



APPLIED ISOTOPE RESEARCH



Colorado
State
University

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The AIRIE Program has pioneered Re-Os (rhenium-osmium) technology, and has been the global leader in setting protocols for dissecting sample media to determine geologic age. Since 1995, AIRIE has produced state-of-the-art Re-Os geochronology and Os isotopic tracer studies, based on forward-thinking geologically-based insights. Two multi-collector Triton mass spectrometers were built and specifically tuned for Re-Os analytical work. Our collaborating partners span 80 countries and our discoveries have benefited an enormous cross-section of the geosciences, from atmosphere to deep earth. We address fundamental scientific questions and use the results to both advance science and enhance discovery in the petroleum and mineral industries. The analytical facility is located at Colorado State University, with research and funding driven through the CEED Centre of Excellence at University of Oslo. The AIRIE Program, salaries and operations, is funded solely by grants and contracts; we receive no support from CSU for the Program.

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

Metals – Our work has led directly to discovery of ore, while challenging long-standing models for ore formation. AIRIE established the protocols for successful Re-Os TIMS dating of molybdenite, from mineral separation to interpretation of isotopic data. We developed a double Os spike to address young (or low Re) molybdenites, sharing this approach with the geochemistry community. We acquired and characterized a molybdenite reference material (RM #8599) from the Henderson molybdenum mine in Colorado – now distributed by NIST for global inter-laboratory comparison. We work with other sulfide and oxide minerals such as pyrite, arsenopyrite, chalcopyrite, and magnetite to provide age and source information through Re-Os isochrons.

Hydrocarbons – Our work with hydrocarbons includes direct dating of organic material in potential source rocks, and dating *in situ* and migrated bitumen and oil. In 2016, we published the first Re-Os isochron for a crude oil. We work with the hydrogenous component in black shales, and for hydrocarbons, we analyze components of the asphaltene and maltene fractions in oils. Re-Os analyses of hydrocarbons are used to model maturation-migration in both conventional and unconventional systems. Our work on sulfides and organic material in shales helps calibrate Earth's timescale, and determine rates for sedimentologic, bio-evolutionary, and tectonic processes, giving perspective on ancient climates, oceans, global correlation of fauna, and atmospheric evolution. We provided the first absolute age for the rise of atmospheric oxygen.

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AIRIE PROGRAM, COLORADO STATE UNIVERSITY: RE-OS PUBLICATIONS

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### Recent Thesis:

DiMarzio, J.M. (2017) Residency of Rhenium and Osmium in a Heavy Crude Oil: M.S. thesis, Colorado State University, 61 p. [funded by Eni, Lundin, and AkerBP under the CHRONOS project] (<http://airieprogram.org/DiMarzioResidencyReOsCrudeOilCSUThesis2017.pdf>)

### Refereed Journal Papers:

Goswami, V., Hannah, J.L., Stein, H.J. (author revisions) Can terrestrial coals be dated using the Re-Os geochronometers? Evidence from the Finnmark platform, southern Barents Sea and the Fire Clay horizon, central Appalachian basin: for *Chemical Geology*.

Tripathy, G.R., Hannah, J.L., Stein, H.J. (author revisions) Refining the Jurassic-Cretaceous boundary: Re-Os geochronology and depositional environment of Upper Jurassic shales from the Norwegian Sea: for *Palaeogeography, Palaeoclimatology, Palaeoecology*.

Hurtig, N.C., Georgiev, S.V., Stein, H.J., and Hannah, J.L. (author revisions) Re-Os in oil – in the company of water:

Stewart, P.W., Roa, K., Stein, H.J. (author revisions) U-Pb,  $^{40}\text{Ar}/^{39}\text{Ar}$ , and Re-Os geochronology of the Fruita del Norte epithermal gold-silver deposit, southeast Ecuador: for *Economic Geology*.

Bussey, S.D., Kakarieka, A., Friedman, R.M., Stein, H.J., Gabites, J.E. (author revisions) Timing of magmatism and skarn mineralization at the Limon, Guajes and Media Luna Au-Ag-(Cu) skarn deposits at Morelos, Guerrero State, Mexico: for *Economic Geology*.

DiMarzio, J., Georgiev, S.V., Stein, H.J., and Hannah, J.L. (submitted) Residency of rhenium and osmium in a heavy crude oil: *Geochimica et Cosmochimica Acta*.

Lu, X. Kendall, B., Stein, H.J., and Hannah, J.L. (in revision) Temporal record of osmium concentrations and isotopic compositions in organic-rich mudrocks: Implications for evolution of the seawater Os reservoir: *Geochimica et Cosmochimica Acta, special issue*.

Hollanda, M.H., Souza Neto, J.A., Archanio, C., Stein, H., and Sartorato, A. (accepted) Age of granitic magmatism and W-Mo mineralization in skarns of the Serido Belt (NE Brazil) based on zircon U-Pb (SHRIMP) and molybdenite Re-Os ages: *Journal of South American Earth Sciences*.

- Lu, X. Kendall, B., Stein, H.J. Li, C., Hannah, J.L., Gordon, G.W., and Ebbestad, J.O. (in press) Marine redox conditions during deposition of Late Ordovician and Early Silurian organic-rich mudrocks in the Siljan ring district, central Sweden: *Chemical Geology*.
- Mohammaddoost, H., Ghaderi, M., Kumar, T.V., Hassanzadeh, J., Alirezaei, S., Stein, H.J., Babu, E.V. (2017) Zircon U-Pb and molybdenite Re-Os geochronology, with S isotopic composition of sulfides from the Chah-Firouzeh porphyry Cu deposit, Kerman Cenozoic arc, SE Iran: *Ore Geology Reviews*, v. 88, p. 384-399. (<https://doi.org/10.1016/j.oregeorev.2017.05.023>)
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- Georgiev, S.V., Stein, H.J., Hannah, J.L., Xu, G., Bingen, B., and Weiss, H.M. (2017) Timing, duration, and causes for Late Jurassic-Early Cretaceous anoxia in the Barents Sea: *Earth and Planetary Science Letters*, v. 461, p. 151-162. (<https://doi.org/10.1016/j.epsl.2016.12.035>)
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