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STRUCTURAL GEOLOGY & HYDROTHERMAL ALTERATION ASSOCIATED WITH THE DEEP STAR OREBODY, NORTHERN CARLIN TREND, NEVADA

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Introduction and Regional Setting

The Deep Star orebody has been considered (Teal and Jackson, 1997) the type-example of a structurally-localized Carlin-type orebody. It is one of many high-grade orebodies that occur along the regional Post-Genesis fault system (**Fig. 1**). Of particular note is the observation that the Deep Star orebody occurs along a north-trending segment of that fault system which to the north and south exhibits the more typical north-northwest strike. Also, noteworthy is the observation that the Little Boulder Basin stock appears to be a displaced portion of the Goldstrike stock, but exposures of the contact of the former against the regional fault system are buried beneath post-mineral Carlin Formation.

Within the immediate mine area, the Deep Star mine is within the hornfels halo (**Fig. 2**) along the southern margin of the Goldstrike stock. The host Popovich Formation has been converted to diopside-garnet hornfels and marble interbeds. The mine is on the northeast limb of the Tuscarora Spur anticline, an upright, open, north-northwest-plunging fold. Sills and dikes of the Goldstrike stock, dioritic to granodioritic in composition, expand the section in the mine workings. The mine workings are accessed by a ramp from a bench in the northwestern portion of the active Genesis open pit.

The structural ***and*** stratigraphic controls on the orebody and wallrock alteration are reported herein.

Rock Units

At last year's Annual Research Meeting, the author reported on a transect across the Deep Star orebody (1998, **Fig. 1**). One of the rock units described by others as "pseudotachylite" has now been demonstrated to be igneous and named the "Deep Star Rhyolite" (**Fig. 3**). The unit occurs as tabular bodies throughout the various mine levels, particularly along the Genesis fault. It is invariably symmetrical with a green, black, and/or red glassy margin that abruptly gives way inward to a banded zone with sparse microlites of orthoclase and green amphibole(?), and into a central zone of spherulitic orthoclase with interstitial quartz. Commonly, in proximity to the orebody, all three zones are argillized (montmorillonite + quartz + marcasite); however, along the Gen fault the rock is commonly unaltered. Chemically, the rock exhibits a typical rhyolite composition (**Figs. 4 & 5**) with >70% SiO_2 and with K_2O contents >5%. Locally, within the mine, multiple dikes with similar

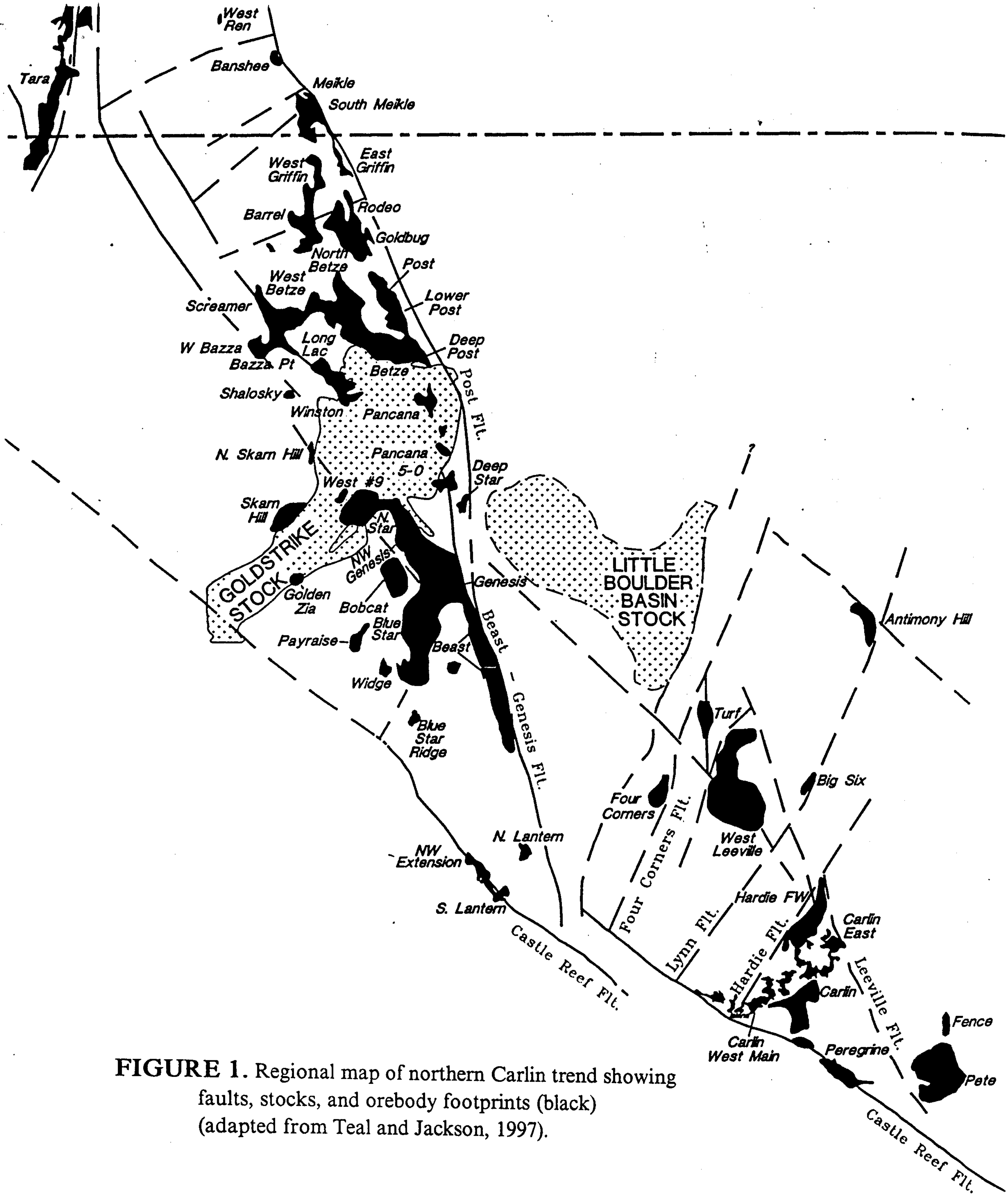
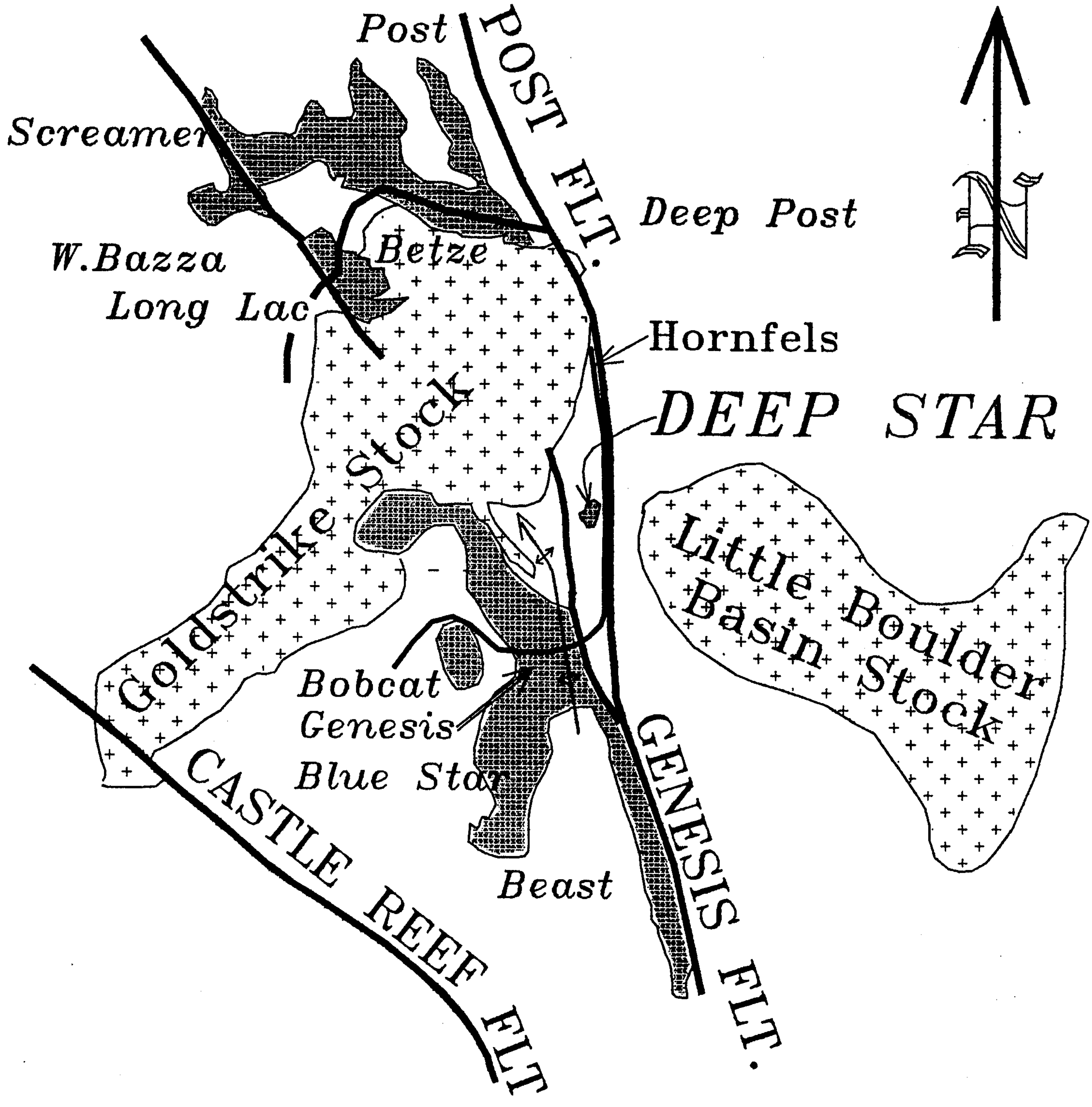


FIGURE 1. Regional map of northern Carlin trend showing faults, stocks, and orebody footprints (black) (adapted from Teal and Jackson, 1997).

FIGURE 2. Index map of Deep Star mine area showing stocks, faults, orebody footprints, and the asymmetrical distribution of hornfels on the north and south sides of the Goldstrike stock.



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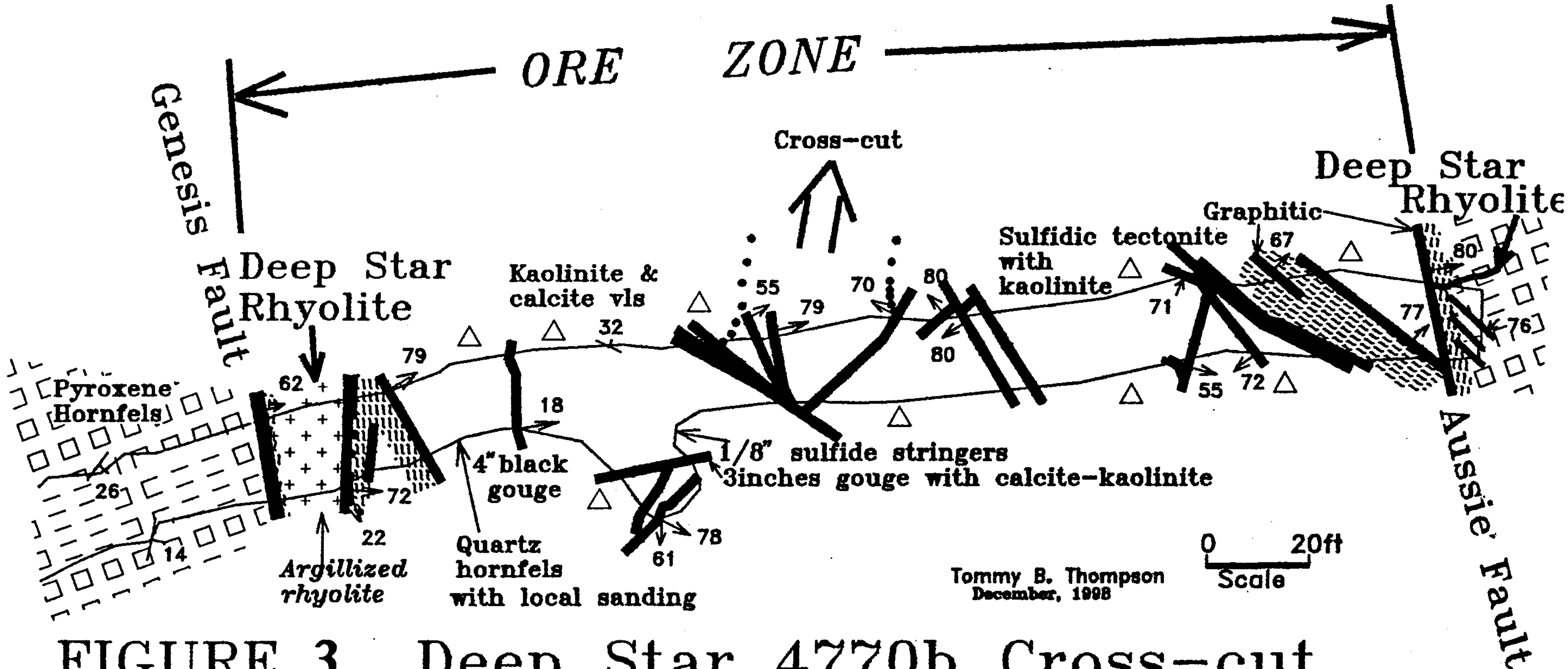


FIGURE 3. Deep Star 4770b Cross-cut Geologic map.

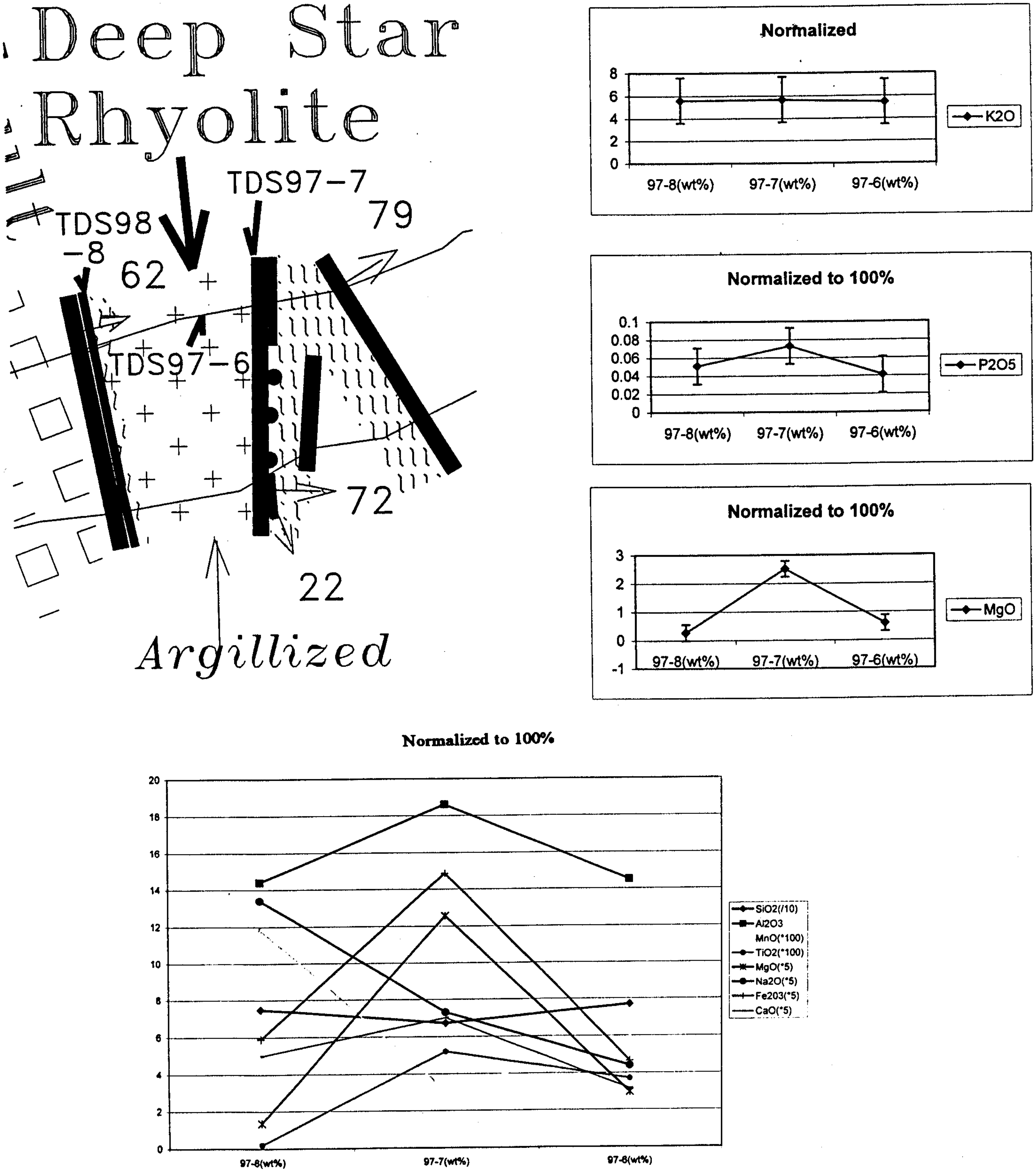
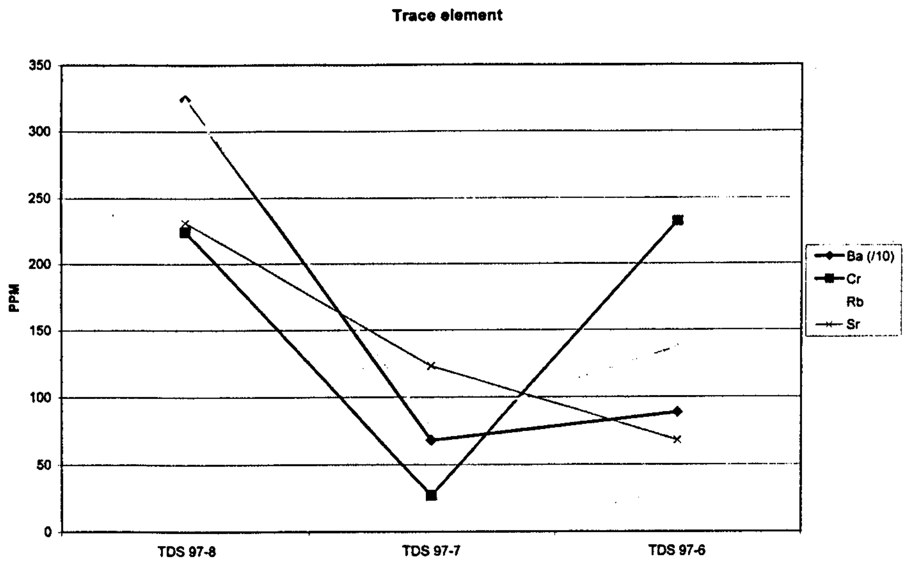


FIGURE 4. Sample location map, 4770B-level, Deep Star mine with major element oxide variations from glass (TDS98-8), banded (TDS98-7), and spherulitic zones (TDS97-6) (Analyses by Melanie Higgins, CREG Graduate Research Assistant).



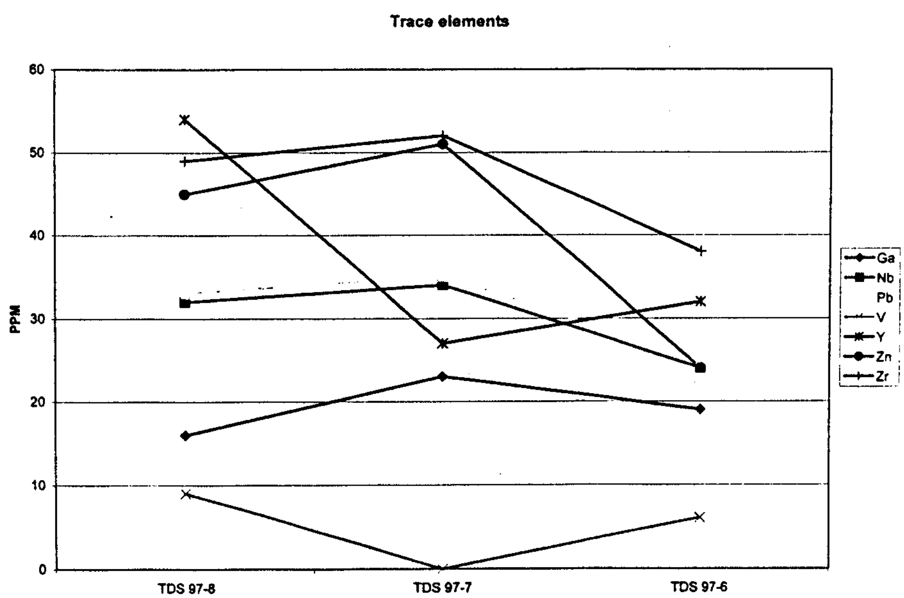


FIGURE 5. Deep Star Rhyolite trace element variations from glass (TDS98-8), banded (TDS98-7), and spherulitic zones (TDS97-6)(See Figure 4 for sample locations) (Analyses by Melanie Higgins, CREG Graduate Research Assistant).

compositions have been emplaced along the same structure. On the 4700C level one such locality has sooty sulfides cutting the earlier dike, while the latter has no veining. Generally, the gold content within the dikes is not ore grade but is anomalous. Two samples, one all glass and the other all orthoclase, have been prepared for $^{40}Ar/^{39}Ar$ dating. Recent transects have identified the Deep Star rhyolitic dike within the Genesis pit, there called the "Annie" dike, that parallelS the K-dikes that extend northeasterly across the Blue Star-Genesis pit area. While totally argillized, the Annie dike shows the same three zones (argillized green glass, banded, and central "aplitic" zones) that are seen underground in the Deep Star mine.

The Deep Star Rhyolite exhibits the northeast trend in underground exposures as well as in the open pit. It is apparent that the rhyolitic magma utilized pre-existing northeast and north- or northwest-trending faults during emplacement. Commonly the margins of the dike exhibit shearing related to recurrent movements along those faults.

The Deep Star orebody is localized within altered diorite and hornfels. There is a noteable correlation between gold grades and iron, sulfur, and arsenic contents of the host rock **(Figs. 6-10)**. Note that analyzed barren rocks contain as much as 5.2 weight percent iron and that even high-grade (>1opt Au) samples have <6 weight percent iron **(Fig. 6)**. Petrographic studies indicate that the iron sulfides, principally marcasite, replaced iron-bearing silicates rather than diopside or garnet. When comparing iron versus sulfur **(Fig. 7)** the transition from >1opt Au parallels the sulfur ordinate; for comparison the pyrite line reflecting ideal pyrite composition, transects diagonally the gold grade change. Arrow "A" shows what the expected grade boundary would look like if pyritization (*i.e.* introduction of both Fe and S) had occurred. It is apparent that the grade change parallels arrow "B", reflecting introduction of sulfur *only*. That control on gold grades is quite evident in **Figure 8**. The importance of arsenic phases, principally arsenian marcasite, and gold grades is shown in **Figures 9 and 10**. Such sulfidation has been demonstrated to be important, as well, in localizing gold at Twin Creeks (Stenger *et al.*, 1998).

Structural Geology

There are four principal fault trends within the mine area: (1) north-south (350-015°; (2) northwest (285-340°); (3) northeast (025-045°); and east-west (80-100°) **(Fig. 11 & 12)**. The northwest-trending faults commonly exhibit arcuate trends on the mine level sheets and merge with the north-south faults; bedding within the convergence zones is sheared with boudinage **(Fig. 12)** or other fabrics that exhibit a sinistral motion. There appear to be 3 mini-domains within the ore zone, each separated by a major northwesterly-striking fault. Within each of the mini-domains the bedding has been rotated counterclockwise due to the shearing within the domain. Bedding west of the Generator fault is reflective of the dips along the northeast limb of the Tuscarora Spur anticline, but to the east of the Gen fault the shearing associated with dextral displacement caused the counterclockwise rotation of bedding **(Fig. 12)**. Slickenlines with shallow to moderate rakes **(Fig. 13)** are common on the north-south and northwest-trending faults.

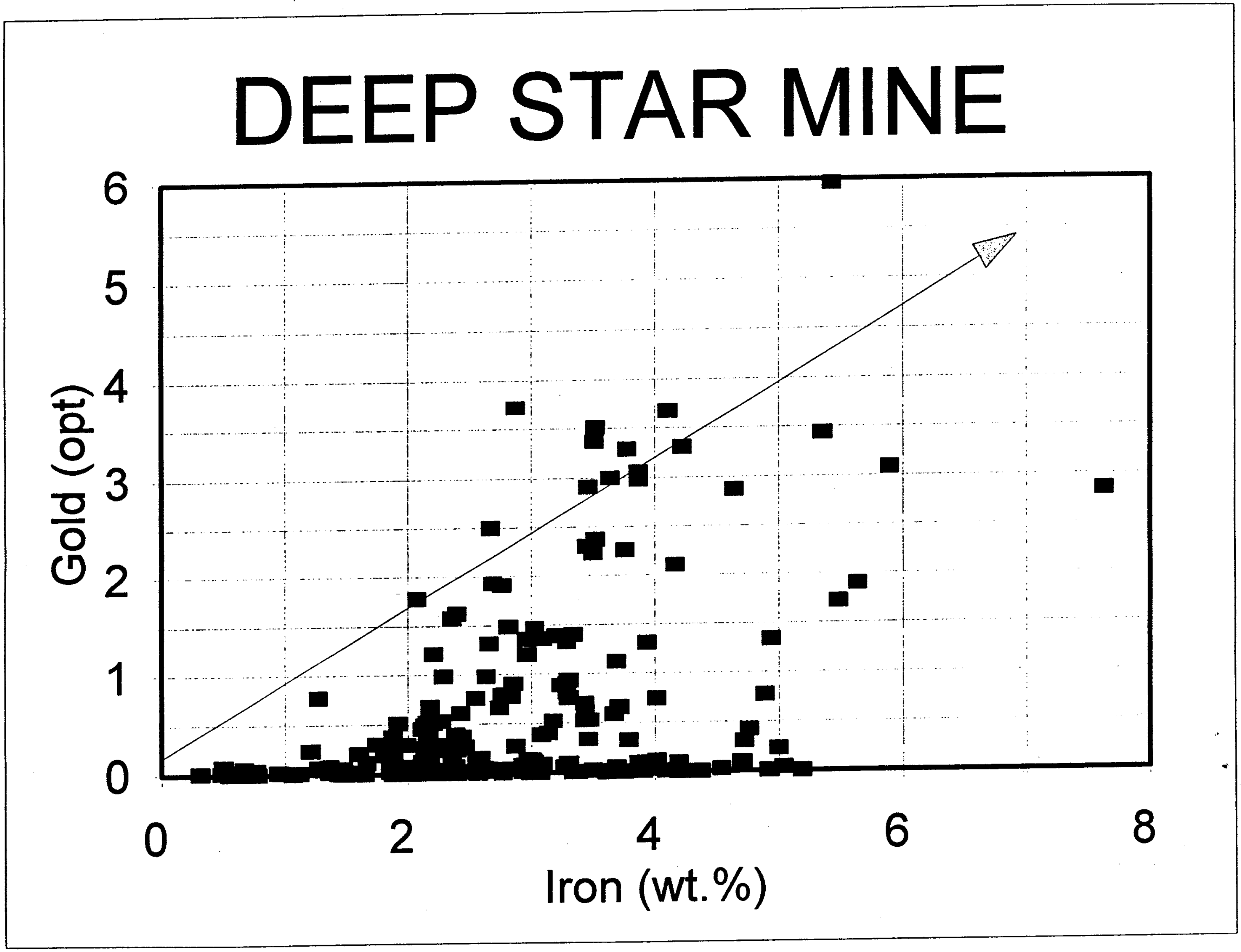


FIGURE 6. Deep Star mine whole-rock gold (opt) versus iron (wt.%) for barren to high-grade samples illustrating whole-rock values ranging up to 6 weight percent Fe.

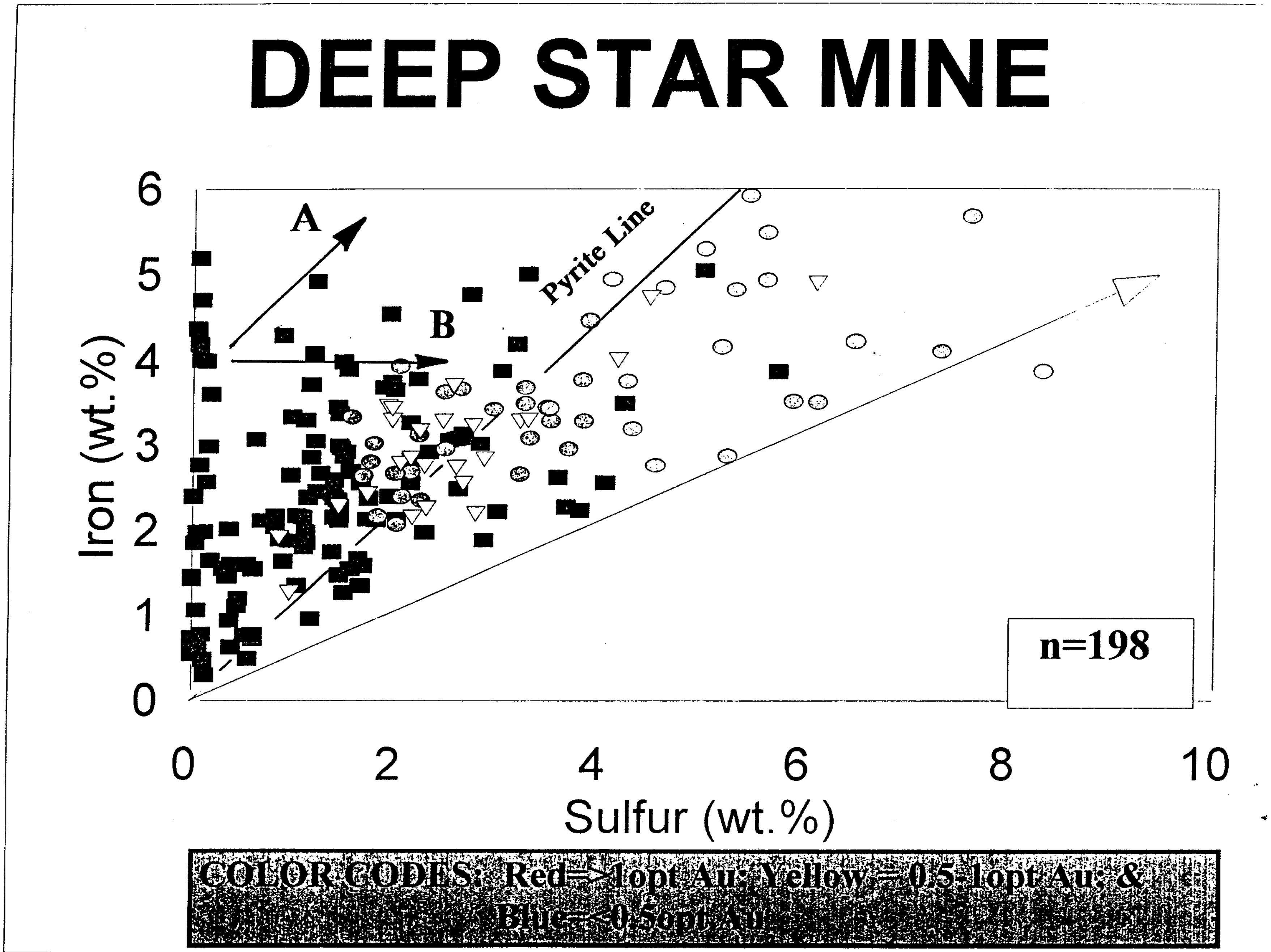


FIGURE 7. Deep Star mine whole-rock iron (wt.%) versus sulfur (wt.%) showing increase in gold grades with increased sulfur. Note that total iron does not exceed 6 weight percent.

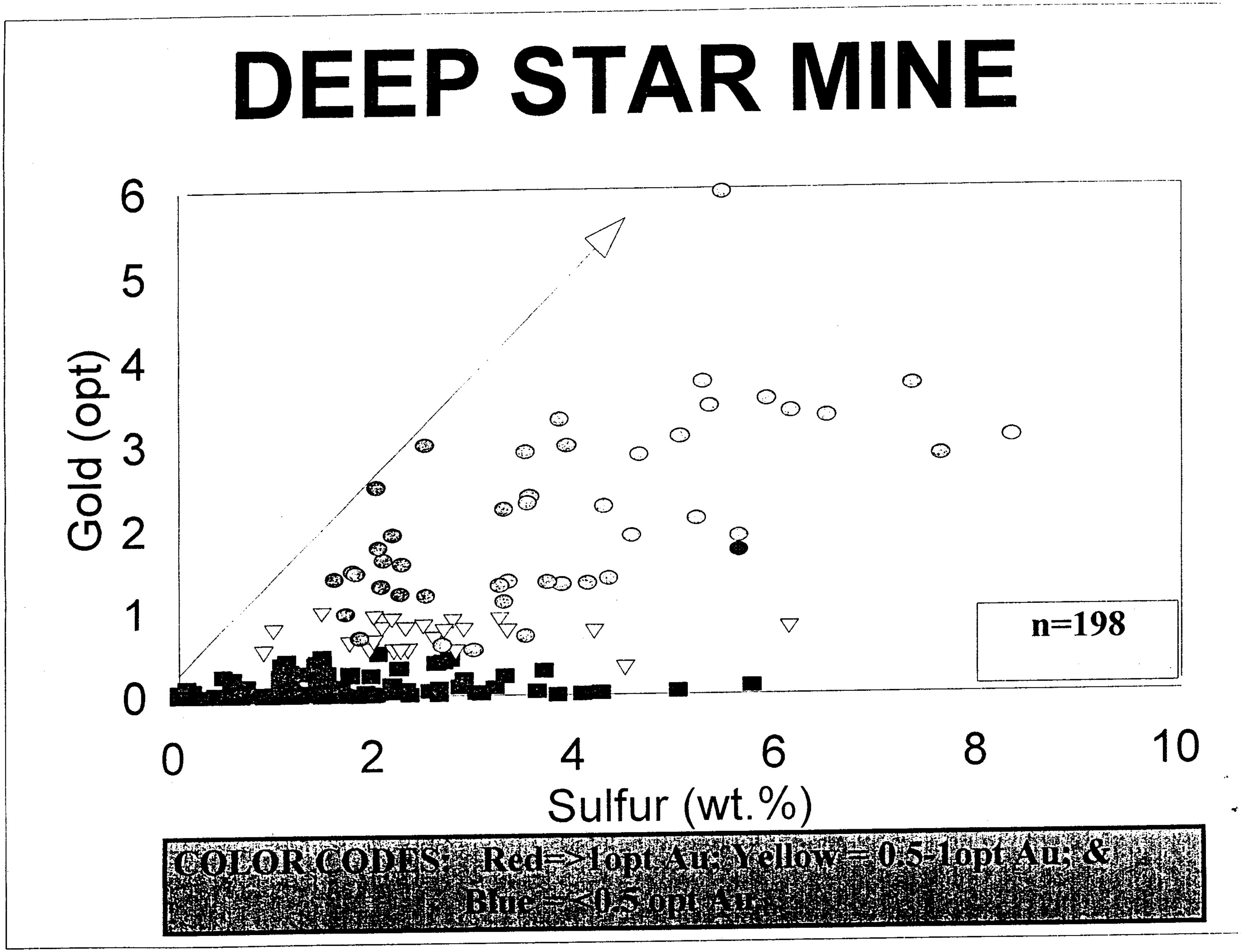


FIGURE 8. Deep Star mine whole-rock gold (opt) versus sulfur (wt.%) showing correlation illustrated in Figure 7 between gold and sulfur (arrow).

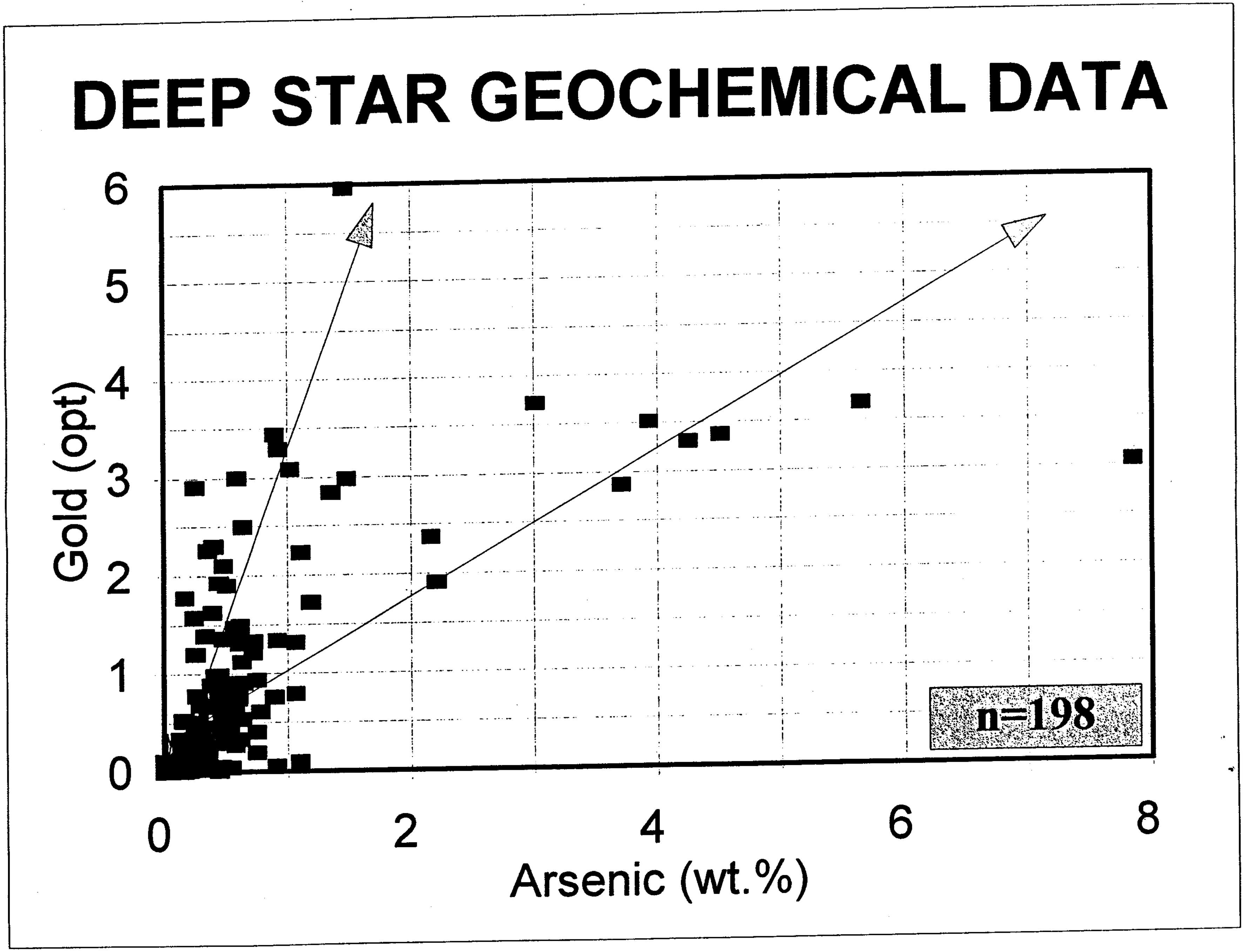


FIGURE 9. Deep Star mine whole-rock gold (opt) versus arsenic (wt.%). Note that there appear to be 2 populations (arrows), related, possibly, to multiple arsenic stages (*e.g.* arsenian marcasite versus arsenopyrite versus late-stage realgar.

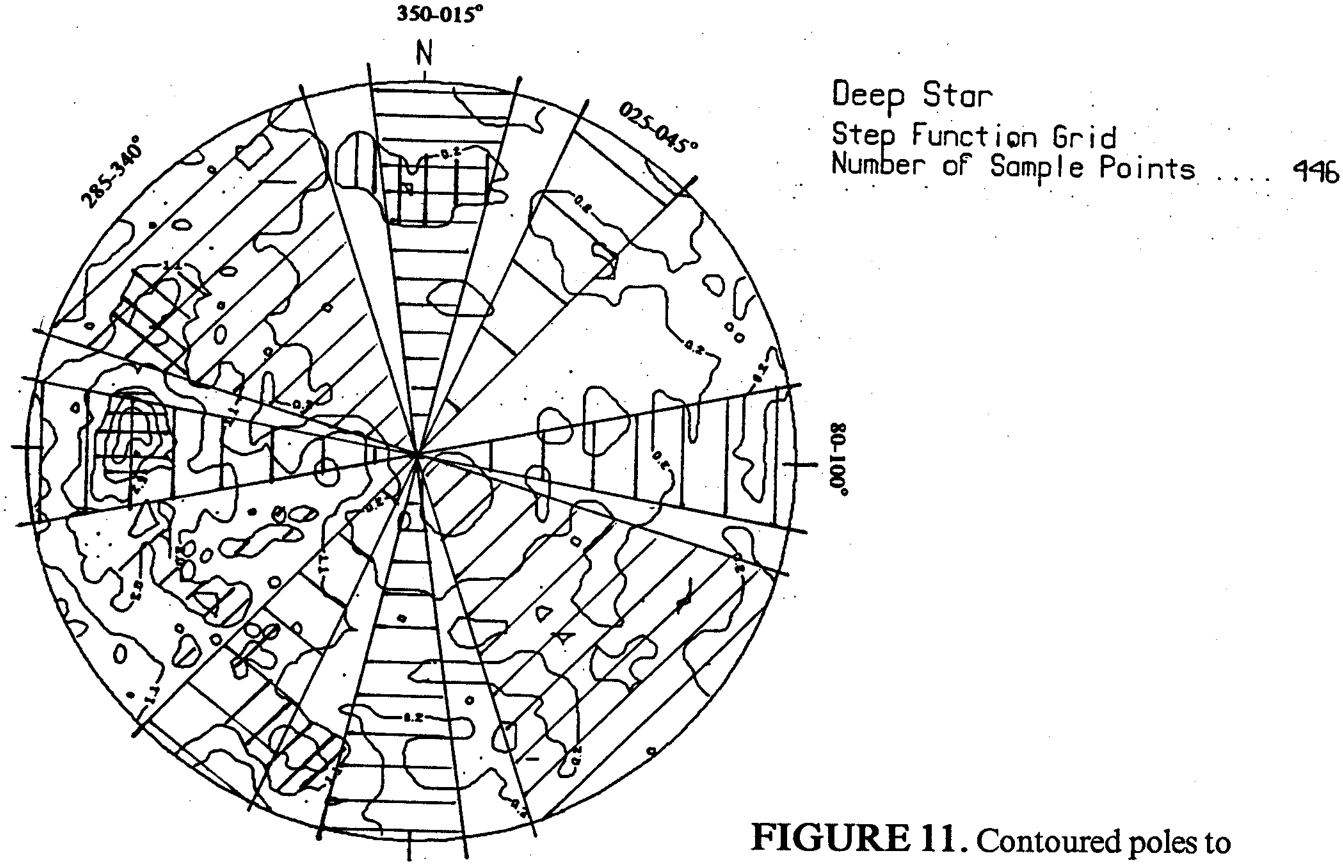


FIGURE 11. Contoured poles to fault planes, Deep Star mine.

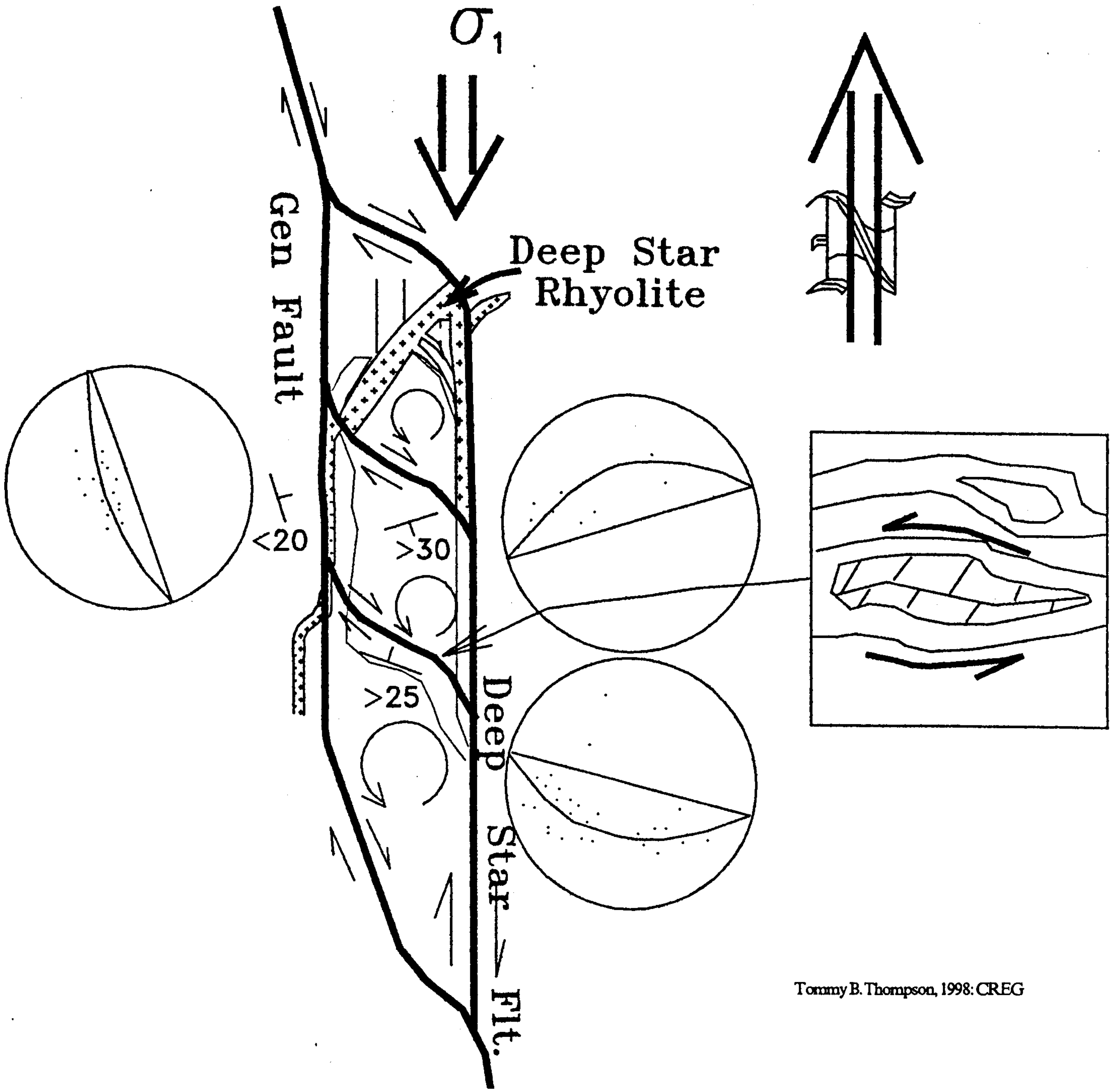
East-west—striking faults are less commonly seen; however, on the 5000E level the southern limit of the orebody is marked by such an oriented structure. Rakes on slickenlines indicate a steep reverse fault sense; the structure is offset by northeast- and northwest-trending faults. Also, the northeast-striking faults are invariably offset by northwest-trending faults.

Discussion. The fault system in the Deep Star mine area is interpreted to have formed in response to north-south—directed compression, yielding conjugate faults with northeast and northwest strikes. The east-west faults are interpreted to be the result of early compression and reverse deplacement. The deviation of the regional Post-Genesis fault system to a local north-south orientation created a setting whereby mini-domains formed between individual cymoid-type structures; shearing as well as local extension allowed for the emplacement of the Deep Star Rhyolite, followed by ore fluid introduction.

Wallrock Alteration

Wallrocks are altered within the mineralized zone, and there are distinct assemblages that reflect different gold grades. Previous work by the mine unit geologists had recognized that the higher grade (>1opt) gold zones were associated with quartz-kaolinite-sulfide alteration; the sulfide was described as "sooty" pyrite. Peripheral to that zone and in lower-grade gold zones (<0.5opt) the wallrocks exhibit quartz-dolomite-sulfide alteration. Although

FIGURE 12. Schematic plan view of Deep Star mine area showing major dextral faults, the 0.2opt Au contour, poles to bedding stereonets for 3 mini-domains, and marble boudin in fault convergence zone at the 5000E level (see text for discussion).



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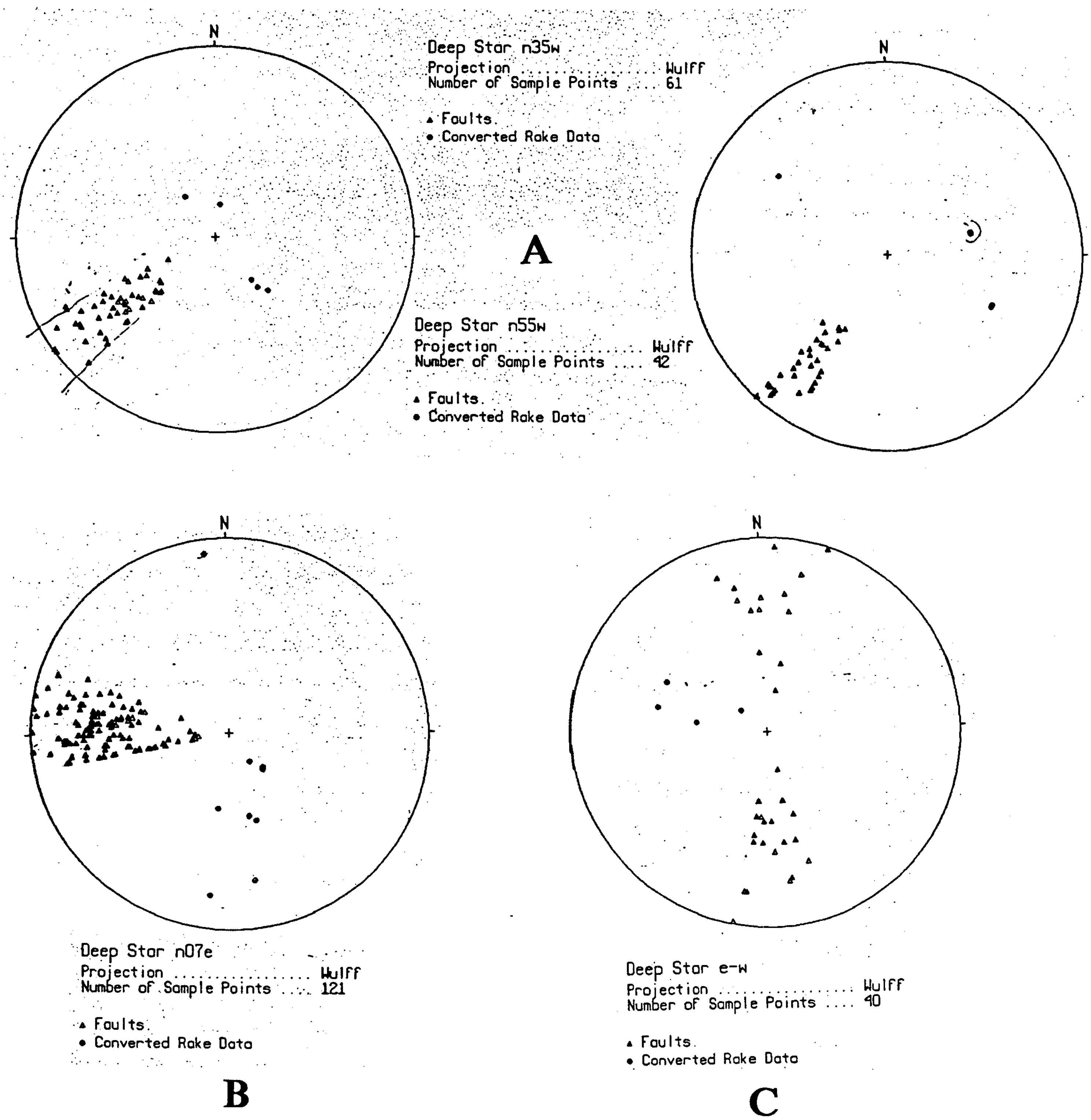

FIGURE 13. Poles to fault planes. **A.** Interval between N35W and N55W exhibiting steep to moderate northeasterly dips. Rakes of slickenlines are plotted and indicate strike separations. **B.** North-striking fault poles (N07E) with shallow to steep fault dips. Rakes indicate strike separations. Field data indicate these are principally related to dextral separations. **C.** East-west fault poles with north or south dips. Rakes on slickenlines indicate significant strike component on displacements.

the previous studies were interpreted to show that the alteration and related gold were closely associated with faults, this study has demonstrated that stratification played an equally important role (**Figs. 14-15**). Along the Hangingwall fault the rocks are decalcified (*not* entirely decarbonatized) and exhibit the most intense alteration and highest gold grades (>2opt) found in the mine; up-dip on that structure it can be seen that both the intense alteration and high-grade gold diverge from the fault and follow bedding along a favorable horizon. The quartz introduction occured during decarbonatization. Breccias (tectonic and dissolution-collapse) are common along the fault as well as along the bedded zone. Dolomite occurs along the high-grade zone as a result of calcite replacement but becomes more common out in the "lower"-grade intervals. Sericite is commonly found in the rocks in which decarbonatization was most intense; it is, also, associated with chlorite in relatively barren diorite close to the Hangingwall fault. Within the higher-grade rocks and along the Hangingwall fault, the most common sulfide is marcasite rather than pyrite.

Realgar is present along the strike length of the Deep Star orebody. It is particularly concentrated in the footwall of the Hangingwall fault and within a specific stratigraphic horizon. East of the Hangingwall fault, it is found in high-grade Au zones, too. Petrographic observations (Altamirano, in progress) indicate that it is paragenetically later than marcasite.

Carbonaceous material is common in the block east of the Hangingwall fault. During mine mapping, it was described as "graphite;" however, petrographic and XRD analyses indicate that it is non-crystalline carbonaceous material. Preliminary studies indicate that it is stratigraphically localized with local remobilization along structures.

Other minerals identified during the alteration study include arsenopyrite, sphalerite (with local chalcopyrite disease), and minor stibnite. Some early diagenetic(?) pyrite has arsenian rims, rims of arsenopyrite, and arsenian marcasite in sequential growth bands. Typically, all the sulfides are extremely fine-grained and result in a rock that is dark-colored. Replacement rather than open-space filling is normal. The increase in sulfides commonly results in rock textures that appear to be breccias (**Fig. 16**); the texture is only the progressive replacement of the rock with "islands" of unreplaced host remaining.

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Stenger, D.P., Kesler, S.E., Peltonen, D.R., and Tapper, C.J., 1998, Deposition of Gold in Carlin-type Deposits: The Role of Sulfidation and Decarbonation at Twin Creeks, Nevada: Economic Geology, v. 93, p. 201-215.

Teal, L. and Jackson, M., 1997, Geologic Overview of the Carlin Trend Gold Deposits and Description of Recent Deep Discoveries: Society of Economic Geologists Guidebook Series, v. 29, p.

FIGURE 14. East-west cross-section through the Deep Star mine showing divergence of arsenic zone from Hangingwall (H.W.) fault sub-parallel to bedding.

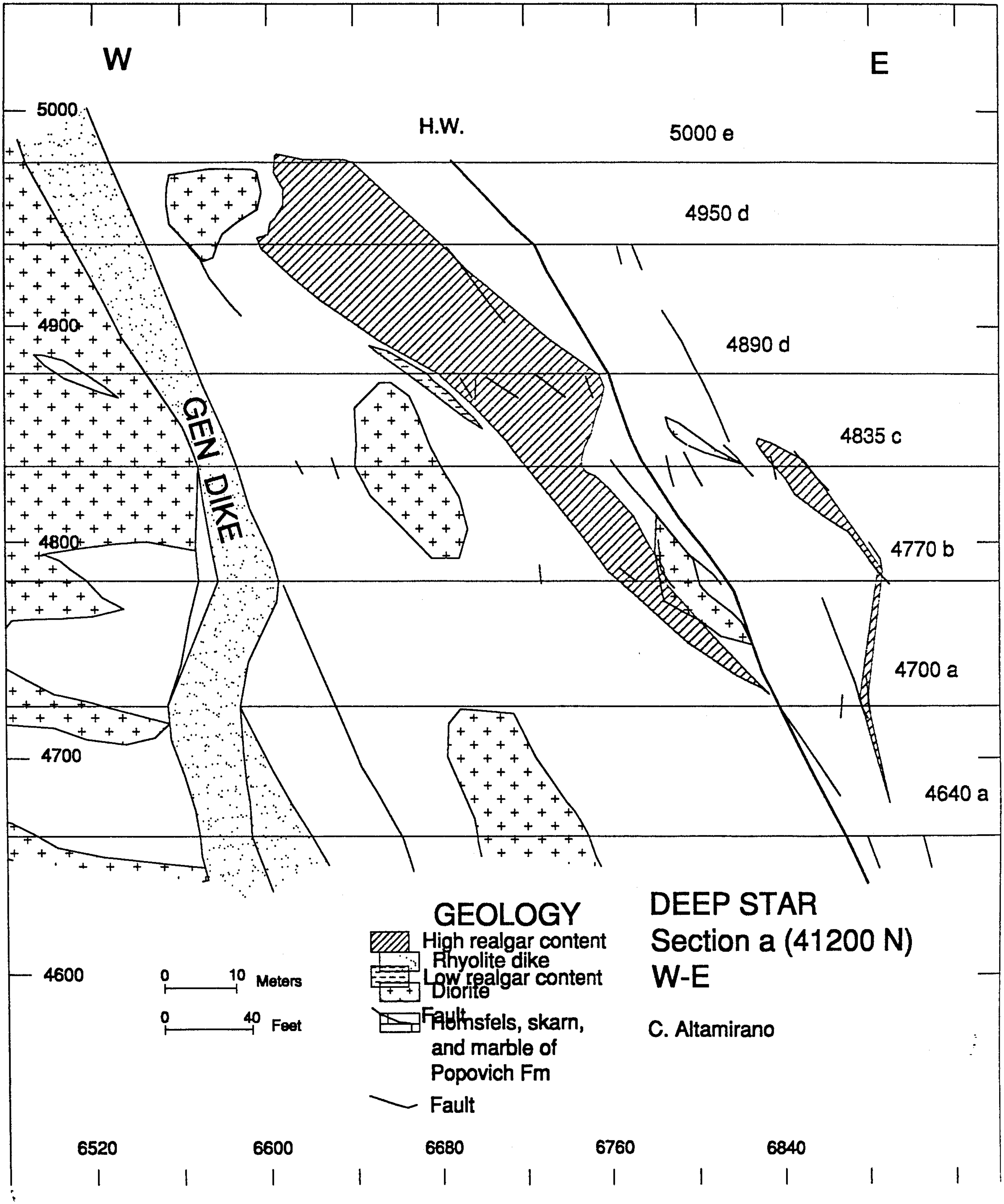
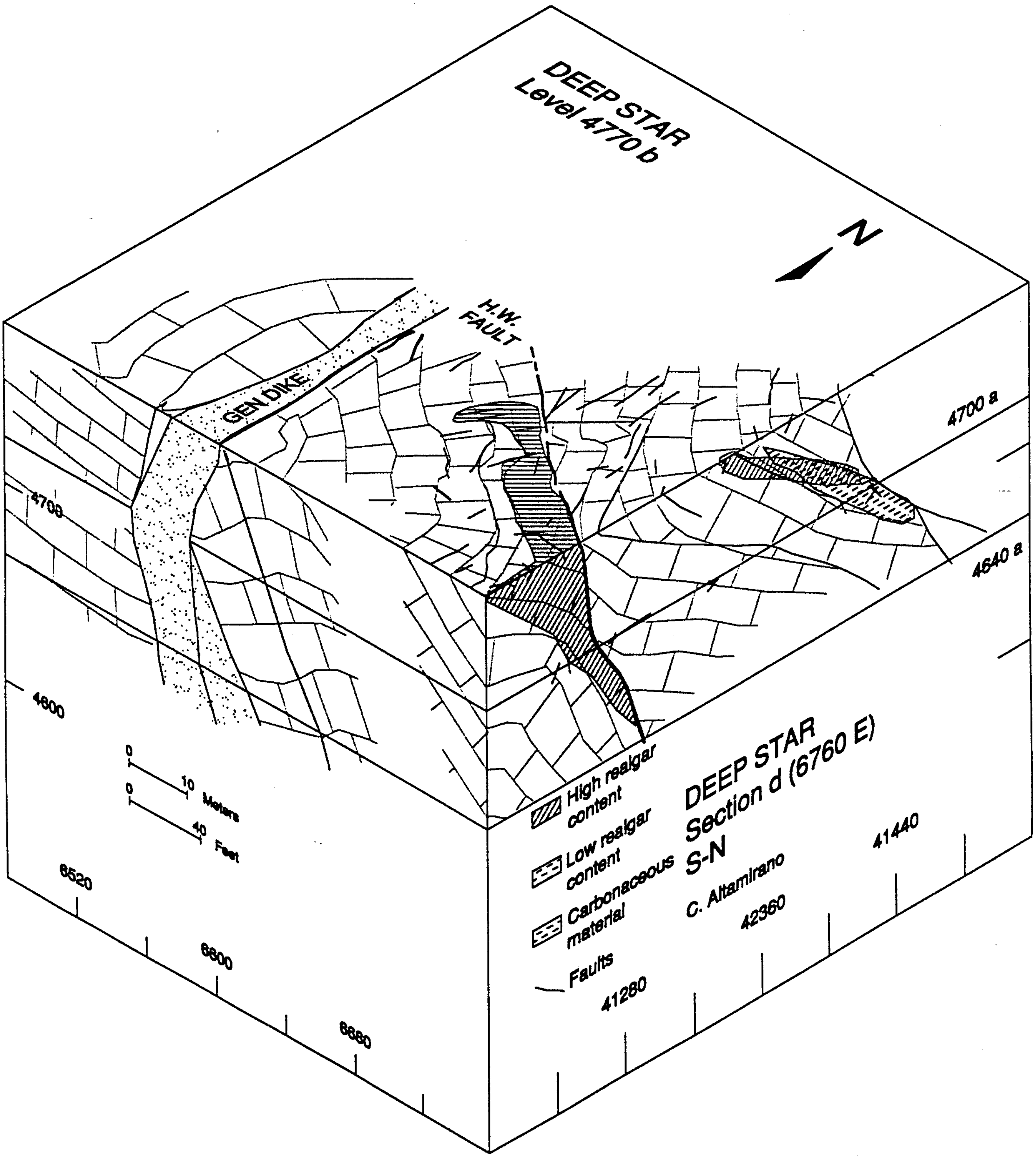


FIGURE 15. Isometric of Deep Star system showing structural and stratigraphic control on realgar.



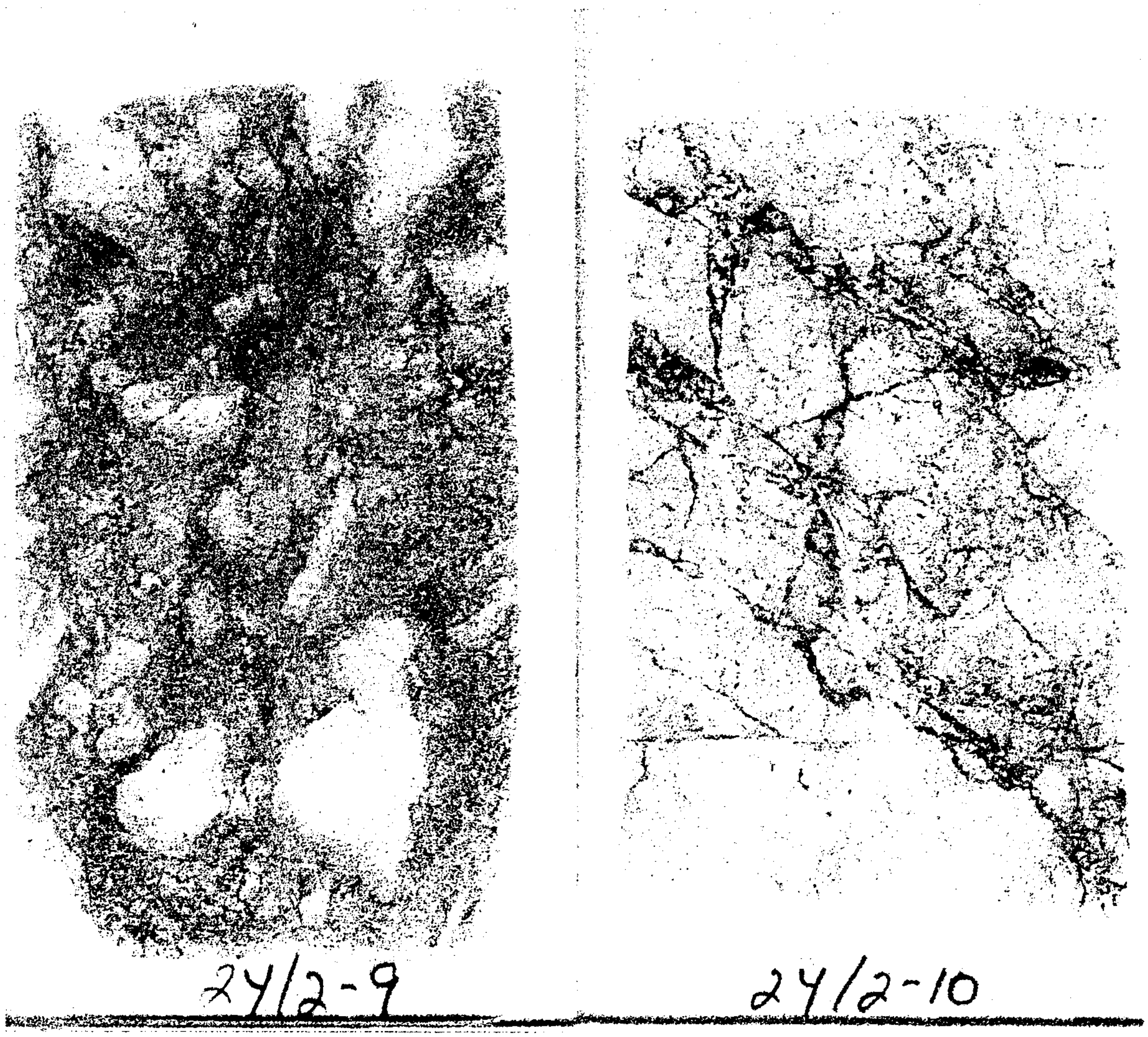


FIGURE 16. Scanned thin sections from adjoining sample sites. Sample on the right is low-grade (<0.5opt Au) while the sample on the left is high-grade (>1opt Au). The low-grade sample exhibits fracture and intergrain sulfide introduction while the high-grade sample has experienced significant replacement by sulfide (arsenian marcasite). The resultant texture has been referred to as "breccia"; no significant rotation of fragments has occurred.