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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). Since 1995, AIRIE has produced state-of-the-art Re-Os geochronology and Os isotopic tracer studies, framed by geologic observation at all scales. Two multi-collector Triton mass spectrometers built for Re-Os analytical work and two wet-chemistry labs belong to the Program. Collaborating partners span 85 countries and discoveries benefit a large cross-section of the geosciences, from atmosphere to deep earth. We address fundamental scientific questions and use analytical results to advance fundamental science and enhance discovery in the petroleum and mineral industries. The AIRIE Program is a designated research unit benefitting Colorado State University, and reporting to the CSU Vice President of Research. All salaries and the Program's operation rely on external grants and contracts; that is, CSU and Geosciences provide no financial support. The AIRIE Program has forged a long-term partnership with research entities in Norway, making Norwegian economic interests the geologic base for fundamental scientific discoveries, for example, Re-Os dating of molybdenite and other sulfides, dating of oils and bitumens, and most recently, reconstruction of whole petroleum systems in absolute time. Our scientific publications and contributions are tallied under the Department of Geosciences' website, and have constituted 30-35% of the Department's yearly research output.

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 and sometimes challenges long-standing models for ore formation. AIRIE established the protocols for successful Re-Os ID-TIMS dating of molybdenite. We discovered the unique phenomenon of parent-daughter (^{187}Re-^{187}Os) decoupling in molybdenite prompting new approaches for acquiring mineral separates. We were the first to develop 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 (NIST, RM #8599) from the Henderson molybdenum mine (mill) in Colorado. We work with other sulfide and oxide minerals such as pyrite, marcasite, arsenopyrite, chalcopyrite, pyrrhotite and magnetite to provide age(s) and fluid source information.**

Hydrocarbons **– Our work with hydrocarbons includes direct dating of organic material in source rocks, and dating *in situ* and migrated bitumen and oil. In 2016, we published the first Re-Os isochron for a single crude oil. We work with the hydrogenous component in black shales, and asphaltene and maltene components in oils. 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, and determines 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 radiometric age for the rise of atmospheric oxygen (*Nature* 2004, 1158 citations; EPSL 2004, 206 citations).**

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AIRIE PROGRAM, COLORADO STATE UNIVERSITY: RE-OS PUBLICATIONS

Holly Stein (Founding Director, Senior Research Scientist and Professor)
Judith Hannah (Professor)
Aaron Zimmerman (Lab Manager and Research Associate)
Svetoslav Georgiev (Research Scientist)
Gang Yang (Research Associate)
Vineet Goswami and Nicole Hurtig (Post-Docs)
Juni Park (Ph.D. Student)

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Refereed Journal Papers:

Goswami, V., Hannah, J.L., Stein, H.J., Ahlberg, P., Maletz, J., Lundberg, F. (in co-author review) Geochemistry and Re-Os geochronology of Tøyen and Alum shales from Sweden: for *Palaeogeography, Palaeoclimatology, Palaeoecology*.

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*.

Georgiev, S.V., Stein, H.J., Yang, G., Hannah, J.L., Böttcher, M.E., Grice, K., Holman, A.I., Simonsen, S., Cloquet, C., and Turgeon, S. (in review) Environmental changes at the Permian-Triassic boundary in the light of multi-isotope (Re-Os-N-Hg) data and trace metal distribution from the Hovea-3 section, western Australia: *Gondwana Research*.

Pollard, P.J., Jongens, R., Stein, H.J., Fanning, M., and Smillie, R. (submitted, in review) Rapid formation of porphyry and skarn copper-gold mineralization in a post-subduction environment: Re-Os and U-Pb geochronology of the Ok Tedi mine, Papua New Guinea: *Economic Geology*.

Hall, W.S., Stein, H.J., Kylander-Clark, A.R.C., Knight, C., Enders, M.S., and Hitzman, M.W. (accepted, with revisions) Re-Os sulfide and U-Th-Pb xenotime geochronology of sedimentary rock-hosted Cu-Ag deposits, Kalahari Copperbelt, Botswana: *Economic Geology*.

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