Premetamorphic hydrothermal origin of the Tungsten Queen vein, Hamme district, North Carolina, as indicated by mineral textures and minor structures

by

Michael P. Foose and John F. Slack
U.S. Geological Survey
Reston, Virginia 22092

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INTRODUCTION

The Hamme Tungsten district is a 13-km long, 2-km wide, northeast-trending belt located in northern Vance County, North Carolina and southern Mecklenburg County, Virginia (Fig. 1). The district contains the largest quartz-wolframite-

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type vein deposits in the United States. Over 50 tungsten-bearing veins occur in this area (Espenshade, 1947), from which more than 1 million short ton units of WO_3 have been produced since World War II. Mining terminated in 1971 after a sharp drop in the price of tungsten; currently, the district is inactive.

The relationship between vein minerals and minor structures in one of the veins, the Tungsten Queen, is the subject of this study. The Hamme mine, located along the Tungsten Queen vein, is operated by Ranchers Exploration and Development Corporation of Albuquerque, New Mexico, and their generosity made possible our underground examination of mine workings. The mine has been developed on eight levels to a depth of 600 meters. Important observations were made on several different levels. Relationships observed on the 1700 level, the deepest of the mine, proved to be the most clearly exposed and most definitive. This level was only recently opened and was unavailable for previous studies by Espenshade (1947) and Gair (1977). Although generally less well-developed, relationships similar to those found on the 1700 level were also noted on the 700, 1100, 1300, and 1500 levels.

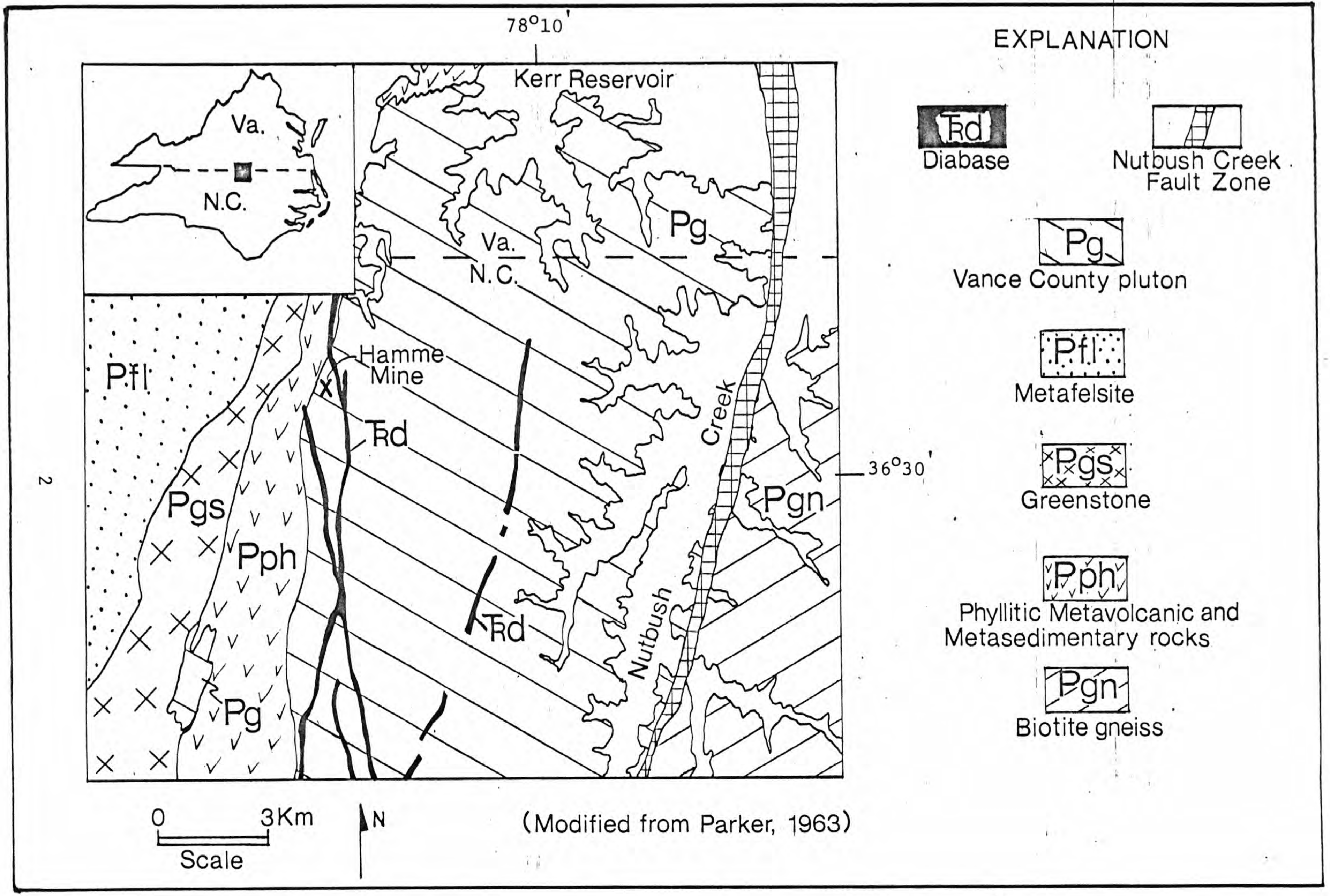

Figure 1. Index and regional geologic map

The genesis of the Hamme deposit has been discussed by a number of workers. White (1945) postulated a hydrothermal origin for the veins in which tungsten-bearing solutions were thought to have emanated from the nearby granitic pluton. Espenshade (1947) supported this hydrothermal theory and believed that the veins had replaced part of the adjacent wall rocks. Gair (1977) elaborated upon this idea by suggesting an origin in which preexisting folds and warps provided channelways along which silica-rich mineralizing solutions had moved; he concluded that the veins replaced the folded schistose country rock, and assumed the form of preexisting fold structures. Parker (1963) presented an extensive discussion of the geologic setting of the district, but only touched on the origin of the veins by describing them as hydrothermal rocks. More recently, Casadevall (in prep.) is addressing the problem of ore genesis through an investigation of the stable isotopes of sulfur, oxygen, carbon, and hydrogen.

This study amplifies and supports our preliminary examination (Slack and others, 1978) of some of the textural features displayed by vein minerals and associated minor structures within the Hamme mine. Our purpose has been to determine and document the relationships between mineralization and deformation in order to better define the origin of the deposit. A conclusion is reached that ore and gangue minerals formed early, possibly as open-space fillings, and that the vein and adjacent country rocks were subsequently deformed by shearing and folding.

REGIONAL GEOLOGIC SETTING

The Hamme tungsten district is situated in the southern Appalachian Piedmont. From west to east, the region may be divided into three geologically distinct terrains (Fig. 1): (1) a 3000 meter-thick, westward-dipping sequence of greenschist-facies felsic and mafic metavolcanic rocks and minor metapelites of the Carolina volcanic slate belt (Parker, 1963; Hadley, 1973, 1974) of probable late Precambrian to early Paleozoic age (Glover and Sinha, 1973); (2) the Vance County pluton, a northeast-trending intrusive body of granitic to tonalitic composition similar to other plutons of the Carolina slate belt that have yielded Rb-Sr and U-Pb ages of 520-620 m.y. (Fullagar, 1971; Glover and Sinha, 1973; Wright and Seiders, 1977), and (3) biotite gneiss of the Raleigh belt (Glover and Sinha, 1973; Parker, 1977) lying east of the Vance County pluton. The granite is intrusive into the Carolina slate belt and the Hamme district is located near a westward bulge in the granite contact (Fig. 1). To the east, the contact between the granite and biotite gneiss is defined by an intensely mylonitized zone which coincides with a prominent air-photo lineament and with regional magnetic anomalies. Casadevall (1977) has interpreted this zone as a major north-south fault in southern Virginia and North Carolina and named it the Nutbush Creek dislocation.

Although the geologic history of the Hamme district has not been worked out in detail, studies 35 km to the west near Virgilina have documented a complex history of deformation and metamorphism. Tobisch and Glover (1971) and Glover and Sinha (1973) proposed that rocks correlative with the phyllites and metavolcanic rocks in the Hamme area were deposited during the latest Precambrian and early Paleozoic and were subsequently deformed by at least two periods of folding and by faulting. Granitic intrusions were emplaced between 575 and 620 m.y. ago, during or just after the deformation. Metamorphism was probable episodic, as some occurred during folding. However, the main metamorphic event may have taken place less than 400 m.y. ago (Butler, 1972).

DEPOSIT SETTING

Quartz veins in the Hamme district concentrate along the western margin of the Vance County pluton (Figs. 1, 2), and occur both within the granite

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Figure 2 near here.

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and in adjacent phyllitic metasedimentary and metavolcanic rocks of the Carolina slate belt. The intrusive contact between the granite and metamorphosed country rocks trends SSW through the main part of the district. Mapping by Espenshade (1947) has identified three principal vein directions (Fig. 2). In the southern part of the district, veins are oriented mainly N-S, whereas those in the northern part are aligned about N35W. Vein orientations in the central area are variable; predominantly they trend N35E, but N-S and NW-trending veins also are common. The significance of these three vein sets is unclear--tungsten minerals occur within all three, but the major production has come from NE-trending veins, such as the Tungsten Queen, located in the central area near the granite-phyllite contact. Movement along the Nutbush Creek dislocation may have destroyed similar tungsten-bearing veins near the eastern margin of pluton.

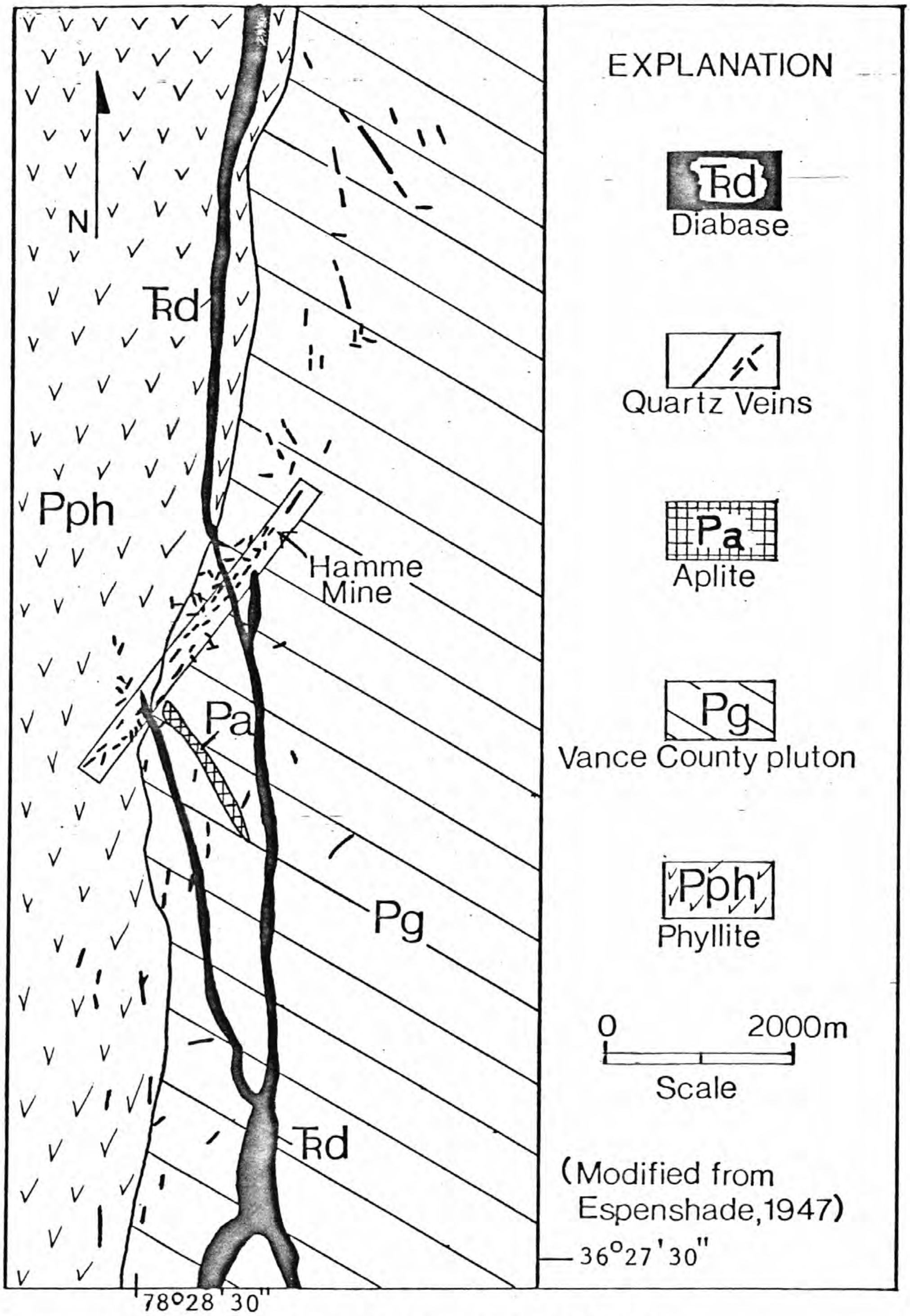

Figure 2. Quartz veins in the Hamme district

The Tungsten Queen (or Sneed-Walker) vein trends N35E, is approximately 3500 meters long, up to 10 meters wide, and generally dips steeply to the southeast. The Hamme mine has developed this vein to a depth of 600 meters, and along strike for approximately 2000 meters. Gair (1977) recognized 8 lodes or ore shoots which plunge south from 42^{o} to 65^{o} along trends between S10E and S10W. Lodes are enclosed in sericitized and sheared granite in the northern part of the mine, and in altered metasedimentary and metavolcanic rocks to the south (Fig. 3). Lodes are arranged in an en echelon pattern with those to

Figure 3 near here.

the northeast successively offset to the east (Fig. 3). Post-ore Triassic dikes cut the vein in two places. Some of the general structural and mineralogical features of the vein are outlined below.

Many of the larger structural features of the vein were recognized and discussed by Gair (1977). In addition to describing the en echelon distribution of lodes, Gair recognized both major and minor folds within the schistose country rock. These folds parallel the ore shoots, plunging on average 60^{o} due south, and also are arranged in en echelon patterns. Gair interpreted the en echelon distribution of folding to have formed during an episode of right-lateral shearing (Fig. 3).

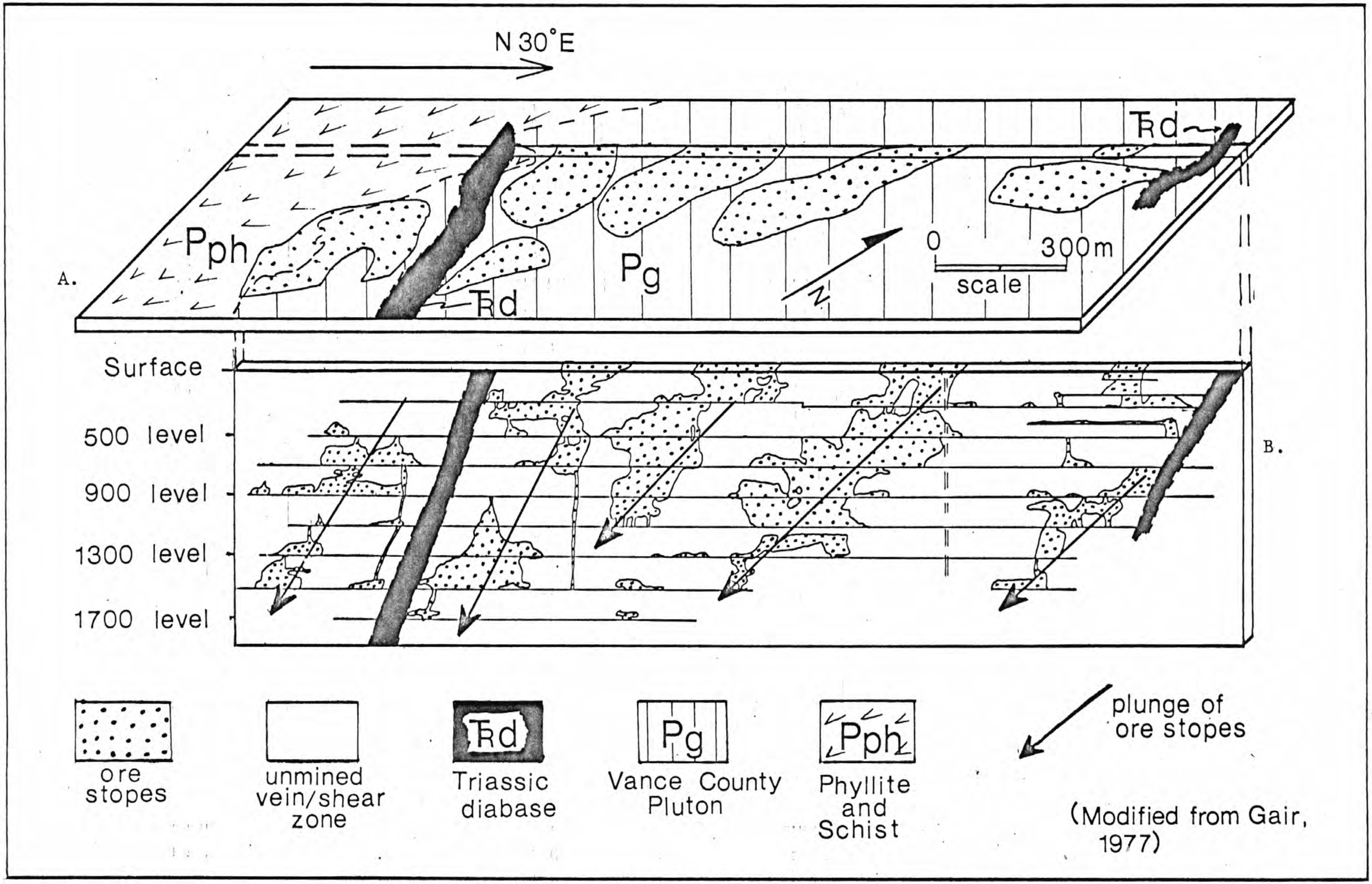

Figure 3. Schematic plan view (A) and longitudinal section (B) of the Hamme mine. Stopes on the plan view are surface projections from mine workings.

Prominent banding is the most noticeable feature observed within the vein (Fig. 4). Banding, with layers up to 1 meter wide, is defined by: (1) thin

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septa of muscovite, (2) tabular or lens-like inclusions of phyllite or schist, (3) sharp changes in the concentration of enclosed ore minerals, especially huebnerite, fluorite, and sulfides, (4) subtle changes in the color and texture of quartz, and (5) by thin partings along which secondary limonite has been deposited. Both the vein and vein banding is observed to pinch and swell along the length of the mine.

The basic mineralogy of the vein has been described by Espenshade (1947). Huebnerite, the manganese end member of the wolframite series, is the principal ore mineral. It occurs in a gangue of quartz, minor fluorite, sericite, and rare carbonate (calcite, rhodochrosite, ankerite, dolomite). Additional minerals include pyrite, sphalerite, galena, chalcopyrite, and tetrahedrite. Trace amounts of gold, scheelite, molybdenite, bornite, apatite, beryl, topaz, and garnet have also been reported (Espenshade, 1947; Shawe and others, 1976). Traces of altaite, volynskite (?) and wittichenite (?) have recently been found in sulfide-rich areas (Slack, 1977, unpub. data). The mineralogy of the vein is remarkably uniform throughout the mine, with an apparent lack of zoning either along strike or with depth.

Figure 4. Typical view showing layering or banding within the vein (field of view across layering is 2 m).

TEXTURES OF ORE AND GANGUE

MINERALS AND RELATED MINOR STRUCTURES

Within the principal vein (Tungsten Queen), the relationships between minerals and minor structures provide valuable information about ore genesis. Most important are the relationships displayed by huebnerite, sulfides, quartz, and fluorite. Minor structures formed during shearing and folding deform these minerals by brittle fracture and by plastic flow.

Mineral-textures.--Huebnerite displays a variety of habits and textural relationships. It generally occurs as individual grains that may show either euhedral or anhedral form. Euhedral grains 1-5 cm long by 1 cm wide are common, with some prismatic crystals as much as 35 cm in length (Fig. 5). Most prismatic grains occur singly and with no preferred orientation. However, in some parts

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of the vein, grains concentrate near sericite or phyllite septa and are oriented perpendicular to vein layering. Rarely, prismatic huebnerites form radiating, multi-grain clusters. On the 1700 and 1300 levels, such clusters were observed near vein layer contacts and are aligned perpendicular to the banding of the vein (Fig. 6).

Figure 6 near here.

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Figure 5. Photograph of a long (35 cm) euhedral huebnerite crystal. Although the crystal has been slightly fractured, its prismatic form has not been significantly disrupted.

Figure 6. Photograph of a huebnerite rich layer within the 1736 stope. Huebnerite grains concentrate near boundaries of vein layers. A radiating cluster of prismatic huebnerite grains occurs to the left of the pencil eraser.

Huebnerite occurs more typically as fractured and anhedral grains. Some fragmented grains have experienced relatively little disruption as their primary euhedral morphology is still readily apparent. Most grains, however, occur as small, angular fragments. Quartz is the dominant matrix for huebnerite, but some huebnerite grains may also be enclosed in sulfides or fluorite.

Both euhedral and anhedral huebnerite grains are concentrated in discrete layers, and in many places may be used to define vein banding. In some areas, layers defined by concentrations of huebnerite show deformation and folding by minor structures. Within these folds, individual huebnerite grains are slightly bent or are broken into many angular fragments.

In doubly polished thin section, huebnerite crystals display conspicuous colored bands in shades of red, brown, and yellow. Electron microprobe studies of a number of such crystals (Bird and Gair, 1976) indicate that the colors of the different bands are due to only minor variations in the content of iron. One thin section (Fig. 7) shows a radiating cluster of prismatic huebnerite crystals

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Figure 7 near here.

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with color banding parallel to grain edges. The patterns are those of typical growth zones in sphalerites from shallow-seated vuggy ores, and are similar to wolframites found in other quartz vein deposits (Landis and Rye, 1974; Shepherd and others, 1976).

Figure 7. Photo micrograph (transmitted light) of a prismatic huebnerite crystal in a quartz matrix. Vertical crystal is part of a radiating cluster of crystals growing from a common base (bottom of section). Color bands which parallel crystal faces probably represent growth zones. Crystal is 2 cm in length. (sample collected by J. Gair on the 1300 level)

Sulfide minerals are found in association with, but more commonly, isolated from huebnerite grains. Most occur as wispy streaks or as clusters of anhedral grains. Stringers and triangular masses of sulfides are found mainly in areas that have been sheared or folded. They are intimately associated with minor structures and have evidently undergone extensive flowage and recrystallization. In relatively undeformed areas, less disturbed textural relationships may be observed. The most significant of these were found in the 1736 stope where epitaxial cappings of sulfides (sphalerite and minor pyrite) were observed on prismatic terminations of euhedral huebnerite grains (Fig. 8). In the same

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stope, rare cubes of pyrite up to 1 cm in size were found enclosed in quartz.

Quartz and fluorite occur as anhedral grains of variable size. Quartz is generally fine-grained and shows a prominant banding defined by subtle color changes (clear, cloudy or turbid) and by differences in grain size. Within some minor structures, quartz has a tendency to break along preferred directions, indicating a structurally controlled mineral anisotropy. Fluorite occurs as thin discontinuous stringers within the vein which either parallel or lie en echelon to vein banding (Fig. 9). In a number of locations, it forms a thin layer which

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separates the vein from adjacent wall rocks. Locally, fluorite is the matrix for fractured grains of heubnerite.

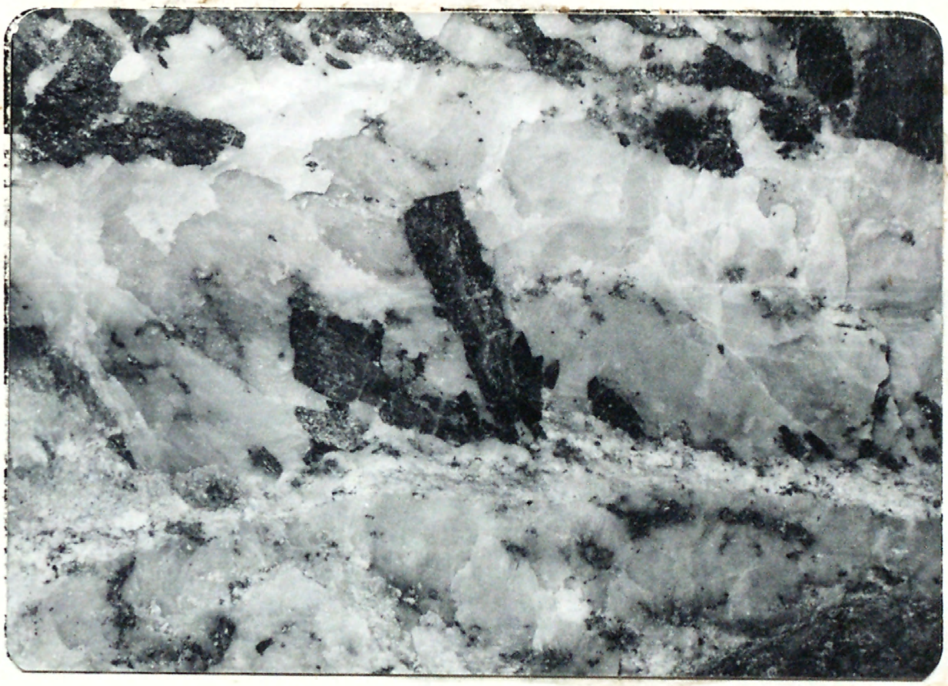

Figure 8. Close up view of the area shown in figure 6 (page 16). Both euhedral and fragmented huebnerites are shown. Thin caps of sphalerite (light grey) and pyrite (not visible) occur on the prismatic terminations of some euhedral grains (the two large grains in the photograph center).

Figure 9. Photograph of vein fluorite. Fluorite stringers (darker grey against lighter grey quartz) both parallel and lie en echelon to vein layering.

Thin septa of schist and sericite are common within the vein. In many places, they form the most easily recognized boundary to vein layering. Folding of these septa is often the only indication of deformation within an otherwise homogeneous appearing mass of vein quartz. The septa typically are discontinuous, and may locally be arranged en echelon. They are lithologically similar to the sericitized granitic country rock which hosts the northern part of the vein system.

Minor structures within the vein.--Minor structures observed within the vein may be placed into two groups. The majority involve orientation of mineral grains into en echelon patterns, presumably in response to right-lateral shearing. Less common are fold structures which deform the country rock, the vein, and enclosed ore and gangue minerals. Two fold sets are recognized--an early, gently plunging set, and a later, more steeply plunging set. The latter set is believed to also be related to the right-lateral shearing which formed the en echelon minor structures as well as the large, mine-scale en echelon distribution of ore shoots previously described (Fig. 3).

En echelon arrangements of minerals are common on all mine levels examined. They are expressed by euhedral or fractured huebnerite grains, schist septa, sulfide wisps, and by fluorite stringers aligned obliquely to vein wall or vein banding (Fig. 9). The preferred parting of some quartz parallel to this direction indicates that it also is aligned within this orientation. Alignment of en echelon grains is approximately N-S, in contrast to the more NE-SW trend of the vein; the acute angle between the elongation direction and vein layering is typically between 25 and 40 degrees. In all cases observed, the en echelon arrangement of these minerals is consistent with right-lateral simple shearing (Ramsay, 1967, p. 84). These minerals are aligned approximately parallel to the principal elongation direction (λ_1) and perpendicular to the direction of flattening (λ_2) of the strain ellipse (Fig. 10). Huebnerite and schist septa have locally been

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mechanically rotated into this direction; most sulfides, quartz, and some fluorite have undergone recrystallization with this new orientation.

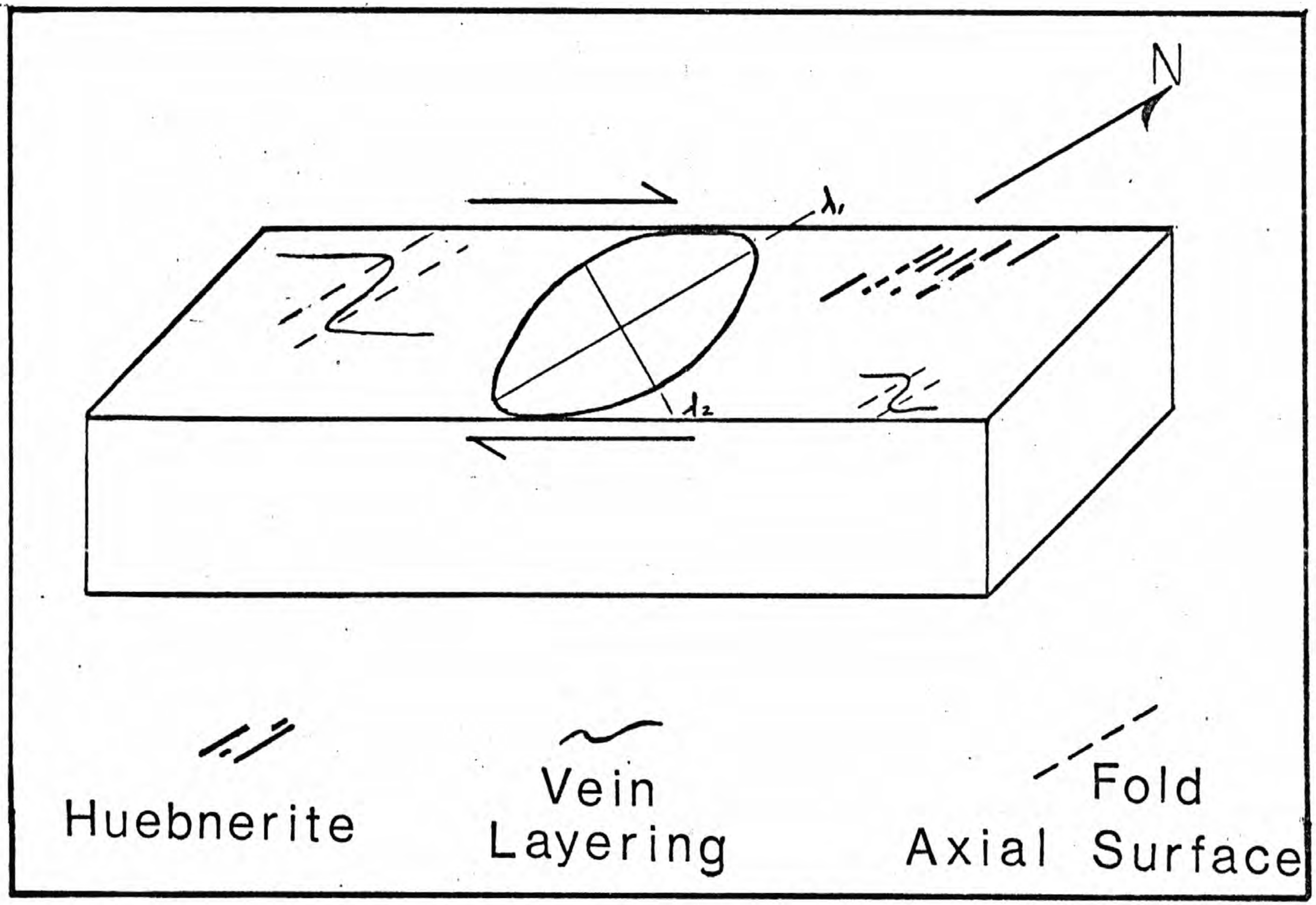

Figure 10. Deformation model of right lateral simple shearing for the Hamme (Tungsten Queen) vein. Axial surfaces of steep plunging folds are approximately perpendicular to the principal direction of shortening (λ_2). En echelon minerals are aligned parallel to the direction of maximum extension (λ_1).

Within many of these en echelon structures, and in some minor folds, spaces between broken huebnerite fragments are filled with quartz, sulfides, or fluorite (Fig. 5) that are interpreted to be boudinage structures formed during extension of huebnerites parallel to the long axis of the strain ellipse (Fig. 10). Huebnerite deformed brittlely, while the more ductle quartz, fluorite, and sulfides flowed into low pressure areas between huebnerite grains. The sulfide fillings formed in this way contrast with the previously described occurrences with cappings of sulfides on prismatic terminations of euhedral huebnerite crystals. This latter occurrence is interpreted as an essentially undisturbed primary texture and is observed only in relatively undeformed areas of the vein.

Fold structures in the quartz vein are less common, but are more striking. The most frequently observed minor folds plunge moderately to steeply south. They are small, tight to isoclinal structures characterized by wavelengths of about 50 cm and amplitudes of approximately 1 meter. (Figs. 11a,11b). In both

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Figures 11a, 11b near here.

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style and orientation, they are similar to the south-plunging folds recognized by Gair (1977) in the schistose country rock. Minor fold assymmetries generally indicate right-lateral shearing in which fold axial surfaces parallel the elongation direction of en echelon minerals and are perpendicular to the principal direction of shortening (λ_2)(Fig. 10). It is believed that this folding occurred during the same shearing which formed the en echelon mineral structures and the larger en echelon mine-scale ore shoots (Fig. 3).

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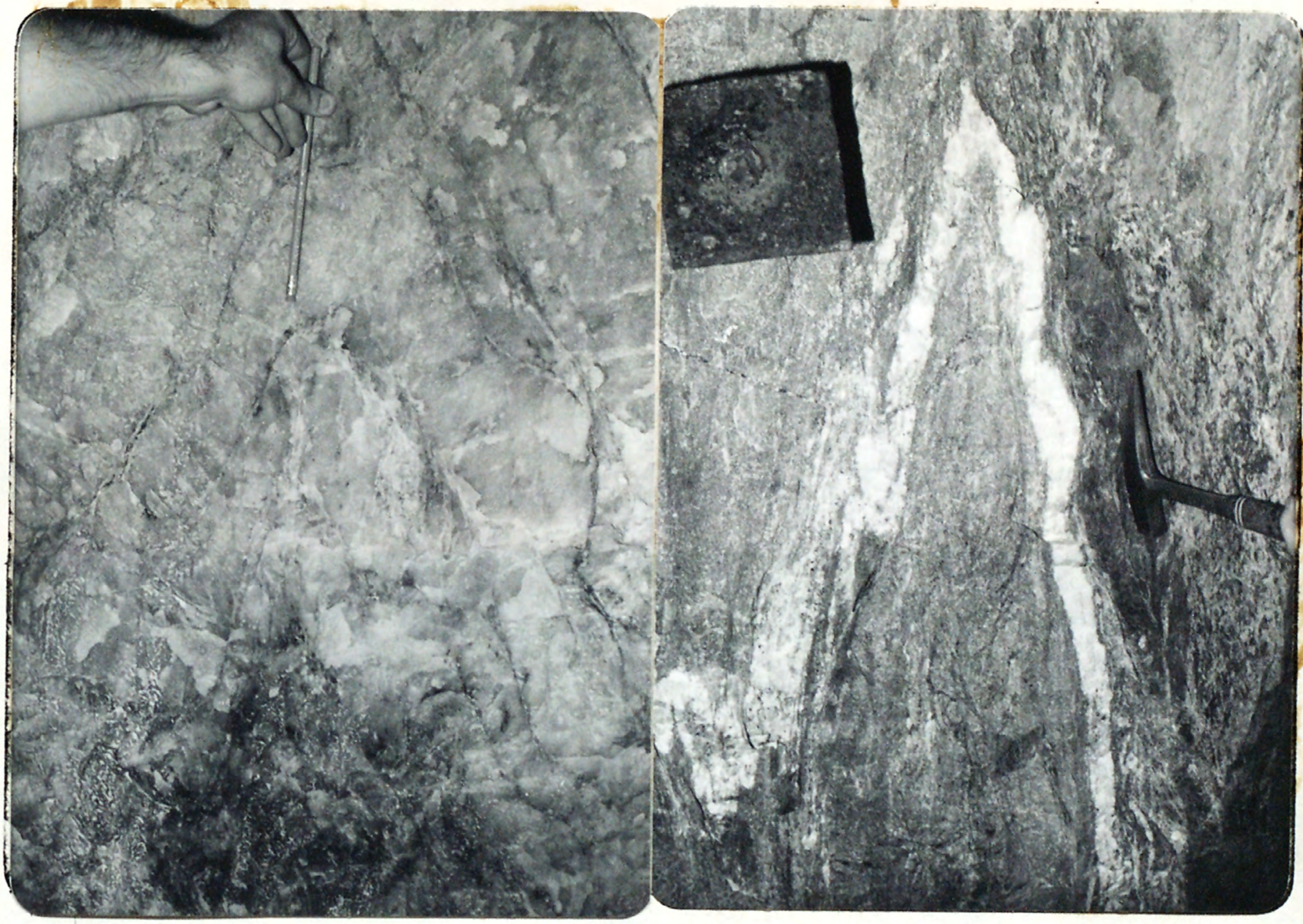

A. B.

Figure 11. Steeply plunging folds. A) Steeply plunging fold in quartz vein. Quartz has flowed hingeward, thickening the fold nose. Huebnerite layers are folded and sulfides are aligned in the fold axial surface. Fold occurs in the 1710 stope. B) Steeply plunging fold in phyllite country rock. Fold is similar in style to the steeply plunging fold found in the vein and has a prominent axial plane foliation. Fold occurs on the 1700 level. Roof bolt is approximately 15 cm across.

These steeply-plunging folds are most clearly defined where interlayers of schist or sericite are present. However, they are also observed in layering expressed by different concentrations of ore minerals or by thin films of secondary limonite or hematite. Quartz layers thicken in fold hinges and thin along fold limbs, indicating hingeward flowage of quartz during folding. Layers defined by concentrations of huebnerite are folded and, within fold noses, individual huebnerite crystals may be slightly bent. In the noses of some folds, elongate huebnerite fragments have been rotated to lie in the fold axial surface. In a few areas, sulfides are concentrated in fold noses parallel to the axial surface. Fluorite and sulfides occur as thin wisps and stringers aligned within the fold axial surfaces, and in some folds quartz exhibits a preferred parting parallel to the axial surface.

Although steeply-plunging folds predominate, some distinctly different gently-plunging folds have been observed. The majority of the gently plunging structures are large, open flexures with wavelengths of approximately 2 meters and amplitudes of about 1 meter. Most fold axes plunge gently northeast, although some plunge gently south; fold axial surfaces may dip steeply or lie nearly horizontal. They are thus distinctly different in style from the smaller, tight, steeply plunging folds described above. The gently plunging folds occur both within the vein and in adjacent wall rocks (Figs. 12a, 12b). They may be more abundant than presently recognized because their low angle of intersection

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with the mine workings generally results in poor exposure.

A

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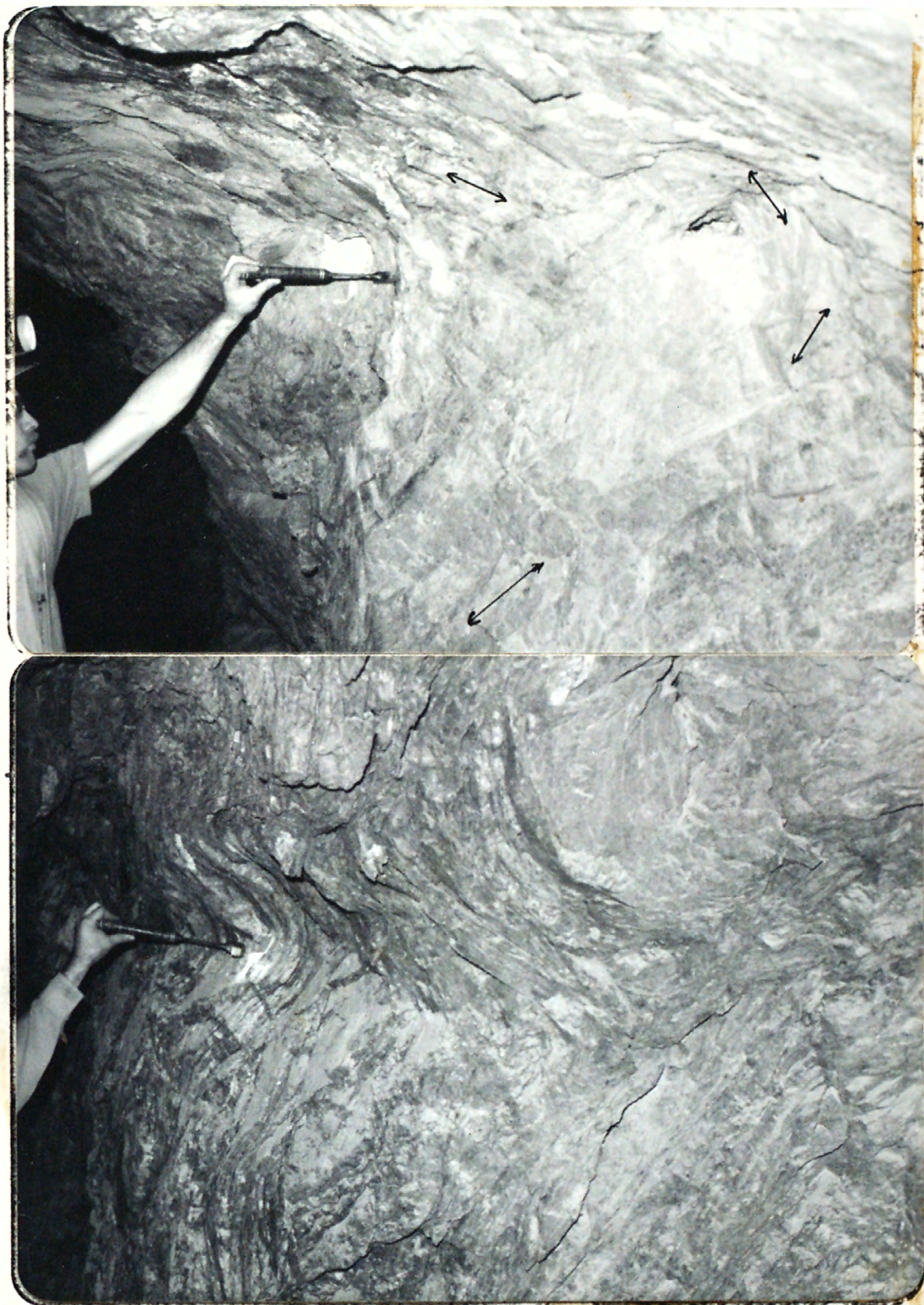

Figure 12. Gently plunging folds. A) An open, gently plunging fold within the quartz vein. Fold occurs in the 1710 stope near the steep plunging, younger fold shown in figure 11A. Vein layering parallels arrows. B) An open, gently plunging fold in schistose country rock on the 1100 level. The fold is similar in style to open folds which deform the quartz vein.

One of these gently -plunging structures, located at the 1700 level (1710 stope), was found to be refolded by steep, south-plunging minor folds. During refolding, the axial surface of the gentle fold was rotated from sub-horizontal to upright, and the fold axis was reoriented from a gentle northeast plunge to a gentle southwest plunge (Fig. 13). These relationships clearly indicate

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that, at least locally, two periods of folding have affected both the vein and country rock of the Hamme tungsten deposit.

The relationships between minerals and the older, gently-plunging folds are similar to those displayed by the steeper plunging, younger folds. Quartz layering is folded, and sulfides, fluorite, and quartz align within the fold axial surface. In places, layering defined by huebnerite concentrations is folded, with some huebnerite grains rotated into subparallel alignment with the fold axial surface.

Correlations of these two fold sets with other regional structures is uncertain. Espenshade (1947) noted gentle north- and south-plunging lineations and crinkles within both the Vance County pluton and in some of the quartz veins. These are probably related to the gentle plunging early folds described above. Farther to the west, Glover and Sinha (1973) have identified macroscopic second-generation folds in the vicinity of Virgilina that have similar gentle northeast or southwest plunges. The younger, steeply south-plunging folds in the Hamme mine apparently do not correlate with any recognized regional structures and may be local features produced by shearing, perhaps associated with movement along the Nutbush Creek dislocation (Casadevall, 1977).

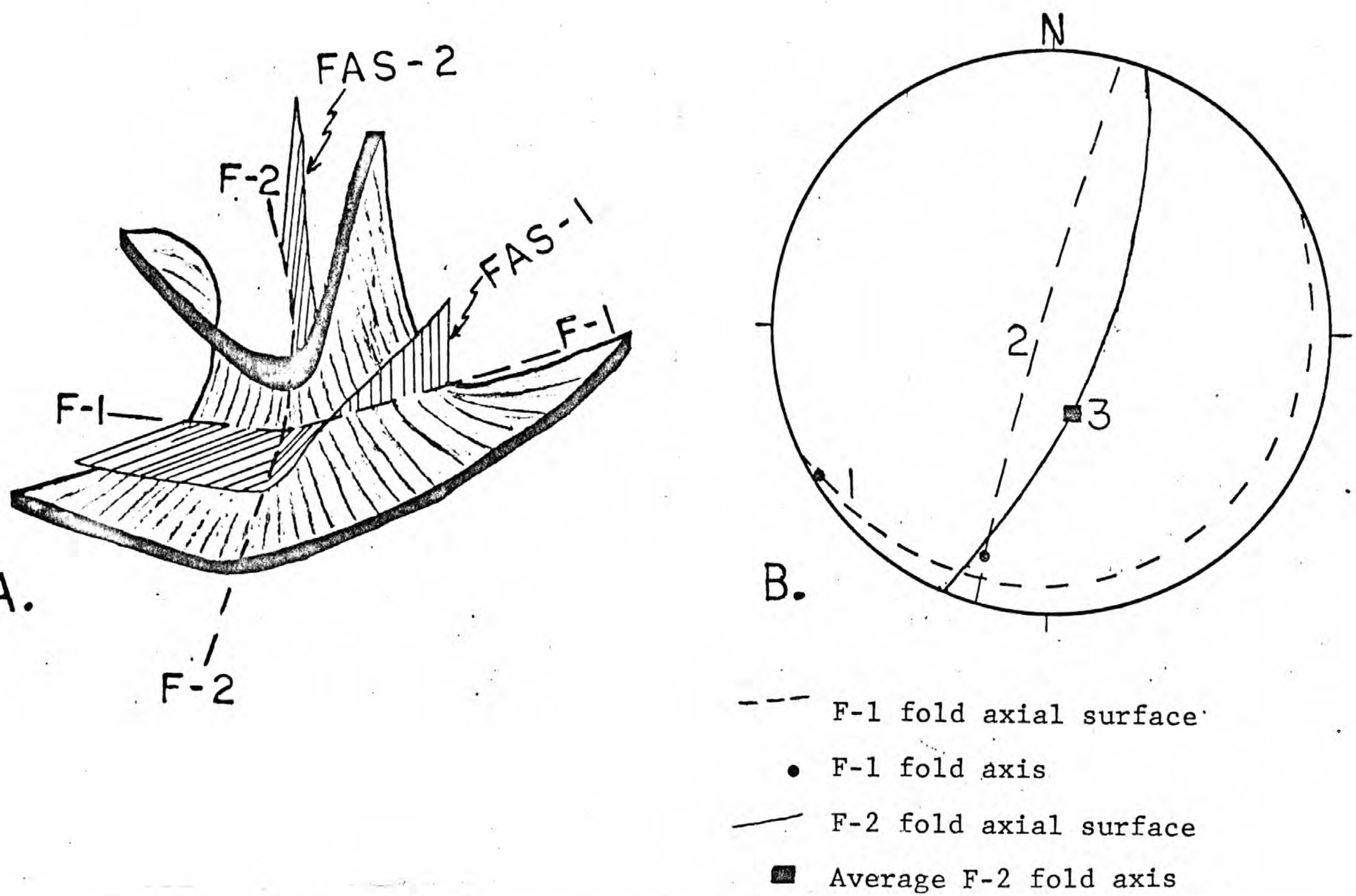

Figure 13. Refolding of open, gently plunging folds by later tighter and steeper plunging folds as observed on the 1710 stope. A) An open, early fold, fold axis (F-1), and fold axial surface (FAS-1) is refolded by a tighter F-2 fold. B) Measurements indicate that the F-1 fold has a nearly horizontal fold axis and axial surface (1) which is reoriented to a slightly steeper fold axis and a nearly vertical axial surface (2) by (3), a tight F-2 fold with a steep axial surface and a fold axis which plunges on average moderately steeply south.

DISCUSSION AND CONCLUSIONS

The mineral-minor structure relationships indicate that ore deposition occurred prior to shearing and folding. This is most clearly documented by the folding of huebnerite-rich vein layers, and by the bending of individual huebnerite grains within fold structures. However, numerous other relationships support this conclusion. During deformation, huebnerite grains behaved as nearly rigid bodies. Although some bent slightly, most broke into angular fragments. These rigid bodies were encased in a more plastic matrix of quartz, fluorite, and sulfides. During shearing, the huebnerite grains rotated parallel to the principal elongation direction of the strain ellipse, forming en echelon arrays of grains. Locally, flattening in the noses of minor folds rotated huebnerites into subparallel alignment with the fold axial surfaces.

Unlike huebnerite, most other minerals deformed plastically. Quartz flowed into the noses of minor folds, thickening hinges. Locally, sulfides, fluorite, and quartz have recrystallized parallel to fold axial surfaces and en echelon to vein layering.

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Plastic deformation of vein material during shearing and folding may offer an explanation for the distribution of ore lodes. Gair (1977) noted that lodes plunge parallel to the steeply south-plunging folds (the younger fold set as described previously) and proposed that the veins replaced preexisting larger folds. Our recognition of minor structures within the vein conflicts with that interpretation, and indicates that vein emplacement occurred prior to deformation. It is tantalizing to speculate that the major mine-scale lodes represent thickened noses which are connected by attenuated fold limbs. During shear-related folding, huebnerite may have been transported as small, rigid bodies within a flowing matrix of quartz. Movement of quartz into fold hinges could concentrate huebnerite in these areas, forming the steeply-plunging ore lodes.

Deformation within the vein has been inhomogeneous. Although most areas appear to have been folded and sheared, some relatively undeformed segments have been preserved. In these areas (particularly the 1736 stope), textural relationships provide information about the initial character of the vein. Most important are the radiating clusters of huebnerite crystals, the rare prismatic huebnerite crystals with epitaxial sulfide cappings, and the delicate compositional growth bandings observed in thin section. These textures are very similar to those in many unmetamorphosed hydrothermal tungsten veins in which ore deposition occurred in several stages by open-space fillings.

The structural and mineralogical relationships, we feel, support a premetamorphic hydrothermal origin for the Hamme tungsten deposit. Genetically similar vein deposits have been described in the Kiangsi province of southeastern China (research group of S. Kiangsi, 1976), at Pasto Bueno, Peru (Landis and Rye, 1974) and at Carrock Fell, England (Shepherd and others, 1976). These districts contain ore which is mineralogically and texturally similar to the Hamme deposit, and in which tungsten-bearing veins are related to granitic intrusions and are localized near the granite-country rock contact. At both Pasto Bueno and Carrock Fell, clusters of prismatic wolframite crystals concentrate along vein walls and, in some areas, multiple episodes of vein opening and mineralization have produced symmetrically banded ores. Intense hydrothermal alteration associated with emplacement of the veins has formed quartz-sericite greisens which may be analogs of the intensely sericitized granitic wall rock found locally at Hamme.

The Tungsten Queen vein differs from these other deposits primarily in that, at Hamme, subsequent deformation has intensely deformed the vein, remobilized the ores into the noses of folds, and obscured most primary textural relationships.

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