

fluid pressure cannot be made because the depth of emplacement of the Belknap Complex has not yet been determined, and estimates cannot be made from the mineral assemblages present.

### Zoning

#### Ground Preparation

Ground preparation was important in controlling the shape of the deposit, and of the zones within each of its three episodes, in two ways. The first was through structural control; fracture sets 2 and 3 allowed mineralizing fluids to migrate through the study area. Deposition was restricted to the vicinity of joints in the Belknap Syenite. Many of the joints at the site are not single fractures, but are fracture zones a few inches wide. The early stages of activity filled some of the zones with an amphibole-dominant assemblage, which was apparently less brittle than was the unaltered syenite. Later microfaulting was restricted to single fractures, rather than to fracture zones, and later deposition therefore occurred along single veins.

In addition to restricting the extent of later fracturing, the early zones appear to have restricted the migration of later fluids into the alteration zone. Alteration to the outside of the amphibole zone, that can be correlated with the cores, is restricted to an overprint of ferrohastingite; however syenite wall rock that is in contact with the cores contains clinozoisite as the ferromagnesian mineral,

suggesting that early vein material controlled the mineralogy of later metasomatic events in addition to restricting their intensity and extent.

#### Parameters Influencing Zoning

It is suggested that mineralogical zoning was controlled by the nature of the incoming fluids; while the adjacent wall rock material, both syenite and early zones of vein material, exerted only local influence over the composition of the later minerals. Members of the clinozoisite-epidote series occur as iron-silicates in the cores of the two earlier vein types regardless of the composition of the wall rock. Where the wall rock adjacent to the epidote-magnetite zone is syenite, the feldspars have been partially replaced by clinozoisite, with no accompanying change in the mineralogy of the adjacent core zone. In addition, the abundant syenite fragments within the epidote-dominant zones were relatively unreactive to mineralizing fluids, as they are seldom replaced to a greater degree than they are in the adjacent wall rock. The mineral composition of vein 3, of the amphibole vein type in the upper cut, does not change with variation in the adjacent material from amphibole to syenite, suggesting that its composition was also controlled by the depositing medium.

Several properties of the incoming fluid may have influenced the zoning and each other as well, making it difficult to single out any one parameter; however constraints can be placed upon some of the fluid properties. Mineral assemblages

suggest that total pressure and temperature were relatively most of the depositional sequence. According to Holdaway (1974, p. 334), a high calcium to sodium ratio in the reactive minerals favors the persistence of epidote over amphibole into the hornblende-hornfels facies. Within each of the episodes, the calcium to sodium ratio increases from unaltered syenite to the core zones; therefore it is possible that the increase in calcium content influenced the zoning.

A second parameter to consider is the fugacity of oxygen ( $fO_2$ ). Variation in  $fO_2$  has been cited in the literature (Holdaway, 1972, p. 337; Keith and others, 1968, p. 1641-1642), as having influenced the compositions and stability fields of the pargasite-ferrohastingsite and clinozoisite-epidote series under experimental conditions. Increasing  $fO_2$  favors epidote over garnet or amphibole (Ernst, 1968; p. 71) and iron-rich epidote over aluminum-rich epidote, or clinozoisite (ibid.). Zoning within each vein type of ferrohastingsite to clinozoisite to epidote, and of magnetite to hematite suggests that  $fO_2$  increased during the course of deposition of each episode. There appears to have been relatively little change in  $fO_2$  during the deposition of the amphibole vein type, and there is no obvious change in the pattern of any of the parameters among the three vein types to indicate a major compositional change at the source of the fluids over the course of formation of the deposit.

### Source

It is suggested that a single source for the mineralizing fluids existed for the three vein types. All have the same initial mineralogy, with relatively little influence being exerted by the host rock. This suggests the initial fluids were of similar composition. An origin of the fluids outside of the complex can be eliminated in the absence of a regional metamorphic event, at the time of their formation, to mobilize large quantities of calcium and iron. A more likely source, although a speculative one due to a lack of field evidence, would be late-stage aqueous fluids from a partially crystallized intrusion within the complex. The metal components could already be present within the fluid or could have been leached from the wall rock between the source and the site of deposition. Such a source has been suggested for other hydrothermal magnetite deposits, notably at Iron Springs, Utah (Mackin and others, 1960) and Laurel Hills, New Jersey (Puffer and others, 1974).

A possible source for the mineralizing fluids is the Conway Granite, which intrudes to within 1800 feet of the deposit on two sides (Fig. 1). The rock type makes up a large volume percent of the complex. Cox (1970, p. D4) suggested the Conway Granite was the source for hydrothermal deposits associated with other complexes in New Hampshire because it was the youngest intrusion in the White Mountain Series large or extensive enough to have created such deposits. Within the Belknap Complex, the Conway Granite often contains

Complex	Iron Springs, Utah	Laurel Hills, N.J.	Mount Gunstock, N.H.
Location	Southwestern Utah	Northern New Jersey	Central New Hampshire
Age of Intrusion	Uncertain, Mio- cene-Eocene	Triassic	Jurassic
Shape of Intrusion	Stock in Mesozoic sedimentary rocks	Plug in Triassic sedimentary rocks	Multiple ring dike complex in Paleozoic metasediments
Structure of Mineral Deposit	Veins in outer shell of quartz monzonite porphyry; massive replacement of country rock (ls) in alteration halo of intrusion; veins surrounded by bleached zones	Veins along joints within pluton; veins surrounded by bleached zones; host rock is a diabase	veins along joints in Belknap Syenite member of complex; Ca, Fe added to wall rock surrounding veins; several episodes of fracturing occurred along veins and was accompanied by mineralization
Minerals Alteration or replacement	Hematite, minor magnetite	Kaolinite, Chlorite, ilmenite, calcite	Ferrohastingsite, magnetite, sericite
Vein	Magnetite, apatite; minor pyroxene, calcite	Dominant ilmeno- magnetite; minor quartz, chlorite, titanite, pyrite, calcite	Dominant epidote, ferrohastingsite, magnetite; minor pyrrhotite, marcasite, apatite, oligoclase, quartz, tremolite, prochlorite, sphene, pyrite
Temperature, 's centigrade	500-600	625-827	400-450, lowering to 350 at end of each vein
Proposed Origins	hydrothermal, unrelated to intrusion (Drew, 1972; p. 520-522) deuteric leaching within intrusion; release of fluids and replacement of surrounding metasediments (Mackin and others, 1960.)	Deuteric leaching within intrusion; deposition of leached materials in adjacent joints (Puffer and others, 1974)	Hydrothermal at site; possibly derived from aqueous fluids from nearly-crystallized intrusion within complex
Source Rock	possibly quartz monzonite porphyry	Diabase	possibly Conway Granite

Figure 22. Table comparing Mount Gunstock deposit with other deposits whose origins are similar to that proposed for Mount Gunstock.

miarolitic cavities, indicating that, at some time in its crystallization history, it contained an aqueous phase. In addition, the only post-Conway units in the complex are the Rowes Vent Agglomerate (Fig. 1) and a few felsic and mafic dikes. Other possible sources for the deposit are the other nearby intrusions: the Albany Porphyritic Quartz Syenite, the Sawyer Quartz Syenite, the host rock Belknap Syenite, and other younger rock units at depth. Compared with the Conway Granite, these intrusions outcrop over small areas. The Belknap Syenite is the only major rock unit in the complex, other than the Conway Granite, to contain miarolitic cavities.

The Iron Springs deposit is classified as igneous-metamorphic, as much of it replaces metasediments inside the alteration halo of the source intrusives. If the Mount Gunstock deposit were shown to have emanated from one of the intrusions surrounding the Belknap Syenite, the veins could also be classified as igneous-metamorphic. As the field evidence does not point toward a specific source, the deposit is classified as hydrothermal, based on the probably nature of the mineralizing fluid at the study site.

#### Mechanism of Formation

Cox (1970, p. D4) suggested that intruding Conway Granite magma domed the country rock, and late-stage aqueous fluids escaped through the resulting tension fractures. Fluids could be released through local fracturing of the roof rocks by:

1. contraction associated with cooling, 2. a buildup of fluid pressure beyond the strength of the roof rocks. In support of the latter, Secor (1965, p. 644) suggested that hydraulic fracturing could occur at depth. A drop in fluid pressure would accompany expansion into the country rock fracture systems, possibly causing deposition of minerals in response to the changing conditions (Reybould, 1976; p. 640). In addition, the fluid pressure drop would allow more of the aqueous phase to evolve from the silicate melt, thus assuring a continued supply of mineralizing fluid. The resulting deposition of the minerals would fill the fractures in the absence of further activity. Given a sufficient supply of the fluid phase, several sets of veins could form in response to a repeated buildup of fluid pressure within the source intrusion and to the subsequent fracturing of the roof rocks. Such a mechanism is similar to that proposed for the Iron Springs deposit (Mackin and others, 1960) and Laurel Hills (Puffer and others, 1974).

Within the Belknap Complex, this mechanism could apply to other intrusions as well as to the Conway Granite. Fracture sets which could have acted as channel ways for the migration of mineralizing fluids, exist in all of the rock units, including the host rock Belknap Syenite. Within the deposit, fracturing was frequent and was generally accompanied by mineralization, suggesting a relationship between the two processes. Mirolitic cavities and other evidence of open space filling is common and suggests that fluid pressure was high.

Thus evidence within the complex and deposit is compatible with the suggested mechanism of formation.

A single source for the three vein types suggests a repeated buildup of fluid pressure at its source, resulting in three episodes of fracturing of the roof rocks. The mineral assemblages within each vein type suggest that the fluid composition within the veins changes with time; while its composition at the source remained relatively constant. This suggests that the fluid was cut off from its source, possibly by deposition, shortly after each fracture was opened. The fluid could have then evolved through the deposition of its constituents. Local buildups of fluid pressure, due to such deposition, could cause additional fracturing within the veins, accompanied by a pressure drop and mineralization. Fracturing could also be caused by outside tectonic activity, for example, by the adjustment of the country rock to the source intrusion.

Thus a possible mechanism of formation for the Mount Gunstock deposit is similar to that proposed by Cox (1970) for mineral deposits surrounding the Conway Granite elsewhere. Buildup of fluid pressure within a nearly-crystallized intrusion bordering, or possibly within the Belknap Syenite caused three episodes of local fracturing of its roof rocks. Some of the fluid was released into fracture systems within the Belknap Syenite. Deposition, possibly due to a drop in fluid pressure, followed and may have cut the fluid within the fractures off from its source. Fluid composition then changed

with time as some of its components were deposited. Local buildups in hydrostatic pressure may have caused later fracturing and mineralization within the veins. On a geologic scale, the deposit probably formed over a short time span during the latest cooling stages of a single member of the Belknap Complex.

## CONCLUSIONS

The Mount Gunstock deposit appears to be a multi-stage hydrothermal vein system localized along northwesterly and northeasterly-trending joint sets.

Although a lack of field evidence makes the suggestion of an origin speculative, the deposit may have formed when local tectonic activity fractured the outer shell of a partially cooled intrusion, allowing small amounts of the late-stage aqueous fluid to escape into an already-formed joint system within the Belknap Syenite. Such an origin has been proposed for similar magnetite deposits at Iron Springs, Utah, and Laurel Hills, New Jersey, and for a number of mineral deposits associated with White Mountain Series intrusions in central and Northern New Hampshire. Within the Belknap Complex, the most likely source rock is the Conway Granite.

Several controls appear to have been influential in determining the nature of the deposit. The intensity of tectonic activity within the complex determined the physical extent of the fracture system and the time span of deposition. This may have been influenced by fluid pressure, both within the source and within the veins. The joint system, developed within the Belknap Syenite prior to mineralization, controlled the general shape of the deposit and the trend of its veins.

The temperature of the intrusion and the bulk composition of its aqueous fluid at its source controlled the initial mineralogy of each vein type. Ground preparation by early amphibole zones controlled the size and shape of the later zones. Once the fluid had been cut off from its source, during the formation of each vein type, the mineralogy may have been influenced by an increasing calcium to sodium ratio and by increasing  $fO_2$ .

The mechanism of formation for each vein appears to have been several episodes of fracturing, followed by open-space filling and replacement of both syenite and early-formed vein minerals. Fluid pressure, both at the source and within the veins, may have been the driving force behind much of the fracturing. A drop in fluid pressure, resulting from expansion into newly-opened fractures, may have initiated precipitation within the fractures. Local fracturing within the veins, in response to a buildup in fluid pressure, may have caused later fracturing. For the epidote-magnetite vein type, much of the fluid migration may have been along one or two pipes, one of which is located at the junction between the epidote-pyrrhotite and epidote-magnetite veins in the lower cut.

The resulting deposit is composed of three vein types that were deposited during separate time intervals. An early epidote-pyrrhotite vein is zoned from early outer amphibole to a later core of epidote followed by pyrrhotite. Other than a sharp boundary, there is no evidence of fracturing

between the amphibole and the epidote stages. An intermediate epidote-magnetite vein type is zoned in a similar manner, from an early amphibole to an intermediate breccia to a late epidote-magnetite assemblage. The veins appear to be localized around one or two pipes. A late amphibole vein type is similar to the early stages of the first two types and is interpreted to represent the waning stages of activity within the deposit. The time interval between veins is unknown except that deposition along one vein type had ceased and, in the case of the epidote-pyrrhotite vein, alteration of the late-forming minerals had occurred prior to the formation of the next vein type.

The deposit is represented by the high-temperature stages in the paragenetic sequences of Lindgren (1937) and Edwards (1947). Plagioclase-ferrohastingsite assemblages suggest that the temperature was approximately 400 to 450 degrees centigrade; while textures indicating open-space filling suggest a generally high fluid pressure. The coarse grain-size, generally small amount of wall rock replacement, and high temperature mineral assemblage suggest a relatively deep origin. The Iron Springs deposit has been labelled 'igneous-metamorphic'; but, although the source has been suggested as the Conway Granite for the Mount Gunstock deposit, a lack of field evidence limits its classification to high temperature-pressures hydrothermal.

## SUMMARY OF THE GEOLOGIC HISTORY OF THE DEPOSIT

1. Intrusion and cooling of the Belknap Syenite stock.
2. (Not necessarily in order)

Formation of joint sets 1 to 3 within the Belknap Syenite.

Intrusion of nearby igneous rocks units, including the Conway Granite.

Intrusion of a west-northwesterly trending porphyritic basalt dike and of aplitic quartz syenite dike.

Formation of the epidote-pyrrhotite vein.

Amphibole mineralization along west-northwesterly trending fractures.

Later epidote and pyrrhotite deposition.

Minor alteration of the pyrrhotite to marcasite and of epidote to tremolite-magnetite.

3. Formation of the epidote-magnetite vein type.

Amphibole mineralization along west-northwesterly trending fractures.

Fluid migration along one or two vertical pipes; intrusion of the epidote-pyrrhotite vein.

Later fracturing, resulting in the brecciation of interzone syenite and the formation of the breccia zone.

Repeated episodes of fracturing, followed by deposition of epidote and magnetite.

4. Formation of the amphibole vein type.

Generally single-stage mineralization along fracture sets 1 through 3 in several pulses.

5. Formation of fracture set 4, followed by the intrusion of aplitic granite dikes and a second porphyritic basalt dike.