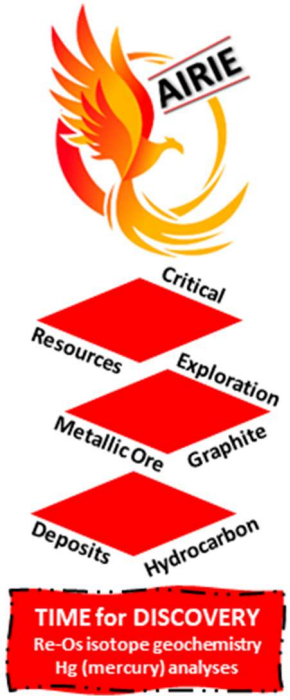

June 2024

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 of Resilience and Determination – The AIRIE Program pioneered Re-Os (rhenium-osmium) protocols for working with resource-related geologic media in crustal rocks (e.g., sulfides, shales, oils). Our first technological breakthroughs were cut short at the USGS when management declared that "Re-Os was a flash-in-the-pan" in connection with their reduction-in-force. Since 1995, AIRIE has produced state-of-the-art Re-Os geochronology and Os isotopic tracer studies, interpreted in geologic context. Two multi-collector Triton mass spectrometers built for Re-Os analytical work and two wet-chemistry labs funded by the Program continue to provide groundbreaking data for academic, industry, and government interests – results that give new interpretations leading to discoveries. Collaborating partners span 90 countries and our work benefits a continuously expanding cross-section of the sciences, from atmosphere to deep earth, transcending geology-biology-chemistry derivatives. We use project-tailored, 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 many of AIRIE's 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 years as a soft-money research group at Colorado State University, elevating the Geosciences, in August 2022 the Department Head without the support of the faculty terminated the AIRIE Program. This presented us with the opportunity to form our own start-up! CSU higher administration opposed termination and allowed AIRIE to retain all instrumentation and laboratory equipment – right down to the lab benches. We reestablished our facility at *Innosphere Ventures* in Fort Collins and our PhD student was able to finish. AIRIE offers quick turnaround, guidance for students, and quality work with interpretation of results.

Re-Os guides and enlightens exploration for metallic and hydrocarbon resources.

Metallic Resources – Our work has led to the discovery of ore and has challenged several long-standing models for ore formation. AIRIE established now globally employed protocols for Re-Os ID-NTIMS dating of molybdenite (*Terra Nova* 2001, 826 citations). We discovered the unique phenomenon of parent-daughter (^{187}Re-^{187}Os) decoupling in molybdenite prompting us to pioneer new approaches for mineral separations. We were the first to develop a double Os spike, particularly useful for young (or low Re) molybdenites, correcting for any initial Os and Os mass 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 fluid-driven processes shaping our dynamic Earth. Most sulfides can be dated by Re-Os.

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 water 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, 1559 citations).

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

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*.

Kyle, J.R., Ugurhan, M., Elliott, B.A., Edey, D.R., Hoffman, C.P., and Stein, H. (in review) Growth and physical transport of molybdenite spherules in a Na-Al-F-rich melt, Cave Peak porphyry Mo deposit, Texas: *Geology*.

Borrajo, I., Tornos, F., Stein, H., Hanchar, J.M. (in review) Geochronology and decoupling controls of Sn-(Ta-Li) and W-(Sn) mineralization in the Iberian Variscan Massif: *Ore Geology Reviews*.

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