Geol. Soc. Malaysia, Bulletin 9, Nov. 1977; pp. 17–29.

The Sierra Nevada Batholith, California, U.S.A., and spatially related mineral deposits

F.C.W. DODGE AND PAUL C. BATEMAN
U.S. Geological Survey, Menlo Park, California, U.S.A.

Abstract: The Sierra Nevada batholith is composed of a great many discrete granitoid plutons of different compositions in sharp contact with one another. Most of these plutons can be assigned to a much smaller number of comagmatic sequences, each representing a single fusion event. Compositional differences between sequences reflect progressive eastward increase in potassium actoss the batholith and less conspicuous decrease in calcium. Uranium, thorium, the oxidation ratio, and $^{86}Sr/^{87}Sr$ initial ratios also increase eastward. Compositional patterns are independent of the ages of the rocks. The oldest granitoid rocks, of Triassic and Early Jurassic age, are on the east side of the batholith. The next older rocks, chiefly Early Cretaceous, are on the west side. The youngest rocks, of early Late Cretaceous age, are in the core of the batholith.

Several workers have pointed out a zonal distribution of mineral deposits in eastern California and have related this zoning to proximity to the Sierra Nevada batholith. Deposits of tungsten, molybdenum, and iron occur within the batholith, and deposits of gold, silver, copper, zinc, manganese, and chromite are present in the country rocks peripheral to the batholith. Preliminary considerations indicate that the metals that occur within the batholith are the ones most likely to have had their source in the batholith. Chromite is syngenetic with enclosing bodies of ultramafic rock older than the batholith, and the source for most gold, copper, lead, zinc, and manganese probably was also in adjacent country rock where volcanogenic or sedimentary processes had previously produced low-grade concentrations. The batholith may have supplied heat required to mobilize meteoric waters, which reconcentrated these metals in deposits of exploitable grade.

INTRODUCTION

The discovery of gold in the foothills of the Sierra Nevada in 1848 led to the California gold rush of 1849, which spurred the growth of San Francisco and the west and notably enriched American literature and folklore. According to folklore, the Sierra Nevada is a storehouse of minerals, and many economic geologists believe that even though the batholith itself contains few ore deposits, the peripheral deposits are genetically related to it. We propose to examine this belief. However, only a preliminary examination is possible at this time. Much additional data, not yet available, are needed for a definitive appraisal. We will first describe the compositional and age patterns across the central part of the batholith, where they have been intensively studied. Then we will examine the distribution of ore deposits in relation to the batholith and its internal constitution.

An important distinction is that the physiographic Sierra Nevada (Snowy Range) and the Sierra Nevada batholith are different entities. Strictly speaking, the Sierra Nevada batholith is the part of the Sierra Nevada that is underlain by granitoids and is confined to the physiographic Sierra Nevada. However, we will use the term more loosely to include adjacent areas to the east underlain by granitoids. The physiographic Sierra Nevada includes, in addition to granitoids, the western metamorphic belt, a strip of Paleozoic and Mesozoic strata that occupies the west part of the north half of the range, and numerous roof pendants that lie within the batholith (Fig. 1).

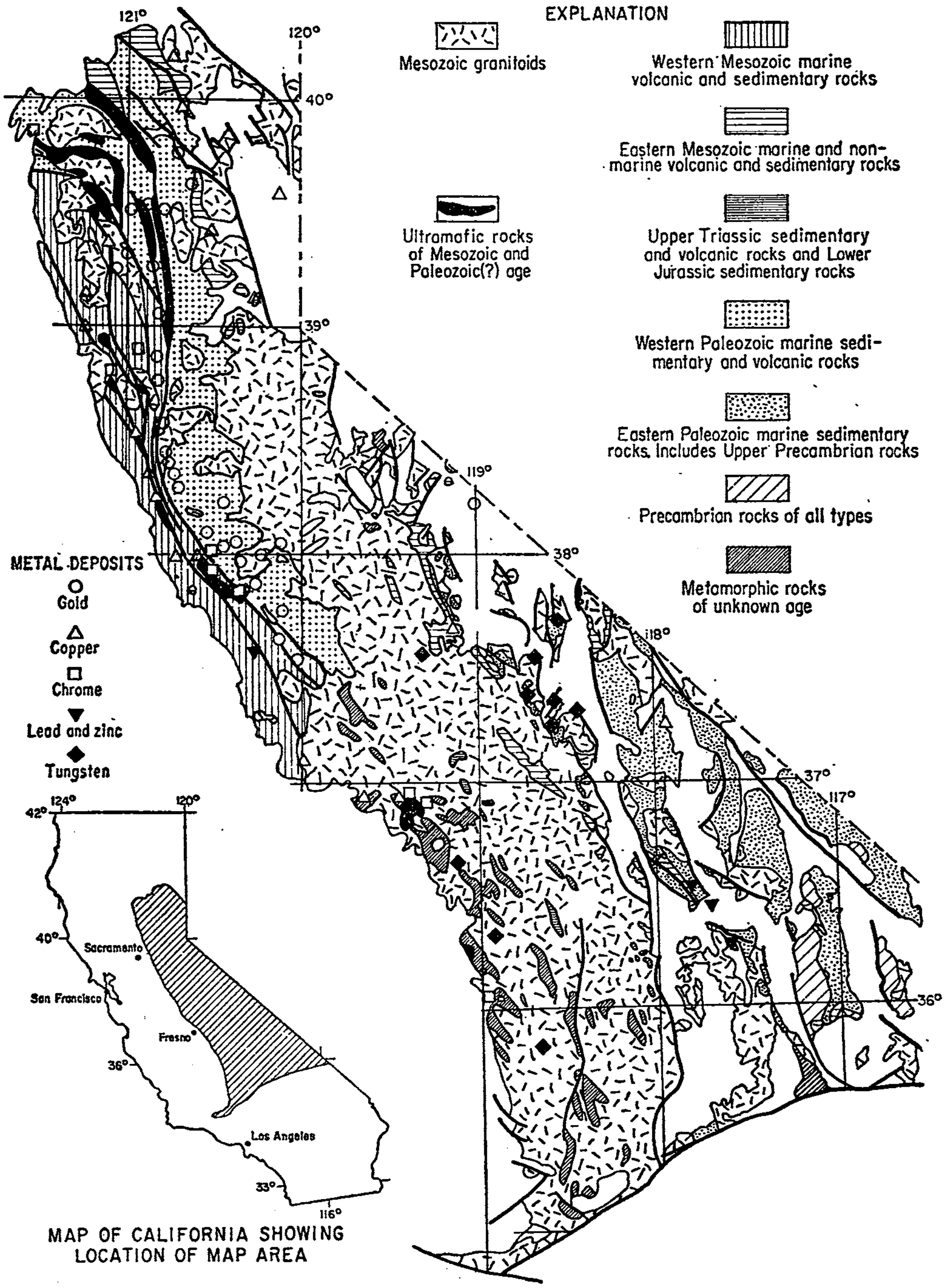


Fig. 1. Sierra Nevada and adjacent areas in eastern California showing the locations of major metal deposits.

COMPOSITIONAL PATTERNS ACROSS THE CENTRAL PART OF THE BATHOLITH

The batholith consists of many discrete plutons that are either in sharp contact with one another or are separated by septa of metamorphic or older igneous rocks (Bateman and others, 1963). These plutons range in size from less than one km^2 to more than 1000 km^2. Fortunately, these rocks can be arranged in a smaller number of comagmatic sequences, each of which is the product of a single fusion event (Bateman and Dodge, 1970; Presnall and Bateman, 1973).

Figure 2 shows the sequences that have been delineated thus far in the central Sierra Nevada. Others will be added as mapping proceeds and understanding of the relations between plutons increases. All of the sequences exhibit extended ranges of composition. Differences between the rocks within a sequence are shown by their differentiation indexes (sum of normative orthoclase, albite, and quartz expressed as percentage of the total rock compostion). Early rocks in a sequence generally have low differentiation indices and contain abundant hornblende, biotite, intermediate plagioclase, and mafic inclusions, whereas younger rocks have high differentiation indices and contain abundant quartz, K–feldspar, and sodic plagioclase.

On a regional scale the gross compositions of the sequences change significantly from west to east across the batholith. The most conspicuous change is eastward increase in K–feldspar, reflecting eastward increase in K_20 (Bateman and Dodge, 1970) This change is accompanied by eastward increase in uranium, thorium, rubidium, and beryllium (Dodge, 1972a; Kistler and Peterman, 1973) the oxidation ratio (Dodge, 1972b), and the initial $^{87}Rb/\ ^{86}Sr$ ratio (Kistler and Peterman, 1973), and by eastward decrease in calcium (Bateman and Dodge, 1970). Other systematic compositional changes doubtless occur but have not been adequately documented.

These changes are reflected in the compositions and textures of the rock sequences In the western foothills, where the rocks are poor in potassium, the compositional range within sequences is from abundant quartz diorite or tonalite, through leucotonalite and leucogranodiorite, to sparse granite, all of which are equigranular. In the medial part of the batholith the common range is from equigranular granodiorite, through porphyritic granodiorite and granite, to equigranular granite. In the eastern part of the batholith, the range is from equigranular monzodiorite, through equigranular monzonite to porphyritic quartz monzonite and granite, and finally to equigranular granite.

AGE PATTERNS

Although many uncertainties remain, recent isotopic dating by the Pb-U method (Saleeby, 1976; Tom Stern, personal commun., 1974–1976) together with instrusive relations observed in the field and K–Ar and Rb–Sr dating (Evernden and Kistler, 1970) define the general sequence of emplacement of granitoids across the central part of the batholith. The granitoids mostly range in age from Triassic to early Late Cretaceous, but preliminary dates by the Pb–U method (Tom Stern, personal commun., 1976) suggest that late Paleozoic granitoids may also be present locally.

Granitoids of Triassic and Jurassic age occupy extensive areas along the east side of the batholith, west of the crest of the range, and plutons of Middle and Late

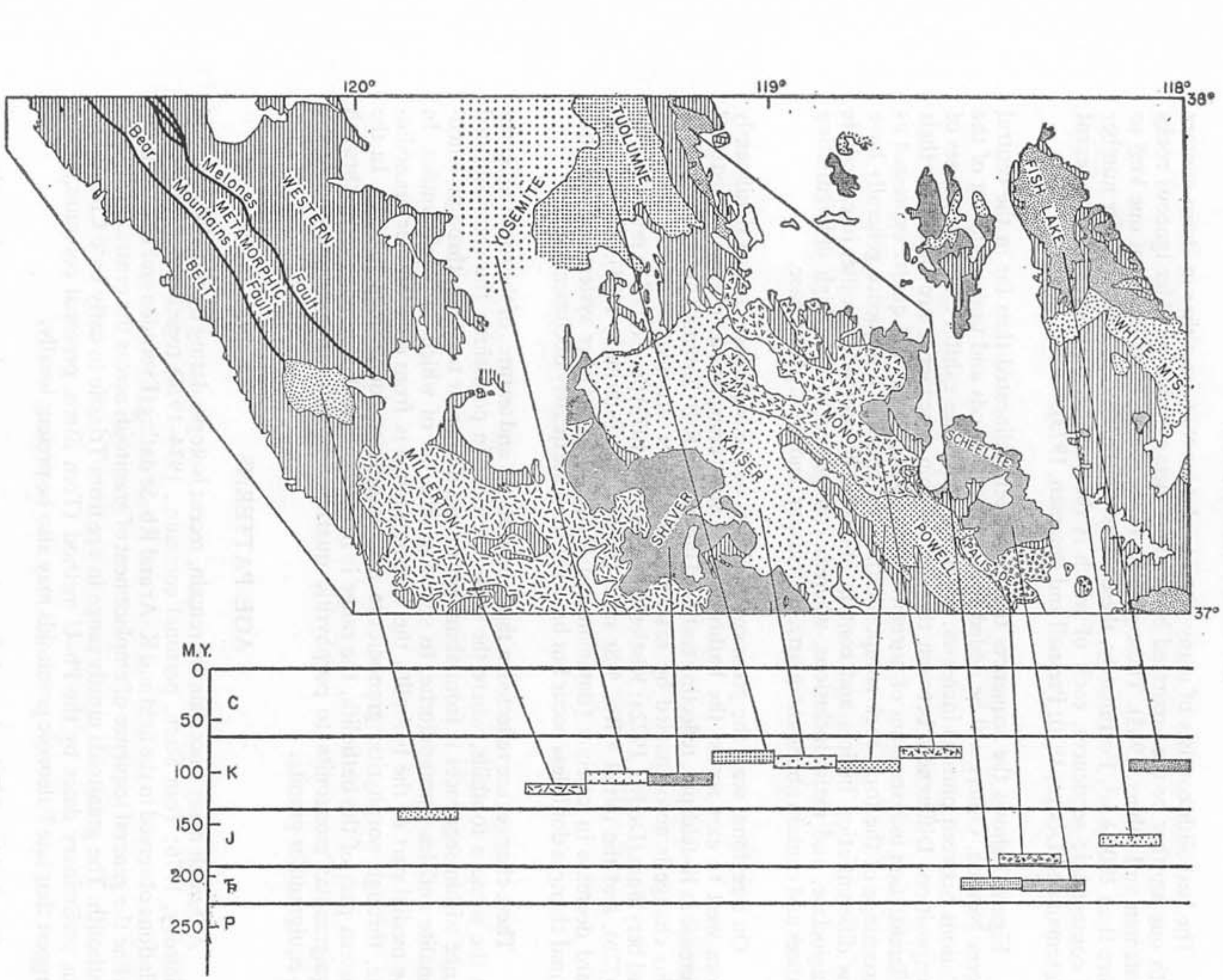


Fig. 2. Comagmatic granitoid sequences of the central Sierra Nevada and a diagram showing their isotopic ages. Pre-batholithic country rocks are shown by ruled pattern.

Jurassic age are present in the western foothills (Saleeby, 1976; Evernden and Kistler, 1970). Whether pre-Cretaceous granitoids once were present entirely across the range is uncertain. Most of the unpatterned areas shown on Figure 2, which lie within the batholith, are occupied by sheared granitoids older than the contiguous granitoids assigned to sequences.

Cretaceous granitoids underlie the broad west slope of the range and make up the medial and western part of the batholith. Among the Cretaceous granitoids, the oldest are in the west, just east of the western metamorphic belt, and are of late Early Cretaceous age. Except for a single reversal, the granitoid sequences are progressively younger eastward toward the crest of the range, the youngest being of early Late Cretaceous age.

One obvious point that nevertheless needs to be emphasized is that the regional compositional changes from west to east across the batholith are independent of the age of the granitoids. This supports the view that the regional compositional variations reflect differences in the composition of the source material from which the parent magmas were formed.

DISTRIBUTION AND DESCRIPTIONS OF THE METAL DEPOSITS

The locations of the largest mines or mining districts of chrome, copper, gold, lead and zinc, and tungsten in and adjacent to the Sierra Nevada batholith are shown in Figure 1, and the distribution of significant deposits of these metals in the central Sierra Nevada, plus deposits of iron and manganese, on Figure 3. The area shown in Figure 3 includes that in Figure 2 but extends further south into areas not yet studied geologically in detail. Contours based on past production are given for gold, copper, and tungsten. Unfortunately, investigation of mineral deposits of the central Sierra Nevada is largely of historical interest, for with only a few exceptions, present-day mining is virtually nonexistent. Production data from the past 125 years, though fragmentary for many deposits, reflect the quantities of metals originally in the deposits.

GOLD

Much of the gold mined from the Sierra Nevada was extracted from placer deposits where rivers emerge from the west side of the range. Nevertheless, lode deposits have also yielded substantial amounts of gold. The largest gold deposits are in the western metamorphic belt (Fig. 3A), but gold is being recovered as a by-product of tungsten mining at Pine Creek, the one major mining district on the east side of the batholith.

Major districts, those in which at least one mine has a recorded gold production valued in excess of one million dollars, are concentrated along and near the Melones fault zone and in the East Gold Belt immediately to the east. Only a few districts lie west of the Melones fault zone. Deposits along the Melones fault zone constitute the famous Mother Lode. Those in the south part commonly are in hydrothermally altered greenstone and schist, whereas those in the north part and most deposits east and west of the Mother Lode are in quartz veins (Knopf, 1929, p. 23). Deposits that lie close to the batholith generally contain abundant pyrrhotite, whereas those farther west and more distant from the batholith contain increasing amounts of pyrite (Knopf, 1929, p. 23). Ores of the East belt are more complex than those of the Mother Lode and commonly contain appreciable amounts of arsenopyrite, chalcopyrite, galena, and sphalerite in addition to iron sulfides (Clark, 1957, p. 216).

Past production of gold districts has been contoured by arbitrarily assigning a value of two to major districts and one to others (Fig. 3A). Placer districts have not

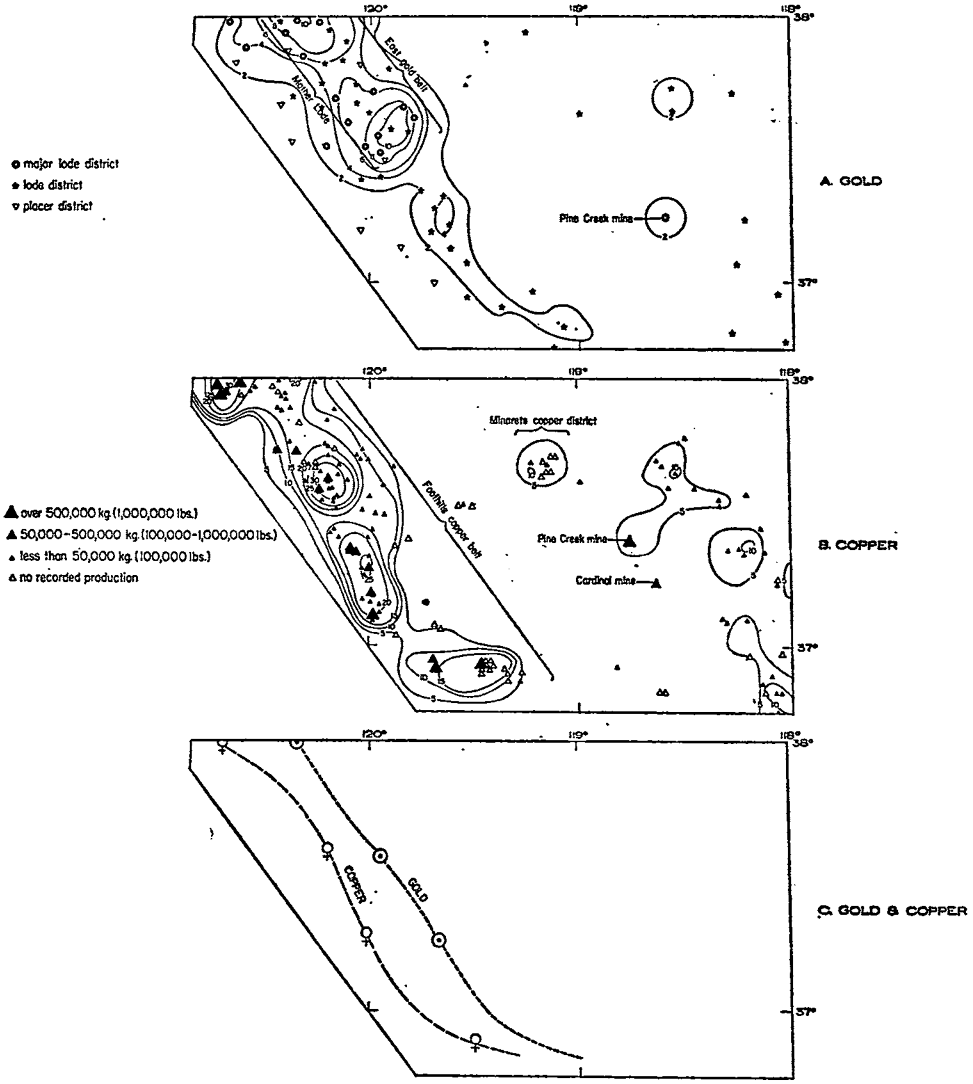
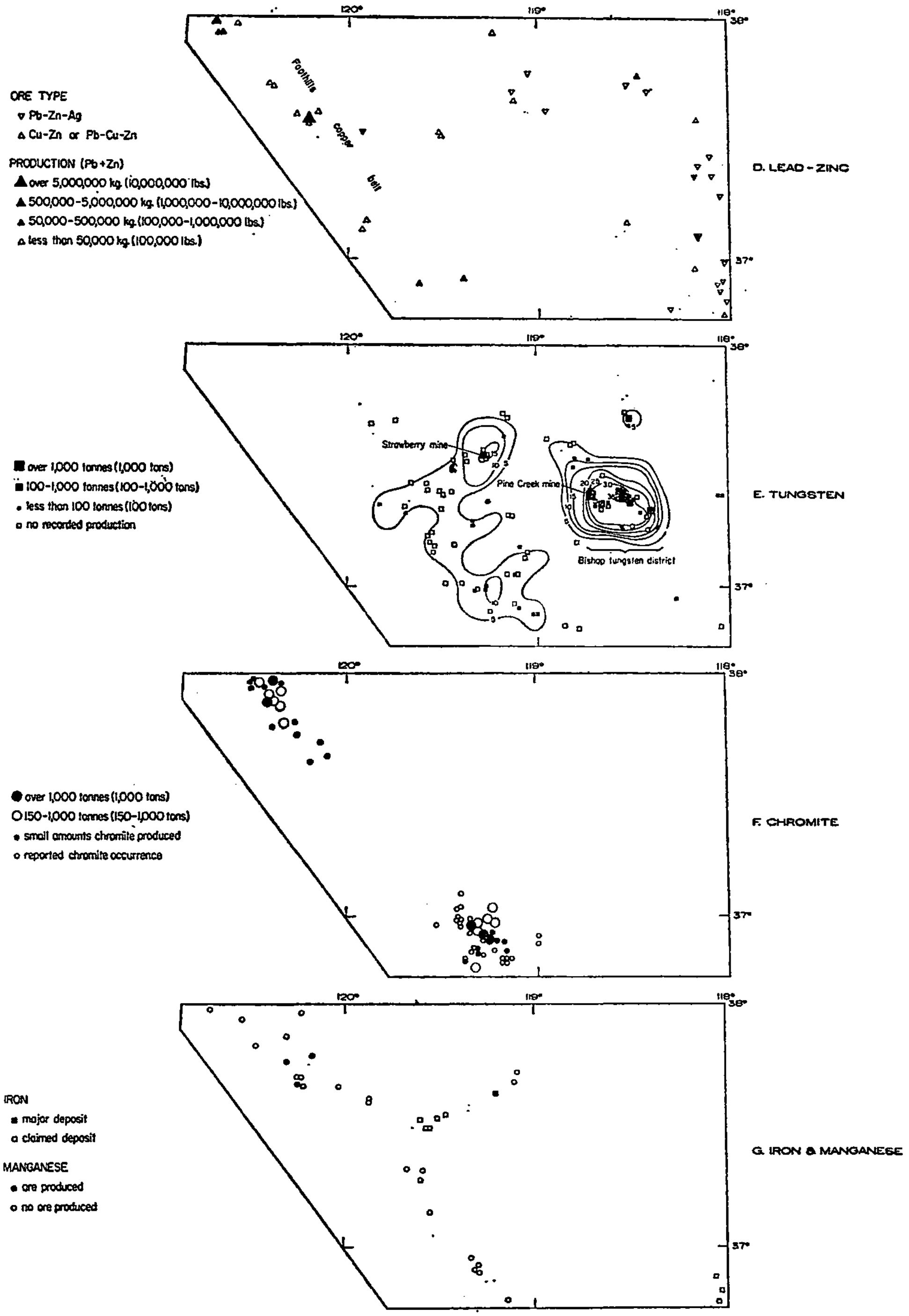


Fig. 3. Mineral deposits of the central Sierra Nevada between lat. 36°45' and 38°N.

A. Distribution, production, and contour map of production of gold. Modified from Clark, 1970
B. Distribution, production, and contour map of production of copper. From Jenkins, 1948.
C. Lines of greatest production and points of individual production highs for copper and gold. Derived from contour maps of the two metals.



D. Distribution and production of lead-zinc. From Goodwin, 1957.

E. Distribution, production, and contour map of production of tungsten. Modified from Jenkins, 1924b.

F. Distribution and production of chromite. From Jenkins, 1942a.

G. Distribution of iron and manganese. Iron modified from Moore, 1966; manganese from Jenkins, 1943.

See text for explanation of contour maps.

been included in the contouring. The linear belt with well-defined highs along it on the west side of the batholith is noteworthy.

COPPER

Most of the productive copper deposits lie along a discontinuous line in the western metamorphic belt, which runs parallel with and west of the linear belt of gold deposits (Fig. 3B and 3C). In the central Sierra Nevada, most copper mines lie on the flanks of the batholith and only scattered small mines and prospects are in the interior of the batholith (Fig. 3B). Mines with significant past production (in excess approximately of 50,000 kg) of copper are concentrated along or near the Bear Mountains fault zone. The deposits are mainly lenticular massive sulfide bodies in hydrothermally altered Jurassic metavolcanic rocks (Eric, 1948, p. 209; Kinkel and Kinkel, 1966, p. 148). The ores contain abundant iron-sulfide minerals, chalcopyrite, generally appreciable quantities of sphalerite, and some gold and silver. Small amounts of galena, tetrahedrite, and bornite are common in many of the deposits (Heyl, 1948, p. 20). As with the gold deposits, iron sulfides show mineralogic zoning: pyrite is prevalent in the north, whereas pyrrhotite is prevalent in the south (Heyl, 1948, p. 28). Some of the ores in the south also contain cobalt (Heyl, 1948, p. 20; Cox and Wyant, 1948, p. 153). The zinc content is highest in deposits in the western part of the belt.

A geometric progression with a common ratio of 2 has been used for contouring (Fig. 3B), that is, mines with a total production of over approximately 500,000 kg (1,000,000 pounds) of copper have been assigned a value of 8, those with approximately 50,000 to 500,000 kg (100,000 to 1,000,000 pounds) a value of 4, and those with less than 50,000 kg (100,000 pounds) a value of 2. Prospects with no recorded production have been counted as 1. The contours define a linear belt with well-defined highs along it, similar to the pattern for gold.

Copper is scarce within and east of the batholith but has been recovered as a by-product at the Pine Creek tungsten and Cardinal gold mines in the eastern part of the central Sierra Nevada. The Minarets copper district in the high Sierra Nevada has had little past production, but apparently a large amount of metal remains in the deposit (Kinkel and Kinkel, 1966, p. 146). The deposit consists of veinlets and disseminations of sulfide minerals in limestone (Erwin, 1934, p. 73, 4).

LEAD AND ZINC

Deposits on both sides of the batholith have yielded lead and zinc (Fig. 3D). Because of past methods of reporting production figures, it is difficult to consider lead and zinc separately. Zinc production has largely been overlooked until comparatively recently (Goodwin, 1957b, p. 358). Much of the zinc from the western Sierra Nevada has come from the massive sulfide deposits of the Foothills copper belt where it is more abundant than lead. Lead predominates over zinc in limestone replacement deposits on the east side of the batholith (Fig. 3D). Some smaller deposits in the interior of the batholith are in contact metamorphic zones, in complex ores more valuable for their gold and silver than for their base metals.

TUNGSTEN

Contact metamorphic tungsten deposits, including some major producers, occur in the central and southern Sierra Nevada (Fig. 3E). Virtually all of the deposits are in skarn developed in calcareous rocks of roof pendants or inclusions along or near contacts with granitoids. The ores generally are complex, and some yield base and precious metals as by-products (Lemmon, 1966, p. 430). Most of the large deposits are in the Bishop district, in the east-central part of the batholith, and others are scattered through the batholith farther to the west. By far the most productive mine in the Bishop district, and one of the most productive in the world, is the Pine Creek mine (Bateman, 1965; Gray and others, 1968).

Past production of tungsten in the central Sierra Nevada has been contoured (Fig. 3E) by assigning a value of 4 to deposits that have yielded more than approximately 1,000 tonnes (1,000 tons) of concentrate containing 60 percent WO_3, 3 to mines that have yielded between 1,000 and 100 tonnes, 2 to mines that have yielded less than 100 tonnes, and 1 to mines that have no recorded production. The contours define an extreme high centered on the Bishop tungsten district and a much lower and broader high farther west.

According to Bateman (1965, p. 146-147) the tungsten deposits in the Bishop district are preferentially associated with two granites, which Bateman and Dodge (1970) have included in the Scheelite sequence of Triassic age (Fig. 2). The important Strawberry mine, farther west in a medial part of the batholith is associated with granitoids that are clearly older than the preponderant Upper Cretaceous granitoids in the area. One of the most striking relations is the dearth of tungsten deposits associated with granitoids of Late Cretaceous age. The scattered deposits in the western part of the batholith are associated with Lower Cretaceous granitoids.

CHROME

Chromite is concentrated in two areas in the western part of the central Sierra Nevada, both of which have had significant production (Fig. 3F). Both areas are underlain by large fault-bounded masses of dunite and serpentinite. The chromite occurs in irregular lenticular to tabular, podiform type (Thayer, 1964) bodies of massive ore with sharp boundaries, and in larger deposits of disseminated ore that grades into barren ultramafic rock (Thayer, 1966, p. 122; Cater and others, 1951, p. 118).

OTHER METALS

Small quantities of manganese have been mined from metamorphosed bedded sedimentary deposits in the western Sierra Nevada (Davis and Hewett, 1966, p. 245) (Fig. 3G). Rhodonite is the principal manganese mineral in these deposits. Piemontite and rhodonite are present in metamorphic rocks in roof pendants within the batholith itself, but have not been exploited.

Noteworthy concentrations of iron occur in Tertiary sandstones as residual cappings and in bedrock in both skarn and massive replacement deposits (Moore, 1966, p. 202); however production has been minor. In the central Sierra Nevada (Fig. 3B), replacement magnetite deposits occur in a belt of metamorphic roof pendants, which crosses the batholith transverse to its axis; iron deposits in the southwes corner of the batholith are in small bodies of spessartite-rich skarn.

Most of the molybdenum deposits of the Sierra Nevada are either in quartz-vein deposits in granitic rocks or skarn deposits in metamorphic rocks adjacent to granitic rocks. Disseminated deposits in granodiorite have also been reported (King, 1966, p. 268). Molybdenite is the principal ore mineral. However, large amounts of molybdenum have been recovered as a by-product at the Pine Creek tungsten mine from molybdenite, powellite, and scheelite (Bateman, 1956, p. 23).

Silver has been recovered largely as a by-product of base metal and gold mining. The Pine Creek tungsten mine has been the leading producer of silver in recent years (Stager, 1966, p. 381).

RELATION OF DISTRIBUTION PATTERNS OF MINERAL DEPOSITS TO THE COMPOSITIONAL AND AGE PATTERNS OF THE BATHOLITH

Tungsten, molybdenum, and some iron deposits lie within the batholith, whereas most deposits of other metals of economic importance are in the peripheral country rocks. Of the metals that occur chiefly within the batholith, data satisfactory for evaluating the distribution of deposits in relation to the compositional and age patterns in the batholith are available only for tungsten; deposits of iron are too few, and molybdenum, though widespread in the medial and eastern part of the batholith but not in the low potassium rocks in the western part, is generally in unrecorded deposits too small to have been prospected.

Tungsten shows some correspondence with the granitoid sequences. Major deposits preferentially accompany rocks of the Triassic Scheelite sequence in the Bishop tungsten district and "older" granitoids in the Strawberry mine area. Only minor deposits are associated with the Early Cretaceous Shaver and Millerton sequences in the western part of the batholith and almost no deposits with the Late Cretaceous sequences in the medial part. In the Bishop district, the tungsten deposits are preferentially associated with late leucocratic members of the Scheelite sequence (Bateman, 1965, p. 146–148), suggesting that tungsten was concentrated in late magmatic phases and from them into mineralizing solutions. However, Krauskopf (1953, p. 9), writing about deposits in the medial and western parts of the batholith, notes that "good" deposits are found at contacts of calcareous rocks with igneous rocks ranging from quartz monzonite to quartz diorite.

Only very general relations between the batholith and the metals that occur chiefly peripheral to the batholith can be considered at this time. Much additional data are needed to evaluate possible relations between these metals and the compositional and age patterns within the batholith.

Chromite is syngenetic with its host ultramafic rocks, and clearly the batholith played no role in its concentration. Hutchinson (1973, p. 1235). Kemp (1976), and Kemp and Payne (1975) have proposed that the copper-zinc massive sulfide ores in the western foothills were derived from the volcanogenic rocks in which they are stratabound. Whether the massive-sulfide deposits are essentially syngenetic with their enclosing volcanic rocks or were reconcentrated at a later time is uncertain. Manganese also is generally believed to have its source in the rhythmically bedded fine-grained chert and volcanic rocks in which the manganese deposits occur (Crittenden, 1956, p. 188). However, the manganese has been reconcentrated, and the batholith may have supplied heat to activate circulation of meteoric waters which brought about the reconcentration.

According to conventional thought, the gold deposits of the western Sierra Nevada are genetically related to the batholith (Richthofen, 1869, p. 28; Tolman, 1933, p. 250; Lindgren, 1933, p. 544; Logan, 1934, p. 8; Emmons, 1937, p. 118; Heyl, 1948, p. 28; Clark, 1966, p. 209; Bateman, 1966, p. 57). Parallel trends of the massive sulfide copper-zinc massive sulfide and lode-gold deposits with the western edge of the batholith suggests some kind of relationship with the batholith, but not necessarily a genetic one. Hallimond (1975, p. 868) has suggested that the gold in the Mother

Lode was reconcentrated from country rocks in which gold had been enriched by sedimentary processes. Three-quarters of a century earlier, Ransome (1900, p.7) anticipated this idea when he stated "in all probability the waters which carried the Mother Lode ores in solution were originally meteoric waters, which after gathering up their mineral freight in the course of downward and lateral movement through the rocks, were converged in the fissures as upward-moving mineral-bearing solutions"

CONCLUSIONS

Recent advances in understanding of the means by which ores are concentrated into exploitable deposits and better understanding of the distribution and associations of the metals that have been mined in the Sierra Nevada suggest the possibility that the source of most metals may have been in country rocks adjacent to the deposits rather than end-stage solutions in the batholith. Tungsten, molybdenum, and iron in skarn, all of which are in deposits that lie within the batholith rather than peripheral to it are the metals most likely to have had their source in the batholith.

Most deposits of gold, silver, copper, lead, zinc, and manganese are peripheral to the batholith and possibly were derived from volcanogenic or sedimentary concentrations in the rocks in which they occur. The metals may have been reconcentrated from the country rocks by mobilized, probably largely meteoric, aqueous solutions. The role of the batholith in the concentration of these metals very likely was to supply the heat required for circulation of meteoric waters in the country rocks.

REFERENCES

BATEMAN, P.C., 1956. Economic geology of the Bishop tungsten district, California. *California Div. Mines Spec. Rept. 47,* 87 p.

BATEMAN, P.C., 1965. Geology and tungsten mineralization of the Bishop district, California: *U.S.* Geol. Survey Prof. Paper 470, 208 p.

BATEMAN, P.C., 1966. Geology of the Sierra Nevada. In "*Mineral Resources of California*" California Div. Mines and Geology Bull., *191,* 54–59.

BATEMAN, P.C., Clark, L.D., Huber, N.K., Moore, J.G., and Rinehart, C.D., 1963. The Sierra Nevada batholith—A synthesis of recent work across the central part. *U.S. G.S. Prof. Paper 414–D,* D1–D46.

BATEMAN, P.C., and DODGE, F.C.W., 1970. Variations of major chemical constituents across the central Sierra Nevada batholith: *Geol. Soc. America Bull., 81,* 409–420.

CATER, F.W., Jr., RYNEARSON, G.A., and Dow, D.H., 1951. Chromite deposits of El Dorado County, California. *California Div. Mines Bull., 134,* part III, chapter 4, 107–167.

CLARK, W.B., 1957. Gold; In "*Mineral commodities of California*". *California Div. Mines Bull., 176,* 215–226.

CLARK, W.B., 1966. Economic mineral deposits of the Sierra Nevada. *In* Bailey, E.H., ed., "*Geology of Northern California*". California Div. Mines Bull. *190,* 209–214.

CLARK, W.B., 1970. Gold districts of California. *California Div. Mines and Geology Bull., 193,* 186p.

COX, M.W., and Wyant, D.G., 1948. The Jesse Belle copper mine, Madera County, California. *In* "*Copper in California*". California Div. Mines Bull., *144,* 199–387.

CRITTENDEN, M.D., Jr., 1956, Syngenetic deposits. In Hewett, D.F., Crittenden, M.D., Pavlides, Louis, and de Huff, G.L., Jr., "Manganese deposits of the United States". Internat. Geol. Cong., 20th, Mexico, Symposium del maganeso, *3,* chap. II, 177–193

Davis, F.F., and Hewett, D.F., 1966. Manganese. In "*Mineral Resources of California*". California Div. Mines Bull., *191*, 243–247.

Dodge, F.C.W., 1972a. Trace element contents of some plutonic rocks of the Sierra Nevada batholith. *U.S. G.S. Bull.*, 1314–F, 13 p.

Dodge, F.C.W., 1972b. Variation of ferrous-ferric ratios in the central Sierra Nevada batholith, U.S.A. *Internat. Geol. Cong., 24th, Montreal*, Sect. 10, 12–19.

Emmons, W.H., 1973. *Gold deposits of the world.* McGraw-Hill, New York, 562 p.

Eric, J.H., 1948. Tabulation of copper deposits of California. In "*Copper in California*". California Div. Mines Bull., *144*, 199–387.

Erwin, H.E., 1934. Geology and mineral resources of northeastern Madera County, California. *California Jour. Mines and Geology*, *30*, 7–78.

Evernden, J.F., and Kistler, R.W., 1970. Chronology of emplacement of Mesozoic batholithic complexes in California and western Nevada. *U.S. G.S. Prof. Paper 623*, 42 p.

Goodwin, J.G., 1957a. Outline geologic map of California showing location of mines with lead and zinc production. *California Div. Mines Econ. Mineral Map of California*, No. 7.

Goodwin, J.G., 1957b. Lead and zinc in California. *California Jour. Mines and Geology*, *53*, 353–724.

Gray, R.F., Hoffman, V.J., Bagan, R.J., and McKinley, H.L., 1968, Bishop tungsten district, California. In Ridge, J.D., ed., "*Ore deposits of the United States, 1933–1967 (Graton-Sales volume)*". Am. Inst. Mining, Metall., Petroleum Engineers, 1531–1554.

Hallimond, A.L., 1975, Minerals and plate tectonics (II): seawater and ore formation. *Science*, *189*, 868–869, 915–917.

Heyl, G.R., 1948. Foothill copper-zinc belt of the Sierra Nevada, California. In "*Copper in California*". California Div. Mines Bull. *144*, 11–29.

Hutchinson, R.W., 1973. Volcanogenic sulfide deposits and their metallogenic significance. *Econ Geology*, *68*, 1223–1246.

Jenkins, O.P., 1942a. Outline geologic map of California showing locations of chromite properties. *California Div. Mines Econ. Mineral Map of California*, No. 3.

Jenkins, O.P., 1942b. Outline geologic map of California showing locations of tungsten properties. *California Div. Mines Econ. Mineral Map of California*, No. 4.

Jenkins, O.P., 1943. Outline geologic map of California showing locations of manganese properties. *California Div. Mines Econ. Mineral Map of California*, No. 5.

Jenkins, O.P., 1948. Outline geologic map of California showing locations of copper properties. *California Div. Mines Econ. Mineral Map of California*, No. 6.

Kemp, W.R., 1976. The foothill copper-zinc belt, Sierra Nevada, California, a volcanogenic massive sulfide province. *Geol. Soc. America Abs. with Programs*, *8*, 387–388.

Kemp, W.R., and Payne, A.L., 1975. Petrochemical associations within the foothill copper-zinc belt, Sierra Nevada, California. *Geol. Soc. America Abs. with Programs*, *7*, P. 332.

King, R.U., 1966. Molybdenum. In "*Mineral Resources of California.*" California Div. Mines Bull. *191*, 262–269.

Kinkel, A.R., and Kinkel, A.R., Jr., 1966. Copper. In "*Mineral Resources of California*". California Div. Mines Bull., *191*, 141–150.

Kistler, R.W., and Peterman, Z.E., 1973. Variations in Sr, Rb, K, Na, and initial Sr^{86}/Sr^{87} in Mesozoic granitic rocks and intruded wall rocks in central California. *Geol. Soc. America Bull.*, *84*, 3489–3512.

KNOPF, A., 1929. The Mother Lode system of California. *U.S. G.S. Prof. Paper 157*, 88 p.

KRAUSKOPF, K.B., 1953. Tungsten deposits of Madera, Fresno, and Tulare Counties, California. *California Div. Mines Spec. Rept. 35*, 83 p.

LEMMON, D.M., 1966. Tungsten. In "*Mineral Resources of California*". California Div. Mines and Geology Bull. *191*, 429–436.

LINDGREN, W., 1933. *Mineral deposits*. McGraw-Hill, New York 4th ed., 930 p.

LOGAN, C.A., 1934. Mother Lode gold belt of California. *California Div. of Mines Bull., 108*, 240 p.

MOORE, L., 1966, Iron. In "*Mineral Resources of California*". California Div. Mines Bull., *191*, 199–212.

PRESNALL, D.C., and BATEMAN, P.C., 1973. Fusion relations in the system $NaAlSi_3O_8$–$CaAl_2Si_2O_8$–$KAlSi_3O_8$–SiO_2–H_2O and generation of granitic magmas in the Sierra Nevada batholith. *Geol. Soc. America Bull., 84*, 3181–3202.

RANSOME, F.L., 1900. Mother Lode district, California. *U.S. Geol. Survey Geol. Atlas*, Folio 63, 11 p.

RICHTHOFEN, F. VON, 1869. Ueber das Alter der goldfuhrenden Gange und der von ihnen durchsetzen Gesteine. *Deutsch. Geol. Gesell. Zeitschr., 21*, 723–740.

SALEEBY, J., 1976. Zircon Pb/U geochronology of the Kings–Kaweah ophiolite belt—southwestern Sierra Nevada foothills, California. *Geol. Soc. America Abs. with Programs, 8*, 405–406.

STAGER, H.K., 1966, Silver. In "*Mineral Resources of California*". California Div. Mines Bull., *191*, p. 381–385.

THAYER, T.P., 1964. Principal features and origin of podiform chromite deposits and some observations on the Guleman-Soridag district, Turkey. *Econ. Geology, 59*, 1497–1524.

THAYER, T.P., 1966. Chromite. In "*Mineral resources of California*". California Div. Mines and Geology Bull., *191*, 120–126.

TOLMAN, C.F., 1933. The foothill copper belt of California. *Internat. Geol. Cong., 16th, Washington, Copper Resources of the World, 1*, 247–250.