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CRETACEOUS AND TERTIARY ORE DEPOSITION IN ARIZONA[1/]

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INTRODUCTION

Many Arizona ore deposits have been described in the literature of the State, whereby the general characteristics of those classed within the Cretaceous-Tertiary group as a whole are well known. Students of metallogenetic epochs realize that the subject of Cretaceous and Tertiary ore deposition in Arizona is as complicated as the regional geology itself. Also, the scope of the subject remains somewhat indefinite because the age assignment for hypogene mineralization in most districts is based solely upon indirect evidence which has not yet been verified by radiometric determinations.

As ably expressed by B. S. Butler many years ago, "Ore deposition is but one phase of a series of closely related geologic events." Our present discussion concerns mainly some common features of the geologic background, as we now see it, in relation to metallogenetic epochs.

GEOLOGIC BACKGROUND

Cycles of Events

The events relating to Cretaceous-Tertiary mineralization have been occurring in a somewhat cyclic way for more than 2 billion years, through older Precambrian into present time. As generally interpreted, each cycle has consisted of (a) geosynclinal accumulation of thick sedimentary and volcanic rock series; (b) a revolutionary period of folding and faulting which culminated with igneous intrusion and extrusion on a regional scale; and (c) ore deposition, genetically related to batholiths and stocks.

In Arizona, four major periods of crustal disturbance and igneous invasion, with associated metallogenetic epochs, are identified as the older Precambrian Mazatzal Revolution, the younger Precambrian Grand Canyon Disturbance, the Triassic-Jurassic Nevadan Revolution, and the Cretaceous-Tertiary Laramide Revolution.

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Older Precambrian

Marking the close of the older Precambrian was the Mazatzal Revolution (Wilson, 1962). Within a rock succession in places 10 or more miles thick, it brought about major folding and foliation that trend prevailingly northeastward and locally north or northwestward; minor folding of west and northwestward trends; thrust faults and steep reverse faults that strike parallel to the folds; steep faults of north-south and east-west trends; and steep northwesterly faults. This pattern extensively influenced structural development, igneous intrusion, and mineralization within the region throughout all subsequent geologic time.

The Mazatzal Revolution culminated with extensive igneous invasions of granitic to gabbroic composition. Its associated metallogenetic epoch is represented by the Jerome ore deposits (Anderson and Creasey, 1958), whose Precambrian age is set by stratigraphic evidence. In addition, the Iron King veins (Anderson and Creasey, 1958) and various gold, tungsten, iron, and pegmatite veins are referred on indirect evidence to this epoch (Wilson, 1962).

Younger Precambrian

Following the Mazatzal Revolution, the region underwent erosion which continued for 100 million or more years and extended deeply into the granite batholiths. This and subsequent Precambrian erosion probably removed any shallow-seated mineral deposits that may have existed previously.

During younger Precambrian time, more than 1,600 feet of Apache strata and more than 12,000 feet of the Grand Canyon series were deposited. The era approached an end with a period of structural deformation termed the Grand Canyon Disturbance. This deformation resulted in structural features of types and trends similar to those of the Mazatzal Revolution, although much more weakly developed, and culminated with extensive diabase intrusion. Its associated epoch of mineralization is important mainly for chrysolite asbestos deposits, iron deposits, and possibly some uranium deposits.

Paleozoic

The close of the Paleozoic Era in Arizona was marked by relatively mild crustal disturbance with which no intrusive rocks and no metallogenetic epoch were associated, so far as is known.

Triassic-Jurassic

During Triassic-Jurassic time, a geosyncline existed in Sonora, Mexico, as implied by a thick succession of fossiliferous beds occurring less than 100 miles from the Arizona border. This geosyncline probably trended northwestward into Nevada, and its northeastern shelf may well have included portions of southern and western Arizona, somewhat as suggested by Tenney (1930) and by Eardley (1949). In Cochise County, the interval between Permian and Early Cretaceous time included a period of strong crustal deformation and subsequent invasion by magmas of granitic and monzonitic composition in the Mule Mountains and southern Dragoon Mountains areas. Andesitic and dacitic volcanic rocks were erupted locally in the Dragoon quadrangle and probably also in some areas farther south. Of these rocks, the intrusive bodies were mapped as Triassic or Jurassic by Gilluly (1956), and the volcanic eruptions were referred to the Triassic or Jurassic by Cooper (1959). This epoch of deformation and igneous activity in the Southwest was termed the Nevadan Revolution by Harrison Schmitt (1938). Mineralization associated with it is exemplified in the Bisbee district and apparently in the Courtland-Gleeson district. Other ore deposits in southern Arizona, including Ajo, could belong to this epoch; no definite evidence either for or against such a correlation is known.

Cretaceous-Tertiary

Beginning in Late Cretaceous time and extending into the Cenozoic Era was the Laramide or Rocky Mountain Revolution. In Arizona, it was relatively moderate for the Colorado Plateau province but intense for the Basin and Range province. For this latter region, its effects are not clearly separable from those of the Nevadan Revolution; also, they appear to blend with the crustal unrest and igneous activity of middle to late Cenozoic time. Thus, the Laramide has no recognized definitive time limits, and its convenient usage to designate an interval is not accepted officially by the U.S. Geological Survey. Many geologists tend to assign its features in Arizona entirely to the Tertiary.

The Laramide structural details in the Basin and Range province are inherently complex, and furthermore they have been isolated, modified, concealed, or obliterated at many places.

In the physiographic division of Arizona called the Mountain region, the Precambrian rocks rise some thousands of feet higher than in the Colorado Plateau province. Visible folding and general evidence of crustal shortening indicate that the Mountain region probably represents a complexly faulted anticlinorium (Wilson, 1962).

It is suggested that broad, open folding may have occurred throughout the Desert region of Arizona during Laramide time. The structural highs and lows within the Desert region are of amplitudes similar to those of the great plateau folds.

The dominant directions of Laramide folding in Arizona were northwest-southeast and north-south. Numerous thrust faults, more or less parallel to the folds, are found in the Basin and Range province. Steeply dipping faults and other fractures occur in as many as eight or more systematic directions (Wilson, 1962), and in numerous places they appear to be inherited from older Precambrian zones of weakness. The various structural features obviously exerted control over Laramide igneous intrusion and ore deposition.

LARAMIDE ORE DEPOSITS

Numerous Arizona districts commonly are considered as representative of the Laramide metallogenetic epoch. The evidence pertaining to age for some well-known examples of them may be summarized as follows:

The ore deposits of the Morenci area are believed to be connected genetically with a stock of granitic and monzonitic composition which invades Late Cretaceous strata (Lindgren, 1905).

In the Globe-Miami (Ransome, 1919; Peterson, 1962) and Superior (Short and others, 1943) areas, the hypogene mineralizing solutions probably came from Schultze Granite and granite porphyry. Nels Peterson (1962) states that the extensive copper metallization of the Globe and Miami districts seems to have been the culminating event in this long period of igneous activity, which may have begun in Late Cretaceous and continued into early Tertiary time. He has shown that the Schultze Granite is later than the anticlinal arching and accompanying faulting of the Pinal Mountains.

The Ray copper deposits are believed to be genetically related to granitic porphyry intrusives. Ransome (1919) stated that "It appears reasonable to regard the intrusion of the granite porphyries as an Early Tertiary event, but it must be admitted that this is little more than conjecture." On indirect evidence, the Ray deposits are classed as Laramide. They, as well as the Superior and Miami deposits, are considerably older than the Miocene Whitetail Conglomerate.

For the San Manuel area, Schwartz (1953) says: "The geologic age of the hypogene mineralization is unknown but, by analogy with other Arizona districts, is assumed as Early Tertiary." It is presumed to be connected genetically with monzonite porphyry. This rock apparently intrudes the Cloudburst unit, and the Cloudburst lithologically resembles Late Cretaceous beds of the Christmas area.

The Christmas copper deposits (Peterson and Swanson, 1956) occur in proximity to contacts of Paleozoic limestone with diorite, a stock of which intrudes andesitic volcanics of probable Late Cretaceous age.

The Bagdad copper-zinc-lead sulfides are believed to have been deposited from hydrothermal solutions supplied by a quartz monzonite intrusion (Anderson, Scholz, and Strobell, 1955). This quartz monzonite invades the Grayback Mountain Tuff, which was tentatively classed by the same writers as Cretaceous or Tertiary.

The Silver Bell copper deposits seem to be related to monzonite stocks which, according to Richard and Courtright (1954), invade rocks of Cretaceous age.

In the Pima district, quartz monzonite porphyry intrudes previously deformed rocks which Cooper (1960) suggests may be of Jurassic or Early Cretaceous age; the ore deposits appear to be related in origin to the porphyry.

In the Tombstone district, many of the ore bodies occur in rocks of Early Cretaceous age, and the hypogene mineralization was controlled by Laramide structural features (Butler, Wilson, and Rasor, 1938).

Mineralization of the New Cornelia ore body, at Ajo, is believed to have taken place in the cupola of the Cornelia quartz monzonite stock (Gilluly, 1946). This stock invades the Concentrator Volcanics, which Gilluly classed as Cretaceous on very tentative bases. Thus, the ore deposit has been assigned provisionally to the Laramide, although the possibility that it is of Nevadan age cannot be denied.

Within the Colorado Plateau province, various uranium deposits, in Mesozoic and Paleozoic rocks, and the White Mesa copper deposit, in Upper Triassic(?) and Jurassic sandstone, are presumed to be Laramide.

For Arizona, the deposits currently listed as Laramide have yielded more metal than all the others combined. This relative importance reflects the abundance of favorable structures, favorable host rocks, and sources of mineralizing solutions. It also depends upon the depths to which post-mineral erosion has effected oxidation and supergene enrichment; furthermore, an unknown number of ore deposits have been stripped away by erosion.

"LATE" TERTIARY ORE DEPOSITS

For many years, the epithermal gold deposits and various manganese deposits in Arizona have been classed as late Tertiary. In fact, the adjectives "epithermal" and "late Tertiary" have become essentially synonymous for them. Any discussion of this classification leads to the question, "What is meant by early, middle, and late Tertiary?" So far as we are aware, there is no accepted quantitative definition of them. If the Tertiary is assumed to be 60 million years long, as according to Holmes, and divided into three approximately equal parts, then early Tertiary would be limited to Eocene; middle Tertiary would include Oligocene and the early one-third of Miocene; and late Tertiary would span the later two-thirds of Miocene, plus Pliocene.

It has become increasingly apparent, as a result of geologic work and radiometric determinations during recent years, that most of the notably mineralized volcanic units in southwestern and western Arizona, which formerly were regarded as Tertiary, may be Mesozoic, and that the stocks intruding them may be Laramide.

The metallogenic epoch to which the Arizona epithermal deposits belongs was not associated with any recognized period of deformation and major igneous intrusion separate from the Laramide. Furthermore, the epithermal mineralization clearly preceded the Basin and Range orogeny; this orogeny extended mainly from early or middle Miocene to Pliocene and continued mildly into the Pleistocene, as Lance (1960) has shown by fossil evidence. It seems, therefore, that the so-called late Tertiary metallogenetic epoch is pre-middle Miocene in age and is not distinguished from the Laramide.

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