Altered Tectonic and Hydrothermal Breccias in Corehole VC-1, Valles Caldera, New Mexico

by

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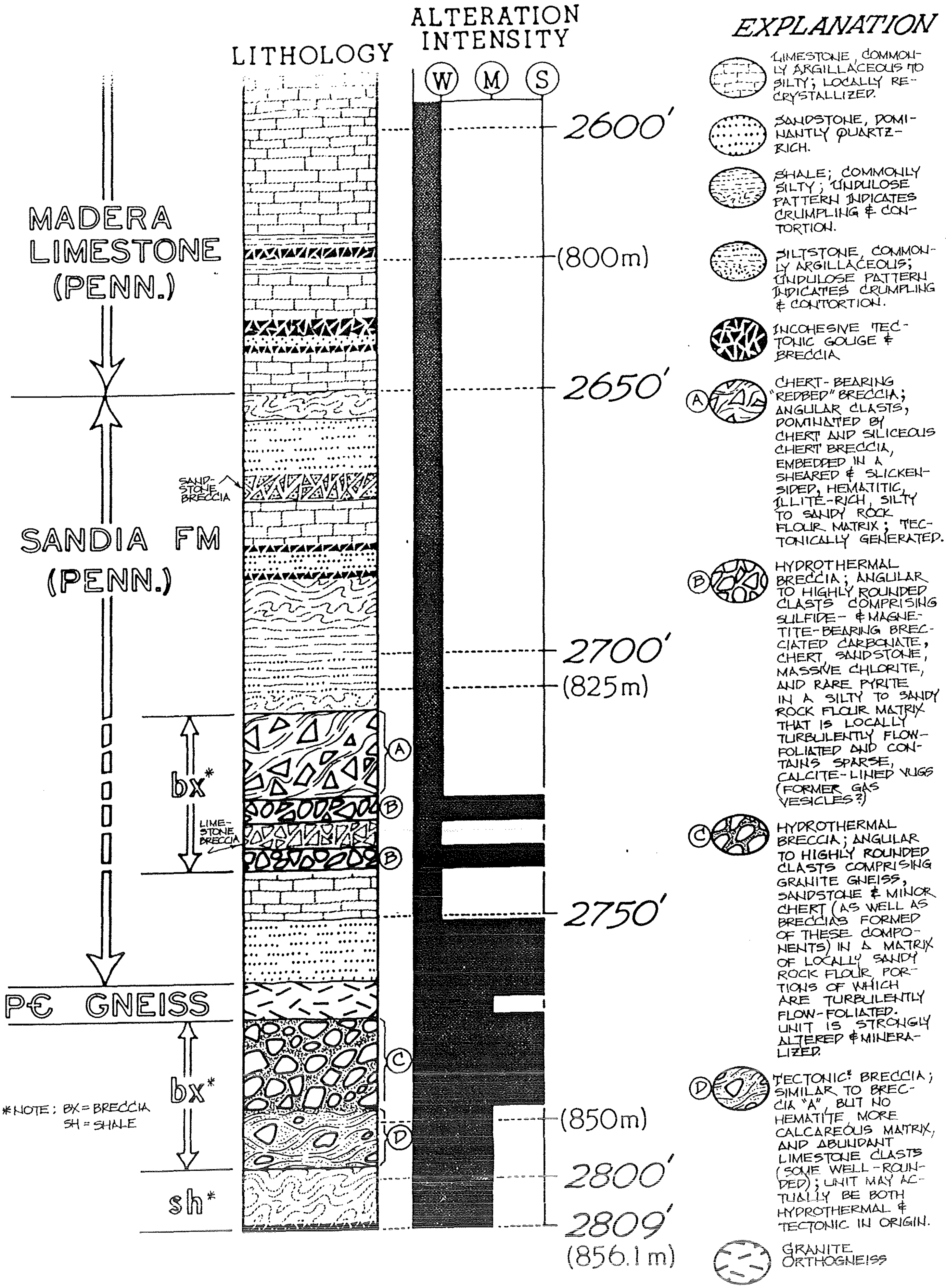

Figure 2. Generalized lithologic and hydrothermal alteration intensity log for the lower 63.7 m of corehole VC-1. W=weak; M=moderate; S=strong

deep in the hole, of strongly altered and sulfide-bearing breccias of both tectonic and hydrothermal origin. Hydrothermal breccias and associated crackle zones or stockworks are known to provide significant secondary porosity and permeability, as demonstrated by their frequent occurrence as ore hosts (Sillitoe, 1985). Therefore, detailed study of the deep VC-1 breccias was undertaken not only to characterize rock disruption and alteration in the immediate vicinity, but also to understand more thoroughly the structural setting of active geothermal systems in the Valles caldera. In this preliminary report, we will briefly discuss each of the major deep breccias in VC-1, examine the style, intensity and paragenesis of their hydrothermal alteration, and speculate on their relationship to the complex Cenozoic volcanic history of the Jemez Mountains.

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The Madera Limestone and Sandia Formation are, respectively, carbonate and clastic-dominated formations of the Pennsylvanian Magdalena Group. The Sandia Formation shows extreme vertical and lateral lithologic variation (e.g. Lovejoy, 1958; Goff et al., 1981), reflecting diverse and rapidly fluctuating depositional environments. In VC-1, silty shales, argillaceous siltstones and quartz-rich sandstones predominate in the Sandia, but argillaceous to sandy limestones occur locally (Fig. 2). The shales are often highly contorted, perhaps having yielded plastically to compressive stresses which fractured and brecciated their brittle neighbors. All Sandia Formation rock types in VC-1 also crop out in the nearest exposures of the unit, near Soda Dam (Fig. 1; Goff et al., 1985), although not necessarily in the same stratigraphic sequence.

Precambrian granite gneiss in VC-1 between 841.8 and 844 m (Fig. 2) is strongly quartz-sericitized and cut by quartz veinlets, but is otherwise texturally identical to weakly foliated, medium-crystalline, quartz-orthoclase-microcline-oligoclase-biotite orthogneiss penetrated below 3170 m in Union Oil Company geothermal well B-12, 5 km to the northeast (Fig. 1). It is also similar to orthogneiss exposed near Soda Dam, site of the nearest Precambrian basement outcrop. The Soda Dam gneiss, however, has been extensively mylonitized.

Breccias and Hydrothermal Alteration. The Sandia Formation and Precambrian gneiss in corehole VC-1 have been thoroughly disrupted between 826.3 and 856.1 m (TD) to form a spectacular sequence of tectonic and hydrothermal breccias, many of which are strongly altered and mineralized. Most of these breccias are cohesive, having been hydrothermally cemented and recrystallized. Incohesive tectonic breccias in VC-1 (Fig. 2) are widely scattered and comparatively thin, accounting in part for superb core recovery (> 95%) from the hole (Goff et al., 1985).

Tectonically generated or modified cohesive breccias form relatively thick zones in VC-1 between 826.3 and 831.3 m (breccia "A"; Fig. 2) and between 849.4 and 852.6 m (breccia "D"). Both are similar in having sheared, silty to sandy, clay-rich matrices but differ in dominant clast shape and lithology.

Breccia "A" can be described as a chert-bearing redbed breccia. It consists of subangular to angular clasts, up to at least 18 cm (average 1-2 cm) in diameter, accounting for 10-20 volume percent, embedded in a sheared, hematitic, argillaceous, silty to sandy, reddish-brown matrix. Most of the clasts are recrystallized chloritic and hematitic chert and chert breccia, commonly cut by quartz ± chlorite veinlets abruptly cut off at clast boundaries. Siltstone, hematitic mudstone and spotted, silicifed and chloritized sandstone clasts occur locally. Many of the chert breccia clasts show evidence of multiple episodes of brecciation and veining. X-ray diffraction analysis reveals the matrix of the redbed breccia to contain principally illite (< 10% expandable interlayers) with minor iron-rich chlorite in addition to hematite and quartz, but petrographic examination shows that these layer silicates occur mostly as disaggregated components in the breccia matrix, and so are probably disrupted authigenic or diagenetic rather than hydrothermal phases. Both matrix and clasts, however, are cut by rare pyrite ± quartz ± sericite microveinlets of undoubted hydrothermal origin.

Like breccia "A", breccia "D", between 849.4 and 852.6 m (Fig. 2) is characterized by an argillaceous, silty to sandy matrix which makes up 80-90% of the rock. The breccia "D" matrix, however, is also very calcareous, probably due to incorporation of rock flour derived in part from adjacent limestone. Clasts in this breccia, which are rounded to angular and average about 7 mm (up to 3 cm) in diameter, comprise sandstone, siltstone, gneiss, chert, and limestone. Alteration effects include recrystallization and the formation of hydrothermal chlorite and quartz. The matrix is cut by abundant, 1-2 mm-wide calcite-chlorite veinlets, which form braided networks at angles of 0-25° with the core axis.

Breccia "A" is clearly of tectonic origin, as indicated by abundant slickensides along with shearing and crushing of the matrix in combination with the dominant angularity of fragments. The breccia was formed by tectonic mixing of formerly separate redbed and chert strata in the Sandia Formation, probably in several stages accompanied or separated by episodes of hydrothermal alteration. Breccia "D" provides ambiguous evidence of origin. Many of its fragments are highly rounded, a feature more characteristic of abrasion in an outward-escaping, highly pressured hydrothermal fluid (e.g. Reynolds, 1954; McCallum, 1985) than of formation in a fault zone. The calcite-chlorite veinlets abundant in breccia "D", however, clearly occupy tectonic fractures; the breccia may have a dual tectonic-hydrothermal origin.

Strong evidence for development or modification by hydrothermal processes can be found in two thin breccia zones (designated "B", Fig. 2) between 831.3 and 832.7 m and between 834 m and 835.4 m. These breccias, separated by a tectonic(?) limestone breccia, contain roughly 50 volume percent angular to highly rounded clasts, up to at least 20 cm (avg. about 2 cm) in diameter, embedded in a turbulently flow-banded, chloritic to locally siliceous and calcareous, silty to sandy matrix. The clasts comprise: sandstone, siltstone and chert; massive, fine-crystalline hydrothermal(?) chlorite; brecciated, partially dolomitized and mineralized limestone; and rare pyrite (in clasts less than 1 cm in diameter). The mineralized limestone clasts, the larger of which are conspicuously angular, contain highly variable amounts of disseminated and veinlet-controlled magnetite, pyrite, hematite, chalcopyrite and galena (rare traces); brecciated, coarsely-crystalline barite is locally present. One large limestone breccia clast, especially rich in pyrite (3 wt. %) at 831.8 m contains 508 ppm arsenic. Except for minor pyritization, all mineralization in the limestone breccia clasts pre-dates their incorporation in breccia "B".

The two breccia "B" intervals are believed to have been created or modified by hydrothermal fluidization, which involves suspension, abrasion and sometimes transport of fragments in an overpressured, outward-escaping, hydrothermal fluid (e.g. Reynolds, 1954; McCallum, 1985). Pressuring of the fluid can be effected by several processes, including resurgent boiling in the upper levels of a hypabyssal pluton (e.g. Burnham, 1979, 1985) and magmatic heating of meteoric water beneath an impermeable seal (e.g. Nelson and Giles, 1985). Features of breccia "B" compatible with formation by fluidization include: abundance of rounded fragments, possibly formed through abrasion and attrition in a fluid stream; absence of slickensides, shearing and crushing; turbulent flow-banding of the matrix (a common feature of pebble dikes such as those cutting the El Salvador porphyry copper deposit, Chile (Gustafson and Hunt, 1975)); and scattered, calcite-lined vugs in the matrix which could represent trapped gas vesicles (c.f. Barrington and Kerr, 1961).

Also of probable hydrothermal origin are intensely altered green breccias, designated "C" in Figure 2, occurring just below the 2 m Precambrian gneiss interval. All original constituents (except primary quartz and zircon) in these breccias have been completely altered to secondary phases, but relict textures generally allow identification of the rock types involved. The highly rounded to angular clasts in these breccias, up to 5 cm in diameter and accounting for 50-90% of the rock, comprise Precambrian gneiss, quartz-rich sandstone and minor chert as well as older breccias formed of one or more of these components. These clasts are embedded in a rock-flour matrix which locally incorporates considerable amounts of well-rounded quartz sand, probably derived by disaggregation of Sandia Formation sandstone. Clasts in the "C" breccia are thoroughly altered to quartz and sericite with variable amounts of chlorite and calcite (both principally replacing former mafic minerals); leucoxene replaces former sphene (and perhaps ilmenite). Relict sedimentary quartz grains in sandstone clasts (or in fragments within these clasts) are commonly surrounded by secondary quartz overgrowths, from which they are separated by rings of solid and fluid inclusions. All types of clasts are commonly cut by quartz ± sericite ± pyrite microveinlets, which are abruptly truncated at clast margins.

The matrix of the "C" breccia is also intensely altered, generally to an aggregate of quartz, sericite, local chlorite and calcite with variable but visually prominent, bright green phengite (or iron-rich sericite). Relict flow-banding is locally apparent even in the most highly altered portions of the matrix. Pyrite concentrations in the matrix frequently parallel the flow-banding, but the texture of this particular pyrite indicates that it formed after rather than prior to brecciation.

Pyrite is the most abundant sulfide in breccia "C", overall accounting for about 1 weight percent, but reaching 3 weight percent in scattered 3-5 cm intervals. It occurs principally as disseminated grains, but also as micro-veinlets with or without quartz, sericite and phengite. Cross-cutting relationships indicate that the pyrite was deposited in several episodes. The veinlet pyrite is accompanied by scattered rare traces of chalcopyrite, galena and probable sphalerite. Traces of molybdenite occur as thin, discontinous films on fracture surfaces between 846 and 848 m. Some of this molybdenite is smeared by slickensides, indicating mild post-mineral tectonism.

Sparsely scattered throughout breccia "C" are very thin breccia dikes, from 2-10 mm in width, which post-date all other brecciation, alteration and mineralization in this interval. These breccia bodies are strongly silicified and contain up to 5 wt. % pyrite. Pronounced rounding of clasts in these breccias suggests that they may have formed, at least in part, by fluidization.

A number of features in the "C" breccia suggest development by hydrothermal processes: locally prominent clast rounding, commonly turbulent flow-banding in portions of the matrix; paucity of slickensides and shearing (slickensides on some molybdenite-coated fractures are a notable exception); and local textures indicating hydraulic fracturing (fragments which appear to have been forcefully ejected from fracture walls).

At least five stages of hydrothermal alteration are probably represented in breccia "C". During the first stage, Sandia Formation sandstone and Precambrian gneiss were intensely fractured, quartz-sericitized, chloritized, pyritized and cut by veinlets of coarse polycrystalline quartz. After brecciation of the altered sandstone and gneiss, the fine-grained matrix of the newly formed breccia was further recrystallized to quartz and sericite (micaceous illite) with minor pyrite. This breccia was hydrothermally rebrecciated through fracturing and subsequent fluidization. The matrix of this late breccia was replaced by quartz, sericite, pyrite and dark green phengite (or iron-rich sericite). Fracturing of the phengitic breccia was followed by sparse molybdenite mineralization, and by a final episode of weak hydrothermal brecciation with quartz-pyrite alteration.

The alteration assemblages documented for breccia "C" were probably developed at higher temperatures than those currently prevailing in borehole VC-1. A bottom hole temperature of 160°C was measured shortly after drilling (Goff et al., 1985); J. Rowley (pers. comm. with D. L. Nielson) believes that equilibrium bottom-hole temperature will be about 180°C. Most hydrothermal molybdenite, by contrast, is generally believed, on the basis of fluid inclusion homogenization temperatures (for inclusions in coexisting quartz), to form above 250°C (for example, Wilkinson et al., 1982; Blake et al., 1979; Bloom, 1981). Illite (and, by inference, phengite) is also a relatively high-temperature phase, typically forming hydrothermally or diagenetically above

200°C and remaining stable to temperatures at least as high as 350°C (Hoffman and Hower, 1979; Henley and Ellis, 1983).

Discussion. The youngest clasts in the deep VC-1 breccias are Pennsylvanian in age, and their matrices are devoid of juvenile components. Their age(s) relative to the Cenozoic volcanic history of the Jemez Mountains, therefore, remains to be determined. Moreover, until one of the hydrothermal phases (most likely sericite or phengite) is dated, the age(s?) of alteration is also unknown. However, the position of VC-1 relative to the Quaternary Valles-Toledo calera complex and the Jemez fault zone (Fig. 1) encourages speculation about how these altered breccias could have developed.

The Jemez fault zone, a small segment of the northwest-trending Jemez lineament, a chain of faulting and Tertiary-Quaternary volcanic activity several hundred miles in length, has been active for at least 20-25 m.y. (Goff et al., 1981). It seems likely that it has been generating tectonic breccias such as the "A" and perhaps "D" zones in VC-1 ever since its inception. The position of VC-1 along the subsurface projection of the Jemez fault zone (Fig. 1) further strengthens the likelihood that deep tectonic breccias in the corehole are related to this structure.

One of the objectives of VC-1 was to obtain stratigraphic and structural information near the intersection of the Jemez fault zone with the ring-fracture zone of the Valles caldera (Goff et al., 1985). This environment would have been highly favorable for development not only of tectonic breccias associated with caldera collapse, but also hydrothermal breccias, such as those in VC-1, violently formed by thermal fluids energized by the Valles or Toledo magma chambers.

The nearest exposures of Sandia Formation and Precambrian gneiss to VC-1 are located in the vicinity of Soda Dam, a natural travertine bridge across the Jemez River (Goff et al., 1985; Fig. 1). Altered breccias and vein mineralization in the gneiss and overlying Sandia show striking similiarities to the breccias and mineralization deep in VC-1. For example, the Soda Dam rocks are locally cut by coarsely-crystalline barite-calcite veins which contain pyrite, chalcopyrite, bornite, galena and sphalerite. Rubblization of these veins might yield breccias very similar to those occurring as clasts in breccia "B", although these, in addition, often contain abundant hydrothermal magnetite. Mylonitized Precambrian gneiss at Soda Dam is invaded by dikes and irregular masses of breccia probably formed by hydraulic fracturing. The rock flour matrix of this breccia, as in VC-1 breccia "C", is extensively altered to quartz and dark green phengite; former sulfides have been oxidized, perhaps accounting in part for bleaching and kaolinization of the host rock (supergene acid-leaching?).

Similarities between the Soda Dam and deep VC-1 breccias, alteration and mineralization suggest that detailed structural and hydrothermal alteration mapping at the former site, when coupled with the VC-1 results, might allow more confident modeling of structural preparation and hydrothermal alteration of the Paleozoic and Precambrian basement within the projection of the Jemez fault zone beneath the Valles caldera. Since the Jemez zone is clearly a major control on thermal fluid flow in the caldera's active geothermal systems (Nielson and Hulen, 1984), such a study is strongly recommended.

Armstrong, 1955

Armstrong and Mamet, 1974

REFERENCES

Baars and Stevenson, 1984

Baltz and Myers, 1984

Barrington, J., and Kerr, P. F., 1961, Breccia pipe near Cameron, Arizona: Geol. Soc. America Bull., vol. 72, p. 1661-1674.

Blake, D. W., Theodore, T. G., Batchelder, J. N., and Kretschmer, E. L., 1979, Structural relations of igneous rocks and mineralization in the Battle Mountain mining district, Lander County, Nevada in Papers on mineral deposits of western North America: Nev. Bur. Mines and Geol., Rept. 33, p. 87-99.

Bloom, M. S., 1981, Chemistry of inclusion fluids--stockwork molybdenum deposits from Questa, New Mexico and Hudson Bay Mountain and Endako, British Columbia: Econ. Geol., vol. 76, p. 1906-1920.

Burnham, C. W., 1979, Magmas and hydrothermal fluids in Geochemistry of hydrothermal ore deposits (H. L. Barnes, ed.): New York, John Wiley, p. 71-136.

Doell et al., 1978

Burnham, C. W., 1985, Energy release in subvolcanic environments -- implications for breccia formation: Econ. Geol., vol. 85, p. 1515-1522.

Dunoyer de Segonzac, 1974

DuChene, 1974

Fitzsimmons et al., 1956

Gardner et al., 1986

Gordon, 1907

Goff, F. E., Grigsby, C. O., Kron, A., Counce, D., and Trujillo, P., Jr., 1981, Geology and geothermal potential of the Jemez Springs area, Cañon de San Diego, New Mexico: J. Volc. Geoth. Res., vol. 10, p. 227-224.

Goff, F., Rowley, J., Gardner, J. N., Hawkins, W., Goff, S., Pisto, L., and Polk, G., 1985, History and results of VC-1, the first CSDP corehole in Valles caldera, New Mexico: Geoth. Res. Council, Trans., vol. 9, pt. 1, p. 435-440.

Heiken et al., 1986

Gustafson, L. B., and Hunt, J. P., 1975, The porphyry copper deposit at El Salvador, Chile: Econ. Geol., vol. 70, p. 857-912.

Henley, R. W., and Ellis, A. J., 1983, Geothermal systems, ancient and modern -- a geochemical review: Earth Sci. Reviews, vol. 19, p. 1-50.

Hulen et al., in prep.

Hoffman, J., and Hower, J., 1979, Clay mineral assemblages as low-grade metamorphic geothermometers--application to the thrust-faulted Disturbed Belt of Montana in Aspects of diagenesis (P.A. Scholle and P.R. Schuger, eds.): Soc. Econ. Paleontol., Mineral. Spec. Publ. 26.

Kelley and Northrop, 1975

Loughlin, 1981

Lovejoy, B. P., 1958, Paleontology and stratigraphy of the Jemez Springs area, Sandoval County, New Mexico: Unpub. M.S. Thesis, Univ. New Mex., Albuquerque, 101 p.

MacKenzie, 1970

McCallum, M. E., 1985, Experimental evidence for fluidization processes in breccia pipe formation: Econ. Geol., vol. 80, p. 1523-1543.

Hulen & Nielson, 1986

Nielson, D. L., and Hulen, J. B., 1984, Internal geology and evolution of the Redondo dome, Valles caldera, New Mexico: J. Geophys. Res., vol. 89, p. 8695-8712.

Loughlin and Koschman, 1942

Roberson & Lahann, 19—

Nelson, C. E., and Giles, D. L., 1980, Hydrothermal eruption mechanisms and hot spring gold deposits: Econ. Geol., vol. 80, p. 1633-1639.

Reynolds, D. L., 1954, Fluidization as a geological process, and its bearing on the problem of intrusive granites: Am. Jour. Sci., vol. 252, p. 557-613.

Self et al., 1986

Stemmers, 1983

Sillitoe, R. H., 1985, Ore-related breccias in volcanoplutonic arcs: Econ. Geol., vol. 80, p. 1467-1514.

Wilkinson, W. H., Jr., Vega, L. A., and Titley, S. R., 1982, Geology and ore deposits at Mineral Park, Mojave County, Arizona in Advances in geology of the porphyry copper deposits, southwestern North America (S. R. Titley, ed.): Tucson, Univ. Ariz. Press, p. 523-542.

Srodon, 1980

Wood & Northrop, 1946

Altered Tectonic and Hydrothermal Breccias in Corehole VC-1, Valles Caldera, New Mexico

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Sedimentary rocks of the Pennsylvanian Sandia Formation and minor Precambrian granite gneiss in corehole VC-1 between 808.9 and 856.1 m (TD) have been extensively disrupted into heterolithologic breccias, many of which are strongly altered and mineralized. The breccias are of diverse origins. Many were clearly produced as rubble along fault zones; others, however, show evidence (such as rounded clasts and flow-banded but unsheared rock flour matrix) of development by fluidization. Clasts in both types of breccia are also commonly brecciated and contain veinlets, patches and disseminations of various hydrothermal phases which are abruptly cut off at clast boundaries, attesting to multiple episodes of brecciation, alteration and mineralization. Hydrothermal pyrite, sericite (illite), chlorite, quartz and calcite are widespread in the breccias; chalcopyrite, sphalerite, galena, magnetite, hematite, dolomite and barite occur locally. Minor molybdenite and abundant green phengite are confined to quartz-veined, strongly quartz-sericitized sandstone/gneiss breccia penetrated between 841.8 and 849.4 m. Mineralogic evidence suggests that this phyllic alteration and molybdenum mineralization took place at higher temperatures (probably greater than 250°C) than those currently prevailing at these depths in VC-1 (about 160°C). The corehole probably penetrates the Jemez fault zone, a major regional structure, near its intersection with the southwestern ring-fracture zone of the Valles caldera. Although the enhanced fracture permeability of this environment is certainly favorable for both mineralization and development of fluidized breccias, the relationship of these features in VC-1 to formation of the Valles and Toledo calderas and related geothermal systems remains to be determined.

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