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TECTONIC FEATURES OF THE REDDING-WEAVERVILLE DISTRICT

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Mining 198
May 31, 1948

TECTONIC FEATURES OF THE REDDING-WEAVERVILLE DISTRICT

Introduction

The area comprising the western half of Shasta County and the northeastern corner of Trinity County, the Redding and Weaverville quadrangles, contains one of the richest base metal districts in California as well as a large part of the rich Klamath Mountains placer province and an extensively developed gold-quartz lode district. Some of these mines were among the earliest discovered in California and almost all of them were in operation by the first few years of the century. As a consequence, mining activity in the district appears to have passed its peak and, although from all accounts good ore remains in economic amounts, the lowered grade and present increased operating costs prohibit any duplication of past performances. In addition, the extensive copper bodies have been all but worked out, and present operations are on a small scale in comparison to the old days at Iron Mountain, Mammoth, and Bully Hill.

Geography

The northern end of the Sacramento Valley terminates abruptly in an arc-shaped escarpment through which is incised the deep canyon of the combined Sacramento, Pit, and McCloud Rivers. In the segment radiating from this arc to the west and north, the topography is complex and rugged, with increasing altitudes toward the northwest culminating in the Trinity Alps

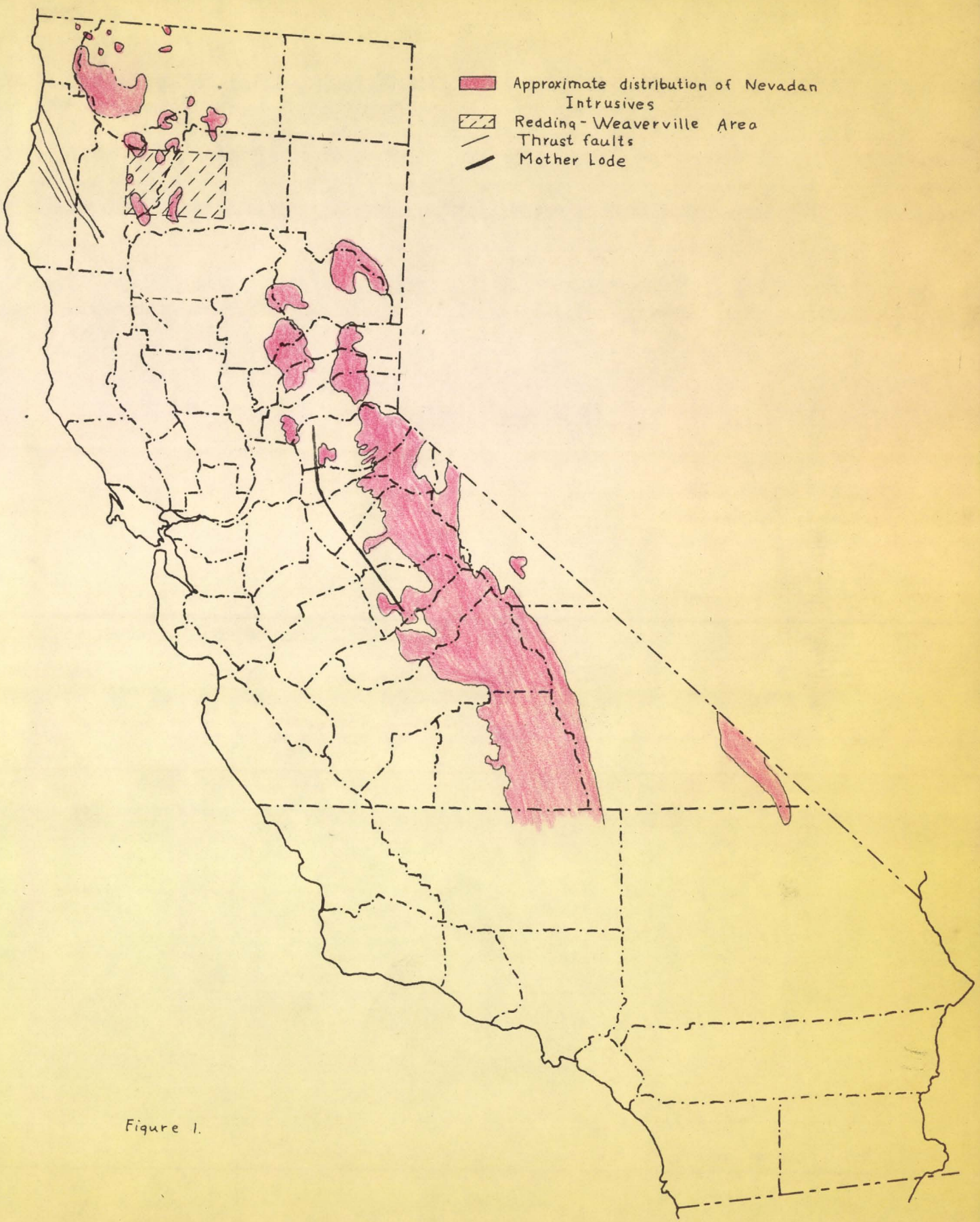

Approximate distribution of Nevadan Intrusives
Redding - Weaverville Area
Thrust faults
Mother Lode

Figure 1.

area. To the northeast and east the transition is more gradual, rising through low foothills to the moderate elevations of the Tertiary volcanic fields and peaks north of Mt. Lassen, and beyond into the extensive lava beds of Lassen and Modoc Counties.

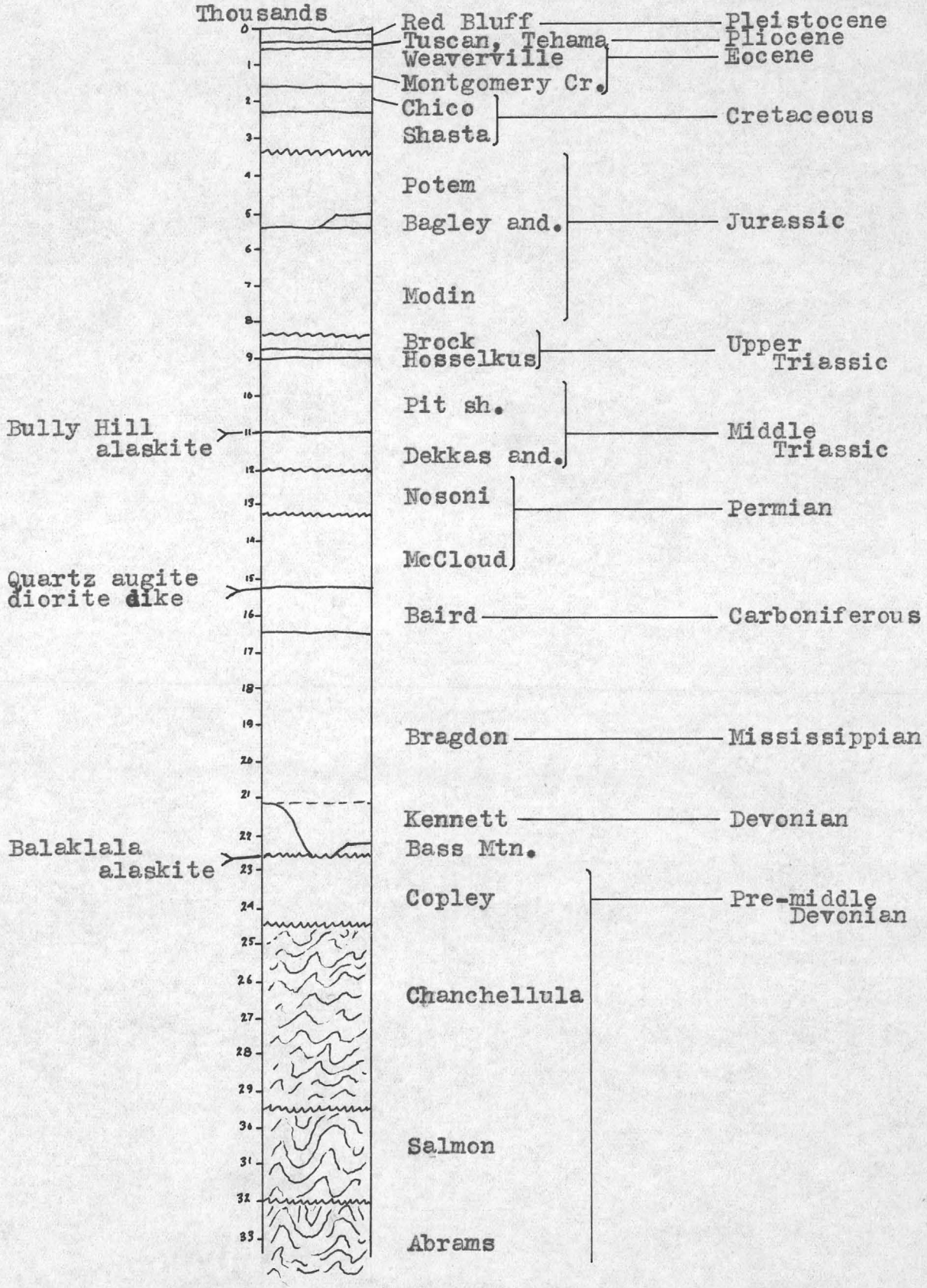
Concentric to the rounded tip of the Sacramento Valley and radially 6 to 8 miles into the mountainous zone lies the so-called copper belt with its eastern tip at the Afterthought Mine 20 miles northeast of Redding and ending on the west at Iron Mountain 9 miles northwest of Redding.

The gold districts are clustered into more equidimensional patches, the most notable groups being the Old Diggings District 10 miles north of Redding, the French Gulch District, the Shasta District centered 4 or 5 miles west of Redding, and the Schilling area several miles to the northwest of Shasta. There is also a small silver area included in the southern part of the Shasta District. About 15 additional mines are scattered at random over the west and northwest part of the Weaverville quadrangle and in the western part of the copper belt.

Stratigraphy

An extremely extensive stratigraphic column is represented in the area under discussion from the standpoint of thickness and time range both. A complex history is represented, with several contacts complicated by deposition on irregular surfaces. Remnants of partly-removed formations

STRATIGRAPHIC COLUMN



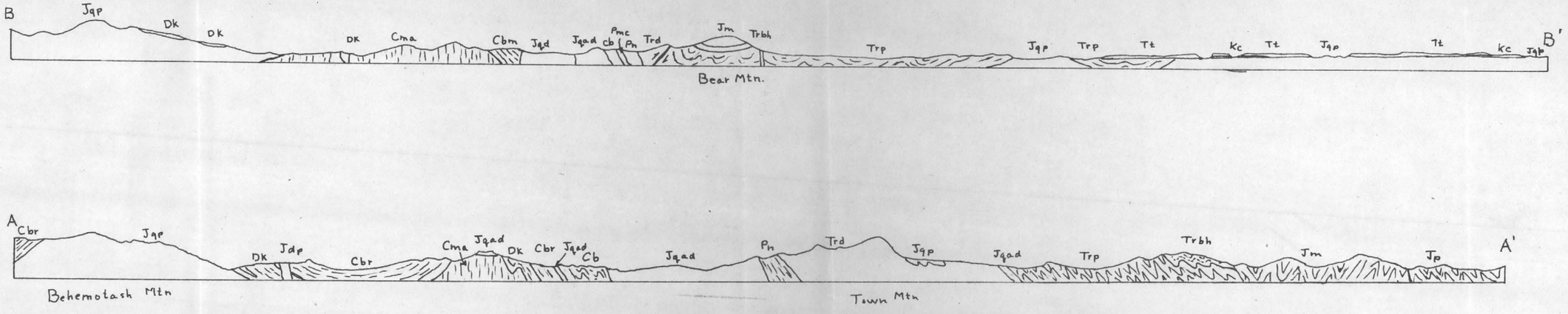
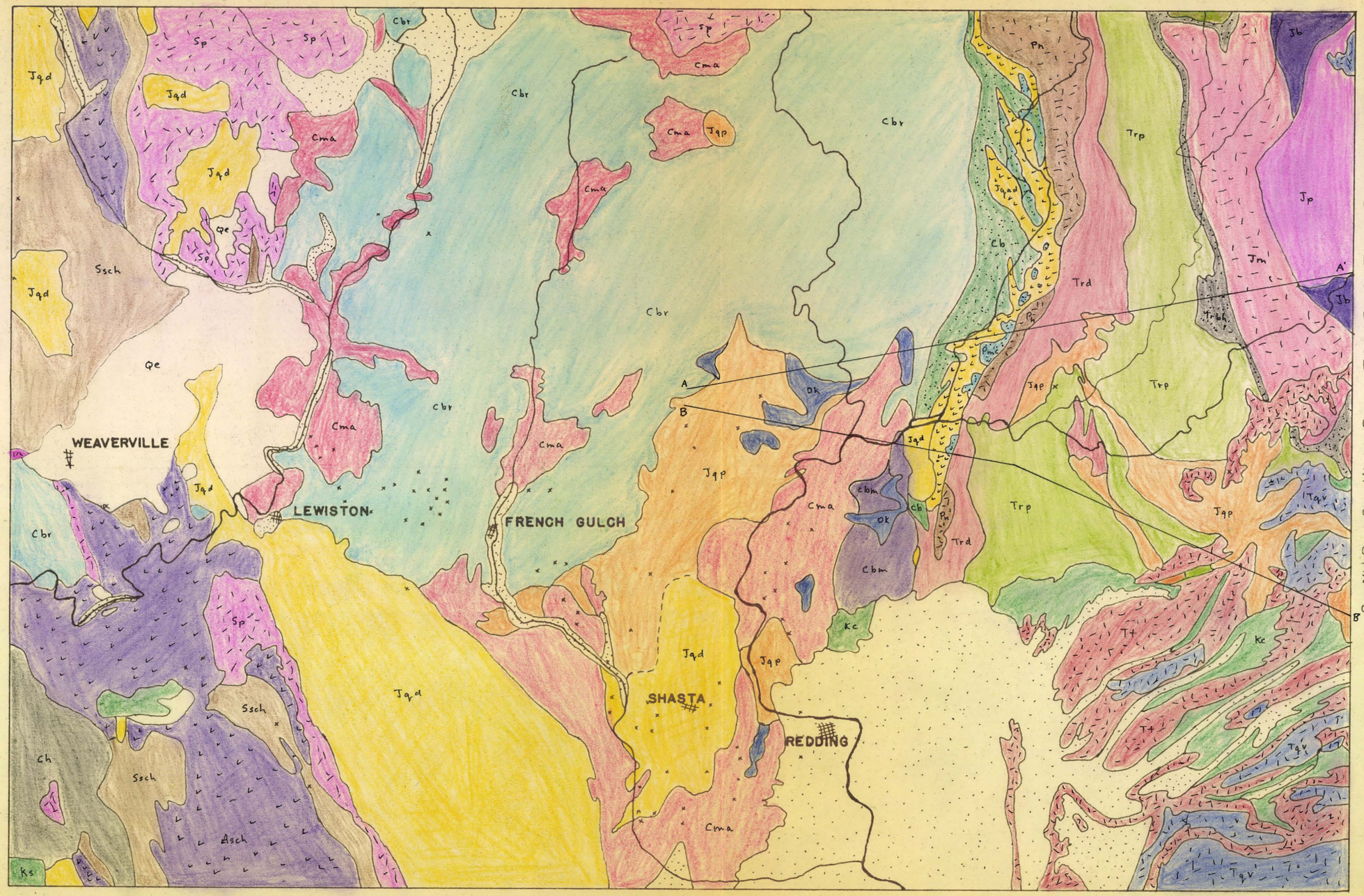


Figure 3.

Sections after J.S. Diller from the Reading Folio. Formation names changed to correlate with more recent work. See figure 2. Geology as mapped by Diller.



Alluvium

Tertiary & Quaternary Volcanics

Tert.
- Tehama & Tuscan
- Eocene Gravels

Cret.
- Chico, Shasta & Knoxville

Juras.
- Alaskite Porphyry
- Quartz Diorite & Granodiorite
- Quartz-Augite Diorite

Pre-Nev. Juras.
- Potem fm.
- Bagley Andesite
- Modin fm.

Trias.
- Brock sh. & Hosselkus ls.
- Pit fm.
- Dekkas Andesite

Perm.
- Nosoni fm.
- McCloud ls.

Miss.
- Baird fm.
- Bragdon fm.
- Bass Mtn. Basalt

Dev.
- Kennett fm.

Pre-Mid. Dev
- Copley Meta-Andesite
- Chanchelulla fm.
- Salmon Schist
- Abrams Schist

Serpentine

Mines

GEOLOGY OF THE REDDING AND WEAVERVILLE QUADRANGLES
(AFTER DILLER, HINDS, AND RUSSELL)

0 4 8 12 MILES

or large windows of older formations are exposed by deformation and erosion prior to the deposition of the younger beds. Widespread vulcanism seems to have been the rule for the southern Klamath Mountains throughout geologic history, and further irregularities arose as a result of the intercalation of local minor igneous bodies.

The Abrams and Salmon schists were classified by Hershey (1) as pre-Cambrian and by Hinds (2) as pre-Middle Devonian and probably pre-Silurian. In any event they are not representatives of products of a very high grade of metamorphism, although the fabric of the Abrams bears the imprint of at least two periods of deformation with unlike tectonic directions. The Abrams is made up ofquartz-mica schist and micaceous quartzites representing cherts and impure quartzose sediments, while the Salmon is mostly actinolitic and chloritic greenschists representing basic or semi-basic volcanics.

The Chanchelulla formation is another metamorphosed sedimentary section similar in original composition to the Abrams, but metamorphosed to a lesser degree. The formation contains basic schists in the upper horizons which Hinds concludes are representatives of thick sills and dikes. He further suggests that these rocks are conceivably intrusive members of the overlying Copley meta-andesite.

The Copley is one of the important formations involved in the later period of ore deposition. The formation is made up of thick flows of pyroxene andesite, with lesser basalt members. Large thicknesses of pyroclastics are also included. The degree of metamorphism varies between wide limits. The

bulk of the Copley is a chloritic greenschist in which the porphyritic, amygdaloidal, and pyroclastic textures are often well preserved. Near intrusive contacts the metamorphism is of a higher degree and the rock is completely recrystallized to an actinolitic schist. Shear zones and faults are abundant in the Copley, and along these a chlorite schist is usually developed.

The Kennett formation is a black slate with interbedded sandstone and marble resting unconformably on the folded and much-eroded Copley. The Kennett itself was very deeply eroded and remains only as scattered remnants at the base of the Bradgon formation so that the Bragdon contact is predominantly based on the Copley meta-andesite. The Bragdon-Copley contact is important as the localizer of the controversial "pocket" gold deposits of the Klamath Mountains as well as the laccolithic type intrusions of alaskite which bear the copper deposits. The Bragdon itself is a thick sedimentary formation consisting of black, thin-bedded, slaty shale with sandstone and conglomerate. Included in the base of the Bragdon is the Bass Mountain basalt.

The Baird formation and McCloud limestone make up a conformable continuation of post-Bragdon deposition. The Baird is variable, grading from tuffaceous and calcareous sandstone and slates to coarse lithic tuffs. The McCloud limestone consists almost entirely of gray fine-grained marble. The McCloud-Baird contact is important as the apparent localizer of a large dike-like body of quartz-augite diorite with which are associated the magnetite deposits of Hirz Mountains

and the Shasta Iron Company near the junction of the McCloud and Pit Rivers.

The major part of the Nosoni formation is made up of lithic crystal tuffs and agglomerates, with flows of basalt and andesite. Upwards in the section these beds give way in importance to tuffaceous shales and sandstones with a little limestone.

The Triassic section includes the Dekkas andesite, Pit shale, Hosselkus limestone, and Brock shale. The Dekkas-Pit contact is the highest horizon of economic importance, for it is probable that this horizon exerted a control on the eastern alaskite intrusion similar to that of the Copley-Bragdon contact to the west. The eastern alaskite and the Pit shale at the igneous contact contain the Bully Hill and Afterthought ore bodies. The Dekkas is composed of flows, tuffs, breccias, and agglomerates of pyroxene andesite. Upwards, shaly members increase so that there is a transition to the slaty shales of the Pit formation. These latter beds also include sandstone, cherts, tuffs, agglomerates, and minor flows. A few intrusive bodies outcrop in the Pit shale and local increases in metamorphic grade suggest underlying igneous bodies. The Hosselkus and Brock formations are thin conformable sediments of siliceous limestone and calcareous slates respectively.

The Jurassic formations are divided into the pre-Nevadan Modin, Bagley, and Potem formations, and the post-Nevadan Knoxville. The Modin is based on tuffaceous beds and a thick andesitic agglomerate, but consists mostly of

argillaceous sandstone. As near as can be ascertained, it is the highest stratigraphic horizon affected by the late Jurassic intrusions. The Bagley andesite is a small, local deposit of lava and tuff lying approximately at the Modin-Potem contact. This latter formation is predominantly sandstone, shale, and tuff.

Following or contemporaneous with the end of the Nevadan orogeny was the deposition of the Knoxville shale and sandstone, but this formation thins toward Shasta County and is overlapped to the north by the Cretaceous formations so that there is some doubt as to whether there was Knoxville deposition in the Klamath Mountain area. Even the Cretaceous sediments merely seem to overlap onto the flanks of the Klamath province, and it is usually suggested that this area has been a highland since Nevadan times. The Shasta formation contains fragments of the quartz diorite of the Shasta Bally intrusive on the west side of the area and the Chico formation rests directly on the Triassic Pit formation on the east side of the valley, indicating the extent of pre-Cretaceous erosion.

The Tertiary formations are the localized auriferous gravels of the Eocene, the Pliocene gravels, sands, and silts of the eastern valley foothills, and the late Tertiary and Pleistocene lavas of the Cascade volcanoes.

The Pleistocene gravels of the Sacramento Valley complete the section.

Intrusives

With the exception of certain basic intrusives of Paleozoic age (3) confined chiefly to the western part of the Klamath Mountains, all of the intrusive rocks in the Shasta-Trinity district appear to be associated with the extensive batholithic intrusions of the Nevadan orogeny. The main mass of these rocks consists of granodiorite and quartz diorite. In northern California these bodies have been described as stocks, bosses, and small batholiths, and it seems a valid supposition that they are actually high areas and apophyses in the roof of a major batholith subjacent to the entire Klamath Mountain region. The consistent composition of the scattered masses is evidence favoring this view as well as the northeasterly trend of these outcrops taken as a whole.

A more interesting conjecture involves the relation of this northern batholith to the main Sierra Nevada mass to the southeast. Composition and time relations coincide but the two are separated geographically by a salient into the west flank made by the Sacramento Valley and a salient into the east flank by the Cascade volcanics. These two features meet and effectively separate the two granitic bodies. The vertical relations are similarly discontinuous; the Sierran block reaches its maximum elevation at its southern end with the crest plunging to the northwest until it disappears in Plumas County beneath the flows of the Mt. Lassen area (see Fig. 1). Since the terrain in southwestern Shasta County is not high in comparison with the elevations reached by the

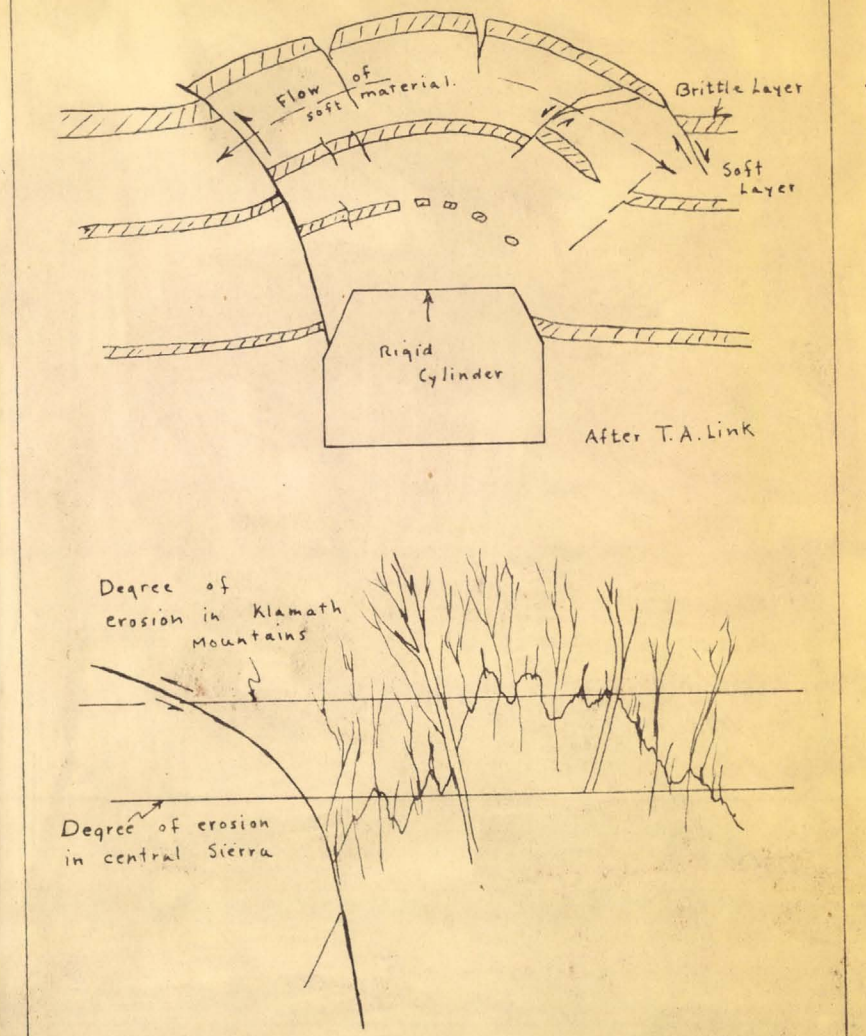
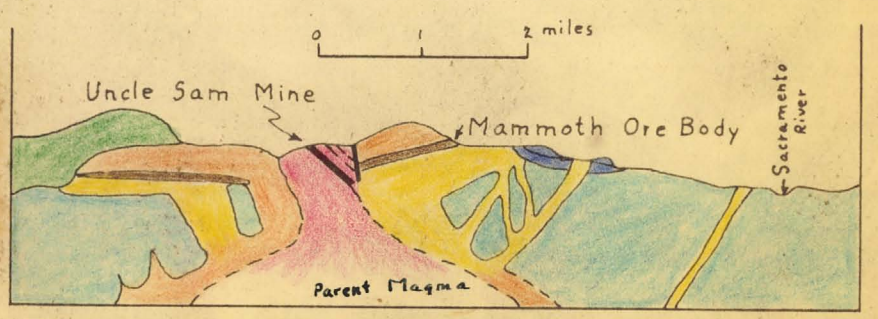


Figure 2.



Quartz Veins
Copper Ore
3rd Alaskite
2nd Alaskite
1st Alaskite
Carboniferous sh.
Devonian ls. & sh.
Copley Meta-And.

Idealized section looking north

(After Averill)

Figure 4.

northern batholith in the Trinity Alps, a reversal of this plunge is necessary to account for the re-emergence of the Sierran batholith if it is indeed connected with the Klamath batholith. Furthermore, the distribution of outcrops in Plumas County suggests that the Sierran body may swing in trend to the north and thus lose its alignment with the Klamath body.

In spite of these objections to an actual connection between the two batholiths there are certain other features which suggest that they are at least very closely related tectonically if not actually one and the same mass. The general overall alignment of the Klamath body with the main axis of the Sierra Nevada is the first outstanding feature that meets the eye. Less apparent, but possibly of greater importance, is the relationship of a set of large thrust faults in Humboldt and Trinity Counties with the Klamath batholith as compared to the relationship between the Sierran batholith and the Mother Lode. From Figure 1 it may be seen that these faults are offset from the intrusive outcrops by a greater distance than the Mother Lode is from the Sierran mass. However, as mapped (4) several of them have a shallower dip than the Mother Lode, and this situation fits the picture to be described. A second feature of importance in connection with these faults is their parallelism with the Mother Lode and with a small thrust segment in western Glenn County.

The suggested relations between these faults and the intrusives is shown in Figure 2. Deformation experiments with clay models has indicated that upward doming by thrust

from below resulting from the rise of a rigid plug may be accompanied by reverse faulting which is initiated at one of the cutting edges of the rising plug. Upwards these reverse faults are effected by slumping away from the domed area so that they are gradually rotated outwards into low angle thrusts. In the field the prevalence of low angle thrusts on the flanks of large uplifts in the Rocky Mountain area has been pointed out by E. Wisser. A characteristic of these thrusts appears to be that they are nearly flat near the surface, becoming steeper at depth. Therefore it is suggested that the Grogan and Redwood Mountain faults in Humboldt County described by Ogle and Manning are the shallow tops of thrusts initiated by the intrusion of the Klamath batholith and kept active by uplift of the solid mas intermittently effective down to Tertiary or even present time. As shown in the diagram these thrusts are counterparts to the Mother Lode and may even be extensions of the same zone which includes the Mother Lode if the two batholiths are connected. The difference in the dip of the two fault systems and their different spatial relation with respect to granitic outcrops is merely a function of the depth of erosion.

Mineralization is almost entirely lacking in northern Humboldt County for several reasons. If these thrusts do have their roots in granitic intrustions hydrothermal solutions should have been available to them. However, by the time these faults had flattened in toward the west the weight of the top block prevented the development of openings. In addition the development of lesser fracture systems in the

roof of the batholith and as a result of slumping of the flanks, uplift above the thrust diverted these solutions and kept them immediately above the batholith. The widespread and abundant injection of dikes into the roof attests the degree to which openings were caused to form in the vicinity of the intrusion. Graton (5) points out that the Mother Lode, if extended, would lead directly into the Shasta-Trinity mineralized area, lending further credence to the idea that mineralization did not stray horizontally beyond the steeper portions of the thrust. However, these ores are astride the approximate axis of the Klamath batholith and therefore are considerably east of the assumed thrust root.

In any event, although the alignment of granitic outcrops on each side of the Tehama County gap is a suggestion of an interconnection, the alignment of these associated faults is much better evidence of a tectonic relation between the two.

Minor intrusives resulting from differentiation of the main batholith run the usual full gamut from pegmatites and aplites to basic and lamprophyric dikes. These minor intrusives, as listed by Ferguson (6), include dacite porphyry, quartz-augite diorite, diorite porphyry, spessartine, and hornblende picrite. The quartz augite diorite dikes cut the Mule Mountain granitic body to be described subsequently. The lamprophyres are very minor in occurrence, but according to Ferguson one of the quartz veins is cut by a small lamprophyric dike, indicating that the final phase of igneous injection extended into the post-mineral period.

Intermediate between the batholithic members and these minor dikes is a series of economically important intrusives injected as laccolithic type bodies and large dikes.

This latter type is described by Hinds (2) as a plutonic dike of quartz augite diorite which rose along the Baird-McCloud contact for a strike length of 25 miles. Apophyses are numerous and the contacts frequently irregular. Large blocks of the walls are included in the intrusive, indicating a stoping action during intrusion. Like its small dike counterparts to the west, this body cuts quartz diorite, indicating similar time relations in differentiation and intrusion between the east flank and the more centrally located protions of the invaded area.

The laccolithic intrusions are the most important rocks in the copper belt, since all of the ore bodies are confined to sheared zones within them or very near to their contacts. In view of extensive roof stoping action, especially in the western or Balaklala segment, Hinds classifies these intrusives as chonoliths, but in any event there is evidence of arching of the beds over these masses while the basement surface remained flat. This feature will be described later. Petrographically these rocks consist of phenocrysts of quartz and albite in a microgranular ground mass of quartz and feldspar. The absence of ferromagnesians allows the use of the term alaskite. At its southeast side the Balaklala alaskite grades with apparent transition through a coarsely porphyritic phase with increasing ferromagnesians into the Mule Mountain stock west of Redding on the boundary between the two

Meta Andesite
" " " Amydaloidal
" " " Agglomerate
Braqdon sh.
Gossan
Alaskite
Iron Ore
" " Breccia
" " Porphyry-1st Series
" " " " -2nd " "
Interporphyry Breccia
Alaskite Porphyry-3rd Series
Quartz Diorite-fine grained
" " " " -coarse grained
L Lamprophyre
Silicified & Pyritized Areas
N
Alluvium
HORNET MINE
IRON MOUNTAIN
GEOLOGIC MAP
OF THE
IRON MOUNTAIN REGION
After O. H. Hershey
Contour interval = 100'
Scale:
0 100 200 300 FT.

Figure 5.

quadrangles. This intrusive is classified as a quartz-rich diorite with local areas deficient in ferromagnesians, but Hinds lists the constituents as being albite-oligoclase, quartz, hornblende, biotite, and minor orthoclase. On the basis of this composition, it is difficult to justify the term diorite. Due to the sodic plagioclase composition the rock is more probably a sodic granite and as such may well be directly associated, through differentiation, with the sodic alaskite. It is suggested that the Mule Mountain stock is a part of the parent magma of the alaskite. See Figure 4.

The detailed work by Hershey (7) at Iron Mountain enabled him to distinguish six separate phases of the alaskite intrusion, offering good indication of active changes in the deeper magmatic reservoir during this period of activity. Hershey's map (Figure 5) indicates the distribution of these phases. The alaskite is a fine-grained, non-porphyritic rock which is assumed to be the earliest intrusion of the alaskite magma. The alaskite breccia is included in the alaskite masses in some cases, but exists as independent masses in others. These early phases are regarded as intrusions distinctly apart from the porphyritic alaskites, since dikes of the latter cross cut the fine-grained form with sharp contacts. The first, second, and third series differ mainly through the increasing development of phenocrysts. The interporphyry breccia was intruded between the second and third series, according to Hershey. This phase consists of angular fragments of Copley meta-andesite, alaskite, and alaskite

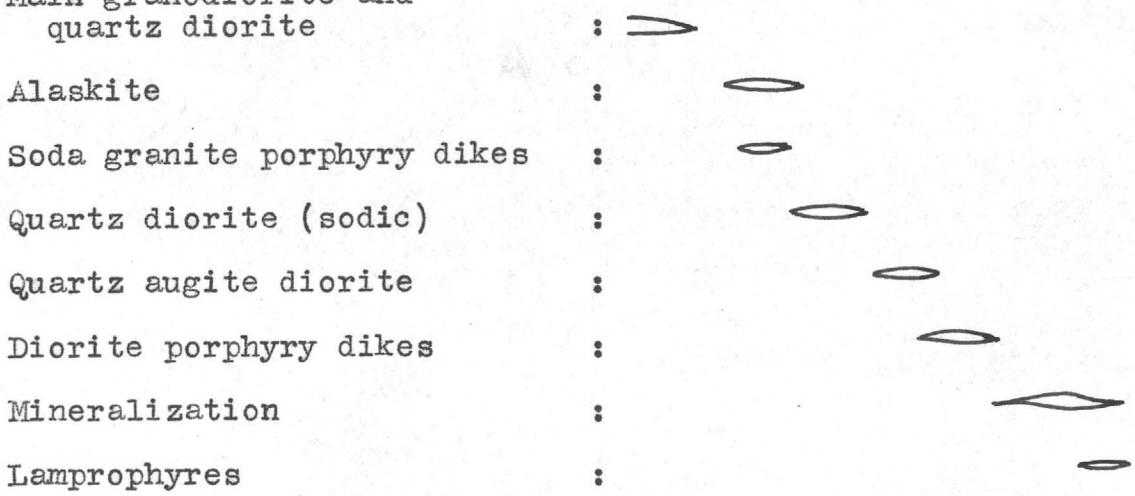
porphyry of the first series. Hershey states that the wide extent of the third series alaskite on the high ridge in contrast to the constricted outline in the canyons of Slick Rock and Boulder Creek is due to the laccolithic spreading of the porphyry beneath the Bragdon shales and above the Copley and earlier alaskite intrusions.

In the Bully Hill segment of the alaskite Wisser (8) noted variations in the appearance of the rock at the Afterthought mine which suggested the presence of several intrusive phases. Here the breccia phase is confined to a zone along the Pit shale contact. Often the rock is brecciated with flow banding concentric to the fragments. At the contact brecciated shale enters into the mixture. This phase is apparently the result of the brecciation of the solidified border zone of the initial intrusion by adjustments in the arched plastic Pit shale to subsequent injections or deforming movements. These conditions point to the conclusion that the alaskite was intruded during a period of maximum tectonic activity. All authors describe intense shearing and brecciation with the development of distinctly schistose phases. Graton (5) points out that this shearing is restricted to the alaskite and is not developed to a comparable degree in the Mule Mountain quartz diorite or the dikes associated with it. Here is evidence that the quartz diorite intrusion is later than the alaskite intrusion and the spatial relation of the two suggests that the deformation of the alaskite is the result of the intrusion of the quartz diorite. As suggested above, the latter may be the parent magma of the

alaskite and, in response to whatever force causes intrusion, simply followed it upward and became emplaced alongside of it where now exposed. The gradational contact between the two is evidence that the roots of the alaskite had still not crystallized at this time.

As will be described later, the lode mineralization is controlled by dikes acting as planes of weakness which provided openings for later mineralization under the influence of deformation. Ferguson (6) states that soda granite porphyry dikes in the Bragdon are the chief lode controls in the Iron Mountain district. A diorite porphyry dike swarm dominates the mineralization in the French Gulch district, while quartz augite diorite is important in the Shasta area. However, all types are found more or less throughout the Weaverville quadrangle. Diller (9) mapped numerous dikes in the Redding quadrangle, but did not break down the petrographic types to the extent that Ferguson did. However, most of these areas have no associated mineralization except in the gold district north of Redding.

From the above consideration it is possible to establish the time relations of the intrusives. It is to be noted that the agreement with the relations to be expected from the usual considerations of magmatic differentiation is good, the acid members having been emplaced first with basic intrusions following.



Structure

The structure in the Redding quadrangle as shown by Diller's sections (Figure 3) consists of a homoclinal dip to the east interrupted by the arching of the Bragdon over the Balaklala alaskite in the west and the arching of the Pit shale over the Bully Hill alaskite in the east. This homocline is made evident chiefly by the sequence of progressively younger formations from west to east; in detail it is complicated by isoclinal folding of varying intensity. The strike of all formations is between north and northwest.

Of particular interest is the structure associated with the alaskite masses. Attitudes in the shales overlying both the western and eastern segments dip away from the flanks of the intrusives in all cases. The constancy of this relation led Diller to the conclusion that these contacts were depositionally conformable and therefore that the alaskite was an extrusive formation. In the light of later information this same constancy is invaluable evidence favoring an arching process. The roof contact is complicated by stoping

in the Balaklala body, but the eastern contacts as seen in the Afterthought Mine (8) appear to be very nearly conformable with the bedding of the Pit shale.

As shown by the sections, the Copley meta-andesite stands nearly vertical and therefore did not take part in the arching. However, this situation does not rule out the possibility that the alaskite was simply intruded along the axis of a pre-existing anticline, especially if intrusion was contemporaneous with folding so that the tendency for opening in the crests would help initiate spreading of the intrusion at preferred horizons such as the contact of the competent meta-andesite with the incompetent Bragdon and the similar contact between the Dekkas andesite and the Pit shale. The alaskite bodies then could be classified as phacoliths. This suggestion may hold best in the case of the Bully Hill alaskite which outcrops in two parrallel elongated masses with the Pit shale conformable to the arched roofs of both of them. The Dekkas and Pit are conformable so it is difficult to imagine a control for the two narrow parallel masses other than folding parallel to the consistent northwest strike of the overall structure. The window of Dekkas in the Pit River canyon south of Copper City lies on the axis of the westernmost of the two alaskite strips, its presence there virtually proving that it is folded with the overlying Pit and alaskite. (See Figure 6.) To the north the folding grows tighter. Also the laccolithic sheet extends across a much wider area. In the vicinity of Bully Hill and Copper City the shale, alaskite, and andesite are tightly folded

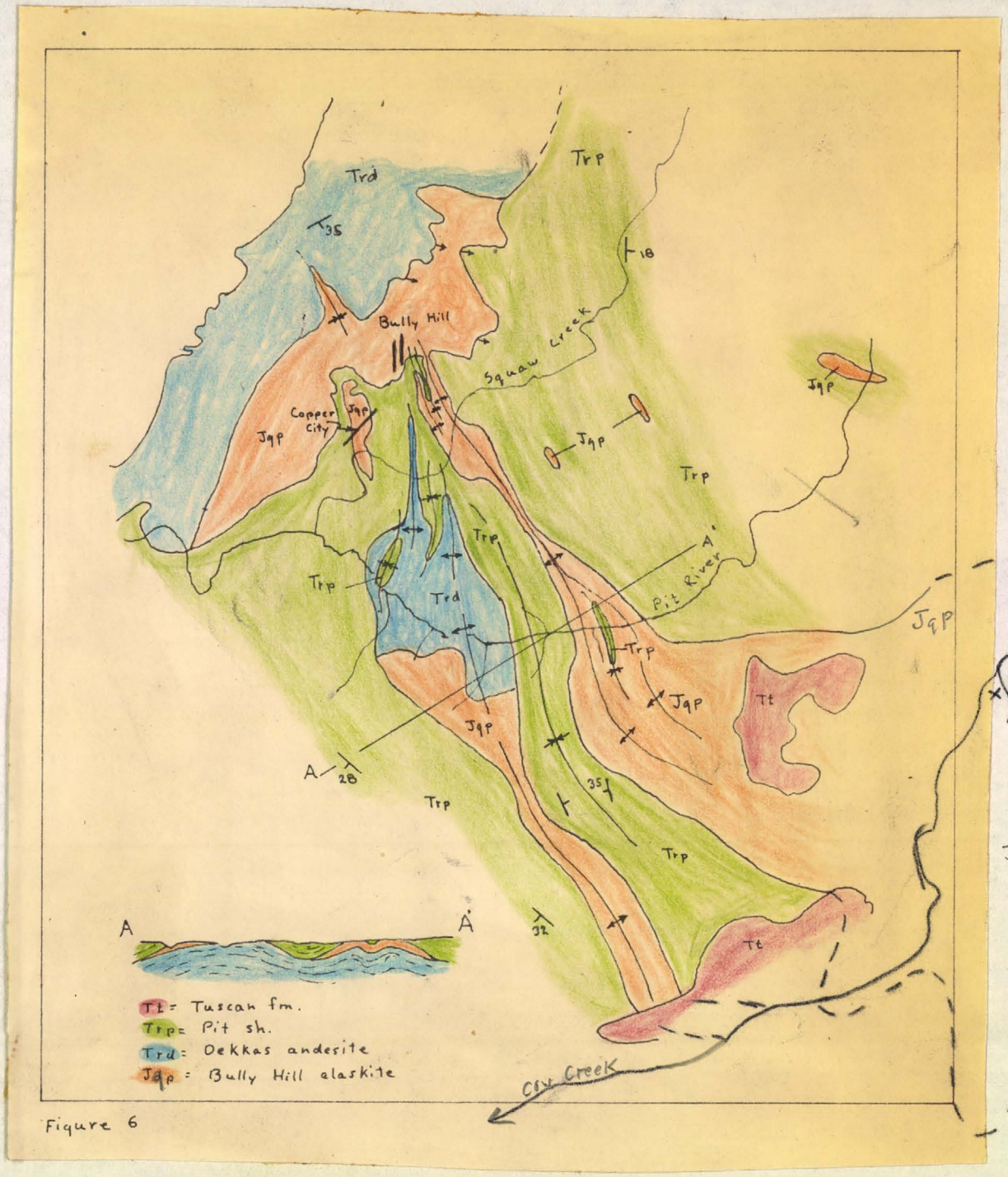


Figure 6

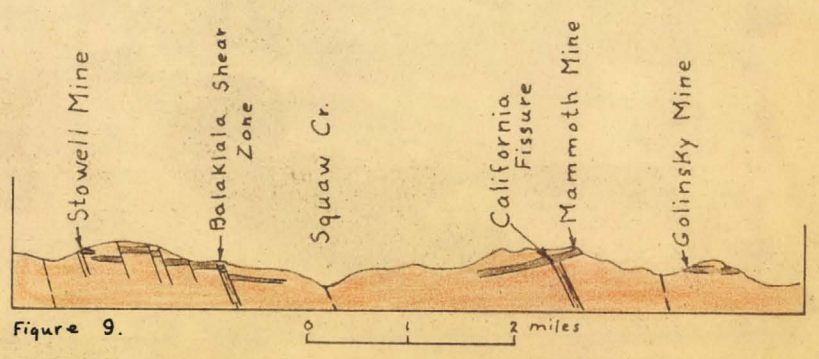


Figure 9.

Copper Ore Alaskite Porphyry

Idealized Section Looking Northwest (After Dittmar)

as indicated by the topographic expression of the contact. Northeast of Bully Hill the folding dies out and the alaskite is a simple intrusive sheet between the shale and andesite. The finger-shaped contact here is the topographic expression of a series of ridges and gulleys cross cutting the easterly dipping contacts. A. C. Boyle (10) notes that the folding in the Pit shale is tight to the point of overturning and shearing in the vicinity of Bully Hill; to the east this folding decreases in intensity until the folds are very open and sometimes barely perceptible.

The Balaklala intrusive probably possesses more of the characteristics of a chonolith. The unconformable Copley-Bragdon contact is more conducive to the spread of an intrusive sheet. Ferguson (6) noted that the Bragdon-Copley contact was marked by heavy gouge wherever exposed, due to adjustment between the competent and incompetent rock types during deformation, and it is believed that this seemingly minor feature would have a very pronounced effect upon the vertical localization of the initial intrusion which would in turn control the larger mass by a gradual initiation of doming action. In addition the Copley strike northeast and its parallel relation to the major axis of the alaskite is often cited as evidence that its vertical bedding planes controlled the rise of the alaskite magma into its present position. In addition, Figure 7 shows that numerous dikes classified as alaskite follow the strike of the Copley very closely. The indicated attitudes in the andesite are after Lauderback (11).

Cbr
Dk
Jqp
39
52
Cma
Pit River
70
Sacramento River
Jqd
Alaskite Dikes
Quartz Diorite Dikes
Quartz veins
Cu Copper Bodies
Cma - Copley fm.
Jqp - Balaklala alaskite
Dk - Kennett fm.
Cbr - Bragdon fm.

Figure 7.

There is room for doubt that the Balaklala alaskite is free from initial fold control. The opposite dips at the north end of the mass clearly express the arching in the Bragdon, but Diller's section and the dip in the northeast corner of Figure 7 clearly show that there is a synclinal structure associated with the arch. This structure passes to the east into a second anticline. It is not readily apparent just how the Balaklala intrusion could result in a series of folds of the magnitude indicated and thus the suggestion is justified that pre-intrusive folding has in part influenced the location and areal distribution of the western alaskite as well as the eastern body.

In the northwestern part of the Redding quadrangle and the northern part of the Weaverville quadrangle the regional easterly dip flattens and even, according to Hershey, makes a broad bowl structure. In contrast to the rapid succession of dipping formations to the east of the area, this bowl is covered entirely by the Bragdon shales. In detail the rocks are isoclinally folded and in the present state of erosion the mean elevation of the Copley-Bragdon contact has nearly been reached. As a result of the involvement of the contact in the tight folding the Copley outcrops in irregular patches where especially deep dissection has truncated these folds below the contact. Hershey (12) notes that the strike of these folds along the Trinity River is east-west, swinging to the northeast as the structure crosses into Shasta County. Since these strikes do not correlate with the northwest strike recorded by Diller just west of the Sacramento River the folding must not be tectonically related to the larger regional

homocline which develops in the Redding quadrangle.

The amplitude of the isoclinal folding is at a maximum of 2,000 feet near Trinity Center, but the folding decreases in intensity to the south.

The Relation of Structure to Intrusion

It is of interest to attempt the correlation of the various types of deformation described above with the various phases of intrusive activity.

From the relations between the alaskite and its enclosing formations, it is concluded that the minor north to northwesterly trending folding of the Redding quadrangle had begun prior to the intrusion of the laccoliths. In view of the shattered border zones and the sequence of separate intrusions the folding deformation probably extended into a period contemporaneous with the intrusion. The intense shearing in the alaskite necessarily followed its crystallization. This phase of the deformation must also have taken place at least in part during the mineralization since shear zones control the base metal ore bodies. Boyle states that the progressive increase in the intensity of folding in the Pit shale from southeast to northwest culminates in shearing when the igneous contact is reached; that is, shearing acts as a limiting phase of the folding and is preferentially developed in the igneous members. He states that there is a transition from a fold to a shear zone in going from shale to an igneous rock. The complex folding passes into over thrusting so that the schistosity developed in the alaskite may be the result of

shear parallel to the axes of overturned folds. Note also in Figure 6 the convergence and tightening of folds to a point at Bully Hill. This location was evidently a point of maximum deformation.

The block diagram of the Afterthought Mine ([redacted]) shows that the shear zones there are probably related to flatter portions of the contact. There is a suggestion that they are controlled in detail by sills which join the main body on these steps. The displacement on the main fault is normal, and Wisser suggests that an uplift of the hanging wall is indicated; the alaskite was forced upward and the steps and embayments, by prohibiting slip on the contact, forced the development of the main fault out in the shale but generally parallel to the contact. During this action the full resistance of the shale would be carried on the flat steps while there would be a minimum of resistance on the steep parts of the contact. The sills apparently acted as reinforcing ribs which prevented shear in the alaskite below them, but the plastic shale between them slipped on the bedding planes and allowed shear couples to develop in the alaskite. In another light the sills may have acted as rigid cutting tools as the main mass shoved against them. The observed schistosity then develops by shear in the alaskite between these sills.

This upward movement does not seem to correlate with the folding force suggested for the Bully Hill area. However, Wisser notes low thrusts dipping toward the alaskite contact and concludes that the up thrusting had a strong horizontal component.

These relations are not entirely satisfactory in the light of available information. However, it is certain that deformation preceded the intrusion and followed it during mineralization. The evidence at Bully Hill suggests that the folding action was continuous in this range. The nature of the activity at the Afterthought opposes such a continuity. However, this location is on a more massive alaskite body which probably would act as a separate tectonic unit, thus accounting for the inconsistency.

The ore bearing shear zones in the Balaklala alaskite are nearly flat-lying. Information bearing on the cause for this condition is not available. An old map (Figure 8) indicates a suggestive alignment of the mineralized areas, but in view of the erroneous mapping of the alaskite contacts this distribution may not be according to fact. The indicated trend does exist and follows the axis of the alaskite mass. The individual ore bodies lying in the shear zones and parallel to the schistosity trend between northeast and east. The dips in the south half are steep. They grow progressively shallower to the north until there is a reversal of dip in the Mammoth body at the north end. (See Figure 9.) Groton states that the Iron Mountain orebody was originally flat, but appears to dip steeply due to the presence of steep boundary faults. He also suggests that the flat shear zones are due to stresses set up in the alaskite concentric to the roof as a result of continued upthrusting and arching after the solidification of the intrusive. Relief of these stresses was in the form of shearing with the

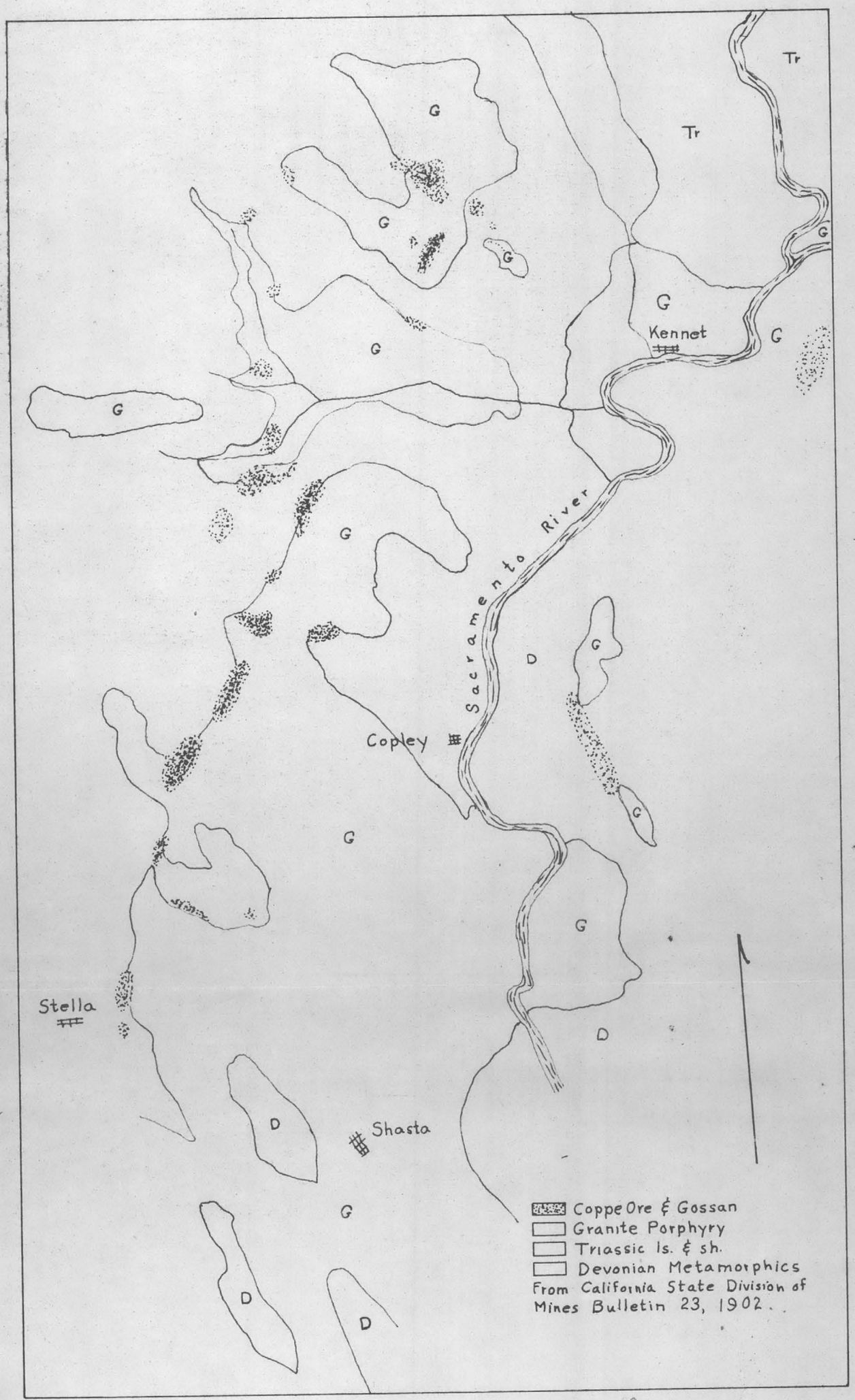


Figure 8.

fig 8

development of strong schistosity in the majority of cases. Sheeted zones and outright faulting develop gradationally as limiting extremes in the nature of the deformation. These variations are probably functions of the velocity of the deformation, the development of schistosity requiring an evenly applied stress acting over a very much longer time, while more rapid deformation will result in rupture and faulting. This suggests that the schistose zones may be closely related to the same even horizontal compression that would result in folding in the sediments.

Balk (13) has noted flat-lying shear zones in sills and intrusive sheets. These zones are restricted to that part of the body which is near the roof of the intrusive and are attributed to the extension of underlying magma in a horizontal direction as the sill or sheet expands laterally. This shearing in the roof helps to adjust the expansion of the area of the roof as doming proceeds. These features should be accompanied by parallel flow patterns in the unaffected portions of the intrusive. Flow structures in the alaskite are mentioned, but there is no data as to their orientation. This picture fits the Balaklala body very well excepting in that as illustrated in Figure 4 the later intrusions are on top of the earlier sheets with the ore bodies lying on the contact. It is very doubtful if the process described by Balk would operate on floor layers as well as in the roof, but the shearing may have taken place in the earlier intrusion when its top surface was the actual roof of the intrusion. This zone was then buried by the

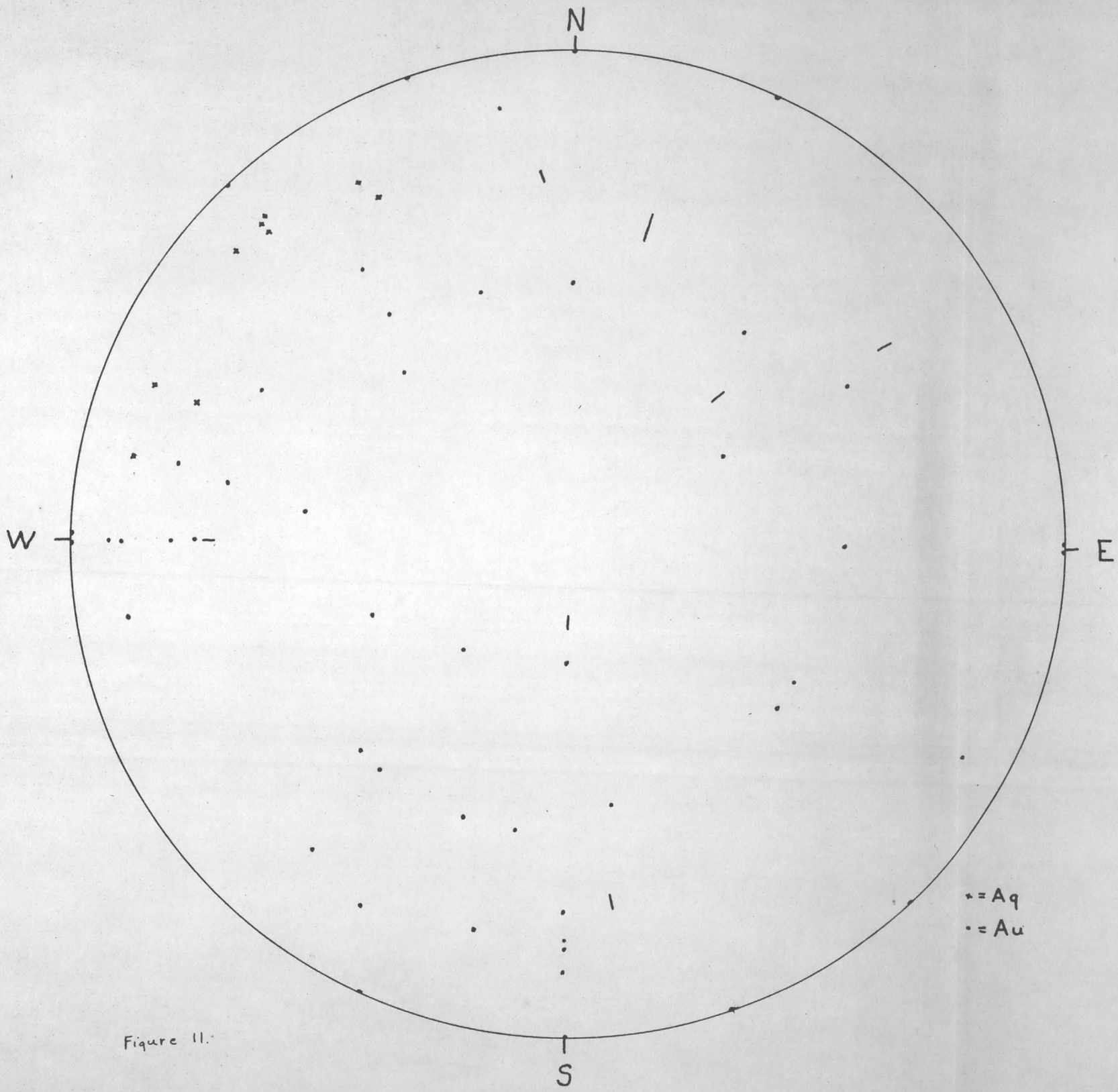


Figure 11.

emplacement of the second alaskite series.

If flow is the explanation of the flat shear, then the mineralization was either during the alaskite intrusive period or else later movements reopened the schistose zones since they were pre-existing planes of weakness. The latter is probably the case. The horizontal sheets would behave as bedded deposits and conceivably the weakened zones would open in the crests of the anticline under the compressional stress of folding deformation. This would account for the straight alignment of the ore bodies. Two separate deformations are involved. The base metal deposits are in the shear zones, but the gold lodes are on steep-dipping fissures that cross cut the copper bodies and the trend of the alaskite. Later dikes also cut the Copley transversely to the earlier alaskite dikes that rose on the Copley strike. (See Figure 7.)

These conditions suggest that the early intrusions and dikes were controlled by the Copley bedding in the west and the beginning of folding in the Dekkas-Pit bedding in the east. Continued east-west compression following this intrusive phase may have been responsible for the opening of east-west tension joints in which the later, more basic dikes were intruded. The nature of the deformation which resulted in mineralization is uncertain because all lodes are controlled by the earlier dikes and igneous contacts. Their trend is merely an expression of the earlier deformation. The typical situation is illustrated at the Brown Bear Mine, Figure 10. The crossed fracture pattern suggests conjugate rupture resulting from compression, but the orientation of the deforming force cannot be determined. At the Brown Bear

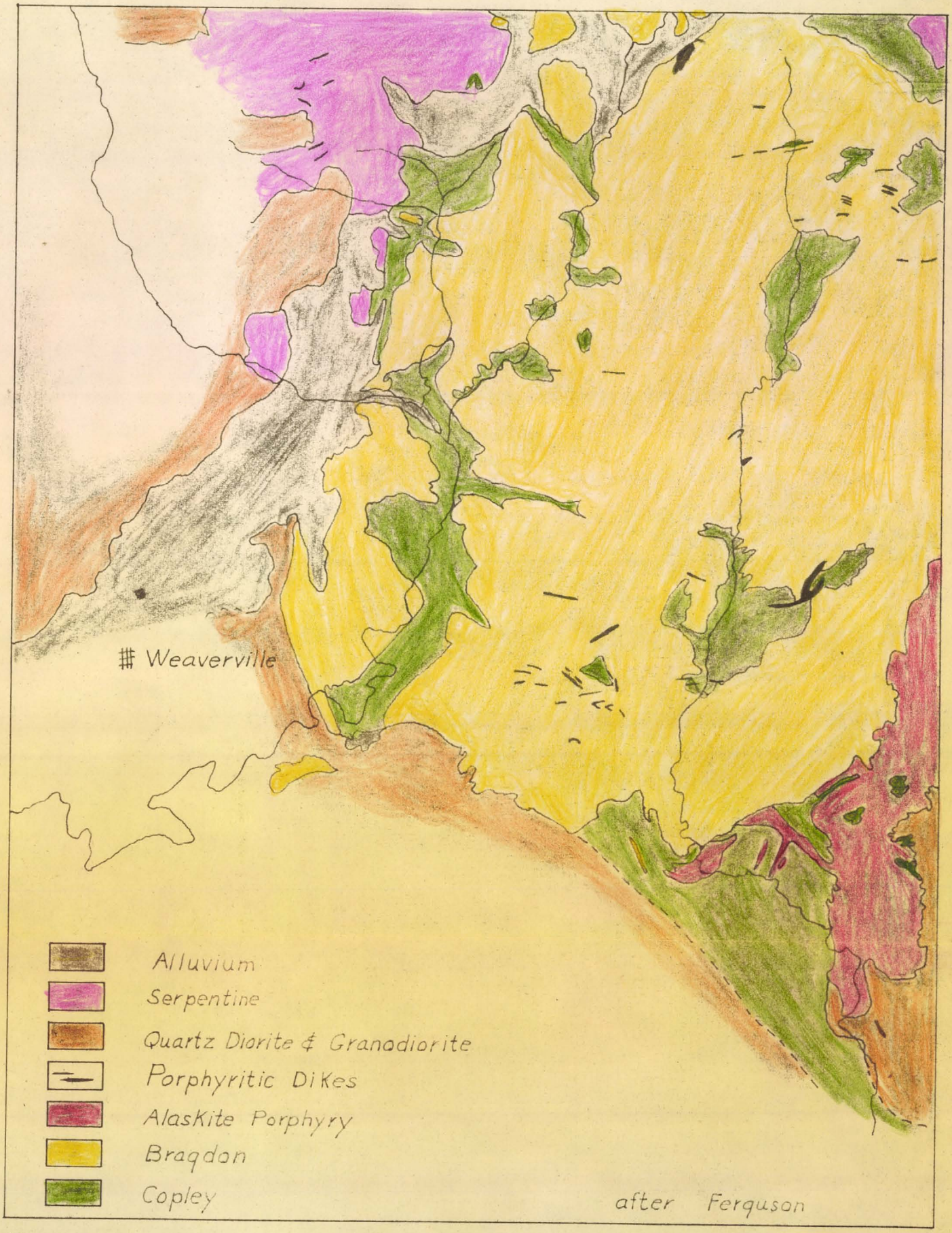

Weaverville
Alluvium
Serpentine
Quartz Diorite & Granodiorite
Porphyritic Dikes
Alaskite Porphyry
Bragdon
Copley
after Ferguson

Figure 12.

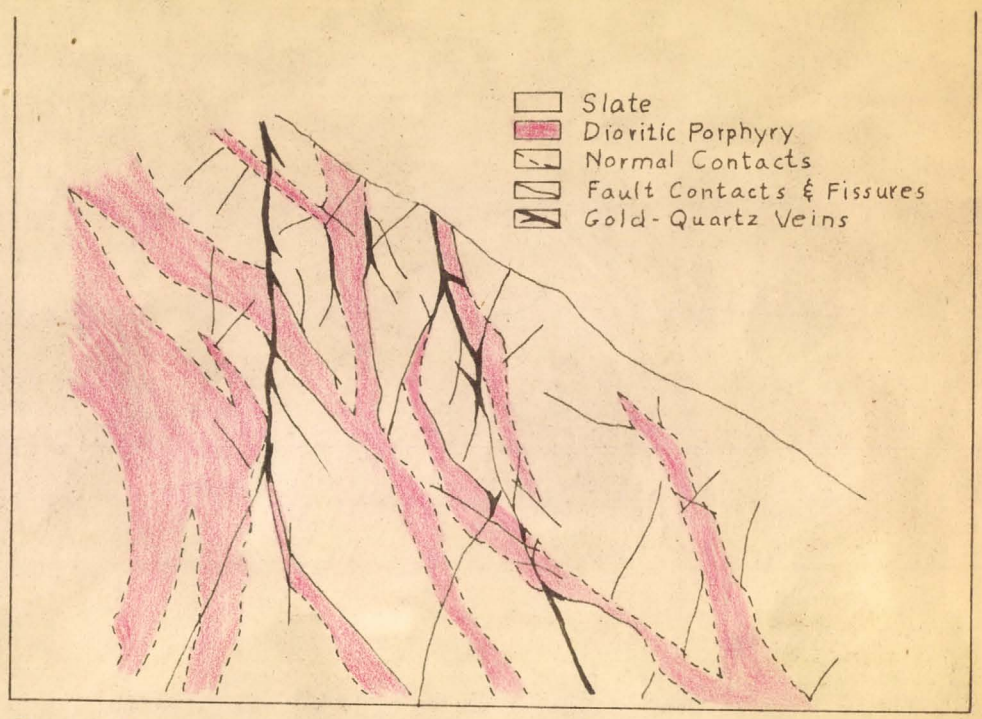
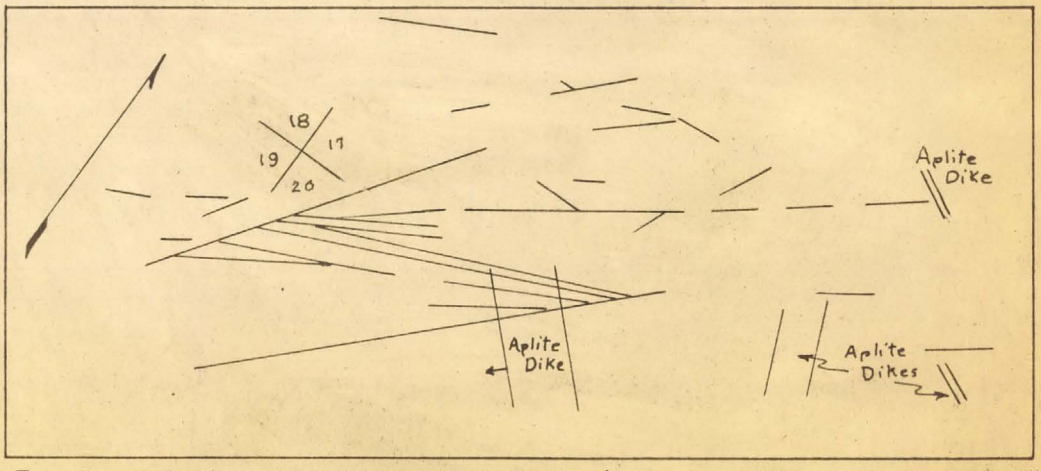


Figure 10.

Brown Bear Mine, Generalized Section Looking East (E.E. Erich)



Fracture Pattern of the Silver Falls & Chicago Mine. Scale: 200'=1"

Figure 13.

it appears to be somewhere in a north-south plane. An equal area net plot of the poles of the lodes reveals two dominant trends nearly at right angles to each other (Figure 11). One trend is east of north, with steep easterly dips. The other trend is less well developed and strikes north of west with steep northerly dips. The dikes mapped by Ferguson (Figure 12) follow the east-west trend in part suggesting that this orientation is related to the east-west trend of the isoclinal folding in the Trinity area. The north-south dikes and lodes would be the tension fissures in this area, in contrast with the situation in the area north of Redding.

Another type of deformation is in evidence in the silver districts southwest of Redding. Here the lodes are controlled by vertical fissures, the pattern of which strongly suggests torsion joints between strike slip faults. (See Figure 13.) These mines are on fissure veins in the Mule Mountain intrusive. Tucker (14) states that the northwest trending fault system traverses the entire mass. The orientation of the torsion joint indicates that the northerly member of the shear couple moved to the northwest. The aplite dikes are not offset, so these fissures must be more of the nature of shear joints rather than faults of any great displacement. Further analysis is not possible from this data, but the point is established that this deformation was late in the sequence since it took place during the mineralization and apparently after dike injection. If the usual sequence of introduction of metals is accepted, the presence of silver as the economically dominant metal further restricts this action to a late stage of metal mineralization.

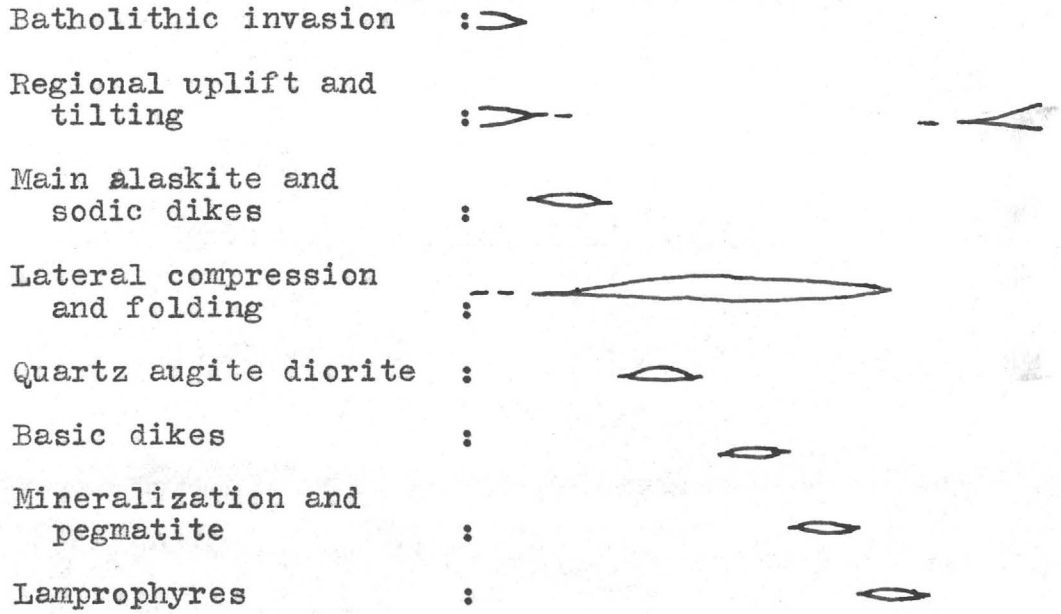
There is an extensive series of dikes in the Bragdon west of the Sacramento River around which no mineralization has occurred. Since the fissuring of these brittle dikes in the matrix of plastic shale channeled the mineralization in the gold district, the lack of mines in the northern area may indicate that there was no deformation here during the introduction of hydrothermal solutions. In other words the belts of minor folding and late deformation are local and associated with the larger intrusive bodies to the south and west.

The last type of deformation to be discussed is the regional easterly dip. If the pre-Nevadan strata remained horizontal throughout intrusion, the Balaklala alaskite would have formed beneath a cover of 19,000 feet; the quartz augite dike would then be a flat sill formed at 11,800 feet; the Bully Hill alaskite would have been covered by 7,600 feet of sediments. The gold mineralization in the Central area would have taken place at a depth of 13,000 feet. The vein deposits are very persistent both in strike and dip, their dimensions being on the order of 2,000 feet at the Gladstone Mine. The Gladstone reaches a depth of 800 feet above sea level, while the Niagara group seven miles distant outcrops at 4,200 feet, giving a vertical range of 3,400 feet provided there is no faulting between the two mines. Therefore the nature of the deposits is consistent with deep burial.

Unless there are undiscovered normal faults of great magnitude separating the main batholith from the remainder of the area on its east flank, the regional dip must necessarily have developed during uplift of the Klamath Mountains

as a block after the intrusion. The intrusion of magma to progressively higher stratigraphic levels from west to east suggests that there may have been tilting prior to the igneous activity at these horizons. At present the floors of the Balaklala and Bully Hill bodies are at the same vertical elevation. The Balaklala body was initially much lower than the Bully Hill alaskite, but a difference of 11,000 feet seems excessive in view of the very similar nature of the two.

On the basis of the foregoing considerations, it is speculated that time relations are as follows:



Zonal Relations

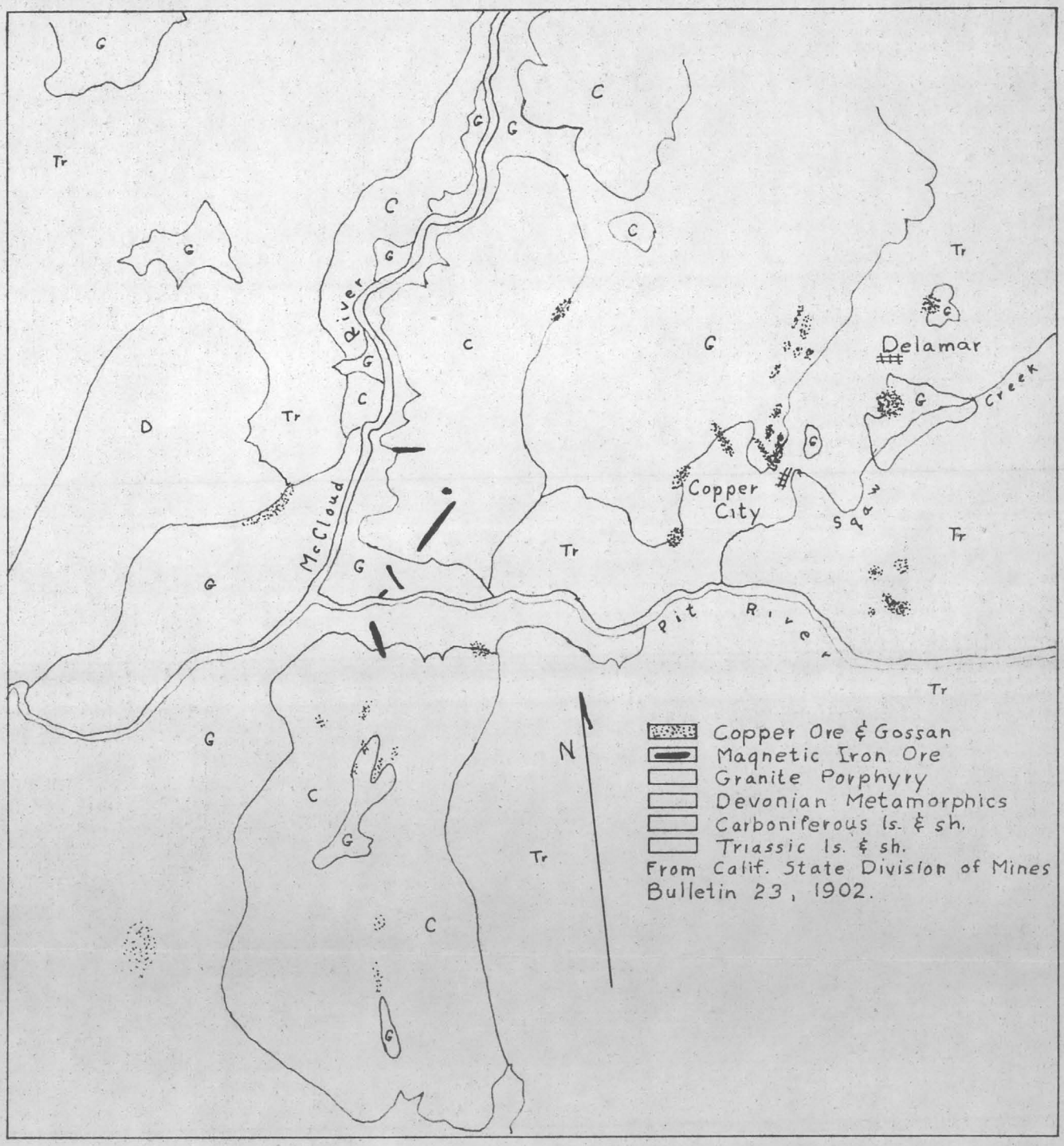
A very definite zoning of the metals exists in the Redding-Weaverville district. At the eastern tip of the copper belt the Afterthought Mine is operated primarily for zinc. At Bully Hill and Copper City both copper and zinc were extracted plus values in gold and silver from the enriched gossan. In the western copper district there are also zinc, gold, and silver, but the copper is the chief

metal. The large gold province of the Shasta-Trinity border overlaps and crosses the copper belt, but as has been pointed out the two types are not closely related structurally. The crescent pattern continues to the south and west and ends in the silver district southwest of Redding. The Afterthought ore is sphalerite-pyrite-chalcopyrite-minor bornite and silver. At Copper City the ore is sphalerite-pyrite-bornite-chalcopyrite. The western copper belt ores consist of pyrite-chalcopyrite-sphalerite with minor galena and bornite. The lodes in this district are quartz veins with gold-pyrite-chalcopyrite. The main gold district farther west carries quartz-calcite-arsenopyrite-pyrite-galena-gold with rare sphalerite and chalcopyrite. In the silver district the ore is quartz with argentiferous tetrahedrite-galena-pyrite-sphalerite-chalcopyrite-gold.

There are two outstanding features to the zoning. First, the change from east to west follows the usual observed order of introduction of metals with a gradation from zinc-copper through copper-zinc, copper-gold, lead-gold to lead-silver-gold. Second, each of these types owes its ore structure to a different type of deformation. The base metals are associated with folding; the gold lodes are associated with some later compression that fractured dikes whose locations were determined by the folding; the silver lodes are associated with an almost regional shear couple. In other words, the early metals were deposited in early structures and late metals were deposited in later structures, the timing of metal release from the magmatic source being

controlled by a definite order or sequence determined by the relative properties of the metals, especially solubility.

It is suggested, therefore, that the zoning in this district is due to the progressive development of openings from east to west as the reactions of the country rock to the deforming forces of intrusion and uplift varied in nature and intensity. Whatever metals were present in the hydrothermal solutions at the time an opening developed were deposited and since there was a progressive change in the composition of the solutions, the geographical shift and spread of the permeable area was reflected in the zoned arrangement of the deposits. The copper belt opened early and remained open throughout most of the period of mineralization; the gold and gold-silver districts opened late and thus received none of the base metal mineralization.


Tr
G
C
D
McCloud River
Pit River
Copper City
Delamar
Sacramento Creek
N
Copper Ore & Gossan
Magnetic Iron Ore
Granite Porphyry
Devonian Metamorphics
Carboniferous ls. & sh.
Triassic ls. & sh.
From Calif. State Division of Mines
Bulletin 23, 1902.

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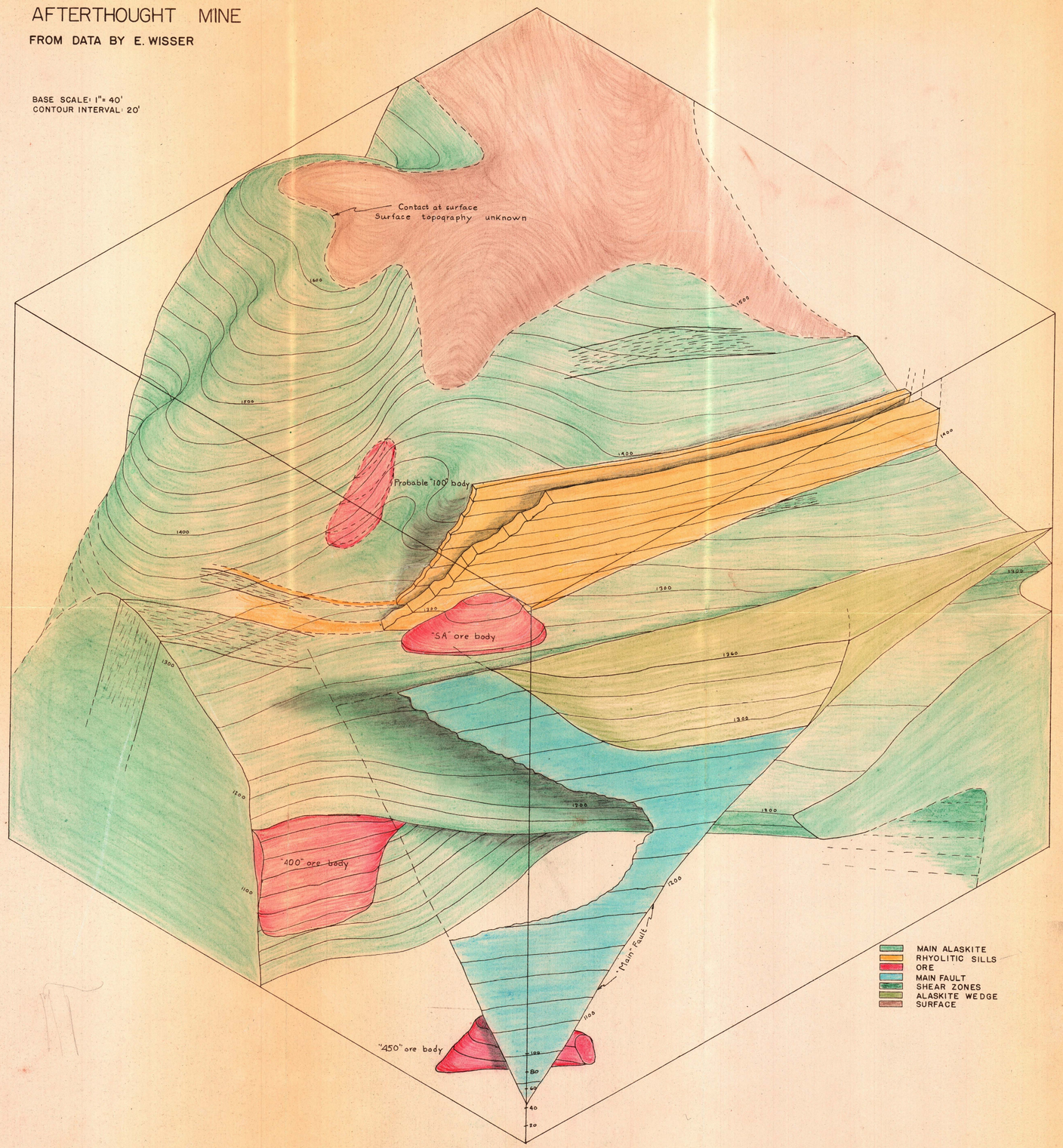
AFTERTHOUGHT MINE

FROM DATA BY E. WISSER

BASE SCALE: 1" = 40'
CONTOUR INTERVAL: 20'



Block Diagram