A Deeper Investment for Deep Time Science

Seven proposals recently funded by the National Science Foundation will ensure more access to laboratories that specialize in geochronology.

Geochronology is about telling time and deciphering Earth's history preserved in the minerals that make up rock and sediment. Laboratories now supported by the U.S. National Science Foundation can date billion-year-old rocks, decipher glaciers' histories, trace sediment across the landscape, and explain how mountains change over time. Credit: P. Bierman, University of Vermont

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Measuring deep time, the science of geochronology, is central to modern Earth science. Not only does geochronology determine geologic histories, it quantifies rates of processes [*Reiners et al.*, 2018]. Examples include understanding Earth's magnetic field, the nature of volcanic and earthquake hazards, the uplift of mountains and their erosion, the explosion of multicellular life in the Cambrian and its several major extinctions, the rise of atmospheric oxygen, and carbon cycling through time. These efforts require precise and accurate geochronology applied to a variety of Earth materials, including rock, minerals, soil, gas, ice, water, and plants. Such work is being done in hundreds of laboratories in the United States, many of which have inconsistent funding for operations and technical support.

Recent reports, based on broad community input, have stressed the need for better and more access to as well as funding for facilities that produce geochronologic data [e.g., *National Research Council*, 2012; *Harrison et al.*, 2015]. These reports emphasized building collaborative geochronology research networks between nonspecialists and geochronologists and covering related analytical costs, including infrastructure maintenance and technician salaries. There have been prior attempts to increase capacity and access to laboratories. For example, the EarthScope Awards for Geochronology Student Research (AGeS) program gives graduate students access to geochronology laboratories and analytical expertise.

Catalyzed by the Harrison et al. and National Research Council reports, federal advisory committees to the U.S. National Science Foundation (NSF) recognized the need for more and better geochronology. NSF responded with solicitation 17-504, focused exclusively in 2017 on technical support for geochronology. The intent was to provide for optimal and efficient operation of advanced instrumentation, analytical protocol development, and user training for Earth sciences research instrumentation in laboratories that were already well equipped but had underutilized capacity owing to a lack of specialized technical personnel. Such personnel are integral to building diverse, collaborative research networks and communities.

Where to Find the Newly Supported Geochronology Laboratories

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In response to the 2017 call, seven proposals were funded, and these laboratories now have technician support enabling better engagement of the broader community (Figure 1). In 2018 and 2019, NSF is soliciting proposals for technician support from *experimental geophysics* and *high-performance computing* laboratories. These stable 5-year funding commitments for geochronology are an important first step toward addressing the community's need for a diverse and inclusive portfolio of resources that helps it meet the increasing demand for time constraints in the geosciences. Such investments in geochronology infrastructure are timely, given the growing community interest reflected by the establishment in 2018 of a Geochronology Division within the Geological Society of America and a geochronology-themed series of Gordon conferences in 2019. Below, we briefly describe the geochronology capabilities supported by NSF under solicitation 17-504.

The Oregon State University Argon Geochronology Laboratory (http://geochronology.coas.oregonstate.edu) has employed argon dating methods since 1969 and now includes two ARGUS VI multicollector mass spectrometers with high precision, accuracy, and throughput. NSF support enables the lab to expand on its tradition as a community facility, improving knowledge of the geodynamic Earth. The laboratory performs dating of late Pleistocene and Holocene sanidine and volcanic samples as young as a few thousand years, studies magnetic reversals and excursions in terrestrial lava flows, analyzes low-potassium basalts, explores new techniques for dating ultralow-potassium clinopyroxene, and studies volcanic centers to improve understanding of eruptive histories and geohazards.

For 25 years, the University of Vermont has hosted a facility (http://uvm.edu/cosmolab) for cosmogenic nuclide sample preparation. Cosmogenic nuclides (such as beryllium-10 and aluminum-26) provide a quantitative means for investigating Earth surface history and processes. Measuring nuclide concentrations in rocks requires pretreatment to purify quartz and then acid dissolution and purification prior to accelerator mass spectrometry. In the laboratory clean room, purpose-built in 2008, there are five perchloric acid laminar flow hoods, allowing simultaneous processing of meteoric and in situ samples, and a separate laboratory dedicated to the rapid, simultaneous purification of quartz from many samples. With NSF support, the Vermont laboratory is now a community facility, dedicated to training students, faculty, and researchers in cosmogenic nuclide extraction techniques, including all phases of sample preparation, in a safe, collaborative environment.

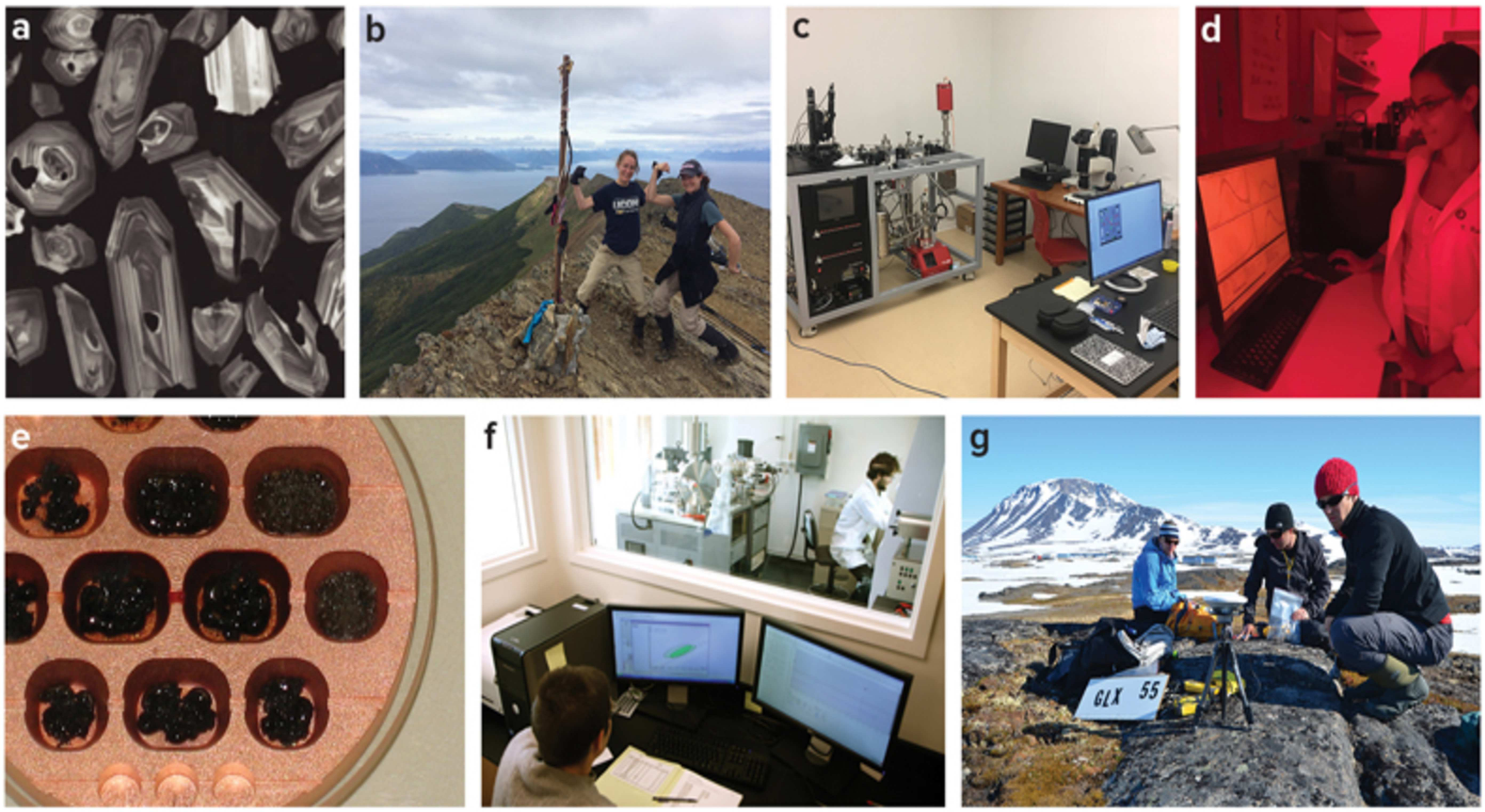

Fig. 1. Examples of geochronology now funded by the NSF. (a) Zircon cathodoluminescence; zircon crystals are luminescent under electron beam bombardment, revealing internal growth patterns invisible to the naked eye (Boise State University Isotope Geology Laboratory). (b) Sample collection in the Andes Mountains with the University of Connecticut Basin Analysis and Helium Thermochronology Laboratory. (c) State-of-the-art Santa Cruz Laser Microfurnace noble gas extraction and measurement line, optimized for measuring subpicomole levels of He at the Illinois lab. (d) Collection of luminescence data under red safelight at the Desert Research Institute luminescence lab. (e) Typical loaded sample tray after analyses and incremental heating of the samples until total fusion, which melts the geological materials into small glass beads (Oregon State University Argon Geochronology Laboratory). (f) Mass spectrometer and data reduction at the

Princeton geochronology laboratory. (g) Sample collection for dating postglacial rebound, east Greenland, part of the Vermont lab's field program.

The Desert Research Institute Luminescence Laboratory (https://www.dri.edu/luminescence-lab), founded in 1994, focuses on applications and technique development in luminescence dating. Typically used to define the burial age of silicate minerals in sediments and rocks ranging in age from decades to ~500 kiloyears, luminescence dating has a broad range of applications, including geomorphological and archaeological studies. The Desert Research Institute lab is equipped to perform preparation and analyses of quartz and feldspar, including measurement of the dose rate. NSF funding supports the lab's mission to serve those in need of luminescence dating, train the next generation of luminescence users and practitioners, and become a centralized learning and user facility for both routine and leading-edge techniques in luminescence dating.

The Princeton geochronology lab (http://www.princeton.edu/geosciences/people/schoene/Radiogenic-Isotopes-Lab/) focuses on high-precision uranium-lead (U-Pb) geochronology using thermal ionization mass spectrometry. Such geochronology relies on the decay of two parent isotopes of U and one of thorium (Th) through three independent decay chains, all of which result in different isotopes of Pb. The complementary geochemistry and half-lives of these different elements permit geochronology of a range of materials from the oldest meteorites in the solar system to single volcanic minerals as young as a few hundred thousand years. Recent projects include measuring young volcanic rocks to calibrate the geologic timescale in sedimentary successions, developing zircon dating methods that reveal how subvolcanic magmatic systems change over time, dating flood basalt volcanism associated with mass extinction events, and dating zircons from the moon.

The Boise State University Isotope Geology Laboratory (https://earth.boisestate.edu/isotope/) broadens access to modern high-resolution U-Pb zircon age analyses and provides personalized education and training to nonspecialists in the acquisition and interpretation of complex geochronometric data. Using laser ablation inductively coupled plasma–mass spectrometry to rapidly collect geochemical and geochronological data from cathodoluminescence-imaged zircons, those results are used to identify and target the crystal domains most effective for high-precision age analysis by chemical abrasion–isotope dilution–thermal ionization mass spectrometry. This tandem approach is well suited to challenging geological problems, including high-precision dating of volcanic ash beds, lending petrological context to zircon ages, and producing accurate maximum depositional ages from the youngest detrital zircon crystals.

The Helium Analysis Laboratory (http://publish.illinois.edu/wrg/u-thhe-dating-lab/) at the University of Illinois at Urbana-Champaign offers visitors and users access to all aspects of the (U-Th)/helium (He) dating process, including (1) grain selection and preparation, (2) aliquot degassing and ^{4}He measurement, and (3) grain dissolution and U, Th, and samarium concentration measurement. Thermochronology quantifies the thermal evolution of rocks through time. Low-temperature thermochronology using the (U-Th)/He method is a key tool for constraining dates and rates of uplift and erosion in mountain belts, plateaus, and cratons. Research in the lab is focused on both expanding the range of (U-Th)/He applications (e.g., Proterozoic thermal histories of cratons and orogens) and advancing method fundamentals through laboratory-based investigations (e.g., understanding He diffusion kinetics). Technician support from NSF allows the Illinois lab to greatly enhance its research capabilities and meet the demands of new technique users in thermochronology.

The Basin Analysis and Helium Thermochronology Laboratory (https://thermochron.uconn.edu) at the University of Connecticut is a new (U-Th)/He facility that focuses on bedrock cooling histories and detrital thermochronology. The Connecticut lab includes a helium gas extraction and measurement line, Thermo Scientific iCAP ICPMS, and petrographic imaging and mineral dissolution facilities. Technician support from NSF promotes development of improved provenance methods across a wider suite of detrital minerals and supports visitors with interests in using low-temperature thermochronology in their research to better understand timing and rates of tectonic deformation and exhumation, landscape evolution, magmatism, and hydrothermal processes.

References

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