August 2023

New at AIRIE – We are now analyzing Hg (mercury) using our state-of-the-art DMA (Direct Mercury Analyzer). Hg concentration data are available for almost any media through our AIRIE-Hg program.

Our History – The AIRIE Program pioneered Re-Os (rhenium-osmium) protocols for working with resource-related geologic media in crustal rocks (e.g., sulfides, shales and oils). The first technological breakthroughs were cut short at the USGS when management determined that "Re-Os was a flash-in-the-pan" in connection with their renowned RIF (reduction-in-force). Since 1995, AIRIE has produced state-of-the-art Re-Os geochronology and Os isotopic tracer studies, interpreted in their geologic context. Two multi-collector Triton mass spectrometers built for Re-Os analytical work and two wet-chemistry labs were funded by the Program. Collaborating partners span 90 countries and discoveries benefit an expanding cross-section of the sciences, from atmosphere to deep earth, transcending geology-biology-chemistry derivatives. We address fundamental scientific questions and use creative approaches to stimulate new and progressive thinking. This advances science and enhances discovery for the mineral and petroleum industries. Starting in 2000, AIRIE forged a long-term partnership with research entities in Norway, making Norwegian economic interests the geologic base for fundamental scientific discoveries. These include Re-Os dating of molybdenite, arsenopyrite and other sulfides, dating of shales, dating of oils and bitumens, reconstruction of whole petroleum systems in absolute time, and most recently dating critical minerals such as graphite. After 25 highly successful years as a soft-money research group at Colorado State University, uplifting the Geosciences, in August 2022, the Department Head without support from the Geosciences faculty terminated the AIRIE Program claiming the Program was not on mission with Geosciences. This presented us with the opportunity to form our own start-up! CSU higher administration did not support his action and allowed AIRIE to retain all instrumentation and laboratory equipment – right down to the lab benches.

Re-Os isotope geochemistry enlightens our understanding of how metallic and hydrocarbon resources are created, interrelated, and where they are located.

Metallic Resources – Our work has led directly to discovery of ore and has challenged several long-standing models for ore formation. AIRIE established now globally employed protocols for Re-Os ID-TIMS dating of molybdenite (*Terra Nova* 2001, 797 citations). We discovered the unique phenomenon of parent-daughter (^{187}Re-^{187}Os) decoupling in molybdenite prompting us to develop new approaches for acquiring mineral separates. We were the first to develop a double Os spike to address young (or low Re) molybdenites and to measure and correct for common Os isotope fractionation. We acquired and characterized a molybdenite reference material (NIST, RM #8599) from the Henderson molybdenum mine (mill) in Colorado to share with the geoscience community. We pioneered Re-Os dating of other sulfide and oxide minerals, for example, arsenopyrite, pyrite, marcasite, bismuthinite, chalcopyrite, pyrrhotite and magnetite providing ages and information on fluid sources, not only for ore deposits, but also for fundamental processes shaping our dynamic planet Earth.

Hydrocarbon Resources – Our work with hydrocarbons includes Re-Os dating of organic material extracted from shales. Re-Os dating of both *in situ* and migrated bitumen and oil also permits tracking interactions between Earth fluids and hydrocarbons using Os as an isotopic tracer. In 2016, we published the first Re-Os isochron for a single crude oil based on its asphaltene and maltene components. Re-Os analyses of hydrocarbons are useful in modeling maturation-migration in both conventional and unconventional systems. Our work on sulfides and organic material in shales calibrates Earth's timescale permitting global correlations, and determines rates for sedimentologic, bio-evolutionary, and tectonic processes, giving perspective on ancient climates, oceans, correlation of fauna, and atmospheric evolution. We provided the first radiometric age for the rise of atmospheric oxygen (GOE, Great Oxidation Event), with citations reaching far beyond the geoscience literature (*Nature* 2004, 1493 citations).

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AIRIE PROGRAM, FORT COLLINS, COLORADO: RE-OS PUBLICATIONS

Holly Stein (Founding Director, Senior Research Scientist and Professor)
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Refereed Journal Papers:

Goswami, V., Stein, H.J., and Hannah, J.L. (in co-author review) Re-Os-Hg geochemistry of Fish Clay, black nodular cherts, and chalks across the Cretaceous-Paleogene (K-Pg) boundary at Stevns Klint, Denmark: for *Palaeogeography, Palaeoclimatology, Palaeoecology.*

Stewart, P.W., Stein, H.J., Roa, K., and Gabites, J. (in co-author review) U-Pb, $^{40}Ar/^{39}Ar$, and Re-Os geochronologic constraints on the genesis of the Fruita del Norte epithermal gold-silver deposit, southeast Ecuador: for *Economic Geology*.

Boni, M., Stein, H., Balassone, G., Yang, G., and Mondillo, N. (in co-author revision) Wulfenite ($PbMoO_4$) in the oxidation zones of the Alpine Zn-(Pb) of the Alpine Zn-(Pb) deposits: first results of Re-Os isotopic analyses: for *Mineralium Deposita*.

Runyon, S.E., Barrier, J., Chapman, J., Brown, T.R., Stein, H., and Autenrieth, K. (in co-author revision) Central alkalic group Au system, Rattlesnake Hills Alkaline Complex, Wyoming: U-Pb and Re-Os geochronology and magmatic evolution: for *Mineralium Deposita*.

Bobos, I., Stein, H., Deng, X.-D., Sudo, M., and Noronha, F. (in review) U-Pb LA-ICP-MS and Re-Os dating of wolframite and molybdenite: Constraints on multiple mineralization and cooling histories ($^{40}Ar/^{39}Ar$) for the magmatic-hydrothermal system at Borralha, northern Portugal: *Ore Geology Reviews*.

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