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Final Report

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Project Title: Comparative Study of Jurassic to Early Tertiary Igneous-Related Metallogeny in the Basin and Range Province

Synopsis

This final report summarizes progress and products through the end of calendar 2010, work that continues from this project, and the additional products that will be generated in the near future. As described in earlier communications, including several progress reports, this project was funded much later than originally proposed and required a modified work plan. Several of the original proposed participants (Brian Rusk, USGS; Daniel Russin, University of Arizona) had taken other positions and were not available; new students were recruited, the focus was modified, and several collaborative efforts were added in conjunction with the MRP Global Assessment project.

The principal goals of this project (from the proposal) are to:

(1) provide a more complete geological and petrological first pass assessment of Jurassic magmatism and related hydrothermal systems in the SW US,

(2) compare selected aspects of the Jurassic systems with the (apparently) better endowed Cretaceous and Tertiary in the same region, and

(3) use these results and develop new evidence on the 3-D character of these contrasting systems.

These have been addressed through the following activities which follow from but also expand on the original anticipated products.

(1) a GIS-based synthesis of Jurassic magmatism and mineral deposits in the Basin and Range (this was expanded to all the SW US and NW Mexico),

(2) a geological and petrological analysis of these patterns focused on features that distinguish mineralized systems and a comparison with Laramide and Tertiary mineralized centers,

(3) focused petrological and geochemical studies of selected systems, and

(4) collaboration with related components of the global assessment effort.

To date, many results have been presented at professional meetings (five abstracts), and in four papers (three published, one in press). Several more manuscripts are in various stages of preparation including parts of two Ph.D. dissertations. These studies have benefited from support leveraged from the Institute for Mineral Resources where geologic studies are funded by 10 mining companies, Science Foundation Arizona, and other Federal grants.

Approaches, work completed, and in progress

This project has followed several threads, based on three types of activities: (1) compiling existing published and unpublished data, (2) generating new field, petrologic, geochronological, and geochemical observations, and (3) using these results as a basis for new synthesis of aspects of magmatism and mineralization in southwestern North America.

Data compilation began with an assembly of existing information from published sources and our previous work to which has been added new results generated in this studye. Excel-based petrologic and geochronologic datasets are geographically located and correlated with a newly generated GIS-based summary of intrusive and volcanic centers. The GIS-based (Arc-GIS) began with the Borderlands compilation 1:2M map (which we completed some years ago in collaboration with Floyd Gray, USGS Tucson). Igneous complexes were abstracted and attributed from this source and supplemented as needed by data from published 1:0.5M and 1:1M scale state maps.

The datasets focus on the Jurassic, but include selected younger igneous complexes such as Laramide intrusive centers in Arizona, Sonora and New Mexico. Information on igneous mineralogy, whole rock major and trace elements, and stable and radiogenic isotopes total over 10,000 records. This work has been done primarily by James Girardi, UA PhD student in collaboration with Lukas Zürcher and Mark Barton. Girardi's doctoral dissertation is focused on the petrogenetic evolution of the Jurassic arc in southwestern North America, and a comparison with other early stage continental arcs in the North and South American cordillera (e.g., Girardi, 2012 ms). Collaborating scientists have included Gordon Haxel (USGS Flagstaff, emeritus) and Bob Powell (USGS Tucson).

Concurrently with the igneous- compilations and syntheses of mineralized systems were expanded from earlier work to address the core metallogenic issues. Porphyry (+ Cu skarn), IOCG (*sensu lato*), advanced argillic, and other types of hydrothermal systems were reviewed and new data added. Eric Seedorff presented a summary of the new results on porphyry systems at the SEG Keystone meeting in October 2010 (Seedorff et al., 2010). A related manuscript is in preparation for a planned special issue of *Economic Geology* on Laramide porphyry deposits. These and earlier results were used in contributing to the new porphyry copper model (John et al., 2010) to which both Barton and Seedorff made contributions, and in generating the new porphyry copper assessment of Mexico to which Lukas Zürcher contributed (Hammarstrom et al., 2010). Focusing on the Jurassic, with short comparisons to other times and places, Barton and others (2010a, b; Barton, 2010) used a combination of the new databases and a summary of mineralized systems to generate a synthesis of Jurassic metallogeny with comparisons to other times and areas. Kreiner and Barton (2010, 2011 ms) summarized, visited, and compared contrasting hydrothermal systems in the Mesozoic and Cenozoic of the western US that contain well developed advanced argillic alteration.

New observations, derived primarily from field work and subsequent laboratory studies comprised the other major component of this project. Girardi with help from others (Kreiner, Haxel, Powell, Barton) completed field work focused on sample collection in 2009 in southern Arizona and southeastern California, and in the Great Basin (with Barton and Kreiner in June 2010). These trips were focused on filling key gaps in the petrologic understanding of Jurassic magmatism and better documenting

hydrothermal alteration in that part of the arc located in the Basin and Range Province. In total, over 50 intrusive centers were visited, about 400 samples of fresh and altered rocks were collected, some 200 polished thin sections completed, about a dozen samples prepared for U-Pb geochronology, and (as of 12/31/2010) several dozen samples are being prepared for whole rock geochemistry including Sr and Nd isotopic analysis pending completion of petrography and (as appropriate) electron microprobe characterization of mineral compositions. Collaborative work continued with Peter Vikre (Reno office) and others on the geochronology and thermal development of the Laramide porphyry and related hydrothermal systems of the Patagonia area in southern Arizona.

Principal results and products through December 2010

As summarized above and enumerated in "References cited" this project has contributed to four new peer-reviewed publications, a number of abstracts and professional presentations, and the education of two doctoral students. It also contributed to the research of Phillip Nickerson, currently a UA PhD student, but who started as a Masters student. Nickerson is contributing to the new treatment of extensional tectonics in the southern Basin and Range province, principally Arizona, with the goal of adding to the 3D understanding of this work. This project supported later aspects of Nickerson's MS work which built on our earlier Porphyry Copper Life Cycle project some of which was published with support from this grant (Nickerson et al., 2010).

Key insights from the work to date can be summarized as follows:

(1) Jurassic metallogeny directly reflects the types of magmas, the crustal levels that are preserved and exposed, and the diversity of non-magmatic fluids (particularly saline fluids) extant at the time (e.g. Barton et al., 2010a,b).

(2) Jurassic igneous rocks are more diverse and more alkaline than acknowledged in recent compilations and papers. In detail, although there are large overlaps with other times, Jurassic compositions have features that are distinct from younger suites in the same areas. This is reflected in the metallogenic signatures (Girardi, in prep.; Barton et al., 2010a,b; Seedorff et al., 2010).

(3) The nature of shallow and distal mineralization, both epithermal and IOCG types vary consistently in time and space with IOCG varieties (and their associated metasomatic signatures) being far more extensive in the Jurassic than at other times (Barton et al., 2010a,b).

(4) Advanced argillic assemblages are clearly of several distinctly different families, with some being classic "high sulfidation" (= acid sulfate) types, but others being low total sulfur, and there being considerable fundamental variation in the settings and metal ratios (Kreiner and Barton, 2010, Kreiner, in prep.). These patterns apply globally.

(5) Cenozoic extension and cover are important in two ways: First, they preserve and hide large fractions of the older, metallogenically productive upper crust in the Basin and Range (Barton, 2010). As much as 80% of the Jurassic is hidden and preserved with implications for resource assessment (Barton et al., 2010b). Second, the 3-D views that extensional faulting and block rotation yield through the upper crust and mineralized systems allow an exceptional look at evidence for fundamental controls on mineralizing processes at the

system scale – an aspect that merits much future focus (Nickerson et al., 2010; Seedorff et al., 2010).

Anticipated additional publications and related products from this project

Many products are in progress; they are summarized here. In most cases, these are at the stage of writing papers and/or finalizing the datasets. The Jurassic petrological and geochronological studies, however, are still in progress as part of James Girardi's dissertation research. The field work and much of the sample preparation has been completed over the two year duration of the project, yet given the time required for all the component parts including recruiting a new PhD student to work on this project), a considerable fraction of the analytical work remains. The analytical work will be completed, along with the final papers and dissertation over the coming 18 months using the complementary sources of support from related funded projects.

In addition to the papers and presentations noted above, a number of finished products will be generated over the next two years as a result of this project. These include papers, parts of two doctoral dissertations, and relevant databases. Specific times are uncertain, but the general framework is outlined here:

(1) A paper for *Economic Geology* on contrasting types of advanced argillic alteration in different hydrothermal environments, with an emphasis on comparisons within the Mesozoic and Cenozoic of the western United States. A first-draft manuscript has been completed, and key results of this study were presented at the GSA Annual Meeting 2010 (Kreiner and Barton, 2010). This work is part of Doug Kreiner's Ph.D. dissertation which should be completed in August 2011, which will acknowledge MRERP support.

(2) A GIS-based data summary of the Jurassic either as a digital supplement to one or more of the other papers, or as an independent product. We would consider a USGS product (e.g., SIR) if our collaborating Survey scientists (e.g, Haxel) think this venue would be appropriate.

(3) At least one paper intended for an international journal that will present the new data and synthesis on the petrogenesis of the Jurassic arc and how it compares and contrasts with other episodes in the southwestern US. This is a key part of the developing Ph.D. dissertation by James Girardi which should be completed in the first half of 2012.

(4) A synthesis paper on porphyry copper and related hydrothermal systems in southwestern North America with a focus on comparing Laramide with other systems. This paper, by Eric Seedorff and others, is intended for a special issue of *Economic Geology* that will be focused on the Laramide porphyry province. Results have already been presented (Seedorff et al., 2010).

(5) A related manuscript for the *EG* special issue will focus on metallogenic controls on the Laramide porphyry province and a comparison and contrast with Jurassic, Cretaceous and middle Tertiary metallogenic episodes in the southwest. This paper, in preparation by Barton, Seedorff, Girardi, Nickerson and others, will draw on the geochemical and geological results of this projects.

References cited

(results to date from this grant, including dissertations [but not manuscripts] in progress)

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