STRATIGRAPHIC AND STRUCTURAL SETTING OF THE SHASTA Ag-Au DEPOSIT (94E)

By Henry Marsden and John M. Moore
Ottawa-Carleton Geoscience Centre
Carleton University

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INTRODUCTION

The Shasta deposit is in north-central British Columbia, approximately 300 kilometres north of Smithers (Figure 2-10-1). The property is reached by a four-wheel-drive road from the Sturdee airstrip, 9 kilometres to the west or from Fort St. James via the Omineca mining road and the Cheni mine road.

The objective of this study is to define the stratigraphic and structural setting of the deposit. Toward this goal 1:10 000 mapping of a 15 square kilometre area around Jock Creek and detailed (1:1000) mapping of the mineralized area were carried out in 1988 and 1989. Marsden and Moore (1989) give an account of the geology outlined by mapping during the 1988 field season. This report presents some additions and revisions to that stratigraphy, integrates field observations with petrographic work and literature research done during the winter of 1988-89, and provides a model for the setting of the Shasta deposit. This model can be used to guide exploration on the property and at a regional scale in exploring for similar geologic environments elsewhere in the Toodoggone district.

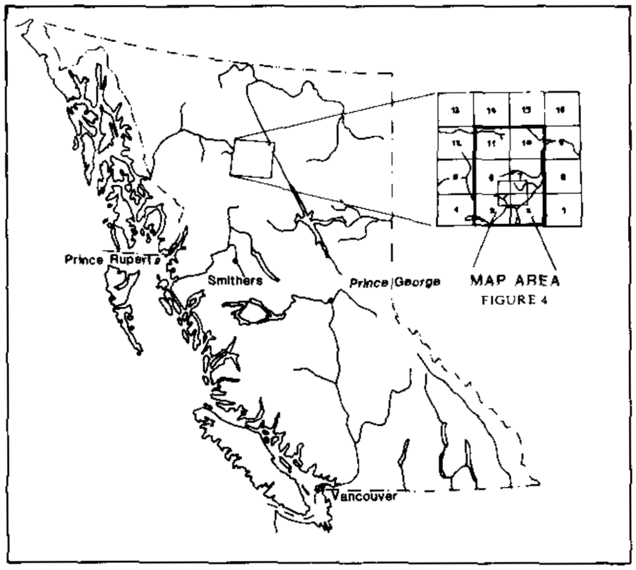

Figure 2-10-1. Location map of the study area.

HISTORY

The Shasta property was discovered in 1972 and has been explored intermittently since 1983. Esso Minerals Canada worked on the property in 1987 and 1988 and Homestake Mineral Development Company Ltd. is currently active on the property after acquiring the interests of Esso in the spring of 1989. The 1987 and 1988 exploration programs (Holbek and Thiersch, 1988; Holbek, 1989) included geological mapping, geochemical and geophysical surveys, trenching and over 13 000 metres of diamond drilling. By the end of 1988, Esso had outlined possible geologic reserves of 537 000 tonnes of 8.7 grams gold equivalent per tonne (70 grams Ag = 1 gram Au) or 1.02 million tonnes of 5.7 grams gold equivalent per tonne (Holbek, 1989).

The current program is a joint venture between Homestake and International Shasta Resources Ltd. that is operated by Homestake. International Shasta is also independently running a small open-pit operation on the property and plans to mine 100 000 tonnes of ore from the JM and Creek zones.

REGIONAL GEOLOGY

The project area lies within the Stikine Terrane along the eastern margin of the Intermontane Belt of the Canadian Cordillera. Stikinia is an allochthonous assemblage of Paleozoic to Jurassic island arc volcanics and associated basinal sediments. The oldest rocks in the terrane, the Stikine assemblage, are Paleozoic mafic volcanics, marine sediments and Permian limestones. These are overlain by tholeiitic arc rocks of the Stuhini Group and Lower to Middle Jurassic arc rocks of the Hazelton Group. This accretionary collection of arc-related rocks is overlain by post-accretion sediments of the Middle to Upper Jurassic Bowser assemblage and the Cretaceous Sustut Group.

The Hazelton Group is exposed around the perimeter of the Bowser basin (Figure 2-10-2). Tipper and Richards (1976) defined it as an island arc sequence deposited in the Hazelton trough between Sinemurian and Callovian time.

Hazelton Group volcanics in the Toodoggone River area are traditionally divided into a western felsic facies called the Toodoggone volcanics (informally named by Carter, 1972)

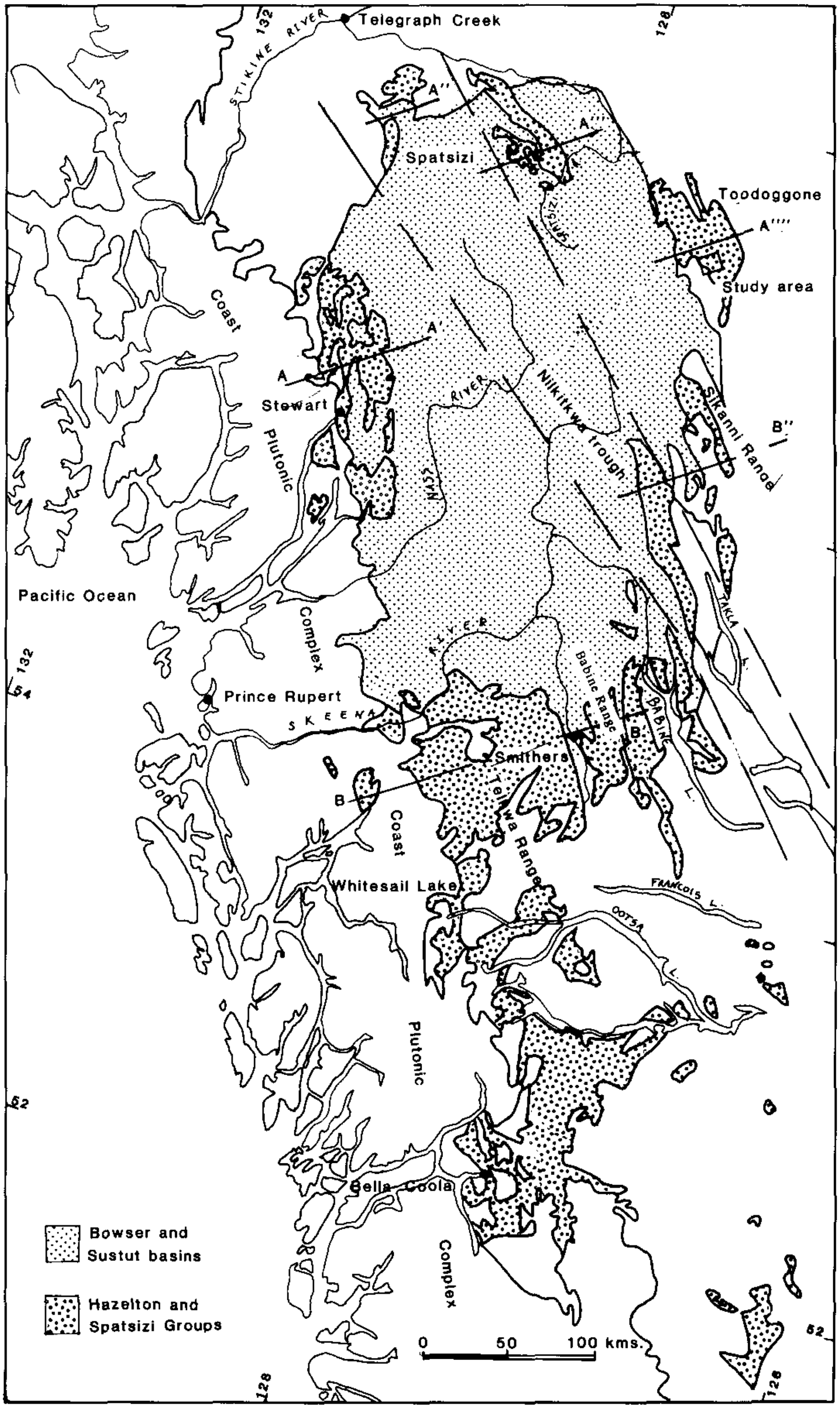

Figure 2-10-2. Distribution of the Hazelton and Spatsizi groups in the northern Intermontane Belt. Rectangle indicates study area.

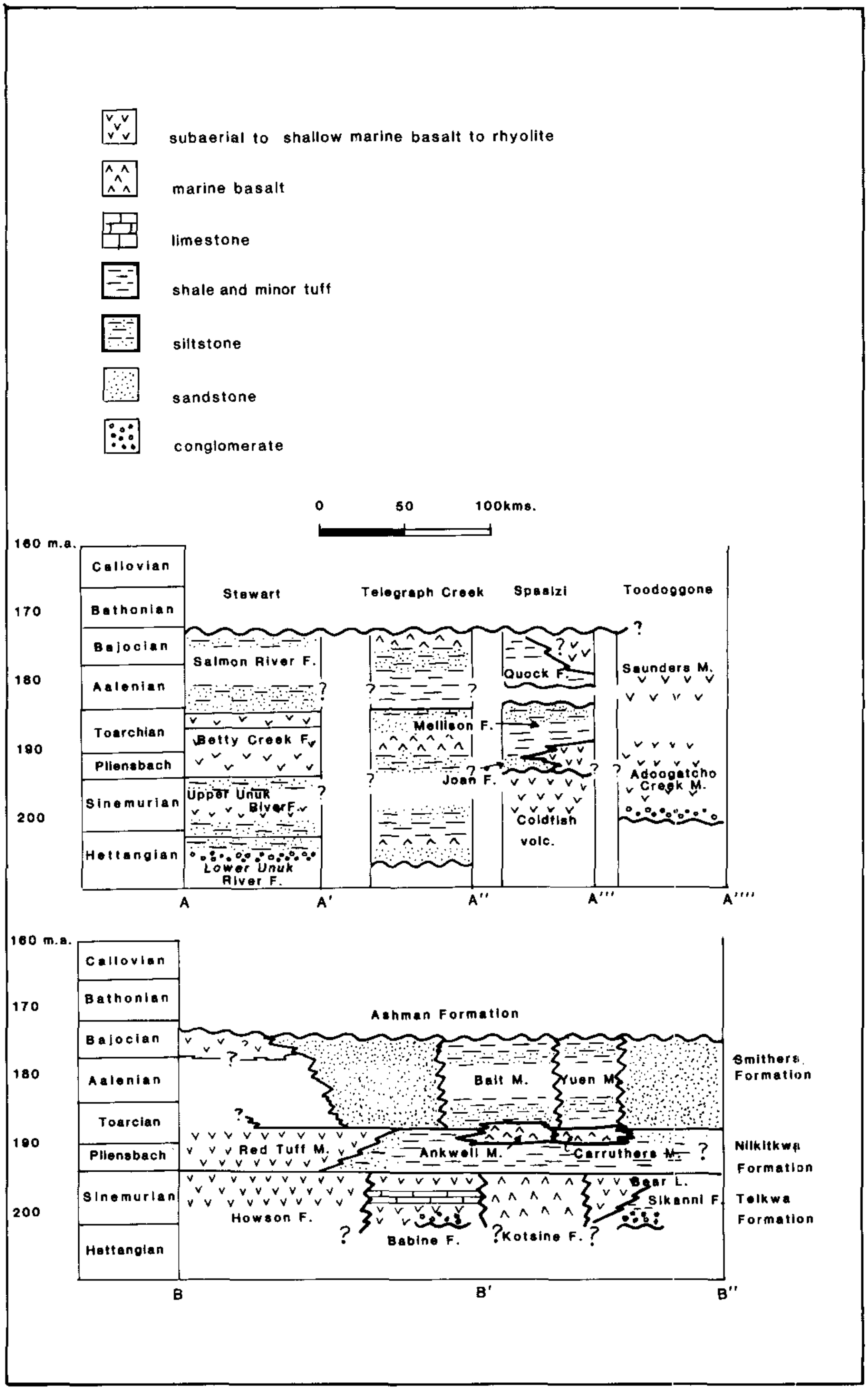

Figure 2-10-3. Time-stratigraphic sections across Figure 2-10-2.

and an eastern facies of predominantly intermediate volcanics. Detailed mapping by Daikow *et al.* (1985) has defined the Toodoggone volcanics as a predominantly calc-alkaline andesitic to dacitic subaerial succession that ranges from Toarcian to Aalenian in age.

A pattern has evolved from the mapping in the Hazelton Group during the last decade. The stratigraphic relationships of the various formations and facies of the Hazelton Group are summarized in Figure 2-10-3, two schematic time-stratigraphic sections across the Jurassic section of the northern Intermontane Belt. Two predominantly subaerial volcanic chains, exposed in the Telkwa-Stewart area and the Toodoggone-Coldfish area are separated by a marine basin 150 kilometres wide. The two volcanic chains may represent a true island arc (the Telkwa-Stewart chain) a marine back-arc (the Nilkitwa trough) and a continental back-arc (the Toodoggone-Coldfish volcanics) similar to the continental back-arc system currently active in New Zealand (Stern, 1985). There is not yet a sufficient database to determine if the two volcanic chains are geochemically distinct and representative of different tectonic environments. De Rosen-Spence and Sinclair (1988) used a very limited collection of data from several sources to suggest that the Telkwa volcanics are calcalkaline and more iron-rich than the alkaline to calcalkaline volcanics of the Nilkitwa trough and Toodoggone-Coldfish arc.

VOLCANIC STRATIGRAPHY

This study concentrates on a small area within the Toodoggone volcanics. Daikow (personal communication, 1988) recognizes three main members within the Toodoggone succession. The Adoogacho Creek member, the oldest, 201 to 204 Ma, is comprised of explosive dacitic volcanics. The middle member, the Metsantan member, is exposed only in the central part of the volcanic belt and is characterized by andesitic to basaltic stratovolcanoes dated at 197 to 200 Ma. The Saunders member is a 182 to 183 Ma massive section of dacitic ash-flow deposits exposed throughout the southern part of the Toodoggone belt. In this paper we propose that there is a fourth member in the Toodoggone area, exposed only to the east of the Saunders fault, that is younger (Bajocian?) than the Saunders member and is, at least in part, correlative with the undivided Hazelton volocanics exposed immediately to the east of the Toodoggone volcanics.

The Toodoggone volcanics are cut by at least two major right-lateral faults. Daikow *et al.* (1985) have documented the Saunders fault, a major feature of the current study area, and Vulimiri *et al.* (1983) have shown that the Attorney fault, exposed in the Cheni mine, is a right-lateral fault that can be traced to the north and south of the minesite.

The study area is transected by the Saunders fault (Figure 2-10-4). The Shasta deposit (Figure 2-10-5) is located on the west side of the fault and the stratigraphy exposed in this area is not the same as that to the east of the fault. This is partly a function of level of exposure; higher stratigraphic levels are exposed on the east side of the fault. West of the Saunders fault, the stratigraphy can be divided into three major parts: the Stuhini Group (Late Triassic), the Jock Creek volcanics (informally named in this paper) and the Saunders grey dacite, dated in this map area at 182 ± 8 Ma. The Jock Creek volcanics are not correlative with any of the main members described above and are correlated with rocks exposed south of the Finlay River (Daikow *et al.*, 1985) that gave a K-Ar date of 189 ± 6 Ma. Very limited observations by the authors at the Cheni mine indicate that the host volcanics in that area are mineralogically similar to the Jock Creek volcanics and occupy a similar position in the stratigraphy. The stratigraphy on the west side of the Saunders fault was described in detail by Marsden and Moore (1989); some revisions and additions to that stratigraphy are outlined below.

The oldest rocks exposed within the map area are mafic volcanics and associated sediments of the Upper Triassic Stuhini Group (Unit 1). The section is dominated by submarine basalts with well-developed pillows and hyaloclastite. The volcanic rocks are overlain by thin to thick-bedded volcanic sediments. The fine-grained sediments are well bedded and commonly graded, with small scale crossbedding and loading structures. These sedimentary rocks were probably deposited from debris flows and associated turbidity currents in a marine basin adjacent to a volcanic edifice. These marine deposits are locally overlain by subaerial or very shallow marine mafic flows. These amygdaloidal augite-feldspar-phyric flows have massive chilled bases and reddened, scoriaceous flow tops. Overlying and lateral to the flows is a sequence of coarse purple and green epiclastic deposits (Unit 2). The base of this unit is always marked by several metres of coarse conglomerate with subrounded cobbles of an intermediate, equigranular intrusive rock. This distinctive deposit is overlain by up to 100 metres of predominantly coarse clastic rocks with green to purple pyroxene-phyric fragments derived solely from the Stuhini Group. The youngest deposit in this sequence is a distinctive purple volcanic conglomerate with cobbles of a fine-grained hornblende feldspar porphyry. These deposits mark the onset of tectonic activity associated with the beginning of Lower Jurassic volcanism.

The Toodoggone volcanics exposed between the Saunders fault and the Black Lake stock (Figure 2-10-4) can be divided into two parts that can each be broken into several units, described in detail by Marsden and Moore (1989).

At the base of the volcanics in the Jock Creek area is a sequence of quartz-hornblende-biotite-feldspar-phyric ash-flow deposits, a felsic dome and volcanic sediments, predominantly coarse laharic deposits. The lowest rocks (Unit 3) consist of thin ash-flow units and abundant purple and green volcanic conglomerates. These rocks, from the earliest episode of Jurassic volcanism, are very small volume deposits that were reworked in an active sedimentary environment.

Unit 3 is overlain by the Shasta dome complex comprising a dacitic dome with steep flanks (Unit 4a), associated epiclastic sediments (Unit 4b) and ash-flow deposits (Unit 5). The dome is a homogenous dark green to purple-green hornblende-biotite-quartz-feldspar porphyry with unbroken phenocrysts in a recrystallized matrix. The outer 25 metres of the dome is flow layered, with fine laminar banding apparent on weathered surfaces. The flow layering is usually parallel to the edge of the dome but is locally contorted. The dome is not present in all parts of the area mapped in detail (Figure 2-10-5) and where absent its stratigraphic position is taken by

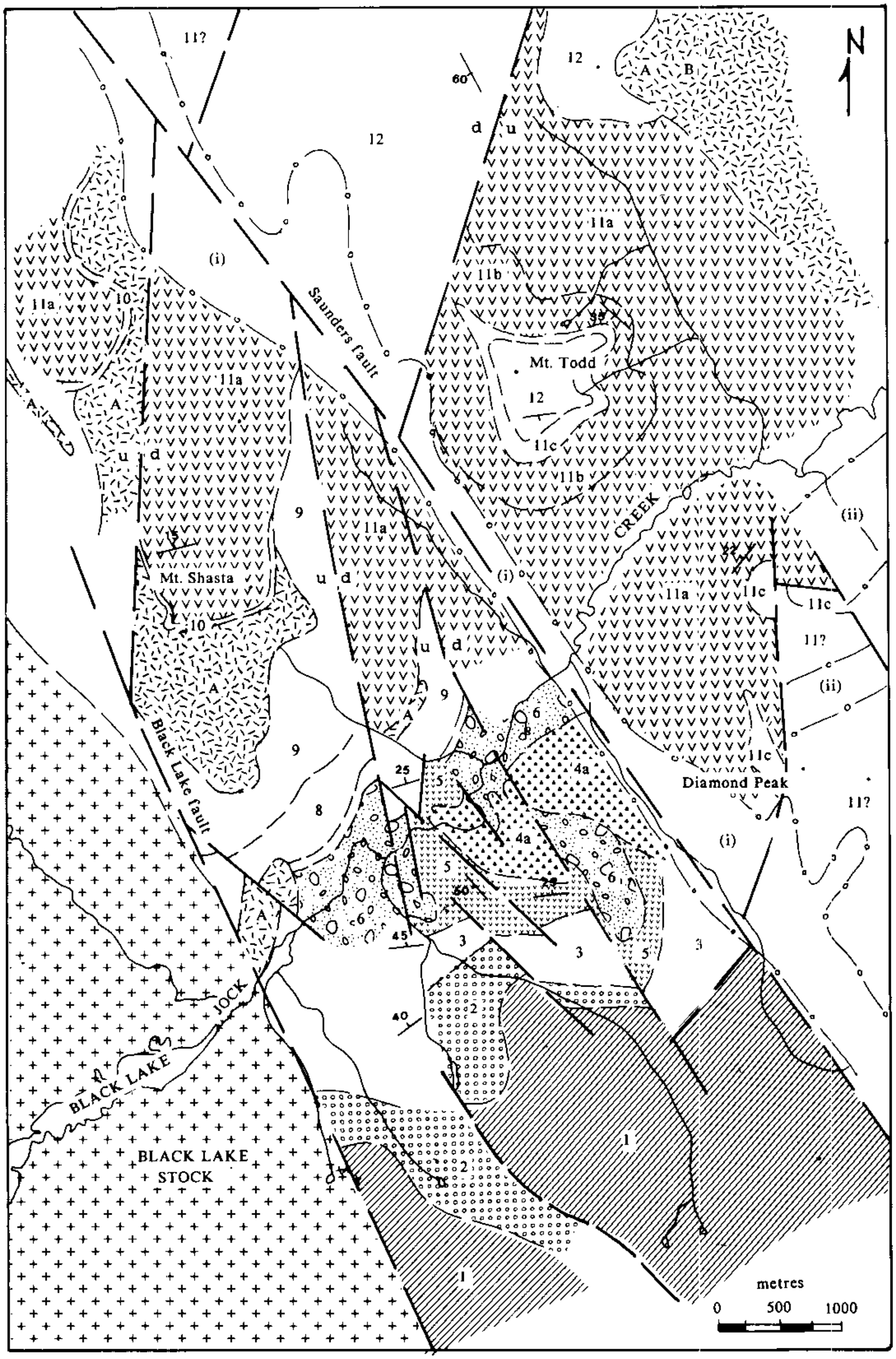

Figure 2-10-4. Local geology. (*see* Figure 2-10-3 for legend.)

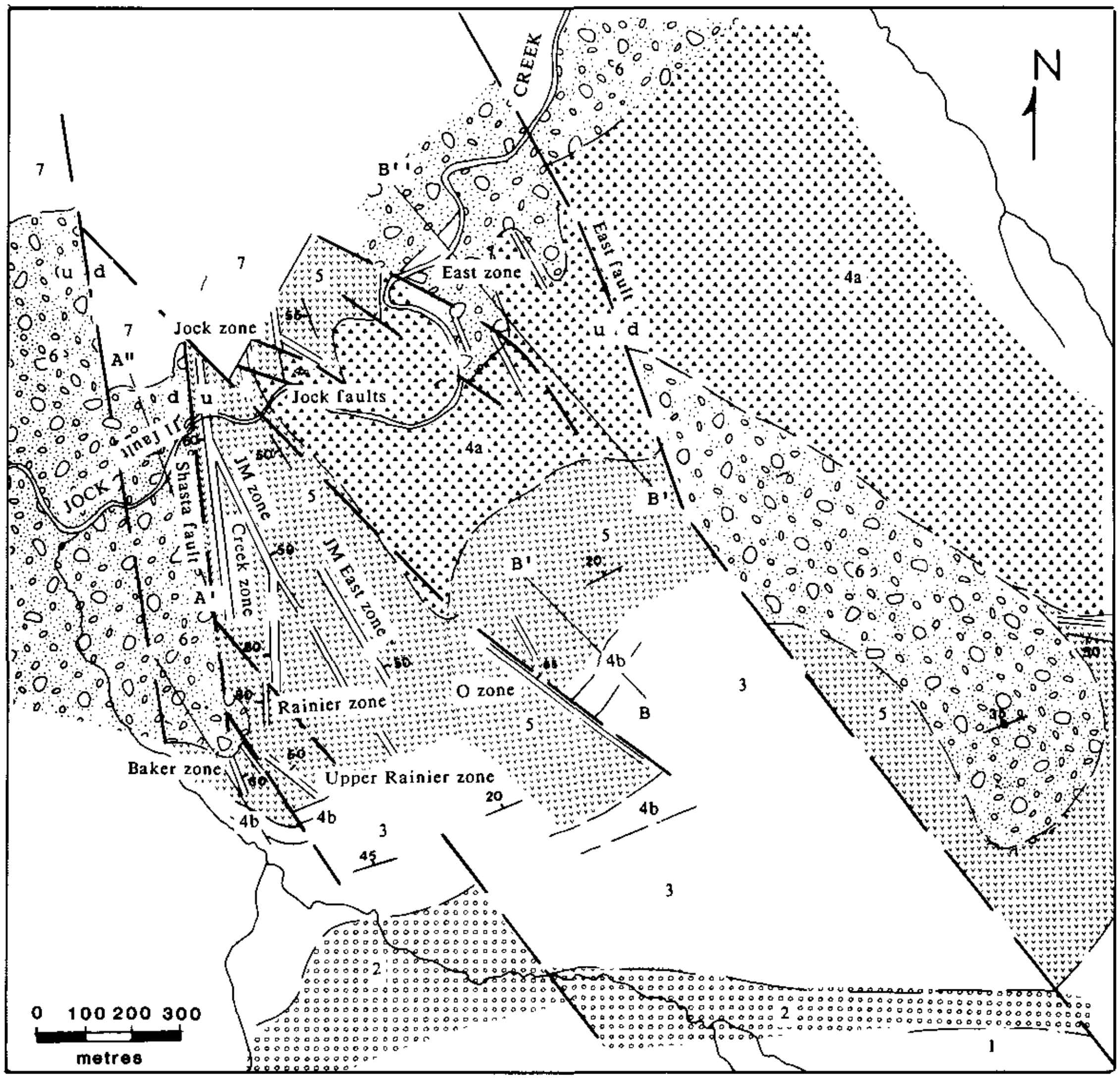

Figure 2-10-5. Geology of the Shasta property. (*see* legend on Figure 2-10-3.)

very coarse epiclastic deposits consisting of angular blocks of welded tuff up to several metres in diameter, of moderately welded tuff and local concentrations (channels) of purple to green volcanic siltstone and sandstone (Unit 4b). Ash-flow deposits (Unit 5) are exposed on the flank and beside the dacite dome. Where the ash flows were deposited on the flank of the dome they dip 50° to the southwest, whereas the rest of the stratigraphy and the ash-flow deposits away from the dome, dip gently to the north (Figures 2-10-6 and 7). The anomalous orientation of the ash flows can be partially attributed to their deposition on the steeply sloping flank of the dome but the 40–50° degree slope required is well beyond the angle of repose for loose material. These deposits must have been deposited on the slope of the dome and then oversteepened by continued dome growth; the dome and the ash flows are cogenetic and coeval. The ash-flow deposits can be divided into a lower section of welded ash tuff with highly flattened essential lapilli and an upper subunit that lacks flattened lapilli and includes more accidental frag-

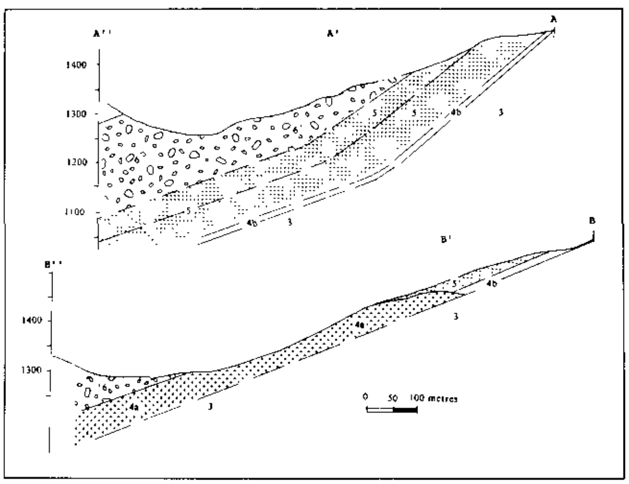

Figure 2-10-6. Cross-sections A-A'', B-B''. (*see* locations on Figure 2-10-5.)

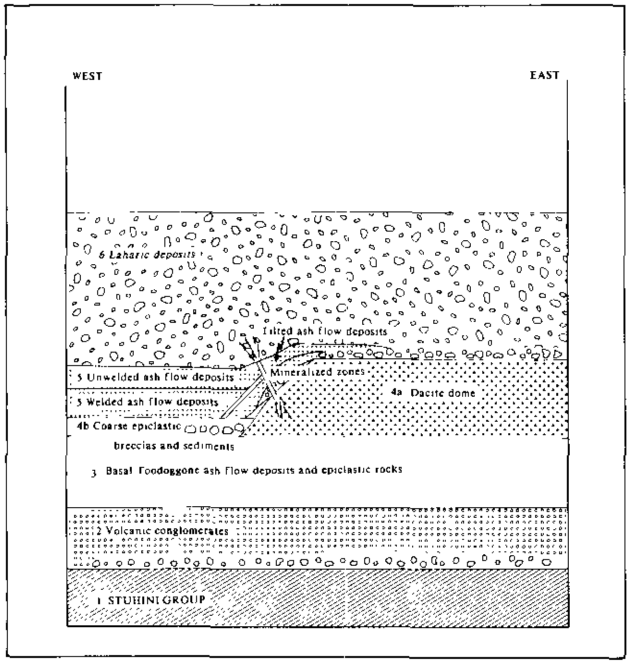

Figure 2-10-7. Schematic section of the Shasta property.

ments. The base of the ash flows is locally marked by green siltstones, a carbonaceous tuff with charred wood fragments and by local concentrations of subangular to subrounded cobbles of the dacitic dome within the ash-flow deposits.

The Shasta dome complex is buried beneath 200 metres of epiclastic deposits (Unit 6) that consist of numerous lobes of coarse, very poorly sorted laharic deposits and minor volcanic sandstone and siltstone. The fine sediments are typically crossbedded and graded and represent minor stream deposits developed on top of individual debris flows. These deposits fill a paleotopographic low adjacent to the dacitic dome and onlap the top of the dome. They all dip moderately to the north; they were deposited after dome growth ceased. Where the sediments are observed overlying the flank of the dome there is a prominent apparent unconformity between the tilted ash-flow deposits and the overlying laharic deposits (*see* Figures 2-10-6 and 7).

The rest of the Jock Creek volcanics consist of a strongly welded chloritic lapilli tuff (Unit 7) that is locally interbedded with the laharic deposits, laminated maroon crystal ash tuffs (Unit 8) and a complex sequence of quartz-free biotite-hornblende-feldspar-phyric volcanic breccia and spherulitic lapilli tuff (Unit 9). This unit is capped by a massive purple-brown to grey hornblende-biotite-feldspar porphyry that was interpreted by Marsden and Moore (1989) as a flow. It is macroscopically similar to subvolcanic intrusive rocks located north of the east end of Black Lake (Figure 2-10-4), and may be a sill (as originally mapped by Daikow *et al.*, 1985).

The Jock Creek volcanics are overlain by the Saunders grey dacite ash flow, a unit described in detail below.

Mapping in the northeastern corner of the study area (Figure 2-10-4) has outlined a previously unrecognized stratigraphy. In this area the oldest rocks that can be positively identified are part of the Saunders grey dacite, a unit that caps the succession in all areas west of the fault.

The Saunders grey dacite is divided into three distinctive subunits. The dominant unit (11a) is a single cooling unit, over 400 metres thick, of dark grey lapilli tuffs containing quartz, biotite, hornblende and feldspar crystals, moderately flattened feldspar-phyric lapilli and accidental intrusive fragments that are contained both within the lapilli and the matrix. The matrix consists of flattened and welded glass shards. The lapilli-rich deposits grade upwards into green crystal-ash-tuff deposits (Unit 11b) with the same phenocryst mineralogy as Unit 11a, rare feldspar-phyric lapilli and small but prominent intrusive fragments. The top of the ash flow deposits is marked by a purple volcanic sandstone to pebbly sandstone (Unit 11c) that consists solely of reworked material from the underlying ash flows.

Overlying the purple sandstones is a heterogeneous sequence of grey-green hornblende-pyroxene-biotite-feldspar-phyric flows, tuffs, subvolcanic intrusives and associated sediments (Unit 12). Medium-grained, hornblende-biotite-feldspar porphyritic subvolcanic intrusive bodies dominate much of the section and on the north ridge of Mount Todd (Figure 2-10-4) one of these is observed in intrusive contact with the Saunders dacite. The second most abundant rock type is coarse volcanic conglomerate with subrounded cobbles identical to the intrusive rocks. On the east ridge of Mount Todd these conglomerates directly overlie purple volcanic sandstones of the Saunders dacite. The conglomerates are usually associated with fine-grained, pastel-coloured purple to green volcanic siltstone, sandstone and mudstone. These deposits are very thin bedded and commonly graded, suggesting deposition from small turbidity currents in a shallow aqueous environment, possibly related to debris flows that deposited the volcanic conglomerates. Higher in the section the sediments are interbedded with fine to medium-grained, weakly amygdaloidal pyroxene-hornblende-feldspar-phyric flows and minor lapilli tuffs. Although Unit 12 everywhere rests on top of the purple volcanic sandstone, the contact is not planar, indicating considerable paleotopography, presumably as a result of synvolcanic faulting. These rocks are intruded by an elongate intrusive body, mapped by Daikow *et al.* (1985), that defines the eastern limit of the current project area. This body is actually an intrusive complex dominated by coarse-grained, subcrowded hornblende-biotite-feldspar porphyry (Unit A) and lesser fine to medium-grained equigranular granodiorite (Unit B). The porphyritic rocks are very similar to subvolcanic rocks in Unit 12 but are slightly coarser grained and less crowded. Daikow *et al.* (1985) mapped all of the Hazelton rocks east of this intrusive body as "undivided Hazelton". These rocks may be at least in part correlative with Unit 12 of this report and therefore in part younger than the Saunders grey dacite (Unit 11).

STRUCTURE

All the rocks within the map area are gently tilted and lack any evidence of ductile deformation. The distribution of the stratigraphy has been disrupted by numerous brittle faults developed at a high level in the crust. The Saunders fault interpreted by Daikow (personal communication, 1987) as a right-lateral fault with approximately 5 kilometres of displacement indicated by the offset of a small plug exposed south of the Finlay River. The fault zone strikes 150° and consists of numerous steeply dipping fault strands within a wide zone of altered and highly fractured rock. The southwestern corner of the map sheet (Figure 2-10-4) is transected by another major fault structure that places the Black Lake stock and part of the Stuhini Group against the Jurassic volcanics. The Black Lake stock does not intrude the Jurassic stratigraphy and there is a small sliver of Triassic basalt between the stock and the Toodoggone volcanics; the stock has been faulted into its current position relative to the Toodoggone volcanics. This Black Lake fault may be part of the Attorney fault system.

Within the project area there are four faults striking 160° to 190° that splay off of the Saunders fault (Figure 2-10-4). Three of them are exposed on the west side of the Saunders fault; they all exhibit east-side-down displacement. The displacement decreases from north to south suggesting that the faults initiated adjacent the Saunders fault and propogated southward.

Smaller scale faults observed on the property are all moderately dipping, normal or normal-oblique faults. The actual slip vector cannot be uniquely determined in most cases, although a potential slip vector can be determined from a stereonet plot of conjugate fault sets; the assumed slip vector is perpendicular to the line of intersection of the fault set (Figure 2-10-8).

The faults on the property are all postmineral structures that offset the mineralized zones. Several of the faults have similar attitudes to the mineralized zones and they reflect a similar structural setting; they are all small-scale extensional structures.

MINERALIZATION

The mineralized structures are quartz-carbonate stockwork zones within larger areas of moderate to strong potassic feldspar alteration. The zones of strong alteration are tabular, with numerous anastamosing quartz-carbonate veinlets in which at least three distinct episodes of veining can be seen (*see* Thiersch and Williams-Jones, 1990, this volume). The veinlets, especially a late carbonate-dominated episode, carry native silver, gold and electrum in association with argentite, galena, sphalerite, pyrite and chalcopyrite. The zones grade outward into less-altered and weakly veined wallrock. The JM and Rainier zones (Figure 2-10-5) are characterized by irregular, steeply dipping central breccia veins. Individual veinlets within and adjacent to each zone, and the central breccia veins, usually have a similar strike to the overall zone, but a steeper dip.

The mineralization is not confined to well-developed stockwork zones; there are numerous mineralized areas on the property and some of the best grades yet obtained are from fracture fillings in weakly altered rock. The main stockwork zones did not control ore deposition but they have localized economically significant widths of precious metal mineralization.

Eleven mineralized zones were recognized by the end of the 1988 exploration program (Holbek, 1989). The 1989 exploration program has extended the known strike length and dip extent of the Creek zone (Figure 2-10-5) and has

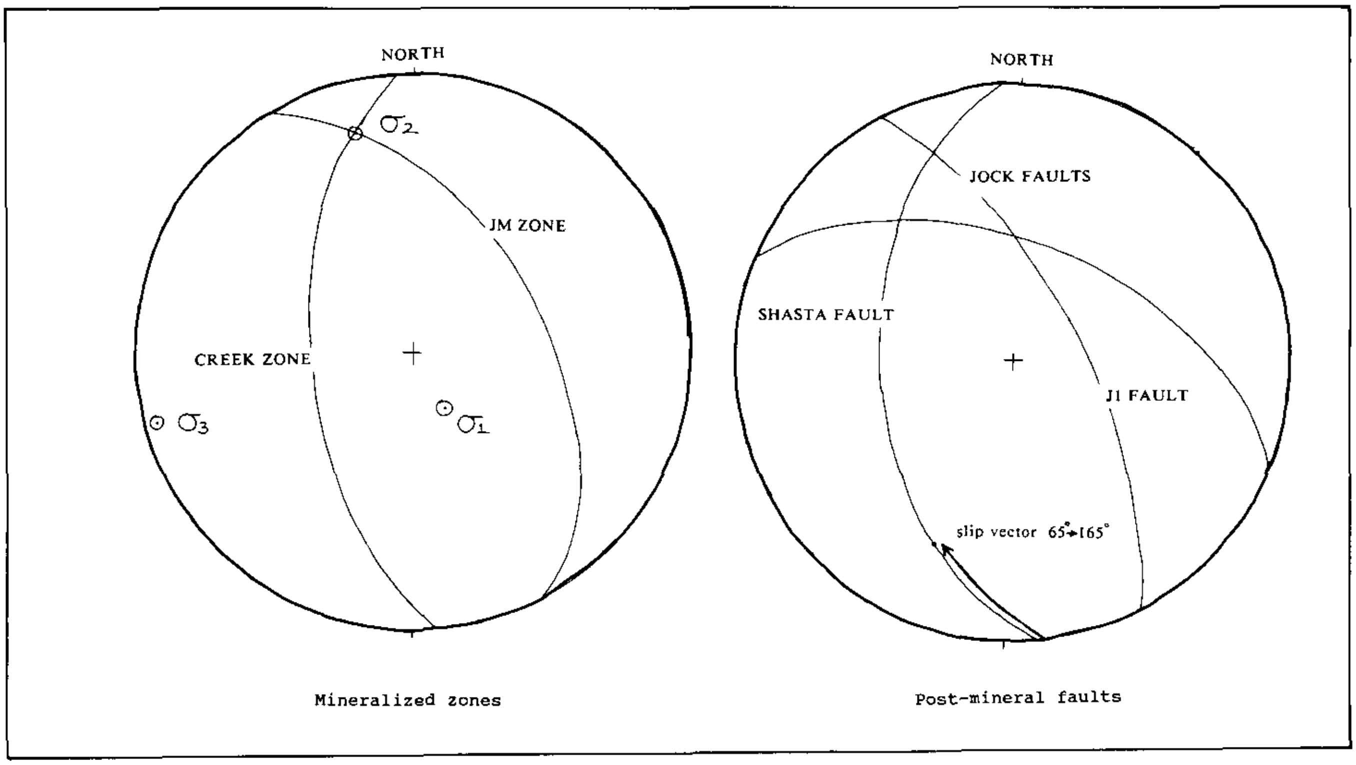

Figure 2-10-8. Equal-area plots from the Shasta property.

shown that the Rainier, Cayley, Baker, Upper Rainier, JM and Creek zones are all segments of a continuous vein sytem.

The core of the deposit is made up of the Creek and JM zones. The Creek zone strikes 170° and dips 60° west; the JM zone strikes 330° and dips 50° to the northeast. The two zones join in Jock Creek. They subtend an angle of 80° and their line of intersection plunges 25° toward 350° (Figure 2-10-8). If the mineralization formed before tilting of the stratigraphy then rotation of the stratigraphy and its contained mineralization back to the horizontal gives a subhorizontal line of intersection and a subvertical maximum compressive stress. As mentioned above, veinlets within the stockwork zones typically have a preferred orientation parallel to the overall strike of the zone but are generally more steeply dipping. This is consistent with minor extensional movement along the two zones (Figure 2-10-9). This pattern has important implications for exploration. Well-mineralized pods resulting from: (1) the intersection of the two main mineralized orientations, or (2) from areas of preferential extension localized by rolls in the fault plane, or (3) as extension gashes within the zone, will all be rod-shaped bodies that plunge to the north, parallel to the line of intersection of the two zones (Figure 2-10-8).

Longitudinal sections along the JM and Creek zones (Holbek, 1989) show that ore-grade mineralization does indeed bottom out along a gently north-plunging line. In the case of the Creek zone this is probably a structural control, but in the JM zone this line coincides with the base of the pyroclastic rocks (Unit 5). Where drill holes intersect the JM zone within the dacitic dome the zone is weakly developed, with no significant width of mineralization. The entire area underlain by the dacite dome between the JM and East zones (Figure 2-10-5) is sporadically mineralized and some spectacular grades have been obtained from minor veinlets, but no significant structure has yet been defined. Alteration has been identified in the overlying laharic deposits (Unit 6) but drilling on the Upper Rainier vein system has shown that the mineralization pinches out in the basal stratigraphy (Unit 3). All of the significant mineralization defined to date is hosted by the pyroclastic rocks (Unit 5).

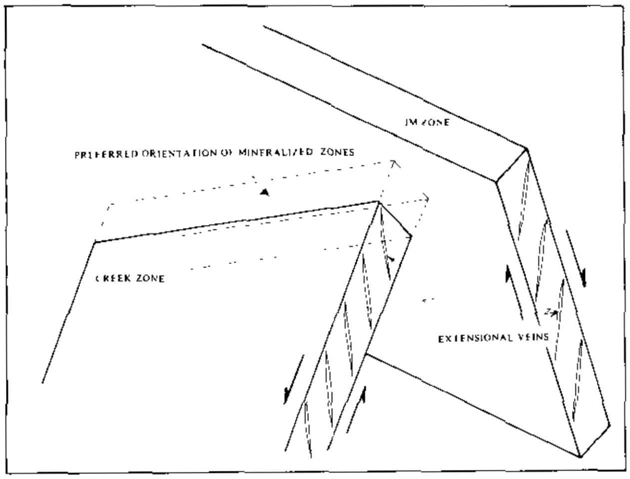

Figure 2-10-9. Structural model for the JM and Creek zones.

SUMMARY

The Shasta silver-gold stockwork deposit is an epithermal precious metal deposit spatially related to a dacitic dome of lower Middle Jurassic age. The mineralization consists of native metals in association with argentite and base metal sulphides within a quartz-carbonate stockwork with potassic alteration envelopes, an assemblage typical of epithermal precious metal deposits formed at moderate depths (several hundred metres). Significant zones are hosted by pyroclastic deposits that were deposited on the flank of a coeval dacite dome.

Economic widths of mineralization are primarily hosted by two predominant vein orientations; 170°/60° west and 330°/50° northeast. This pair of structures is a set of conjugate extensional fractures that intersect near Jock Creek. The geometry of the zones is such that the richest ore-shoots are rod-shaped elements that plunge gently north.

These zones are not within a major fault structure and did not form in response to a high applied stress. They may be preferentially located in the pyroclastic rocks because this unit was an aquifer and the high pore-fluid content helped initiate rock failure and dilation, concentrating fluid flow and resulting in mineral precipitation.

This exploration model can be used on the property in three ways. The dip of an individual zone can be quickly estimated based on its strike and the orientation of contained veinlets. Poorly developed structures such as the O zone and the East zone (Figure 2-10-5) can be traced into the pyroclastic rocks of Unit 5 where they may be better developed. The stratigraphic throw and an estimated slip vector on the Shasta fault can be combined to predict the location of a blind offset of the JM zone.

Although ages for the dacite dome and the mineralization are not available it is likely that there is a close genetic relationship between the two. Previous dating in other parts of the Toodoggone region (Daikow, 1985; Clark and Williams-Jones, 1988) has shown that the mineralization is close in age to the volcanics, a typical scenario for most active hydrothermal systems. The dome and its source area may not only have provided the heat that drove hydrothermal convection, but the oversteepening of deposits on the flanks of the dome may have created an inherent instability that encouraged extensional failure. Further exploration in the southern part of the Toodoggone belt should concentrate on locating similar dacitic flows and tuffs in stratigraphy of equivalant age (*ca.* 190 Ma). Within suitable host stratigraphy, additional favourable exploration criteria are anomalous stratigraphic orientations indicating possible domal or graben structures (*see* Vulimiri *et al.*, 1983) and pink altered feldspars (associated with elevated K_2O values) within dacitic tuffs or flows.

ACKNOWLEDGMENTS

The ideas presented in this paper are a compilation of the efforts of several individuals. Peter Holbek has been supervising the Shasta project for three years. Peter Thiersch has also been involved in the project for the last three years and is currently preparing an M.Sc. thesis on the mineralization. Margaret MacPherson has been mapping and producing core logs that are a joy to work with for the last two years. Critical appraisal by Ron Britten has kept the work on track and the ideas reasonable.

We would like to express our gratitiude to Homestake for offering generous support and exceptional freedom for the final year of this project. A research grant from the British Columbia Ministry of Energy, Mines and Petroleum Resources will allow the research to be concluded during the present academic year.

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