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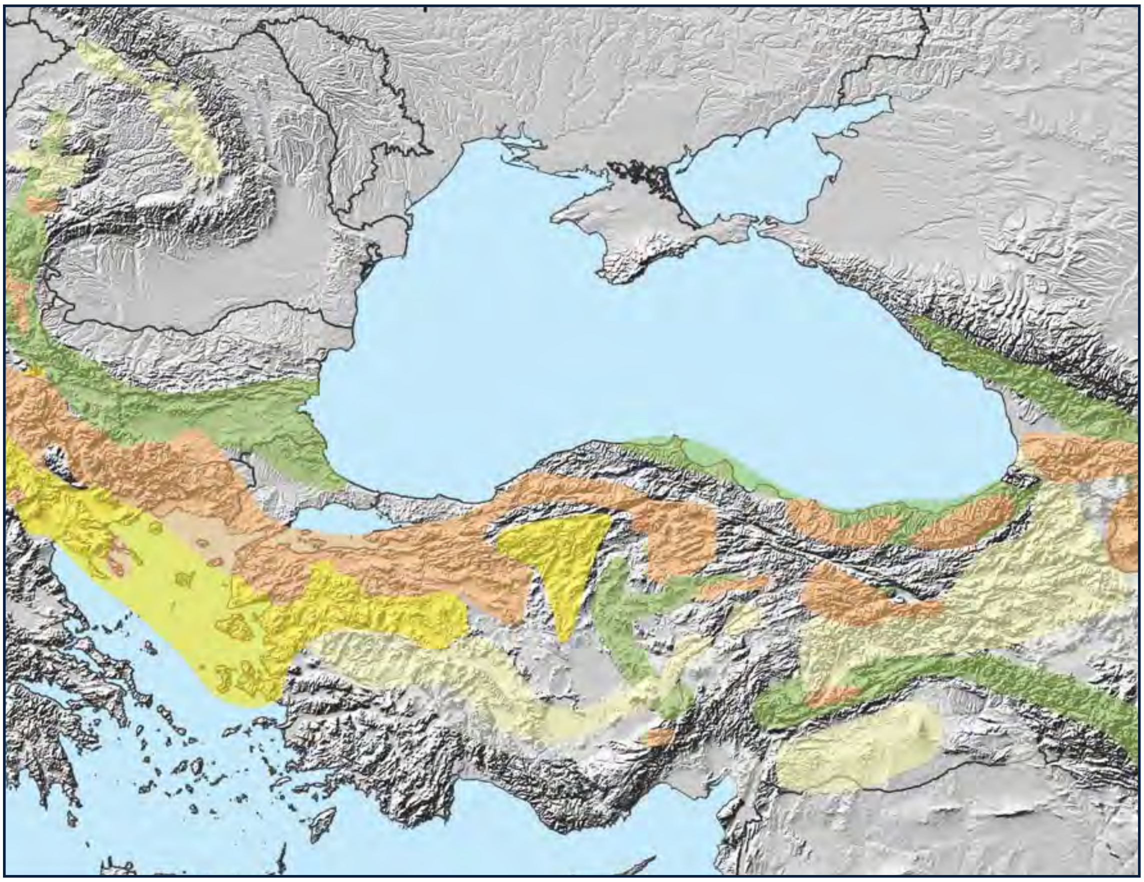
Tectonics and Metallogeny of the Tethyan Orogenic Belt



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On the cover: The western Tethyan magmatic belt, from the paper by Baker et al.

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Contents

Preface

The Tethyan orogenic belt stretches from the Alps, through the Carpathians and Balkans, Taurides and Caucasus, Zagros, Makran, and Himalayas, to Indochina and into the southwest Pacific Ocean. It represents a complete Wilson Cycle, from opening and closure of the Paleotethys Ocean in the mid-Paleozoic to the Late Triassic, opening of the Neotethys Ocean in the Permian-Early Triassic, and its progressive closure throughout the late Mesozoic and Cenozoic eras. The current state of the orogen includes all stages of convergence from active subduction beneath the Makran and eastern Mediterranean, through advanced continental collision in the Caucasus/Taurides and Zagros, to syn- to postcollisional readjustment in the Carpathians, Balkans, Himalayas, and Indochina (Richards, 2015).

The region has been the focus of significant recent attention from geologists interested both in its tectonic evolution and metallogeny, made possible by increased accessibility to many of the geographic sections of the orogen. Key breakthroughs in understanding its tectonic history have come through improved geochronological techniques and expansion of the database of samples and events dated, combined with more accurate paleogeographic and tectonic models. In parallel, an improved understanding of the subtle relationships between tectonomagmatic and metallogenic processes have refined interpretations that were once based on simplistic assumptions (e.g., that porphyry deposits only form above active subduction zones). Indeed, economic geologists have been among the key drivers of these advances by demanding more accurate and predictive tectonomagmatic models for ore formation that can reliably inform mineral exploration.

Consequently, the Tethyan orogen is now understood to be the best preserved global example of a collisional orogen, where all stages of convergence can be observed in real or recent geological time, and the detailed relationships to ore formation, commonly reflecting tectonic changes measured on submillion-year timescales, can be accurately documented and modeled.

In this volume, we present a selection of papers that showcase this advancement in knowledge, with examples from Eastern Europe to South Asia.

Beginning in the Balkans, Knaak et al. (2016) describe the variety of mineral deposits that occur in the emergent world-class Timok region of eastern Serbia. The origin of the Late Cretaceous Timok Magmatic Complex remains debated, but the authors propose that arc magmatism was focused by dextral transtensional structures, followed by complex structural rearrangement in the Cenozoic. Porphyry Cu-Au deposits, polymetallic replacement deposits, and sedimentary rock-hosted Au deposits occur in close spatial, and possibly genetic, relationship to the Late Cretaceous arc rocks. A key contribution of this study is the detailed reconstruction of later Cenozoic fault movements that led to structural dislocation and oroclinal bending, complicating geologic and metallogenic correlations in the region.

Siron et al. (2016) describe the tectonomagmatic setting of porphyry Au-Cu and Au-rich polymetallic carbonate-hosted replacement deposits in the Kassandra mining district of northern Greece, which together contain resources of over 12 Moz Au. Postcollisional extension-related magmatism in the district occurred in two pulses in the late Oligocene and early Miocene, with an increasingly alkaline (shoshonitic) character that culminated in the formation at ~20 Ma of the Pt-Pd-enriched Skouries porphyry Cu-Au deposit, illustrating the unique metallogeny of postcollisional tectonic settings.

Three papers report on recent porphyry and epithermal Cu-Au discoveries in western Turkey. Baker et al. (2016) describe the important (16.8 Moz Au) Kişladağ high-K calc-alkaline to shoshonitic porphyry Au deposit, which formed at ~14.5 Ma in a postcollisional extensional setting within the Menderes massif of western Anatolia. Kişladağ is classified as a gold-only porphyry deposit due to its low Cu content but economic concentrations of Au, possibly reflecting shallow emplacement. The Biga peninsula of northwestern Turkey has been the focus of recent exploration since the discovery of the Halilağa and TV Tower porphyry-epithermal Cu-Au deposits. Smith et al. (2016) describe porphyry Cu-Au and high-sulfidation epithermal Au mineralization at Karaayi, adjacent to the TV Tower property, and suggest that these deposits formed in two separate events, with porphyry mineralization associated with the 40 to 38 Ma Kuşçayir pluton, and high-sulfidation epithermal deposits forming ~10 m.y. later in association with a younger plutons emplaced at ~29 Ma. These igneous suites formed during the transition from collisional to postcollisional extensional and transtensional tectonics in northwestern Turkey, in response to rollback of the subducting African plate. Sánchez et al. (2016) explore this structural transition in more detail, and document the evolution of half-graben volcano-sedimentary basins and their control on the formation of high- and low-sulfidation epithermal vein systems, and deeper seated porphyry systems related to metamorphic core-complex exhumation.

Moritz et al. (2016) provide an update on their recent work in the previously poorly described Lesser Caucasus region, which is host to numerous porphyry and epithermal deposits, including the large Teghout porphyry Cu (146 Ma), Agarak porphyry Cu-Mo (44 Ma), and Kadjaran porphyry Mo-Cu (27 Ma) deposits. The region records the transition from Mesozoic arc tectonics and magmatism, associated with early volcanic-hosted massive sulfide and later porphyry-epithermal deposits, reflecting arc maturation, to early Cenozoic microplate accretion associated with Eocene porphyry Cu-Mo and epithermal Au-Ag deposits, and finally to Neogene collisional and postcollisional tectonics associated with the formation of porphyry Cu-Mo deposits.

The Zagros and Alborz sections of the Tethyan orogenic belt in Iran host several large mineral deposits, including the Sungun (21 Ma; 850 Mt containing 0.62% Cu, 0.01% Mo) and Sar Cheshmeh (13 Ma; 1.7 Gt containing 0.65% Cu, 0.03% Mo, 0.06 g/t Au) porphyry Cu-Mo deposits, and the Sari Gunay (11 Ma; 52 Mt containing 1.77 g/t Au) epithermal Au deposit. Richards and Sholeh (2016) describe the tectonic evolution of the region, from Late Cretaceous-Paleogene convergent margin and terrane accretion events to Neogene Arabian-Eurasian continental collision, and the relationship between these tectonic processes and the formation of volcanoplutonic belts and related porphyry and epithermal deposits. Many of the largest deposits formed in the mid-Miocene and are thought to reflect collisional tectonomagmatic processes. The authors note that Iran has been relatively well explored for exposed porphyry deposits, but that large areas of prospective terrane remain untested beneath younger sedimentary and volcanosedimentary rocks. In contrast, systematic exploration for epithermal deposits is less well advanced despite widespread evidence for their occurrence.

Zürcher et al. (2016) combine the complex tectonomagmatic history of Iran with uplift and exposure records to provide predictive tools for mineral exploration in terms of the likelihood of mineral deposit preservation or burial. They conclude that the most productive and prospective terranes are those where subequal proportions of volcanic and coeval subvolcanic plutonic rocks are exposed, and where cover by younger rocks is minimized. Fonseca et al. (2016) take the exploration focus a step further by using magnetic and infrared remote sensing data to generate regional-scale structural and alteration patterns. In combination with published geologic maps, they use these data to infer that major basement structures and premineralization dilational zones controlled the localization of porphyry deposits in the Kerman belt of east-central Iran (including the giant Sar Cheshmeh porphyry Cu-Mo deposit).

A major north-south dextral fault system, the Neh-Zahedan fault or Sistan suture, separates the collisional Eocene-Miocene Kerman belt in southeast Iran from arc rocks of broadly similar age in the Chagai belt of western Pakistan. This region is host to numerous porphyry Cu-Mo-Au centers, including the Saindak mine (22 Ma) and world-class Reko Diq deposit (12 Ma; Perelló et al., 2008). Razique et al. (2016) provide a comprehensive description of mineralization and alteration zoning in the paired H14 and H15 deposits at Reko Diq, which together define a currently unexploited resource of 5.35 Gt containing 0.41% Cu and 0.22 g/t Au.

The world's most spectacular continent-continent collision zone, the Himalayas, was long assumed to be unprospective for porphyry-type mineralization because of the cessation of oceanic plate subduction following collision, and extensive uplift and erosion of older arc rocks. However, this view has fundamentally changed with the discovery of numerous Miocene porphyry Cu-Mo deposits in the Gangdese belt of eastern Tibet (e.g., Qulong, 16 Ma; Yang et al., 2009), which postdate the onset of collision by up to 30 m.y. (Hou et al., 2009). In addition to these postcollisional deposits, numerous porphyry systems of Mesozoic to Cenozoic age occur along the eastern margin of the India-Asia collision zone and extending south into the accretionary terranes of Indochina (e.g., Yangla, 233 Ma; Pulang, 213 Ma; Yulong, 47 Ma; Hou et al., 2006; Li et al., 2011; Zhu et al., 2015).

Searle et al. (2016) review the tectonic setting and varied mineral occurrences in this geologically complex region, with a particular focus on Indochina, including Myanmar and Thailand. They suggest that detailed knowledge of tectonic processes can explain the occurrence of mineralization ranging from orthomagmatic-, through metamorphic-, to hydrothermal-, and sedimentary-related deposits.

Numerous models have been proposed for the formation of collisional and postcollisional porphyry systems in the Gangdese belt of Tibet. In this volume, Yang et al. (2016) propose that the Miocene adakite-like porphyry magmas were generated by water-fluxed melting of subduction-modified Tibetan lower crust, triggered by underthrusting of the Indian continental plate and intrusion of ultrapotassic mafic magmas. The metal endowment in these postcollisional magmas may reflect remobilization of metal sulfides left in deep crustal cumulates during precollisional arc magmatism (Richards, 2009; Hou et al., 2015).

Continuing with the theme of magmatic fertility for porphyry ore formation, Lu et al. (2016) present LA-ICP-MS U-Pb age and trace element data for zircons from mineralization-related and -unrelated plutons from Tibet, Iran, and elsewhere, which suggest that fertile magmatic suites can be distinguished best by high Eu/Eu* and (Eu/Eu*)/Y ratios in zircons. They interpret these data to indicate high magmatic water contents and oxidation states in fertile magmas, and suggest that the trace element composition of detrital zircons can be used as an exploration indicator in remote or covered terranes.

The final paper in the volume, by Herrington et al. (2016), reviews the weathering and erosion history of the central Tethyan region that led to the formation of bauxite and Ni-Co-laterite deposits, the latter derived from ophiolitic protoliths. The authors find that the bulk of these deposits formed during the Paleogene-Eocene thermal maximum, when subequatorial climatic conditions promoted deep weathering throughout the region.

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J. P. Richards

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