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NBM Bull. 69

RELATION OF WESTERN MINING DISTRICTS TO TECTONICS AND IGNEOUS ACTIVITY

JEROME and COOK

NEVADA BUREAU OF MINES

Vernon E. Scheid, Director

BULLETIN 69

RELATION OF SOME METAL MINING DISTRICTS IN THE WESTERN UNITED STATES TO REGIONAL TECTONIC ENVIRONMENTS AND IGNEOUS ACTIVITY

By

S. E. JEROME

and

D. R. COOK

MACKAY SCHOOL OF MINES

UNIVERSITY OF NEVADA

1967

PLATE 1

EXPLANATION OF SYMBOLS USED ON PLATES 2 THROUGH 17

Value of production and estimated reserves of mining districts in dollars.

Clusters of mineral localities with small production.

- Less than $100 thousand
- $100 thousand to $1 million
- $1 million to $10 million
- $10 million to $100 million
- $100 million to $1 billion
- More than $1 billion

Precambrian younger sedimentary and volcanic rocks

Precambrian older sedimentary and volcanic rocks

Precambrian granite and intermediate type intrusive rocks

Younger orogenic belt

Older orogenic belt; dashed where later orogeny is superimposed

Maximum limit of orogenic belt

Area with predominant tendency to be emergent

Position of epeirogenic area; dashed where later orogeny is superimposed

Shifting position of epeirogenic area

Position of major shoreline; dashed where later orogeny is superimposed

Isopachous lines showing shifting positions with time

Eastern limit of Paleozoic geosyncline (on Paleozoic environmental plates)

Thick accumulations of sediments; dashed where later orogeny is superimposed

Abbreviations used on environmental plates

E	Early	P	Permian
Mid	Middle	IP	Pennsylvanian
L	Late	M	Mississippian
		D	Devonian
K	Cretaceous	S	Silurian
J	Jurassic	O	Ordovician
Ћ	Triassic	Є	Cambrian

Nevadan (Mesozoic) intrusive rocks

Laramide (Tertiary) intrusive rocks

Foliation

Normal fault

Thrust fault

Fold Axis

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Reno, Nevada
1967

STATE OF NEVADA

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NEVADA BUREAU OF MINES

VERNON E. SCHEID, *Director*

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Osmond, J. C., Jr., 1960, Tectonic history of the Basin and Range Province in Utah and Nevada: Mining Eng., v. 12, no. 3, p. 251–265.

Paige, Sidney, 1916, Description of the Silver City quadrangle, New Mexico: U. S. Geol. Survey Geol. Atlas, folio no. 199.

Peterson, N. P., 1952, Structural history of the Globe-Miami district, *in* Arizona Geol. Soc. guidebook for Geol. Soc. America Cordilleran Sec. meeting, Tucson, Ariz., Apr. 10–14, 1952, p. 122–127.

............................, 1962, Geology and ore deposits of the Globe-Miami district, Arizona: U. S. Geol. Survey Prof. Paper 342.

Ransome, F. L., 1904, The geology and ore deposits of the Bisbee quadrangle, Arizona: U. S. Geol. Survey Prof. Paper 21.

Richard, K. E., and Courtwright, J. H., 1954, Structure and mineralization at Silver Bell, Arizona: Mining Eng., v. 6, no. 11, p. 1095–1099; Am. Inst. Mining Metall. Petroleum Engineers Trans., v. 199.

Roberts, R. J., 1966, Metallogenic provinces and mineral belts in Nevada, *in* Papers presented at the AIME Pacific Southwest Mineral Industry Conference, Sparks, Nevada, May 5–7, 1965: Nevada Bur. Mines Report 13, Part A, p. 47–72.

Rose, A. W., and Cook, D. R., 1965, Radioactive age dates of porphyry copper deposits in western United States [abs.]: Econ. Geology, v. 60, p. 1557.

Spencer, A. C., 1917, The geology and ore deposits of Ely, Nevada: U. S. Geol. Survey Prof. Paper 96.

Stose, G. W., compiler, 1932, Geologic map of the United States: U. S. Geological Survey, scale 1:2,500,000.

Sullivan, C. J., 1948, Ore and granitization: Econ. Geology, v. 43, no. 6, p. 471–498.

Wisser, E. H., 1959, Cordilleran ore districts in relation to regional structure, *in* Symposium on saturation prospecting: Canadian Inst. Mining Metall., Bull. 561, p. 34–42.

SUMMARY AND CONCLUSIONS

Large and small scale map combinations, such as those presented, are useful in revealing and studying distribution patterns of mining districts in the western United States and elsewhere. Although this work has been limited to gold, silver, copper, lead, and zinc, the techniques used can be expanded to other metals even though conclusions to be drawn might be different. Much remains to be done at large scale to correct or strengthen some of the generalizations that have been made.

In a broad way orogeny, intrusives, and the districts with the five metals become progressively younger eastward in the western United States. Exceptions to this generalization exist in any specific geologic province. As for example, significant structural adjustments are taking place today along the Pacific Coast.

Apparently a combination of deeply penetrating zones of weakness, deepseated igneous activity, thermal activity, and major concentrations of metalliferous material at depth are needed to produce the belts or clusters of districts as we see them today. These combinations have occurred at specific time intervals during the evolution of the Cordilleran system. If persistent faults alone were the answer, the great structures along the Pacific Coast should provide magnificent plumbing systems, and lines of major districts should occur in and parallel to them. This is not the case, but possibly the magmas, thermal activity, and ore deposits are yet to come.

We believe that most western mining districts containing gold, silver, copper, lead, and zinc show no preferred localization in shield, shelf, basin, or geosynclinal environments, and that they are found in all kinds of host rocks. In specific examples we see such a remarkable coincidence of structure, intrusive igneous centers, and timing of intrusive igneous activity with the formation of orebodies, that we derive little comfort from source bed or granitization concepts as guides in planning the search for new gold, silver, copper, lead, and zinc districts in the western United States. The same conclusion may not apply to certain other metals, however.

REFERENCES

Anderson, C. A., Scholz, E. A., and Strobell, J. D., Jr., 1955, Geology and ore deposits of the Bagdad area, Yavapai County, Arizona: U. S. Geol. Survey Prof. Paper 278.

Bauer, H. L., Jr., Cooper, J. J., and Breitrick, R. A., 1960, Porphyry copper deposits in the Robinson mining district, White Pine County, Nevada, *in* Guidebook to the geology of east-central Nevada: Intermountain Assoc. Petroleum Geologists and Eastern Nevada Geol. Soc., 11th Ann. Field Conf., p. 220–228.

Beeson, J. J., 1925, Mining districts and their relation to structural geology: Am. Inst. Mining Metall. Petroleum Engineers Trans., v. 75, p. 757–792.

Billingsley, P. R., and Locke, Augustus, 1941, Structure of ore districts in the continental framework: Am. Inst. Mining Metall. Petroleum Engineers Trans., v. 144, p. 9–59.

Burnham, C. W., 1959, Metallogenic provinces of the southwestern United States and northern Mexico: New Mexico Bur. Mines and Min Res., Bull. 65.

Butler, B. S., 1929, Relation of the ore deposits of the southern Rocky Mountains region to the Colorado Plateau: Colorado Sci. Soc. Proc., v. 12, p. 23–36.

Callahan, W. H., 1964, Paleophysiographic premises for prospecting for strata-bound base metal mineral deposits in carbonate rocks, *in* Mining geology and base metals: Central Treaty Organ. (CENTO), Turkey, Sept. 14–29, 1964, p. 191–248; also *in* Papers presented at the AIME Pacific Southwest Mineral Industry Conference, Sparks, Nevada, May 5–7, 1965: Nevada Bur. Mines Report 13, Part C, p. 5–50 [1966].

Cohee, G. V., chairman, 1961, Tectonic map of the United States exclusive of Alaska and Hawaii: U. S. Geol. Survey [publisher] and Am. Assoc. Petroleum Geologists, scale 1:2,500,000.

Eardley, A. J., 1951, Structural geology of North America: New York, Harper and Bros., 624 p. (2nd ed., 1962, 743 p.)

Flawn, P. T., 1965, Basement—not the bottom but the beginning: Am. Assoc. Petroleum Geologists Bull., v. 49, no. 7, p. 883–886.

Gabelman, J. W., 1953, Definition of a mineral belt in south central Colorado: Econ. Geology, v. 48, no. 3, p. 177–210.

Goodspeed, G. E., 1952, Mineralization related to granitization: Econ. Geology, v. 47, no. 2, p. 146–168.

Hill, J. M., 1912, The mining districts of the western United States, with a geologic introduction by Waldemar Lindgren: U. S. Geol. Survey Bull. 507.

Hill, R. T., 1928, Trancontinental structural digression [abs.]: Geol. Soc. America Bull., v. 39, no. 1, p. 265.

Horton, R. C., 1966, Statistical studies of the distribution of mining districts in Nevada, *in* Papers presented at the AIME Pacific Southwest Mineral Industry Conference, Sparks, Nevada, May 5–7, 1965: Nevada Bur. Mines Report 13, Part A, p. 109–123.

Huddle, J. W., and Dobrovolny, Ernest, 1945, Late Paleozoic stratigraphy of central and northeastern Arizona: U. S. Geol. Survey Oil and Gas Inv. Prelim. Chart 10.

King, P. B., and others, 1944, Tectonic map of the United States: Am. Assoc. Petroleum Geologists, scale 1:2,-500,000. (prepared under dir. of Comm. on Tectonics, Nat'l. Res. Council)

Knight, C. L., 1957, Ore genesis—the source bed concept: Econ. Geology, v. 52, no. 7, p. 808–817.

Knopf, Adolf, 1948, The geosynclinal theory: Geol. Soc. America Bull., v. 59, no. 7, p. 649–669.

Locke, Augustus, Billingsley, P. R., and Mayo, E. B., 1940, Sierra Nevada tectonic patterns: Geol. Soc. America Bull., v. 51, no. 4, p. 513–539.

Lovering, T. S., and Goddard, E. N., 1950, Geology and ore deposits of the Front Range, Colorado: U. S. Geol. Survey Prof. Paper 223.

Mayo, E. B., 1958, Lineament tectonics and some ore districts of the Southwest: Mining Eng., v. 10, no. 11, p. 1169–1175; Am. Inst. Mining Metall. Petroleum Engineers Trans., v. 211, 1959.

McCartney, W. D., and Potter, P. R., 1962, Mineralization as related to structural deformation, igneous activity and sedimentation in folded geosynclines: Canadian Mining Jour., v. 83, no. 4, p. 83–87.

New Mexico Geological Society, 1953, Generalized geologic map of the Silver City region, Grant County, New Mexico: New Mexico Geol. Soc., Guidebook, Fourth Field Conf., Oct. 15–18, 1953, p. 65.

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ILLUSTRATIONS

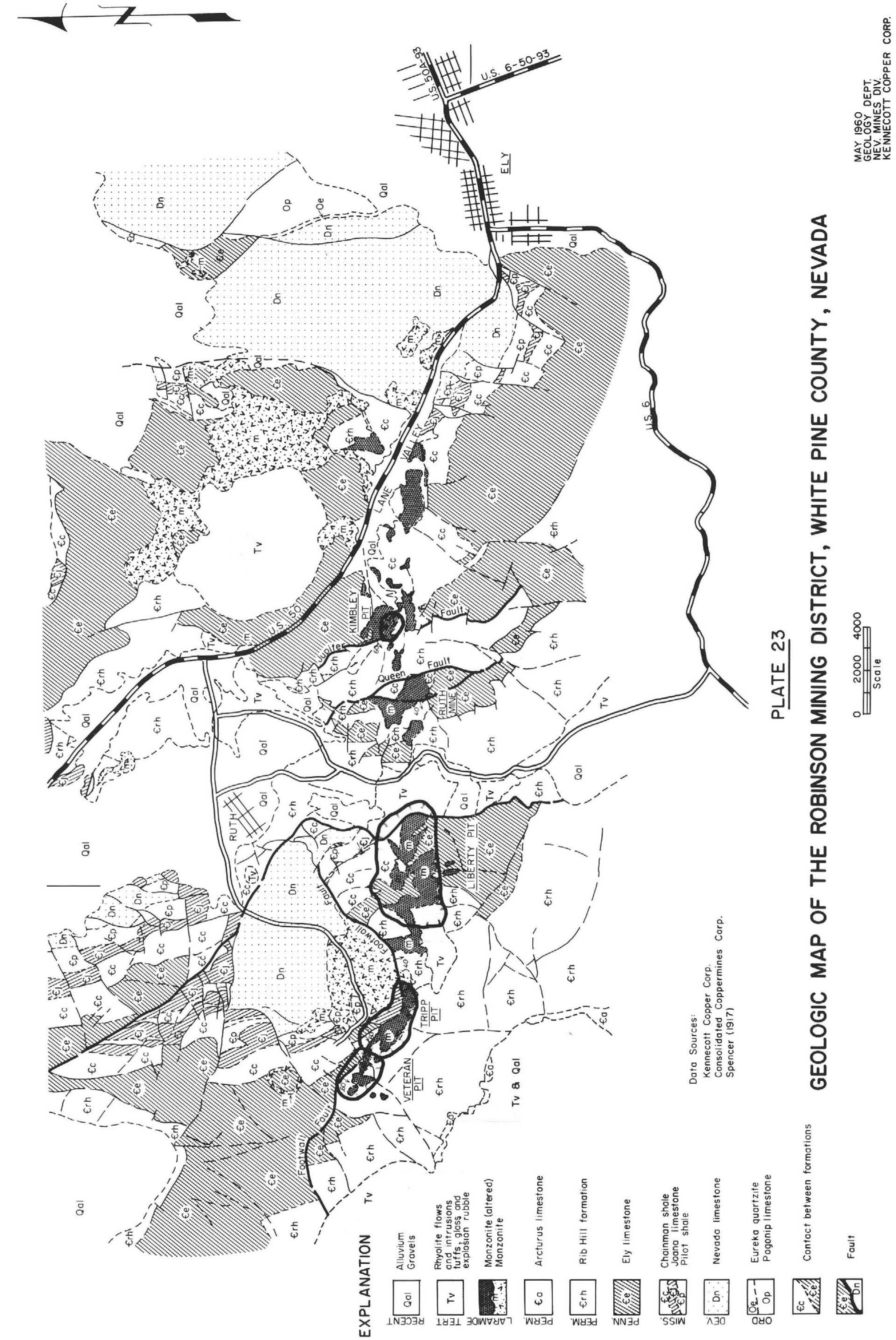
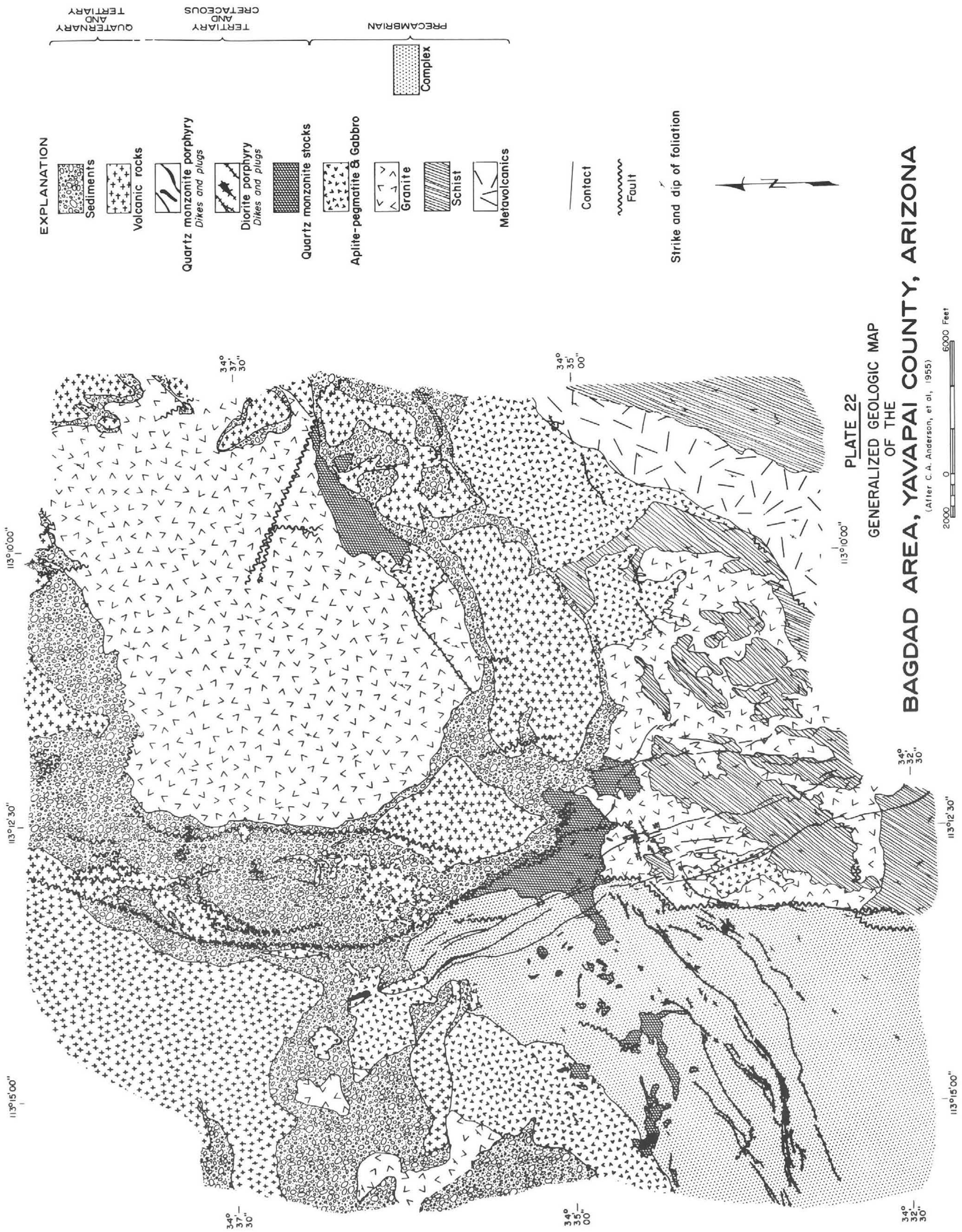


PLATE 23

GEOLOGIC MAP OF THE ROBINSON MINING DISTRICT, WHITE PINE COUNTY, NEVADA



RELATION OF SOME METAL MINING DISTRICTS IN THE WESTERN UNITED STATES[1] TO REGIONAL TECTONIC ENVIRONMENTS AND IGNEOUS ACTIVITY[2]

By S. E. JEROME[3] and D. R. COOK[4]

ABSTRACT

By comparing a metallization map with geologic and tectonic maps, emphasis is given to the close correspondence of western United States mining districts containing gold, silver, copper, lead, and zinc, to igneous centers, and to the importance of zones of structural weakness, visible or implied, in localizing these centers and individual ore deposits within districts. A review of regional environments beginning with the Precambrian, shows no preferred localization of mining districts in shield, shelf, basin, or geosyncline. Intrusive rocks and related ore bodies are found in schists, gneisses, granites, foliated and non-foliated eugeosynclinal assemblages, non-foliated miogeosynclinal assemblages, sediments of other than geosynclinal origin, and in acid and intermediate volcanics. The common denominator of most western mining districts appears to be a dynamic situation in which parts or all of the more or less classical sequence of folding, faulting, intrusion, faulting or brecciation, and mineralization can be recognized. Extrusive activity and post mineralization faulting often are evident. The history of repeated faulting infers the maintenance of openings in deeply penetrating fundamental "plumbing" systems; it is suggested by the writers that the intrusives and eventually the metals found their way into such systems from major concentrations deep within the crust or in the mantle. Areas involved only in shallow thrusting commonly are barren of intrusives and metals. The fundamental controls frequently give rise to striking regional alignments and to clusters of intrusives, mining districts, and individual ore bodies. Some examples of structural control and alignments in Arizona, New Mexico, and Nevada are discussed briefly.

The environmental maps tend to reaffirm the generally decreasing age from west to east, of intrusives and their associated metals. Major orogenic movements, except for Tertiary-Quaternary block faulting and adjustments along the Pacific coast, show a similar eastward shift with time.

The methods of this study can be applied to any other metallic mineral occurrence in any other part of the World, but depending on the commodity involved the conclusions might differ in some respects from those made above.

INTRODUCTION

All persons expending energy and private or government funds in the exploration for ore deposits have speculated as to why important metal mining districts are localized where they are. As one studies the pertinent literature and discusses the problem with contemporaries, he finds a variety of answers to the question. Some will suit his fancy and some will not, depending on how his education has been tempered by experience. Knight (1957) suggests that source beds are all-important in mining district localization, and that structure and igneous activity are unimportant; there certainly are examples of ore deposits in the world for which this suggestion may be attractive, i.e. the Kupferschiefer, White Pine copper, and the Witwatersrand gold deposits. Some observers, Goodspeed (1952) and Sullivan (1948), have linked ore formation with the process of granitization. Knopf (1948) and others [note McCartney and Potter's (1962) review of the Russian literature] have summarized the tectonic or geosynclinal cycle, and suggest that ore deposits are end products of such cycles. This is a tempting suggestion, and possibly is a good meeting ground for many of the diverse views, but those deposits that lie outside of geosynclinal belts compel reexamination of the concept of geosynclinal control both from geographic and genetic standpoints.

Probably the majority of geologists who work on western ore deposits of the types being considered, emphasize the close spatial and temporal relationship of these deposits to structural and igneous activity. The writers are not exceptions, but have been stimulated to study the relationship of metalliferous districts to regional environments in order to reevaluate this belief and to determine, if possible, whether or not source bed and granitization concepts of origin and the possible influence of geosynclines on the location of districts, can be really useful in designing major exploraton programs in the western United States.

[1]As used in this bulletin, "the Western United States", excludes Alaska and Hawaii.

[2]Modified from a presentation before the National A.I.M.-M.E. Meeting in New York on February 17, 1958.

[3]Manager of Mineral Exploration, Kerr McGee Corporation, formerly Associate Director, Nevada Bureau of Mines.

[4]Exploration District Manager, Northwest District, Bear Creek Mining Company.

The nature of the ore fluid, its source, and the mechanism by which it is mobilized and transported, are very poorly understood. A better understanding of the formation and interrelationship of rock minerals, alteration minerals, and sulfides is essential to progress in the understanding of ore genesis. The rapidly increasing results from mineral stability studies in silicate and sulfide systems and other experimentation are critical to this understanding, but we believe they must be correlated with observed field relationships in mining districts.

The writers were led to investigate regional environments and genetic relationships by the need to select those areas where the potential rewards seem to merit the greatest expenditure of exploration time, talent, and money. It is obvious in making such selections that some of the principles used will vary between mineral commodities. Because of the frequent coincidence in the occurrence of gold, silver, copper, lead and zinc, this study is confined to those districts in which one or more of these five metals occur prominently. Some of the district relationships would be different from those discussed, if metals such as iron, antimony, mercury, tungsten, and uranium had been included.

As a basis for this study, the senior writer began 12 years ago to assemble tectonic, geologic, geophysical, and commodity distribution data for the western United States on clear plastic sheets at the scale of 1:2,500,000. The objective was to compile one category of basic information on each sheet and then to assemble various combinations of sheets for comparison. For example, one combination might include four sheets showing tectonic lines, Nevadan intrusives, Late Cretaceous-Tertiary intrusives, and mining districts (see pl. 16). Colors are necessary to bring out differences when the sheets are combined and photographed or printed.

The plates in this bulletin present some significant combinations of mining district distribution patterns with tectonic and intrusive environments from Precambrian to Tertiary in age. The result is of two-fold value, as it illustrates a useful method for studying the described ore deposits, as well as others. The method, which may be employed at either large or small scale for any area, also calls attention to some informative regional relationships. The scale used may lead to some over-generalizations, but these do encourage subsequent inspection in more detail.

ACKNOWLEDGMENTS

The writers are aware of the great influence that many of their contemporaries and predecessors have had on the views expressed in this bulletin. Of the many who deserve mention, the stimulus of Billingsley and Locke's (1941) and Eardley's (1951) writings is particularly acknowledged. A. J. Eardley has kindly authorized the use of eleven colored plates, published in the 1951 edition of his book *Structural Geology of North America,* as the basis for three of the generalized environmental combinations used herein. The color scheme used for his plates has been followed with only slight modification. Not enough difference was found between the colored tectonic plates presented in the 1951 and 1962 editions of Eardley's book to justify revising our plates, originally assembled in 1957.

The geologic and tectonic maps of the United States published by the U. S. Geological Survey (Stose, 1932) and the American Association of Petroleum Geologists (King and others, 1944; Cohee, 1961) have been used freely in compilation of certain sheets, and their use is acknowledged in specific plate descriptions. Reference has been made to geologic and tectonic maps of Canada and Mexico, but, except for intrusive rocks, no material from them has been incorporated.

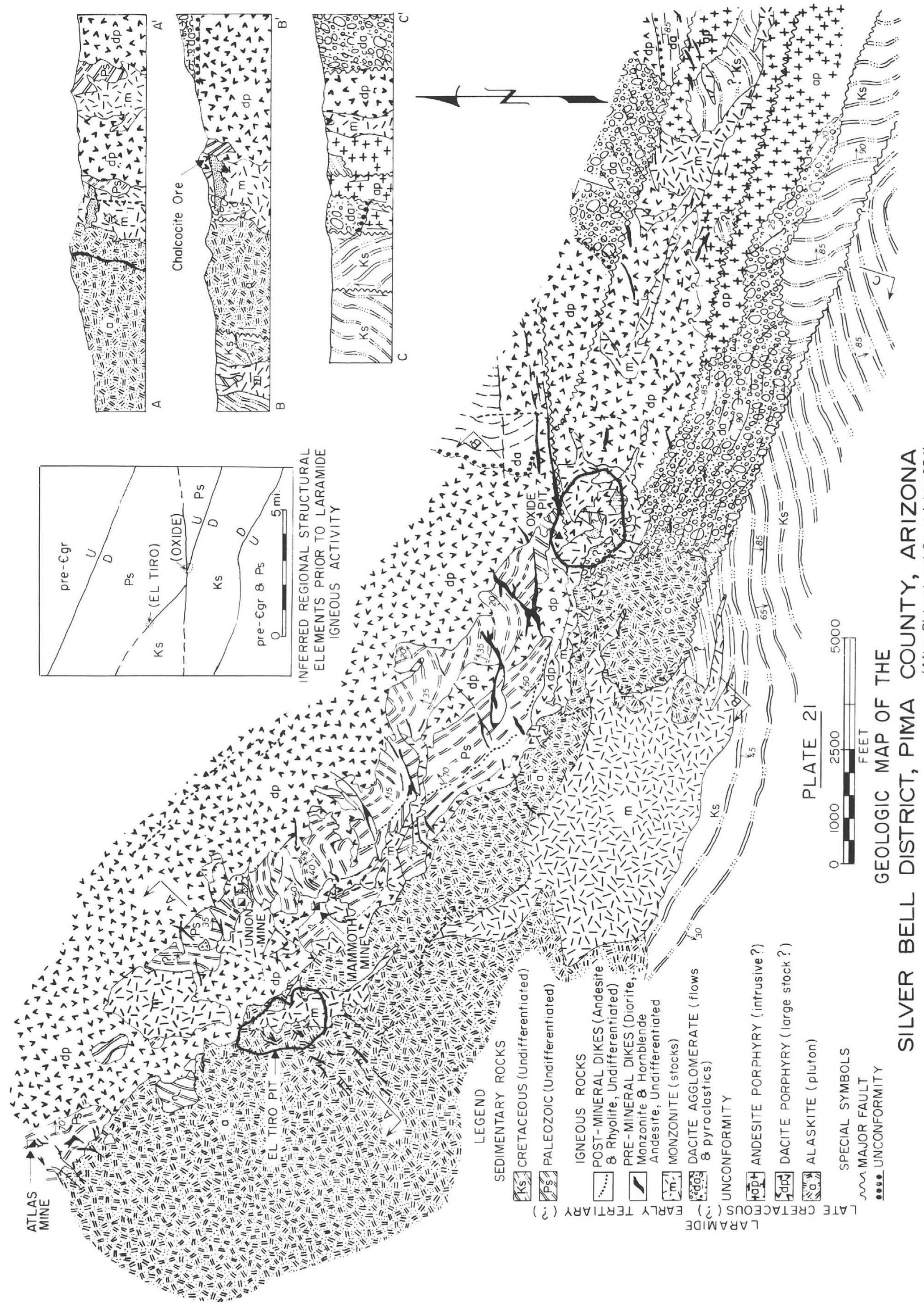
Vernon E. Scheid, Director of the Nevada Bureau of Mines, encouraged reworking and updating the original paper, while the senior writer was Associate Director of the Nevada Bureau of Mines.

For their enthusiasm, technical skill, and dedication to overcoming the many problems attending publication of a report with plates as complex as those herein, the writers extend highest commendation to Ira A. Lutsey, Technical Editor, and to Barbara Webb and Richard Paul, draftsmen.

Bear Creek Mining Co. assisted the writers by allowing time in 1957 and 1958 for preparation of the original paper, and has given permission to publish this material.

DISTRIBUTION PATTERNS OF GOLD, SILVER, COPPER, LEAD, AND ZINC MINING DISTRICTS IN THE WESTERN UNITED STATES

Plate 2 shows the distribution and approximate dollar value of production and reserves of the mining districts of the western United States known to have produced any or all of the five metals: gold, silver, copper, lead, and zinc. (Reference should be made to plate 1, which contains the explanation for plates 2 through 16.) The data have been compiled from published information and in some cases from non-confidential estimates of reserves made by the writers. Being exploration-minded geologists, we feel certain that we have underestimated the potential of some of the smaller districts. Of all reference material used, particular mention should be made to the work of Hill (1912), showing district distribution state by state. This work served as an excellent starting point. The mineral resource volumes of the U. S. Geological Survey, the Minerals



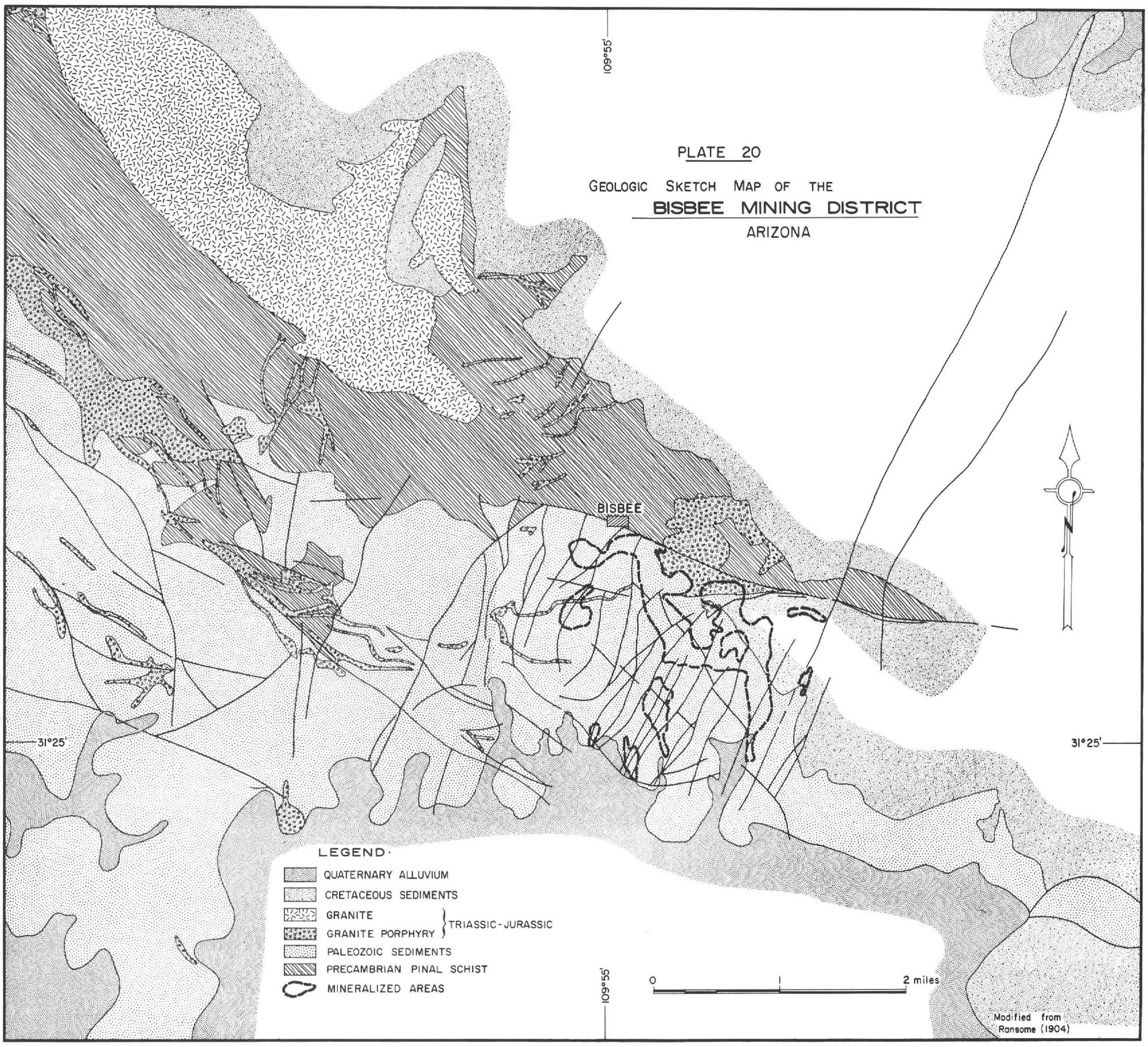
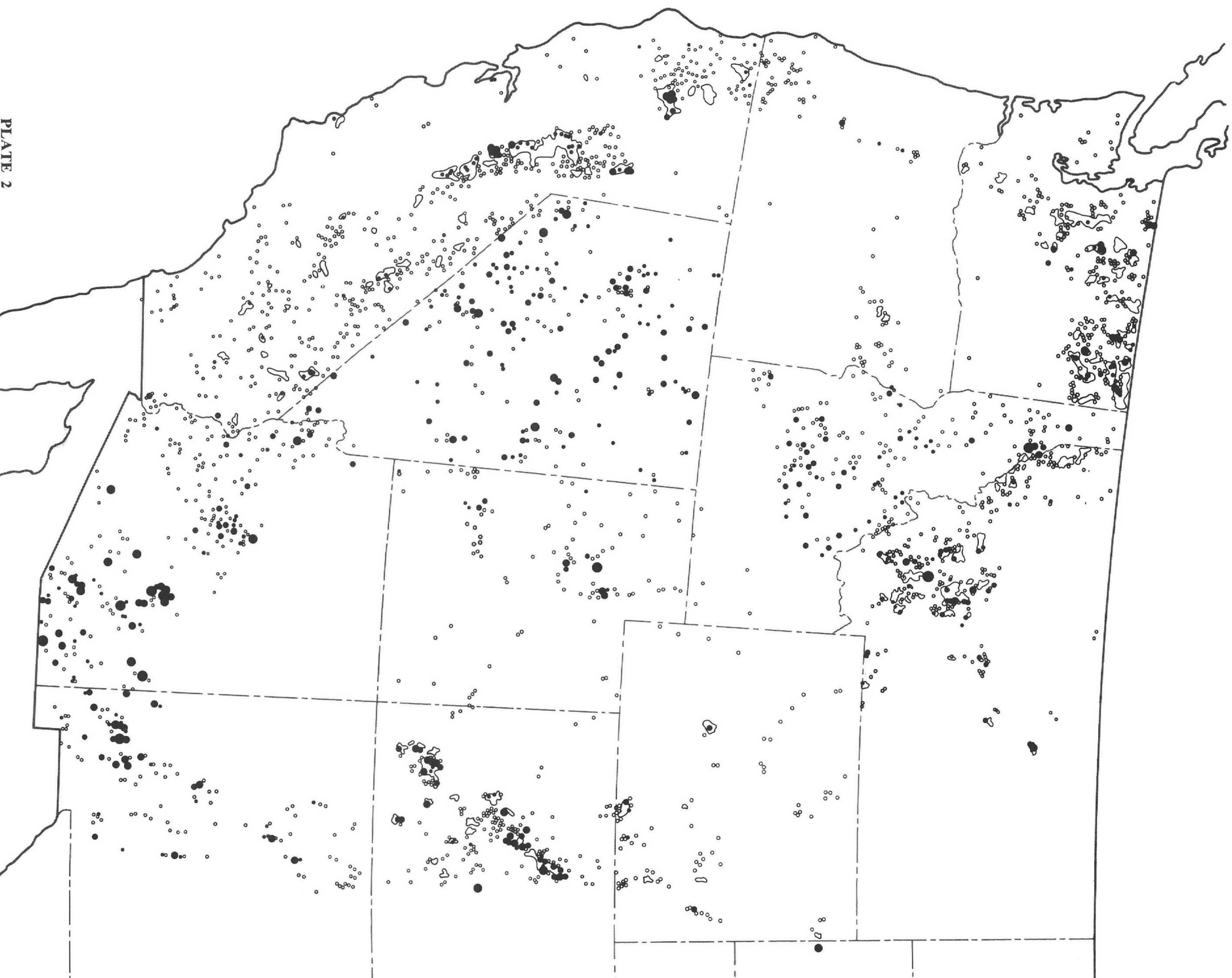


PLATE 2
Distribution patterns of gold, silver, copper, lead, and zinc mining districts in the Western United States.



Yearbooks of the U. S. Bureau of Mines, publications of state geological organizations, and trade journals all have been fertile sources of information, but in spite of this coverage it has been difficult to assemble accurate total information for all districts, especially the smaller ones. This can be disturbing to persons assembling the data, but for the current study only generalized district totals actually are needed.

The pattern of districts shown results from a combination of factors, four of which are indicated in the following paragraphs.

First, it reflects a fundamental geologic tendency for districts to occur in clusters or alignments, although what appear to be random patterns at this, or larger, scale, also are evident. It should be emphasized that the concept of alignments of mineral belts is regarded with healthy skepticism by some, while others who accept the concept may hotly debate the reasons therefor. Noble (1963) observed that the closer to true scale one gets, as for example the view to be obtained from a modern passenger jet at a height of 33,000 feet, the less convincing is the occurrence of districts on long, continuous lines. While the writers have made some of the groupings below as a convenience for subsequent discussion, they do join those who are skeptical of alignments unsupported in detail by structural orientations such as faults, folds, and foliation, or the distribution of certain lithologies favorable to mineralization. We prefer to think of alignments as belts rather than lines, for one's thinking can become so tied to a line that he may fail to look on either side of it.

Second, the pattern reflects the distribution and obscuring effects of post-mineralization sedimentary and volcanic rocks and alluvium. If such post-mineralization cover could be stripped from large areas of the Western States, the overall pattern would change substantially. However, a great deal can be learned from the present pattern.

Third, the pattern reflects the accident of discovery and more recently the level of exploration activity as influenced by economic, political, and social factors.

Fourth, it represents a combination of the maturity of development of individual districts and the level of geologic knowledge for each district.

Attention is directed below to random occurrences, clusters, alignments, and to major barren areas. The distribution patterns of some of the most important districts are obscured to some extent by the inclusion of the apparently less important districts. To assist the reader in orienting himself, the district patterns have been combined with geographic information in plate 3.

1. The gross pattern in Washington, Oregon, northeastern California, northwestern Nevada, and southern Idaho is due in large part to the disposition of the post-mineralization volcanics of the Columbia River and Modoc plateaus and the Snake River downwarp, and to a lesser extent to areas of Tertiary and Quaternary sediments and alluvium.

2. A large cluster of major and minor districts, which might be termed "the Border cluster", occurs in northern Washington and southern British Columbia. Although the pattern appears random, many examples of local stratigraphic, structural, and igneous controls exist within the cluster.

3. Several major districts and many minor ones, including Butte and Coeur d'Alene, lie along the northwest trending "Lewis and Clark line" of Billingsley and Locke (1941). A part of this lineament is coincident with the Osborn fault, a major structure with strike-slip movement.

4. Small- to moderate-sized districts occur somewhat randomly in east-central Oregon and in the northern two-thirds of Idaho. The distribution pattern is strongly influenced by the Idaho batholith and the Columbia River basalts.

5. A northeasterly alignment of districts, (the transverse porphyry belt) is evident through central Montana, and some of what appear to be randomly situated districts in Idaho are on the southwesterly projection of this belt. This corresponds to a porphyry belt, transverse to the Lewis and Clark line. Butte is at the intersection of the two "lines".

6. A number of minor districts are contained in a northerly alignment in western Washington and Oregon.

7. Scattered, unproductive districts in Wyoming occur in northwesterly trending mountain ranges of potentially favorable host rocks margined by basins of post-ore Tertiary sedimentary rocks and Quaternary alluvium. One northerly aligned group of districts is evident.

8. Probably the most spectacular and convincing regional alignment of districts in the West is the Colorado mineral belt, described by Lovering and Goddard (1950), that strikes northeastward through the Front Range and certain other ranges of Colorado. Although this trend is interrupted on the southwest by volcanic rocks, it may be coextensive, beneath the lavas, with districts of the San Juan Mountains. The presence of some volcanic centers on the Colorado Plateau along the southwestward projection of this trend is interesting. Gabelman (1953) has called attention to another less important zone in Colorado striking at right angles to the mineral belt. Some other districts in the state, the most important of which is Cripple Creek, lie outside of these two belts.

9. At first glance, Nevada and western Utah appear to show a random distribution of districts, and anyone with a straight edge can draw any trend that pleases him. One of the senior writer's former colleagues, perhaps a little impatient with the subject of trends, humorously produced a map for Nevada showing concentrations of districts on the circumferences of increasingly large circles. Several other students of the problem, however, have directed attention to a number of northwest and northeast-to-east alignments of districts in these two states.

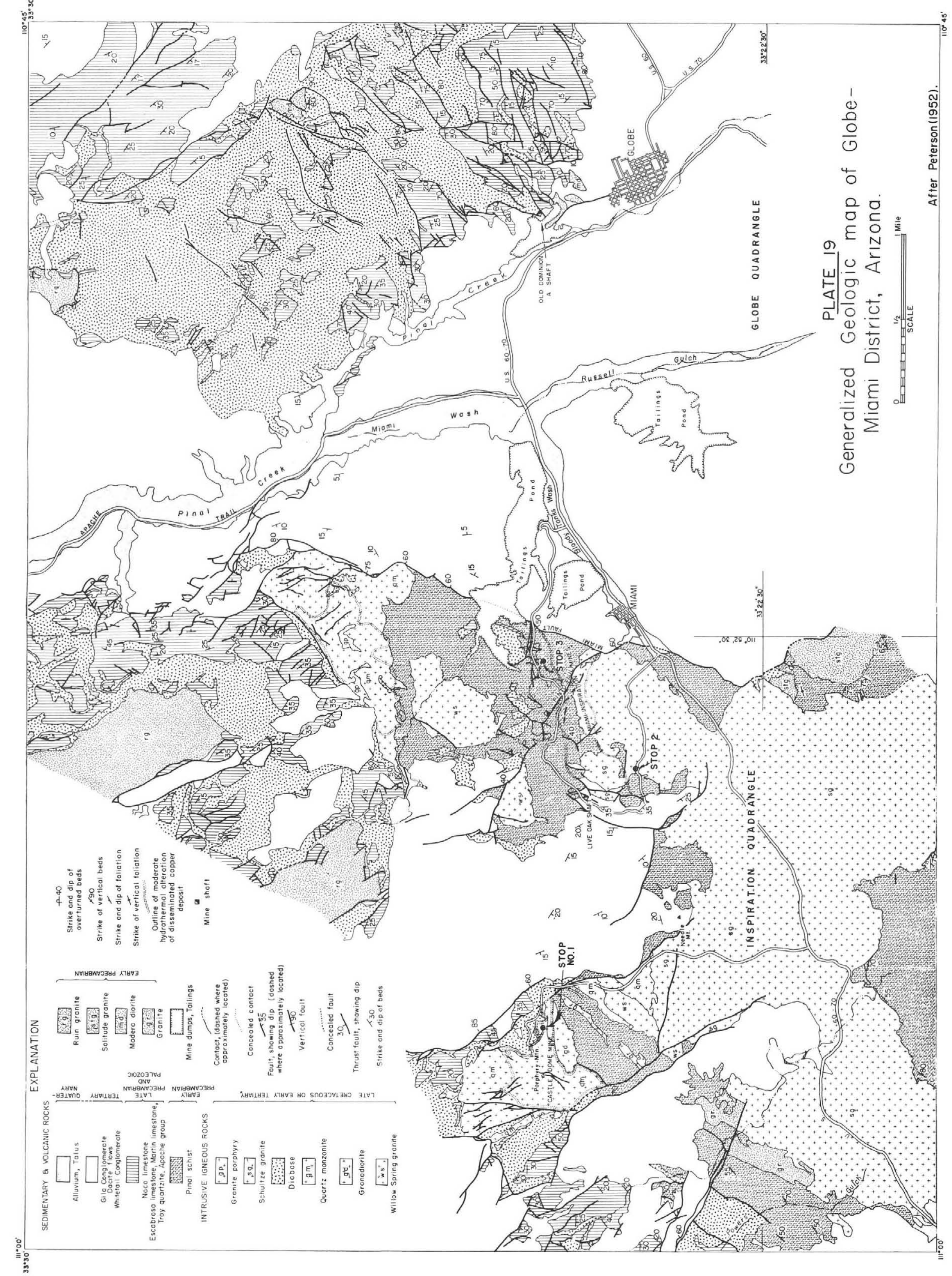


PLATE 19
Generalized Geologic map of Globe-Miami District, Arizona.
After Peterson (1952).

GLOBE–MIAMI DISTRICT, GILA COUNTY, ARIZONA

Plate 19 represents the work of Peterson and others (1952, 1962) of the U. S. Geological Survey.

The situation resembles the Silver City region in many ways. The structural elements include the northeast foliation direction in the Precambrian (which we believe to be the fundamental control), northeast mineralized faults, and later, generally barren, northwest faults. A major belt of base-metal mineralization, including Laramide intrusive rocks and at least three porphyry copper deposits, is superimposed on this country from Superior to Globe. Unfortunately the geology of the Superior area is not included in this plate, but it will be recalled that the Magma vein structure at Superior strikes east and is possibly part of the same broad belt. The ores of the region occur in a variety of rock types including schists, diabase, limestone, and intermediate intrusive rocks.

BISBEE DISTRICT, COCHISE COUNTY, ARIZONA

Plate 20 is a modified version of a map by Ransome (1904, pl. 1).

Although not suggested by the pattern, foliation in the Precambrian rocks tends to be northeasterly. The N. 20° E. faults and the N. 60° W. faults have both pre- and post-ore movement, but the pattern of mineralization in veins and adjacent limestones suggests that the northeast faults were the most important ore localizers. We think it is the intersection of the northeast-trending structural elements with the major northwest-trending Dividend fault zone, and continued adjustment along them, that determined the position of the Sacramento Hill stock and eventually the orebodies (the open pits are not shown). The granite porphyry dikes are controlled by foliation and by steep northeast and northwest faults.

SILVER BELL DISTRICT, PIMA COUNTY, ARIZONA

Plate 21 represents the work of Richard and Courtright (1954) of American Smelting and Refining Co.

The structural components effecting the localization of intrusives and ore are well displayed on plate 21. Control of the intrusives by northwest-trending faults and bedding seems obvious. The reasons for the exact positions of the ore bodies are less obvious, but importance is given to the east-trending fault that intersects the major northwest-trending zone at the Oxide orebody, and to swarms of northeast-trending joints that intersect the northwest-trending zone at both the Oxide and El Tiro ore bodies. We interpret the northwest-trending zone as a deeply penetrating fundamental structure, kept open by repeated movement that spanned the times of intrusion, alteration, and the introduction of ore fluids.

BAGDAD DISTRICT, YAVAPAI COUNTY, ARIZONA

Plate 22 is generalized from Anderson, Scholz, and Strobell (1955). The Precambrian environment is partially obscured by Tertiary gravels and volcanics, and by Quaternary alluvium.

The structural elements are north-, northwest-, and northeast-trending faults that cut a variety of lithologic types. Foliation direction averages about northeast, but is more northerly next to the major north-trending faults. Two dike swarms are evident; the N. 60° E.-trending diorite porphyry dikes are controlled by the foliation but tend to angle slightly across it. The swarm of quartz monzonite porphyry dikes strikes about N. 20° W. The large intrusive body, in and near which the porphyry copper ore deposit is found, evidently was localized at the intersection of structural elements which were capable of enough continuity of adjustment to admit the intrusive, shatter it, allow the ore fluids to enter the broken "sponge," and then to displace slightly some of the veinlets. The north-trending fault zone and the northeast-trending foliation are regarded as the fundamental controls. Northeast of the mineralized intrusive is a similar but unmineralized intrusive, largely hidden by gravels and basalt flows.

ROBINSON (ELY) DISTRICT, WHITE PINE COUNTY, NEVADA

A group of intermediate intrusives are aligned easterly in the Robinson mining district, as shown on plate 23. The writers believe the control is by a deep basement fault, and in this belief support Bauer, Cooper, and Breitrick (1960). At least four separate porphyry copper ore bodies are closely associated with the intrusive rocks and are independent of the kinds of sedimentary rocks they penetrate.

Visible faulting is both irregularly parallel to and at an angle with the line of intrusives, but it locally controls them. It may be tensional faulting reflecting adjustment on deep east-west breaks. The relatively young diatremes and other manifestations of near-surface activity associated with the intrusives attest to the repeated structural and igneous events. Occasional surface faults of east-west orientation are known both east and west of the district, but the situation generally is blurred by the complex structural pattern dominated by northwest-trending faults. The same trend as that in the Robinson district, when projected westward, includes the Mount Hamilton district.

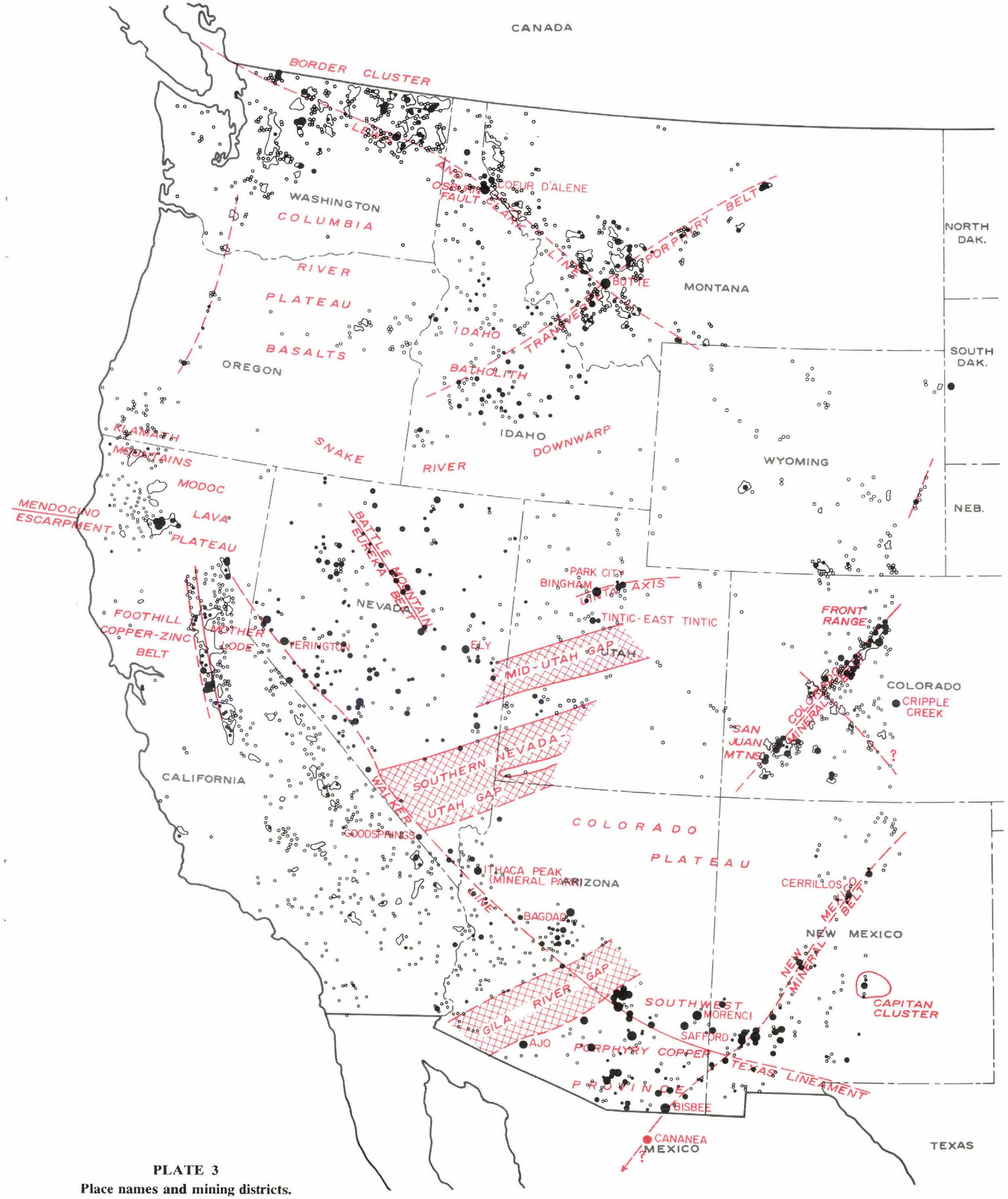


PLATE 3
Place names and mining districts.

In Utah the N. 80° E.-trending Uinta axis with the important districts of Park City and Bingham, has been discussed by Billingsley and Locke (1941), and Beeson (1927). The districts are contained within a much broader band of districts, including Tintic and East Tintic, aligned about N. 80° E. This band is separated from a parallel band on the south by a wide, mostly barren zone which we designate the "Mid-Utah gap." The southernmost productive band has another zone south of it with little known mineralization, extending across southern Nevada; we designate this the "Southern Nevada-Utah gap."

If one likes to think in really broad terms, the Uinta axis might be related to the Mendocino escarpment at essentially the same latitude off the coast of California. A less venturesome projection of the Uinta axis can be made eastward to include the cluster of intrusive rocks and minor districts on either side of the Colorado-Wyoming border.

Roberts (1966) outlines eight northwest-trending belts, two northeast-trending belts, and four east-trending mineral belts in Nevada; only two of them are shown on plate 3.

Locke, Billingsley, and Mayo (1940) earlier called attention to the structures apparently controlling one of the belts, the Walker line, extending northwestward across southern Nevada into California. Horton (1966) statistically analyzed the distribution of districts in Nevada and concludes that two northwesterly aligned mineral belts may be valid: the broad Walker line, and a narrower belt in the north-central part of the State that coincides with Roberts' (1966) Battle Mountain-Eureka belt.

Here and elsewhere within the broad regional trends, many shorter, narrower, and diversely oriented trends can be outlined; these are useful in defining specific exploration objectives.

10. The concentrations aligned northwesterly to northerly in California include the districts of the Mother Lode gold belt, and the copper-zinc deposits of the Foothill belt, west of and parallel to the Mother Lode. These concentrations may extend under the Modoc lava plateau and correlate with the scattered deposits in the Klamath Mountains in northwestern California.

Southern and eastern California and southwestern Arizona show a random distribution of relatively unimportant districts.

11. The Colorado Plateau, though composed of pre-ore sediments, except for the widespread young volcanic rocks, is largely devoid of the types of metal-bearing districts considered here. The reasons for the existence of apparently barren areas such as the Colorado Plateau are as important in designing exploration programs as are the reasons for the concentration of districts in clusters or belts.

Butler (1929) called attention to the concentration of districts around the borders of the Colorado Plateau and compared this with the concentrations around the volcanic plateaus in the Northwest. The reasons for the concentrations are quite different however. In the Northwest it is a matter of post-ore cover; in the case of the Colorado Plateau the control is due to concentrated structural and igneous activity along its border.

12. The New Mexico mineral belt, aligned northeasterly, contains most of that state's districts important in terms of the five metals here considered, and can be projected into southeastern Arizona and on into Mexico. Within the belt are local, diversely oriented, alignments. The Capitan cluster lies to the east.

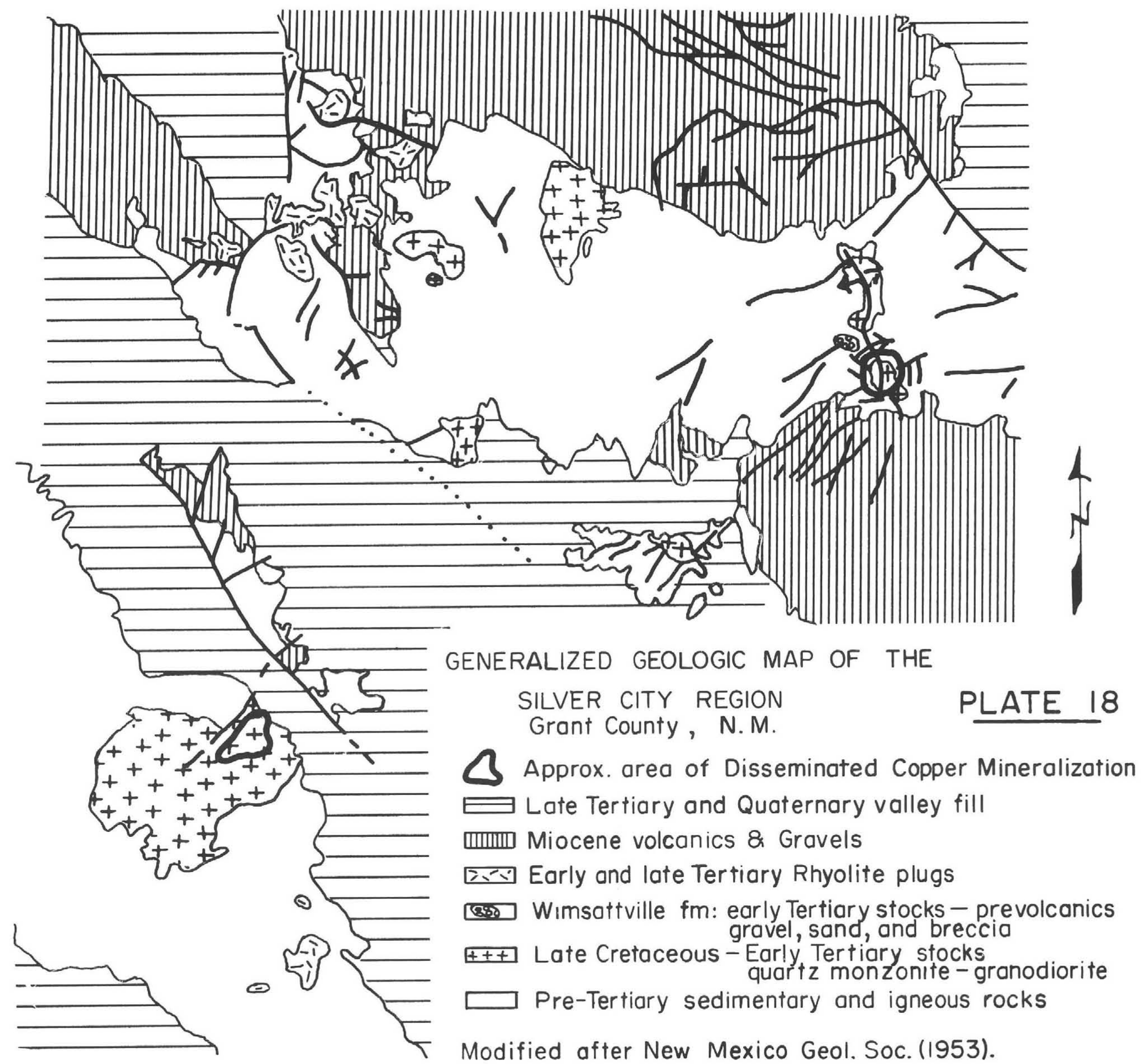
13. One of the most remarkable metallogenic provinces in the world in terms of volume of metal, dollar value, and number of individual major orebodies, is the cluster of districts in southeastern Arizona, southwestern New Mexico and Mexico, designated the Southwest porphyry copper province. Although porphyry copper orebodies dominate this province, major vein and replacement orebodies containing any or all of the five metals, and occasionally iron, also are present. Porphyry copper orebodies at Bagdad and Ithaca Peak, Arizona, lie outside of the main province. The northwest alignment of districts parallel to the southern edge of the Colorado Plateau is along the "Texas lineament" of Hill (1928) which is to be correlated with the southeastward projection of the Walker line; the writers favor the use of the "Walker line" as the inclusive term.

Within the Southwest porphyry copper province are northeast, northwest, and east-west alignments of districts and/or orebodies. North of the Walker line, east and northeast local alignments predominate. South of it northwest alignments seem most abundant. The northeast alignments may reflect shallow cover and the nearness of basement controls. The northwest alignments may represent the effects of later deformation. Mayo (1958) has discussed local alignments in some detail.

14. The small cluster of deposits north of the Walker line in central Arizona is mostly in Precambrian host rocks whose grain shows a strong north to northeast component.

15. South of the Walker line the porphyry copper province in southeastern Arizona is separated from the unimportant, scattered districts in the west-central part of the state by a wide, northeasterly aligned, largely barren band of potentially favorable host rocks and broad alluvial areas. This barren band, which we designate the "Gila River gap," is subparallel to, and is to be compared with, similar bands in Nevada and Utah. The gap may be on the extension of the Mid-Continent ridge.

For a somewhat different presentation of district patterns, especially in Nevada, Utah, and California, the reader should examine Burnham's (1959) maps outlining metallogenic provinces in the southwestern United States.



SOME GENERAL RELATIONS BETWEEN MINERALIZATION AND IGNEOUS ACTIVITY

Many of the Western mining districts show a well developed zonal pattern of metals and hydrothermal alteration products. The outward zonation from a molybdenum-copper core, to zinc-lead, and finally silver-manganese is observed in some important districts including Bingham, Butte, Santa Rita, Morenci, Bisbee, Cananea, and Ithaca Peak, as well as a number of smaller districts. The central molybdenum-copper zone is frequently represented by disseminated and stockwork mineralization whereas the other metals occur as irregular replacement orebodies in reactive carbonate rocks, or as tabular deposits in permeable areas of breccia and faulting. The central zone is coincident with the most intense igneous activity, as expressed by steeply inclined stocks, porphyry plugs, dike swarms, and explosive features such as breccia pipes and pebble dikes. The pervasive hydrothermal alteration effects are crudely zoned with respect to intrusives and mineralization. Secondary potash-bearing silicate minerals are frequently coincident with centers of intrusive activity and sulfide mineralization. Argillic minerals and quartz-sericite-pyrite are peripheral to this center while a propylitic facies is the outermost effect of hydrothermal alteration. Individual orebodies and vein structures are often surrounded by potash and sulfide alteration envelopes that have formed by the reaction of the ore fluid with the country rock. Pervasive sulfide mineralization favors the central zone but is ubiquitous throughout all the alteration facies. Ideal patterns are strongly modified by structural features and lithologic discontinuities. Reactive rock types, such as carbonates and diabase, have a strong influence in the distribution of mineralization.

SOME EXAMPLES OF THE COINCIDENCE OF STRUCTURE, INTRUSIVES, AND MINING DISTRICTS

After examining the regional distribution of districts significant with respect to one or more of the five metals, it is illuminating to inspect several situations in more detail. The examples reviewed are the porphyry copper type of district from the Basin and Range province. For locations see plate 17. These normally have significant vein and replacement orebodies associated with the main copper orebody. Gold, silver, copper, lead, and zinc are present in variable but important combinations.

SILVER CITY REGION, GRANT COUNTY, NEW MEXICO

Plate 18, a modification of Paige's (1907) map of the Silver City region, was taken from a guidebook of southwestern New Mexico prepared by the New Mexico Geological Society (1953). The Laramide intrusives and the two large areas of copper mineralization at Santa Rita and Tyrone are emphasized. The area is part of the New Mexico mineral belt.

The writers believe that data on plate 18 strongly suggest the influence of structure on the localization of intrusives and ore deposits. We see a broad northeasterly trending band of Late Cretacious-Early Tertiary stocks crossing the southwestern part of New Mexico and extending into Arizona. Although the absolute control is not so obvious as might be preferred, we postulate that a northeast grain in the Precambrian is responsible. Adjustment took place along this direction and broke the younger rocks, as is evidenced by the swarm of northeast-trending faults and dikes in the Central district and elsewhere. Movement occurred on those faults over a long period of time at the right times to localize important stockwork, vein, and replacement deposits. The result is an important base-metal province of about the same orientation as the belt of intrusives. The ores occur under such a variety of conditions that we see nothing resembling source bed control unless someone wants to appeal to the Precambrian for source beds as we do for fundamental channeling structures. Since shelf conditions prevail, appeal cannot be made to the geosynclinal cycle to explain the concentrations.

The northwest-trending faults show several ages of movement, but seemingly had less influence on the disposition of intrusives and ore deposits than did their northeast-trending counterparts. They may represent revived movement on northwest-trending basement faults, but their last adjustment was of the classical basin-and-range block fault variety that determined the positions and elongations on the present ranges. It is possible that intersections of older northwest-trending structures and the northeast-trending structures have determined the positions of districts or orebodies within districts here and elsewhere, as discussed in detail by Mayo (1958).

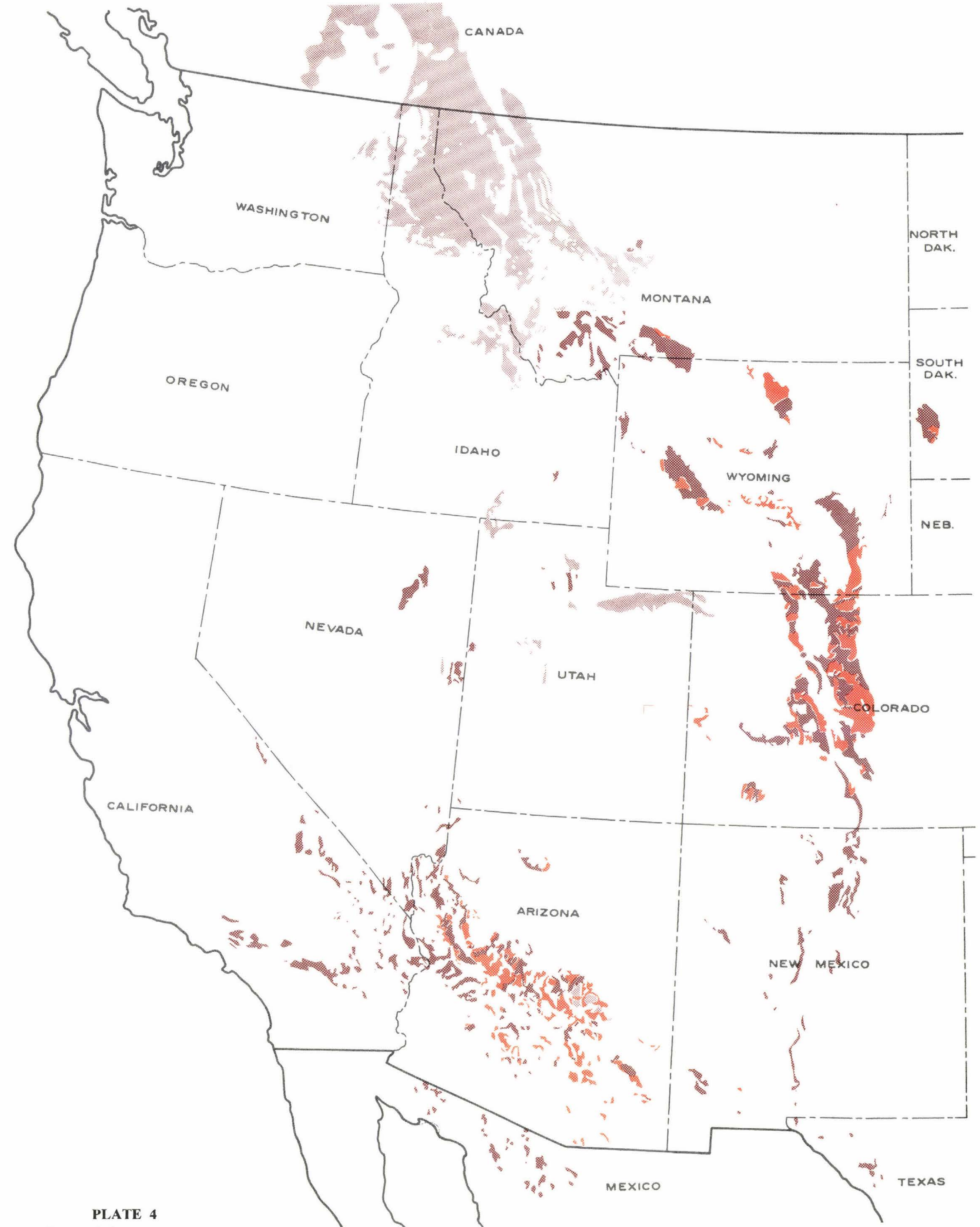


PLATE 4
Precambrian exposures.

COMPARISON OF PRECAMBRIAN EXPOSURES AND MINING DISTRICTS

Plate 4, showing exposures of Precambrian rocks in the western United States, was taken primarily from the Geologic Map of the United States by the U. S. Geological Survey (Stose, 1932), but was modified somewhat to accord with the 1961 edition of the Tectonic Map, (see pl. 1 for explanation).

In the present state of knowledge it is impossible to show the total distribution of Precambrian rocks and the varied environmental conditons they reflect, but the pattern of exposures confirms that such rocks are basement for the eastern half of the Cordilleran system. Rock exposures of unquestioned Precambrian age are totally lacking for large areas of the western half. This may imply the existence of an oceanic crust there rather than a continental one.

From these exposures a great deal can be learned of the lithology and structure of the first rocks to influence both sedimentation and the disposition of later intrusives and ore deposits. Without these exposures, speculation on conditions at depth could be considerably more undisciplined than they sometimes are. Recently Callahan (1964) and Flawn (1965) have emphasized the importance of the basement in influencing subsequent events.

A remarkable coincidence of mining districts with areas of Precambrian rock outcrops is seen in the eastern half of plate 5. The Colorado mineral belt crosses a variety of Precambrian rock types, including intrusive and metamorphosed sedimentary and volcanic rocks. Ore deposits do not correspond to any particular Precambrian lithology, but are closely related to Late Cretaceous-Tertiary intrusive rocks controlled by Precambrian foliation and faults. Similar generalizations apply in Idaho, Montana, and in the Southwest, particularly in Arizona. In Washington, Oregon, California, and Nevada it is only possible to speculate about Precambrian controls, but fortified by evidence as clear-cut as that in the Colorado Front Range, it is not unreasonable to believe that they exist.

Where the Precambrian is shallow, the possible effect of its structure in controlling the ingress of intrusives and ores seems obvious, and may be demonstrated by geophysics and drilling. Where it is deeply buried, however, folds and faults in the younger covering rocks may provide so many diverting channelways for the exit of intrusives and ore fluids that the pattern of fundamental Precambrian control is substantially modified or completely obscured—it may be too deep to be proven convincingly by the drill or by geophysics. Apparently this is the situation in Nevada. However, the fact that the Battle Mountain-Eureka mineral belt of the State cuts northwesterly across the north- to northeast-trending surface grain, and is not bound to any particular lithology, suggests that some deep structural control does exist.

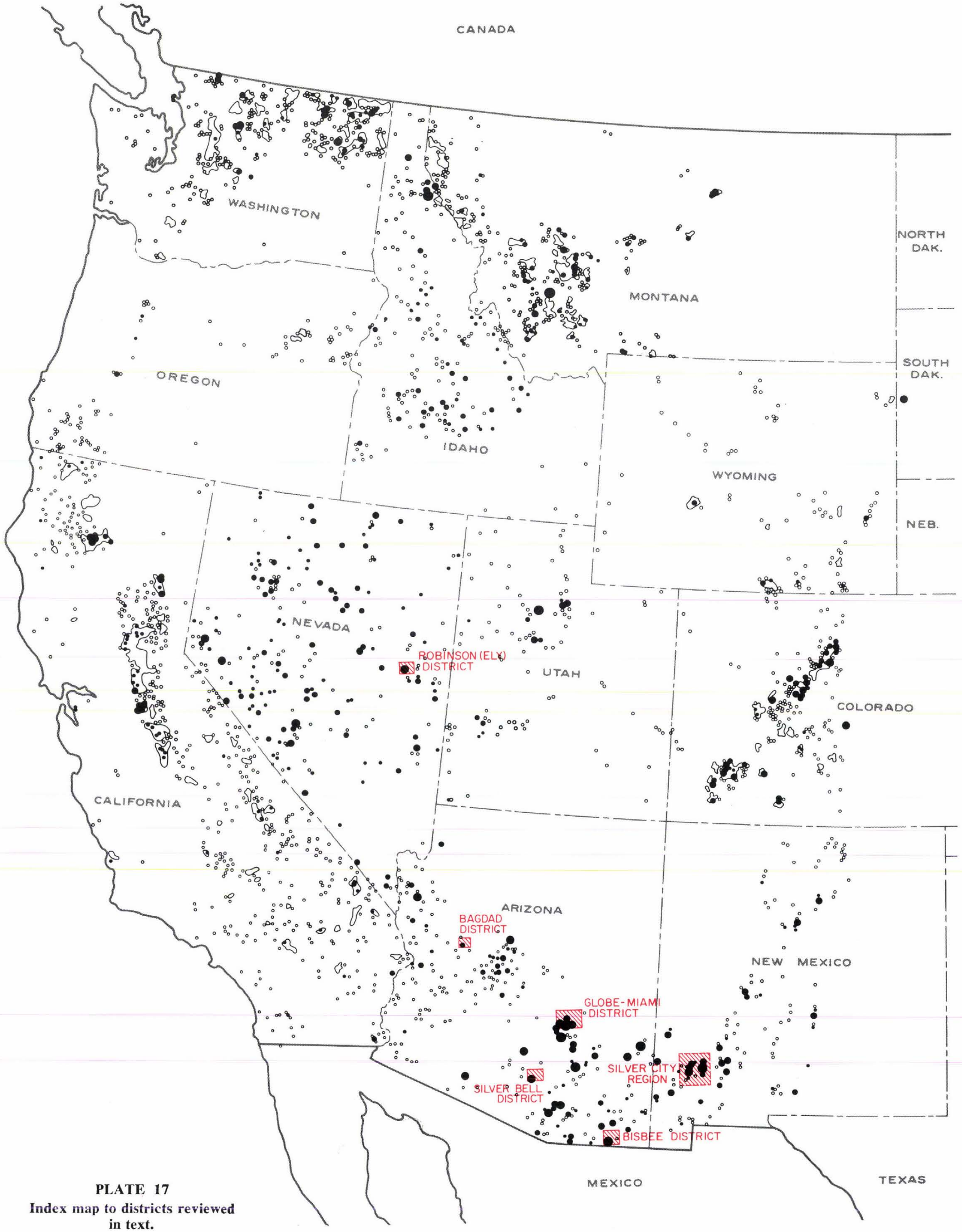


PLATE 17
Index map to districts reviewed in text.

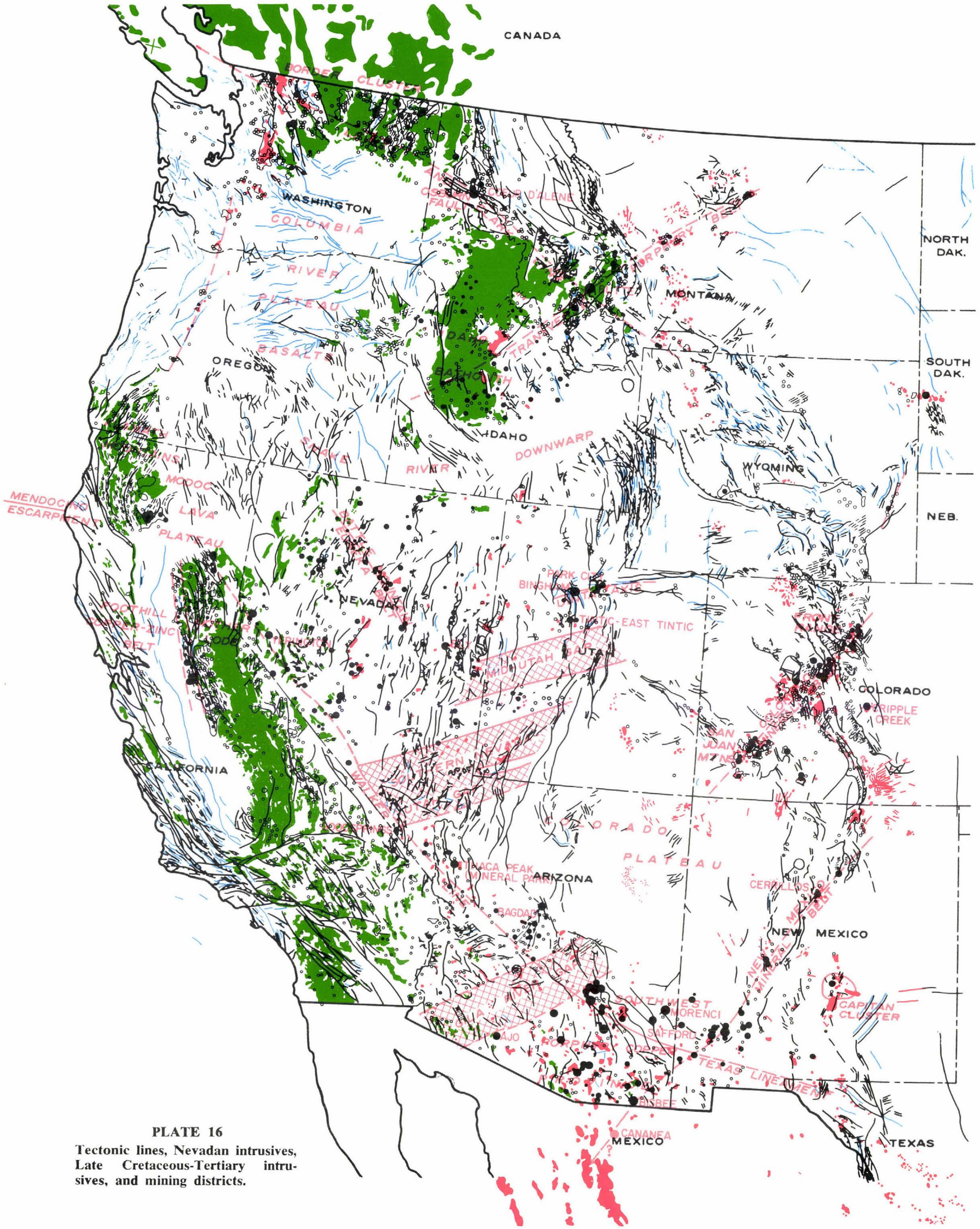


PLATE 16
Tectonic lines, Nevadan intrusives, Late Cretaceous-Tertiary intrusives, and mining districts.

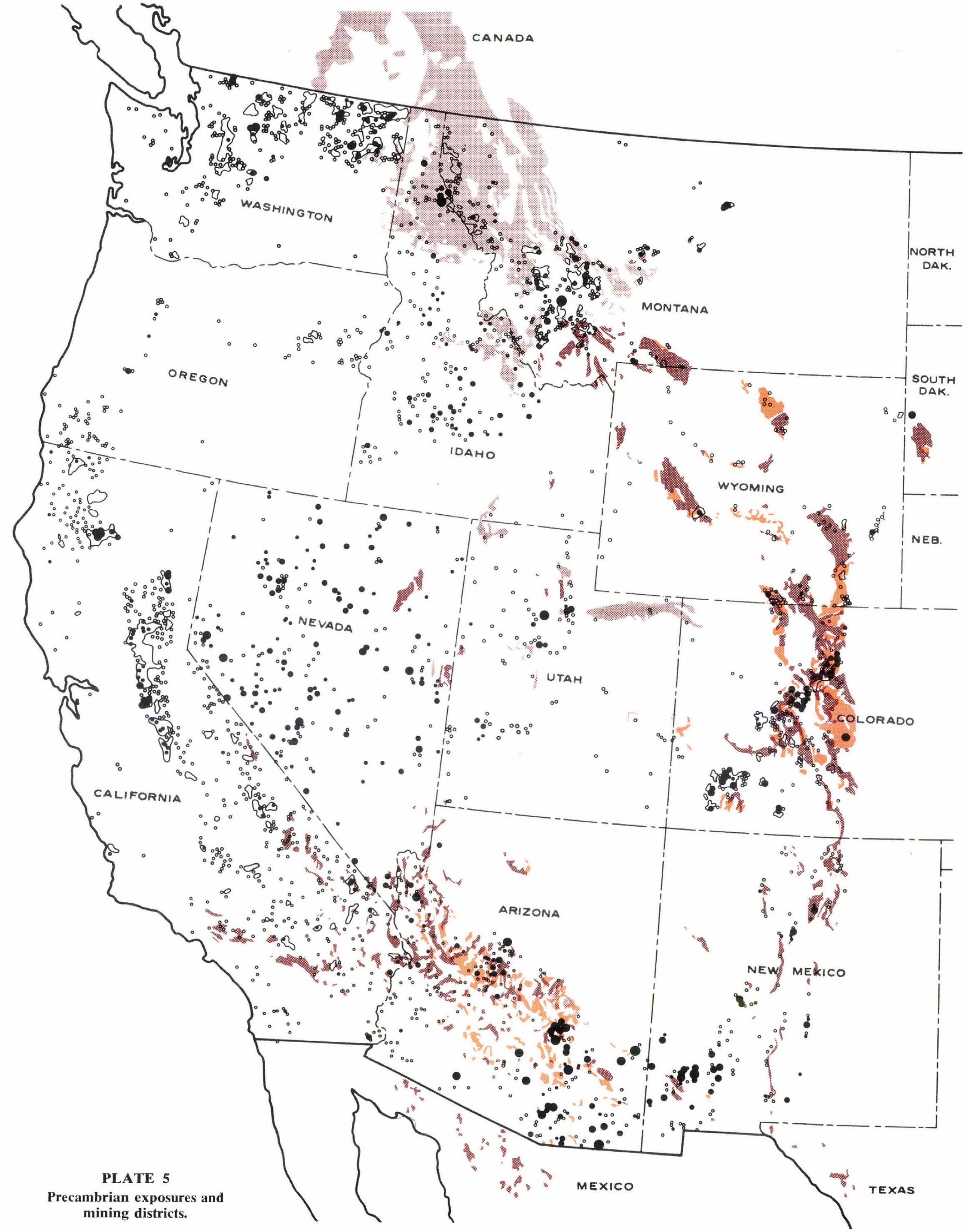


PLATE 5
Precambrian exposures and mining districts.

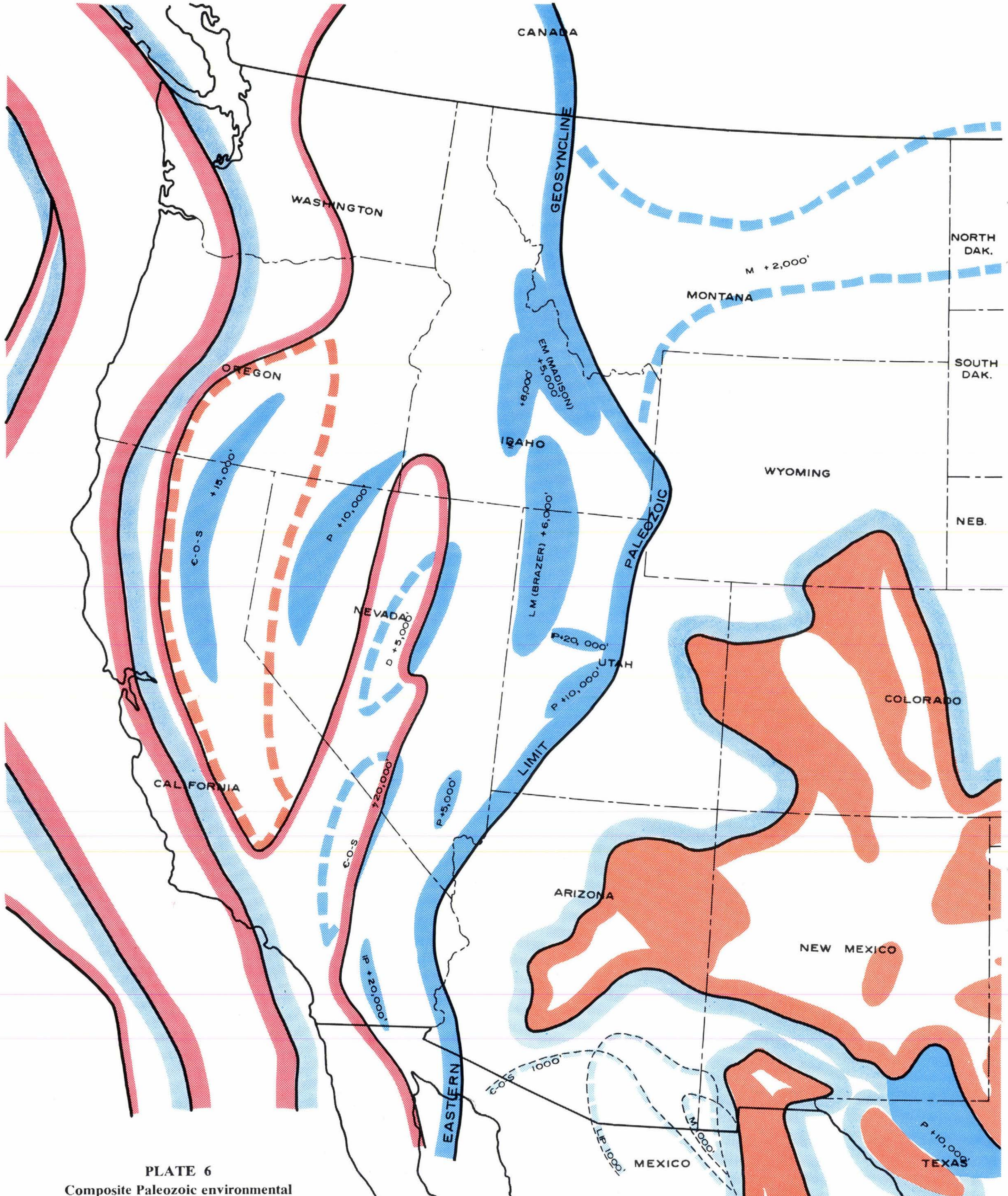


PLATE 6
Composite Paleozoic environmental conditions.

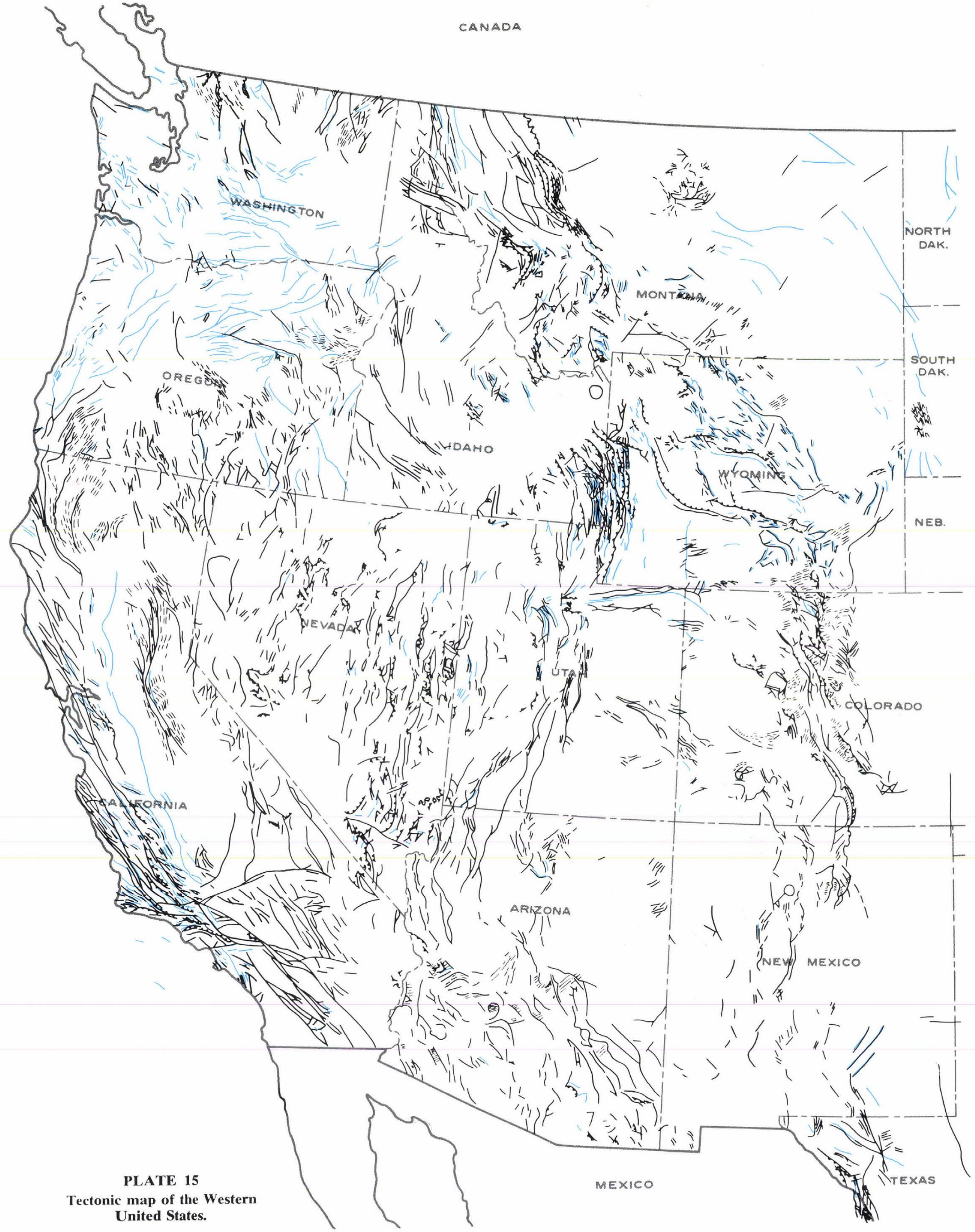


PLATE 15
Tectonic map of the Western United States.

So many porphyry copper deposits are dated as less than 70 million years of age that it might be questioned if any are older. A summary of potassium-argon dates for intrusives related to porphyry copper mineralization is shown on plate 14 (Rose and Cook, 1965). The mineralized intrusives of the Southwest porphyry copper province show a remarkably narrow spread in ages between 56 and 69 million years. Porphyry copper type intrusives in the eastern area of the Cordillera show a younger age group at 40 to 47 million years (Bingham, Cerrillos) and an older western group at 110 to 123 million years (Ely, Yerington).

COMPARISON OF TECTONIC LINES, NEVADAN INTRUSIVES, LATE CRETACEOUS–TERTIARY INTRUSIVES, AND MINING DISTRICTS

The information on plate 15 is largely from the Tectonic Map of the United States (Cohee, 1961). It is a composite of lines of folding, foliation, thrust faulting, and block faulting from Precambrian through Recent times. Inclusion of fold axes, particularly on the Colorado Plateau and the northwest volcanic plateaus, complicates and clutters the picture; these relatively gentle folds have little bearing on the distribution of the known five-metal districts, as is convincingly shown on plate 16. Also, some of the more important ore-controlling fault structures are obscured by prominent bands of late block faults, especially in the Basin and Range province and along the west coast. Though these faults may represent old lines of weakness, they rarely exert control over major mineral deposits. Obviously the next step, and what would have been a desirable first step, is to separate all structures by age and relate them successively to well-dated intrusives and to ore deposits. So far the information required to perform this task satisfactorily is lacking except for local areas.

Note the foliated rocks in California, in the western part of the geosyncline, and the belt of thrusts and steep faults along its eastern edge in Montana, Idaho, Wyoming, Utah, Nevada, and Arizona. The Colorado Plateau part of the shelf area suffered gentle deformation, but more violent deformation occurred in the eastern Laramide orogenic belt, as represented by steep faults, thrusting and folding, in Montana, Wyoming, Colorado, and New Mexico. The Lewis and Clark line is well defined; the Walker line of the Southwest is somewhat less obvious. Unfortunately the Precambrian grain is quite obscure on this plate except in the Colorado Front Range; while the trend is quite complex there, it is predominantly northeast.

Plate 16 shows the relationship of structure, intrusives, and districts. A presentation somewhat resembling this plate was made earlier by Wisser (1959).

In the main geosyncline the basic control is not obvious, but superficially the mining districts are related to faults, folds, foliated rocks and intrusives. As previously observed, Nevada has a scattered pattern difficult to resolve. In the southern part of the State some of the structures control the belt of districts along the Walker line, but only a few structural elements of the central mineral belt show up in a dominantly north-trending structural grain. The gold and base-metal belts of the Sierra Nevada are reasonably linear and parallel to Nevadan foliation and fault directions.

Four obvious mineral belts with considerable structural control include the Lewis and Clark line, the transverse porphyry belt of Idaho and Montana, the Colorado mineral belt (note, however, that the northwest faults so prominent on the plate have exerted little to no control—except of individual orebodies), and the New Mexico mineral belt. The Southwest area shows a combination of northeast-trending Precambrian grain and younger north-, northeast-, and northwest-trending steep faults and thrusts. The coincidence of two or three of these elements often provided the channelways for intrusives and ore.

Some of the mineral belts and barren zones cross visible structures as often as they parallel them, suggesting a control that is more than skin deep. Also, some of the older structures have been obscured by younger ones. Age dates suggest that older intrusive and ore-controlling structures may at times be reactivated, and may repeatedly localize intrusives and ore deposits. The Colorado mineral belt probably is the best example of such resurgent intrusion and mineralization.

COMPARISON OF COMPOSITE PALEOZOIC ENVIRONMENTAL CONDITIONS AND MINING DISTRICTS

Plate 6, depicting Paleozoic environmental conditions, is compiled from six of Eardley's plates (1951). Though it obviously is difficult to show on one map average conditions during a period of nearly 400 million years, we are interested only in broad environmental relationships that persisted over long periods of time, not in the minute details of their evolution. This plate will be described in more detail than will subsequent ones. Refer to plate 1 for the explanation of symbols and colors.

Beginning on the west side of plate 6, the broad red bands mark the average position of an orogenic belt, presumed to be a volcanic archipelago. West of it is the Pacific Ocean basin. The narrow red bands on either side of the broad ones mark tentative maximum eastern and western limits of the orogenic belt during the Paleozoic. The narrow red bands over Nevada show the position of the Missippian Manhattan geanticline, or Antler orogenic belt as many now prefer to call it. The blue bands outline the position of the Cordilleran geosyncline; that part west of the Antler orogenic belt is the eugeosynclinal portion which received abundant volcanic additions from the archipelago and the sea floor. It was partially epeirogenic after the Silurian. East of the Antler orogenic belt lies the miogeosynclinal portion, which was relatively uncontaminated with volcanic material except at its northern end, when during Permian time, volcanic rocks spilled into it from the west. Within the main geosyncline the areas in solid blue mark particularly thick accumulations of sediments. Maximum thicknesses are shown as well as the periods in which the maxima were achieved. It is evident that the axes of these thick accumulations shifted from time to time. In keeping with the concept that geosynclines or portions thereof are sites of subsequent orogeny, the Antler belt developed in and expanded from the center of the main geosyncline.

At the eastern edge of the geosyncline is the beginning of the shelf environment. The line marking this transition is repeated on subsequent environmental plates. The thicker accumulations of sediment on the shelf are shaded dark blue, as in Texas. To the north the east-west sag in the shelf during Mississippian, shown in dashed blue, is the Madison-Brazer basin.

In the southeast part of the plate the orange band outlines a large, irregular epeirogenic area. It was alternately above and below sea several times, with some localities having a tendency to sag more and accumulate thicker marine sediments. The solid orange indicates the positions of the ancestral Rockies, emergent during Late Pennsylvanian time. Conditions in Arizona and New Mexico oscillated between emergence and submergence, but at no time did the thickness of sediments reach geosynclinal proportions. Mazatzal Land in Arizona, is oversimplified; rather than being a completely positive mass, it has been shown by Huddle and Dobrovolny (1945) to have been a series of islands and shallow basins.

The 1,000-foot isopachous lines in dashed blue show that the direction of deepening of the shelf was south from Arizona.

The effect these varied sedimentary and tectonic environments exerted on the disposition of post-Paleozoic mining districts now can be examined.

Plate 7 shows a wide distribution of districts under a variety of conditions in the main geosyncline. However, the district patterns, as previously outlined, seem to bear no specific relationship to axes of thick sedimentation, to the volcanic archipelago, to orogenic belts, to the area of Permian marine vulcanism in the Northwest, nor do they seem to reflect any relative favorability of one type of geosyncline over the other. The barren zones and the mineral belts, with the possible exception of the Mother Lode and the Foothill belts of California, cross the major axes of all of the above elements.

The eastern edge of the geosyncline at the shelf must be unique tectonically, and may have been significant in influencing the positions of major mining districts. Although impressive alignments along this "shoreline" are lacking, Billingsley and Locke (1941) make cases for localization of Butte, Bingham-Park City-Tintic, and Goodsprings at the intersection of structural elements, one of which in each case is near and parallel to this "shoreline." Burnham's (1959) central metallogenic belt, though considerably broader, closely parallels it.

The transverse mineral belt of Montana and Idaho crosses both shelf and geosynclinal environments.

Districts are widely scattered on the shelf; probably in tons of metal and dollar value the greatest concentrations are there. As in the geosyncline, the important alignments and clusters do not favor a particular environment. The Colorado mineral belt indiscriminately crosses emergent areas and shallow basins nearly at right angles to their axes; the same applies to the New Mexico mineral belt. If source beds in the Paleozoic have had any influence, it would seem that the distribution of districts might reflect lines along which conditions of sedimentation changed; this does not appear to be the case.

In the Southwest porphyry copper province the major districts are located both in areas of emergence and in areas of shallow marine deposition. The northeast-trending district and orebody alignments cross the basin and highland axes while the northwest-trending alignments parallel these axes.

Anyone can conclude from plate 7 that the sedimentary and tectonic environments of the Paleozoic exerted little obvious influence on positions of the mining districts. Conditions in the geosyncline appear to have been no more favorable for the evolution of major deposits than did conditions on the shelf.

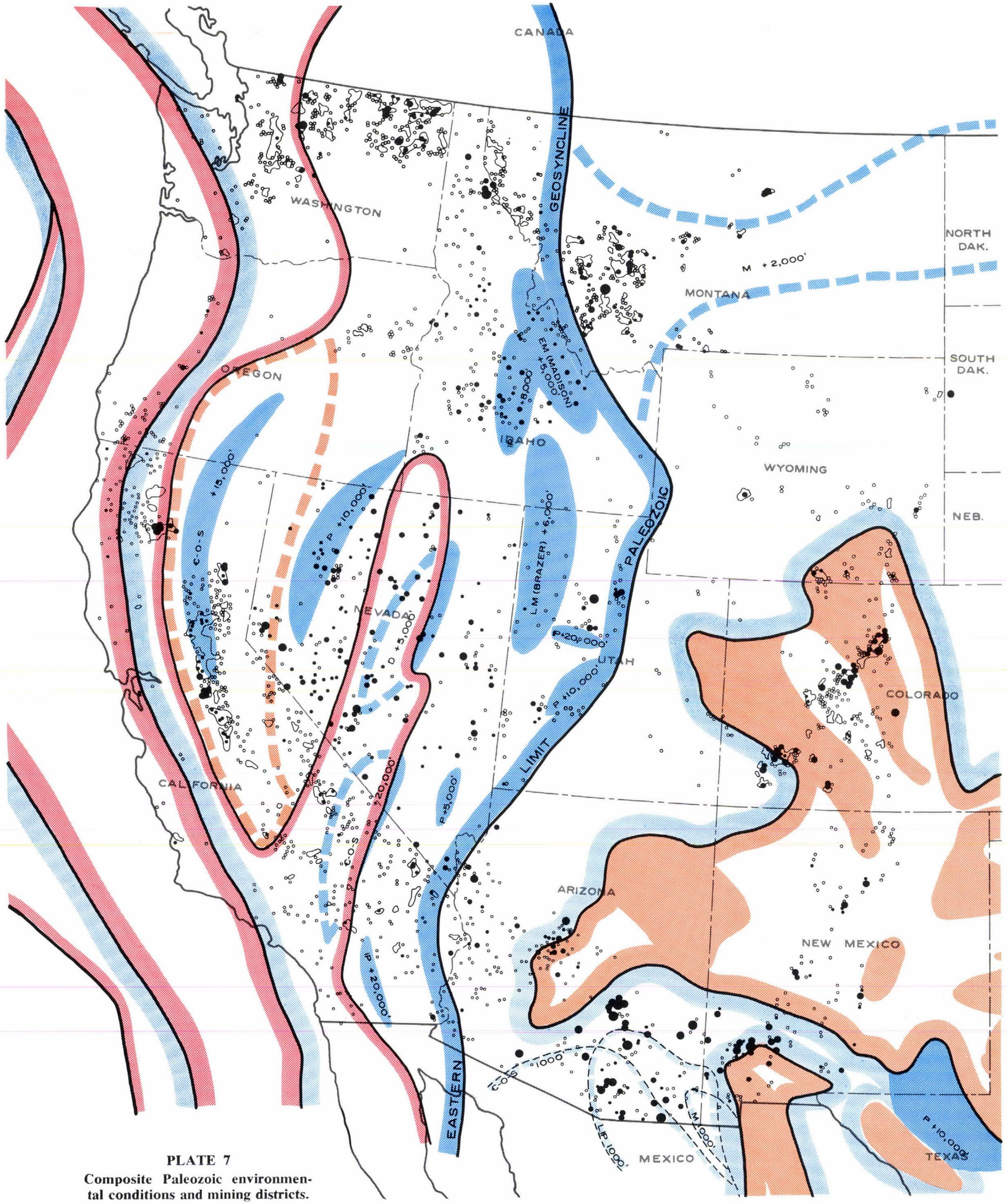


PLATE 7
Composite Paleozoic environmental conditions and mining districts.

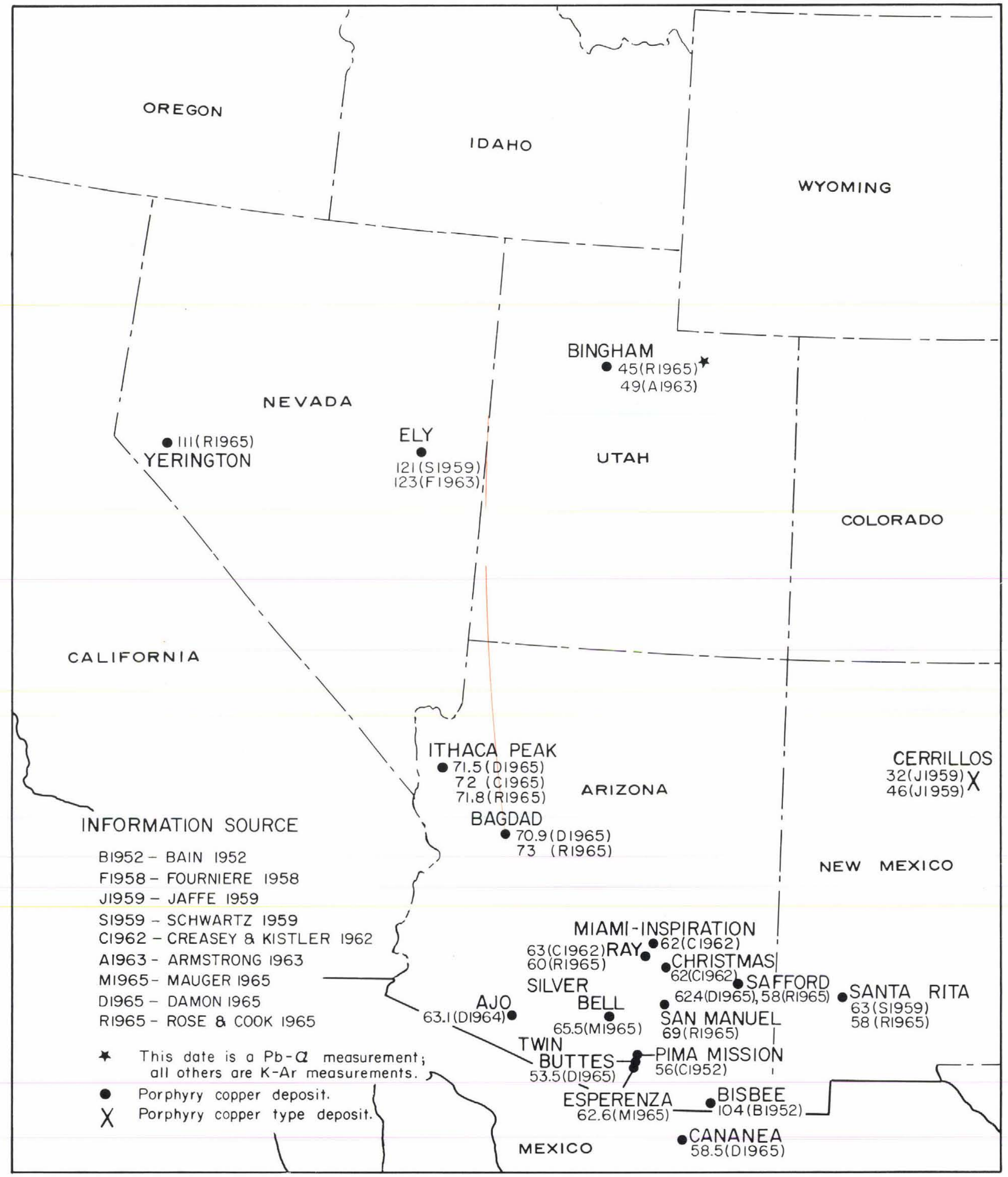


PLATE 14

SUMMARY OF PORPHYRY COPPER INTRUSIVE AGE DATES

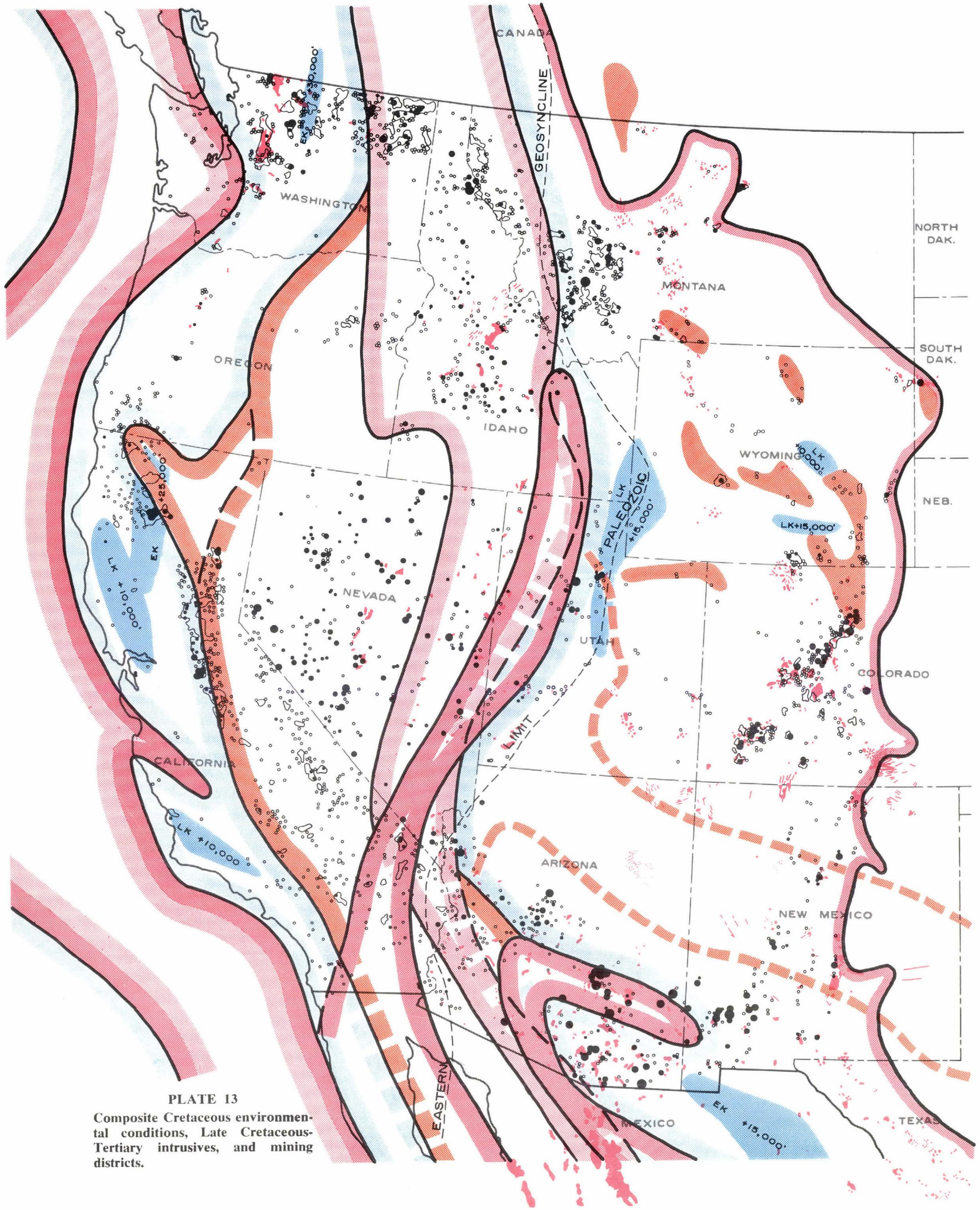


PLATE 13

Composite Cretaceous environmental conditions, Late Cretaceous-Tertiary intrusives, and mining districts.

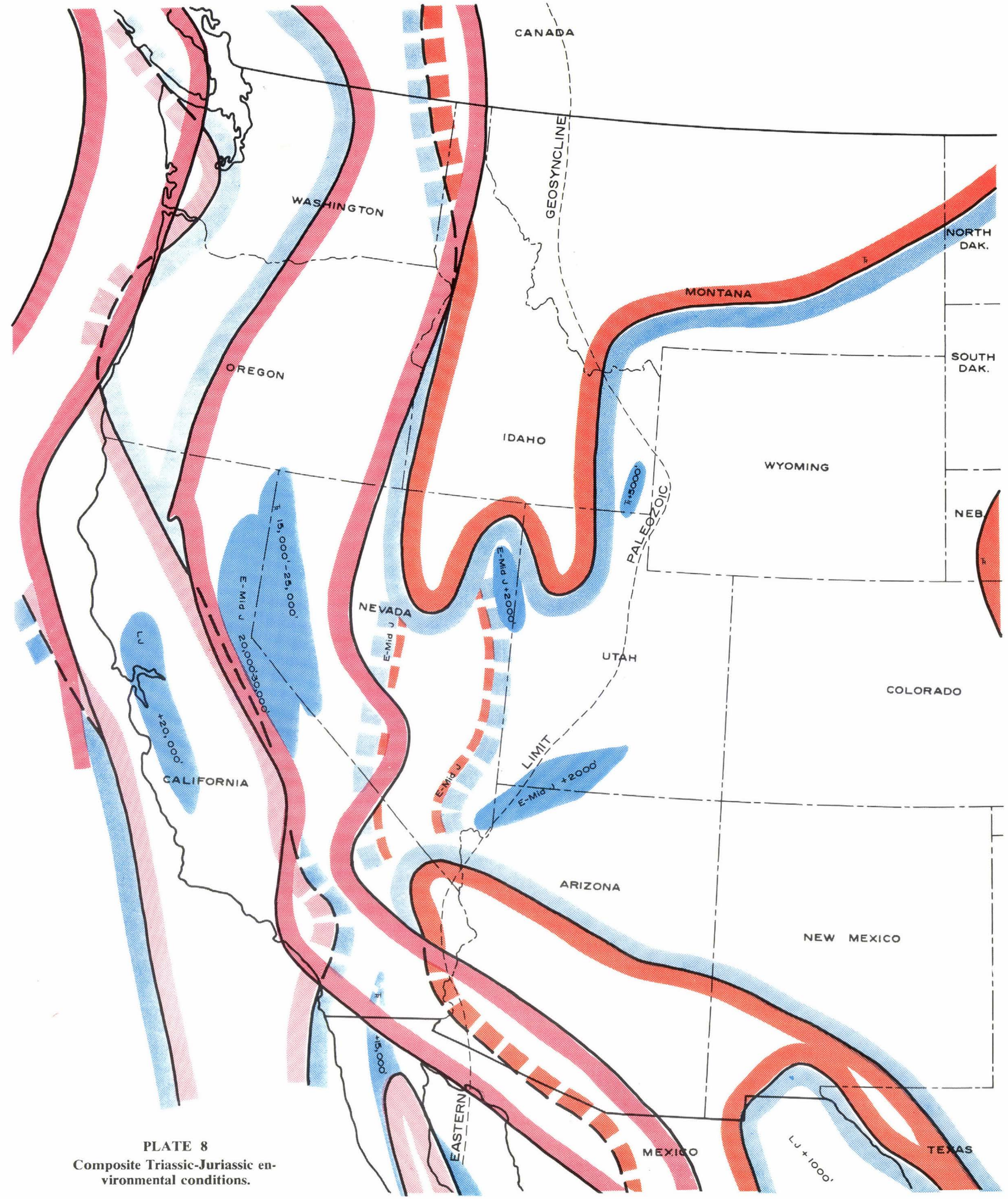


PLATE 8

Composite Triassic-Juriassic environmental conditions.

COMPARISON OF COMPOSITE TRIASSIC–JURASSIC ENVIRONMENTAL CONDITIONS, NEVADAN INTRUSIVES AND MINING DISTRICTS

Plate 8 showing Triassic and Jurassic sedimentary and tectonic environments was composited from three of Eardley's plates (1951). The pale red bands enclose the site of the Triassic orogenic belt. East of it thick eugeosynclinal sedimentary rocks accumulated. The axis of thickest sedimentation shifted westward in Early and Middle Jurassic time when 20,000 to 30,000 feet of sediments were added. The California trough, in which over 20,000 feet of sediments accumulated, developed directly over the Triassic orogenic belt in Late Jurassic time. A deep miogeosyncline, in which sedimentary rocks in excess of 15,000 feet thickness were deposited, developed early in Baja California and later was the site of orogeny. The two areas margined by red are the Early Jurassic western orogenic belt and the Late Jurassic eastern orogenic belt, generally referred to as Nevadan in age.

On and adjacent to the shelf are emergent areas. Between these only shallow sedimentation occurred, except for three basins shaded in blue, where nonvolcanic sediments up to 5,000 feet thick were deposited. The shelf was isolated from the geosyncline during Early and Middle Jurassic time by a ridge which, along with the Nevadan orogenic belt, marked the beginning of the Cordilleran geanticline. The west side of the geanticline represents a substantial westward shift of what had been the edge of the main Paleozoic geosyncline.

An area of shallow marine sedimentation in the Southwest became emergent and was partially involved in orogeny. At the same time shelf sedimentation continued in the region of the Colorado Plateau, but it did not produce any thick sections. The Mexican geosyncline began to develop in Late Jurassic time.

The Nevadan orogeny extended from Late Jurassic time into Early, and perhaps Middle Cretaceous time. Its main characteristics are summarized below:

1. The deformation principally involved eugeosynclinical rocks.
2. The rocks were isoclinally folded and metamorphosed, so much so that they closely resembled and often have been mistaken for Precambrian rocks.
3. Little thrusting has been attributed to the Nevadan orogeny, perhaps because of ignorance of full details concerning it.
4. Great batholiths were intruded. These are in sharp contrast in size to later Laramide stocks. Some geologists prefer to regard many of these as granitized sediments, but at the level at which they now are exposed many of them appear to be intrusive, with some granitization effects in the bordering and included rocks.

For the purpose of this report we view the events of the Nevadan as no younger than 100 million years.

On plate 9 the Nevadan intrusives are shown in combination with mining districts. The intrusives are taken from the Tectonic Map of the United States, 1961 edition (Cohee, 1961). These are added to the composite Triassic-Jurassic environment in plate 10. Unfortunately the age of the Nevadan intrusive rocks overlaps the environmental sheet of the Cretaceous, which partially explains why the Idaho batholith lies outside of the Late Jurassic eastern orogenic belt. It might have been more appropriate to have bent this belt sharply eastward in plate 8 to include this batholith and its eastern outliers.

The batholiths of Washington, Oregon, Idaho, and California occupy the main Cordilleran geosyncline, and with the exception of the Idaho batholith, are principally in its eugeosynclinal portion. The absolute distribution of the intrusives related to the Nevadan orogeny, like that of the Precambrian rocks, cannot be shown due to cover and the lack of comprehensive dating information. However, since this paper was first prepared in 1958, a substantial number of age dates have become available. This has made it possible to refine, complicate, and extend distribution patterns, as will be evident in comparing the 1944 and the 1961 editions of the Tectonic Map (King, 1944; Cohee, 1961). It has been demonstrated that intrusive rocks of Nevadan age occur in small bodies in the eastern part of the main geosyncline; this previously had been suspected but not proven. The debated situation on the eastern side of the Idaho batholith is somewhat clarified, and more of the intrusive masses originally classified as of Laramide age now are grouped with the Nevadan. Some persons will be quite reluctant, however, to accept the age of Butte mineralization as Nevadan.

As is strikingly shown by plate 9, many districts in British Columbia, Washington, Oregon, California, Idaho, Montana, and Nevada coincide with positions of Nevadan intrusives, but most of the major base-metal deposits lie well to the east of these intrusive masses. It is concluded from this that geosynclines are not exclusive birthplaces for major ore deposits and that the relation of some of the districts to sites of Nevadan intrusives may be more apparent than real. Some ore deposits in the main geosyncline have been found near smaller intrusives which definitely cut the larger Nevadan intrusives. The Bethlehem copper deposits in the Highland Valley area of British Columbia are examples.

The transverse porphyry belt of Idaho and Montana is an epeirogenic and orogenic area. Bingham is on the shelf at the edge of an emergent area. The Colorado mineral belt and the New Mexico mineral belt are in an environment of shallow shelf sedimentation. The districts in southern California, Arizona, and New Mexico are in an emergent area which underwent extensive deformation, but most of the major districts in Arizona and New Mexico lie northeast of the principal orogenic belt. Bisbee, and Mexico's Cananea are within the belt. This suggests that the northwest alignment of districts south of the Walker line may be influenced more by Nevadan tectonic patterns than by those assigned Precambrian and Laramide ages.

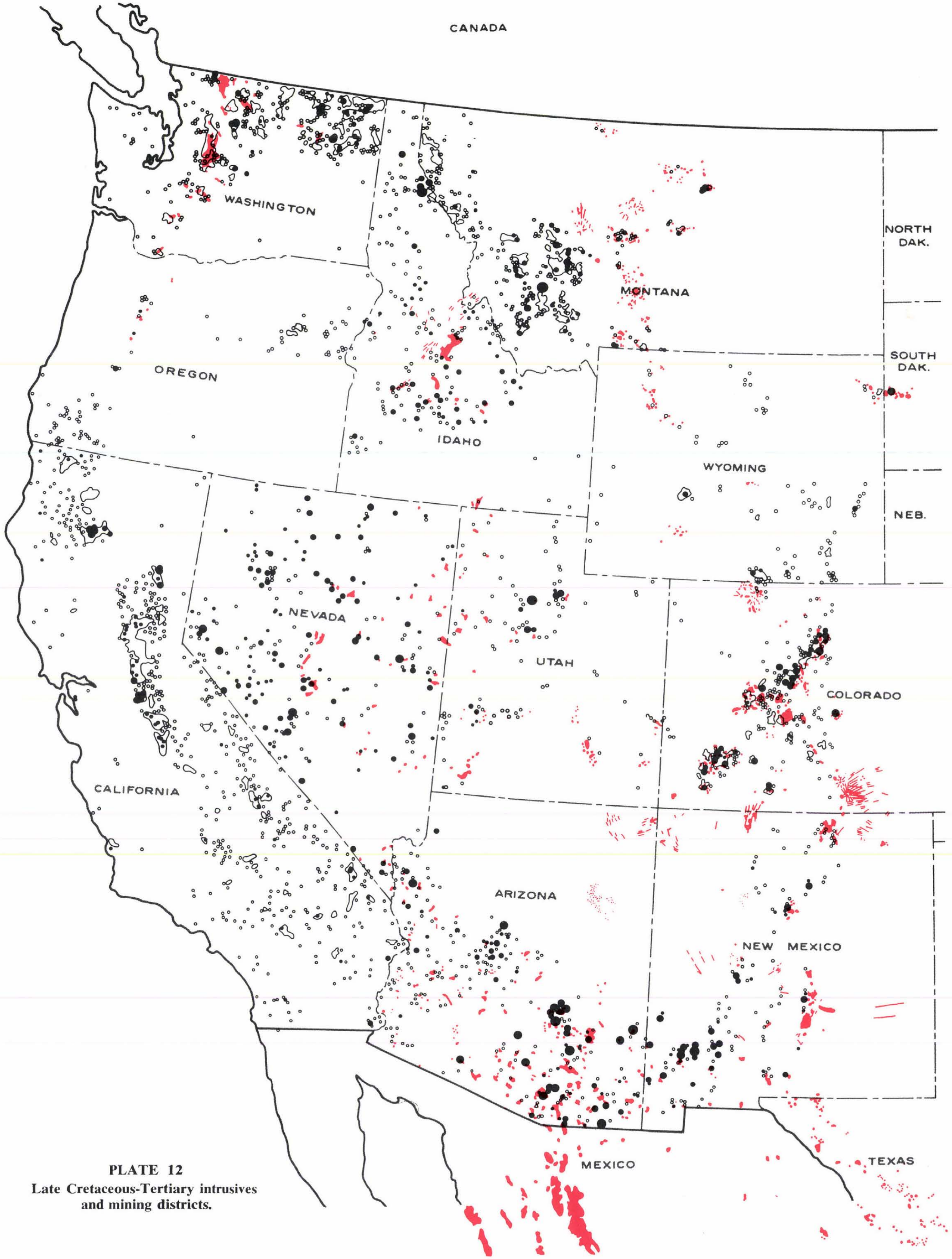


PLATE 12
Late Cretaceous-Tertiary intrusives and mining districts.

COMPARISON OF COMPOSITE CRETACEOUS ENVIRONMENTAL CONDITIONS, NEVADAN INTRUSIVES, LATE CRETACEOUS–TERTIARY INTRUSIVES, AND MINING DISTRICTS

Plate 11 is compiled from several plates and illustrations in Eardley's book (1951) with some modifications incorporated from the Tectonic Map and the Geologic map of the United States (Cohee, 1961; Stose, 1932).

The volcanic archipelago continued to be a site of orogeny throughout the Cretaceous. What had been the broad Cordilleran geosyncline of Paleozoic time continued to give way to the growth of the Cordilleran geanticline. The geosyncline was a relatively narrow, but deep, regionally persistent slot within the borders of the West Coast States. In Early Cretaceous time 25,000 feet of sediments accumulated in north-central California and 30,000 feet in Washington and British Columbia. Sedimentation decreased toward the end of the Cretaceous, but two sections exceeding 10,000 feet in thickness were deposited in California.

The eastern part of the early geosyncline either was epeirogenic or was undergoing orogeny. The most intense orogenic movements were concentrated in what had been the miogeosyncline, and were especially intense along the eastern edge of the old Paleozoic geosyncline.

A broad, northwesterly oriented orogenic belt involved southern Arizona. Shallow marine deposition continued on most of the shelf, except for three basins in which sediments of almost geosynclinal proportions collected in Late Cretaceous time. In the northeastern part of the plate seven northwesterly-trending, and one easterly-trending, epeirogenic areas are reminiscent of the pattern of the Paleozoic ancestral Rockies, although the latter were generally farther south.

Gentle epeirogenic movements creased the site of the Colorado Plateau at various places, but major orogenic activity occurred east and northeast of it in New Mexico, Colorado, and Wyoming.

In the Mexican geosyncline over 15,000 feet of mostly miogeosynclinal sediments accumulated in Early Cretaceous time. The approximate limit of the eastern effects of the Laramide orogeny and intrusives is shown by the narrow, irregular, red band.

In comparing plate 11 with plate 6, showing Paleozoic conditions, and plate 8, showing Triassic-Jurassic conditions, the eastward progress of orogeny and the growth of the Cordilleran geanticline with lapse of time are striking features. Billingsley and Locke (1941) show this in sections depicting eastward moving structure waves. Osmond (1960) shows the changes by a series of plans and sections, but visualizes a welt growing in the center of the Paleozoic geosyncline and expanding eastward and westward with time.

The characteristics of the Laramide orogeny contrast with those of the Nevadan as follows:

1. Except for activity in the western volcanic archipelago, the Laramide orogeny principally involved miogeosyncline, basin, and shelf environments.
2. Little isoclinal folding took place. Rather, low angle thrusts, steep faults, and asymmetrical folds developed.
3. Evidence for regional metamorphism is rare. Most metamorphic changes were of the contact variety.
4. Most intrusive rocks were stocks of local extent emplaced 75 million to 40 million years ago.

The pattern of Late Cretaceous and Tertiary intrusive rocks in plate 12 was taken with slight modification, from the Tectonic and Geologic maps of the United States. The plate includes Laramide and younger intrusive rocks, since it was impractical without comprehensive information on ages to separate them. The wide distribution of the younger intrusive rocks, including the feeders for volcanics, in the eastern two thirds of the plate is impressive (compare with pl. 9 and see pl. 13), as is the paucity of Nevadan intrusives in the same area. Overlaps of the two major ages of intrusives occur in Washington, British Columbia, Idaho, Nevada, southern California, and southern Arizona; as more age dates become available, it may be found that more rocks of both ages occur in the overlap zone.

Plate 13 shows the coincidence of a large number of major districts with sites of Nevadan orogeny and intrusive activity: a similar coincidence occurs between sites of Laramide orogeny, intrusive activity, and mining districts. Most of the very young volcanic centers lack important districts, possibly because they are not eroded deeply. As was observed for the Nevadan, the younger intrusives and ore deposits span a variety of environments and host rocks. Age dates now available for many intrusives confirm the eastward progress of intrusive activity with time, and broadly speaking the ore deposits become increasingly younger eastward. Since this is not completely true in detail, it might be preferable to avoid confusing the issue, to state that ore deposits in the western half of the western United States tend to be older than those in the eastern half of the western United States but that local exceptions do occur. Those to the west probably are mostly Nevadan in age; those to the east probably are mostly Laramide and younger. As regards relating the age of the alteration and mineralization to the age of intrusion, sericite formed by hydrothermal processes has been dated at a number of districts such as Safford, Ariz.; Butte, Mont.; and Ely, Nev. The results show a date that is within the experimental error of the date for the intrusive, or slightly younger. We believe these data strongly support the common origin of both igneous and hydrothermal activity. These data also suggest to us a close genetic relation between metallogenic and petrologic provinces.

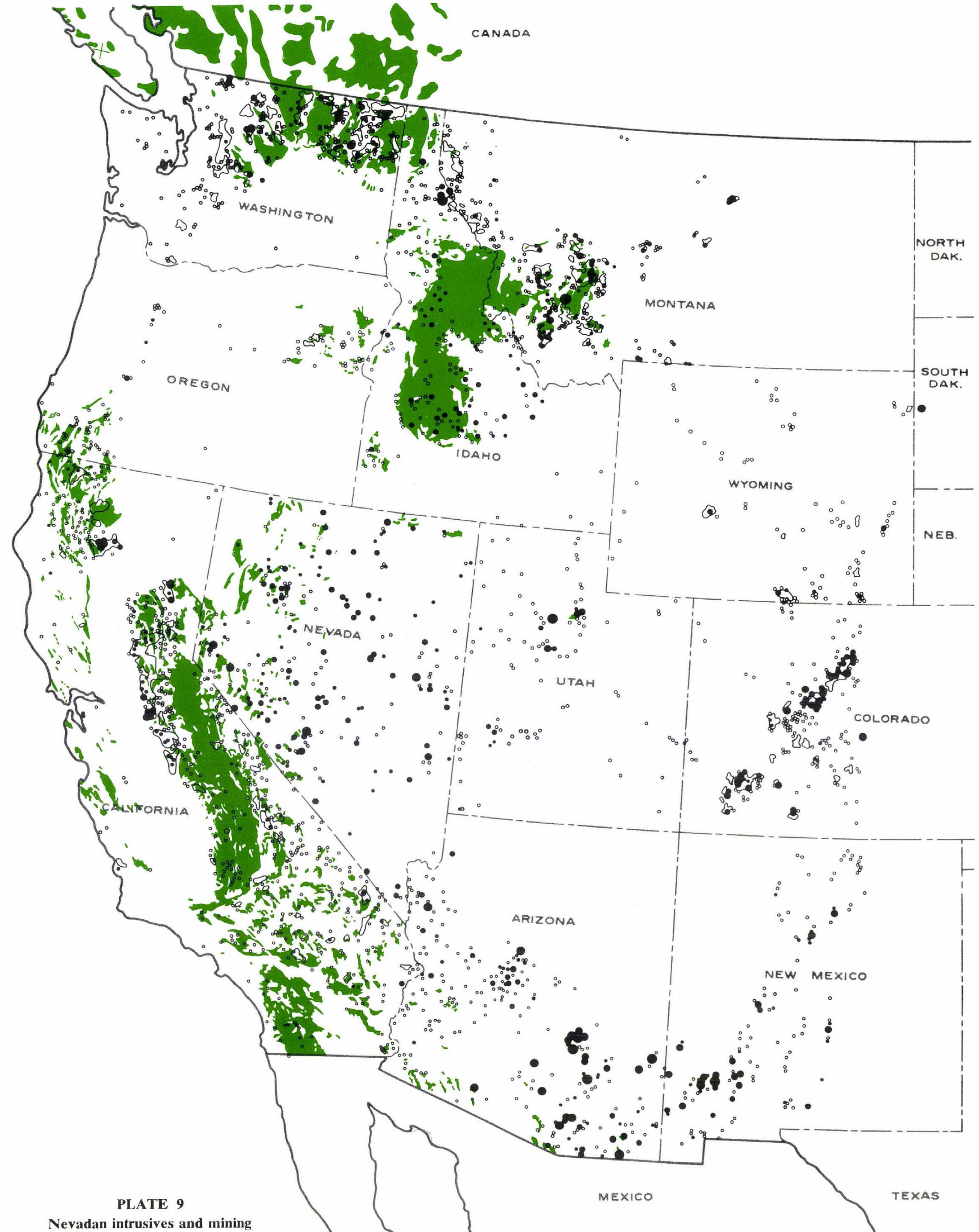


PLATE 9
Nevadan intrusives and mining districts.

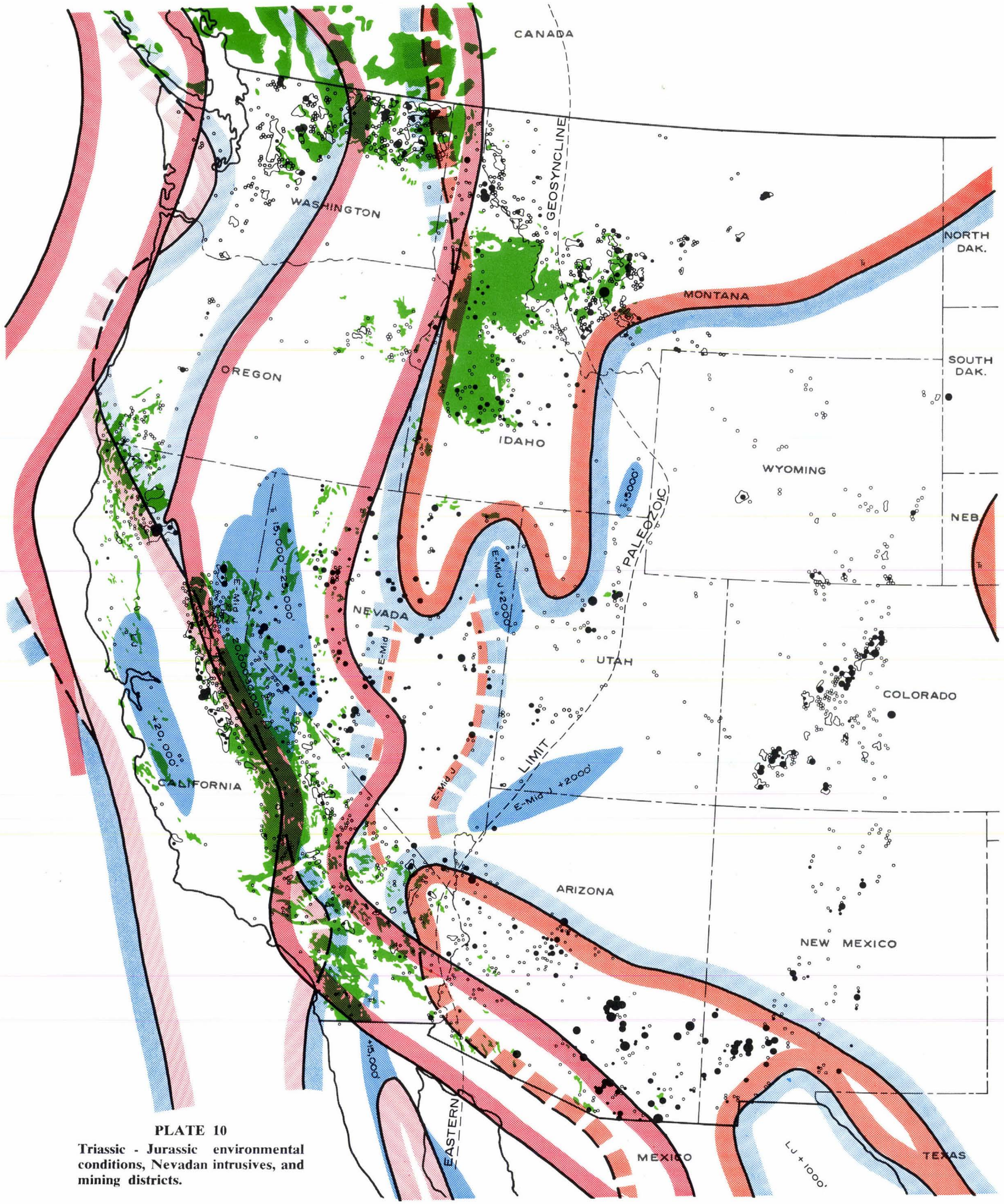


PLATE 10
Triassic - Jurassic environmental conditions, Nevadan intrusives, and mining districts.

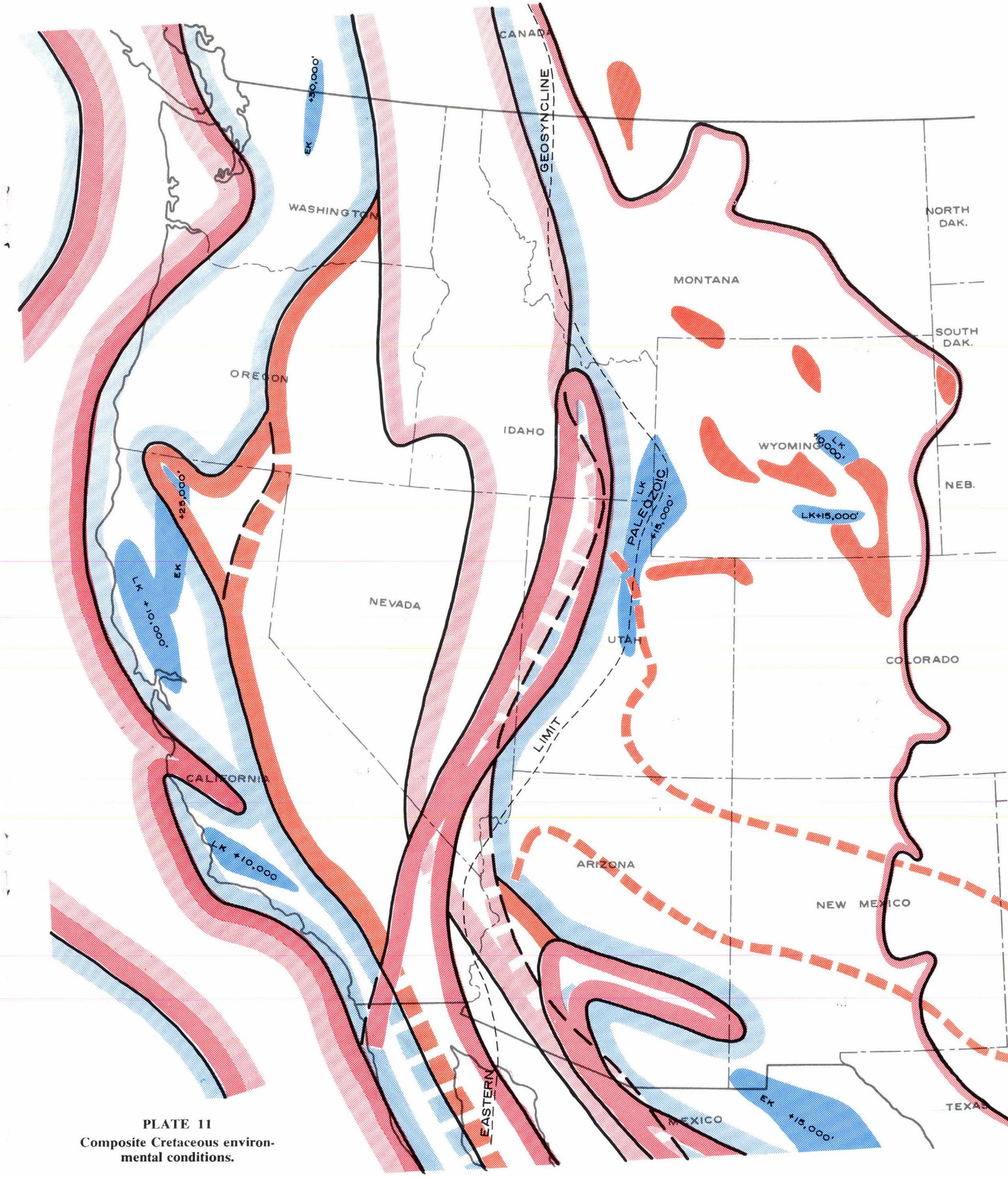


PLATE 11
Composite Cretaceous environmental conditions.