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JOINT ANALYSIS APPLIED TO STRUCTURES OF THE SILVERTON VOLCANIC CENTER

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INTRODUCTION

Within the extensive volcanic pile of the San Juan Mountains of southwestern Colorado, several collapse centers have been recognized. These centers are characterized by faults and joint systems typically associated with calderas developed during repeated cycles of doming and collapse (Luedke, 1965, personal communication; Luedke and Burbank, 1961; Smith and Bailey 1963, p. 87). Insight can be gained into the development of the Silverton volcanic center from a study of these structures in a peripheral area, such as Minnie Gulch, where the effects of caldera-forming processes are well displayed. Sequence of events, mechanics of structural development, a magmatic "primary cause" for fracturing, and economic implications can be deduced from such a study. Original work for this paper was done as part of the writer's doctoral thesis (Schwarz, 1967) .

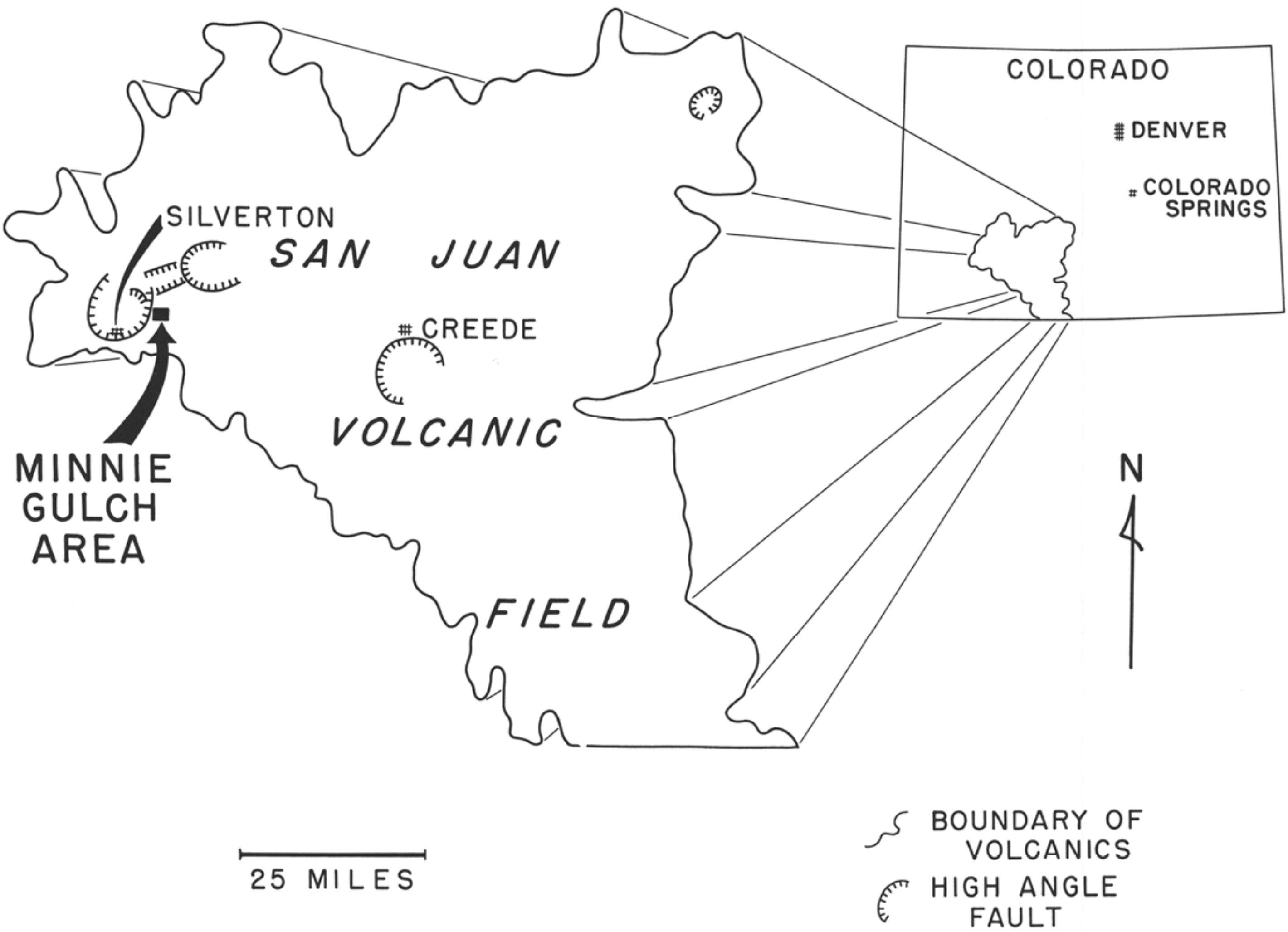

FIGURE 1.
Generalized geologic location map of Minnie Gulch area, San Juan County, Colorado

SETTING

Minnie Gulch, located 8 miles northeast of Silverton, Colorado (Fig. 1), is outside the east edge of the Silverton caldera, a down-dropped, semi-elliptical block of volcanic rock approximately 8 to 10 miles in width. Stratigraphic relationships indicate that this block has subsided 1000 to 2500 feet (Burbank, 1933, pp. 160-162). The Minnie Gulch area has not been disturbed by large intrusions or affected by secondary structures such as large radial grabens, tangential sags, or post-collapse intrusions. For this reason, structures here may be representative of those on the flanks of an ideal caldera complex where structures related to doming and subsequent collapse have been preserved for observation.

Prominent fracture systems related to the Silverton center are radial and concentric to the caldera; a third system is inclined to the radial and concentric directions (Burbank 1933, pp. 174-181). These inclined or "epicycloid" (Varnes, 1962, p. 42) fractures are referred to as transverse fractures in the following discussion.

The three fracture systems are present in Minnie Gulch both as veins and as dominant directions of jointing. Transverse fractures, less well-developed than either the radial or concentric types, curve in plan to become more concentric further from the caldera center. Burbank (1941, pp. 15-161; 1933, pp. 214-216) has suggested that the "spiral dike" around the Stony Mountain stock west of Ouray and the Camp Bird vein southwest of Ouray are similarly recurved and that they were formed by an outward intrusive push from the Stony Mountain stock and the Silverton center respectively. Varnes (1962, pp. 22-25) described a similar genesis for his epicycloid fractures.

STRATIGRAPHY

A simplified geologic map of the Minnie Gulch area (Fig. 2) shows fracture patterns developed in a series of

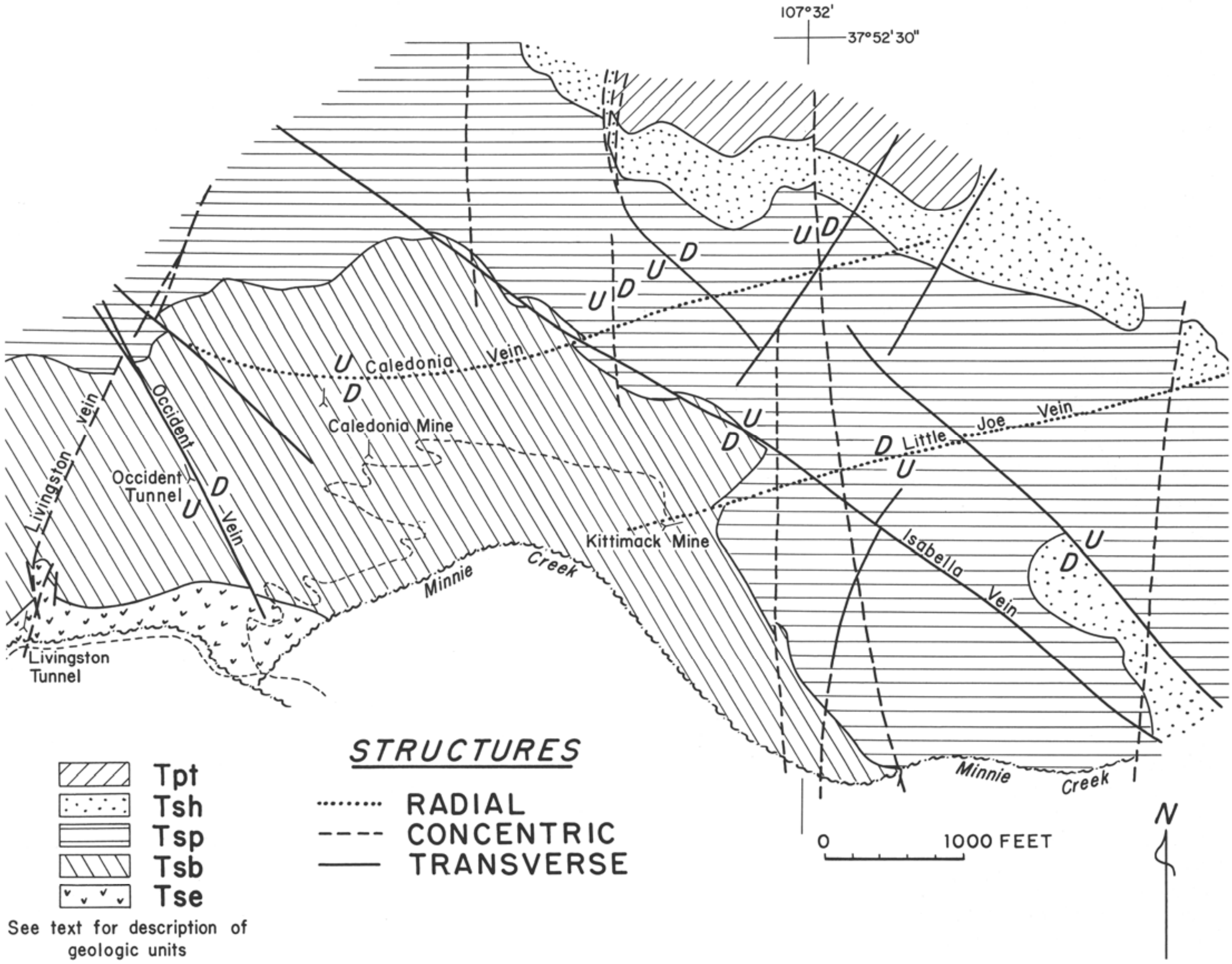

FIGURE 2.
Generalized geologic map, Minnie Gulch area.

nearly horizontal volcanic formations: the Eureka Rhyolite (Tse), Burns Quartz Latite (Tsb), Pyroxene Quartz Latite (Tsp), Henson Tuff (Tsh), and the Treasure Mountain Rhyolite (Tpt), following the nomenclature of Larsen and Cross (1956, pp. 75-80, 117-124). The rocks comprise a series of layered and interbedded volcanic flows, flow breccias, tuff breccias, ash flow tuffs, and reworked tuffs, mostly of intermediate composition. These variations in rock type and competency cause many fractures to behave differently as they cross lithologically contrasting units; the stronger fractures are not influenced, however, and tend to be more persistent and simpler in plan.

The Eureka Rhyolite is a dull-green, thinly interbedded reworked tuff and ash-flow tuff. The uppermost 1000 feet of the unit is exposed at the mouth of Minnie Gulch and is unconformably overlain by the Burns Quartz Latite.

The green to black flows, breccias, and tuffs of the Burns Quartz Latite are divisible into three groups as described by Burbank (1933, pp. 145-150) : the lower "tuff breccia," middle "latite flow," and upper "tuff" members. The Burns, up to 1300 feet thick, is separated from the overlying Pyroxene Quartz Latite by a tuff-veneered erosional surface.

The Pyroxene Quartz Latite consists predominantly of dense, dark gray to red, purple porphyritic quartz latite flows with fluidal banding, trachytic textures, and up to 10% of pyroxene phenocrysts. Approximately 1300 feet of the unit is exposed in Minnie Gulch. Upper flows are truncated by an irregular erosion surface against which beds of the overlying Henson Tuff abut.

The Henson Tuff is a black, poorly indurated, well-bedded reworked tuff interbedded with ash flow tuff and tuff breccia. The fissile and friable nature of the unit gives rise to prominent talus slopes obscuring the sub-outcrop thickness of 300 feet. The Henson-Treasure Mountain Rhyolite contact is an unconformity (Larsen and Cross, 1955, p. 80), although in Minnie Gulch the units appear conformable.

The Treasure Mountain Rhyolite consists of pale pink, non-welded to moderately welded quartz latitic ash-flow tuff. The unit represents composite sheets of ash-flow deposits as described by Smith (1960, pp. 157-158). It is 230 feet thick where it caps a ridge in the northern portion of the area.

LOCAL STRUCTURES

Several structures in Minnie Gulch have been mineralized sporadically along their length. The larger veins were explored in the Caledonia Mine, Kittimack Mine (Little Joe and Isabella veins), Occident Tunnel, and the Livingston Tunnel. A few unexplored veins showing lesser mineralization parallel those just mentioned. The prominent structures shown on figure 2 are simple both in plan and section, and usually contain veins of brecciated quartz apparently formed during periods of tensional reopening. Analysis of internal structure of the volcanics in the area indicates that no major or minor structures are related to the cooling history of the volcanic rocks, except perhaps coincidentally.

Veins radial to the caldera center (Fig. 2) contain base metals with minor gold and silver in a quartz gangue. The veins in the Caledonia Mine and the Little Joe workings of the Kittimack Mine follow pre-ore fractures, cut earlier fracture-associated alteration, and have oreshoots which rake 30° to 50° east and widen with depth. A shallow graben has developed between the two veins. On air photographs, both structures can be traced for several miles to the east.

One of the more prominent structures in Minnie Gulch, the Livingston vein, is concentric to the caldera and dips steeply west toward it (see Fig. 2). Excepting the Livingston vein, which extends several miles northward, concentric veins, although more abundant, are not generally so persistent as radial fractures.

Radial and concentric joint systems are both well developed, but concentric jointing appears to dominate. Both types typically show plumose patterns which Badgley and others (Badgley, 1965, p. 101) attribute to tensional development at shallow depths. These joints are distributed evenly throughout the volume of exposed rock, the fractures occurring, however, in slightly greater density adjacent to major vein structures. More intense alteration is associated with the concentric joints, and more frequent displacement of radial joints by concentric joints can be noted.

A number of radial and concentric structures, such as the west end of the Caledonia vein, terminate in "splays" similar to those pictured by De Sitter (1964, p. 123, Fig. 73) for tensional faulting. Many radial and concentric structures, in addition to those shown on figure 2, are present in the area, but they are apparently barren of mineralization.

The relationships noted above suggest that the radial and concentric structures are largely formed by tensional forces, and that radial fracturing began earlier than concentric fracturing.

Veins belonging to the transverse system of structures intersect radial and concentric structures at high angles. The two most prominent structures, the Isabella vein of the Kittimack Mine and the Occident vein, appear to extend for several miles to the southeast as air photograph linears. Along their length, these linears gradually curve, tending to become concentric with the ring-fault zone of the caldera.

The major orebody along the Isabella vein raked 20° to 30° to the southeast and contained up to 25% base metal sulfides, important sliver values, and a trace of gold. The vein structure cuts rocks altered earlier along a high-angle transverse zone of pre-ore en-echelon fractures. In the major orebody, the vein structure is confined by a flattened, dilated section of the pre-ore fracture system. En-echelon fractures strike 10° to 30° clockwise from the general trend of the vein structure. A right-lateral 100-foot offset of the radial Little Joe vein along the transverse Isabella vein can be observed in the mine and on surface.

Transverse jointing occurs almost entirely adjacent to major transverse veins and faults. Transverse joints a) offset both radial and concentric joints, b) are slickensided,

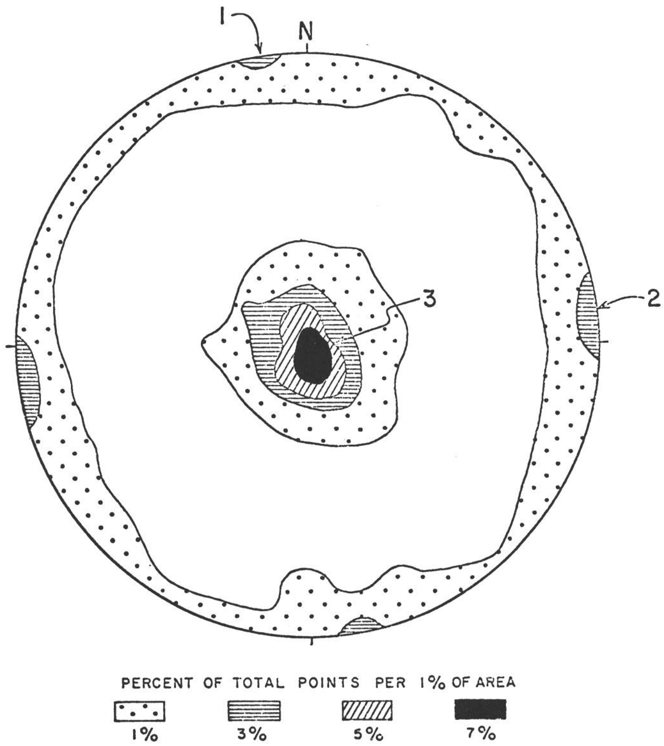

FIGURE 3.
Lower hemisphere joint-pole and joint intersection lineation plot. Synoptic diagram of 1009 points (Zones 1, 2, and 3 referred to in text).

and c) lack plumose surfaces. Transverse structures shown on figure 2, with their associated jointing, are essentially the only fractures of this type in Minnie Gulch.

The relationships mentioned above for transverse fractures suggest that they developed initially along strike-slip shear zones, and that transverse fracturing occurred later than radial-concentric fracture. The Isabella structure, for instance, originally developed as a left-lateral shear fracture zone.

STRESS AXES

If the fractures in Minnie Gulch are, indeed, structures generated by effects of magmatic doming and collapse—not by local adjustments or cooling history, for instance—it should be possible to define the principal stress axes. Bloom (1965, p. 109) points out that equal area net plots of fracture intersection lineations and of normals to fractures, taken together, display maxima which represent the principal stress axes. Joint poles and joint intersection lineations observed in the Minnie Gulch area are plotted together on figure 3, and the stress axes located as follows: No. 1: N10W: No. 2: N87E; No. 3: approximately vertical. The N87E stress direction corresponds well with a direction from the geographic center of the Minnie Gulch area to the geographic center of the Silverton caldera between Storm Peak and Gladstone. It is assumed therefore that this direction is radial to the original domal apex and that the caldera center and domal apex are coincident. The N10W axis of figure 3 represents the concentric stress direction on the dome at Minnie Gulch, and the approximately vertical axis represents an intermediate axis as assumed by Varnes (1962, p. 35) in his discussion of fracture patterns in the South Silverton area.

CONSIDERATION OF AN IDEAL VOLCANIC CENTER

A mechanism for forming these systems of fractures is suggested by consideration of an idealized dome under different stress situations. In figure 4, such a dome is pictured under two different regimens of stress—doming and collapse—together with the types of fractures to be expected in each situation. The location of a hypothetical Minnie Gulch area is outlined by a rectangle on the eastern flank of the dome N87E from its apex.

On the expanding dome, within the hypothetical rectangle test area, joints radial and concentric to the domal apex will plot as maxima at "r" and "c," respectively, as illustrated in figure 5. Concentric fractures, "c" would form from radially directed tensional stretching, "Tr." Radial fractures, "r," would form from concentrically directed tensional stretching, "Tc." If "Tc" is a greater tensional force than "Tr," as suggested by the observation that radial fractures form earlier than concentric fractures, then poles to the diagonal tear fractures would plot near "D."

Should an established dome begin to collapse, (Fig. 4), another type of stress-fracture relationship would develop. Rocks on the flanks of the dome would be compressed and crowded in radial directions. If, as with the Silverton caldera, the apex has developed a caldera along tension-generated concentric fractures, the central block may subside as a unit causing stresses to be concentrated around the edges of the block. Conjugate shear fractures would develop at an angle to the radially oriented compressive stress, provided that the approximately vertical rock load acted as an intermediate stress. These fractures would correspond to Varnes' (1962) epicycloid fractures—conjugate shears which have a spiral configuration in plan and which develop where maximum principal stresses are radially oriented. Radial fractures, some established before collapse, would form as cross fractures parallel to the principal stress axis (Badgley, 1965, pp. 99-100). Concentric fractures established before collapse would be compressed, but might later be reactivated as compression release fractures.

The theoretical plot of joints developed in the outlined area on the ideal collapsing dome is illustrated in figure 5. The portion of the outlined area is related to the dome so that the angle between the radially directed stress, compressional stress "Cr," and the transverse or shear fractures plotted at "G" is about 30°. Radial cross fractures, plotted at "A," and later, compression-release fractures, plotted at "B," complete the picture. Note on figure 5 that the same radial, transverse, and concentric fracture directions can develop during collapse as during doming—excepting that transverse fractures and tear fractures would diverge, further from the caldera.

OBSERVED FRACTURING IN MINNIE GULCH

The synoptic lower-hemisphere fracture-pole plots for

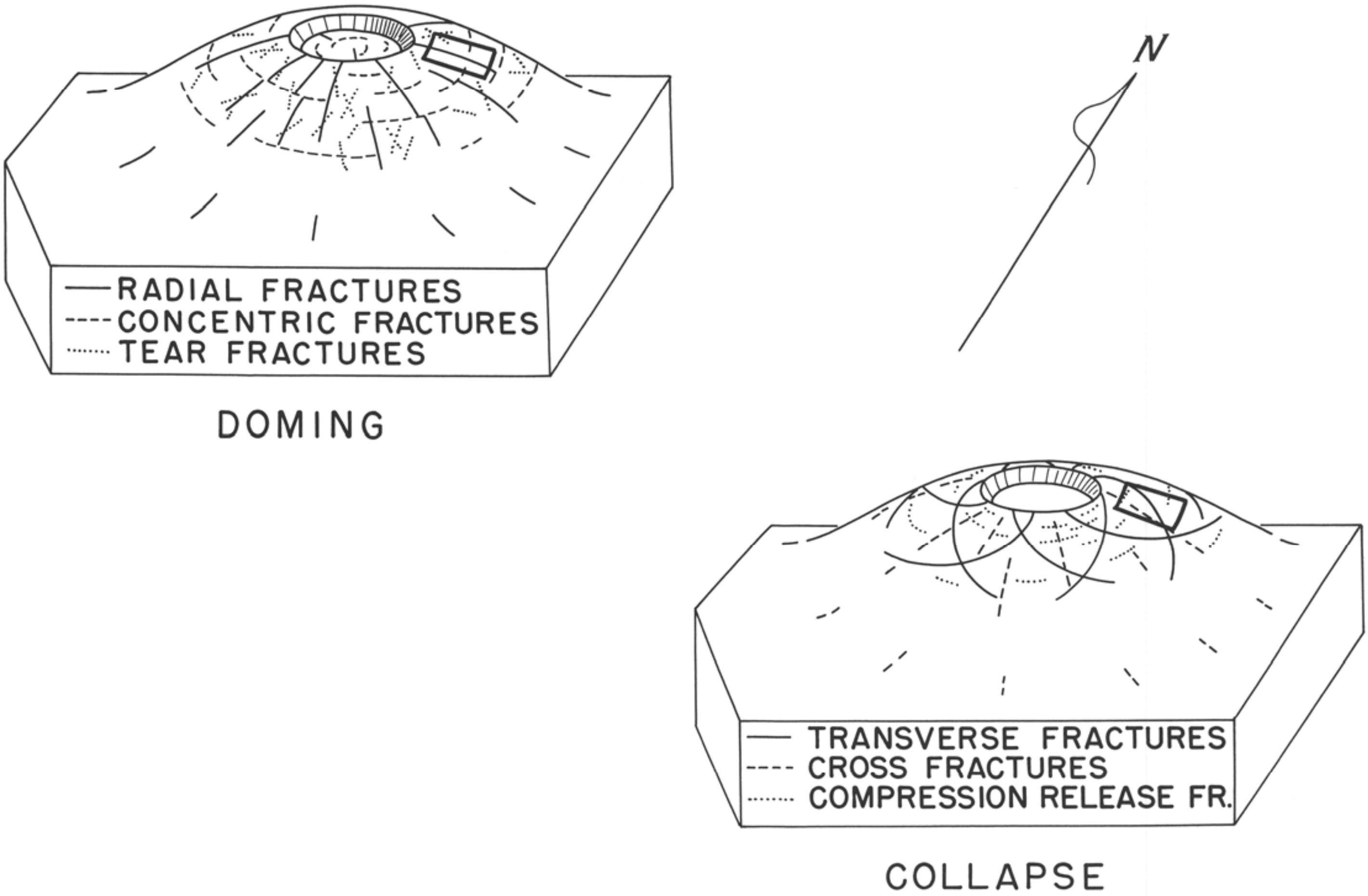

FIGURE 4.
Types of fractures to be expected on an expanding dome (left), and on an established dome after the beginning of collapse (right).

joints and quartz veins observed in Minnie Gulch (Fig. 6) reveal significant fracture concentrations. Comparisons with the theoretical joint plots of figure 5 are favorable and reveal predicted concentration patterns of east-west radial, north-south concentric, and northeast and northwest transverse joints. Transverse joints occur at about 35° from the approximately east-west trending joints.

To compare later stage quartz veins with earlier joints, the Minnie Gulch area was divided into 200 meter squares, and each vein mappable at 1"=200' was counted each time it appeared in a square. On figure 6, the resulting vein pattern is similar to the joint plot and reflects the predicted fracture concentrations of figure 5. Differences between the vein and joint plots can be interpreted to reflect relative initial fracture densities as well as a bias for reactivation along certain directions. For example, caldera-centered tensional stresses should preferentially reactivate concentric and transverse structures, affecting radial structures less significantly. However, veins controlled by east-west radial fractures and those along northwest-southeast transverse fractures appear with about the same frequency, significantly less than for concentric veins. Relative initial density of transverse fractures was therefore less than that of radial or concentric fractures. Consideration of the greater strength of rock under compression further suggests that transverse fractures were compression generated.

ECONOMIC IMPLICATIONS

Several economically significant implications can be derived from the data discussed above. For instance, transverse structures should develop mineralization along en-echelon fracture zones or in steeply raking ore shoots with distinct walls. Throughgoing radial or concentric fractures can develop mineralization along breccia-filled zones. Intersections between compressionally reactivated transverse and radial or concentric fractures, or between two sets of transverse fractures, may be structurally complex, whereas intersections between radial and concentric fractures may be relatively simple. Direction and magnitude of lateral offsets along transverse structures are predictable. Transverse structures should be more persistent than radial or concentric fractures and should tap deeper mineralizing sources for greater durations of time. A greater proportion of concentric fractures than of radial fractures should be

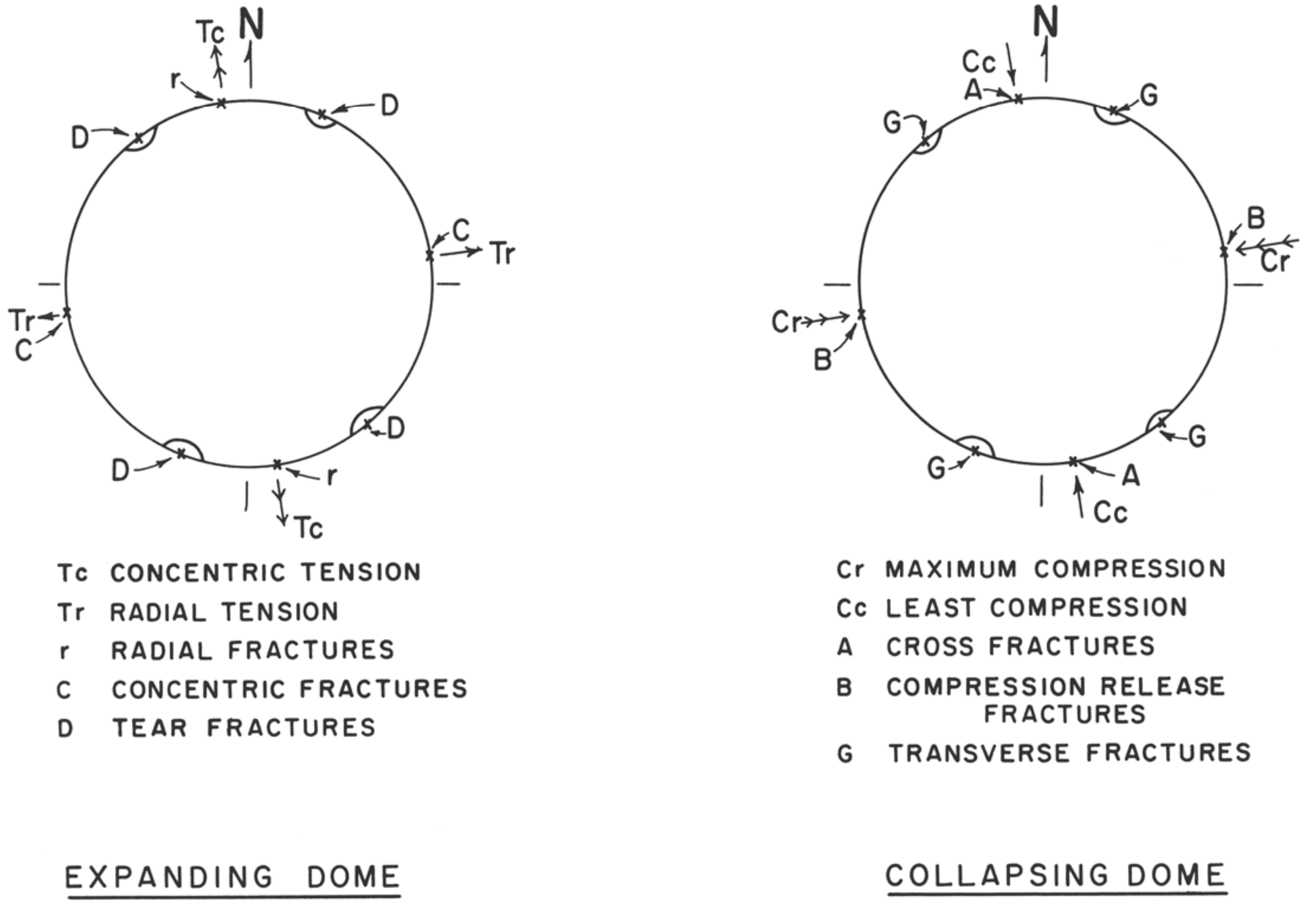

FIGURE 5.

Theoretical joint-pole plot for fractures in the outlined area on the ideal expanding dome (fig. 4, left), and on the collapsing dome (fig. 4, right).

mineralized, since the former are reactivated by both doming and collapse. Finally, mineralization during cycles of structural reactivation should lead to complex cross-cutting relationships between barren wallrock, zones of alteration, quartz veining, and ore-phase mineralization.

SUMMARY AND CONCLUSIONS

Most major fractures around the Silverton volcanic center are remarkably persistent and often highly mineralized. Neglecting those formed by effects secondary to magmatic doming and collapse, these fractures fall into three general categories: a) radial, b) concentric, and c) transverse. Transverse structures curve and tend to become concentric where they can be traced any distance away from the caldera.

The three classes of structures are developed in Minnie Gulch, an area on the periphery of the caldera which seems affected only by caldera-forming processes. Fracture patterns in Minnie Gulch have symmetry that conforms with predictions based on consideration of ideal doming and collapse mechanics.

Several differences exist between fracture types. Slickensides, en-echelon fractures, associated jointing, and orientations inclined to radial and concentric fractures are significant characteristics of transverse structures. Plumose fracture surface patterns, simplicity in plan, even frequency distribution, and radial or concentric orientation around the caldera are significant characteristics of radial and concentric structures.

Radial and concentric fracture sets are tensional in origin, whereas transverse fractures are conjugate cornpressional shear structures produced by entirely different regimens of stress. First radial, then concentric fractures developed in a tensional environment during initial doming. Transverse fractures formed during a later stage of radially directed compression around a central plug when the dome collapsed. Major fractures and associated jointing were formed by magmatic forces as an immediate, primary cause: accumulation and intrusion of magmas caused doming, and lateral movements and extrusion triggered subsidence. The writer believes that evidence presented here does not support Badgley's (1965, pp. 493-507) appeal to ". . . both lateral compression and vertical

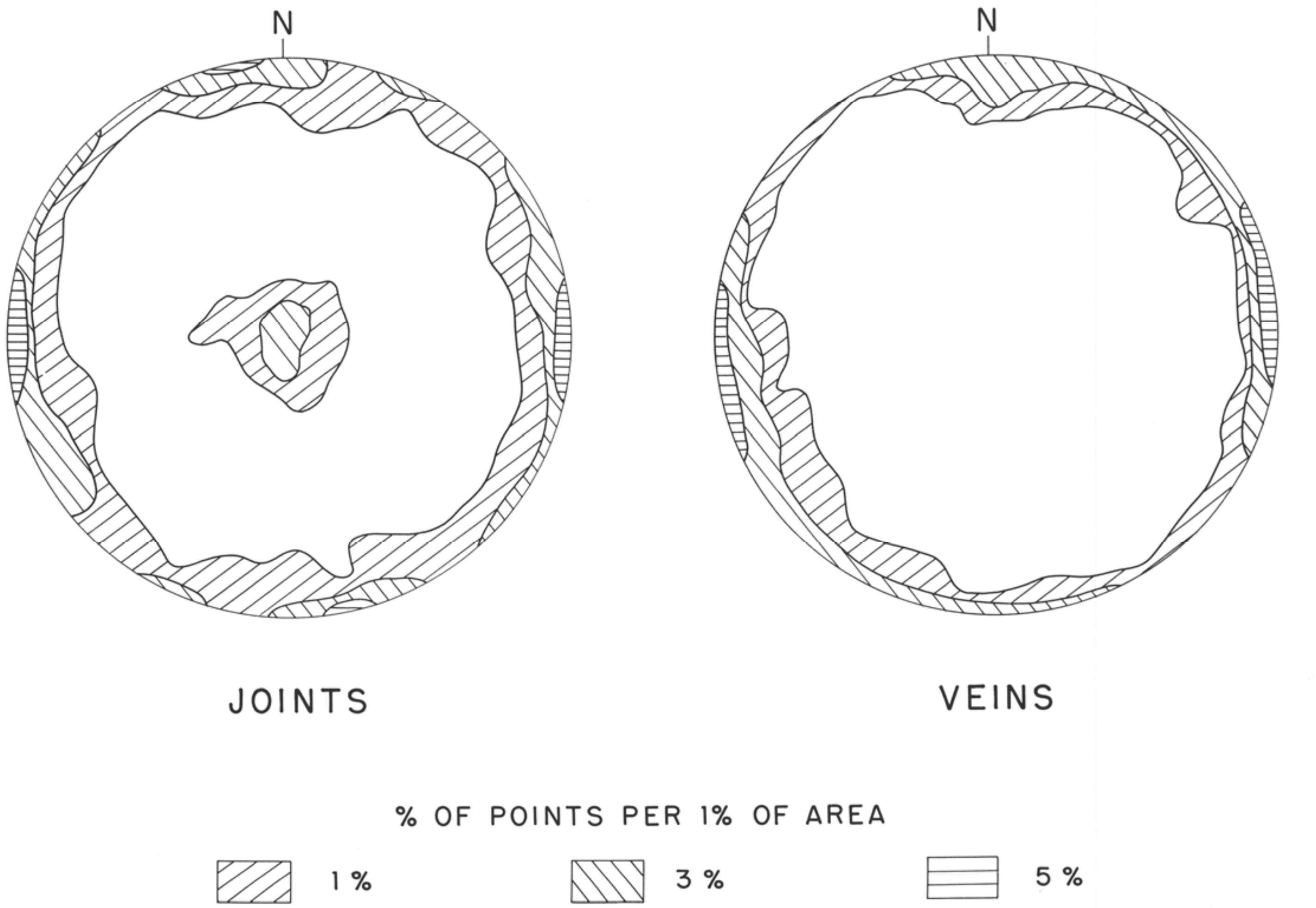

FIGURE 6.
Synoptic lower hemisphere fracture-pole plots for joints (left) and quartz veins (right) observed in Minnie Gulch.

horsting effects" or Wisser's (1960, p. 1, 5) emphasis on doming accompanied by fracture or plastic flow, as explanations for the fracture patterns of the Silverton center of the southwestern San Juan Mountains.

Movement of mineralizing solutions was controlled by earlier-formed fractures complexly reactivated during contrasting deformational cycles. Consideration of ore controls and ore continuity suggests that transverse structures may be more persistent, mineralized more erratcially, and structurally more complex than radial and concentric fractures; whereas the latter may be interrupted, offset, mineralized more consistently, and structurally simple.

REFERENCES CITED

Badgley, P. C., 1965, Structural and tectonic principles: New York, Harper and Row, 521 p.

Burbank, W. S., 1933, Vein systems in the Arrastra Basin and regional geologic structure in the Silverton and Telluride quadrangles, Colorado: Colo. Sci. Soc. Proc., V. 13, No. 5, pp. 136-215.

Burbank, W. S., 1941, Structural control of ore deposition in the Red Mountain, Sneffels, and Telluride district of the San Juan Mountains, Colorado: Colo. Sci. Soc. Proc., V. 14, No. 5, pp. 141-261.

Bloom, D., 1965, Geology of the Horseshoe district and ore deposits of the Hilltop Mine, Park County, Colorado: Colo. School of Mines D.Sc. Thesis 1019, 154 p.

Cloos, E., 1955, Experimental analysis of fracture patterns: Geological Soc. America Bull., V. 66, pp. 241-256.

De Sitter, L. U., 1964, Structural Geology: McGraw-Hill Book Co., Inc., 552 p.

Kelley, V. C., 1957, Veins and fault systems of the Western San Juan Mountains mineral belt, Colorado: New Mexico Geol. Soc. 8th Field Conf. Guidebook, pp. 173-176.

Larsen, E. S., and Cross, W., 1956, Geology and petrology of the San Juan region, Colorado: U. S. Geol. Survey Prof. Paper 258, 303 p.

Luedke, R. G., and Burbank, W. S., 1961, Central vent ash-flow eruption, western San Juan Mountains, Colorado: U. S. Geol. Survey Prof. Paper 424-D, pp. 94-96.

Schwarz, F. P., 1967, Geology and ore deposits of Minnie Gulch, San Juan County, Colorado: Colo. School of Mines D.Sc. Thesis 1115, 238 p.

Smith, R. L., 1960, Zones and zonal variations in welded ash-flow tuffs: U. S. Geol. Survey Prof. Paper 354-F, 159 p.

Smith, R. L., and Bailey, R. A., 1963, Geology of volcanic and hypabyssal intrusive igneous rocks: U. S. Geol. Survey Prof. Paper 475-A, p. 87.

Varnes, D. J., 1962, Analysis of plastic deformation according to Von Mises' Theory with application to the south Silverton area, San Juan County, Colorado: U. S. Geol. Survey Prof. Paper 378-B, 49 p.

Wisser, E., 1960, Relation of ore deposition to doming in the North America cordillera: Geol. Soc. America Memoir 77, 112 p.