PROGRESS REPORT: Darwin Project
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The following is an attempt to summarize my conclusions and hypotheses about the Darwin orebodies after several weeks of petrography at Stanford and 4 weeks of mapping at Darwin. T. W. Sisson and I have spent approximately one week mapping in the Darwin stock and immediately adjacent metamorphic rocks at 1" = 1000' and three weeks mapping a portion of the surface on the western intrusive contact at 1" = 200'. Figure 1 is a Xerox of a portion of a field sheet, showing the detail of mapping. Tom has concentrated on structures and sedimentary features in the upper plate (less metamorphosed/metasomatized) of a major thrust; I have worked on the lower plate in the altered metamorphics and intrusive rocks.

Darwin is one of a small number of deposits in the Western US where galena and sphalerite occur with garnet skarn. It is, to my knowledge, the largest of such deposits. A major thrust of this research is to determine or at least suggest, an origin for this unusual ore association. A second is to suggest what happens to this skarn at depth, i.e. whether it grades into a more "normal" (sphalerite-pyroxene, garnet-chalcopyrite or garnet-pyroxene-scheelite) skarn. As originally conceived, detailed underground mapping and core logging were to be the basic tools employed. However, it became clear after some surface examination that important geologic phenomena had not been recognized by previous workers (e.g. intrusive and skarn breccias), thus remapping has been carried out, with the intent of better-learning the local setting for the ore deposit. My present attitudes toward the deposit are

1. that it is akin to typical hedenbergitic Zn skarns, except formed in more aluminous host rocks and a more-oxidizing environment,
2. its formation is not genetically related to the immediately-adjacent granodiorite stock, but rather to the intrusive system which gave rise to the intrusive breccias, and

3. there is a possibility that the intrusive breccias are related to a copper orebody at depth.

GENERAL GEOLOGY

The Darwin ore deposit is located within the Keeler Canyon formation, an extremely heterogeneous package of calcareous turbidites and limestones, which have been contact-metamorphosed to wollastonite-idocrase ± pyroxene-garnet hornfelses adjacent to a heterogeneous body of granodiorite, diorite, quartz diorite, quartz monzonite, and altered granodiorite. The deposit consists of fissure veins, massive sulfide-quartz-calcite replacement bodies, and sulfide-bearing skarns. Roughly 80-90% of the sulfide-bearing rocks are skarn, but no more than half of the ore mined (1874-1976) was skarn (mostly fissure-vein and massive replacements). The orebodies are in large part structurally controlled, either in or near major E-W and N-S faults. The deposit has been cut-off by the Davis thrust, a major N-S trending fault with probably 0.5 – 1 km. movement. Figure 2, a sketch map adopted from our 1" = 200' maps, shows these features.

STRUCTURE

As Figure 2 suggests, the structure of the Darwin area is extremely complex. The formation of the ore deposit is related to this complexity, as much of the ore is along faults or adjacent to them. Three basic sorts of faults have been recognized: ~E-W reverse, ~N-S unknown movement, and ~N-S thrusts. Mapping by T. W. Sisson on the upper plate (Figure 3) has shown that this block is dissected by numerous small thrusts into an imbricate thrust sheet, at least in its upper portion. Cumulative displacement on these faults may be great. Furthermore, successively older overlying stratigraphic units, which lie to the east, are in fault contact with the Keeler canyon formation and with one another. A possible reinterpretation of the regional structure is that these faults are also thrusts, thus forming a series of on lapping thrust sheets, as opposed to an overturned syncline (as suggested by Hall and McEvitt). The upper member of the Keeler Canyon formation has clearly been folded into an overturned syncline in the area immediately north of the Darwin tear fault, but the lateral extent and magnitude of this structure is presently unknown. If the structure consists essentially of a series of imbricate thrusts, the implication for the underground stratigraphy is great – i.e., increasingly marble-rich units (older) rather than siliceous (younger) with depth. This difference is important for skarn potential of the rocks.

Another difficulty with the overturned syncline model of Hall and McEvitt (1962) is the tectonic cause of the deformation. They ascribe formation of the syncline to "forceful emplacement of the Coso batholith." Recent Pb/U dating of the Darwin stock and Coso batholith, however (Chen, 1978) shows that the Coso batholith is considerably younger than the Darwin stock, and thus post-dates major folding.

My work to the east of the Davis thrust suggests that it is not only post-intrusive, but (in contradiction to Eastman, 1979, and Hall and McEvitt, 1962) post-metamorphic, and, importantly, post-mineralization as well. This is important, because instead of making the upper plate rocks unfavorable hosts (as suggested by Hall and McEvitt), the upper plate has simply removed part of the original ore body and is in fault contact with the remainder. Evidence for this hypothesis includes: radical change in metamorphic grade across the thrust, termination of all skarn-bearing fissures at the thrust, (Figure 4) lack of base metal sulfide mineralization in or west of the thrust, the occurrence of diorite bodies in metamorphics only west of the thrust and the occurrence of quartz monzonite bodies and associated garnet specular hematite skarns only west of the thrust. The last point is of particular interest, because the QM and associated skarn near Ophir Mountain are virtually identical to QM and skarns in the Coso batholith, about 3 km. west. There are several ramifications of the post-mineralization thrust hypothesis, the most important of which are the implication that

1. the surface exposures in the northern mine area (Essex-Independence) are brought up from depth, and thus represent deeper exposures of the skarns, and
2. the likelihood that some of the N-S faults to the east of the Davis (e.g. the 570 fault) have vertical, post-mineralization movement. Again, this implies a shuffling of the orebody and a consequent change in metal zoning patterns. This point will be discussed below.

The Davis is offset by two faults – the Copper and Mickey Summers faults. These two faults do not possess skarn mineralization but rather are characterized by ferroan calcite-jasper-FeOx-copper carbonates. The copper is probably exotic, and may represent remobilization from some deep source, as there is virtually no copper sulfide in the skarn or fissures to 1300’ depth.

STRATIGRAPHY

T. W. Sisson’s mapping has shown that the Keeler canyon fm on the upper plate consists of calcareous turbidites and marble, generally in lenses of at most 300’ strike length. The great strike-length, as well as down-dip variability in the formation is an important feature, particularly as there are particular hosts which are conducive to mineralization. Within the lower plate, I have broken out two major units: massive idocrase-wollastonite and thin-to-medium-bedded wollastonite (garnet-idocrase-pyroxene) hornfels. The first unit is generally adjacent to the intrusive on the surface and is found near the Davis thrust. Exposures of the massive hornfels near the Davis thrust and north of the Copper fault suggest that there are several lenses of massive hornfels separated by thin-bedded hornfels and marble.

The thin-to-medium-bedded hornfels are clearly a metamorphosed carbonate turbidite, as it commonly contains remnant sedimentary structures, interbeds, etc. Several important lithologies are present within this unit: 1-5’ thick bleached marble beds, 0.1-2′ thick garnet beds (metamorphosed calcareous mud?), occasional chest horizons, and so-called swiss cheese, lizard skin and wollastonite knob beds. Swiss Cheese beds consist of clasts or perhaps boudins of relatively pure marble in a metamorphosed marl (idocrase > garnet?) matrix. Similar beds with a less-metamorphosed matrix, are found in the upper plate of the Davis thrust. These beds are important, because they indicate that the majority of the calc-silicates (idocrase, wollastonite, low-Fe garnet etc.) are of a metamorphic, not metasomatic origin (point discussed below) and because they are ideal hosts for mineralization. Swiss cheese beds with wollastonite clasts in an idocrase matrix are also common.

Lizard-skin beds consist of 1 mm. clasts of wollastonite in a calc-silicate matrix, giving a knobby appearance on a weathered surface. Wollastonite knobs are egg-shaped (former clasts?) converted to coarse wollastonite, in generally a siliceous matrix. Again, less-metamorphosed equivalents are found to the west of the Davis thrust. These three distinctive lithologies tend to lens in and out, rarely having a strike length exceeding 400′, and a bed width exceeding 15′.

On the surface, there are two main stratigraphic intervals containing swiss cheese marble; both are in thin-bedded wollastonite hornfels – the first is just above massive idocrase-wollastonite hornfels and the second is about 200′ up section. Swiss cheese beds do not occur to any major extent south of the Defiance fault, which in part explains the lack of orebodies in the southern part of the mapped area. Marble is an important part of the section N of the Essex thrust, but this represents a lower portion of the stratigraphy which has been thrust up.

The implications of this stratigraphy for ore deposition are discussed below.

<u>METAMORPHISM/METASOMATISM</u>

Much of the confusion in the literature about Darwin concerning timing of ore deposition relative to skarn formation has been caused by the interpretation of the majority of calc-silicate rocks as metasomatic, thus implying a considerable time/chemical lag between calc-silicate metasomatism and ore metasomatism. Furthermore, it implies an incredible amount of material to be transported to the hornfelses, with very little ore to show fir it. Rather, the Keeler Canyon formation had ample calcite, clay, and silica in it to account for the calc-silicates present. Furthermore, the ample cross-cutting relations between skarn and hornfels suggest a time lag between metamorphism (induced by the Darwin stock) and metasomatism, implying that the Darwin stock, at least the present level of erosion, was not responsible for the ore deposits. The rather extensive metamorphic halo around the stock, however, suggests relatively high temperatures of metamorphism (> 500^{o} C) and an intrusive which enlarges considerably with depth. The considerable differences in mineralogy of the skarns from the hornfelses suggests to me a completely different intrusive/hydrothermal episode for their formation.

Metasomatism began with formation of thin (0.1-5′ width) garnet-wollastonite ± (pyrite, chalcopyrite, scheelite) around the outer perimeter of the Darwin stock. I believe that these skarns are associated with release of fluid form the Darwin granodiorite, and especially pegmatitic phases of the granodiorite. These skarns have been mined in the past for minor copper, with probably no production. Ore bodies and skarns not directly related to the contact of granodiorite with metasediments contain no wollastonite, are generally vuggier, contain abundant sulfides, and are structurally controlled. I do not believe that they are genetically related to the granodiorite.

Excluding the contact-skarns, then, there are three basic varieties of ore bodies – skarns, calcite-sulfide-silica replacement bodies, and open fissures. There are three varieties of skarn –

1. skarn pipes ± sulfides
2. skarn beds, along favorable lithologies, and
3. skarns formed along fissures.

There are more than 6 skarn pipes that I have found in the Darwin area. The first is a large mass on the ridge between the Deviance and Mickey Summers faults; it surrounds an intrusive breccia containing leucocratic quartz monzonite, and porphyry fragments, and is wholly surrounded by calc-silicate producing partly "eaten" clasts of hornfels in a massive garnet-pyroxene-calcite-orthoclase (?) matrix. It contains 0.5-2% Py, but no appreciable ore, except in small patches. It also contains up to 2% scheelite and probably averages about 0.05% WO_3. A second, near the Thompson portal, is similar, but contains less intrusive breccia. A third is found in the stock ~300' east of the Independence workings. A fourth is the so-called Defiance pipe, which apparently contains the same mineralogy as the others, but in addition, approximately 10-20% ore-grade material (Pb, Zn, Ag). Particularly near the bottom of known exposures (1300 level), it contains significant amounts of chalcopyrite, very high Ag/Pb, and (according to a Mexicanus Colorado log), AgS. The true extent of these skarn pipes is not known because, frankly, the matrix looks like a grey-green hornfels and even where intrusive clasts are present, the rock has been mapped and logged as "silted lms." or "hornfels" or "garnetized lms." Had I not seen the outcrop relationships and the clasts, I probably would have called it a hornfels also. Hall and McEvitt (1962) mention a "dike" of similar mineralogy containing spl on the 800 level, so there may be a considerable number of such pipes, both ore-bearing and barren, in the area. More work would be desirable, but virtually all the drill core is stored underground, and exposures of ore grade skarn pipe are only found underground.

Possibly transitional to the skarn pipe (at least in the Defiance area) are beds of skarn containing sulfides. In the Defiance area, these skarn beds project into the Defiance pipe and replace swiss cheese marble, not pure marble. Thin section examination of such skarn suggests that sphalerite replaced pyroxene, and was partly contemporaneous with garnet, and galena replaced calcite. Swiss cheese marble is an ideal host for these skarns because the clasts of marble get replaced by sulfides while the calc-silicate matrix is replaced by garnet. Massive calcite-silica-pyrite-sulfide bodies are commonly peripheral to these skarns, or may replace swiss cheese marble instead of skarn. In many places on the surface, these skarns appear to be localized along E-W fissures, spreading out laterally up to 20' along strike. In the area between the Copper and Essex faults, such fissures (although small) are common, and virtually all of the swiss cheese marble, and much of the wollastonite hornfels, have been converted to skarn. The wollastonite hornfels form very "tight" garnet skarns with virtually no sulfides, except in late fissures.

Marble is abundant north of the Essex thrust, and considerable amounts of garnet-galena skarn is present, particularly adjacent to marble-hornfels contacts and marble-dike contacts. A critical reading of Eastman (1979) suggests that much of the skarn in the Essex area has formed in this manner, with galena interstitial to garnet. Whether skarns in the Essex area bottom in pipes is not known, and is not possible to directly ascertain, given the current level of underground mapping and DD core logging.

Generally 0.1-5' of skarn is present adjacent to all the major faults (Defiance, Essex, 434, Bernon, Water Tank etc.) where they cross-cut metamorphosed rocks. Surface exposures are poor, but they do not usually appear to contain appreciable ore, rather they are cross-cut by late fissures with ore.

There are two basic varieties of fissures: ~E-W and ~N-S. The E-W faults generally contain some fissure ore, but are highly erratic in grade and width.

The ~N-S fissures are generally wider and more continuous in grade and width. Both contain calcite, quartz, and sulfides (± fluorite, garnet), but the ~N-S fissures contain exceedingly coarse calcite. The ~N-S fissures are localized along units of contrasting lithology – i.e. skarn/hornfels contacts, calc-silicate hornfels/siliceous hornfels contacts, skarn/marble contacts, intrusive/skarn contacts, etc. There are 3 fissures and one skarn/replacement body on the surface in the Defiance area, each along a different lithologic contact. Similar fissures occur in the Essex area. That these fissures were at one time open is suggested by the presence of "foreign" clasts, e.g. in the Defiance area a fissure between skarn and hornfels contains several boulders of marble, a lithology foreign to the area. Similarly the garnet in these fissures is (in thin section) broken, fractured, and partly altered, suggesting that it was broken off the walls and transported (up?).

In general, the various types of orebodies – pipes, bedded skarns, replacement bodies, and fissures – are transitional to each other, representing a decline in temperature of the ore-forming system. Figure 5 is a cartoon of the relationships in the Defiance area. I suspect that in part the lower-temperature orebodies (fissures) may have "robbed" ore from adjacent skarn, inasmuch as their grade varies with the type of rock they cross-cut.

<u>INTRUSIVE ROCKS</u>

I have saved this topic for last because I understand it the least and the most confusion exists in the literature concerning the identity and relationships of the intrusive rocks. The older literature refers to a stock of diorite, Hall and McEvitt (1962) call it all quartz monzonite and aplitic granite and Anaconda maps make mention of diorite, granodiorite, and "porphyry" (they also mention a "blue bastard rock" however). The Darwin stock consists of an assemblage of both internally heterogeneous and homogeneous intrusive bodies ranging from diorite or monzo-diorite to syenite. From a practical standpoint there are 3 and possibly 4 intrusive bodies present:

1. coarse grained, equigranular dioritic-to-monzo-diorite containing large, ragged, bronze biotite, small subhedral glassy dark brown biotite, and little or no hornblende;
2. a large mass of seriate-to-porphyritic (k-feldspar phenocrysts) medium grained hornblended-biotite granodiorite with sparse but ubiquitous 1-2" fine-grained elliptical mafic inclusions;
3. a very heterogeneous fine-grained porphyritic, moderate-to-extremely leucocratic intrusive which varies between granodiorite and quartz monzonite. This unit may be a differentiate of the aforementioned granodiorite;
4. quartz monzonite porphyry (may be the same as 3.)

Diamond drill core and occasional surface exposures of the coarse-grained diorite suggest that it may be an extensive body, it is early relative to granodiorite, and may be responsible for much of the metamorphism in the area.

Hornblende-biotite granodiorite displays interesting contact relations with the surrounding meta-sediments. Within thin border zones, dikes, and sills it consists of monzonite, syenite, pegmatitic syenite, and quartz monzonite, with variable development of endoskarn alteration (pyroxene-placioclase-kspar). Portions of the contact intrusives contain 0.1-3% disseminated and vein pyrite ("D" veins) ± sericite; hypogene and super-gene alteration of these rocks produces a very leucocratic rock which is difficult to impossible to distinguish from the heterogeneous leucocratic intrusive. It may in part <u>be</u> the same.

Quartz monzonite porphyry (?) occurs as clasts within skarn pipes. In the breccia in the vicinity of the Defiance Mine, intrusive fragments have been heavily altered and recognition of the original intrusive type is questionable. In the breccia near the Independence Mine, skarn fragments are suspended in a fine grained, slightly leucocratic porphyritic intrusive matrix. The surrounding intrusive ins slightly coarser and contains a slightly higher mafic content (biotite and hornblende). The breccia is cut by dikes of material intermediate in size and mafic content between the intrusive matrix and the surrounding intrusive. Within the breccia, small dikes and irregular zones of very leucocratic, graphically intergrown quartz and K-feldspar isolate and include or infill areas of particularly intense breccia (bodies?)*. Several small fragments have been observed which consist of skarn included by fine grained intrusive included in turn by graphic granite. This intrusive breccia body interfingers with fine grained leucocratic, porphyritic rock with increasing depth (down a steep hillside). At the moment it is not at all clear whether the breccia bodies are related to the heterogeneous leucocratic intrusive, a later genetically related intrusive, or a completely separate body (quartz monzonite porphyry). Be this as it may, breccia dikes and pipes are unusually common in the Darwin area and appear genetically related to formation of much of the skarn.

SUMMARY

The Darwin mine area is considerably more complex in both variety and structural setting of rock types and ore bodies than indicated by the published literature. Part of the strangeness is due to the nature of the host rocks (carbonate turbrodites), the fact that they were metamorphosed prior to the mineralization episode, and the probable lack of genetic relationship between the majority of the exposed intrusive rocks and the orebodies. I would summarize my current impressions of the geologic history below:

1. Folding, emplacement of diorite, possibly the gd, metamorphism;
2. Formation of small skarns around the gd;
3. Cooling of gd, reverse faulting (in response to intrusive body below?)

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4. Emplacement of quartz monzonite porphyries, breccias and skarn pipes;
5. (?itional)* formation of replacement bodies and fissures;
6. Thrust faulting, loss of portions of the orebody, re-shuffling of others.

In general, I believe that the formation of the orebodies may be related (???) porphyry with related skarn pipes. This body (???) or have given rise to copper skarns, at depth. Clearly a study of these pipes and their associated skarns and fragments should be undertaken to learn about the underlying intrusive (???).

RECOMMENDATIONS FOR FURTHER STUDY

At this point, it is clear to me that the published geologic framework of the Darwin area which has been presumed by all studies post 1962 is seriously in doubt. In order to completely understand the origin of the Darwin mines and to intelligently explore for other related orebodies re-mapping of both surface and underground exposures is necessary. This would require a project – expensive in terms of both time and personnel – and frankly goes far beyond the scope of the project as funded by the National Science Foundation. A more limited approach, designed simply to better understand the skarns, and their relations to presently known orebodies and intrusive rocks is within the framework of the NSF project but cannot hope to fully address the problems of ore potential of the district. In either event, access to underground exposures is critical to any real understanding of the skarn and associated ore. Past mining and exploration of the Darwin mines has been based almost exclusively on the "hit-or-miss" approach; if any mining is to take place in the future, it is critical that some understanding of the ore-forming process and ore controls be understood. I am therefore requesting access to at least some underground exposures at Darwin. Furthermore, because the scope of

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the project has expanded considerably due to an increased knowledge of the previously unknown geologic complexity of the area I am requesting funding for field and analytical expenses. In any event, I am planning to return in the Fall and complete detailed surface mapping and log additional drill core, if nothing else.

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