DAVID BLOOM

AES 277

A.E.S. 277 - Field Mapping of Ore Deposits

Yerington District, Nevada

Marco T. Einaudi

Spring Break Field Trip

AES-277, FIELD MAPPING OF ORE DEPOSITS

M.T.Einaudi

The field portion of this course is held during Spring Break and can be taken alone for 1 unit credit; students specializing in ODEX are required to write two papers summarizing the results and interpretation of their mapping at two different sites. These reports are written during Spr Qtr and yield 2 additional credits (total 3 credits). Register during Spring Qtr. This course is open to anyone who has taken: Geo 103A,B or equivalent; and AES 120 or consent of instructor. Anyone wanting to come for any portion of the trip and not desiring credit, please see MTE.

Advanced Preparation:

Students planning to take this course are required to attend two preparatory lectures, as follows:

1. March 11, noon, B-59 Mitchell - General introduction to geology of Yerington district, Nevada; organization and procedures during trip; presentation of mapping techniques employed.

2. March 13, noon, B-59 Mitchell - Geology of skarns and porphyry deposits in the Yerington district.

Students also are required to read the following articles before the departure date of March 20 (on reserve in Branner):

1. Einaudi, M.T. (1977) Petrogenesis of copper-bearing skarn at the Mason Valley mine, Yerington district, Nevada: Econ. Geol., v. 72, p. 769-795.
2. Einaudi. M.T. (1982) Description of skarns associated with porphyry copper plutons, *in*, Titley, S.R. (ed.) Advances in the Geology of the Porphyry Copper Deposits, Southwestern North America: Univ. Ariz. Press, Tucson, p. 139-183.
3. Harris, N.B., and Einaudi, M.T. (1982) Skarn deposits in the Yerington district, Nevada I. Metasomatic skarn evolution near Ludwig: Econ. Geol., v.77, p. 877-898.
4. Proffett, J.M., Jr. (1977) Cenozoic geology of the Yerington district Nevada and implications for the nature and origin of Basin and Range faulting: GSA Bull., v. 88, p. 247-266.
5. Proffett, J.M., Jr., and Proffett, Beth H. (1976) Stratigraphy of the Tertiary ash flow tuffs in the Yerington district, Nevada: Nev. Bur. Mines Geol., Rpt. 27, 28 p.

Proposed Schedule:

March 20 (Friday) - Departure from Stanford at noon; arrival at Yerington 6 pm.

March 21 (Saturday) - *Excursion* over Singatse Peak. Study of lower Tertiary erosion surface and of overlying Tertiary *ash flow tuff sequence*. Examination of flat faults (rotated normal faults) formed during *pre-Basin and Range extension*. Patterns of wall-rock alteration in *Ann Mason porphyry copper system.*

March 22-24 (Sun-Tues) - *Mapping* of surface trenches at MacArthur prospect, a *porphyry copper deposit* of Jurassic age tilted on its side by pre-Basin and Range faulting. One-half day on recon of alteration-mineralization patterns as a function of paleodepth-- we have 8 km of paleovertical relief to work with. Two and one-half days on detailed (1 in = 20 to 50 ft) geological-mineralogical mapping to deduce time/space relations in mineralized core of system (both hypogene and supergene processes will be evaluated).

March 25 (Wed) - *Excursion* through *contact metamorphic-metasomatic aureole* developed in Triassic-Jurassic sedimentary-volcanic rocks on the margin of the Jurassic Yerington batholith. Metamorphic hornfels, reaction skarns, skarnoids, endoskarns, exoskarns, and their space-time relations.

March 26-28 (Thurs-Sat) Detailed surface outcrop mapping (1 in = 50 ft) of the Casting Copper *skarn deposit* near Ludwig. This is one of the most spectacular and best exposed skarn deposits that I know of.

March 28 (Sat) - Departure for Stanford around noon, depending on weather conditions at Donner pass.

IF YOU INTEND TO PARTICIPATE IN ANY WAY, PLEASE SIGN UP ON THE BOARD OUTSIDE B-57 (MTE's office).

The official base camp for this trip is:

In-Town Motel, Yerington, Nevada
702-463-2164

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Summary of Geology of Yerington District

Proffett, J. M., Jr., and Dilles, J. H., 1984, Geologic Map of the Yerington District, Nevada: Nevada Bureau of Mines and Geology, Map 77.

(Text accompanying map)

INTRODUCTION

The geologic map of the Yerington district has been made by geologists employed or supported by the Anaconda Minerals Company, a division of the Atlantic Richfield Company. Geologic mapping started in the early 1950's when the Yerington porphyry copper deposit was put into production and Anaconda began exploration in the district. In the thirty years since, more than twenty-five geologists have contributed greater than eight man-years of geologic mapping in the area.

ACKNOWLEDGMENTS

The authors wish to thank the Anaconda Minerals Company for its support of this effort. J. M. Proffett, Jr. was employed by Anaconda in the Yerington district from 1966 to 1977, in part while undertaking dissertation studies at the University of California at Berkeley. J. H. Dilles has been supported by Anaconda during dissertation studies at Stanford University in the 1980's.

Special thanks go to J. P. Hunt, C. Meyer, and M. T. Einaudi, who have encouraged this project; to K. L. Howard, Jr. and J. DeLong of the Anaconda Minerals Company, who have facilitated it; and to S. L. Tingley of the Nevada Bureau of Mines and Geology and A. Barkley of Anaconda Minerals Company, who have guided it to completion.

GEOLOGIC HISTORY

The Yerington district is underlain by early Mesozoic volcanic and sedimentary rocks intruded by two Middle Jurassic batholiths and an early Mesozoic pluton. Mesozoic rocks are unconformably overlain by Oligocene ignimbrites and Miocene andesites, sediments, and basalts. Major east-west-striking steep faults developed in Middle Jurassic time, and east-dipping normal faults and related westward tilting developed in late Cenozoic time. All pre-late Miocene rocks have been tilted steeply west; thus, the surface map reveals what would have been nearly a cross-sectional view before tilting.

Early Mesozoic volcanic and sedimentary rocks are exposed at McConnell Canyon and Ludwig in the southern Singatse Range, in Guild Canyon in the northern Singatse Range, and along Schurz Highway in the northern Wassuk Range. The volcanics of McConnell Canyon are the oldest rocks, dated at 214.7 ± 6.8 m.y. (Late Triassic?) by the whole-rock Rb-Sr method (Proffett, Livingston, and Einaudi, in prep.). This unit is comprised of a thick pile (4300 ft) of submarine(?) andesite and felsite flows, breccias, and sediments cut by quartz porphyries. Two sections of rocks mapped as Ŧr? and Ŧa? may be older than the volcanics of McConnell Canyon; one section is south of 38°55'N on the east half of the map area, and the other is south of the Jurassic granodiorite porphyry dike (which occupies a major fault) in Sand Canyon, southern Singatse Range, on the west half of the map area. On the east half of the map area Ŧr? and Ŧa? are intruded by diorite of the earliest phase of the Strosnider Ranch pluton. Petrographically similar diorite in the northern Wassuk Range has a concordant U-Pb zircon date of 230 m.y. (J. H. Dilles and J. E. Wright, unpub. data). The Strosnider Ranch quartz monzonite-diorite pluton is probably Middle Jurassic or older and is petrographically dissimilar to the large Middle Jurassic Yerington and Shamrock batholiths.

The volcanics of McConnell Canyon are disconformably overlain by limestone with uppermost Karnian (lower Upper Triassic) ammonoids. At Schurz Highway this limestone is the lowest unit exposed. At McConnell Canyon the limestone is overlain by a 1600-foot-thick sequence of carbonaceous calcareous argillite, volcaniclastic sediments, and limestone with Norian fossils (middle Upper Triassic). Possibly correlative rocks are 8600 feet thick at Schurz Highway. These rocks are overlain at McConnell Canyon and Ludwig by a massive Norian(?) limestone, 875 feet thick, perhaps equivalent to Noble's (1962) limestone in the Oreana Peak Formation. The Norian(?) limestone is conformably overlain by a sequence of thin-bedded limestone, bedded felsitic siltstone and tuffs, and carbonaceous and calcareous argillite in which volcanic detritus decreases upward. This sequence spans the Triassic-Jurassic boundary and may be equivalent to parts of Noble's (1962) Gardnerville Formation.

The Karnian to Lower Jurassic volcaniclastic and limestone sequence appears to have formed in a moderately shallow-water marine shelf environment near an active volcanic arc and is overlain by Lower to Middle Jurassic beds that record the closing of a shallow basin and its dessication, without concurrent volcanic activity. The lowest unit of these beds is the thin limestone of Ludwig, a calcarenite probably formed in a beach or perhaps supratidal environment. The limestone of Ludwig was succeeded by bedded gypsum, indicative of evaporite formation in a closed basin. Above the gypsum is a unit of well-sorted, subrounded quartz sandstone with minor arkosic beds that probably originated as wind-blown dune sand transgressing across the basin as it dried; it is probably correlative with Noble's (1962) Preacher's Formation. At the top of the sandstone unit, thin arkosic beds appear to be intercalated with basal andesitic tuff-breccia and sediment of the andesite of Artesia Lake. The andesite of Artesia Lake consists of andesitic and dacitic flows, breccia, sandstone, and tuff that form a thick and complex subareal(?) volcanic pile centered over the Yerington batholith. The andesite of Artesia Lake marks the beginning of a Middle Jurassic pulse of volcanic and plutonic activity.

Mesozoic plutonic rocks compose 80% of the pre-Tertiary rocks exposed in the Yerington district; the area may be considered a Jurassic part of the Sierra Nevada batholith. The plutons were emplaced to relatively shallow levels and shouldered aside the early Mesozoic volcanic and sedimentary rocks, which are now exposed as folded pendants within the batholiths. At Ludwig they now form an overturned anticline between two Middle Jurassic batholiths. Here they have undergone contact metamorphism to upper albite-epidote facies and hornblende hornfels facies (Harris and Einaudi, 1982). The voicanics of McConnell Canyon consist of biotite- or hornblende-bearing schists and hornfels.

Three major plutons were intruded in the map area. They are the Middle Jurassic Yerington batholith, the younger Middle Jurassic Shamrock batholith to the south, and the Strosnider Ranch pluton, of probable Middle Jurassic or older age.

The Yerington batholith is a pluton bordering between alkali-calcic and calc-alkalic in composition; it underlies most of the central part of the map area and originally formed a 100 mi² east-west elongate mass centered in the Yerington district ranging from the northern Wassuk Range on the east to the northern Pine Nut Range on the west. The batholith is composite and is strongly differentiated from early granodiorite to quartz monzonite to porphyritic quartz monzonite and finally to quartz monzonite porphyry, with a successive decrease in the volumes of intrusions. Concordant U-Pb zircon dates (J. H. Dilles and J. E. Wright, unpub. data) show that the entire batholith was emplaced within 1 million years at 169 m.y. (granodiorite is 169 m.y. and quartz monzonite porphyry is 168 m.y.).

The earliest intrusive phase of the Yerington batholith consists of a large body of fine-to medium-grained biotite-hornblende granodiorite associated with small bodies of layered cumulate hornblende gabbro in deep and border exposures. At shallow levels granodiorite was emplaced as a series of stocks, dikes, and sills that intimately intrude the andesite of Artesia Lake. In these exposures the granodiorite is texturally similar to andesite, suggesting that the two may have been emplaced nearly contemporaneously and may be comagmatic. The granodiorite shows many internal crosscutting contact relations and a range of chemical compositions (58%–62% SiO_2), suggesting that it was emplaced as a series of pulses of magma. Along the contacts with the carbonate part of the early Mesozoic section, the granodiorite is commonly converted to grossular-andradite garnet-plagioclase endoskarn, and the adjacent metasedimentary rocks are converted to grossular-andradite garnet hornfels (skarnoid) as part of an early high-temperature metamorphic-metasomatic event (Harris and Einaudi, 1982).

The second phase of the Yerington batholith is medium-grained biotite-hornblende quartz monzonite that formed an irregular, flat-topped intrusion into the center of the granodiorite. Contacts are marked by a fine-grained, more silicic border phase, suggesting that the granodiorite had crystallized and partly cooled by the time the quartz monzonite was emplaced. The quartz monzonite shows a variety of textures and compositions and was emplaced to relatively shallow levels that are below the top of the granodiorite.

Proffett and Dilles, 1984a, (text-continued)

The next major intrusion was medium-grained hornblende-biotite porphyritic quartz monzonite; this intrusion is coarser grained and was emplaced relatively deeply and centrally within the batholith as a stock with a series of cupolas along its top. Swarms of quartz monzonite porphyry dikes which originate from the porphyritic quartz monzonite below cut through the tops of the cupolas. The dikes form major swarms that were oriented northwest-southeast and dipped almost vertically in Jurassic time. Porphyry copper mineralization formed contemporaneously with the emplacement of the porphyries and occurs locally where they cut the apices of the porphyritic quartz monzonite cupolas, such as at the Yerington Mine and in the Mickey Pass (Ann-Mason) area. At the Yerington Mine at least four ages of porphyry dikes occur; the earlier two contain copper mineralization (Einaudi and others, in prep.). Extensive sodium-calcium (Carten, 1981), potassic, albitic, propylitic, and sericitic alteration developed around the porphyry copper centers due to the circulating hot hydrothermal fluids. The porphyry dikes and fluids are probably synchronous with the development of copper and magnetite skarns within the adjacent early Mesozoic carbonate (Einaudi, 1977; Harris and Einaudi, 1982).

Shortly following the emplacement of the main part of the Yerington batholith, Middle Jurassic latitic volcanics of Fulstone Spring erupted, a large east-west graben structure enclosing the Yerington batholith formed, and faults of the graben structure were intruded by granodiorite porphyry dikes. It is not clear whether these events are related to the final stages of magmatic activity of the Yerington batholith or to a distinctly younger event. In the Buckskin and Pine Nut Ranges to the west of the map area, the Middle Jurassic volcanics of Fulstone Spring, consisting of latite and quartz latite domes, flows, breccias, and ash-flow tuffs of subareal origin, discomformably overlie the andesite of Artesia Lake. Unaltered dikes of Jurassic granodiorite porphyry were intruded, commonly along major east-west Jurassic faults that cut the volcanics of Fulstone Spring, the Yerington batholith, and older rocks. In the Wassuk Range, Bingler (1978) reports two such dikes occupying east-west structures; near the Northern Lights Mine, a dike occupies a high-angle fault that displaces the early Mesozoic section more than 8000 feet down to the north (pre-tilt), and the second parallel fault is 5 miles north near White Mountain and has approximately the same displacement of early Mesozoic rocks, but displacement of Mesozoic rocks is down to the south (pre-tilt). Thus, in the northern Wassuk Range the two faults define a major (pre-tilt) graben structure that has downdropped a block containing the Yerington batholith shortly after and possibly during its emplacement. The graben structure continues westward into the Yerington district; the southerly fault is marked by the Jurassic granodiorite porphyry dike exposed along 38°55'N on the east half of the map and in Sand Canyon in the southern Singatse Range on the west half of the map area. The northerly fault is marked by a dike in the northern Buckskin Range that continues into the northern Pine Nut Range (Castor, 1972).

The Shamrock batholith forms the second major Middle Jurassic batholith and has a concordant U-Pb zircon age date of 165 m.y. (J. H. Dilles and J. E. Wright, unpub. data) near Shamrock Hill in the southern Singatse Range. The batholith consists of biotite-hornblende quartz monzonite and crops out from the southern Singatse Range to the Pine Nut Range. In the Pine Nut Range between Mt. Siegel and Mt. Como, Stewart and Noble (1979) have referred to it as the Mt. Siegel batholith. In the Singatse Range, it lies to the south of the Yerington batholith and is separated from it by a pendant of early Mesozoic rocks. On Mt. Como the Shamrock batholith cuts the volcanics of Fulstone Spring. West of Sand Canyon the Shamrock quartz monzonite trends across the westward projection of the Jurassic granodiorite porphyry dike of Sand Canyon, and it is therefore inferred to be younger than that porphyry.

The final pre-Tertiary rocks that were emplaced are narrow flow-banded, crystal-poor rhyolite dikes and fine-grained, crystal-poor dark andesite dikes. Andesite dikes cut the Shamrock batholith and rhyolite dikes but do not cut Late Cretaceous plutons in the northern Schurz quadrangle; they are inferred to be Late Jurassic or Early Cretaceous.

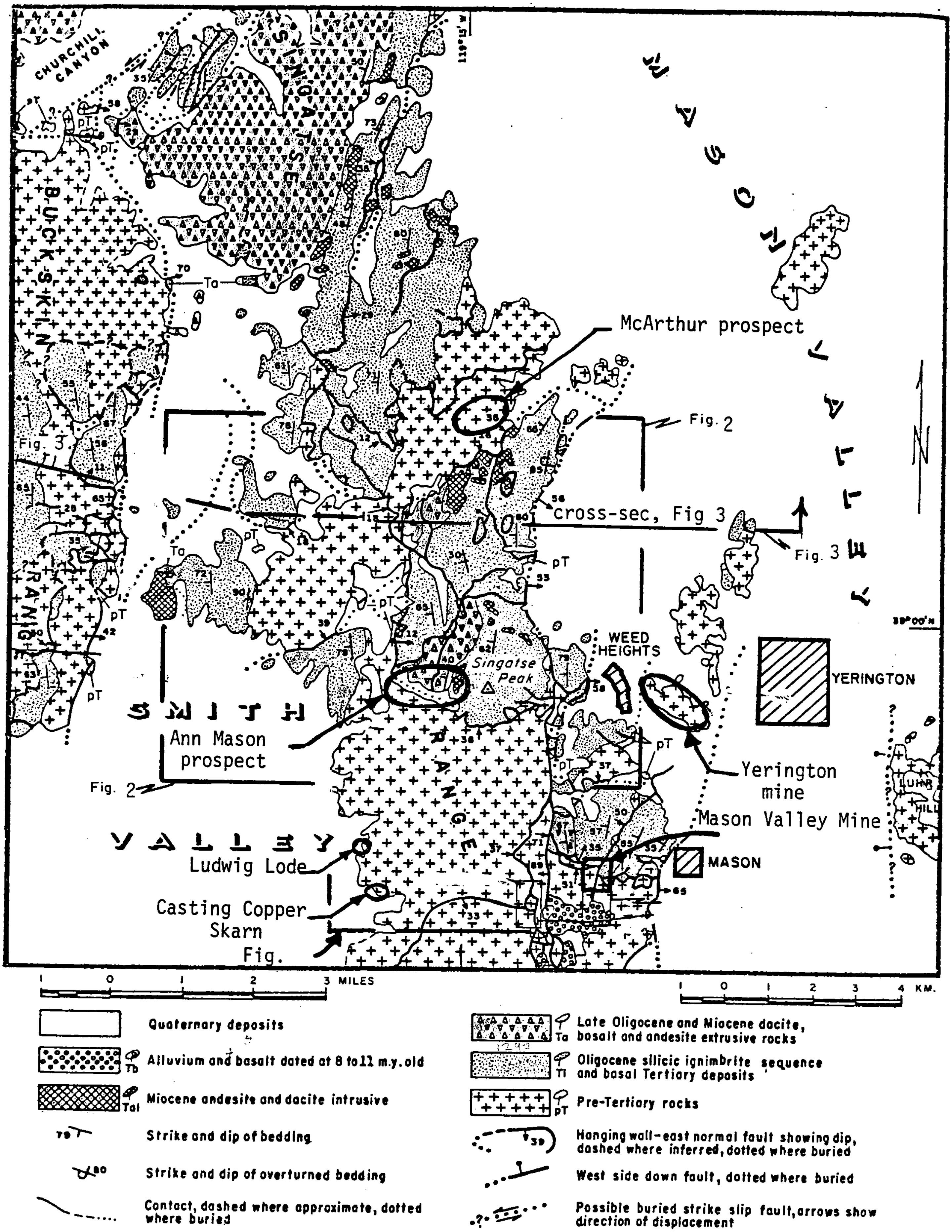
Following the emplacement of the Jurassic batholiths there is a long hiatus in the stratigraphic record until the Oligocene. During this period, uplift and erosion occurred over most of the area, stripping much of the upper portions of the batholiths and the early Mesozoic section. Cretaceous plutons are inferred to have been emplaced in the area at depth because they occur in the Pine Nut Range (Noble, 1962) to the west and the Wassuk Range (Bingler, 1978) to the east. Additionally, K-Ar radiometric dates from the Yerington batholith have been widely reset to ages as young as 91 m.y. (Anaconda Co., unpub. data). Garnet-muscovite-bearing granite that could be Cretaceous occurs in deep drill core from the McLeod Hill area.

Some structural tilting appears to have occurred in this period. Geissman and others (1982) hypothesize, based on paleomagnetic data, that Mesozoic rocks were tilted 20°-40° or more westward about northeasterly structural axes.

Near the end of the period of erosion, conglomerates and basalts were deposited within an early Tertiary west- and northwest-trending river channel (Proffett and Proffett, 1976). The basal Tertiary deposits were subsequently overlain by a series of ash-flow tuff sheets primarily comprised of quartz latite. After filling over 4000 feet of early Tertiary topography, the ignimbrite sheets flowed out over the tops of Tertiary hills; up to 7500 feet of tuff were deposited. Five major Oligocene tuffs were erupted, ranging from approximately 28 to 24 m.y. old (Proffett and Proffett, 1976). The tuffs were, from oldest to youngest, the Guild Mine Member and the Weed Heights Member of the Mickey Pass Tuff, the Singatse Tuff, the Bluestone Mine Tuff, and the tuff and breccia of Gallagher Pass. Two other thin Oligocene tuffs are locally present: early ignimbrite remnants (pre-Guild Mine Member) and the Blue Sphinx Tuff (above Bluestone Mine Tuff and below the tuff and breccia of Gallagher Pass). The Oligocene tuffs are part of widespread sheets that have been traced as far as Carson City to the west-northwest and as far as Luning to the east-southeast (see Ekren and others, 1980). The source of part of the Bluestone Mine Tuff has been identified about 50 miles to the east (Ekren and Byers, 1976), but the other tuffs are from unknown sources. The Guild Mine Member and the Weed Heights Member of the Mickey Pass Tuff are compositionally zoned from 65% SiO_2 near the base to 72% SiO_2 near the top, while the Singatse Tuff is relatively unzoned; all three are quartz latites. The Bluestone Mine Tuff is rhyolitic (75%-76% SiO_2), while the tuff and breccia of Gallagher Pass is dacitic (64% SiO_2). The ignimbrites represent very large volume eruptions (Guild Mine Member, >600 km^3; Singatse Tuff, >3500 km^3) (Proffett and Proffett, 1976).

The Oligocene ash-flow tuffs were followed by local flows of early Miocene olivine pyroxene basalt. The basalts are overlain by flows, flow-breccia, tuff-breccia, and sediments of the Miocene hornblende andesite of Lincoln Flat; they are intruded by related dikes and plugs of hornblende andesite and hornblende or biotite dacite. Hornblende andesite volcanism began about 19 m.y. ago, and as it died out 17-18 m.y. ago, basin-and-range normal faulting began. The normal faults dip east and are curved, concave upward, with net displacements in an east-west direction of up to 2.5 miles. Movement along the faults resulted in steep (average 60°) westward tilting of the Miocene andesites and of all older rocks. As faulting and tilting progressed, faults were rotated to gentle east dips and became inactive, and movement was taken up on younger, higher angle faults. More than 100% east-west extension took place across the district due to normal faulting (Proffett, 1977).

Fanglomerate, sandstone, and tuffaceous sediments were deposited locally in basins that were formed after the onset of normal faulting. These sediments are less tilted than pre-early Miocene rocks and include sediments correlative to the 7.5-12.5-m.y.-old Wassuk Group of Gilbert and Reynolds (1973). Flows of olivine pyroxene basalt dated at 8-11 m.y. (Proffett, 1977) are interbedded with and cap some coarse conglomerate in the southern Singatse Range. Lower flows are tilted 6°-20° westward, and the uppermost flows are tilted 5°-6° westward; thus, most low-angle normal faulting and tilting in the area had taken place by 8 m.y. Similarly, most normal faulting to the south of the map area occurred prior to 7.5 m.y.; the younger high-angle normal faults that are responsible for much of the modern topography are Quaternary (Gilbert and Reynolds, 1973). In the Yerington district, normal faults that cut 8-11-m.y.-old basalt and younger alluvium dip steeply east. Some of these occur along active range fronts and displace Quaternary sediments (Proffett, 1977). Within the modern basins, alluvium (including pediment gravels and flood plain silts, sands, and gravels) have been deposited with minor windblown sand and lake deposits. Alluvium, sand, and lake deposits range in age from late Pliocene(?) or Pleistocene to Holocene.



Generalized geologic map of Yerington district, Nevada, showing major Cenozoic features.

Figure 1

	Thickness	Description		Name
Q	variable	Alluvium, fanglomerate, sandstone, lake and flood-plain deposits.		
		MINOR ANGULAR UNCONFORMITY		
8-11 M.Y	±270'	Flows of pyroxene olivine basalt. 8-11 Ma		
8-11 M.Y	±400'	Coarse basal conglomerate, overlain by fanglomerate, in turn overlain by pebble-cobble conglomerate, sandstone, and siltstone.		
		MAJOR ANGULAR UNCONFORMITY		
MIOCENE	1300'+ (top not mapped)	Flows, breccia, tuff-breccia, sediments, and intrusions of grey andesite with abundant hornblende or hornblende and plagioclase phenocrysts. Hornblende pyroxene andesites common in northern Singatse Range. Associated intrusions of hornblende biotite. Dacite quartz porphyry present.		HORNBLENDE ANDESITE OF LINCOLN FLAT 17-19 Ma
		EROSIONAL OR SLIGHT ANGULAR UNCONFORMITY		
?	0–600	Flows and breccia of olivine pyroxene basalt.		
		EROSIONAL UNCONFORMITY		
OLIGOCENE	0–520'	Crystal-rich dacite tuff-breccia, breccia, and ash-flow tuff with plagioclase, biotite, and pyroxene. ~24 Ma		TUFF AND BRECCIA OF GALLAGHER PASS
		EROSIONAL UNCONFORMITY		
OLIGOCENE	200–980'	MAP UNIT 10 – White to pale-colored crystal-poor, unwelded tuff, tuff-breccia, and sediments interbedded with two crystal-poor, pale brown to reddish, poorly welded tuffs.		BLUESTONE MINE TUFF
		EROSIONAL UNCONFORMITY		
OLIGOCENE	800–1350'	MAP UNIT 9 – Brown to red-brown, strongly to moderately welded, crystal-rich ash-flow tuff with plagioclase, quartz, sanidine, biotite, and hornblende phenocrysts and sparse pumice fragments. Relatively biotite rich.	Single cooling unit	SINGATSE TUFF 27.2 ± 1.1 Ma
OLIGOCENE	100–300'	MAP UNIT 8 – Similar to unit 9 but with buff color and abundant foreign rock fragments.	Single cooling unit	SINGATSE TUFF
OLIGOCENE	0–150'	MAP UNIT 8a – Similar to unit 9.	Single cooling unit	SINGATSE TUFF
OLIGOCENE	100–370'	MAP UNIT 7 – White, pale green, or pale pink rhyolitic unwelded tuffs and sediments.		MICKEY PASS TUFF
OLIGOCENE	200–470'	MAP UNIT 6 – Buff to lavender to reddish brown moderately welded, moderately crystal-rich ash-flow tuff with plagioclase, sanidine, quartz, biotite, and abundant white pumice fragments.	Cooling unit	MICKEY PASS TUFF – WEED HEIGHTS MBR.
OLIGOCENE	0–70'	MAP UNIT 5 – Rhyolitic sediments.		MICKEY PASS TUFF
OLIGOCENE	0–90'	MAP UNIT 4 – White, poorly welded tuff.		MICKEY PASS TUFF
OLIGOCENE	0–160'	MAP UNIT 3 – Unwelded rose pink tuff.	Lower cooling unit	MICKEY PASS TUFF – GUILD MINE MEMBER 27.5 ± 1 Ma (K-Ar)
OLIGOCENE	0–800'	MAP UNIT 2 – Brownish-pink to lavender-gray crystal-rich ash-flow tuff with sanidine, quartz, plagioclase, minor biotite, and large white pumice fragments. Moderately welded.	Lower cooling unit	MICKEY PASS TUFF – GUILD MINE MEMBER
OLIGOCENE	0–1700'	MAP UNIT 1 – Crystal-rich, strongly welded, brown ash-flow tuff. Plagioclase, biotite, and pyroxene phenocrysts at the base become less abundant upwards. Sanidine, quartz, some plagioclase, and biotite phenocrysts are present near the top.	Lower cooling unit	MICKEY PASS TUFF – GUILD MINE MEMBER
		EROSIONAL UNCONFORMITY		
EARLY TERTIARY	0–400'	Erosional remnants of moderately welded ash-flow tuff with quartz, plagioclase, and sanidine.		BASAL TERTIARY DEPOSITS (Unnamed)
EARLY TERTIARY	0–300'	Flows, breccia, and tuff of pyroxene basalt.		BASAL TERTIARY DEPOSITS (Unnamed)
EARLY TERTIARY	0–200'	Coarse, unsorted, unstratified landslide breccia.		BASAL TERTIARY DEPOSITS (Unnamed)
EARLY TERTIARY	0–400'	Conglomerate. Well rounded cobbles, pebbles, and boulders in sandy matrix; clasts are 25% pre-Tert lithologies, 75% Tert. andesite.		BASAL TERTIARY DEPOSITS (Unnamed)
		MAJOR UNCONFORMITY		
MESOZOIC		Granitic and metamorphic rocks; red, deeply weathered below lower Tert unconformity.		

FIGURE 2. Tertiary stratigraphic section for the Yerington district, Nevada.

Figure 2 (see fig. 1 for location)

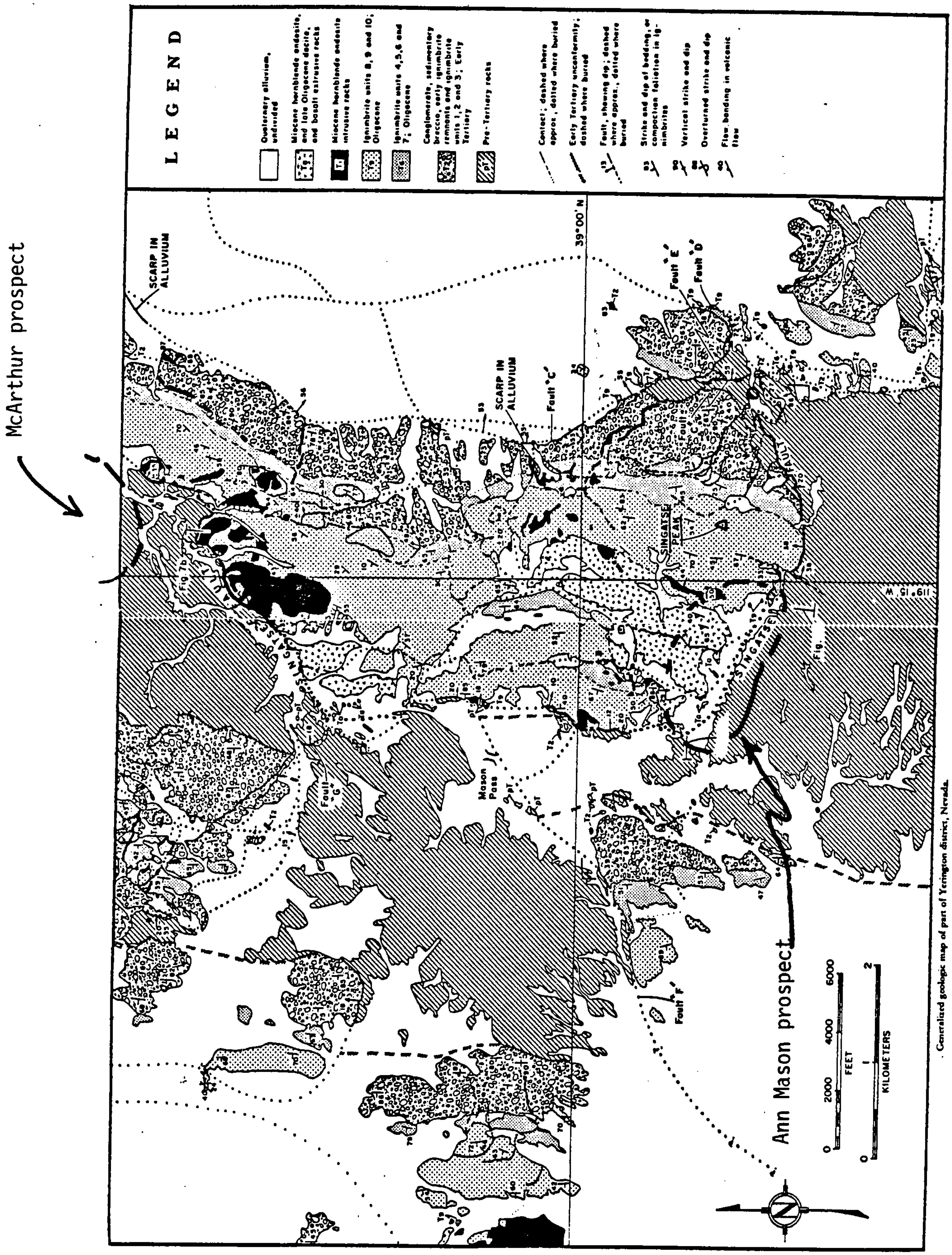
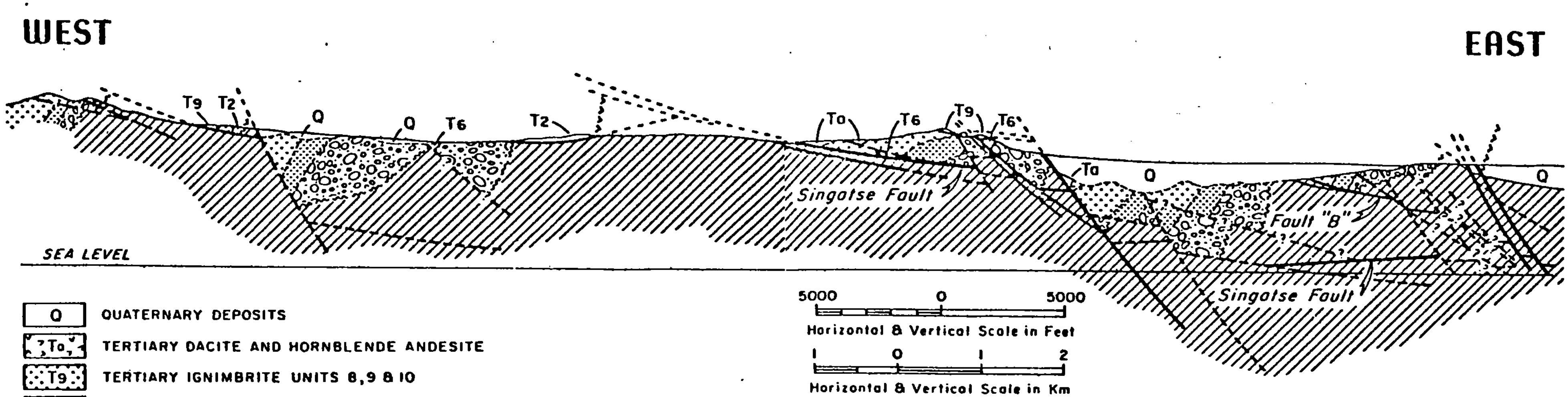


Figure 2



- Q — QUATERNARY DEPOSITS
- Ta — TERTIARY DACITE AND HORNBLENDE ANDESITE
- T9 — TERTIARY IGNIMBRITE UNITS 8,9 & 10
- T6 — TERTIARY IGNIMBRITE UNITS 4,5,6 & 7
- T2 — TERTIARY CONGLOMERATE & IGNIMBRITE UNITS 1,2 & 3
- pT — PRE-TERTIARY ROCKS

- Fault (location and dip accurately known)
- Fault (approximate location, accurate dip)
- Fault (accurate location, approximate dip)
- Inferred faults (location and dip questionable
- Faults projected above surface
- Early Tertiary unconformity (accurate)
- Early Tertiary unconformity (approximate)
- Early Tertiary unconformity (projected above surface)
- Contact (accurate)
- Contact (approximate)

Typical east-west cross section through Yerington district, Nevada. Constructed from detailed surface and drill-hole mapping supplemented with geophysical data.

Figure 3
(see Fig. 1 for location)

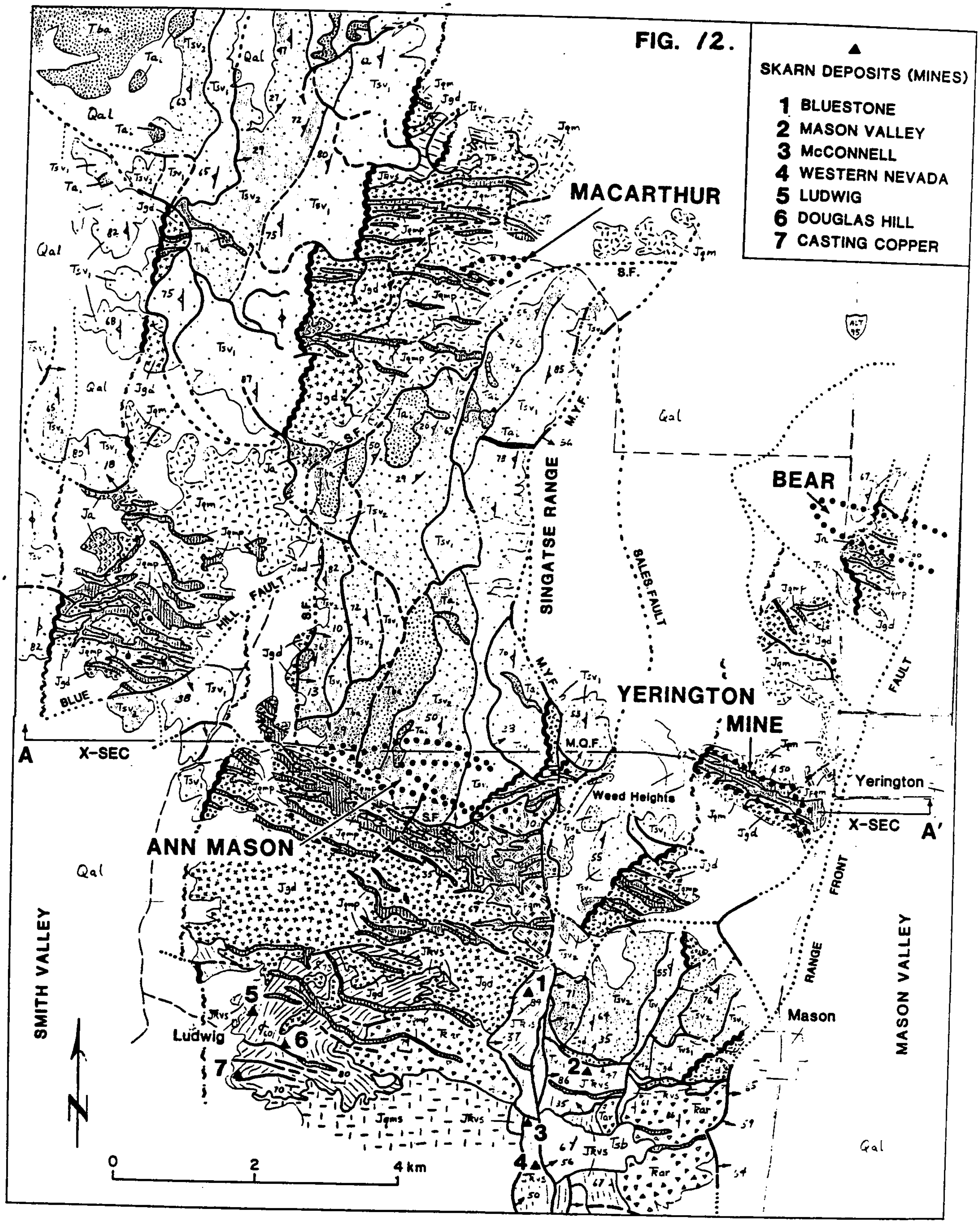
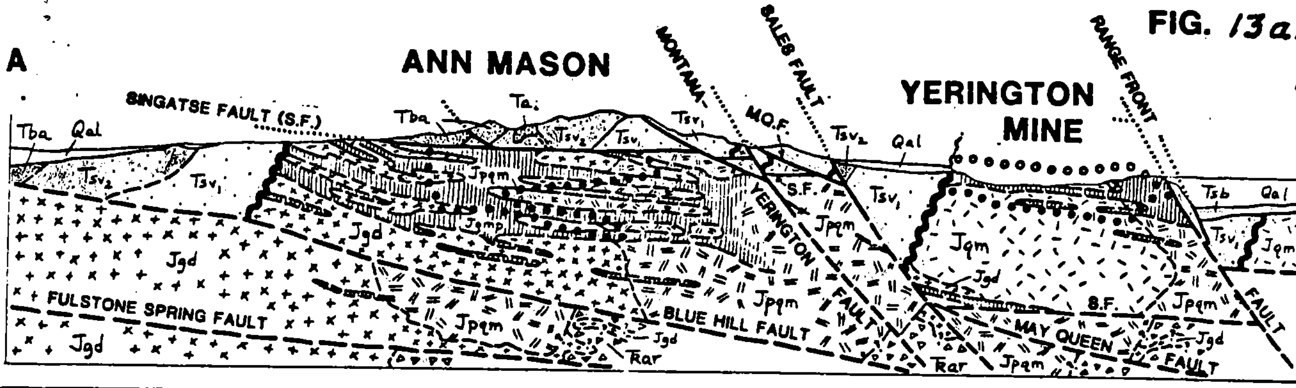

SKARN DEPOSITS (MINES)
1 BLUESTONE
2 MASON VALLEY
3 McCONNELL
4 WESTERN NEVADA
5 LUDWIG
6 DOUGLAS HILL
7 CASTING COPPER
MACARTHUR
BEAR
YERINGTON MINE
ANN MASON
SINGATSE RANGE
SALES FAULT
BLUE HILL FAULT
RANGE FRONT FAULT
SMITH VALLEY
MASON VALLEY
Weed Heights
Yerington
Mason
Ludwig
X-SEC
A
A'
M.Y.F.
M.O.F.
S.F.
0
2
4 km

FIG. 12.

FIG. 13a.



KEY:

FAULT. Dashed where inferred, dotted where buried or projected into air.

M.Y.F. — Fault trace on unfaulted cross section. Letter abbreviations for names (see figs. 1A & 1B).

CONTACT. Dashed where inferred, dotted where projected into air.

Dip arrows on faults & contacts are perpendicular to strike.

strike & dip of compaction foliation in ash-flow tuff.

strike & dip of bedding.

strike & dip of metamorphic schistosity.

▲ Skarn deposits (see fig. 1A)

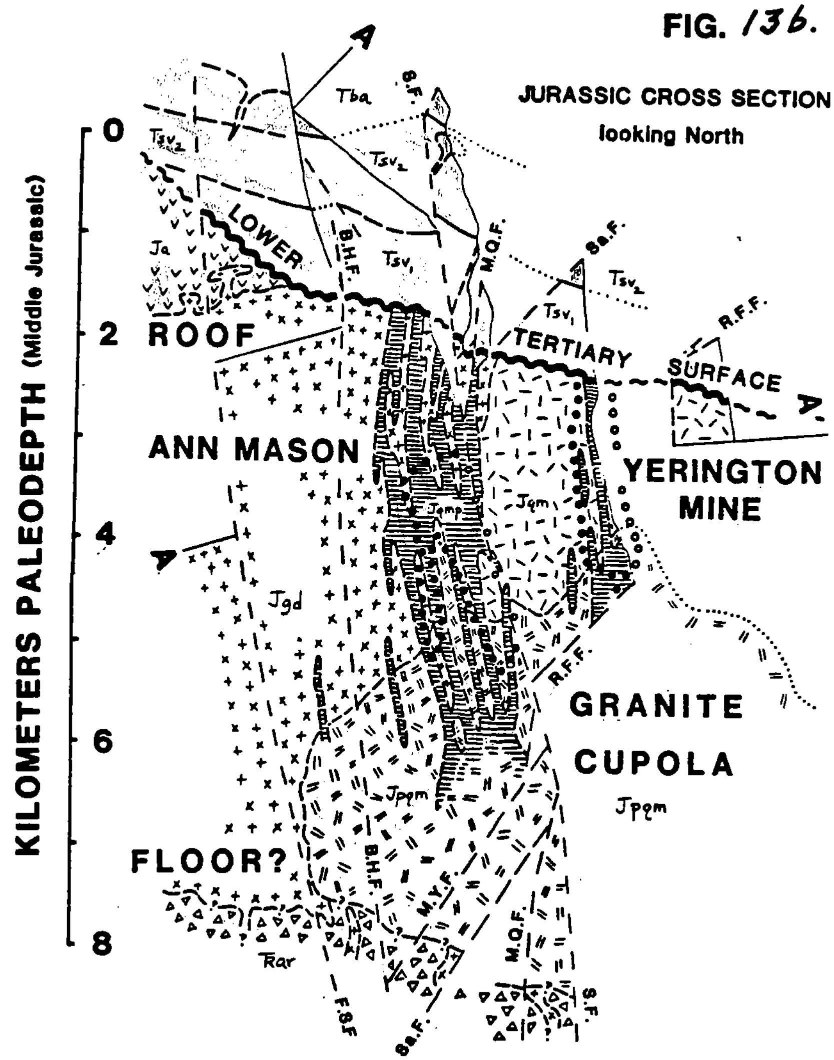
• • • • • • • • • • Approximate limits of +0.2 wt % Cu in porphyry copper deposits. (projected from the subsurface in Ann Mason & Bear deposits)

• Copper prospect in Jgd & Jqm

0 1 2 kilom.

FIG. 13b.

JURASSIC CROSS SECTION
looking North



Quaternary		Qal	Alluvial deposits.
mid-late Tertiary	Late Miocene	Tsb	Sediments & basalt.
	Early Miocene	Tba Tai	Basalt & andesite. Tba mostly andesite flows. Tai andesite plugs, dikes, sills.
	Late Oligocene	Tsv2	Silicic volcanics. Mostly dacitic to rhyolitic ash-flow tuff & breccia. Includes Singatse Tuff.
		Tsv1	Silicic volcanics. Quartz latite to rhyolite ash-flow tuff. Includes Mickey Pass Tuff.

Lower Tertiary unconformity

Shamrock batholith		
Middle Jurassic	Jqms	Quartz monzonite. Bio-hbl, seriate.
Yerington batholith		
	Jqmp	Quartz monzonite (IUGS granite) porphyry dikes. Hornblende-biotite, aplitic groundmass.
	Jpqm	Porphyritic quartz monzonite (IUGS granite) stock, deep cupola. Hornblende-biotite.
	Jqm	Quartz monzonite (IUGS quartz monzonite) stock, core of batholith. Bio-hbl, seriate.
	Ja	Andesite flows, breccia, conglomerate. Extrusive equivalent of Jgd.
	Jgd	Granodiorite (IUGS quartz monzodiorite) margin of batholith. Biotite-hornblende, seriate.
Early Jurassic	JЋvs	Volcanics & sediments. Limestone, calc shale, felsic volcaniclastics. Gypsum, sandstone top of section.
Late Triassic	Ћar	Andesite & rhyolite. Flows, breccia, sediment.

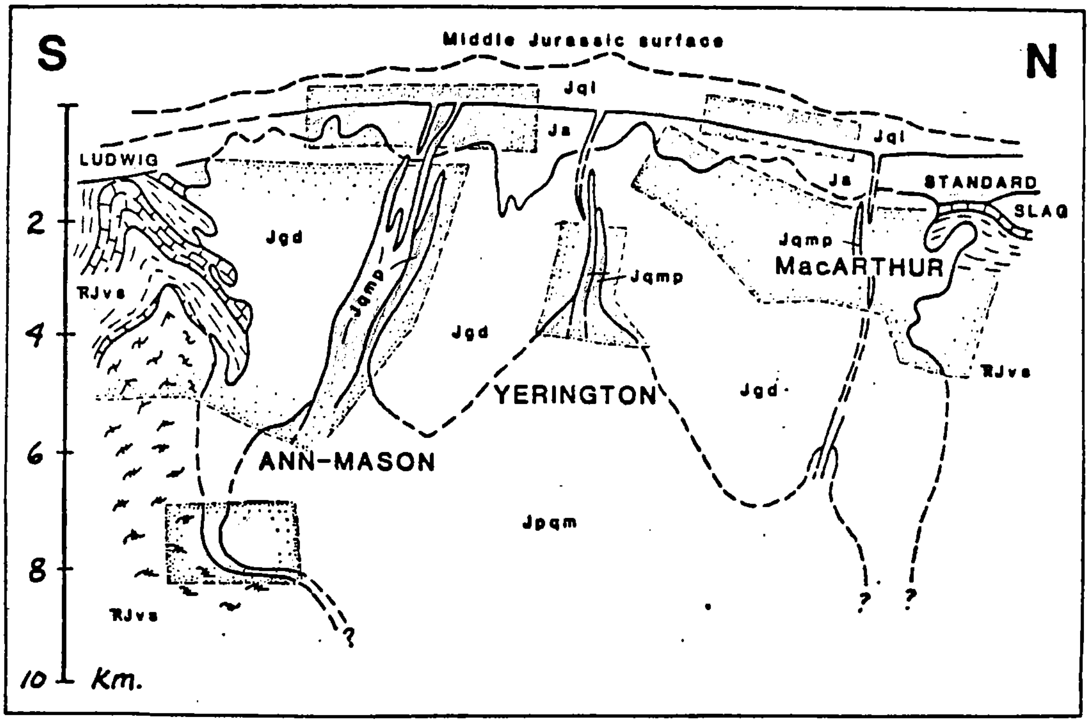


Fig. 14. SPATIAL RELATION OF PORPHYRY COPPER DEPOSITS AND EXTENT OF PALEOVERTICAL EXPOSURE OF JURASSIC AGE, YERINGTON DISTRICT, NEVADA. Schematic vertical north-south cross section through the Yerington district in Middle Jurassic time, illustrating the extent of paleovertical exposure that can be studied from present day surface exposures and drill core (stippled areas). As a consequence of westward rotation during the Cretaceous and during extensional faulting from 18 Ma to the present, Jurassic and older rocks are tilted 90° to the west (Proffett, 1977; Geissman et al., 1982). Therefore, present plan views are Jurassic age cross sections with "up" to the west (Proffett, 1977; Geissman et al., 1982). The Yerington batholith intruded a sequence of marine volcanic and sedimentary rocks of Late Triassic to Early Jurassic age (TrJvs) and its cogenetic andesitic to dacitic volcanic cover rocks (Ja and Jql) (Proffett and Dilles, 1984a). The bulk of the batholith above 5 km depth is composed of medium-grained equigranular granodiorite and younger equigranular quartz monzonite (Jgd); these rocks were intruded by an irregular mass of porphyritic quartz monzonite (Jpqm) to within 3 km of the volcanic surface, forming three prominent cupolas. The quartz monzonite porphyry dike swarms (Jqmp) emanated from the cupolas and are spatially related to porphyry copper deposits (Ann-Mason, Yerington, and MacArthur). Cu and Fe skarn and replacement deposits formed in carbonate wall rocks (Ludwig and Standard Slag) during the hydrothermal activity associated with emplacement of the Jpqm magma (Harris and Einaudi, 1982).

Geology of the Yerington Porphyry Cu Deposit

The field and compilation methods employed to date at Yerington are described in this section in order to illustrate the level of detailed observation and recording of data that form the basis for many of the figures presented and the conclusions related thereto.

Yerington Field Studies

Field studies in the Yerington mine were conducted by the geologic staff of The Anaconda Company during the period 1967-1972 (Einaudi et al., in prep.), and additional work was conducted in 1979-1980 (Carten, 1981). Field studies in the district and at the Ann-Mason porphyry Cu deposit were conducted by the geologic staff of The Anaconda Company mainly during the period 1966-1969, and additional topical studies were pursued in 1977-1981 (Proffett and Proffett, 1976; Proffett, 1977; Einaudi, 1977a; Geissman et al., 1982; Harris and Einaudi, 1982; Dilles, 1983; Proffett and Dilles, 1984).

The northern Singatse Range, which encompasses the majority of the Yerington district, was mapped at 1:12,000 and 1:4800 scale for rock type, structure, alteration, and sulfide-limonite associations. In addition, several tens of thousands of feet of drill core in the Ann-Mason deposit and in other district prospects yielded information on subsurface geology and structure. Compilation and synthesis of these data resulted in the detailed understanding of district geology that we have today (Proffett, 1977; Proffett and Dilles, 1984). Of fundamental importance is the fact that the Yerington district underwent approximately 100% extension during rotational faulting on listric normal faults during the Cenozoic. The westward tilting that resulted is extreme--an average of 70° of tilt is recorded by all rocks older than 35 Ma, including the porphyry Cu deposits of Jurassic age. An additional 20 deg of westward tilt during the Cretaceous (Geissman et al., 1982) results in a present-day surface exposure that represents a Jurassic age cross section through the crust at depths ranging from the volcanic surface to batholithic depths of up to 8 km (see Fig. 3). We know of no other paleovertical exposures of this magnitude in any other hydrothermal system.

A detailed study of the geology of the Yerington mine was initiated in 1967 by the Anaconda Company for the purposes of generating a description and an understanding of the deposit that could be applied in porphyry copper exploration in the district and elsewhere. A staff of 2 to 3 geologists worked on this research project full-time for a period of 6 years. Emphasis was placed on following shovel advances through hypogene sulfide ore zones, in order to gather data on hypogene mineralogy, and on relogging the 260,000 feet of drill core available in the mine and its immediate periphery. Pit mapping was conducted at 1:600 scale, and the results were posted and interpreted at 1:600 scale (see Fig. 4). Approximately 10 level maps, spaced at vertical intervals of 25 feet, were completed for various portions of the deposit between 3975 and 4300 feet elevation; selected portions of these level maps were used to compile the composite plan view (Jurassic cross section) of the Yerington mine presented in Figure 6. Core logging was conducted at 1:240 scale, summarized on strip logs at 1:1200 scale, and posted and interpreted on cross sections at 1:1200 scale. Fifty north-south cross sections were completed at intervals of 100 feet from the east end to the west end of the deposit. One centrally located cross section was chosen to be drilled out to the limits of alteration, 2000 feet below the bottom of the pit (Fig. 7).

Core logging and pit mapping techniques were similar; here we will describe the pit mapping method, which was a modified version of mapping methods developed by Anaconda geologists at Butte, Montana, and later at El Salvador, Chile. The key element of the mapping involved hand lens identification of minerals present in each of the magmatic mineral sites of the original igneous rock (as opposed to mapping "phyllic" or "potassic" alteration); a total of 13 alteration types were later defined on the basis of key minerals present as compilation of results progressed. The following items were recorded on a continuous basis by color-coded symbols and written notes:

1) strike and dip of faults, contacts, veins, and veinlet sets.

2) age relations between different faults, vein and veinlet types, and igneous intrusions.

3) percent groundmass and texture and grain size of groundmass in porphyries, percent mafic minerals.

4) classification of veins into 4 categories resulted from descriptions of vein and veinlet mineralogy, texture, thickness, continuity, and alteration halos. During mapping, veins and veinlets were identified as belonging to one of the categories and for each category the following was recorded: strike and dip of veins (each vein plotted on field sheet), strike and dip of veinlets and veinlet sets, average width and spacing (yielding density of different vein types), mineralogy of vein and of alteration halo if present, and relative ages. Particular care was placed on noting which vein types were cut at intrusive contacts.

5) percent sulfide, percent magnetite, sulfide ratios, and mode of occurrence (in veinlets or "disseminated").

6) for hornblende sites, continuous color-coded key for fresh hornblende, chloritized hornblende, biotitized hornblende, chloritized biotitized hornblende, or pale green (chloritized-sericitized) to tan (sericitized) hornblende sites.

7) for feldspar sites, continuous color-coded key for: hard, glassy, dark gray to purple (fresh); hard, porcelaneous white, cleavage preserved (secondary oligoclase-albite), hard, lavender, cleavage preserved (secondary orthoclase) hard, cloudy-dull, cleavage preserved (weak sericitization); moderately hard, white, cleavage preserved (moderate sericitization); soft, white to gray, cleavage destroyed (totally sericitized).

These data were then posted on mylar sheets for each level. Each level was represented by 4 separate sheets: rock type and structure, alteration, sulfide associations, and blast hole copper assays. These posting sheets served as the data base for generating interpreted maps, such as those illustrated in Figure 4.

The Yerington mine was shut down in June, 1978, and presently is inaccessible. However, we have access to all the maps, cross sections, and progress reports that date from the 1967-1972 period, and to all of the assay data from drill core, rotary holes, and some blast holes. These data presently are in the files of the Anaconda Minerals Company in Reno, Nevada. We also have access to drill core and samples collected during mapping, which are stored near the mine site. The Yerington portion of the proposed research is focussed on petrological and analytical study of samples that can be acquired with little or no more field mapping.

Fig. 15. MAPS SHOWING THE GEOLOGY, ALTERATION, SULFIDE ASSEMBLAGES AND COPPER GRADE FOR A SMALL AREA IN THE CENTRAL PORTION OF THE YERINGTON MINE, 4050 L. Based on mapping by M. T. Einaudi, J. M. Proffett, W. W. Atkinson, Jr., and others, 1970, at the scale 1 in = 50 ft; compiled by M. T. Einaudi, 1970, at the scale 1 in = 50 ft. Plan maps, with north to the right, are pre-tilt Jurassic age cross sections when viewed from east to west.

a. *Rock types and structure base map:* Shows the location of the shovel advances mapped. Quartz monzonite porphyry dike swarm invaded granodiorite (GRD) wall rocks. Porphyry dikes identified from oldest (QMP-1) to youngest (QMP-3) on the basis of crosscutting relations. Fine-grained, chilled porphyries (QMP-C) are mostly of QMP-1 age.

b. *Alteration map:* Shows the succession of hydrothermal alteration styles as a function of repeated intrusion of magma. The earliest porphyry swarm (QMP-1) is associated with the most intense potassic alteration which declines in intensity with distance from the QMP-1 apex; QMP-2 displays less intense potassic alteration at this structural level and cuts off quartz veinlets with potassic alteration halos related to QMP-1. QMP-2.5 cuts both earlier porphyries and their veinlets; it is weakly altered to a propylitic assemblage. Sericitic alteration did not commence within the structural levels exposed in the mine until after the emplacement of QMP-2.5, a conclusion based on the absence of quartz-sericite-pyrite veinlets cut off by any porphyry older than QMP-3.

Alteration Key:

BIO-KSP: Pervasive alteration of plagioclase to K-feldspar (and local epidote) and of hornblende to shreddy green biotite, accompanied by 1.5 - 3 vol % bornite, 2 - 5 vol % magnetite, and 10 - 25 vol % quartz veinlets. Mineral assemblage: K-feldspar + biotite + bornite + magnetite + quartz. Related to QMP-1 apex.

BIO-(KSP): Pervasive alteration of hornblende to shreddy biotite, and with BIO-KSP alteration restricted to selvages of quartz veinlets.

BIO: Pervasive alteration of hornblende to shreddy biotite associated with 1 - 5 vol % quartz veinlets, 0.5 - 1.5 vol % bornite, 1 - 2 vol % magnetite; local chalcopyrite instead of bornite + magnetite. Represents outer potassic alteration related to both QMP-1 and QMP-2 intrusions.

BIO-(CHL-KSP): Same as BIO-(KSP) except for presence of partly chloritized biotitized hornblende, an enhanced epidote content, and chalcopyrite more abundant than bornite; 1 - 5 vol % quartz veinlets.

CHL: A propylitic alteration type, with minor sericite and clay in plagioclase sites, partly chloritized hornblende (no hydrothermal biotite), traces of disseminated pyrite, and no quartz veinlets. Elsewhere in pit, this alteration overprints fresh QMP-2.5 containing fresh hornblende, fresh feldspars, and traces of disseminated magnetite and chalcopyrite. In QMP-2.5, CHL alteration could predate or be contemporaneous with sericitic alteration in QMP-2.5. In QMP-3, CHL alteration postdates the beginning of sericitic alteration at this structural level. Within this map view, CHL alteration postdates all potassic assemblages.

CHL-(SER): Plagioclase moderately altered to sericite, mafic minerals pervasively chloritized, K-feldspar largely fresh, accompanied by 0.5 - 1 vol % pyrite > chalcopyrite. Generally, CHL-(SER) alteration occurs as an outer fringe on zones of more intense sericitic alteration.

SER-(CHL): Majority of feldspars altered to sericite (minor relic K-feldspar), mafic minerals totally replaced by chlorite + sericite, and opaque mineral assemblage dependent on quantity and character of precursor opaque minerals (magnetite + chalcopyrite in areas of precursor bornite + magnetite; pyrite + chalcopyrite in areas of precursor minor chalcopyrite or magnetite + chalcopyrite); averages 1 - 5 vol % pyrite > chalcopyrite in QMP-2.5, and 1 - 2 vol % chalcopyrite in areas affected by potassic alteration around QMP-1 and QMP-2. Rock texture is preserved. Equivalent in age to QTZ-SER alteration.

QTZ-SER: Original rock converted to quartz + sericite + rutile + pyrite > chalcopyrite; rock texture destroyed. Shown as black areas on Figure C-1b. Open circles within black areas of Figure C-1b denote relics of precursor BIO-KSP alteration. Centered on swarms of pyrite-(quartz) veins, and as isolated, 1 - 5 cm wide selvages on pyrite veins. In the area of Figure C-1b, QTZ-SER alteration is structurally controlled along the contact of QMP-2.5 and the QMP-1,2 zone.

c. *Sulfide assemblages:* Illustrates the evolution of sulfide assemblages as a function of successive intrusions and of hydrothermal alteration. Comparison with Figure C-1b (alteration map) shows that low sulfur sulfides (bornite-chalcocite, and bornite) are associated with potassic alteration, whereas high sulfur sulfides (chalcopyrite-pyrite, and pyrite) are associated with sericitic alteration. In general, hydrothermal magnetite accompanies the low-sulfur sulfide assemblages, disappearing at the point where chalcopyrite becomes the dominant Cu-Fe-sulfide. Boundaries between sulfide zones are generally gradational in the potassic zone related to QMP-1,2; however, boundaries between the cp, cp-(bn) zones related to QMP-1,2 and the py zone related to QMP-2.5 are abrupt and also marked by a decrease in total sulfide content of from 1-2 vol % to less than 0.5 vol %.

d. *Copper grade distribution map:* This map is based on a geologic interpretation of blast hole assays. The high grade zone (>0.8% Cu) correlates with potassic alteration and bornite-magnetite mineralization related to the QMP-1 apex. The low grade zone (<0.1 % Cu) corresponds to the late porphyries, QMP-2.5 and QMP-3. Grades of 0.2 - 0.8% Cu occur in these late barren porphyries only in areas of quartz-sericite alteration.

Fig. 15a.

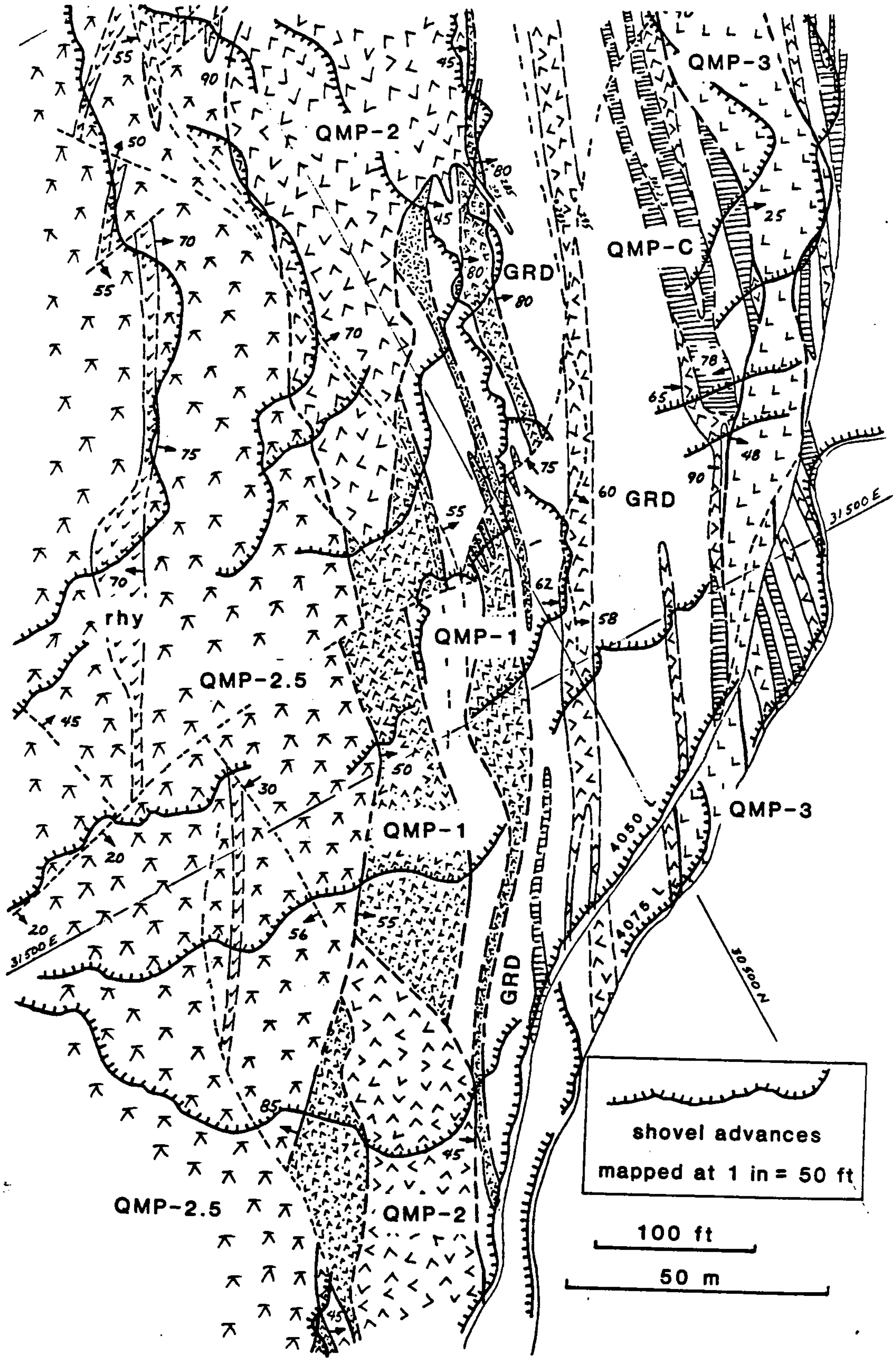

QMP-2
QMP-3
QMP-C
GRD
GRD
rhy
QMP-1
QMP-2.5
QMP-1
QMP-3
GRD
QMP-2.5
QMP-2
31500 E
31500 E
4050
4075
30500 N
shovel advances
mapped at 1 in = 50 ft
100 ft
50 m

Fig. 15b.

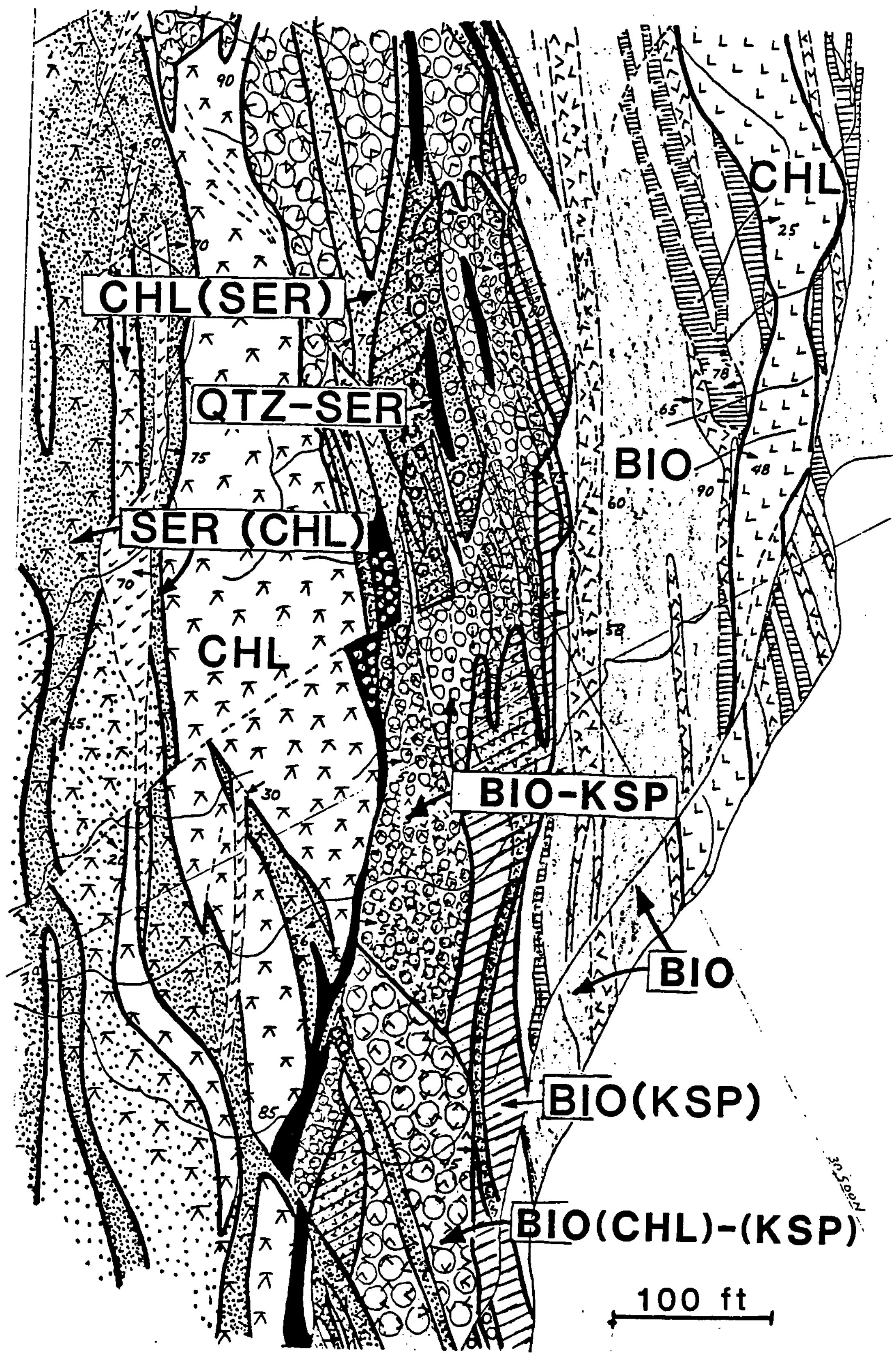

CHL(SER)
QTZ-SER
SER (CHL)
CHL
CHL
BIO
BIO-KSP
BIO
BIO(KSP)
BIO(CHL)-(KSP)
100 ft

Fig. 15c.

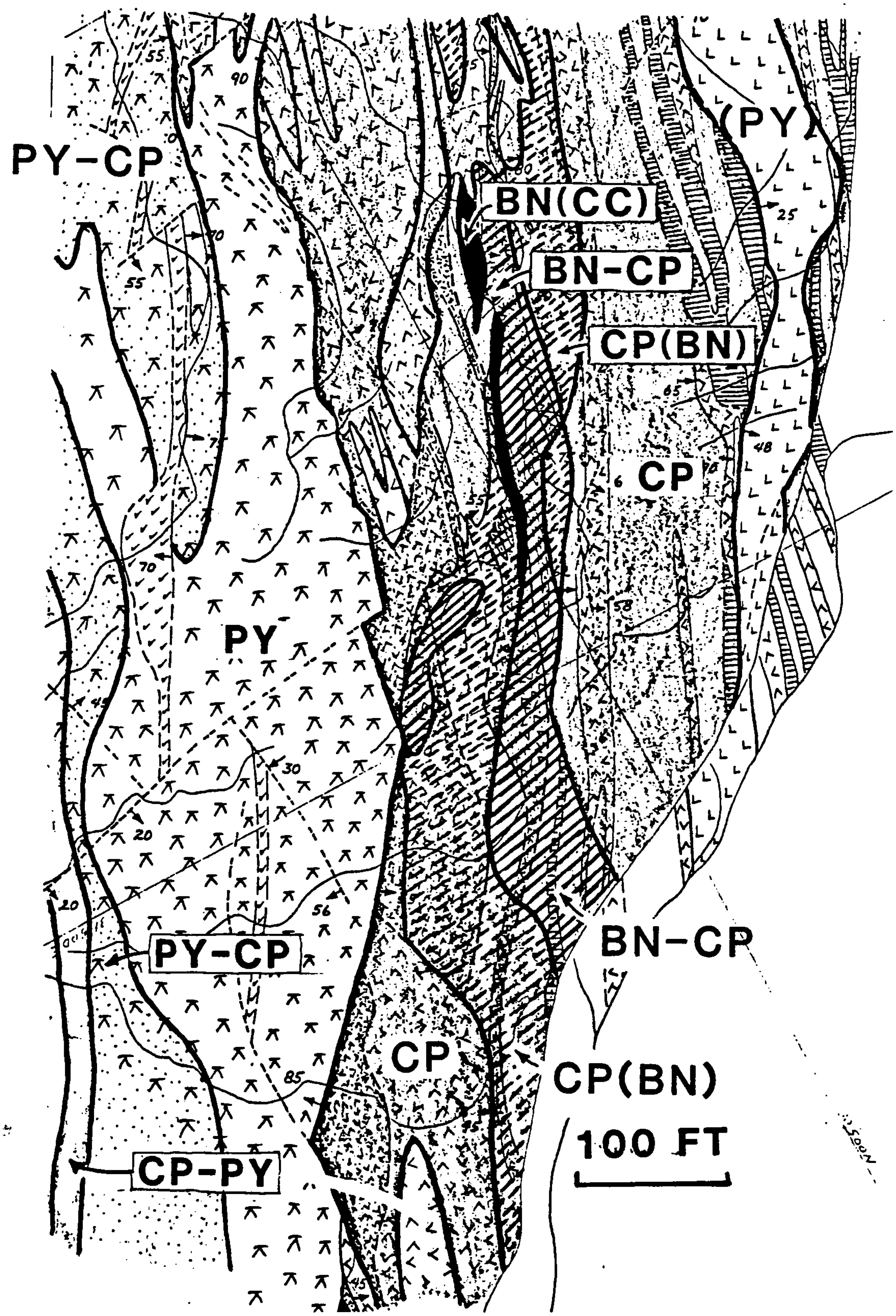


Fig. 15d.

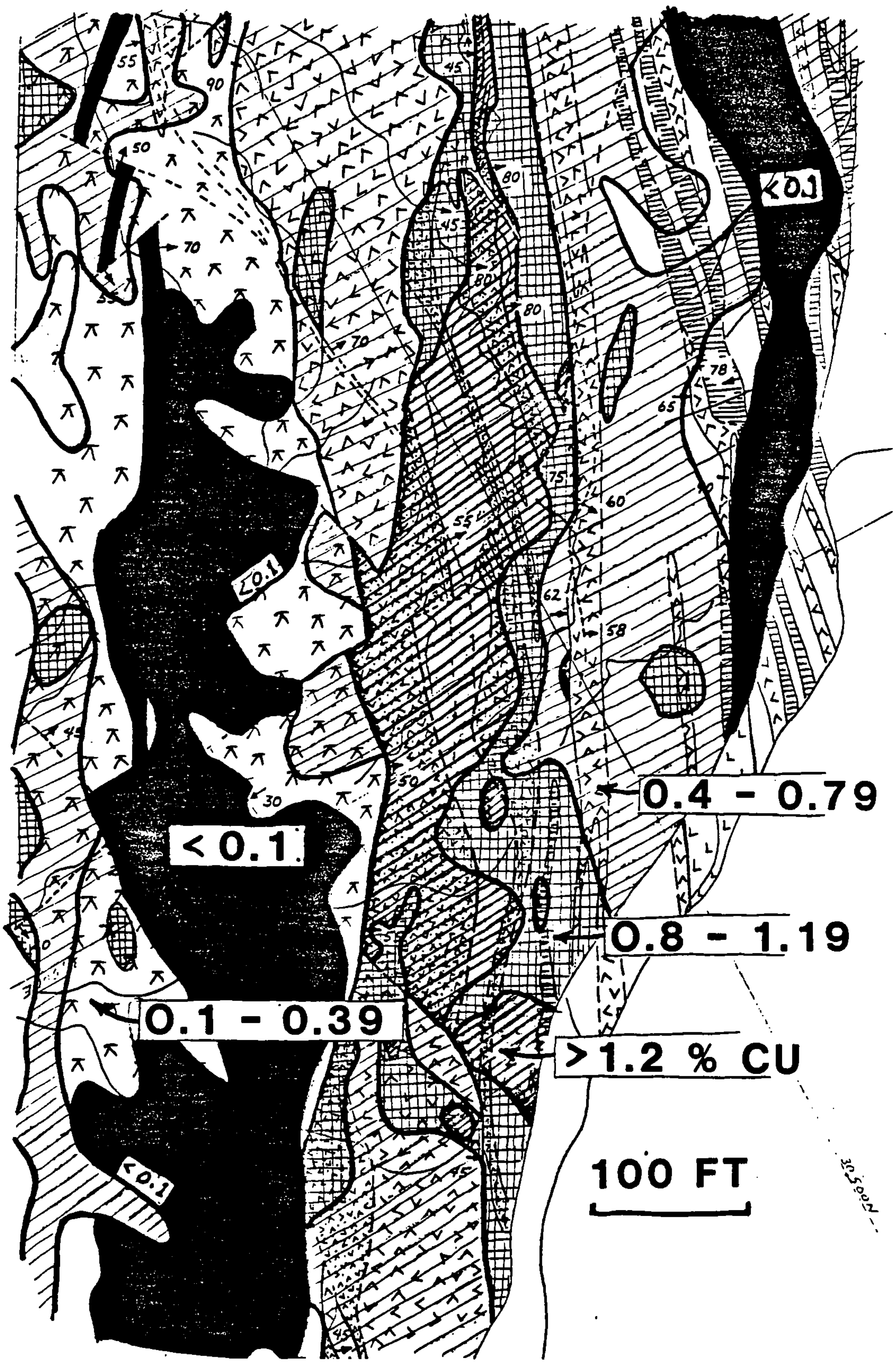


Fig. 16. PLAN MAPS (JURASSIC AGE CROSS SECTIONS) OF THE YERINGTON PORPHYRY COPPER DEPOSIT, NEVADA. Based on mapping by M. T. Einaudi, J. M. Proffett, D. L. Gustafson, G. H. Ware, and others, 1967 - 1972, and by Carten (1981), at the scale 1 in = 50 ft; compiled by M. T. Einaudi, 1975-1976 and 1981-1982, at the scale 1 in = 100 ft. When viewed from east to west, these plan maps represent pre-tilt Jurassic age cross sections that illustrate geologic relations over 2 km of paleovertical exposure (Fig. 3).

a. *Rock types and structure:* This Jurassic age cross section illustrates the porphyry dike swarm (QMP) emanating from, and breaching, a cupola of porphyritic quartz monzonite (PQM) at depth. In black is the earliest recognized intrusion in the central portion of the pit (QMP-1, see Fig. 4). The apex of QMP-1 is well-defined by mapping on several levels and by core drilling--this intrusion did not vent to the surface, but created a major high grade ore zone (see Fig. 5). At depth, QMP-1 merges with, or is cut off by, the major North dike intrusion (QMP-n), which grades at depth into PQM. The PQM cupola is breached by the QMP-2 dike swarm, which cuts QMP-1 in the central portion of the pit and extends to the lower Tertiary erosion surface. QMP-1, along with QMP-2, are thought to have introduced all of the copper into the Yerington system. These intrusions are cut by QMP-2.5, which was emplaced as a plug-shaped mass whose upper contact is marked by a zone of crenulate pegmatite (quartz + magnetite) 10 to 20 cm thick. The last intrusion was a single dike, QMP-3; it extends to the lower Tertiary surface and may have vented at the Jurassic surface.

b. *Alteration:* Illustrates the multiple overlap of alteration in space and time. The key patterns are an early (QMP-1 age) and middle (QMP-2 age) stage of potassic alteration (K1 and K2, respectively) near the apices of dike swarms, and of linked sodic-calcic alteration (A; A1 and A2 not distinguished on this map) at depth in the region of the PQM cupola. Potassic alteration has been described in the caption of Figure 4. Sodic-calcic alteration consists of oligoclase-quartz-sphene alteration on the margins of quartz, quartz-epidote, and quartz-oligoclase veins. In the upper portion of the sodic-calcic zones, quartz-tourmaline veins occur with oligoclase-quartz envelopes. Beyond the oligoclase-quartz-sphene assemblage, the rock is altered to quartz-oligoclase-actinolite-(epidote). A late stage of alteration is marked by sericitic alteration that is pervasive in the upper portions of the system and limited to margins of pyritic veins in the central portion and by albite-chlorite alteration at depth. Both of these events are accompanied by tourmaline, and tourmaline-sericite-chlorite-(albite) is a characteristic alteration mineral assemblage in the fringe of the deposit. Both of these late events postdate the emplacement of QMP-2.5, which is the barren plug that cuts high-grade potassic alteration, and both leached Cu-Fe sulfides, magnetite, and Fe-Mg silicates. Quartz-sericite-tourmaline breccia dikes mark the terminal hydrothermal event.

c. *Density of quartz veinlets:* Illustrates the density of quartz veinlets (vol %) associated with potassic alteration. Volume percent was recorded during mapping by estimating, for each set of veinlets over a given length of bench face, the average thickness of, and average spacing between, veinlets. Veinlets are dominantly quartz, but also contain other minerals of the potassic association. "A" veinlets are the earliest in any given cycle of potassic alteration; they are random, discontinuous, less than 1 mm wide, and consist of an aplitic-textured intergrowth ranging from quartz-magnetite-(bornite) to K-feldspar-quartz-biotite-(bornite-magnetite). In areas of low density of A veinlets, the veinlets have distinct K-feldspar-biotite alteration selvages; in areas of high density, the wall rocks are pervasively altered to K-feldspar-(biotite). A-veinlets largely may have formed by replacement. They constitute approximately one-half of the total veinlet volume within the zones of >5 vol % veinlets and are rare outside these zones. "B" veinlets cut and offset A-veinlets of any given cycle; they are through-going on the scale of a hand sample and in some cases on the scale of a bench face, and range from 1 to 3 mm in thickness. B veinlets have straight walls and are filled largely with quartz which displays symmetrical inward growth terminated by a vuggy center line containing disseminated Cu-Fe-sulfides; B veinlets formed by open-space filling. In contrast with A veinlets, B veinlets lack prominant alteration selvages. The outer limit of B veinlets coincides with the outer limit of biotitization at intermediate levels.

d. *Sulfide distribution:* Illustrates the volume percent total sulfides and dominant sulfide assemblages. Minor occurrences of pyritic veinlets cutting bornite or chalcopyrite zones are ignored. Pyrite does not occur in contact with bornite, although rarely they may occur in the same hand sample. The time-space relation is one of outward progression in the early stages of potassic alteration from bornite-chalcocite-magnetite, through bornite-magnetite, to chalcopyrite accompanied by a decrease in sulfide abundance; sodic-calcic alteration is accompanied by no sulfides. Late stages of hydrothermal activity sulfidized previous assemblages and created the pattern of upward increasing total sulfide abundance and pyrite : chalcopyrite ratios.

e. *Copper grade distribution:* Based on geological interpretation of blast hole and diamond drill hole assays, this map illustrates: the close association of the majority of high grade areas with potassic alteration related to the emplacement of QMP-1 and QMP-2; the very low grades of QMP-2.5 except where it is cut by late quartz-sericite-pyrite-chalcopyrite veins in the vicinity of high-grade potassic zones; and the moderate to low grades of sericitic and sodic-calcic alteration.

Fig. 16a.

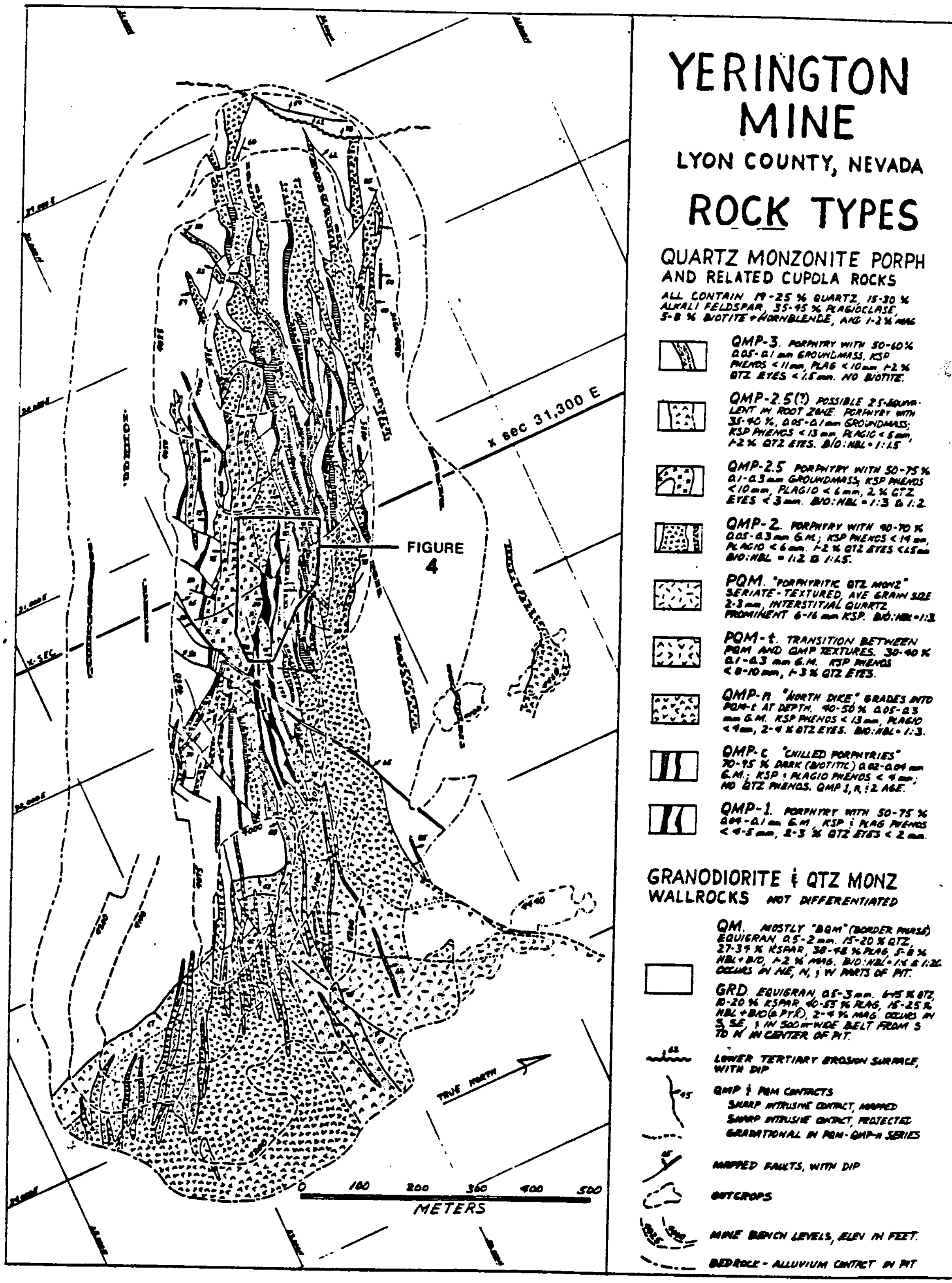

YERINGTON MINE
LYON COUNTY, NEVADA
ROCK TYPES
QUARTZ MONZONITE PORPH AND RELATED CUPOLA ROCKS
ALL CONTAIN 19-25 % QUARTZ, 15-30 % ALKALI FELDSPAR, 35-45 % PLAGIOCLASE, 5-8 % BIOTITE + HORNBLENDE, AND 1-2 % MAG
QMP-3. PORPHYRY WITH 50-60 % 0.05-0.1 mm GROUNDMASS, KSP PHENOS < 11 mm, PLAG < 10 mm, 1-2 % QTZ EYES < 1.5 mm. NO BIOTITE.
QMP-2.5(?) POSSIBLE 2.5-EQUIVALENT IN ROOT ZONE. PORPHYRY WITH 35-40 %, 0.05-0.1 mm GROUNDMASS; KSP PHENOS < 13 mm, PLAGIO < 5 mm, 1-2 % QTZ EYES. BIO:HBL = 1:1.5
QMP-2.5 PORPHYRY WITH 50-75 % 0.1-0.3 mm GROUNDMASS, KSP PHENOS < 10 mm, PLAGIO < 6 mm, 2 % QTZ EYES < 3 mm. BIO:HBL = 1:3 to 1:2
QMP-2. PORPHYRY WITH 40-70 % 0.05-0.3 mm G.M.; KSP PHENOS < 14 mm, PLAGIO < 6 mm, 1-2 % QTZ EYES < 1.5 mm BIO:HBL = 1:2 to 1:1.5.
PQM. "PORPHYRITIC QTZ MONZ" SERIATE-TEXTURED, AVE GRAIN SIZE 2-3 mm, INTERSTITIAL QUARTZ PROMINENT 6-16 mm KSP. BIO:HBL = 1:3
PQM-t. TRANSITION BETWEEN PQM AND QMP TEXTURES. 30-40 % 0.1-0.3 mm G.M. KSP PHENOS < 8-10 mm, 1-3 % QTZ EYES.
QMP-n "NORTH DIKE" GRADES INTO PQM-t AT DEPTH. 40-50 % 0.05-0.3 mm G.M. KSP PHENOS < 13 mm, PLAGIO < 4 mm, 2-4 % QTZ EYES. BIO:HBL = 1:3.
QMP-c "CHILLED PORPHYRIES" 70-95 % DARK (BIOTITIC) 0.02-0.04 mm G.M.; KSP & PLAGIO PHENOS < 4 mm; NO QTZ PHENOS. QMP 1, n, & 2 AGE.
QMP-1. PORPHYRY WITH 50-75 % 0.04-0.1 mm G.M., KSP & PLAG PHENOS < 4-5 mm, 2-3 % QTZ EYES < 2 mm.
GRANODIORITE & QTZ MONZ WALLROCKS NOT DIFFERENTIATED
QM. MOSTLY "BQM" (BORDER PHASE) EQUIGRAN 0.5-2 mm. 15-20 % QTZ, 27-39 % KSPAR, 38-48 % PLAG, 5-8 % HBL + BIO, 1-2 % MAG. BIO:HBL = 1:1 to 1:2. OCCURS IN NE, N, & W PARTS OF PIT.
GRD. EQUIGRAN, 0.5-3 mm. 6-15 % QTZ, 10-20 % KSPAR, 40-55 % PLAG, 15-25 % HBL + BIO (& PYX), 2-4 % MAG. OCCURS IN S, SE, & IN 500 m-WIDE BELT FROM S TO N IN CENTER OF PIT.
LOWER TERTIARY EROSION SURFACE, WITH DIP
QMP & PQM CONTACTS
SHARP INTRUSIVE CONTACT, MAPPED
SHARP INTRUSIVE CONTACT, PROJECTED
GRADATIONAL IN PQM-QMP-n SERIES
MAPPED FAULTS, WITH DIP
OUTCROPS
MINE BENCH LEVELS, ELEV IN FEET.
BEDROCK - ALLUVIUM CONTACT IN PIT
FIGURE 4
x sec 31,300 E
TRUE NORTH
0 100 200 300 400 500
METERS

Fig. 16b.

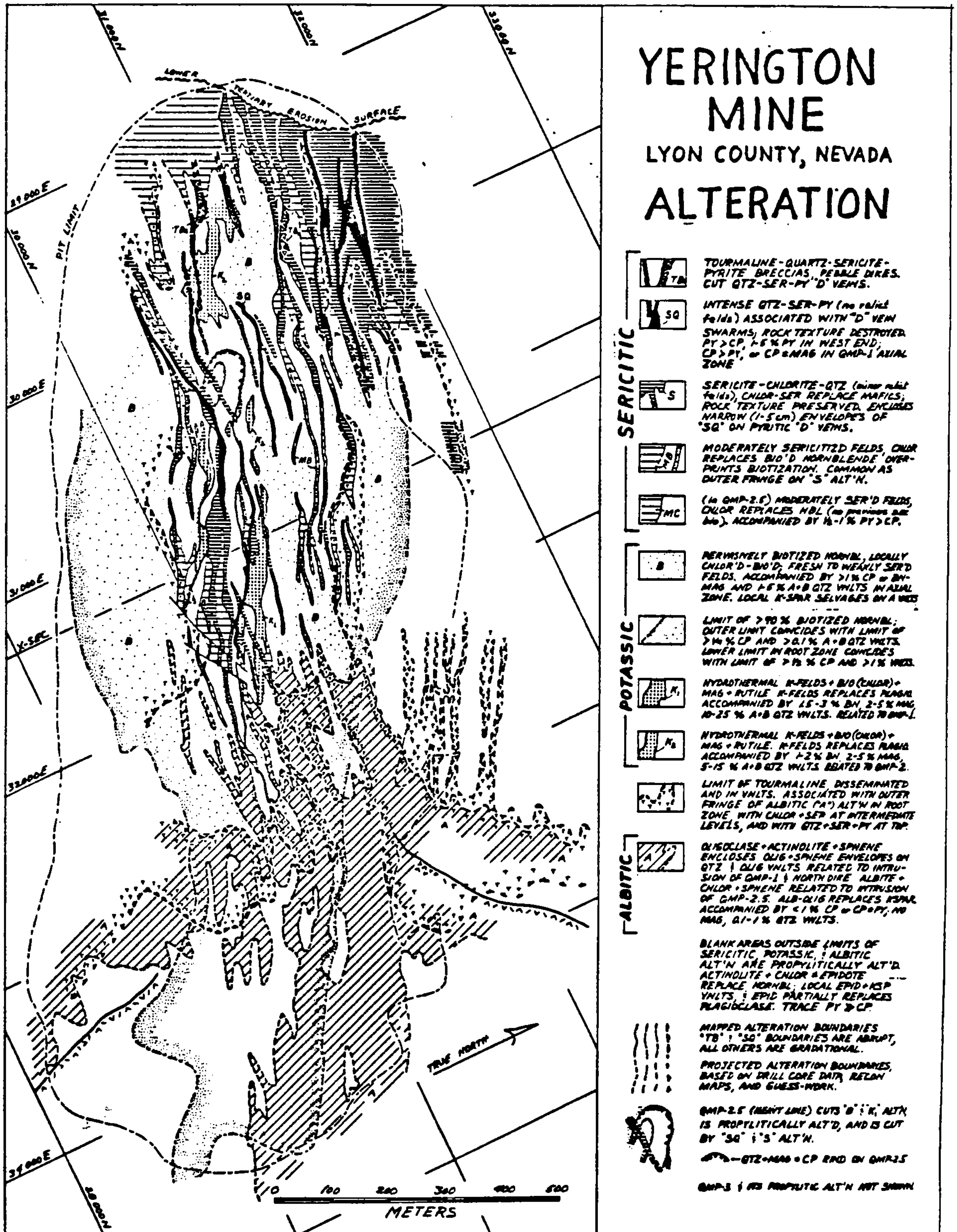

YERINGTON MINE
LYON COUNTY, NEVADA
ALTERATION
SERICITIC
TOURMALINE-QUARTZ-SERICITE-PYRITE BRECCIAS, PEBBLE DIKES. CUT QTZ-SER-PY "D" VEINS.
INTENSE QTZ-SER-PY
ASSOCIATED WITH "D" VEIN SWARMS, ROCK TEXTURE DESTROYED. PY > CP, 1-5 % PY IN WEST END; CP > PY, or CP ≈ MAG IN QMP-1 AXIAL ZONE
SERICITE-CHLORITE-QTZ
CHLOR-SER REPLACE MAFICS; ROCK TEXTURE PRESERVED. ENCLOSES NARROW (1-5 cm) ENVELOPES OF "SQ" ON PYRITIC "D" VEINS.
MODERATELY SERICITIZED FELDS, CHLOR REPLACES BIO'D HORNBLENDE. OVERPRINTS BIOTIZATION. COMMON AS OUTER FRINGE ON "S" ALT'N.
MODERATELY SER'D FELDS, CHLOR REPLACES HBL
ACCOMPANIED BY ½-1 % PY > CP.
POTASSIC
PERVASIVELY BIOTIZED HORNBL, LOCALLY CHLOR'D-BIO'D; FRESH TO WEAKLY SER'D FELDS. ACCOMPANIED BY >1 % CP
AND 1-5 % A+B QTZ VNLTS IN AXIAL ZONE. LOCAL K-SPAR SELVAGES ON A VEINS
LIMIT OF > 90 % BIOTIZED HORNBL; OUTER LIMIT COINCIDES WITH LIMIT OF > ¼ % CP AND > 0.1 % A+B QTZ VNLTS. LOWER LIMIT IN ROOT ZONE COINCIDES WITH LIMIT OF > ½ % CP AND > 1 % VNLTS.
HYDROTHERMAL K-FELDS + BIO (CHLOR) + MAG + RUTILE. K-FELDS REPLACES PLAGIO. ACCOMPANIED BY 1.5-3 % BN, 2-5 % MAG, 10-25 % A+B QTZ VNLTS. RELATED TO QMP-1.
HYDROTHERMAL K-FELDS + BIO (CHLOR) + MAG + RUTILE. K-FELDS REPLACES PLAGIO. ACCOMPANIED BY 1-2 % BN, 2-5 % MAG, 5-15 % A+B QTZ VNLTS. RELATED TO QMP-2.
LIMIT OF TOURMALINE DISSEMINATED AND IN VNLTS. ASSOCIATED WITH OUTER FRINGE OF ALBITIC ("A") ALT'N IN ROOT ZONE, WITH CHLOR + SEP AT INTERMEDIATE LEVELS, AND WITH QTZ + SER + PY AT TOP.
ALBITIC
OLIGOCLASE + ACTINOLITE + SPHENE ENCLOSES OLIG + SPHENE ENVELOPES ON QTZ & OLIG VNLTS RELATED TO INTRUSION OF QMP-1 & NORTH DIKE. ALBITE + CHLOR + SPHENE RELATED TO INTRUSION OF QMP-2.5. ALB-OLIG REPLACES KSPAR. ACCOMPANIED BY < 1 % CP or CP + PY; NO MAG, 0.1-1 % QTZ VNLTS.
BLANK AREAS OUTSIDE LIMITS OF SERICITIC, POTASSIC, & ALBITIC ALT'N ARE PROPYLITICALLY ALT'D. ACTINOLITE + CHLOR + EPIDOTE REPLACE HORNBL; LOCAL EPID + KSP VNLTS, & EPID PARTIALLY REPLACES PLAGIOCLASE. TRACE PY ≫ CP.
MAPPED ALTERATION BOUNDARIES "TB" & "SQ" BOUNDARIES ARE ABRUPT, ALL OTHERS ARE GRADATIONAL.
PROJECTED ALTERATION BOUNDARIES, BASED ON DRILL CORE DATA, RECON MAPS, AND GUESS-WORK.
IS PROPYLITICALLY ALT'D, AND IS CUT BY "SQ" & "S" ALT'N.
— QTZ + MAG + CP RIND ON QMP-2.5
LOWER TERTIARY EROSION SURFACE
PIT LIMIT
TRUE NORTH
29 000 E
30 000 E
31 000 E
32 000 E
34 000 E
X-SEC
28 000 N
30 000 N
31 000 N
32 000 N
33 000 N
0 100 200 300 400 500
METERS

Fig. 16c.

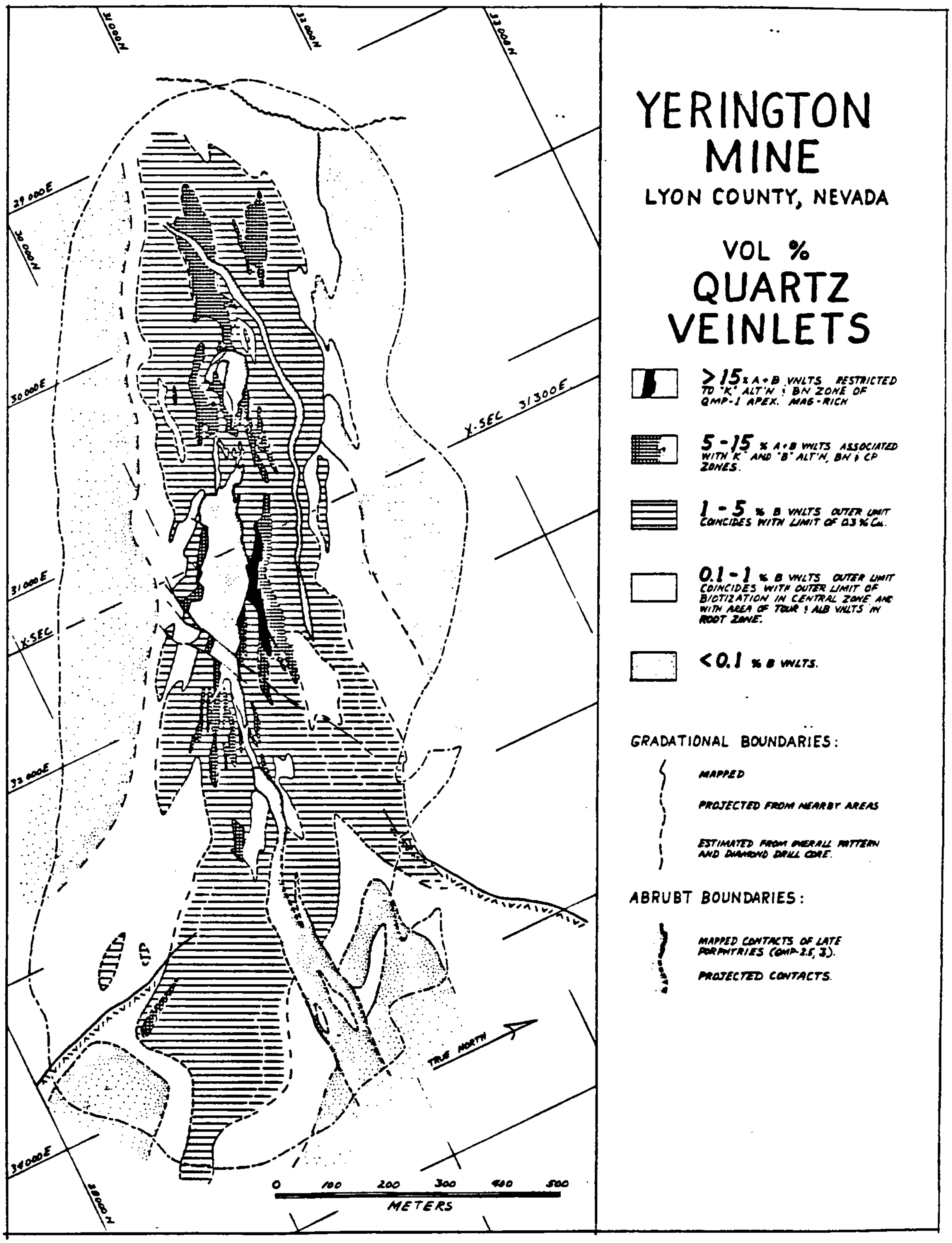
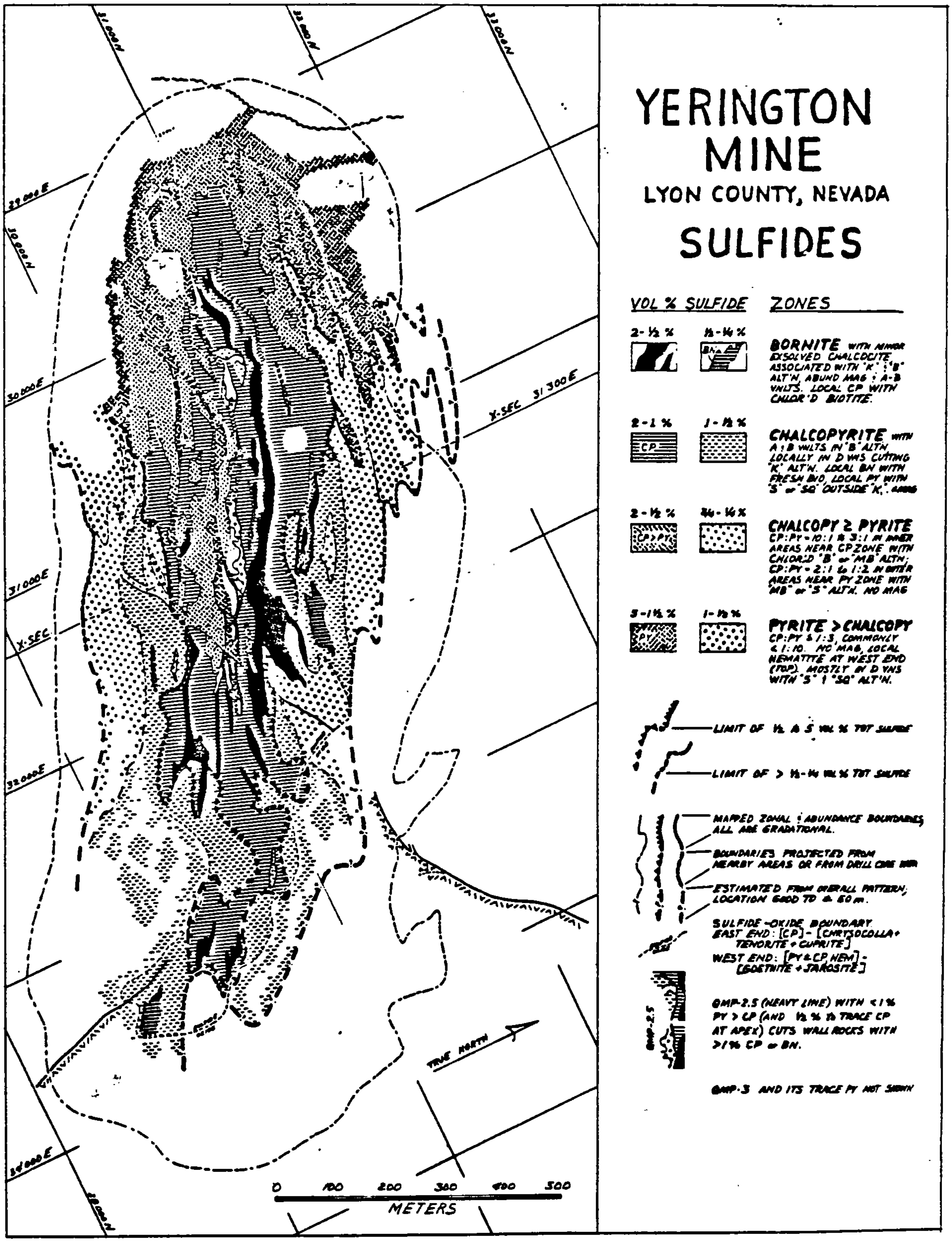

YERINGTON MINE
LYON COUNTY, NEVADA
VOL %
QUARTZ VEINLETS
>15 % A+B VNLTS RESTRICTED TO 'K' ALT'N ; BN ZONE OF QMP-1 APEX. MAG-RICH
5-15 % A+B VNLTS ASSOCIATED WITH 'K' AND 'B' ALT'N, BN ; CP ZONES.
1-5 % B VNLTS OUTER LIMIT COINCIDES WITH LIMIT OF 0.3 % Cu.
0.1-1 % B VNLTS OUTER LIMIT COINCIDES WITH OUTER LIMIT OF BIOTIZATION IN CENTRAL ZONE AND WITH AREA OF TOUR ; ALB VNLTS IN ROOT ZONE.
<0.1 % B VNLTS.
GRADATIONAL BOUNDARIES:
MAPPED
PROJECTED FROM NEARBY AREAS
ESTIMATED FROM OVERALL PATTERN AND DIAMOND DRILL CORE.
ABRUBT BOUNDARIES:
MAPPED CONTACTS OF LATE PORPHYRIES (QMP-2.5, 3).
PROJECTED CONTACTS.
31 000 N
32 000 N
33 000 N
29 000 E
30 000 N
30 000 E
31 000 E
32 000 E
34 000 E
28 000 N
X-SEC
X-SEC 31300E
TRUE NORTH
0
100
200
300
400
500
METERS

Fig. 16d.



YERINGTON MINE
LYON COUNTY, NEVADA
SULFIDES
VOL % SULFIDE
ZONES
2-½ %
½-¼ %
BORNITE WITH MINOR EXSOLVED CHALCOCITE, ASSOCIATED WITH "K" & "B" ALT'N, ABUND MAG & A-B VNLTS. LOCAL CP WITH CHLOR'D BIOTITE.
2-1 %
1-½ %
CP
CHALCOPYRITE WITH A & B VNLTS IN "B" ALTN LOCALLY IN D VNS CUTTING "K" ALT'N. LOCAL BN WITH FRESH BIO, LOCAL PY WITH "S" or "SQ" OUTSIDE "K".
2-½ %
¾-¼ %
CP>PY
CHALCOPY ≥ PYRITE
CP:PY = 10:1 & 3:1 IN INNER AREAS NEAR CP ZONE WITH CHLOR'D "B" or "MB" ALTN; CP:PY = 2:1 to 1:2 IN OUTER AREAS NEAR PY ZONE WITH "MB" or "S" ALT'N. NO MAG
3-1½ %
1-½ %
PY
PYRITE > CHALCOPY
CP:PY ≤ 1:3, COMMONLY < 1:10. NO MAG, LOCAL HEMATITE AT WEST END (TOP). MOSTLY IN D VNS WITH "S" & "SQ" ALT'N.
LIMIT OF ½ & 5 VOL % TOT SULFIDE
LIMIT OF > ½-¼ VOL % TOT SULFIDE
MAPPED ZONAL & ABUNDANCE BOUNDARIES, ALL ARE GRADATIONAL.
BOUNDARIES PROJECTED FROM NEARBY AREAS OR FROM DRILL CORE
ESTIMATED FROM OVERALL PATTERN; LOCATION GOOD TO ± 50 m.
SULFIDE-OXIDE BOUNDARY
EAST END: [CP] - [CHRYSOCOLLA + TENORITE + CUPRITE]
WEST END: [PY & CP HEM] - [GOETHITE + JAROSITE]
GMP-2.5
GMP-2.5 (HEAVY LINE) WITH < 1% PY > CP (AND ½ % to TRACE CP AT APEX) CUTS WALL ROCKS WITH > 1% CP or BN.
GMP-3 AND ITS TRACE PY NOT SHOWN
31 000 N
32 000 N
33 000 N
29 000 E
30 000 N
30 000 E
X-SEC 31 300 E
31 000 E
X-SEC
32 000 E
33 000 E
28 000 N
TRUE NORTH
0 100 200 300 400 500
METERS

Fig. 16e.

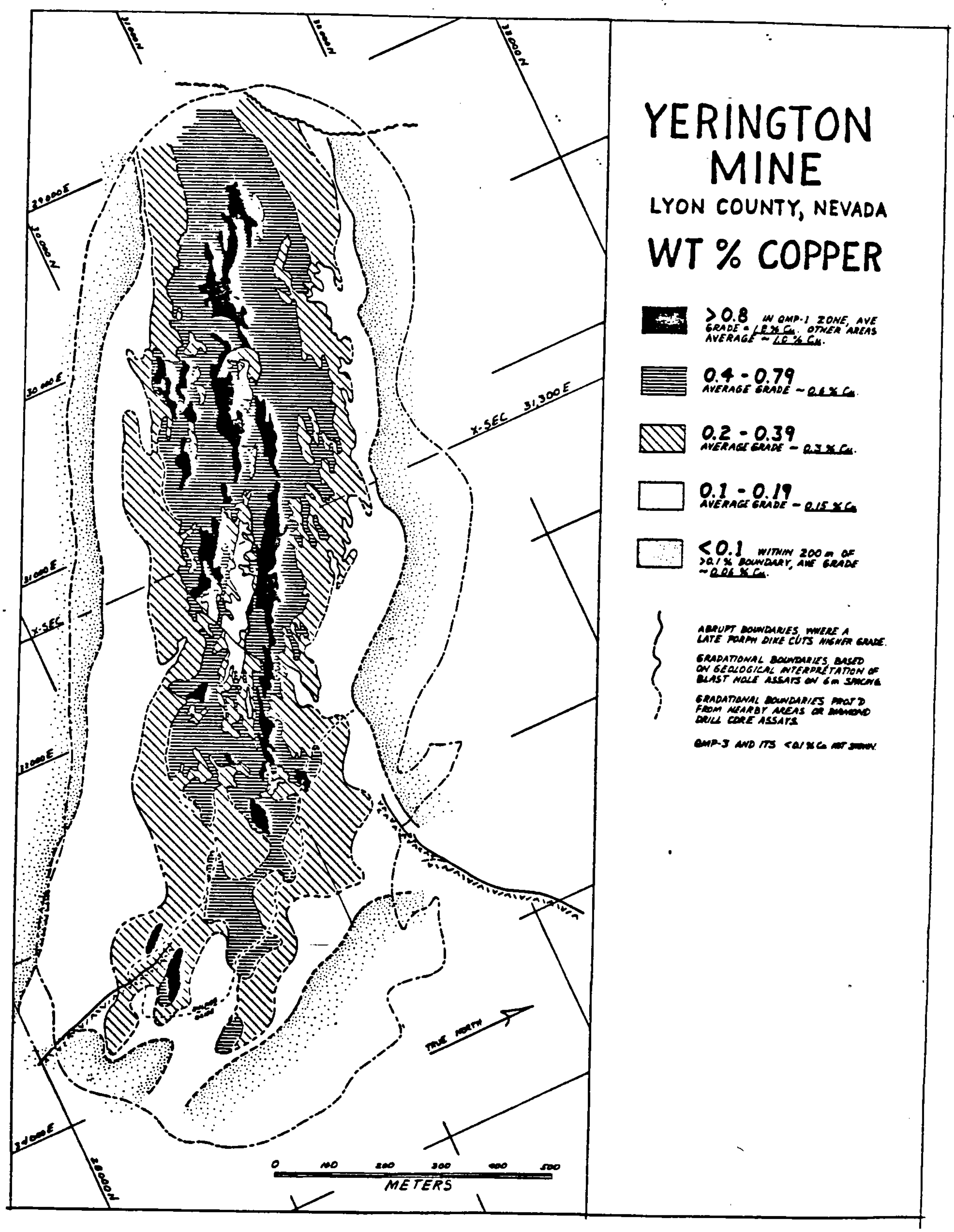

YERINGTON MINE
LYON COUNTY, NEVADA
WT % COPPER
>0.8 IN QMP-1 ZONE, AVE GRADE = 1.8 % Cu. OTHER AREAS AVERAGE ~ 1.0 % Cu.
0.4 - 0.79 AVERAGE GRADE ~ 0.6 % Cu.
0.2 - 0.39 AVERAGE GRADE ~ 0.3 % Cu.
0.1 - 0.19 AVERAGE GRADE ~ 0.15 % Cu
<0.1 WITHIN 200 m OF >0.1 % BOUNDARY, AVE GRADE ~ 0.06 % Cu.
ABRUPT BOUNDARIES, WHERE A LATE PORPH DIKE CUTS HIGHER GRADE.
GRADATIONAL BOUNDARIES, BASED ON GEOLOGICAL INTERPRETATION OF BLAST HOLE ASSAYS ON 6 m SPACING
GRADATIONAL BOUNDARIES PROJ'D FROM NEARBY AREAS OR DIAMOND DRILL CORE ASSAYS
QMP-3 AND ITS <0.1 % Cu NOT SHOWN.
X-SEC 31,300 E
TRUE NORTH
0 100 200 300 400 500
METERS

Fig. 17. CROSS SECTION (JURASSIC AGE PLAN VIEW) OF THE YERINGTON PORPHYRY COPPER DEPOSIT, NEVADA. Based on drill core logging by M. T. Einaudi, 1969-1970. See keys and captions of Figure 6 for explanation of symbols and discussion. Features brought out by this Jurassic age plan view (with Jurassic "north" to the left) include:

a. *Rock type:* The Yerington porphyry intrusive complex is a dike swarm that was emplaced along a prominent WNW-ESE structural grain; coalesced multiple intrusions form a central mass that is about 400 m thick and elongate in the WNW direction. Individual dikes, most commonly 10 to 25 m thick and separated by granodiorite and quartz monzonite wall rock, extend beyond the central porphyry knot for distances of up to 1 km in the WNW direction. The original ESE side of the intrusive complex has been removed by erosion, but is presumed to have been symmetrical with the WNW side. A progressive change in strike of dikes as a function of age reflects changing regional stress patterns: N 70 W for QMP-1 and QMP-n; N 60 W for QMP-2, N 35 W for QMP-3; and N 30 E for andesite and rhyolite dikes that postdate hydrothermal activity.

b. *Alteration:* Potassic and sericitic are the main alteration types at this structural level. The distinct age difference of these two alteration types is revealed not only by the observed age relations at any given locality, but also by the overall map pattern which shows that potassic alteration is elongate in the N 70-60 W direction in concert with structural controls operating during QMP-1 and QMP-2 time, whereas sericitic alteration is controlled by N 30 W structures characteristic of QMP-3 time.

c. *Sulfides:* In Jurassic age plan view at this structural level, the highest total sulfide content occurs in the core of the pattern. The zone containing >0.5 vol % sulfides is 600 m wide at right angles to the strike of the porphyry dikes and may have been 1 km in length along the strike.

d. *Copper and molybdenum distribution:* The highest grades of Cu and of Mo are distinctly separated in space. The highest grade of Cu occurs in the core of the pattern associated with potassic alteration; the highest grade of Mo (within the zone of +0.001% Mo, the average grade is 0.0018% Mo) is peripheral to Cu along the strike of the dike swarm and is located in the transition from chalcopyrite to chalcopyrite-pyrite assemblages. The relative ages of molybdenite and chalcopyrite-pyrite and the mineralogical associations of molybdenum mineralization have not been documented. See Figure 15 for comparison of zonal relations of Cu and Mo between Yerington and other porphyry copper deposits.

Fig. 17a.

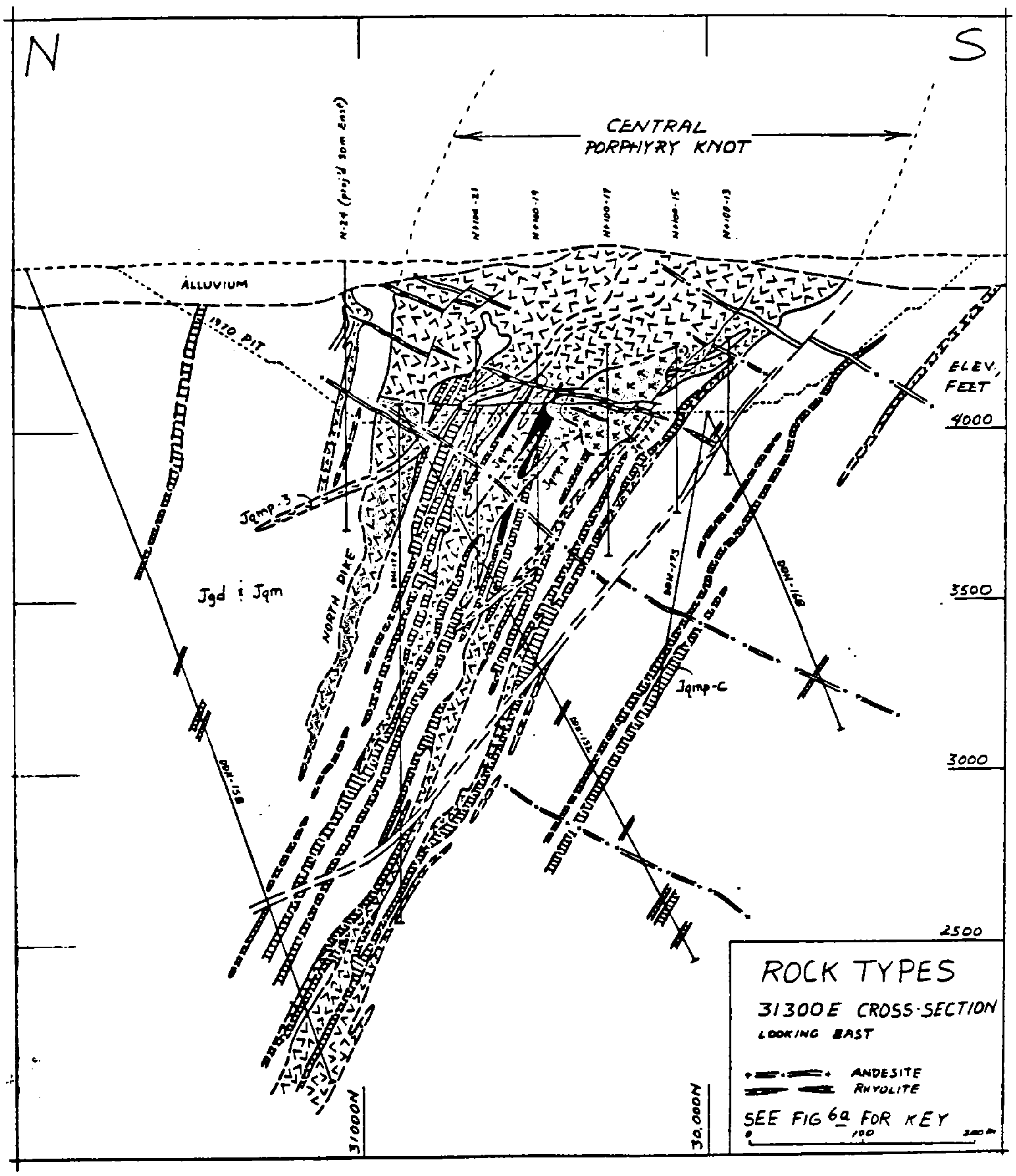
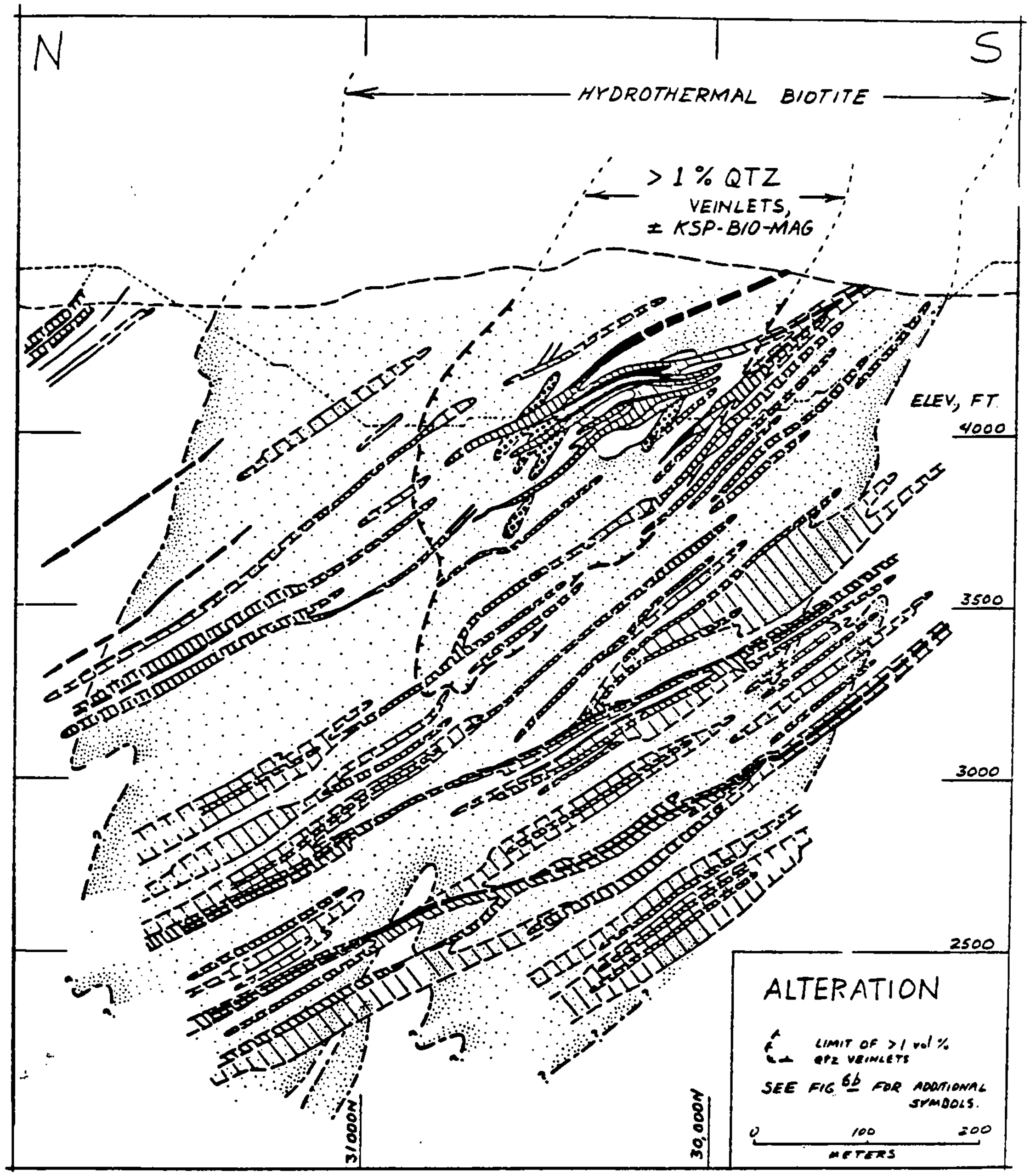
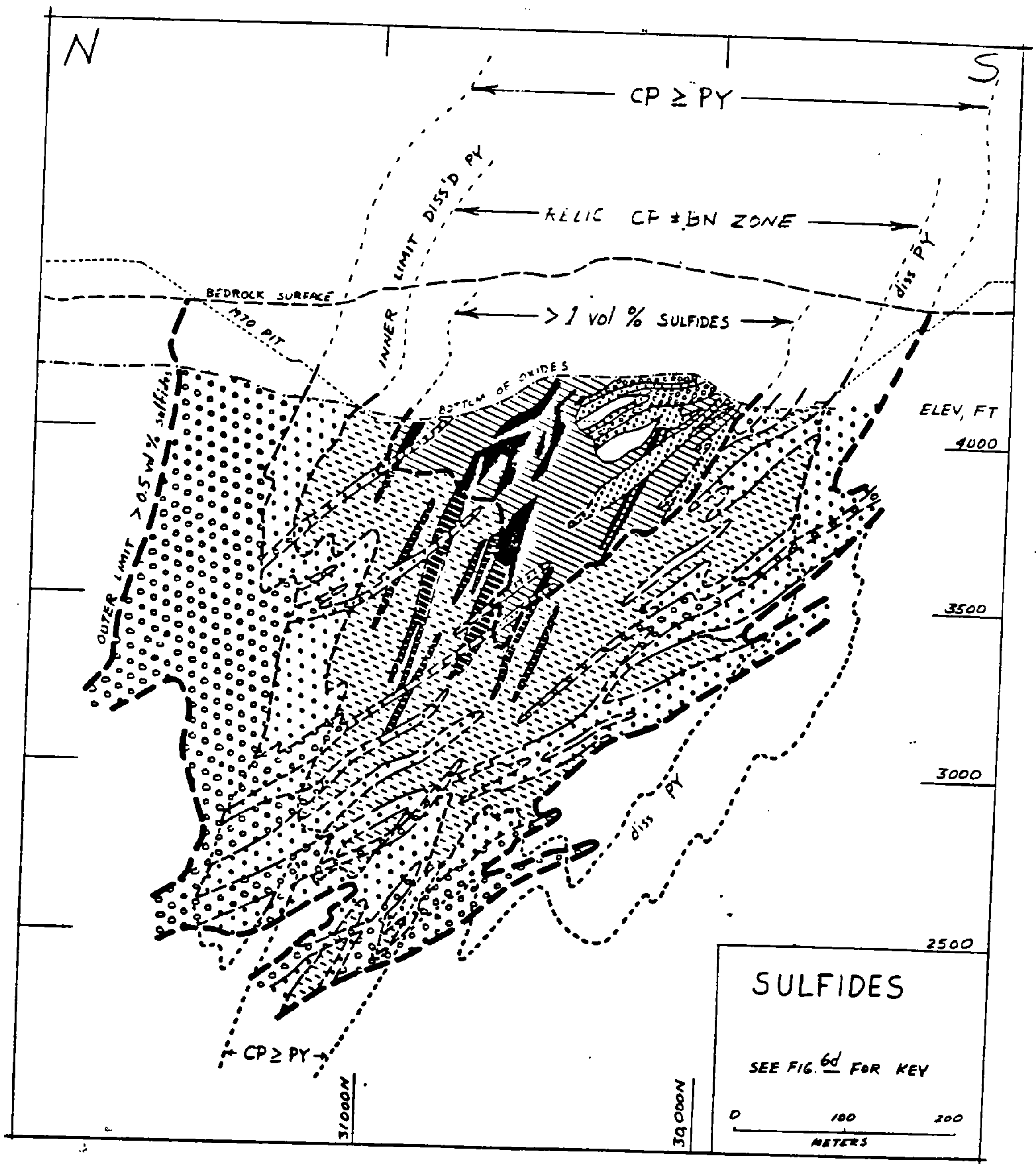

N
S
CENTRAL
PORPHYRY KNOT
ALLUVIUM
1970 PIT
ELEV. FEET
4000
3500
3000
2500
Jqmp-3
Jgd & Jqm
NORTH DIKE
Jqmp-C
31000N
30,000N
ROCK TYPES
31300E CROSS-SECTION
LOOKING EAST
ANDESITE
RHYOLITE
SEE FIG 6a FOR KEY

Fig. 17b.


N
S
HYDROTHERMAL BIOTITE
> 1 % QTZ
VEINLETS,
± KSP-BIO-MAG
ELEV, FT
4000
3500
3000
2500
31,000N
30,000N
ALTERATION
LIMIT OF >1 vol %
QTZ VEINLETS
SEE FIG 6b FOR ADDITIONAL
SYMBOLS.
0
100
200
METERS

2

Fig. 17c.



N
S
CP ≥ PY
INNER LIMIT DISS'D PY
RELIC CP ± BN ZONE
diss PY
BEDROCK SURFACE
1970 PIT
> 1 vol % SULFIDES
BOTTOM OF OXIDES
ELEV, FT
4000
3500
3000
2500
OUTER LIMIT > 0.5 vol % sulfides
diss PY
CP ≥ PY
31000N
30,000N
SULFIDES
SEE FIG. 6d FOR KEY
0
100
200
METERS

Fig. 17d.

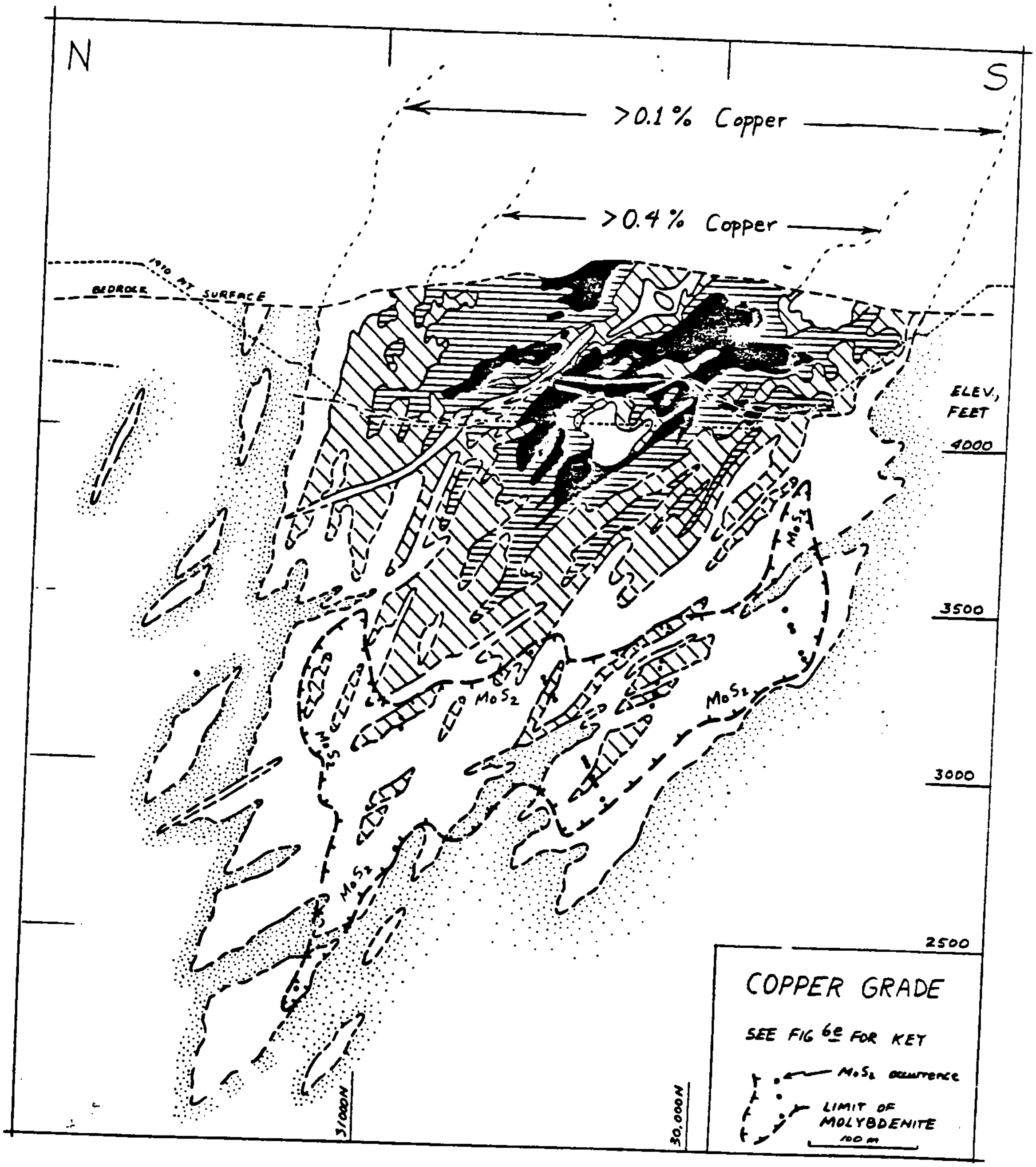

N
S
>0.1 % Copper
>0.4 % Copper
BEDROCK
1910 PIT SURFACE
ELEV, FEET
4000
3500
3000
2500
MoS2
31000N
30,000N
COPPER GRADE
SEE FIG 6e FOR KEY
MoS2 occurrence
LIMIT OF MOLYBDENITE
100 m

Fig. 18. RECONSTRUCTION OF THE SEQUENCE OF INTRUSIONS AND ACCOMPANYING ALTERATION-MINERALIZATION, YERINGTON, NEVADA. Based on Figure 6, these time frames are constructed on the basis of documented age relations at each point in the pit combined with the time lines provided by individual porphyry intrusions. To the extent that age relations and time lines have been correctly interpreted, these time frames are not speculative and cover only the area of mapped exposures. These figures are presented as the data base for Figure 9, and a general discussion of the space-time sequence of events is presented in the caption to that figure.

a. Emplacement of QMP-1 and North dike (QMP-n).

b. Emplacement of QMP-2 dike swarm.

c. Emplacement of QMP-2.5 and QMP-3.

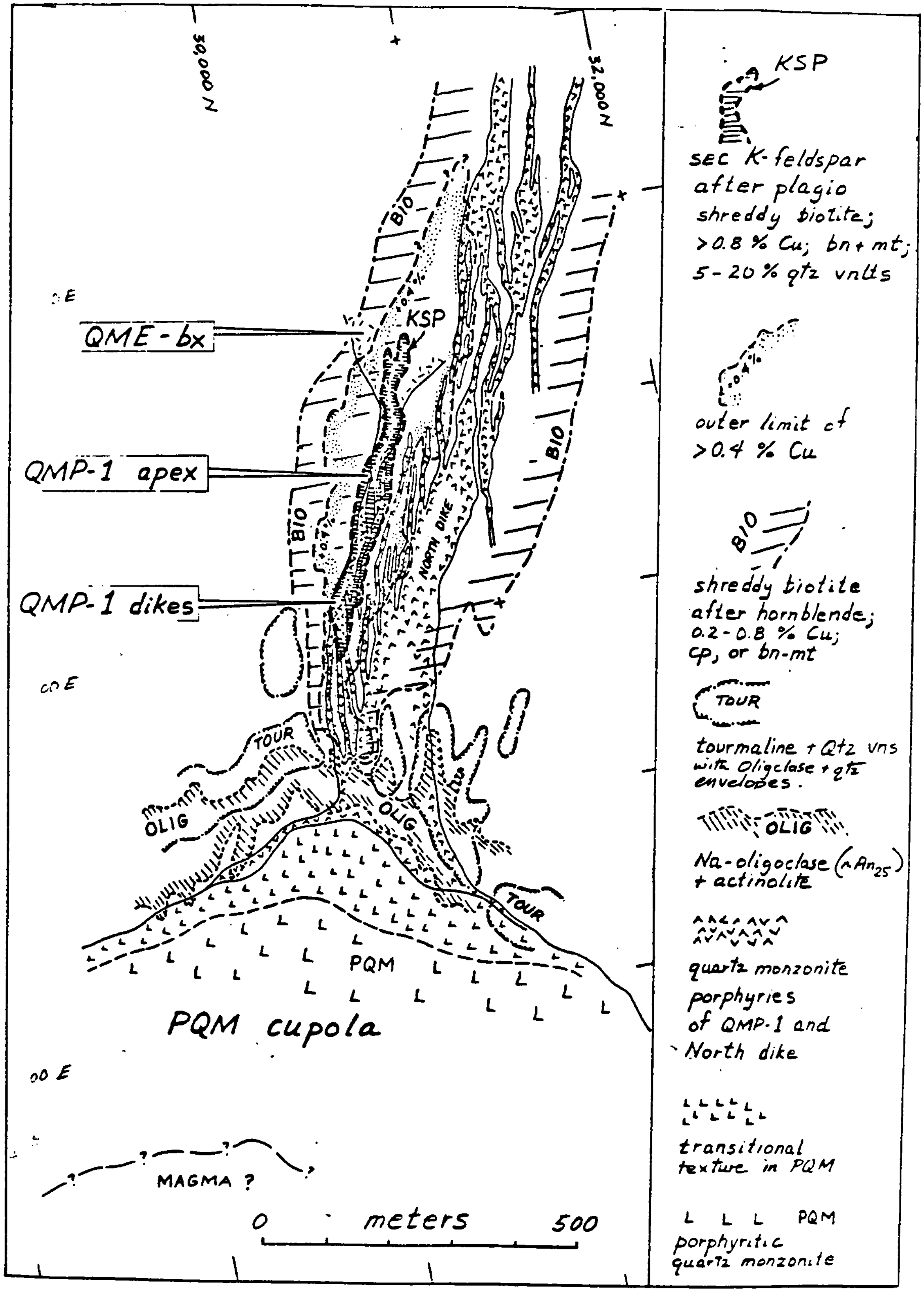

30,000 N
32,000 N
QME-bx
QMP-1 apex
QMP-1 dikes
KSP
BIO
NORTH DIKE
TOUR
OLIG
PQM
PQM cupola
MAGMA ?
0 meters 500
KSP
sec K-feldspar after plagio shreddy biotite; >0.8 % Cu; bn + mt; 5-20 % qtz vnlts
outer limit of >0.4 % Cu
BIO
shreddy biotite after hornblende; 0.2-0.8 % Cu; cp, or bn-mt
TOUR
tourmaline + Qtz vns with Oligclase + qtz envelopes.
OLIG
Na-oligoclase (~An_{25}) + actinolite
quartz monzonite porphyries of QMP-1 and North dike
transitional texture in PQM
L L L PQM
porphyritic quartz monzonite

Fig. 18b.

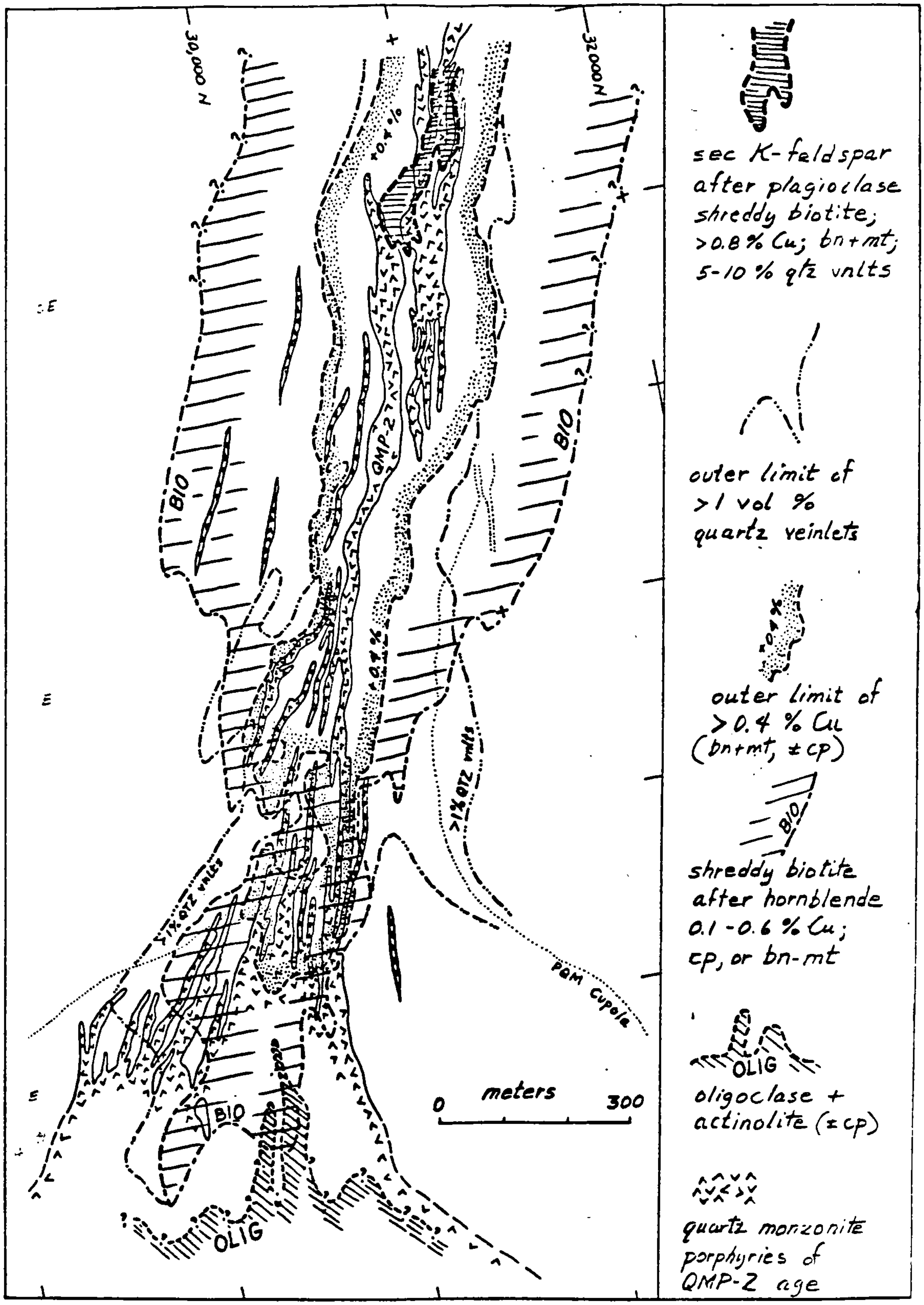

30,000 N
32000 N
+0.4 %
QMP-2
BIO
BIO
>0.4 %
>1% QTZ vnlts
>1% QTZ vnlts
PQM Cupola
BIO
OLIG
0 meters 300
sec K-feldspar after plagioclase shreddy biotite; >0.8 % Cu; bn+mt; 5-10 % qtz vnlts
outer limit of >1 vol % quartz veinlets
outer limit of >0.4 % Cu (bn+mt, ± cp)
shreddy biotite after hornblende 0.1-0.6 % Cu; cp, or bn-mt
OLIG
oligoclase + actinolite (± cp)
quartz monzonite porphyries of QMP-2 age

Fig. 18c.

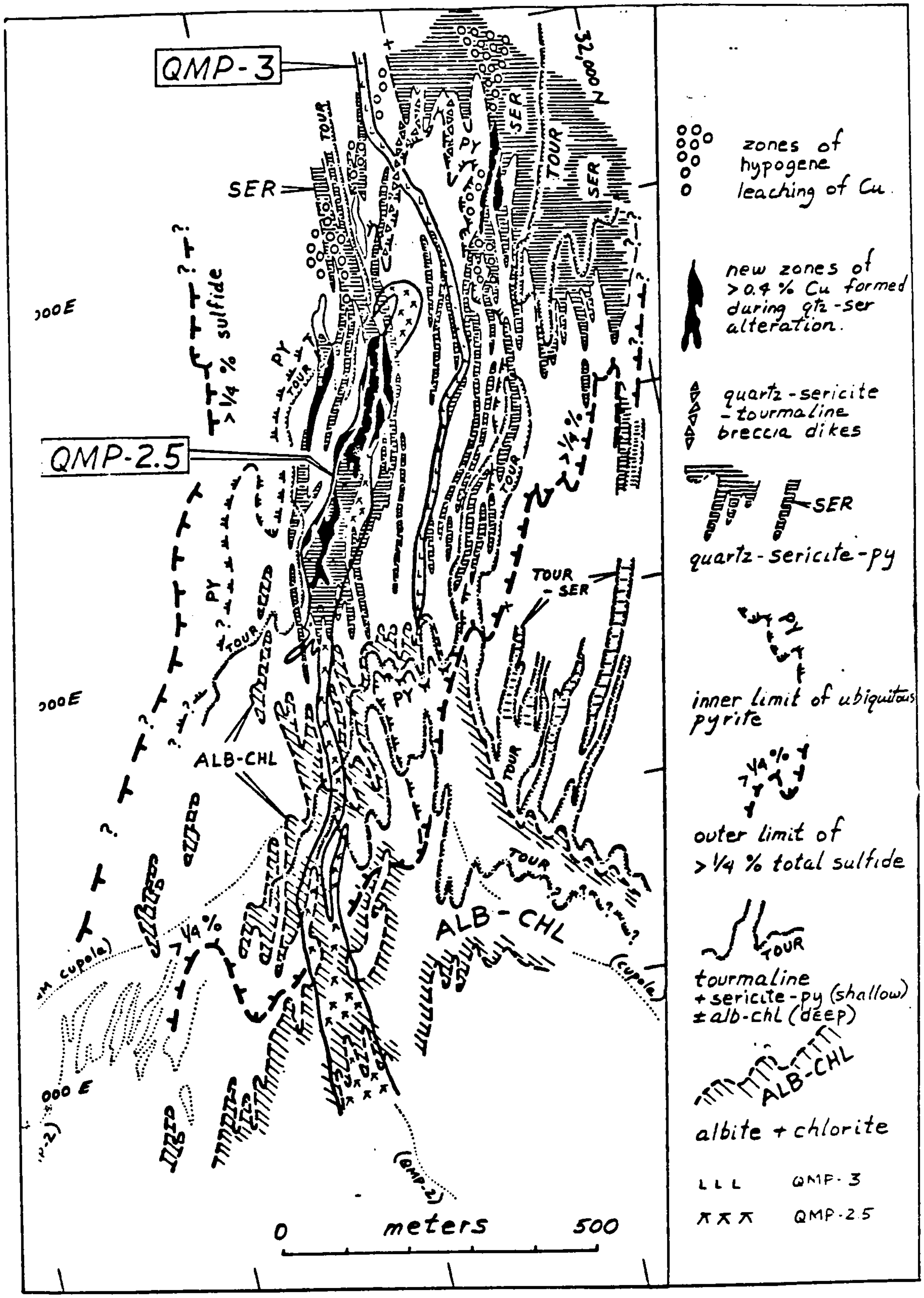

QMP-3
QMP-2.5
SER
TOUR
PY
> 1/4 % sulfide
TOUR - SER
ALB-CHL
1/4 %
32,000 N
(QMP-2)
cupola
0 meters 500
zones of hypogene leaching of Cu
new zones of > 0.4 % Cu formed during qtz-ser alteration
quartz-sericite-tourmaline breccia dikes
quartz-sericite-py
inner limit of ubiquitous pyrite
outer limit of > 1/4 % total sulfide
tourmaline + sericite-py (shallow) ± alb-chl (deep)
albite + chlorite
QMP-3
QMP-2.5

Fig. 19. MORPHOLOGY OF ORE ZONES RELATED TO APICES OF PORPHYRY INTRUSIONS, YERINGTON, NEVADA.

Reconstruction (in Jurassic age vertical cross section) of alteration zoning, opaque mineral assemblages, and distribution of copper grades associated with the earliest quartz monzonite porphyry dike intrusion (QMP-1), based on maps of the type illustrated in Figure 4. Younger events are stripped on the basis of mapped age relations. A zone of >1.2% Cu, as bornite-(chalcocite)-magnetite associated with K-feldspar-biotite alteration and 10 - 25 vol % quartz veinlets, is located at the apex of the intrusion (that this is the top of the intrusion is confirmed by mapping on several levels). The late magmatic character of the mineralization event is demonstrated by the style of quartz-K-feldspar-magnetite-bornite veinlets: in many cases these veinlets merge into the groundmass of the porphyry and are discontinuous, en-echelon, and locally ptygmatic in appearence. Additional evidence for magmatic-hydrothermal introduction of copper is the fact that this high grade mineralization is cut by an igneous breccia which had its source in the apex of the QMP-1 dike. The traverse away from the QMP-1 apex along which samples were collected for a study of gains and losses of components during intense potassic alteration (Fig. 16) is shown near the top of the figure.

Fig. 19.

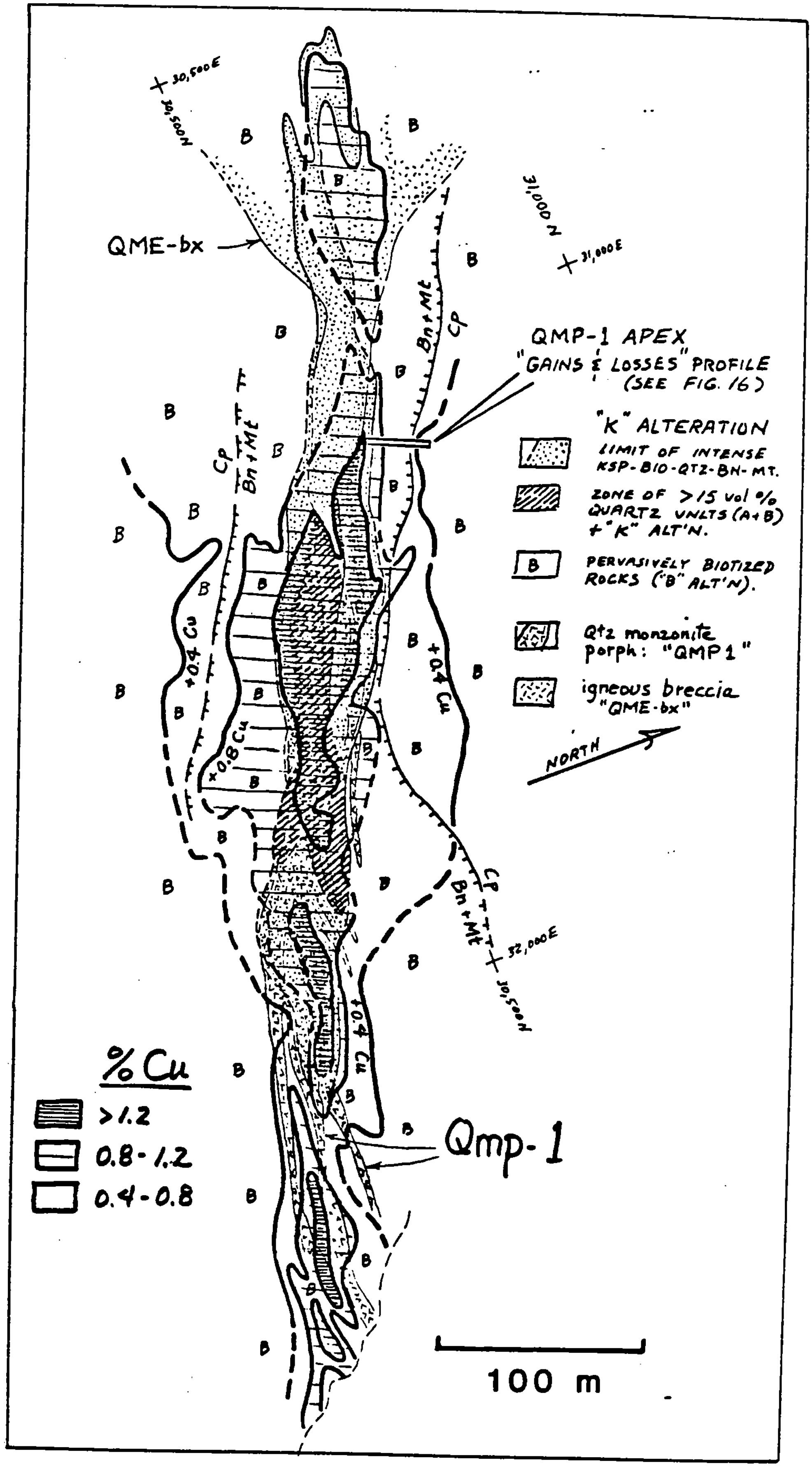

30,500E
30,500N
31,000N
31,000E
32,000E
30,500N
QME-bx
QMP-1 APEX
"GAINS & LOSSES" PROFILE
(SEE FIG. 16)
"K" ALTERATION
LIMIT OF INTENSE KSP-BIO-QTZ-BN-MT.
ZONE OF >15 vol % QUARTZ VNLTS (A+B) + "K" ALT'N.
PERVASIVELY BIOTIZED ROCKS ("B" ALT'N).
Qtz monzonite porph: "QMP 1"
igneous breccia "QME-bx"
NORTH
Bn+Mt
CP
+0.4 Cu
+0.8 Cu
% Cu
>1.2
0.8-1.2
0.4-0.8
Qmp-1
100 m

Fig. 20. Space - time diagram for the evolution of alteration along the axis of the porphyry dike swarm at the Yerington porphyry Cu deposit. Vertical time-lines are the sequential porphyry intrusions, which are taken to represent instants in time. Alteration at the surface during porphyry-1, -N, and -2 time is unknown, but may have been non-existant.

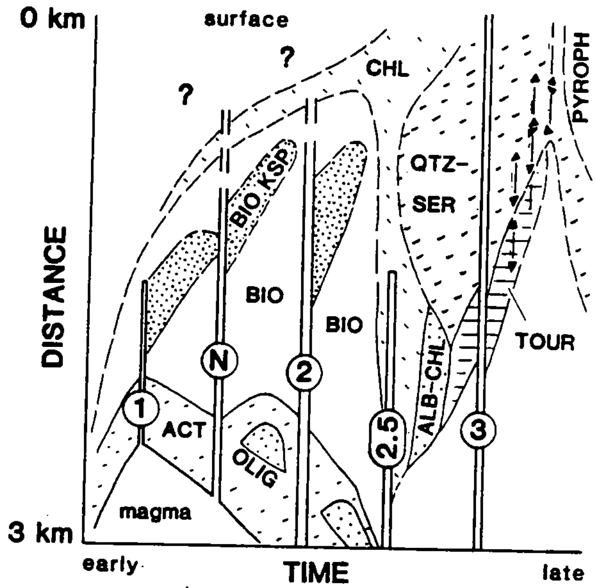


Fig. 21. JURASSIC-AGE CROSS SECTIONS DEPICTING SEQUENTIAL DEVELOPMENT OF YERINGTON PORPHYRY SYSTEM. Based on (Einaudi et al., unpub. data) and regional geologic relations in the Singatse Range and Buckskin Range (Carten, 1981; Dilles, 1983; Proffett and Dilles, 1984a; Einaudi et al., unpub data).

a. Emplacement of earliest porphyry dikes (QMP-1) from apex of PQM magma cupola located at 3 km below the surface. QMP-1 apex is locus of intense potassic alteration (K-feldspar-biotite-bornite-magnetite) and high-grade copper mineralization. A fine-grained igneous breccia (QME-bx) formed as a funnel-shaped mass that expands upward from the QMP-1 apex.

b. Emplacement of North dike to side of QMP-1, and crystallization of magma in the PQM cupola to depths of at least 3.5 km. Hydrothermal fluids of magmatic origin continue to dominate the central axis, causing a second zone of potassic alteration and copper mineralization and setting up secondary circulation of local waters which enter the crystallized PQM cupola at depth and on heating cause sodic-calcic (oligoclase-actinolite) alteration.

c. Emplacement of QMP-2 dike swarm through crystallized PQM cupola. These dikes cut earlier sodic-calcic alteration in PQM and cut potassic alteration related to QMP-1. The sodic-calcic plus potassic couplet is repeated during the QMP-2 event, but the intensity of alteration-mineralization is less and the spatial separation is greater. Hydrothermal fluids may have reached the surface at this time, generating hot springs and related silicification, sericitic alteration, and pyrite-hematite mineralization.

d. Emplacement of late porphyries (QMP-2.5 and QMP-3) postdates the bulk of copper introduction. The late porphyries are weakly propylitized and largely are barren. Pyrite-quartz veinlets with quartz-sericite-pyrite-(tourmaline) alteration halos form at high structural levels, while albite-chlorite alteration forms at greater depths. These two alteration types may have formed contemporaneously. Both postdate the emplacement of QMP-2.5, and both remobilized earlier-deposited copper. Pervasively sericitized dacitic volcanic rocks exposed in the Buckskin Range contain silicified ledges with pyrophyllite, representing the late stage venting of hydrothermal fluids.

Fig. 21

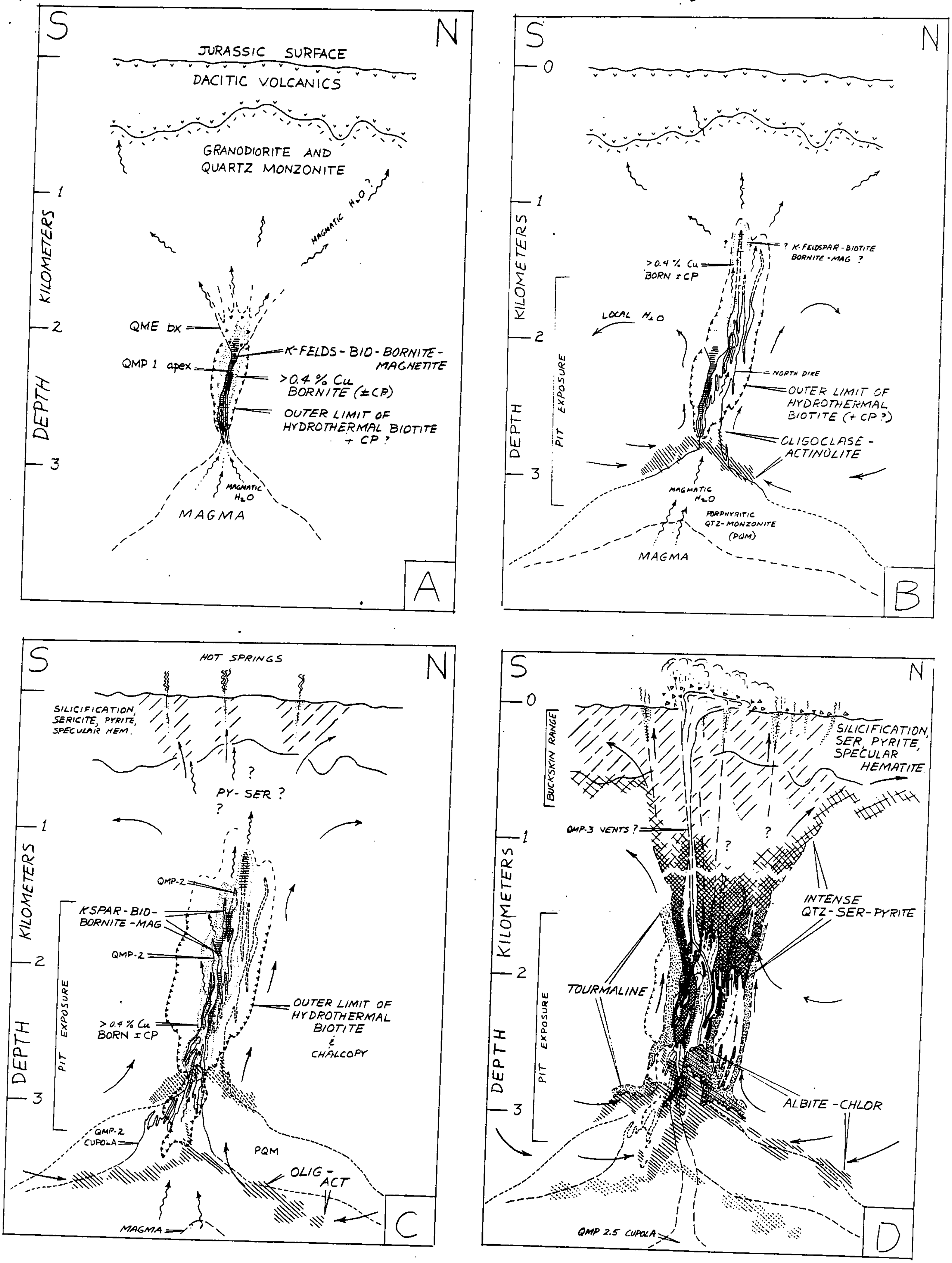

S
N
JURASSIC SURFACE
DACITIC VOLCANICS
GRANODIORITE AND
QUARTZ MONZONITE
MAGMATIC H2O ?
KILOMETERS
DEPTH
1
2
3
QME bx
QMP 1 apex
K-FELDS - BIO - BORNITE - MAGNETITE
>0.4 % Cu BORNITE (±CP)
OUTER LIMIT OF HYDROTHERMAL BIOTITE + CP ?
MAGMATIC H2O
MAGMA
A
0
? K-FELDSPAR - BIOTITE BORNITE - MAG ?
>0.4 % Cu BORN ± CP
LOCAL H2O
PIT EXPOSURE
NORTH DIKE
OUTER LIMIT OF HYDROTHERMAL BIOTITE (+ CP ?)
OLIGOCLASE - ACTINOLITE
PORPHYRITIC QTZ-MONZONITE (PQM)
MAGMA
B
HOT SPRINGS
SILICIFICATION, SERICITE, PYRITE, SPECULAR HEM.
PY - SER ?
QMP-2
KSPAR - BIO - BORNITE - MAG
OUTER LIMIT OF HYDROTHERMAL BIOTITE & CHALCOPY
QMP-2 CUPOLA
PQM
OLIG - ACT
MAGMA
C
BUCKSKIN RANGE
SILICIFICATION, SER, PYRITE, SPECULAR HEMATITE
QMP-3 VENTS ?
INTENSE QTZ-SER-PYRITE
TOURMALINE
ALBITE - CHLOR
QMP 2.5 CUPOLA
D

Fig. 22 North-south vertical cross section through a portion of the Yerington district, Singatse Range, Nevada, during Jurassic time. Cross section is based on surface mapping in an area extending from Ann Mason on the north to the Casting Copper mine on the south (see Fig. 12); this area represents a virtually continuous exposure of the batholith and of its contact aureole over a horizontal distance of 6 km and over paleodepths ranging from 1 km to 5.5 km. Geologic relations and alteration patterns in the upper portion of the cross section, from 1 km paleodepth to the paleosurface, are schematic and based on relationships observed in the Buckskin Range, west of Yerington; in unfaulted reconstruction, the Buckskin Range fits in a westerly, high-level fringe position relative to outcrops in the Singatse Range.

KEY TO FIG. 3.

ROCK TYPES:

Middle Jurassic
- Ja – andesite flows, breccia and minor sediment.
- Jgd – quartz monzodiorite and granite of Yerington batholith.

Early Jurassic
- Jq – sandstone quartzite.
- Jgy – gypsum and anhydrite.
- Jl – massive limestone.
- JTRlc – thin-bedded carbonaceous argillite and limestone.
- JTRvc – bedded, felsic volcaniclastic sediments and tuff.

Late Triassic
- TRlb – thin-bedded argillaceous limestone.
- TRl – thick-bedded, massive limestone.
- TRad – andesite-dacitic tuff and breccia.
- TRvl – interbedded felsic volcaniclastics and limestone.
- TRt – felsic pyritic tuff and sediment interbed in TRla.
- TRla – thin-bedded carbonaceous calcareous argillite.
- TRll – thick-bedded dolomitic limestone
- TRar – andesite and rhyollite flows, breccias, and sediments.

OTHER GEOLOGICAL FEATURES:

- Approximate position of 169 Ma old surface (paleovolcanic surface at time of alteration-mineralization).
- Ja / Jgd – Approximate roof of batholith (contact between Jgd and Ja).
- Lower tertiary erosion surface; dashed where buried under Qal.
- Approximate position of 168 Ma old erosion surface; base of Middle Jurassic andesite sequence (Ja).
- Limit of pre-Tertiary exposure
- Jgd – Mapped contact between batholith Jgd and metavolcanic-metsedimentary wall rocks (TR, JTR, and J)
- Limits of structural block.
- 168 Ma old normal faults.

ALTERATION:

Late Alteration in igneous rocks
- Advanced argillic alteration: quartz + pyrite + hematite + pyrophyllite.
- (ser) sericitic: sericite + quartz + pyrite ± tourmaline.
- (alb-chl) limit of late sodic alteration. Albite + chlorite + sericite + pyrite ± tourmaline.
- (chl) limit of strong propylitic (>50% chlor'd mafics). chlorite + albite + hematite + epidote ± pyrite.
- (± chl). limit of weak propylitic (>10 % chlor'd mafics) chlorite + albite + hematite ± epidote.

Early Alteration in igneous rocks
- blank areas generally unaltered except within limits of late alteration (see above)
- (±bio) weak biotitic alteration (<100% bio'd hbl) biotite + epidote
- (bio): biotitic (potassic) alteration: biotite + epidote + quartz + albite ± K-feldspar ± chalcopyrite
- (±olig): weak sodic alteration: epidote + sphene ± oligoclase ± quartz ± actinolite.
- (olig.): intense sodic alteration: oligoclase + quartz + sphene + epidote ± actinolite.
- (ENSK) Endoskarn: grossular + diopside + clinozoisite + plagioclase ± idocrase.
- hydrothermal breccias.

Alteration in volcanic-sedimentary rocks
- andradite - salite - chalcopyrite skarn.
- skarnoid and calcsilicate hornfels.
- hornfels and schist.
- black calcareous argillite; ± tremolite.
- marble (TRl, Jl)

MINERALIZATION:

- outer limit of 100 ppm Cu in Ann Mason porphyry Cu deposit.
- zone of >1000 ppm Cu in Ann Mason porphyry Cu deposit.

Fig. 22.

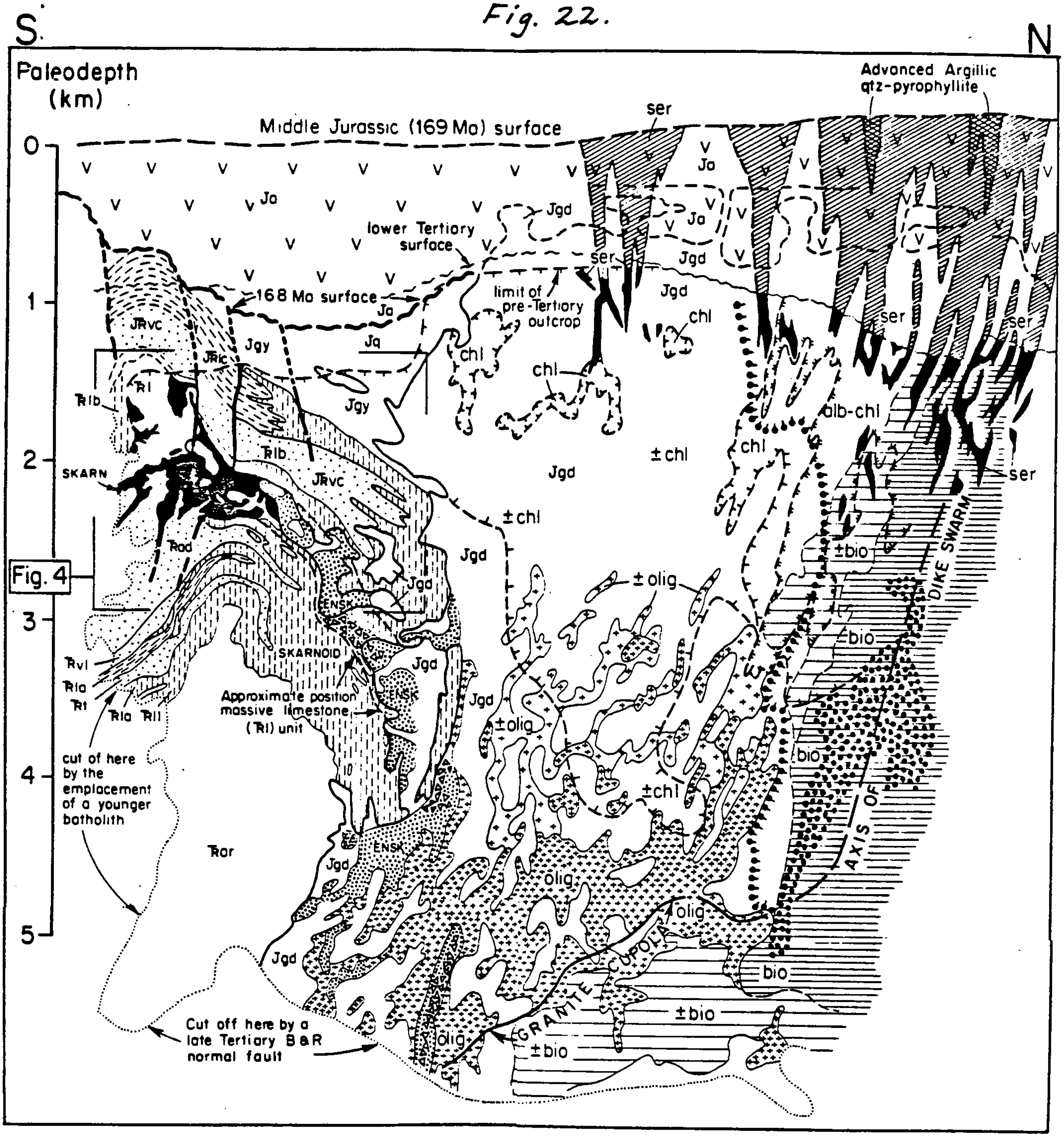
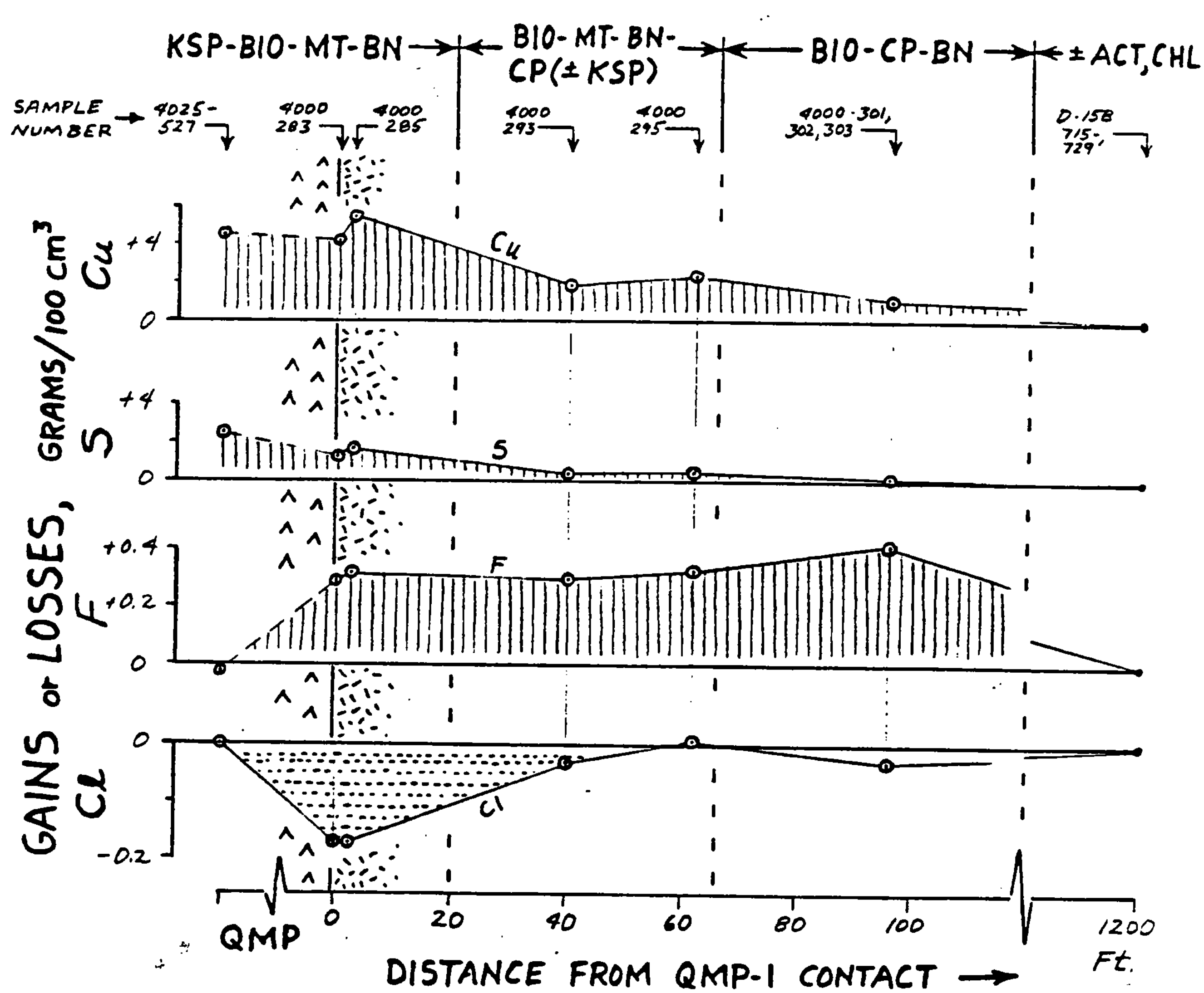
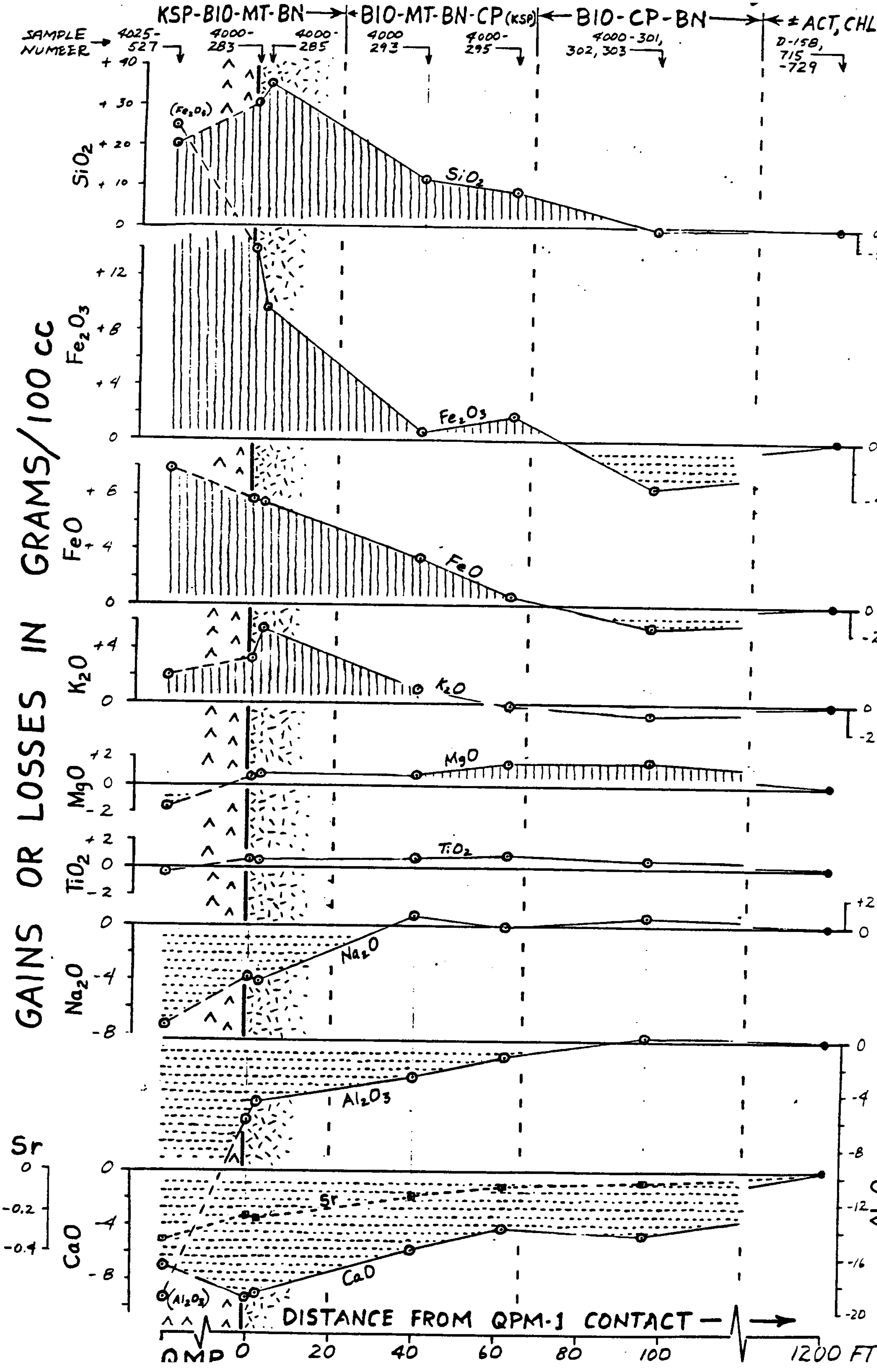

S
N
Paleodepth
(km)
0
1
2
3
4
5
Middle Jurassic (169 Ma) surface
Advanced Argillic
qtz-pyrophyllite
ser
Ja
Jgd
lower Tertiary
surface
168 Ma surface
limit of
pre-Tertiary
outcrop
chl
±chl
alb-chl
±bio
bio
±olig
olig
SKARN
SKARNOID
Approximate position
massive limestone
(Trl) unit
cut of here
by the
emplacement
of a younger
batholith
Trar
Cut off here by a
late Tertiary B&R
normal fault
GRANITE CUPOLA
AXIS OF DIKE SWARM
Fig. 4
Jgy
JTrvc
Trlb
ENSK

Fig. **23.** ELEMENTAL GAINS AND LOSSES DURING POTASSIC ALTERATION, YERINGTON, NEVADA.

Elemental gains and losses (in grams/100 cm^3 of original rock) in horizontal traverse away from QMP-1 contact (Fig. 5) in granodiorite wall rocks calculated from bulk rock chemical analyses and rock density measurements. Gains and losses in granodiorite are computed relative to a composite of carefully picked samples of granodiorite with weakly chloritized hornblende from diamond drill core on the fringe of the alteration pattern and on line with the traverse; gains and losses in QMP-1 are computed relative to an average of three analyses of quartz monzonite porphyry dikes in and outside of the pit that exhibited fresh feldspars and weakly chloritized mafic minerals. The frame of reference is one of constant volume of the original igneous rock combined with an increase in volume of the system based on the volume percent of open-space quartz veinlets. Thus, gains and losses, although cast in terms of volume of original rock, are for the system as a whole (volume of original rock + volume of open space veinlets).





KSP-BIO-MT-BN
BIO-MT-BN-CP (KSP)
BIO-CP-BN
± ACT, CHL
SAMPLE NUMBER
4025-527
4000-283
4000-285
4000 293
4000-295
4000-301, 302, 303
D-158, 715 -729
GRAMS/100 cc
GAINS OR LOSSES IN
SiO2
Fe2O3
FeO
K2O
MgO
TiO2
Na2O
Al2O3
CaO
Sr
DISTANCE FROM QPM-1 CONTACT
QMP
1200 FT

41

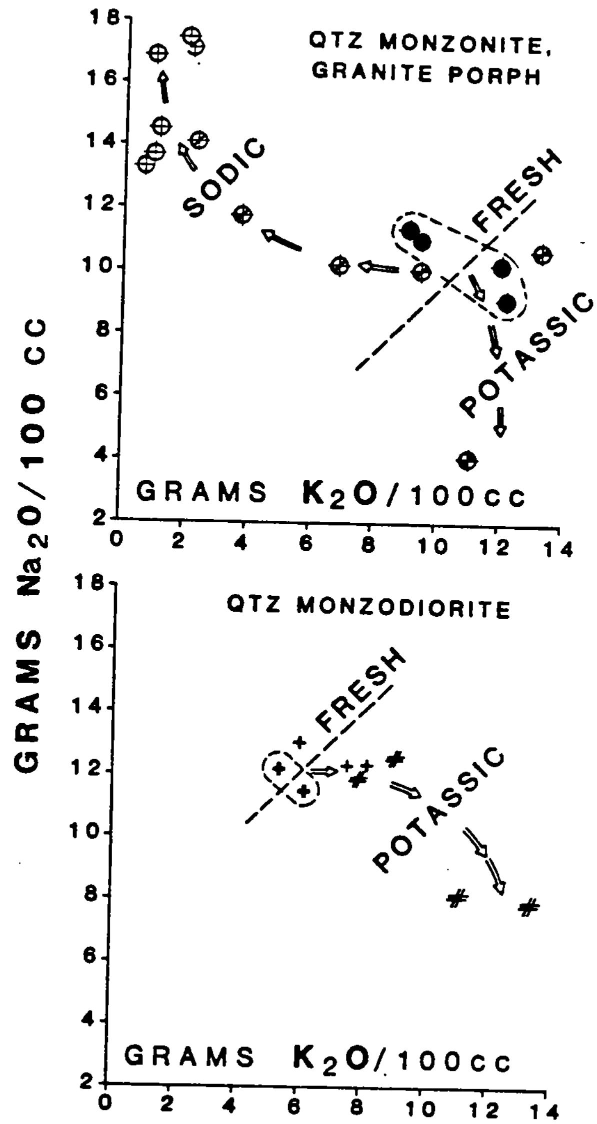


Fig. 24. Orthogonal plot of gains and losses of Na2O and K2O during potassic and sodic alteration at the Yerington porphyry Cu deposit, Nevada, based on Einaudi (unpub. data) and Carten (1986). Calculated on a constant volume basis for each of the major rock types. See Fig. 25 caption for key to symbols.

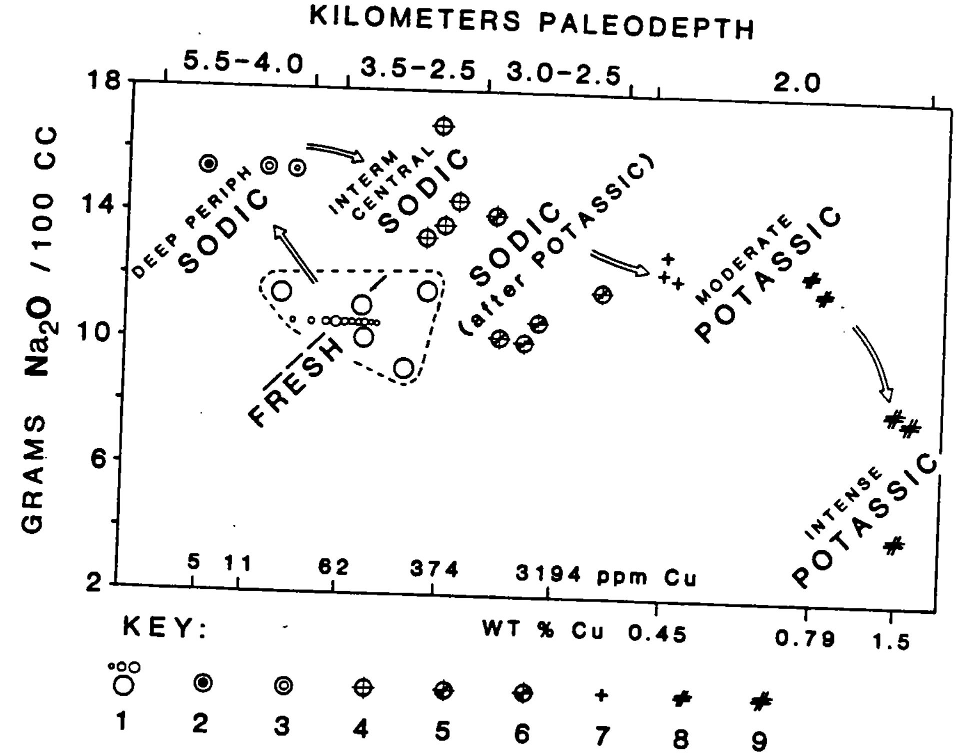


Fig. 25. Orthogonal plot of gains and losses of Na2O and Cu during potassic and sodic alteration in the Yerington district, Nevada, based on Dilles (1984) and Carten (1986), assuming constant volume. The arrows link hydrothermal alteration zones that could represent the cycling of one packet of fluid (see Fig. 21). During the conversion of fresh quartz monzonite to sodic assemblages in the deep peripheral portions of the granite cupolas (see Fig. 22), 51 ppm Cu was leached per unit volume while 6 g/100 cc Na2O was added by external hydrothermal fluids that were following a prograding thermal path. Based on the estimated volume of deep sodic alteration at Ann Mason, these prograding fluids were capable of leaching 5.82 X 10(11) g Cu. The estimated amount of Cu deposited at Ann Mason is 5.4 X 10 (12) grams, which indicates that only some 11 % of the Cu in the deposit could have been contributed by inwardly convecting hydrothermal fluids that leached copper from the wall rocks. Similar calculations made for other components indicate that, although the components leached by inward cycling hydrothermal fluids are the same components that were fixed in zones of potassic alteration at higher structural levels, insufficient copper, silica, and iron was leached from sodic zones to account for the amounts added in potassic zones. For these components, as well as for some others, a magmatic source is indicated.

Key: (1) small circles represent 45 samples of fresh quartz monzodiorite averaging 62 ppm Cu. Large circles represent represent 5 individual samples of fresh quartz monzonite and granite. (2) Average of 5 samples of quartz monzodiorite and quartz monzonite with pervasive Na-Ca alteration (olig-act-qtz-sphen-epid, no Kspar). Average 4.8 ppm Cu. (3) Represents six samples of quartz monzodiorite and quartz monzonite with moderate sodic-calcic alteration (olig-qtz-sphene-epidote-+/-actinolite, relict andesine, Kspar, hbl). Average 20 ppm Cu.

(4) Four samples of quartz monzonite, Yertington mine, with pervasive Na-Ca lateration (olig-qtz-sphene-epidote+/-actinolite), 0% veins, 0% magnetite, 0% sulfides, range from 277 to 489 ppm Cu. (5) Three samples of quartz monzonite, Yerington mine, with Na-Ca alteration superimposed on earlier potassic alteration (bio-qtz, orig Kspar), 1.5-4% vein quartz, 0% magnetite, tr - 0.6% bornite, 0.3 - 0.6% chalcopyrite. Range from 931 to 6849 ppm Cu. (6) Two samples of quartz monzonite, Yerington mine, representing deep potassic alteration (qtz-bio), 1-2% vein quartz, 1.0-2.5% magnetite, 0.6% chalcopyrite. Average 1970 ppm Cu.

(7) Three samples of quartz monzodiorite, Yerington Mine, representing weak potassic alteration (bio-qtz) at high structural levels; 3.8% vein qtz, 0 % magnetite, 0.25% bornite, 0.25% chalcopyrite. Average 0.45 wt% Cu. (8) Two samples of quartz monzodiorite, Yerington mine, representing moderate potassic alteration (bio-qtz+/-Ksp) at high structural levels; 5% vein qtz, 3% mag, 0.5% bn, 0.2% cp. Average 0.8wt% Cu. (9) Three samples of qtz monzodiorite and granite porphyry, Yerington mine, representing intense potassic alteration (bio-qtz-kspar) at high structural levels; 7-18% vein qtz, 5.6% mag, 1% bn, 0.2% cp. Range of Cu is 1.4 to 1.7 wt%.

Fig. 26. Diagram illustrating T - K:Na relations in aqueous fluids coexisting with Kspar and albite. Path A represents the retrograde path of magmatic hydrothermal fluids at Yerington that cooled during flow toward higher structural levels; these fluids caused potassic alteration and deposited most of the copper-iron sulfides (bornite-magnetite). Path B represents the prograde path of externally-derived hydrothermal fluids that were heated during flow into the cupola regions at deep structural levels; these fluids caused sodic-calcic alteration and leached much of the K, Fe, Cu, and S from the wall rock.

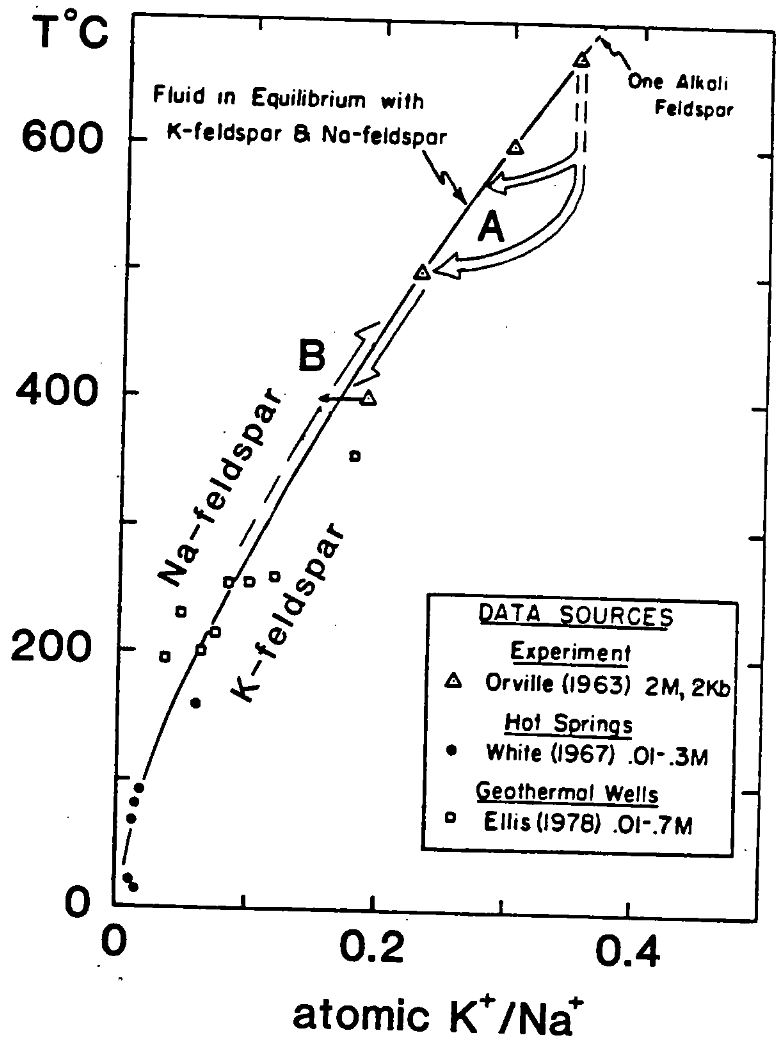
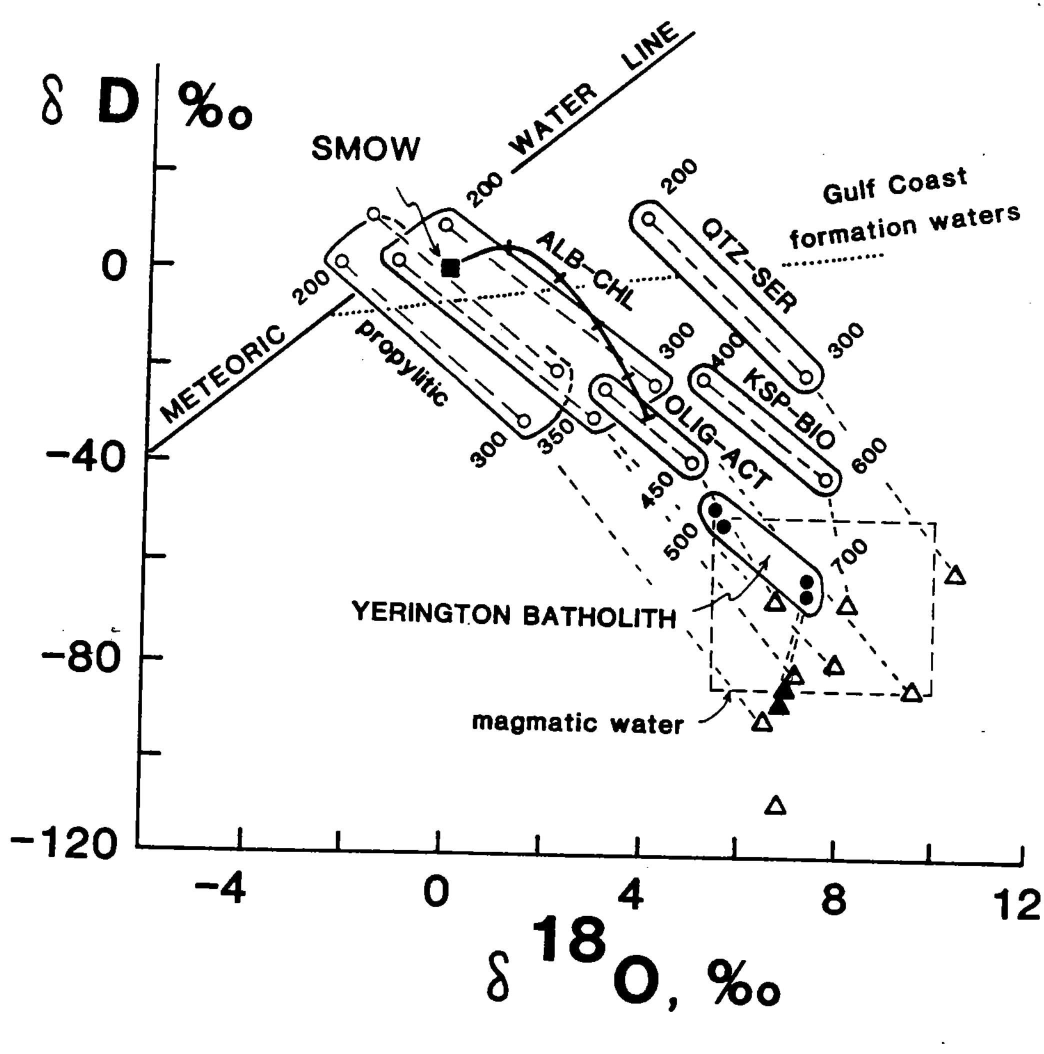


Fig. 27. Plot of delta D versus delta O-18 for Ann Mason, Yerington district, based on Dilles (1984). Values for mineral pairs (feldspars or whole-rock versus amphiboles or micas) are shown by triangles. Values for coexisting waters at the temperatures indicated (boxes) were calculated from: the equation of Suzuoki and Epstein (1976) for D/H fractionation between hydrous minerals and water; the equation of Bottinga and Javoy (1973, 1975) for feldspar-water oxygen isotope fractionation using mineral compositions determined by electron microprobe analysis and optical studies. The MAGMATIC WATER box and the trend of GULF COAST FORMATION WATERS are taken from Taylor (1974). SMOW is standard mean ocean water. Temperatures of alteration waters are based on fluid inclusion studies, mineral equilibria, and isotopic fractionation. QTZ-SER represents sericitic alteration, ALB-CHL is late sodic alteration, OLIG-ACT is early sodic-calcic alteration, KSP-BIO is potassic alteration. YERINGTON BATHOLITH represents calculated water compositions in equilibrium with freshest granite porphyry and quartz monzodiorite at 500 to 700 C. The heavy solid curved line with tick marks represents the evolution of path for exchanged ocean water calculated using the Suzuoki and Epstein (1976) and Bottinga and Javoy (1973, 1975) mineral-water fractionation equations and the following assumptions: 1) rock is qtz monzodior (plagio + hbl) with 45 wt% oxygen, 0.5 wt% H2O, delta D = -88 per mil, delta O-18 = 6.8 per mil, 2) initial fluid reacts to equilibrium at 200 C, 3) the resultant fluid infiltrates fresh qtz monzodior and reacts to equilibrium at successive 50 degree intervals (tick marks) to the final equilibrium temp of 400 C, and 4) water:rock ratio (equal to atomic ratio of oxygen) is equal to 1:10.

The data shown indicate that at least two types of waters were responsible for hydrothermal alteration at Yerington: (1) a magmatic hydrothermal fluid was involved in potassic alteration (the deuterium-shift possibly caused by very high salinity fluids generated during two-phase boiling) and possibly involved in early sodic-calcic alteratiop; and (2) sea water or isotopically heavy meteoric water near sea water composition responsible for propylitic, sericitc, and late soidic alteration and possibly a major component in sodic-calcic alteration.



Field Trip Log

YERINGTON SKARNS

Marco T. Einaudi
Stanford University

INTRODUCTION

What follows is a description of stops we will make. The relatively unique exposure of a vertical cross-section through the contact aureole is due to 90° of westward tilt caused by Pre-Basin and Range faulting. As we look at the rocks, keep reminding yourself that original up is to the west. Stops 2 and 8 will be metamorphic hornfelses and "skarnoid"; stops 9 through 12 will be in sulfide-bearing skarns. The main theme of the trip will be study the evolution of these complex calc-silicate rocks and to contrast the ore-bearing andradite-salite environment ("true skarn") with the barren grandite-diopside environment (garnet hornfelses or "skarnoid").

STOPS

Stop 1.

3000 feet west of range front — a good view of the metasedimentary rock septum (Triassic-Jurassic) between the Yerington and Southern batholiths (Jurassic). Due east of us are the remains of the old Ludwig mine (1906–1923, 200,000 tons of 2-6% Cu), and just to the north is the gypsum pit. The skyline is a ridge composed of calc-silicated limestone; on the crest is the Douglas Hill mine (1911–1920?, 70,000 tons 5% Cu). At the southern termination of the crest is the Casting Copper mine (1912–?, 450,000 tons of 3% Cu). All of these mines are skarn deposits (the Ludwig is in part a breccia vein with quartz-pyrite matrix) and they all are related to hydrothermal activity generated by the emplacement of the Yerington batholith. Our trip will commence at the southern end of the contact metasomatic aureole, will follow a shale unit along strike toward the batholith through increasing grades of metamorphism and metasomatism, and then will swing uphill through endoskarns and high-temperature calc-silicate zones into a massive limestone unit that contains the majority of skarn. We will then follow this massive limestone unit in a southwesterly direction, away from the batholith, and toward the peripheral skarns (Douglas Hill and Casting Copper). See Figs 1, 2 & 3 for areal geology and strat section.

Stop 2.

Thin-bedded, black, calcareous argillite with black silty limestone interbeds; this is map unit Ћlc, near the top of the Triassic-Jurassic sedimentary section. A chemical

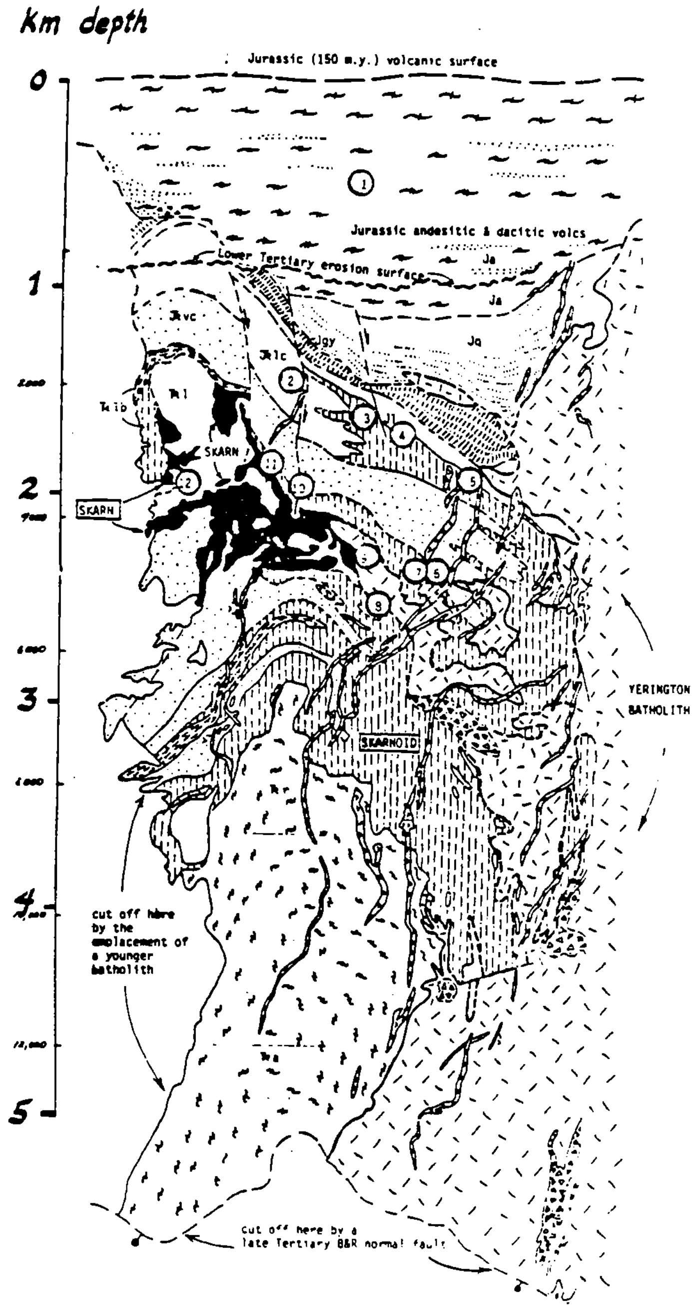
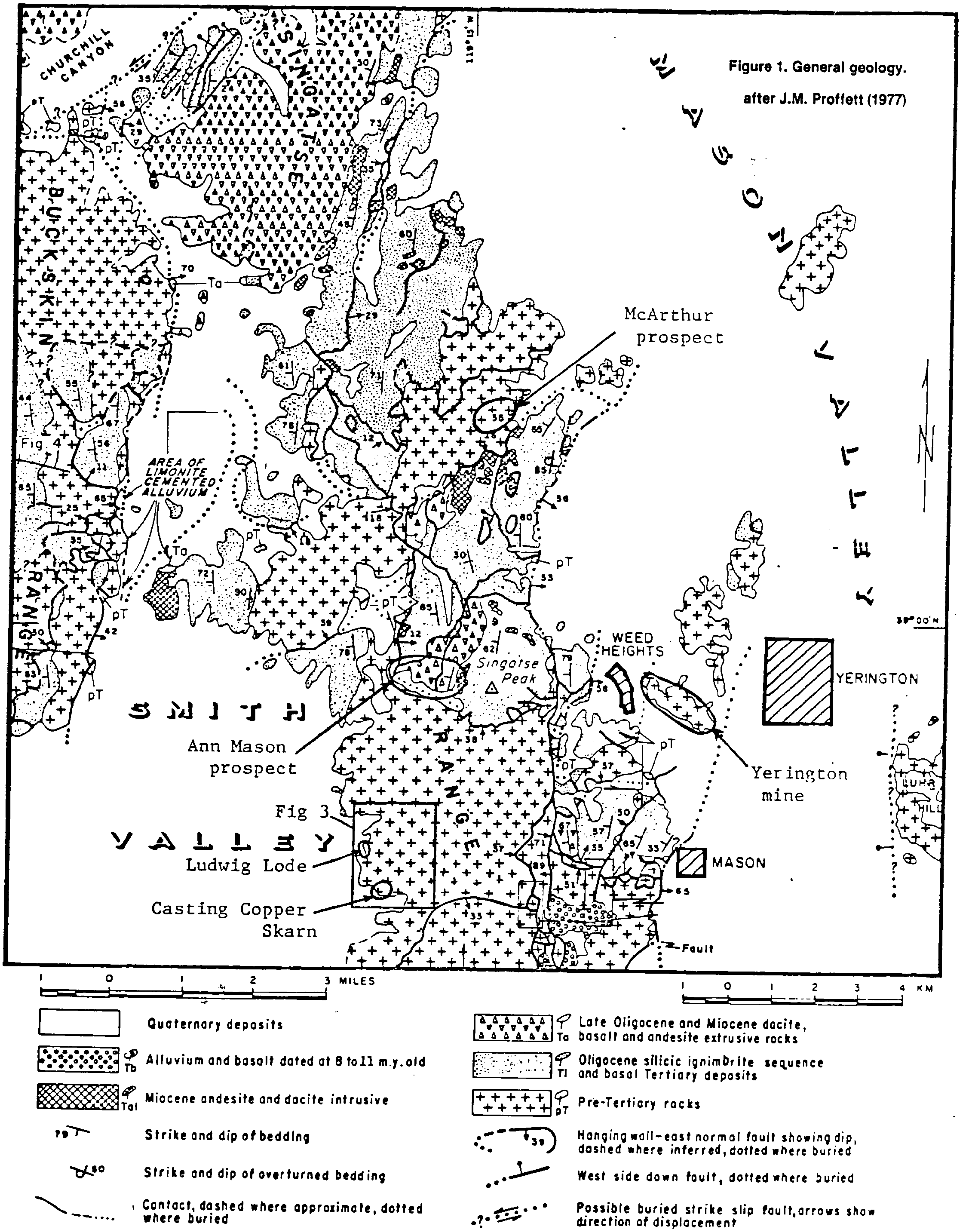


Figure A. Stop map.

45



Generalized geologic map of Yerington district, Nevada, showing major Cenozoic features.

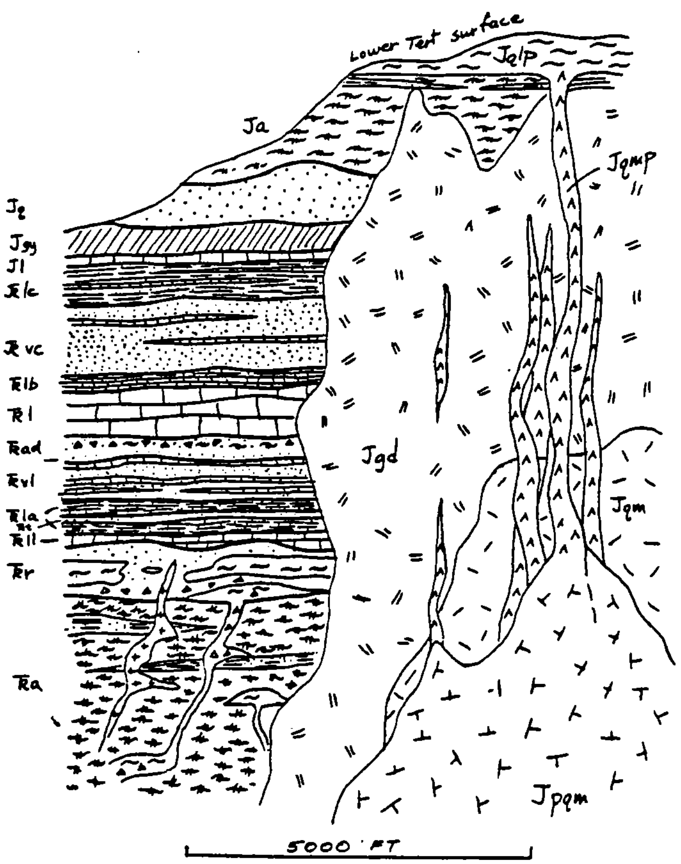


Figure 2. Stratigraphic section of the early Mesozoic rocks in the Yerington district, Nevada.

(M.T. Einaudi, 1975)

TABLE I
CHEMICAL (wt%) AND MODAL (vol%) ANALYSES OF HORNFELS AND SKARNOID COMPARED WITH ORIGINAL ROCKS

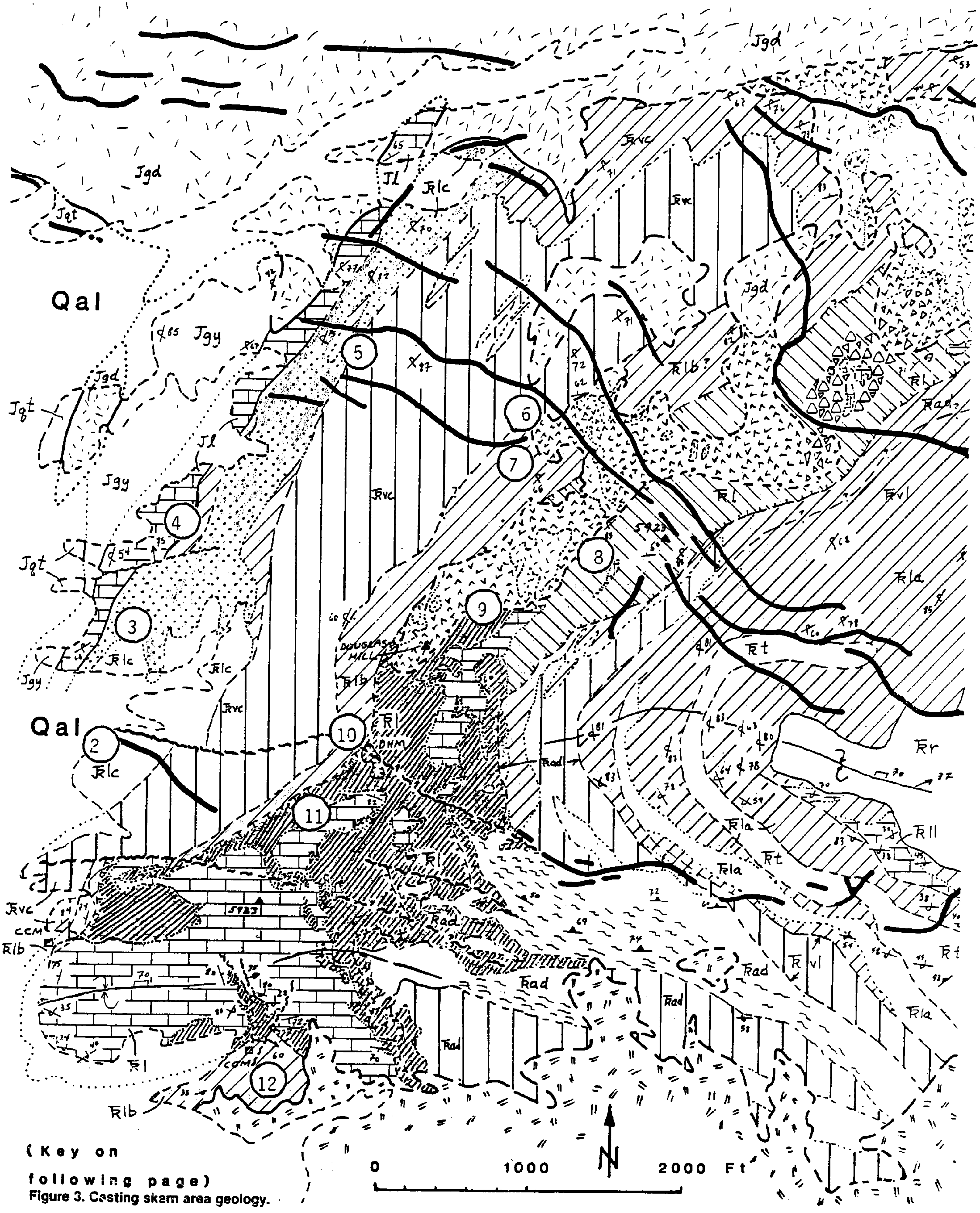
	blk limy shale		woll-gar hfls	skarnoid	felsic volcano-clastics	skarnoid
	1	2	3	4	5	6
orig lithology	calc shale	calc shale	calc shale	calc shale	felsite	felsite
map unit	TRlc	TRla$_2$	TRlc	TRla$_2$	TRvc	TRvc
anal. number	F-18	F-4	A-7	A-2	F-14	A-4
SiO_2	54.02	44.08	51.68	43.40	72.56	52.17
Al_2O_3	11.06	11.50	11.18	11.61	12.86	8.39
Fe_2O_3 (tot Fe)	2.44	2.54	2.33	12.72	1.66	10.79
MgO	2.49	1.45	3.32	1.02	1.28	0.28
CaO	20.48	22.66	23.50	29.27	4.11	25.86
Na_2O	1.01	1.07	0.93	1.12	5.22	0.02
K_2O	3.74	5.96	3.84	0.06	1.45	0.04
S	0.15	0.02	0.37	0.01	0.01	0.02
Cal	20	45	5	8	6	12
Qtz	12	15	6	5	23	16
Woll	0	0	44	0	0	0
Cpx	28	18	17	6	8	15
Amph	0	tr	0	4	10	0
Gar	20	10	20	55	0	45
Plag	10	5	5	10	45	tr
Epi	0	0	0	6	0	5
Mont	8	5	0	5	5	2
Py	2	2	3	0	3	0

and mineralogical analysis of a 200 ft channel sample of this unit is given in column 1 (#F-18), Table 1. Black, pyritic shales similar to this unit occur lower in the section (col 2, #F-4, Table 1). Although we are located outside the "visible" limit of contact metamorphism, these rocks contain about 40% garnet + pyroxene of metamorphic origin (grossularitic and diopsidic) — note that carbonaceous matter is still present. Moving northward toward stop 3, we will pass through a fairly abrupt, but bedding-controlled, transition into white wollastonite-diopside ± garnet hornfels.

Stop 3.

Same unit as at stop 2, but we have passed through the wollastonite "isograd" (think about why the term "isograd" is not strictly applicable in this environment). Note the stratigraphic control of wollastonite development, in that it is best developed in the argillaceous beds and many of the limestone interbeds are simply recrystallized. Local control of calc-silicate development is one feature that would suggest a metamorphic, rather than metasomatic, origin for these hornfels. Another feature suggestive of metamorphic origin is the rather gradual "wollastonite front", which, although abrupt on the map scale, occurs over tens of feet in any given lithology along strike. Most "appearance-of-phase fronts" in metasomatic rocks are abrupt on the scale of a thin section! The detailed nature of the wollastonite front is worth spending some time on — if you cast about and break a lot of rocks, you will note that some rocks are black with gray spots, some are gray with white spots, and some are all white, are very difficult to break, and have a knotty aspect. This range of color and texture gives you a handle on the progressive nature of metamorphism at this locality and allows you to conlude that the wollastonite-forming reaction (cal + qtz = woll + CO_2) occurs at individual nucleation sites, and, as the spots grow, they eventually coalesce. These are classic "spotted hornfelses".

A few comments on mineralogy: The white wollastonite needles, commonly in "sprays", are best seen along bedding fractures — in many of the dense white hornfels you will not be able to see the crystal forms and you might guess that these are wollastonite hornfelses on the basis of past experience and geological setting. Tremolite can look identical to wollastonite in the field, and the ultimate test would be X-rays or thin section. In this locality, white plagioclase and dipside also are present with wollastonite as stubby, v.f.g. crystals that are not visible with the hand lens. If you see very pale buff to cream-colored spots, these are grossularitic garnets.



(Key on following page)

Figure 3. Casting skarn area geology.

KEY:

- No. BATHOLITH grd-monzodior, fresh to weakly albititized
- So. BATHOLITH
- QMP DIKE
- ENDOSKARN--OLIG-PYX-CZ -GAR
- SKARNOID, PYX > GAR
- SKARNOID, GAR >> PYX
- PYX ± GAR HORNFELS
- WOLL-DIOP ± GAR HORNFELS
- IRON-RICH SKARN, including salite-, andradite-, and epidote-rich
- IGNEOUS AND CALC-SILICATE BRECCIAS
- SCHISTOSE ROCK
- MARBLE: dolomitized, de-dolomitized, and un-dolomitized
- NON-HORNFELSED/NON-METASOMATIZED ROCKS (many different types)
- PLUTONIC/SED-VOLC CONTACTS
- STRATIGRAPHIC CONTACTS
- HW & FW OF MASSIVE LIMESTONE UN
- ALTERATION BOUNDARIES
- FAULTS

Proceeding northward toward the batholith, we will see increasing amounts of garnet, much of it in bedding streaks or as well-formed pale brown crystals lining cavities.

Stop 4.

LUDWIG mine. BE CAREFUL HERE!! There are many vertical open stopes that go down several hundred feet. The Ludwig deposit is a narrow quartz-pyrite fissure, displaying several episodes of brecciation, and localized along a stratigraphic contact between the Ɉlc unit and an overlying thick-bedded limestone unit (Jl). The beds are overturned in this locality, so the limestone forms the footwall of the vein. Hypogene sulfides consisted of pyrite with lesser chalcopyrite (possible traces of sphalerite and galena) in the dominantly quartz matrix of the breccia. Breccia fragments consist of various altered rock types (the hanging wall here consists of garnetized Ɉlc, the footwall of recrystallized limestone, Jl) — try to determine whether the breccia vein formed dominantly in the hornfels or in the marble and why! If you look hard you may find fragments of silicified qtz-eye porphyry (a porphyry dike is exposed along the vein underground). Would you use the term "jasperoid" in referring to the gossany outcrop of the Ludwig lode?

The stopes at the surface appear to be located largely in the footwall marble, yet, underground, below oxidation, the marble is not mineralized. Can you figure out why the stopes at the surface are located in marble rather than in the quartz-sulfide vein itself?

Stop 5.

Road cut 400 ft east of gypsum pit. The purpose of this stop is to take one last look at purely metamorphic rocks. We are near the upper contact of the Ɉlc unit — although we have passed large areas of garnetized Ɉlc (such as in the hanging wall of the Ludwig lode) (see col 4, anal. A-2 for chem & mineral composition of a typical garnet skarnoid developed from limy shale, Table 1), the majority of this unit consists of woll-cpx-plag (± garnet, idocrase) hornfels. Note again the bedding control of individual mineral abundances and the presence of interbedded white marble. The contention that these calc-silicate hornfelses are of metamorphic origin is supported by the bulk chemical analysis of samples taken at this locality (col 3, anal. A-7, Table 1; compare with column 1). The bulk mineralogy is 44% woll, 20% gar (very pale buff, hard to see), 17% diopside, and 5% each of qtz, cal, and plag. An additional mineral, idocrase, shows up here — it is the bright yellow-green mineral concentrated along bedding planes. Idocrase (vesuvianite) is compositionally similar to grossular garnet, has the ideal formula $Ca_{19}(Al,Mg,Fe,Mn,Ti)_{13}Si_{18}O_{69}(OH,F)_9$, found as small tetragonal crystals or straited columnar aggregates. It is a common minor phase in wollastonite hornfels of regionally metamorphosed rocks and in the wollastonite zones of skarn deposits. Idocrase is a major phase only in the aluminous skarns mined for tungsten or tin.

Stop 6.

In gully 2000 ft east of gypsum pit. A particularly good exposure of the complex relations between garnet hornfels or "skarnoid" and garnet endoskarn. We are near the contact between map units Ɉvc and Ŧlb (see strat section, Figure 2) — in this zone of intense calc-silicate development the identification of original lithologic units is based in part on projection from areas to the south and in part on relic textures and structures. Identification of original lithologies can rarely be made on the basis of present calc-silicate mineral compositions or bulk composition of

TABLE II

CHEMICAL (wt%) AND MODAL (vol%) ANALYSES OF GARNET-RICH HORNFELS (SKARNOID) IN THE YERINGTON DISTRICT, NEVADA

	1	2	3	4	5
Orig lithology	grd	dacite tuff	rhyolite seds	limy shale	pure limestone
map unit	Jgd	Ŧad	JŦvc	Ŧla	Ŧl
anal. number	A-8	A-6	A-4	A-2	A-5
SiO_2	47.82	39.10	52.17	43.40	37.62
Al_2O_3	14.13	14.50	8.39	11.61	15.29
(tot Fe) Fe_2O_3	4.18	11.51	10.79	12.72	8.36
MgO	8.97	1.86	0.28	1.02	1.43
CaO	26.70	34.75	25.86	29.27	36.03
Na_2O	0.90	0.34	0.02	1.12	0.38
K_2O	0.29	0.00	0.04	0.06	0.08
Cal	tr	0	12	8	5
qtz	0	2	16	5	3
cpx	50	10	15	6	6
amph	tr	0	0	4	0
gar	10	80	45	55	70
plag	10	3	tr	10	3
epid	14	0	5	6	3
mont	3	5	2	5	7
musc	10	0	0	0	0

the calc-silicate rocks because these are essentially identical for a broad variety of original rocks ranging from granodiorite to dacitic tuff, felsic volcaniclastics, calcareous shale and limestone (see chemical and mineral analyses of garnet skarnoid developed from these four original rock types in columns 1 to 5, respectively, Table 2). Essentially, we see evidence for large scale homogenization, in terms of composition and mineralogy, of an originally complex and varied sedimentary-volcanic section. Mass balance calculations indicate that the bulk composition of garnet-rich hornfels or skarnoid is almost identical to the bulk composition of the sedimentary-volcanic section — the suggestion is that these garnet-rich rocks could have formed during hydrothermal exchange of components between unlike lithologies and need not have required introduction of components, except for iron, from outside the sed-volc pile. Viewed on the scale of the contact aureole, these are metamorphic rocks, whereas viewed on the scale of individual beds these are metasomatic rocks.

Back to the outcrops. The JŦvc unit consisted of thin to medium-bedded volcaniclastic sediments and tuffs, minor calcareous tuffs and thin flow units, all of felsic or rhyolitic composition — probably soda-rhyolites or keratophyres (Table 1, col 5, anal. F-14). Outcrops on the south side of the entrance to the gully represent the basal portion of the JŦvc unit — you should be able to recognize relic bedding striking N. 45° E. and steeply dipping — the unit now largely consists of pale buff garnet, roughly $gross_{70}andra_{30}$ in composition (50–70 vol %), subequal proportions of quartz and diopsidic cpx (cpx + qtz = 15–30%), and 5–10% dark green epidote (much of the epid appears to be late) (Table 1, col 6, anal. A-4).

Outcrops on the north side of the gully consist largely of garnet-plagioclase-clinozoisite endoskarn that replaced granodiorite — the granodiorite body here is part of a large dike-like mass, 400 to 500 ft thick, that was emplaced along the contact between the Ŧl and Ŧlb units (see figure 1). A local source for Ca was clearly a requisite for the formation of endoskarn, as can be deduced from close spatial correlation of endoskarn and originally limy sedimentary rocks (see figure 1). Here, at this locality, the Ca-source was units Ŧlb and Ŧl, exposed up the hill to the east. Careful search will reveal some outcrops that contain relatively unaltered relics of granodiorite, and the transition in texture and mineralogy from relatively unaltered GRD to endoskarn can be seen (plag + cpx → clinozo + plag + cpx → garnet + clinozo). The clinozoisite varies in color from white through pale pink to bright pink; the garnets typically are pinkish brown. In general, endoskarn contains more plagioclase and clinozoisite than does skarnoid that developed from sedimentary-volcanic rocks.

Also of interest at this stop is the awesome development of very large idocrase crystals, some up to 10" in diameter and zoned from emerald green through yellow-green to brown. The idocrase here is associated with blue calcite, and white tremolite and diopside, and appears to be part of late retrograde assemblage.

Quartz monzonite porphyry dikes (heavy black lines on figure 3) were emplaced after granodiorite and probably after the bulk of the garnet hornfelses and endoskarn had formed. One such dike is exposed along the crest of the small ridge on the north wall of the gully — you probably noted the adit driven into its footwall as you walked up to this stop. The endoskarn assemblage in the qmp dikes is quite different than that found in the GRD — it is dominated by Fe-rich, dark green epidote, commonly accompanied by magnetite and/or pyrite, and minor calcite. The mineral assemblage of early endoskarn in GRD (plag + grandite) versus late endoskarn in qmp (epid + mag + cal) could be related by a general reaction such as:

$$\underset{\text{anorthite}}{2\,CaAl_2Si_2O_8} + \underset{\text{grandite}}{2\,Ca_3AlFeSi_3O_{12}} + 4\,Fe^{++} + 2HCO_3^- + 7/2\,H_2O + 5/4\,O_2 = \underset{\text{epidote}}{3\,Ca_2Al_2FeSi_3O_{12}(OH)} + \underset{\text{mag}}{Fe_3O_4} + \underset{\text{cal}}{2\,CaCO_3} + \underset{\text{qtz}}{SiO_2} + 6\,H^+$$

which reveals that the late stage fluids associated with emplacement of qmp dikes may have evolved to higher oxidation states and contained a higher concentration of Fe in solution than early stage fluids. This difference between early and late endoskarn may be mirrored in the difference between the early garnet hornfelses and the late, Fe-rich andraditic skarns we will be visiting in stops 9 to 13.

Stop 7.

Uphill and around the corner in the gully we find an excellent exposure of banded calc-silicate rocks ("reaction skarns") developed in Ŧlb. Note the development of extreme compositional inhomogeneity between layers, in part inherited from original compositional differences between beds in this shaly, thin-bedded limestone unit, and in part enhanced by bimetasomatic exchange between beds. We see here the arrested process of component exchange, which, if it had been allowed to continue,

TABLE III

CHEMICAL (wt%) AND MODAL (vol%) ANALYSES OF LIMESTONE (1) AND METASOMATIC ROCKS THAT REPLACED IT

	limestone	dolo'd limestone	garnet skarnoid	salite skarn	andradite skarn
	1	2	3	4	5
orig lithology	1s	1s	1s	1s	1s
map unit	Ŧl	Ŧl	Ŧl	Ŧl	Ŧl
anal. number	F-12	F-11	A-5	MVM-3	MVM-1
SiO_2	0.87	1.84	37.62	37.90	35.83
Al_2O_3	1.97	3.41	15.29	2.38	4.50
Fe_2O_3 (tot Fe)	0.00	0.00	8.36	24.12	21.76
MgO	0.70	11.64	1.43	7.16	1.95
CaO	52.40	41.02	36.03	20.58	30.91
S	0.01	0.01	0.01	10.08	1.41
cal	94	44	5	3	8
qtz	tr	tr	3	4	6
dolo	0	54	0	0	0
cpx	0	0	6	55	5
amph	0	0	0	7	6
talc	tr	tr	0	0	0
gar	0	0	70	5	68
plag	0	0	3	0	3
epid	0	0	3	0	0
chl	tr	tr	0	0	4
mont	0	0	7	6	0
py	0	0	0	20	2.5
cp	0	0	0	tr	0.5

would have resulted in the more homogeneous garnet-pyroxene hornfelses with only faint relic bedding that are characteristic of much of the inner portion of the contact aureole.

Stop 8.

West slope of Hill 5923, at elevation 5700 ft. We have climbed up (eastward) through the thick dike-like mass of Jgd, which exhibits a variety of endoskarn assemblages, and have arrived at its southeastern contact with what was originally a massive, thick-bedded limestone unit, Ŧl (Table 3, column 1, anal. F-12). In addition to massive garnet skarnoid (Table 3, column 3, anal A-5), the Ŧl unit contains large areas of dolomitic marble (Table 3, column 2, anal F-11), whose spatial relations to broad areas of calc-silicate development suggests that it is of hydrothermal origin (see Figure 3). The timing of dolomitization relative to garnet skarnoid formation is unclear because the two alteration types are never found in contact; however, it is clear that the dolomitization predated the formation of Mg-rich skarns because we see abundant evidence for the encroachment of the latter onto dolomitized marble (this evidence will be studied at stops 11 and 12). Suffice it to say that dolomitization may have occurred during the skarnoid event or as a precursor to the development of late ore-bearing skarns.

The purpose of this stop is to examine the nature of Mg-skarn in the deeper, higher temperature environment proximal to the batholith. Reference to Figure A shows that we are approximately 2.5 km below the surface at the time of hydrothermal activity — this is the deepest we will go on this trip! High-temperature magnesian skarns are generally zoned from diopside (commonly aluminous fassaite) and spinel near vein centers or pluton contacts to forsterite and calcite on the dolomitic marble side. At this locality, we find a very high temperature analogue to cal + diop + forsterite, monticellite ($CaMgSiO_4$), which is stable only at temperatures above approx 675 °C for the P-X_{CO_2} conditions estimated (P = 0.5kb, X_{CO_2} = 0.05). Monticellite occurs as colorless to gray prismatic crystals, here constituting some 90% of the rock, with interstitial calcite and late tremolite. Other minerals characteristic of magnesian skarns that are found nearby and only in this deeper environment near the batholith include periclase (MgO), szaibelyite ($MgHBO_3$), ludwigite ($(Mg,Fe)(Fe)BO_5$), and magnesioferrite ($MgFe_2O_4$)-rich magnetite. Ca-cpx is diopsidic, ranging up to 20 mole % hedenbergite ($CaFeSi_2O_6$), and garnets are intermediate grossular-andradite (30-50 mole % gross ($Ca_3Al_2Si_3O_{12}$). To the southwest (away from the batholith and toward the original surface), magnetite, pyroxene and garnet become more iron rich, the borates disappear, and olivine-type minerals (forsterite, monticellite) probably never formed, their place being taken by lower-temperature analogues such as talc and serpentine. As we walk toward the next stop, you will see yellow and yellow-green veins in dolomitic marble — these are serpentine veins.

Stop 9.

On saddle 500 ft east of Douglas Hill. To this point you have probably been wondering what all this discussion of mineralogy, mineral compositions and stabilities, skarnoids, etc., has to do with finding mineral deposits! Well, at this stop, you will be rewarded . . . You may have been tempted to call many of the rocks we have seen so far "skarn" — afterall, they are relatively coarse-grained calc-silicate rocks formed by the metasomatic replacement of carbonate rocks and associated siliceous rocks. BUT, we can ascribe most of these rocks to the passage of non-specialized hydrothermal fluid, perhaps of connate-metamorphic origin, put into convective motion by the emplacement of the grd batholith. Most of the components present could have been locally derived. The calc-silicates are pale in color, low in iron, and are not associated with sulfides. Here, we pass into a new world — you are standing on "true skarn", composed of coarse-grained, dark-colored andradite garnet ($Ca_3Fe_2Si_3O_{12}$) with interstitial calcopyrite. Clinopyrozene (as we will see later) is coarser-grained, bladed, and dark green, with 30–55 mole % hedenbergite. The most distinctive compositional feature of these rocks is their very high Fe-content (Table 3, cols. 4 & 5) — this, in addition to their Cu and S content, and their physical aspect, sets these "true skarns" apart from the hornfelses and skarnoids. One is led to suspect that highly specialized hydrothermal fluid was responsible for the formation of these skarns, a fluid that introduced exotic components from outside the contact aureole, and may have had genetic ties to fluids responsible for the formation of porphyry copper deposits in the batholith to the north.

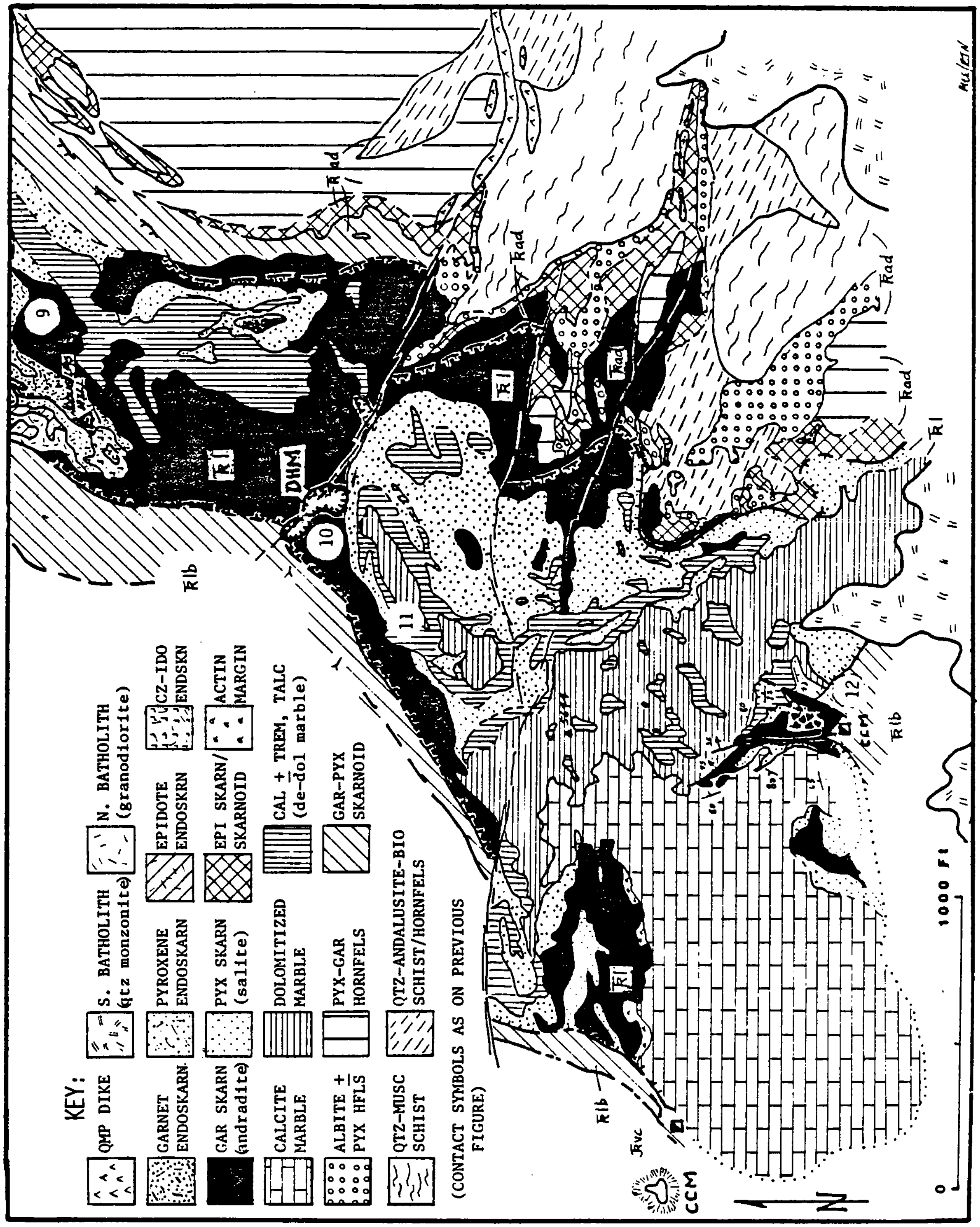


Figure 4. Detailed skarn geology casting area.

Stop 10.

DOUGLAS HILL mine. Be careful!! We will cross a narrow rock bridge between two large open glory holes — this bridge, though solid, is overhanging on its western side — DO NOT APPROACH THE EDGE.

We have been walking along strike in the TRl unit, away from the batholith. We are well beyond the outer limit of skarnoid in TRl, and in the skarn environment. Mixed sulfide-oxide ores of Cu were mined from andradite skarn at the Douglas Hill mine; most of the sulfides (chalcopyrite>pyrite) fill vugs in garnet or occur in cross-cutting veins with minor quartz and actinolite. A close spatial association of chalcopyrite with andradite, rather than with pyroxene, is characteristic of all skarns in the district. Andradite skarns are separated from dolomitic marble by zoned envelopes of pyroxene, tremolite, talc, and calcite. We will study these zoned relations at the next stop.

Stop 11.

Saddle between Douglas Hill and Hill 5644. At this locality the massive andradite skarn, composed of dark green and brownish-green garnet ranging in composition from 95 to 100 mole % andradite, is about 200 ft thick and localized along the upper contact of TRl with TRlb. Separating the andradite from dolomite is an irregular zone, a few feet to tens of feet thick, of medium gray-green pyroxene (salite, with 30 to 55 mole % hedenbergite, 1 mole % johannsenite, and the remainder diopside component). Within this salite skarn are numerous small discontinuous veinlets of pale salmon-brown garnet (intermediate grandite with 50 to 70 mole % andradite) — this pale garnet can also be found veining the dark andradite skarn and is, therefore, the youngest garnet recognized in the district. On the marble side of the pyroxene zone, salite veins with tremolite envelopes and outermost talc (or serpentine) and magnetite envelopes finger out into dolomitized marble. In some cases, you may find innermost cores of pale garnet. In effect, the district-scale zonal pattern, so well-illustrated in figure 4, is mimicked on the scale of a few cm in a hand sample.

Stop 12.

In gully at base of south slope of Hill 5644 — southern workings of CASTING COPPER mine. This is our final stop. To this point we have seen evidence for prograde, outward growth of skarn zones — inner zones encroaching on outer zones as these in turn encroached further into marble: garnet veins pyroxene, pyroxene veins tremolite-talc, tremolite-talc veins marble, etc. Here, at the Casting Copper mine, we see evidence for the reversal of this pattern — the paragenesis from old to young matches the zoning from proximal to distal (vein center to marble). This reversal in the paragenetic sequence was initiated by a major brecciation episode, and followed by local retrograde alteration of andradite to cal + qtz + magnetite.

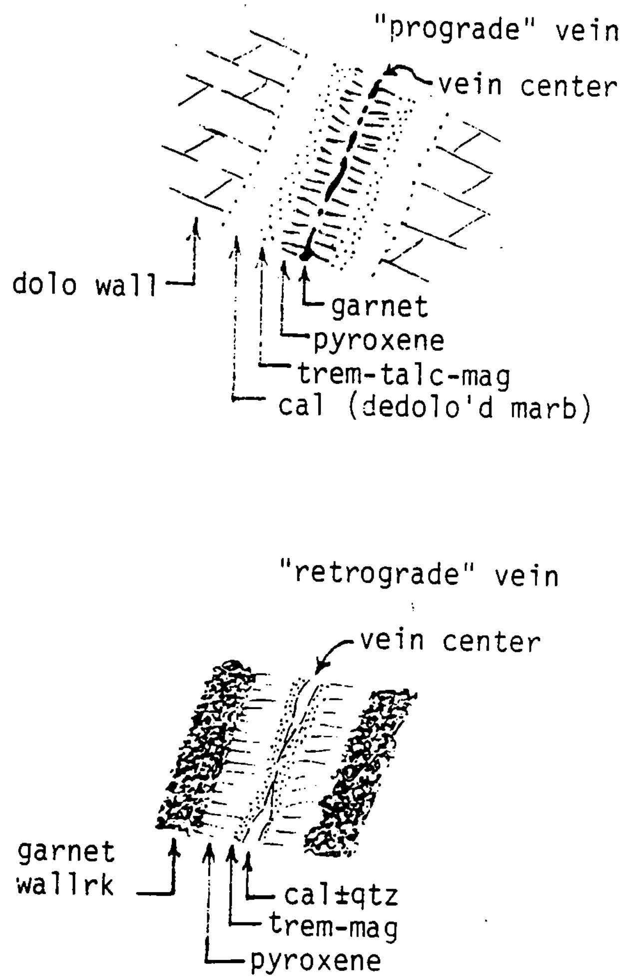


Figure 5. Vein mineralogy.

Summary of mapping technique

Detailed mapping (or core logging) scheme developed at Yerington in the 1970's, based on similar methods used at El Salvador, Chile.

The essential idea is to record, by means of a color code, the various important features of rock type, structure, veins, alteration and mineralization. Pay particular attention to relative age of veins, and record carefully in notes. Because of the large number of observations which need to be made and recorded, one can use either a series of overlays (this works well for continuous outcrop mapping) or a series of columns each of which represents closely related features (this works well for core logging or tunnel and bench mapping). The latter approach is given below.

After laying out the tape, a base line is established which represents either the toe of a bench face or the wall of a tunnel. This base line serves to divide your mapping sheet into two portions: 1) the rock side is used to record faults, veins, mineralization, lithologic contacts, strike and dip, etc.; 2) the air side is used to record alteration and rock type. The following types of observations and color codes (colors are keyed to "Eagle Verithin," which I recommend for mapping because of their fine and relatively hard leads) have been established for mapping in porphyry copper environments (similar schemes have been successful in other environments):

"Staedtler Mars-Lumochrom" pencils are also very good. The importance of a hard lead which can be sharpened to a fine point cannot be overemphasized!

I. Alteration of Mafic mineral grains (inner column next to base line)
   A. of hbl
      1. fresh - write lower case h's along base line.
      2. chloritized - green (739)
      3. biotized - olive green (739½)
      4. tan-colored pseudomorphs (sericite?) - orange (737)
      5. absent - black (generally used for qtz-ser rock).
   B. of biotite
      1. fresh - olive green (739½)
      2. chloritized - green (739)
      3. tan-colored pseudo (sericite?) - orange (737)
      4. absent - black (general used for qtz-ser rock).

II. Alteration of feldspars (outer column)
   A. To secondary K-spar - magenta (759)
   B. To secondary albite - yellow (735)
   C. To sericite (and or clays) - brown (756)

1. hard, clear, glassy, good cleavage - leave blank
2. hard, white, good cleavage (i.e., "bleached") - sparse brown dots.
3. partially soft, white to pale green, cleavage still present (i.e., moderate sericite) - closely spaced brown dots.
4. soft, no cleavage, but rock texture still preserved - continuous light brown line.
5. qtz-sericite rock, texture obliterated - continuous dark brown line.

C. To epidote - olive green (739½)

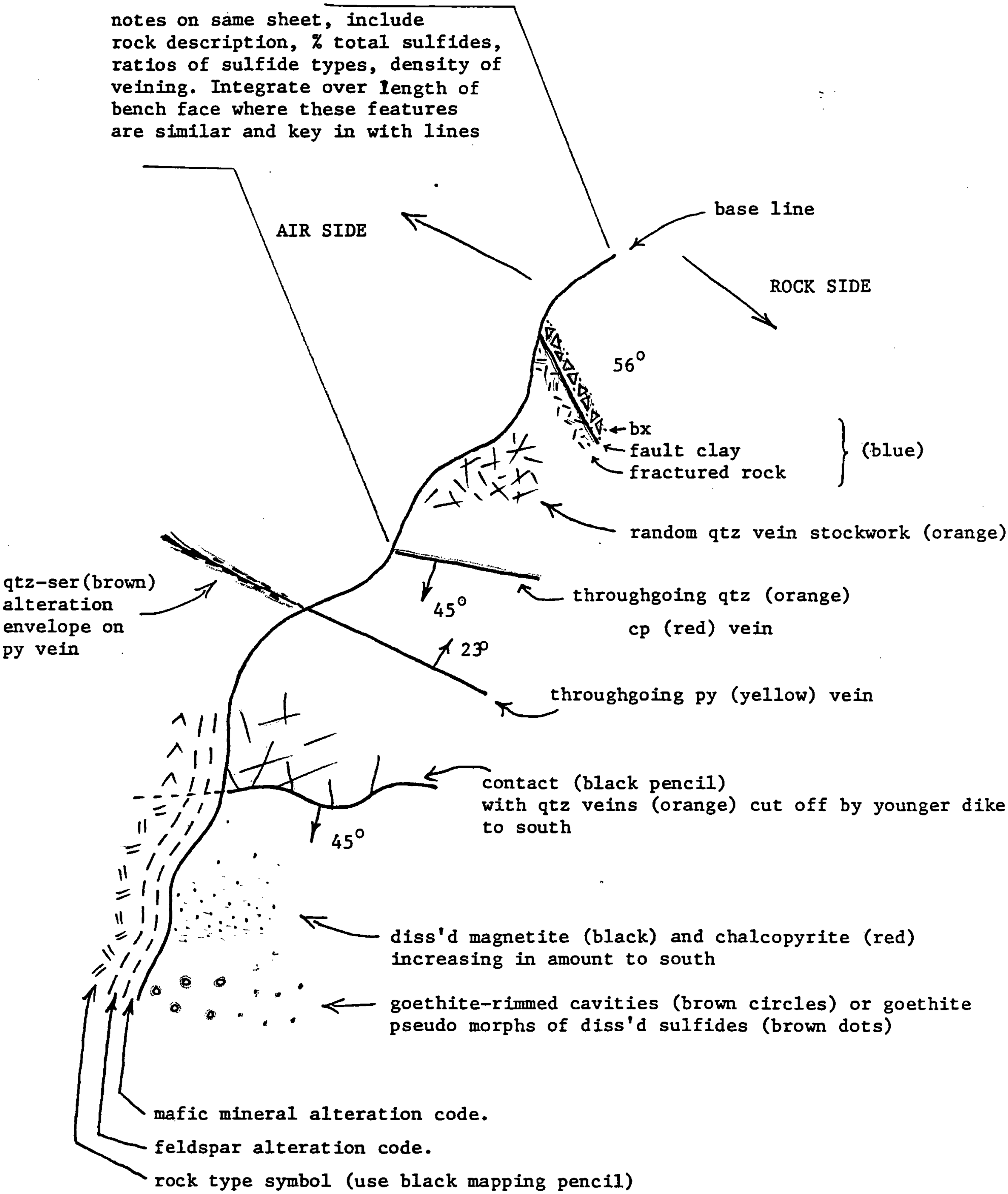
III. Veins - Plot strike of vein, using color of dominant mineral(s) (see color code below), on the rock side of base line. If vein has an alteration envelope, use color of dominant alteration mineral as a continuation of vein on air side of base line.

IV. Mineralization - schematic representation of mineral distribution (density and texture) plotted on rock side with appropriate color. Dots for disseminated, random short lines for stockwork veinlets, continuous lines for through-going veins.

A. Hypogene
1. chalcopyrite, bornite - red (745)
2. sphalerite - brown (756)
3. molybdenite - green (739)
4. pyrite - yellow (735)
5. magnetite, hematite - black (mapping pencil)
6. quartz - orange (737)
7. tourmaline - lavender (742½)

B. Supergene
1. oxide Cu (chrysocolla, malachite, tenorite) - true green (751)
2. goethite - brown (756)
3. glassy limonite - red (745)
4. jarosite - yellow (735)

V. Faults - sketched to scale, plotted with true strike - indigo blue (741).


notes on same sheet, include
rock description, % total sulfides,
ratios of sulfide types, density of
veining. Integrate over length of
bench face where these features
are similar and key in with lines
AIR SIDE
base line
ROCK SIDE
56°
bx
fault clay
fractured rock
(blue)
random qtz vein stockwork (orange)
qtz-ser(brown)
alteration
envelope on
py vein
throughgoing qtz (orange)
45°
cp (red) vein
23°
throughgoing py (yellow) vein
contact (black pencil)
with qtz veins (orange) cut off by younger dike
to south
45°
diss'd magnetite (black) and chalcopyrite (red)
increasing in amount to south
goethite-rimmed cavities (brown circles) or goethite
pseudo morphs of diss'd sulfides (brown dots)
mafic mineral alteration code.
feldspar alteration code.
rock type symbol (use black mapping pencil)

Note that the division of your mapping sheet into imaginary columns ensures that there is not an excessive overlap of symbols, and allows the continuous recording of over 25 different mineralogical features with only 10 colors:

green	739
olive green	739½
orange	737
magenta	759
yellow	735
brown	756
red	745
true green	751
indigo blue	741
lavender	742½

There are numerous advantages of this mapping system over those currently in use:

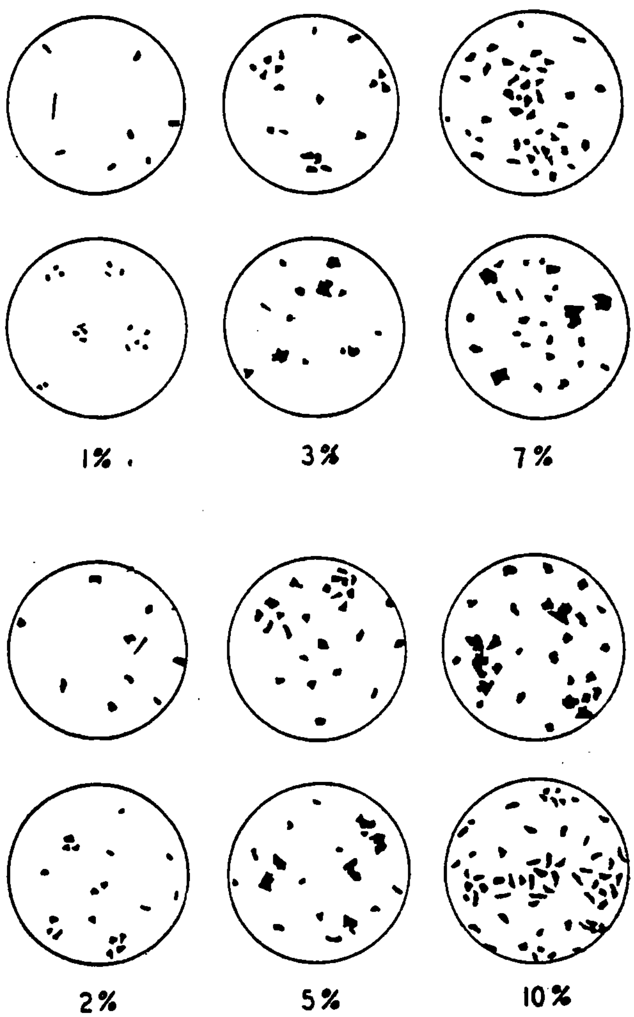
1) It forces you to make continuous observations (a blank spot on your map implies no outcrop)
2) Once you get used to the scheme, it yields more information than note taking and cuts down on note taking (note, however, that there is no pictorial provision for rock descriptions, including grain size, textures, mineral abundances and proportions - such notes have to be recorded).
3) The finished mapping sheet gives you a pictorial color-coded representation which can be correlated by eye with nearby areas.

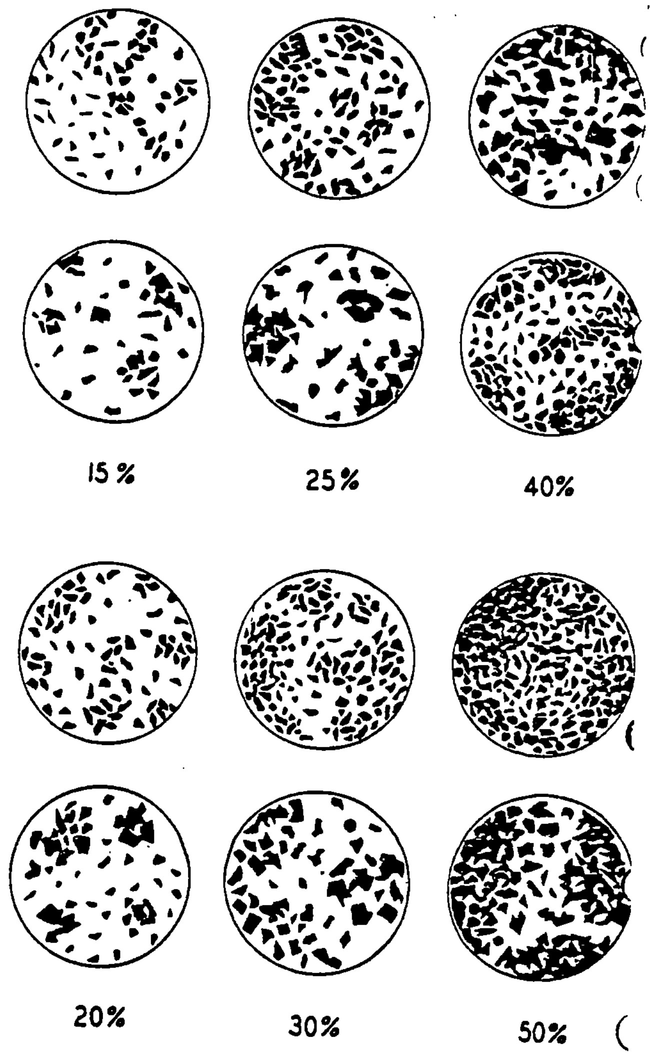
Note that all features are plotted on a horizontal plane--the elevation of the plane is genearlly taken as chest height. Features which do not project to chest height within a reasonable distance of the base line (e.g., flat faults at ankle level) should be recorded in notes and/or a quick sketch of the vertical bench face should be made. The advantage of projecting all geology to a horizontal plane, rather than simply sketching the vertical face (which is easier), is that in normal circumstances, you would be attempting to correlate what you see in one cut or tunnel with observations made at the same elevation elsewhere on surface or in a mine. In other words, vertical cross-sections generally are based on completed plan maps, combined with available drill hole data.

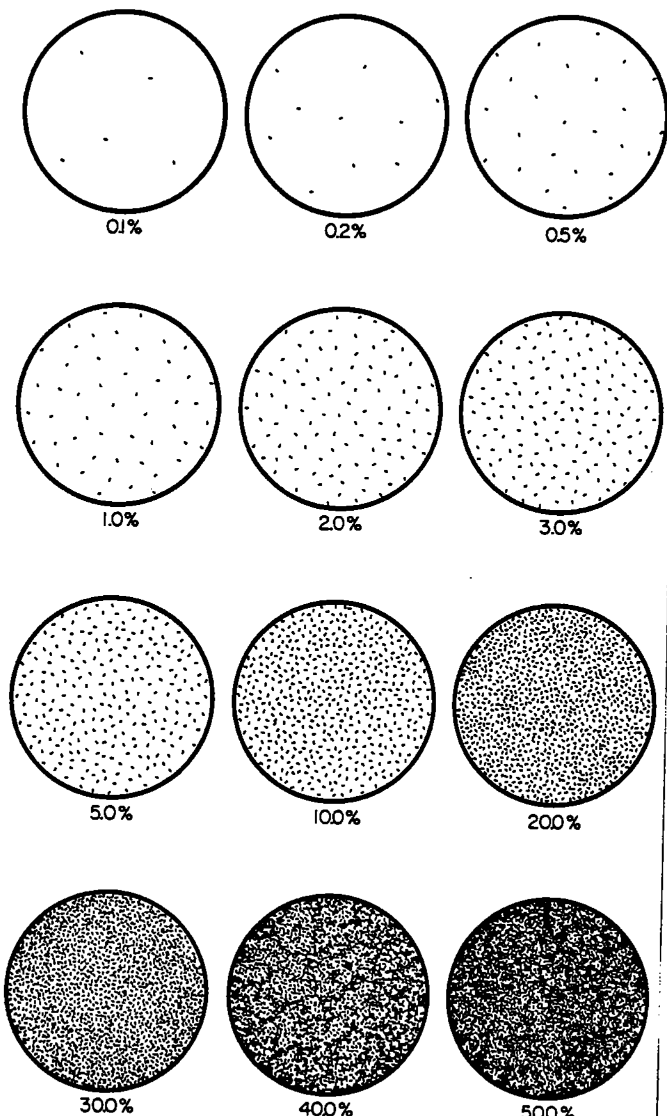
AGI
6

COMPARISON CHART FOR ESTIMATING PERCENTAGE COMPOSITION

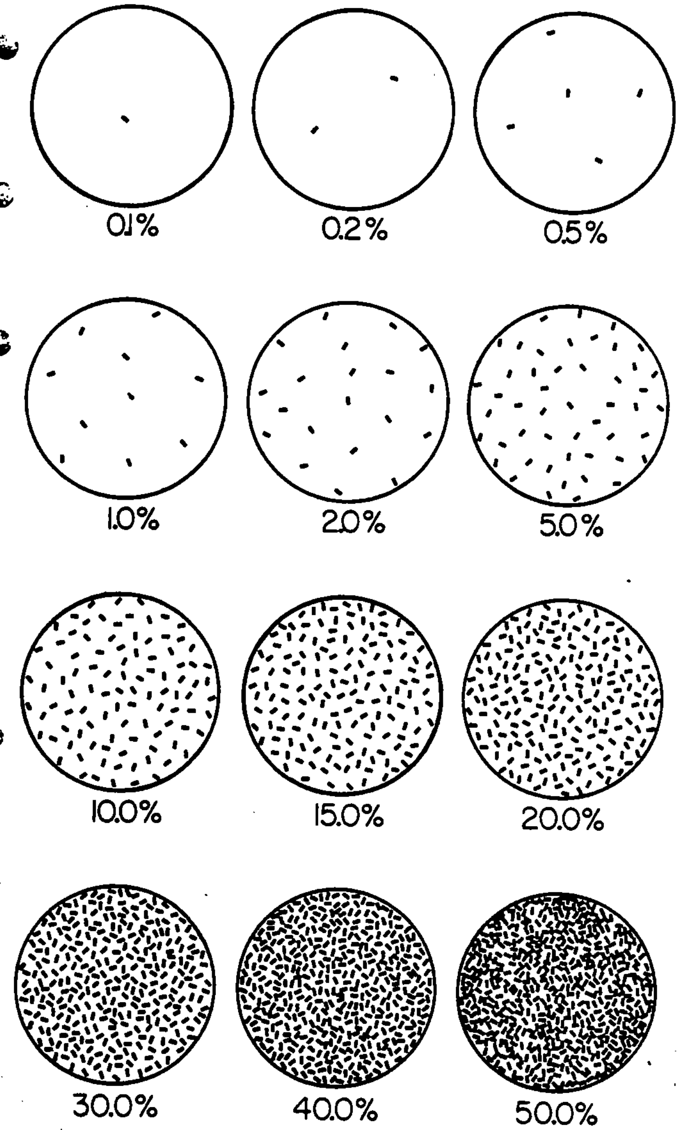
by Richard D. Terry and George V. Chilingar,
Allen Hancock Foundation, Los Angeles
Reprinted from Jour. Sed. Pet., v. 25, no. 3,
p. 229-234, Sept. 1955







particle size 0.47mm x 0.21mm



particle size 1.05mm x 0.46mm

useful items

LIST OF ITEMS YOU WILL NEED

1. 8½ x 11" grid paper, ∿20 sheets
2. ✓ plastic scale-protractor (I have a few left) 1:50 1:20
3. clip board, rubber bands
4. hard cover note book, pocket size
5. color pencils, erasers
6. brunton (if you don't have one, sign one out from Geology Dept.)
7. hammer
8. knife
9. hand lens
10. ✓ hand magnet
11. acid bottle with dilute HCl
12. sample bags, waterproof felt markers (if you want to collect samples, optional)
13. backpack, small-med size
14. sleeping bag
15. 100-foot cloth tape (I have a limited supply; bring yours if you have one).
16. wind breaker, down jacket or vest
17. assorted useful items: sunglasses, hat, camera, toilet paper, water bottle, etc.
18. long underwear!!!!

gloves

cups, bowl, spoon

8 - 8½x11 mylar

60 8½x11 Mylar - fairly thin

Final Report - AES 277

Your report should consist of a summary of field observations, sketches and mapping at MacArthur and Casting Copper.

MACARTHUR - your original mapping sheets should be included with your report. Based on these mapping sheets, compile the following (for each trench you mapped):

1. Base Map - rock type and structure. Extend the geology 100 feet beyond the base line, but be careful of cross-cutting faults, contacts, etc., on which you might have no information. In extending faults, give priority to major zones of brecciation and gouge.
2. Alteration Map - with your base map as guide, draw a map illustrating the distribution of alteration types. Include only those faults which appear to place different alteration types in contact and include only those rock-type contacts across which alteration types change. Alteration types should include: K-silicate, albitic, propylitic, sericitic (define each in legend or separate sheet) and additional features such as quartz veins, tourmaline, etc. Assume that changes in alteration types are parallel to the general trend of the porphyry dikes, unless you have evidence to the contrary.
3. Mineralization Map - with your base map as guide, show the distribution of oxide minerals, e.g., limonite (goethite), jarosite, chrysocolla, malachite, tenorite, glass limonite. Use dots for disseminated oxide products which are pseudomorphous after primary minerals; small open circles for leaches cavities; random short lines for oxide concentrations on random fractures; through-going lines for oxides associated with faults or oxidized primary veins. In the above maps use any color code you desire.

In addition to your general description of rock types and alteration and presentation of the above maps, your report should include a discussion of the following specific topics (considered with respect to the trenches you mapped and not the deposit as a whole):

1. What evidence did you see for the original presence of primary sulfides?
2. What are your estimates of: a) percent total sulfides; b) approximate ratio of cp/py; and c) textural occurrence of original sulfides. How do the above vary with changes in rock type or primary alteration types?
3. What features appear to be the major controls of the distribution of oxide copper and iron mineralization? That is, what rock types, alteration types, and/or structures?
4. In light of the above, what physiochemical arguments can be made to explain the precipitation of secondary Cu-minerals at MacArthur?
5. Where in the MacArthur alteration/mineralization pattern might you expect to find the greatest abundance of supergene copper sulfides? Why?

CASTING COPPER -

The main ephasis in the Casting paper should be: 1) a description of the skarn body and its surroundings; and 2) an interpretation of its temporal and spatial growth.

Description. Present your field map and outcrop-scale sketches as the basis for this section. Do not add to your field map any interpretations that you did not make in the field--use an overlay to complete the map on the basis of discussion with others in the group or on the basis of your imagination. Your description should include the following:

1. District and Local Setting of the Deposit. One or two paragraphs should suffice.

2. General Statement. Include here a brief description of the morphology, size, structural control, and general mineralogy of the skarn body. Describe its position relative to hornfels and limestone. Set the stage for the detailed description that follows.

3. Description of the skarn. Here you should outline the details of texture, mineralogy, mineral assemblages, timing of events supported by the evidence, for each of several different "zones" or "styles" of skarn. For example you could discuss these aspects for each of several areas in the

skarn that are relatively distinct spatially or texturally:

a. skarn-hornfels contact zone
b. massive garnet zones
c. coarse grained bladed pyroxene zone
d. breccia zone
e. contact against marble
f. veins in marble
g. distribution and timing of sulfides and oxides
h. distribution of retrograde alteration of garnet and pyroxene.

Interpretation. Use your observations, described in the previous section, to propose a "space-time" model for the evolution of the skarn. By the term "model", I mean a description of the textural and mineralogical development, not a geochemical model. The best way to approach this is to draw a series of 4 or 5 time frames illustrating your idea of the growth of the deposit. The text in this section should be short.

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