brown (personal communication) mapped the rocks around the Desert View mine in detail (Figure 2). The mine lies in a small roof pendant, no more than a few hundred meters across, of the middle Cambrian Bonanza King Dolomite, which has been metamorphosed to wollastonite grade in the immediate vicinity. The mine consists of a few dozen square feet of surface workings in the exposed part of the orebody, and an adit about 15 meters long which was intended to intersect the ore at depth, but failed to do so.



Figure 4. Desert View mine adit. Photo by Jimmie D. Patton.

The outcrop of the orebody is about 15 meters across and about 7 meters high, striking NNW and dipping W at about 75°, roughly parallel to the contact with the dolomite. The outcrop is 1 to 2 meters thick and, being black, stands out prominently against the surrounding white marble. The deposit is a well-known fluorescent mineral locality and has been heavily collected; consequently there is an extensive apron of rubble spreading out at the base of the ore outcrop. With the exception of sparse, late veins lined with small (2 to 3-mm) green andradite crystals, all of the minerals of the deposit are massive.



Figure 5. Oblique view of outcrop from below. Photo by Jimmie D. Patton

PREVIOUS WORK

Paul (1986) described some of the minerals of the mine and reported several mineral assemblages, including hetaerolite ($ZnMn_2O_4$) + zincite + quartz with associated willemite (Zn_2SiO_4) + calcite, magnetite (in solid solution) + andradite + willemite + epidote + quartz, and calcite + grossular + wollastonite + altered Mg silicate. He identified hetaerolite as the most abundant metallic oxide, and proposed a complex origin for the deposit involving deposition of manganese oxide in a shallow water setting, high-temperature contact metamorphism to form the grossular + wollastonite assemblage, contact metasomatism by solutions saturated with zinc sulfide which reacted with the manganese oxides to produce the hetaerolite, and later-stage and retrograde reactions to form the other mineral assemblages.

CURRENT WORK

In the summer of 1998 a suite of more than 50 samples was collected from the orebody and surrounding marble, and a sketch map made of their locations (Figure 3). The samples were examined in shortwave ultraviolet light to determine the distribution and intensity of the red fluorescence, and thus of the Mn content, of calcite (Fig. 3), and to find wollastonite, which fluoresces yellow, and willemite, which fluoresces green. Most samples were subjected to X-ray diffraction analysis, using a computer-controlled

diffractometer and analytical software to determine the minerals present (Table 1). EDAX analysis was performed on selected samples to provide compositional information; however, polished sections were not prepared, so the results are only semiquantitative. A dozen thin sections of the texturally and mineralogically complex samples were prepared for transmitted light-polarized light microscopy (PLM).

The most abundant ore mineral assemblage in the samples collected is hematite ± magnetite ± quartz. The hematite rock is black, dense, and fine-grained; several samples have dark green crusts of andradite garnet coating fracture surfaces. Hematite rock appears to compose most of the surface outcrop of the orebody (Fig. 3). The rock appears rusty when weathered, providing a means of identification in future fieldwork. Associated with the hematite rock are masses of andradite garnet skarn, with minor non-fluorescent calcite. Hetaerolite is much more restricted in its distribution: only one sample was collected in place, from the base of the outcrop (Fig. 3, sample 22.), and a few others from nearby float. Sample 22 is dense, black to brownish black hetaerolite, superficially weathered to sooty Mn oxides; this difference in weathering distinguishes hetaerolite from hematite rock. Associated with the hetaerolite rock is mineralized marble containing fluorescent manganese-rich calcite, minor green-fluorescent willemite in grains measuring 1 to 2 mm, and trace zincite. Quartz was not observed in this assemblage.

Skarns containing fluorescent calcite, wollastonite, grossular and (in one sample) vesuvianite occur at the periphery of the hetaerolite ore. The intensity of fluorescence in calcite varies with distance from the ore, and in particular with distance from the hetaerolite ore, suggesting that there is an Mn-enriched halo in the marble surrounding the orebody.

Table 1. Mineralogy of samples from the Desert View mine, based on visual observation, fluorescence, and X-ray diffraction analysis. Numbers correspond to locations in Figure 1.

1. Calcite, willemite	23. Calcite, willemite	41. Quartz, magnetite
2. Hematite	24. Calcite	42. Quartz, hematite
3. Calcite, grossular	25. Calcite	43. Quartz, hematite
4. Calcite, wollastonite	26. Wollastonite, calcite, grossular	44. Andradite
5. Calcite, grossular, wollastonite	27. Wollastonite, calcite	45. Quartz, hematite
9. Quartz, microcline, wollastonite	28. Calcite, wollastonite	46. Grossular
10. Wollastonite, grossular	29. Wollastonite	47. Quartz, garnet
11. Grossular, minor calcite	30. Calcite	48. Hematite
12. Calcite	31. Grossular, calcite	50. Andradite, hematite, magnetite
13. Calcite	32. Calcite, magnetite	51. Calcite
14. Calcite	33. Calcite, wollastonite	52. Calcite
15. Calcite, wollastonite	34. Calcite, willemite, grossular	53. Calcite
16. Calcite	35. Andradite	54. Wollastonite, calcite
17. Quartz, hematite	36. Andradite, magnetite	55. Calcite, wollastonite
18. Calcite	37. Quartz, magnetite	56. Calcite
20. Calcite, grossular	38. Quartz, magnetite	57. Calcite, wollastonite
21. Grossular, calcite	39. Quartz, hematite, magnetite	58. Wollastonite, grossular
22. Hetaerolite, willemite	40. Quartz, hematite, magnetite	

DISCUSSION

Despite the location of the deposit in a roof pendant and the proximity of the granodiorite, the iron-rich portions of the Desert View deposit do not have the characteristics of metasomatic, iron-rich skarns typified by the deposits in southeastern Pennsylvania (Spencer, 1908; Lapham and Gray, 1973.) The Pennsylvania deposits are coarse and variably grained, have abundant magnetite and rare hematite, and contain accessory sulfides, and quartz is rare or absent in the massive ore. The Desert View deposit is fine-grained, hematite is more abundant than magnetite, quartz is abundant in some samples, and sulfides are absent. Paul (1986) proposes a hybrid exhalative-contact metasomatic origin for the Desert View deposit, but we believe that the deposit can be more simply characterized as purely exhalative.

Exhalative deposits have formed by deposition of minerals from waters which emanate from vents or springs into fresh or marine waters; typically the latter are of lower temperature, higher pH, and different chemistry than the exhalative waters. Oxide deposits contain iron, manganese, or rarely both. Huebner (1976) notes that hausmannite, MnMn_2O_4 , is stable under conditions where hematite and magnetite coexist, but that manganese is normally separated from iron in sedimentary deposits because of the greater solubility of manganese in acid waters. In addition, Mn has higher oxidation states with higher oxidation potentials than Fe^{3+} , and higher oxides of manganese are not typically found with hematite.



Figure 6. Sampling area (to right of outcrop). Photo by Jimmie D. Patton.

The most widespread exhalative oxide deposits are the fresh-water “bog irons” which are found in quiet lacustrine and swamp environments with low clastic sedimentation rates. They are composed of poorly crystallized iron hydroxides and oxides collectively called “limonite,” and were widely mined on a small scale for iron ore up until the middle of the 19th century; e.g., bog iron supported the iron smelting industry of the Pine Barrens of southern New Jersey. The iron is dissolved in ground water which is similar in

temperature and pH to the surface water, but which is less oxygenated; on reaching the surface in springs, the water becomes aerated and the iron oxidizes and precipitates.

The Jurassic Buckeye manganese deposit in the California Coast Ranges southeast of San Francisco has been studied intensively by Huebner and Flohr (1990). It lies in melange of the Franciscan Complex, and has been metamorphosed to blueschist grade. It contains banded ores rich in manganese silicates, oxides (particularly hausmannite and braunite, Mn_7SiO_{12}), and rhodochrosite, $MnCO_3$. Iron minerals are absent. The host rocks are turbidites and cherts. The deposit is small, less than 250 meters across in maximum dimension. The Buckeye is similar to other bedded manganese deposits (Huebner, 1976), but is different from the Desert View in geologic setting and especially in lacking associated iron oxides.

The Franklin and Sterling Hill deposits of New Jersey have been extensively studied (Fron del and Baum, 1974; Johnson, Rye, and Skinner, 1990; a comprehensive bibliography may be found in Dunn, 1995.) Each deposit was continuously mineable for more than 500 meters along strike. The country rock is the Franklin Marble, a highly mineralized dolomitic marble. The scattered and localized distribution of the ore suggests that it may have been deposited in a restricted rift environment (Drake, 1990). The marble is part of the New Jersey Highlands of late Precambrian (Grenville) age, which have been strongly deformed and metamorphosed at granulite grade, at a temperature of about 750°C and a pressure of about 5 kb, during the Grenville Orogeny.

At Franklin and Sterling Hill, zinc was a major component of the ores, and iron, zinc and manganese were found together, predominately in the mineral franklinite, a Zn-Fe-Mn spinel of complex composition (Leavens and Nelen, 1990.) Iron is predominantly trivalent and manganese divalent in franklinite; Leavens (1988) suggested that this close association indicated that the iron had been deposited originally as oxides and hydroxides, and the zinc and manganese as carbonates and silicates, under conditions of buffered or restricted f_{O_2} . Additional important ore minerals were willemite, Zn_2SiO_4 , and zincite, ZnO. Distinct bands of ore minerals and manganese-rich calcite appear to be original beds, highly recrystallized and deformed (Metzger *et al.*, 1958). Johnson, Rye and Skinner (1990) showed that the ores were depleted in ^{18}O relative to the surrounding marble, and that they could not have been deposited by the waters that deposited the original limestone. Using realistic assumptions, they concluded that the waters which deposited the ores had equilibrated with other sedimentary rocks, probably pelites, and were in the temperature range of 100 - 125°C.

The iron-manganese deposits of the Bergslagen district, Sweden (Moore, 1970) are Archean in age. Långban is the most famous of these deposits, but over 1,000 small mines and prospects are known in the Bergslagen district. They are enclosed in dolomitic marble and lie stratigraphically above metavolcanic rocks ("leptites"); the rocks have been highly deformed, and metamorphosed to amphibolite grade. Iron and manganese ores are separated but adjacent, with manganese ores stratigraphically above iron ores. The iron ores are typically composed of hematite, magnetite, and quartz; the manganese ores are predominantly hausmannite and braunite. The manganese, like the iron, is predominantly trivalent.

Banded iron formations and bedded manganese deposits of late Archean to Proterozoic age are widespread. Although too extensive to be considered exhalative spring deposits, they all contain similar minerals and were chemically precipitated in aqueous environments. The largest bedded manganese deposit in the world is the Kalahari manganese field in South Africa (Wilson and Dunn 1978; Tiskos *et al.*, 2003). Of middle Proterozoic age (about 2100 mya) and covering more than 1,100 km², the deposits were probably deposited from hypersaline waters in a restricted marine basin. The deposits are underlain by lava flows, which are topped by red hematitic jasper, followed by pisolitic hematite lutite (fine-grained sediment), which grades up into microcrystalline, kutnohoritic, pisolitic braunite lutite (Von Bezing *et al.*, 1991); there are three such cycles of jasper and lutite. Minor minerals in the manganese ores include hausmannite, jacobsite ($MnFe_2O_4$), and hematite.

Differences in the mineral associations in these various deposits may depend on the chemistry and

temperature of the exhalative waters, but seem particularly dependent on oxidation potential and pH. Bog ores are deposited in freshwater, slightly acid to slightly alkaline environments in equilibrium with modern atmospheric oxygen. The Buckeye was deposited in a deep-water marine environment, more alkaline than fresh water, but with calcium carbonate absent (Huebner and Flohr, 1990); it presumably formed below the carbonate compensation depth. The presence of rhodochrosite in the ores suggests a somewhat lower oxidation potential for this deposit than for typical bog ores. In carbonate environments, exhalative waters would be buffered to slightly alkaline conditions more rapidly than waters in a non-carbonate environment, such as the siliciclastic environment around the Buckeye. Deposition of manganese would be much more rapid in the carbonate environment, and the iron and manganese minerals could be precipitated together. The particular species deposited would depend on the oxidation potential of the environment as well as on the pH. This model may explain why Franklin, Sterling Hill, Långban and the Desert View, all in carbonate rocks, contain both iron and manganese minerals, unlike many other exhalative deposits.

The Desert View deposit appears to have the distinct separation of iron and manganese minerals characteristic of the Långban-type deposits, but it contains a number of minerals characteristic of Franklin/Sterling Hill: franklinite, hetaerolite, willemite, and zincite, none of which are reported from Långban (Moore, 1970.) Hetaerolite is particularly significant: it was originally described from Sterling Hill (Palache, 1935) as a secondary mineral formed by the weathering of franklinite ore: the iron from the franklinite formed associated ferric oxides and hydroxides. Hetaerolite was subsequently detected in one high-temperature ore sample from Franklin by Leavens and Nelen (1990), who interpreted it as primary exhalative hetaerolite that had survived the granulite-grade metamorphism of the Franklin deposit. If this model is correct, the massive hetaerolite at the Desert View could have been an original mineral of the exhalative ore. Zincite and willemite can be generated in a number of ways by metamorphism of appropriate sedimentary precursors (Leavens, 1988); in the way that is chemically simplest, zincite (ZnO) would form from the decarbonation of smithsonite ($ZnCO_3$) and willemite ($ZnSiO_4$) from the dehydration of hemimorphite ($Zn_2Si_2O_7(OH)_2$). Hetaerolite, smithsonite and hemimorphite are associated in oxidized ore at the Wolfstone mine, Leadville, Colorado, although their formation as primary exhalative minerals has not been established.

A substantial problem with the exhalative model for the origin of the Desert View deposit is a source for the iron, manganese, and especially zinc to form the deposit in a quiet continental shelf environment. There is little hope of determining such a source, as much of the earlier geology of the area has been obliterated by the intrusion of granodiorite. However, the deposit does fit the exhalative model in structure and mineralogy. More work is needed to find the full extent of the ores, determine the distribution of iron and manganese minerals, and decipher the geologic history of the Desert View deposit, but we believe that chemically and genetically it is intermediate between the Långban and the Franklin/Sterling deposits. So few of these deposits are known (the Champion Mine in the Keweenaw Peninsula of Michigan is another possible analog) that further study of the Desert View deposit would enhance our understanding of their nature and formation. Such a study should include mapping of fluorescence in the calcite around the ores, and ideally would include measurement of oxygen isotopes in the marble, both around the deposit and at greater distances from it. If the deposit is exhalative and the exhalative waters were recycled marine water, the isotopic signatures of the marble and of carbonates of the deposit away from skarns (and therefore removed from the influence of metamorphic decarbonation reactions) should be similar. If the exhalative waters were derived from clastic sediments such as pelites, the isotopic signature of the marble close to the ores would be different from that of the more distant marbles. If the deposit is partly of contact-metasomatic origin, as suggested by Paul (1986), the oxygen isotopes should show signs of equilibration with water derived from granitic rocks, as magmatic waters are typically very different isotopically from ocean water (Taylor and Sheppard, 1986; Valley, 1986).

A number of other prospects and small mines are indicated on the Fawnskin quadrangle. The most

prominent is the Greenlead mine, named for nearby Greenlead Creek, which lies about 1 km southwest of the Desert View. The road between the two is about 1.5 km long and has both a drop and a climb of about 200 meters; the Greenlead mine is substantially more isolated and difficult of access than the Desert View. There was not enough time or appropriate transportation to visit the Greenlead during the field visit in the summer of 1998, but there are reports from collectors that there are fluorescent minerals there. The fluorescent minerals calcite, wollastonite, and willemite found at the Desert View all contain manganese, and it seems possible that if there are indeed fluorescent minerals at the Greenlead, they would be manganese-bearing. This possibility would warrant the effort necessary to visit the Greenlead deposit in any future study. There is also a cluster of prospects about 8 km east of the Desert View, above the headwaters of Caribou Creek, which might be worthy of investigation.



Figure 7. At the Desert View mine, July 1998. Left to right: J. D. Patton, John Jenkins, Dan McHugh and Jack Neiburger..

COLLECTING ACCESS

The Desert View mine is currently under claim by Claudia Mitchell and Lyman V. Hays, P. O. Box 5592, Oxnard, CA 93031. Unauthorized collecting at the site is strictly prohibited.

ACKNOWLEDGMENTS

Manuel Robbins first called our attention to fluorescent calcite and willemite at the Desert View mine a number of years ago. Howard Brown provided information, advice, and the detailed map included in this report. We thank them.

BIBLIOGRAPHY

BOWMAN, J. R. (1998) Basic aspects and applications of phase equilibria in the analysis of metasomatic Ca-Mg-Al-Fe-Si skarns. In Lentz, D.R., ed., *Mineralized Intrusion-Related Skarn Systems*.

- Mineralogical Association of Canada Short Course, Volume 26, 1-49.
- BROWN, H. J. (1986) Stratigraphy and paleogeographic setting of Paleozoic rocks in the northern San Bernardino Mountains. In Kooser, M. A. and Reynolds, R. F., eds., *Geology Around the Margins of the Eastern San Bernardino Mountains*. Inland Geological Society IV, 105-115.
- DUNN, P. J. (1995) *Franklin and Sterling Hill, New Jersey: the World's Most Magnificent Mineral Deposits*, Part 1, 1-66. Franklin-Ogdensburg Mineral Society.
- DRAKE, A. A. (1990) The regional geologic setting of the Franklin-Sterling Hill District. In *Character and Origin of the Franklin-Sterling Hill Orebodies*. Proceedings volume, Lehigh University Department of Geological Sciences and the Franklin-Ogdensburg Mineralogical Society Symposium, 14-31.
- FRONDEL, C., and BAUM, J. L. (1974) Structure and mineralogy of the Franklin zinc-iron-manganese deposit, N. J. *Economic Geology*, **69**, 157-180.
- HUEBNER, J. S. (1976) The manganese oxides, a bibliographic commentary. In Rumble, D., ed., *Oxide Minerals*, Mineralogical Society of America Short Course Notes, Volume 3, SH1-SH17.
- HUEBNER, J. S., and FLOHR, M. J. K. (1990) Microbanded manganese formations: protoliths in the Franciscan Complex, California. *U. S. Geological Survey Professional Paper 1502*. 72 pages.
- JOHNSON, C. A., RYE, D. M., and SKINNER, B. J. (1990) Petrology and stable isotope geochemistry of the metamorphosed zinc-iron-manganese deposit at Sterling Hill, New Jersey. *Economic Geology*, **65**, 1133-1161
- LAPHAM, D. M., and GRAY, C. (1973) Geology and origin of the Triassic magnetite deposits and diabase at Cornwall. Pennsylvania Geological Survey, 4th series, *Mineral Resources Report 56*. 343 pages.
- LEAVENS, P. B. (1988) Protore and metamorphism of the Franklin and Sterling Hill (New Jersey) Zn-Fe-Mn ore deposits. Program and abstracts, V. M. Goldschmidt Conference, Baltimore, Maryland.
- LEAVENS, P. B., and NELEN, J. A. (1990) Franklinites from Franklin and Sterling Hill, New Jersey, and oxygen fugacities of the deposits. In *Character and Origin of the Franklin-Sterling Hill Orebodies*. Proceedings volume, Lehigh University Department of Geological Sciences and the Franklin-Ogdensburg Mineralogical Society Symposium, 49-62.
- LEAVENS, P. B., and PATTON, J. D. (2000) The Desert View Mine, San Bernardino Mountains, California: a possible intermediate between Långban, Sweden, and Franklin, New Jersey. *San Bernardino County Museum Association Quarterly*, **47** (1), 17-21.
- METZGER, R. W., TENNANT, C. B., and RODDA, J. L. (1958) Geochemistry of the Sterling Hill deposit, Sussex County, New Jersey. *Geological Society of America Bulletin* **69**, 775-788.
- MILLER, F. K., MATTI, J. C., BROWN H. J., and POWELL, R. L. (1998) Digital geologic map of the Fawnskin 7.5' quadrangle, California, v. 1.0: U. S. Geological Survey Open-File Report 98-579.
- MOORE, P. B. (1970) Mineralogy and chemistry of Långban-type deposits in Bergslagen, Sweden. *Mineralogical Record*, **1**, 154-172.
- PALACHE, C. (1928) The phosphorescence and fluorescence of Franklin minerals. *American Mineralogist*, **13**, 330-333.
- PALACHE, C. (1935) The minerals of Franklin and Sterling Hill, Sussex County, New Jersey. *U. S. Geological Survey Professional Paper 180*. 135 pages.
- PAUL, T. A. (1986) Minerals of the Desert View Mine. In Kooser, M. A. and Reynolds, R. F., eds., *Geology around the Margins of the Eastern San Bernardino Mountains*. Publication of the Inland Geological Society IV, 117-120.
- SPENCER, A. C. (1908) Magnetite deposits of the Cornwall type in Pennsylvania. *U. S. Geological Survey Bulletin* **359**. 102 pages.
- TAYLOR, H. P., and SHEPPARD, S. M. F. (1986) Igneous rocks I: processes of isotopic fractionation and isotopic systematics. In Valley, J. W., Taylor, H. P., and O'Neil, J. R., eds., *Stable isotopes in high temperature geological processes*. *Reviews in Mineralogy*, **16**, 227-272.

- TISKOS, H., BEUKES, N. J., MOORE, J. M., and HARRIS, C. (2003) Deposition, diagenesis, and secondary enrichment of metals in the Paleoproterozoic Hotazel Iron Formation, Kalahari manganese field, South Africa. *Economic Geology*, **98**, 1449-1462.
- VALLEY, J. W. (1986) Stable isotope geochemistry of metamorphic rocks. In Valley, J. W., Taylor, H. P., and O'Neil, J. R., eds., Stable isotopes in high temperature geological processes. *Reviews in Mineralogy*, **16**, 445-486.
- VON BEZING, K. L., DIXON, R. D., POHL, D., and CAVALLO, G. (1991) The Kalahari manganese field: an update. *Mineralogical Record*, **22**, 279-297.
- WILSON, W. E., and DUNN, P. J. (1978) Famous mineral localities: the Kalahari manganese field. *Mineralogical Record*, **9**, 137-153.