Oil, meteorites and metals

Dr Holly Stein discusses her work in the nascent field of Re-Os geochemistry, outlining her current affiliations and highlighting what inspires her most about this area of geochemistry

The AIRIE Program is a recipient of a US National Science Foundation (NSF)-funded multi-collector Triton mass spectrometer, and in 2013 a second Triton was funded by industry. How is this equipment utilised by the Program?

The mass spectrometers are used to determine the concentrations of parent rhenium (Re) and daughter osmium (Os) isotopes. Before mass spectrometry begins, we chemically isolate Re and Os. One of our laboratories is dedicated to the mineral molybdenite, the only sulphide that naturally concentrates Re. Molybdenite is the silver bullet in Re-Os dating, and the AIRIE Program developed this technology. Once in the mass spectrometer, Re (or Os) is separated into its different isotopes by passing a stream of ions carrying these elements through a strong magnetic field. The lighter masses are deflected more easily. At the end of what we call the flight tube, ion counters or counting cups electronically tally the number of ions of each mass of parent Re and daughter Os. With these data, we can calculate the age.

What do you most enjoy about this line of investigation?

After the geochemistry, the most enjoyable aspect is compiling and merging the geologic record with geochemical evidence to decipher the past. As similar stories emerge from different studies on different continents, geologists connect the dots to infer past global events (eg. events of global anoxia make good source rocks for oils). Our job is not complete until the evidence is interpreted. Anyone can compile data, but imagination is required to interpret and diagnose.

How does the AIRIE Program remain relevant and competitive?

Obtaining funds from national science foundations is increasingly difficult, partly because less is invested in them. Research doesn't happen over a long weekend in the laboratory. Scientific breakthroughs are preceded by years, even decades, of investment and effort. Our most pressing issues in science are global and they cross political boundaries. The geologic record shows us that climate crises are part of the inhale-exhale of Earth, but humans play an exacerbating role. To remain relevant and competitive, we view science from two sides – the fundamental and the applied. We tackle the important scientific questions of today, at the same time benefiting industry sponsors driving the world's economy.

Are you working to encourage more women to join the Program?

I hire the best applicants, and it just so happens that currently I have six men. However, I recently put in a bid for new graduate students, and the top three are women – best of all, their backgrounds are in physics and organic geochemistry. Students who bring skills from other scientific disciplines to geology are in demand, and strengthen the Program. Women can excel, and I can help inspire them to succeed.

Could you explain your affiliation with Norway?

Norway is a major, stable producer of oil. The Director of the Geological Survey of Norway, Dr Arne Bjørlykke, helped shape my career by inviting me to visit in 2000 with my US Fulbright Research Fellowship. Five years later, he asked me to work on dating source rocks for oil, which at the time I had no knowledge of – I'm an ore geologist by training.

Now I hold a professorship at a brand new Centre for Earth Evolution and Dynamics (CEED), a Centre of Excellence at the University of Oslo in Norway where I spend around half of my time. The scientists here work on everything from the Earth's interior to climate crises to the impact history on Mars. It's a wonderfully interdisciplinary environment – the way science should work.

Looking ahead, do you intend to automate your scientific approach?

Re-Os geochemistry is still a new field. In geology, our greatest challenge is that we work with wildly inhomogeneous media and unpredictable processes. When we obtain a drill core of black shale, we can image it with a CT scan. The heterogeneity is astounding. What appears to be the most homogeneous and monotonous black shale is in fact a world of miniature sedimentary layers, invisible pyrite, tracks and burrows of long extinct sediment-dwellers, and an infinite number of micro-fossils that settled from the water above into bottom muds of long ago. Every minute irregularity is exposed and immortalised and any thoughts of mathematical symmetry on Earth are put to rest.

The dating game

A self-made team of researchers working collectively under the auspice of the **AIRIE Program** has been advancing a new method of radiometric dating for the last 20 years. Now, it is among the most useful tools in geochemistry

THE EARTH'S SURFACE is the domain of prospectors and treasure hunters engaged in an increasingly difficult search for the underground resources that drive human life at the surface – metals and hydrocarbons. Utilising the latest technology, modern-day geology benefits from radiometric dating methods that allow scientists to more precisely locate, date and explore the formation and evolution of these resources.

One of the most exciting tools to arise in this field over the last few decades has been rhenium-osmium (Re-Os) chronometry. First developed by Dr John Morgan formerly at the US Geological Survey (USGS) in Reston, Virginia, Re-Os dating was initially used to investigate meteorites, drawing conclusions about the early Solar System. Like any other radiometric clock, this system is based on an isotope parent-daughter pair, in this case ^{187}Re and ^{187}Os with a known half-life: 41.6 billion years. By measuring the isotopic ratios for Re and Os, it is possible to establish an isochron that will give the sample's age.

NO FUNDING? NO PROBLEM

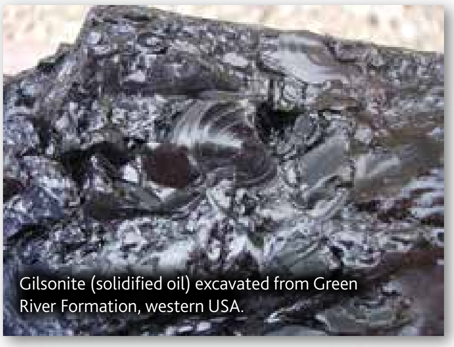
This system worked very well for Morgan and his meteorites, but it was his protégé Dr Holly Stein who thought to apply it to the complex mixture that is the Earth's crust. Re and Os were ideal candidates for understanding Earth's resources; both elements are found in high concentrations in hydrocarbon deposits such as oil and tar, and Re is chalcophilic, or sulphur-loving, which makes it perfect for dating sulphide ores of metals such as copper, molybdenum and gold. If the Re-Os dating method could be applied, then the implications for resource exploration might be huge. Stein soon succeeded in demonstrating this was indeed possible, but shortly after her promising start, the USGS made sweeping cutbacks and ceased to support her work.

In collaboration with friend and colleague Dr Judith Hannah, Stein was able to secure lab space at Colorado State University (CSU). Although the institution was unable to provide any funding, Stein and her team remained steadfast and quickly established the AIRIE Program to allow work in the field of Re-Os dating to continue. Today, almost 20 years later, the AIRIE Program is maintained with substantial grants and gifts; the small group involved, described by Stein as 'insanely dedicated', has established Re-Os as a crucial part of geoscience, and a tool that is much sought after by other researchers and industry.

IN BUSINESS

Because Re-Os analysis is such a potent tool, the AIRIE Program has led Stein and her colleagues to collaborate with hundreds of academic and industry scientists from more than 80 countries around the world. This approach has meant they can continue to refine Re-Os methods while simultaneously employing the tools in real-world settings. For metallic ores, the Program was the first to date gold deposits using pyrite and arsenic-rich arsenopyrite. For hydrocarbons, the researchers have collaborated with several petroleum companies in order to precisely date major oil source rocks in Sicily, Italy, characterising and mapping the expulsion of oil and the formation of bitumen veins in absolute time.

The work conducted in Sicily is a strong example of how the AIRIE scientists were able to win the confidence of industry, and secure future funding in the process. Unbeknown to Stein, the petroleum prospectors in this case already held some evidence for the results her group obtained. To some extent, this project was an opportunity for the fuel companies to test an unproven technology, and Re-Os passed with flying colours, securing industry partners still working with the AIRIE Program



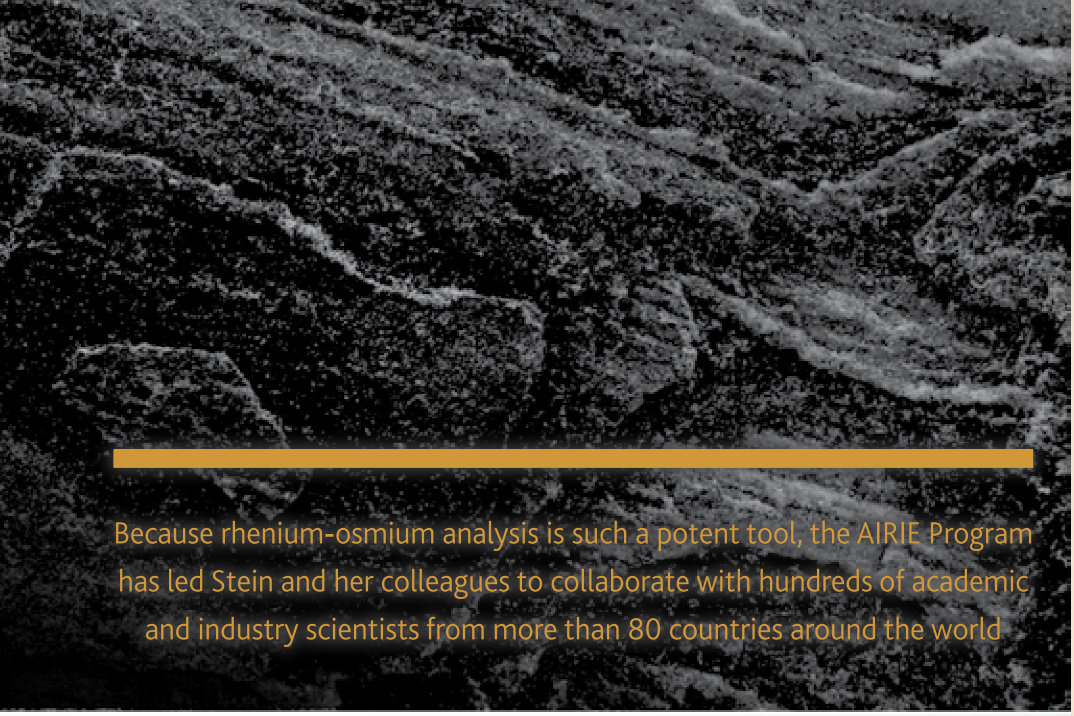
Gilsonite (solidified oil) excavated from Green River Formation, western USA.

today. Collaborating with industry is a win-win situation for Stein: "Fewer drill holes puncturing the Earth's crust saves money and the environment, and industry is challenged by our unconventional ideas", she asserts.

DISCOVERY AND DIVERSITY

The Program has also provided invaluable assistance for other research scientists across the world, and in many fields of study. Using this brand of geochemistry has helped provide a deeper insight into palaeontology, climatology, oceanography and all forms of geology, as well as being an attractive tool for any scientist conducting research related to these fields. As Stein underlines: "The spin-offs from our original developmental research keep coming".

Over the last five years, the AIRIE Program has delved into palaeoclimate change through the examination of mass extinctions, and documented metal toxicity in the marine and terrestrial environments preserved in the geological record. It has also focused on the palaeogeography of ancient tectonic plates, such as those surrounding the Central Indian Tectonic Zone (CITZ), aiding in the reconstruction of ancient colliding land masses and giving insight into the locations of lost continents and oceans. By placing absolute time pins into the geological record,



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they can make detailed correlations of Earth events between hemispheres in the deep past. Working closely with biostratigraphers – scientists who use the appearance and disappearance of a species in the fossil record as an indicator of geological time – the Program is striving to determine whether species are actually diachronous, living at different times in different hemispheres, and therefore not as sound a bio-chronometer as had previously been thought.

The last two years have also brought on acceleration of research into hydrocarbon migration, with Stein and her team identifying how oil is formed and what causes it to move from its source to a reservoir rock. In addition, the mobility of metal in the Earth's crust has continued to be an important topic, with the ultimate goal being to understand how metals coalesce into ore deposits. As global demand for these resources increases, it is these findings that will influence exploration models, and help mitigate environmental impact.

REPLICATING RESEARCH

As a world leader in Re-Os methods, the AIRIE Program takes a proactive role in helping other labs to utilise this technology. Having been established as one of the most important geochemical tools, Re-Os is quickly becoming the new gold standard in geochronometry and has recently become the pursuit of three new labs setting up in Europe. AIRIE is sharing its expertise by producing reference materials for these new labs, helping them to calibrate their results against the Program's own findings.

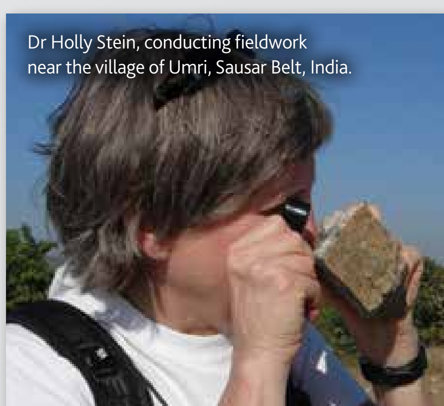
And the AIRIE Program is not only in demand for its unique technical expertise. Increasingly, Stein's lab is being approached by other researchers and industry groups eager to find out more about how they succeed through collaboration, and the methods they use to bring science to concrete applications.

An example of molybdenite (metallic gray-blue) from the Sørumsåsen mine, Oslo Rift, Norway.

PAST, PRESENT, FUTURE

The story of the AIRIE Program's overwhelming success may be among the most inspirational of any team in research today. When it comes to working with minimal resources the team is a prime example of what can be achieved, as Stein affirms: "I have proven that you can make it – and I want women in particular to take this message home".

The story of Re-Os isotope geochemistry, however, is only just beginning; from geology to biology, from health to climate, this is a method that may help scientists answer questions in all fields – elucidating the most distant past, but also the immediate future of Earth.



Dr Holly Stein, conducting fieldwork near the village of Umri, Sausar Belt, India.

INTELLIGENCE

AIRIE PROGRAM

OBJECTIVES

- To produce state-of-the-art analytical work in Re-Os (rhenium-osmium) geochronology and tracer studies to answer important questions in geoscience
- To develop projects with the mineral and petroleum industries to create 'science you can use' to advance understanding of resource formation and simultaneously address the big questions in geoscience
- To keep geochemical work grounded in geologic truth derived from field studies

KEY COLLABORATORS

Dr Judith L Hannah, Professor, Department of Geosciences, Colorado State University

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HOLLY STEIN is an expert in Re-Os isotope geochemistry in ore and hydrocarbon systems, and Director and founder of the AIRIE Program. She is a Senior Research Scientist and Professor in the Department of Geosciences at Colorado State University. She holds dual appointments in Norway, first starting in 2000 with the Geological Survey in Trondheim, and second in 2012 with the University of Oslo. She is currently a member of a new centre of excellence, the Centre for Earth Evolution and Dynamics (CEED) at the University of Oslo. Stein's current projects span the interests of the petroleum and mineral industry from the Arctic to Australia. This combination gives the AIRIE Program an unprecedented advantage in holistically understanding fluids in the crust that lead to ore deposits; are associated with maturation and migration of hydrocarbon; or reside in magmas and sediments from the land surface to beneath the oceans.

AIRIE APPLIED ISOTOPE RESEARCH

CEED

Colorado State University

UiO : Universitetet i Oslo