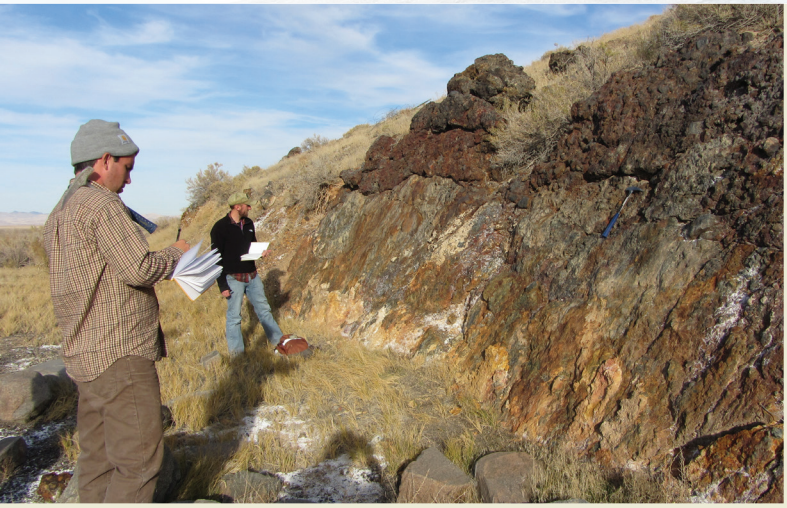
Mackay School of Earth Sciences and Engineering
College of Science
University of Nevada, Reno

Nevada Bureau of Mines and Geology

NEVADA BUREAU OF MINES AND GEOLOGY
OPEN-FILE REPORT 2020-04

Biennial Report of the Nevada Bureau of Mines and Geology

2018–2019



James E. Faulds
Director and State Geologist

PREPARED FOR
The Board of Regents of the Nevada System of Higher Education
2020

NBMG Contact Information

The Nevada Bureau of Mines and Geology (NBMG) is a research and public service unit of the University of Nevada, Reno (UNR) and is the state geological survey, applying its expertise across the entire state. NBMG is part of the Mackay School of Earth Sciences and Engineering within the College of Science at UNR.

NBMG scientists conduct research and publish reports on mineral resources, engineering geology, environmental geology, hydrogeology, geologic hazards, and geologic mapping. Individuals interested in Nevada geology are encouraged to visit, call, write NBMG, or visit our website.

http://www.nbmg.unr.edu

Most NBMG scientists (Director and research faculty) and cartographic and administrative staff are located on the **University of Nevada, Reno campus**, 775-794-6691.

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Cover photos

Background photo: Stateline Peak in the Fort Sage Mountains, Washoe County, Nev. The northern Walker Lane, in western Nevada, is a region of distributed deformation that accomodates right-lateral shear associated with the North American and Pacific plates along north-oriented normal faults and northwest-oriented strike-slip faults including the Warm Springs Valley fault. Photographer: Colin Chupik

Upper left photo: Graduate students mapping faults. Photographer: Jim Faulds

Upper right photo: Steamboat Hills, geothermal field, Washoe County, Nev. Photographer: Jack Hursh

Lower left photo: GPS antenna used by NBMG geologists to precisely measure the minute changes over time in the location of the antenna to then precisely map where deformation is building up that leads to future earthquakes. Photographer: Bill Hammond

Lower right photo: The north end of the Arrow Canyon Range, Clark County, Nev. Photographer: Jack Hursh

NEVADA BUREAU OF MINES AND GEOLOGY

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Biennial Report of the Nevada Bureau of Mines and Geology 2018–2019

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The Nevada Bureau of Mines and Geology Advisory Board with Bureau staff in front of the Great Basin Science Sample and Records Library, aka the "Gold Building" during the Advisory Board meeting on September 6, 2019. *Photographer: Jack Hursh.*

Drilling rig at the Fallon FORGE Engineered Geothermal System research site in March 2018, Churchill County, Nev. *Photographer: Bridget Ayling.*

Executive Summary

Nevada is a unique state with many opportunities and some challenges resulting from its distinctive geologic, geographic, economic, and demographic heritages. It is richly endowed in natural resources but is also prone to earthquakes, floods, and other natural hazards. The Nevada Bureau of Mines and Geology (NBMG) is the state geological survey of Nevada and is tasked with analyzing and characterizing these resources and hazards for the benefit of Nevada's citizens.

As defined by state statutes (NRS-514), NBMG serves as the state's official locus of data, analysis, and exchange on Nevada's geology, natural resources, and geologic hazards. We disseminate this information to local, state, and federal agencies, major industries, engineers, educators, and to the general public. Our primary mission is to provide geologic information to enhance the safety of Nevada's citizens and to facilitate environmentally sound and sustainable economic development of Nevada's mineral and energy resources, applying geologic research for the public good throughout the state. We are a statewide public service unit that resides in the Mackay School of Earth Sciences and Engineering in the College of Science at the University of Nevada, Reno (UNR). Since its inception in 1929, NBMG has produced geologic maps for much of the state and catalogued more than 320,000 geologic specimens and reports. This report summarizes NBMG activities, programs, and accomplishments for 2018 and 2019.

To fulfill its mandate, NBMG employs about 30 individuals, including geoscientists, GIS (geographic information systems) and cartographic professionals, technicians, and staff. NBMG conducts research and publishes reports on mineral, geothermal, and oil and gas resources, engineering geology, geologic hazards, hydrogeology, geologic mapping, and Nevada's overall geologic framework. NBMG cooperates with numerous state and federal agencies in conducting this research and in providing geologic and resource information. Research results are published as NBMG bulletins, reports, maps, and special publications, as well as in federal publications and scientific journals. In the 2018–2019 period, NBMG produced dozens of publications on Nevada's geology, natural resources, and geologic hazards, including 11 NBMG geologic maps, 20 NBMG reports and other publications, and more than 90 papers in nationally and internationally recognized scientific journals. Geologic research conducted by NBMG has benefited many industries in Nevada (e.g., the mining, mineral, and geothermal industries) and enabled the state to become leading producers of gold and geothermal power (see charts below). Geologic information managed by NBMG also helps government officials make informed decisions on the use of Nevada's lands.

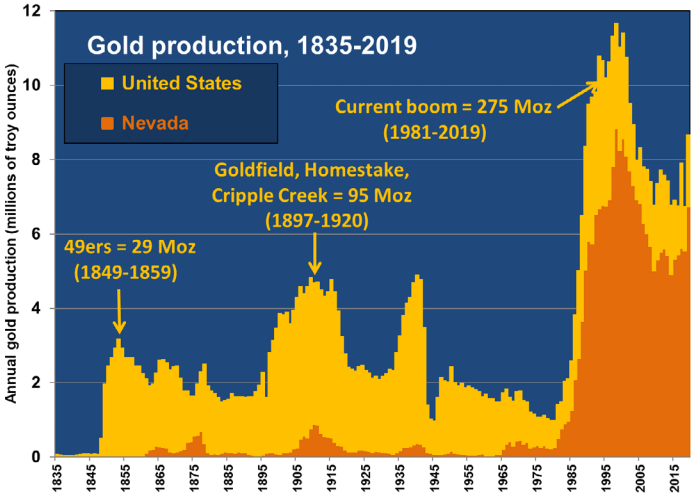
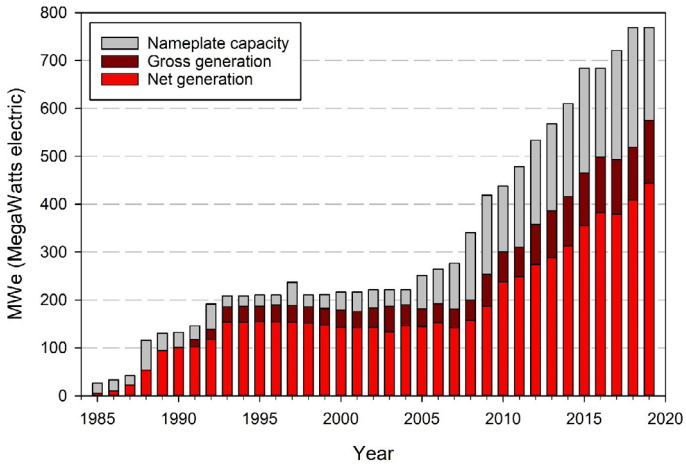


Chart comparing U.S. and Nevada gold production from 1835 to 2019.



Cumulative nameplate generating capacity and net geothermal power production in Nevada from 1985–2019, as reported to the Nevada Division of Minerals. Net generation is calculated by dividing annual net generation in megawatt-hours by the number of hours in a year. MWe, megawatts electricity.

To preserve and provide public access to this information, NBMG manages and operates the Great Basin Science Sample and Records Library (GBSSRL, photo to the right), whose staff catalogues and archives geologic reports, rock and mineral samples (including cuttings and core from geothermal and oil-gas wells), mining district files, aerial photographs, and geologic and topographic maps. About half of the NBMG staff are supported by State funding, with the other half supported by external grants. NBMG has been very successful in acquiring external grants and expended ~$5.43M in external funds on statewide projects in fiscal years 2018 and 2019. State funding during this period totaled ~$2.74M.

Continued rapid population growth in Nevada has resulted in increasing needs for mineral, energy, and groundwater resources, land-use and infrastructure planning, and assessments of geologic hazards. NBMG's major programs are geared toward applying cutting-edge technology to satisfy these needs. NBMG's major activities are briefly described below and reviewed in greater detail in subsequent chapters.

View of Las Vegas, which is the largest city in Nevada with over two million in the metropolitan area.

View of the Reno-Sparks metropolitan area, which has a population of more than 500,000.

Great Basin Science Sample and Records Library (GBSSRL), managed and operated by NBMG. It is the repository for geologic information for Nevada. *Photographer: Charlotte Stock.*

Geologic Mapping: Geologic maps show the distribution of different rock units as well as faults and folds that deform those units (see Geologic Mapping, page 6). These maps provide the foundation for analyzing mineral and energy resources and geologic hazards. For example, geologic maps in urban settings help planners consider geologic hazards, such as earthquakes. expansive soils, and floods, as they plan and design infrastructure and development. Studies show that geologic maps save developers and engineers about $50,000 for every construction project. Many different companies utilize the same map, which greatly multiplies the cost savings and value of any particular map. As shown in a recent cost-benefit analysis, every dollar allocated to NBMG for geologic mapping returns >50 times that amount in benefits to the state. Since its inception, NBMG has produced many hundreds of geologic maps, but due to the size of Nevada (7th largest state) and its geologic complexity, nearly 70% of Nevada still lacks adequate, modern geologic maps.

Mineral Resources: Nevada produces more gold than any other state. Nevada consistently ranks in the top 5 gold producers worldwide. It also produces large amounts of many other minerals, including copper, silver, and lithium and has led the nation in non-fuel mineral production for the past five years. Lithium is critical for the rapidly growing electrical automotive and energy storage industries. Nevada has the only operating lithium mine in the country. NBMG scientists have been instrumental in understanding the processes that control the formation and location of these mineral resources (e.g., Carlin-style gold deposits; see Mineral Resources and Economic Geology, page 10). NBMG also produces annual reports describing mining activities and mineral production in the state.

Geothermal Resources: Nevada has more geothermal resources than any other state and is currently second in the nation in the production of geothermal electricity. Geothermal energy is a clean source of renewable energy with a minimal carbon footprint and ability to operate 24/7. All studies indicate that Nevada has enormous untapped potential for producing much greater amounts of geothermal energy. NBMG scientists are developing new methodologies for geothermal exploration (see Geothermal, page 14), which have 1) led to the discovery of blind geothermal systems hidden beneath the surface (with no surface hot springs or steam vents), 2) reduced the risks of geothermal drilling, and 3) facilitated development of new geothermal power plants.

Geologic Hazards: Nevada's tectonic setting has generated its stunning and rugged landscapes of alternating lofty mountains and impressive valleys. Nevada is the most mountainous of the 48 contiguous states. Many of the mountain ranges are bounded by active fault zones, making Nevada the third most seismically active state in the country, with a number of large magnitude earthquakes shaking the state in the recent past. The high topographic relief also makes the region vulnerable to landslides and floods. NBMG scientists conduct analyses to better understand the locations of faults and landslide deposits, how often large earthquakes occur along individual faults (including a major ongoing study in Las Vegas Valley and several studies of major faults near Reno), extent and age of flood plains along major streams and rivers, and distribution of debris flow deposits resulting from flash floods (see Geologic Hazards, page 21). NBMG also develops guidelines to mitigate damage and educates the public about possible damage and injury from these natural hazards.

Tectonic Setting: Nevada owes its unique setting to its location within the Pacific–North American plate boundary, where tectonic stresses drive crustal blocks to slide past one another along major faults (akin and related to the San Andreas Fault in California) and also to extend or stretch in the horizontal dimension. These motions make Nevada literally the fastest-growing state in the country, as the stretching adds new land at the rate of several acres every decade. Through the Nevada Geodetic Laboratory (see Nevada Geodetic Laboratory, page 27), NBMG is documenting and tracking these crustal motions to better understand the implications for earthquake risks, as well as the subtle but measurable effects of groundwater withdrawal and climate change on these crustal motions.

Cartography & GIS: As the publishing house for the Bureau, the Cartography and GIS team assists and supports all NBMG programs, and external organizations as well, with publications, maps, and web applications disseminated to the public and stakeholders. A total of 12 new maps, 14 reports, and 2 calendars were published in 2018–2019, as well as a major update to one publication in 2019 (see Cartography & GIS, page 31).

Data Dissemination: NBMG has a responsibility to broadly disseminate its geologic reports and maps to mitigate the effects of geologic hazards and thereby enhance public safety, promote well-planned infrastructure, and facilitate environmentally sound and sustainable development of its natural resources. Geologic and geographic information activities include: 1) creating and updating databases on mining districts, active mines and prospects, and geothermal and petroleum exploration and production; 2) implementation and development of statewide geographic information systems and the digital maps needed for these systems; and 3) maintenance of core and cuttings from wells across the state, rock and mineral collections for research, aerial photographic imagery and maps, and extensive files on Nevada geology and resources. Many of these datasets have been digitized and are disseminated through the NBMG website and Open Data portal (see Open Data, page 36; http://www.nbmg.unr.edu/; https://data-nbmg.opendata.arcgis.com/). Physical specimens and archived reports are available at the GBSSRL (see GBSSRL, page 33, http://pubs.nbmg.unr.edu/aboutus.asp).

Education and Outreach: NBMG is dedicated to education and outreach within the state (see Education and Outreach, page 37). NBMG scientists have teaching obligations and advise more than 1/3 of the graduate students in the UNR geoscience programs and participate as adjunct faculty at UNLV. NBMG scientists are particularly focused on training the next generation of geoscientists to better understand Nevada's natural resources and geologic hazards. For example, both the Center for Research in Economic Geology and the Great Basin Center for Geothermal Energy reside within NBMG. These centers are focused on analysis, education, and outreach of mineral and geothermal resources, respectively. Earth science education projects include writing guidebooks for the general public, teachers, and students; presenting lectures, short courses, and workshops; and assisting with science fairs, curriculum development, and conferences. Specific examples include publishing geologically oriented guidebooks for the general public and tourism and conducting K-12 teacher workshops in southern and northern Nevada. NBMG staff members also assist the public, industry, and government agencies by answering specific questions regarding Nevada geology, resources, and hazards.

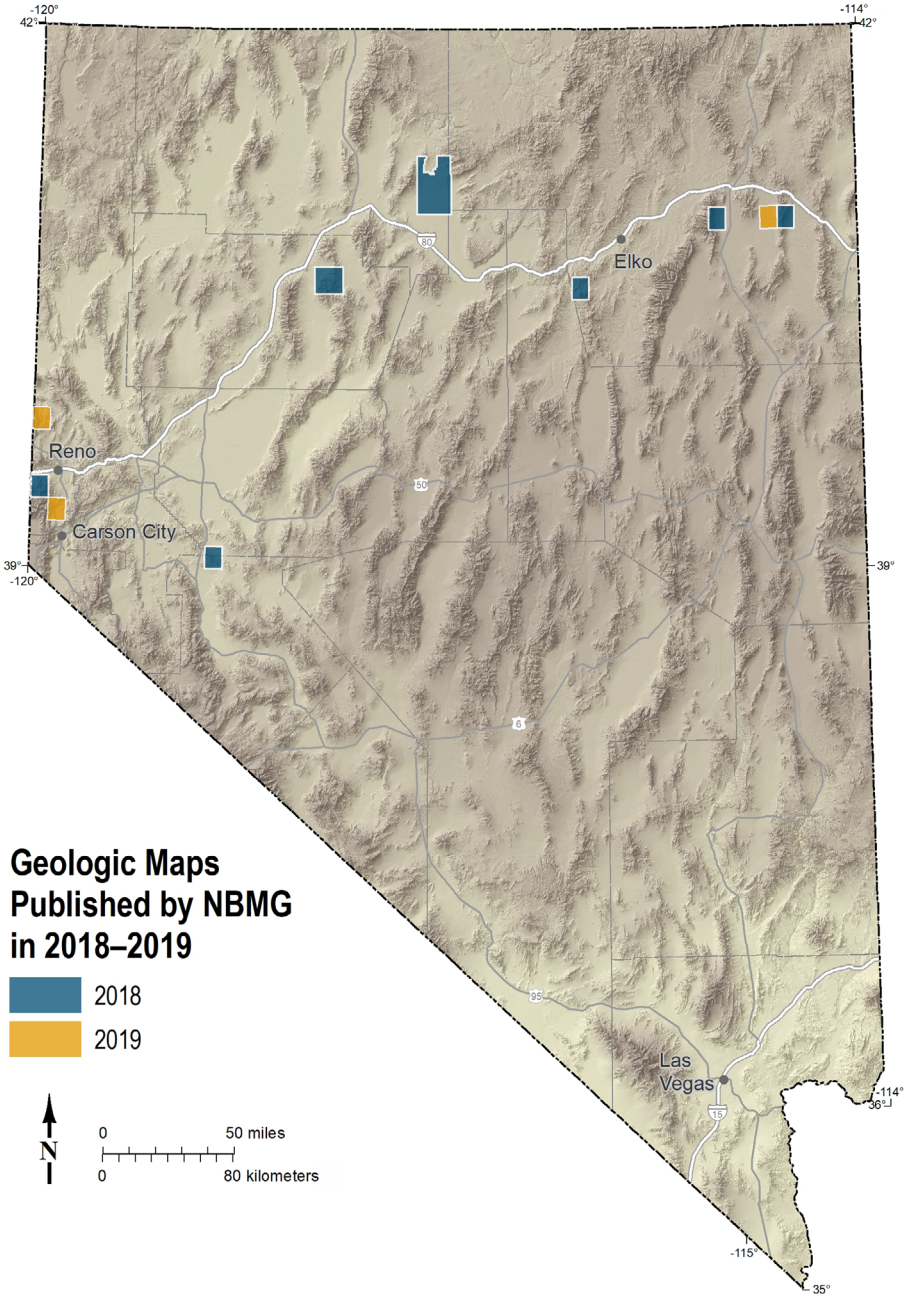
Geologic Mapping

by Seth Dee, Andrew Zuza, and Michael Darin

Geologic maps are typically two-dimensional but represent a vast amount of three-dimensional geologic information. They convey the age, composition, geometries, and/or spatial relationships of rocks, surficial unconsolidated sediments, and structures at and near the Earth's surface. This information is the foundation for addressing both applied and basic research questions in the Earth Sciences. For example, mapping by NBMG geologists is used to understand the origin and distribution of mineral deposits and energy resources around the state of Nevada and documents the geologic history of earthquakes, floods, and landslides critical for characterizing and planning for natural hazards. This same mapping can also be used to investigate academic research questions about how the Earth's crust changes through time, including the multiple tectonic events that have shaped our landscapes, magmatic processes operating in ancient volcanoes, and the evolution of North America's western plate boundary. The long-range geologic mapping plan of the NBMG has two major goals that benefit the state directly:

- To facilitate the growth of Nevada's urban centers and statewide infrastructure by providing information on geological hazards, resources, and environmental protection and,
- To assist in the environmentally responsible economic development of mineral, energy, and groundwater resources, which also facilitates economic diversification.

Current geologic mapping priorities focus on rapidly expanding urban areas, including Las Vegas and Reno– Carson City, mineral resources in northeastern Nevada, and geothermal resources throughout the state. Funding that supports the NBMG geologic mapping program is awarded annually by the U.S. Geological Survey STATEMAP program.

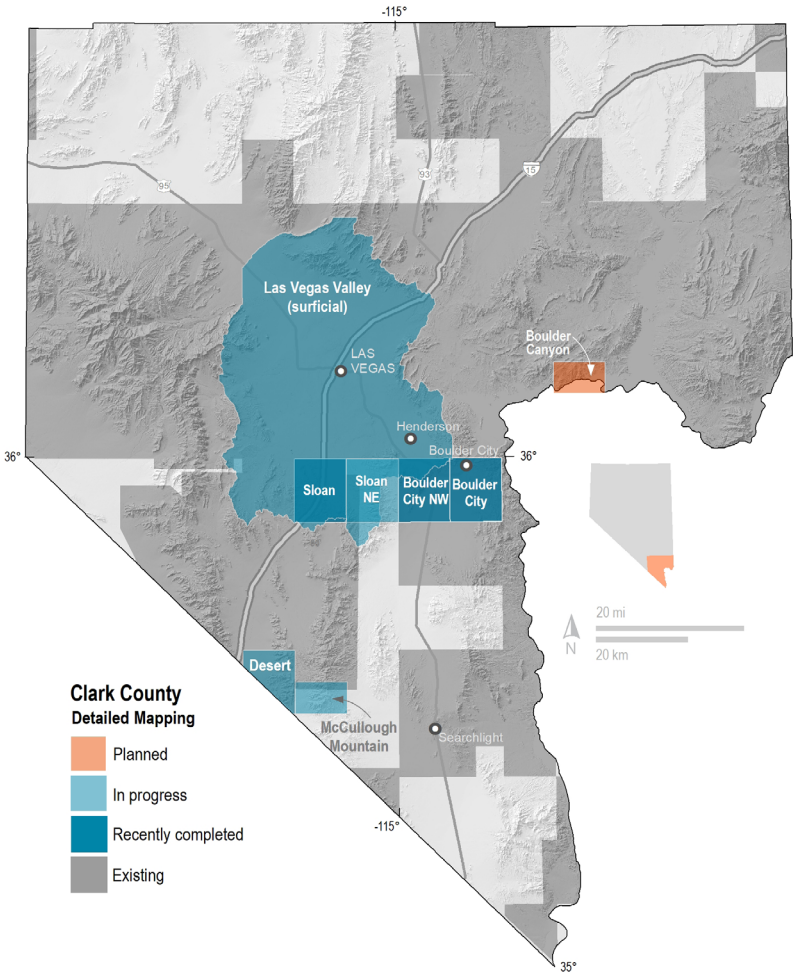


NBMG RESEARCH HIGHLIGHT

Geologic Mapping in Clark County, Nevada

Clark County is a priority focus area for the geologic mapping program at NBMG due to its large growing population, effects of that growth on natural habitats, and historically underappreciated natural hazards, such as earthquakes and floods.

Geologic mapping in southern Nevada. NBMG's detailed mapping of the different rock and soil types, documenting locations of young flood deposits, and studying active faults is essential to planning for hazards and infrastructure engineering and design. *Photographer: Seth Dee*



NBMG RESEARCH HIGHLIGHT

Geologic Framework of the Ruby Mountains–East Humboldt Range Area, Northeast Nevada

The region surrounding the Ruby Mountains–East Humboldt Range, east of Elko, is the focus of ongoing geologic mapping and research by NBMG. The goal of the project is to gain a better understanding of the geologic history of the region. These findings will help to address several fundamental research questions in the area that will contribute to the understanding of the origin and distribution of mineral deposits, as well as geothermal and hydrocarbon resources.

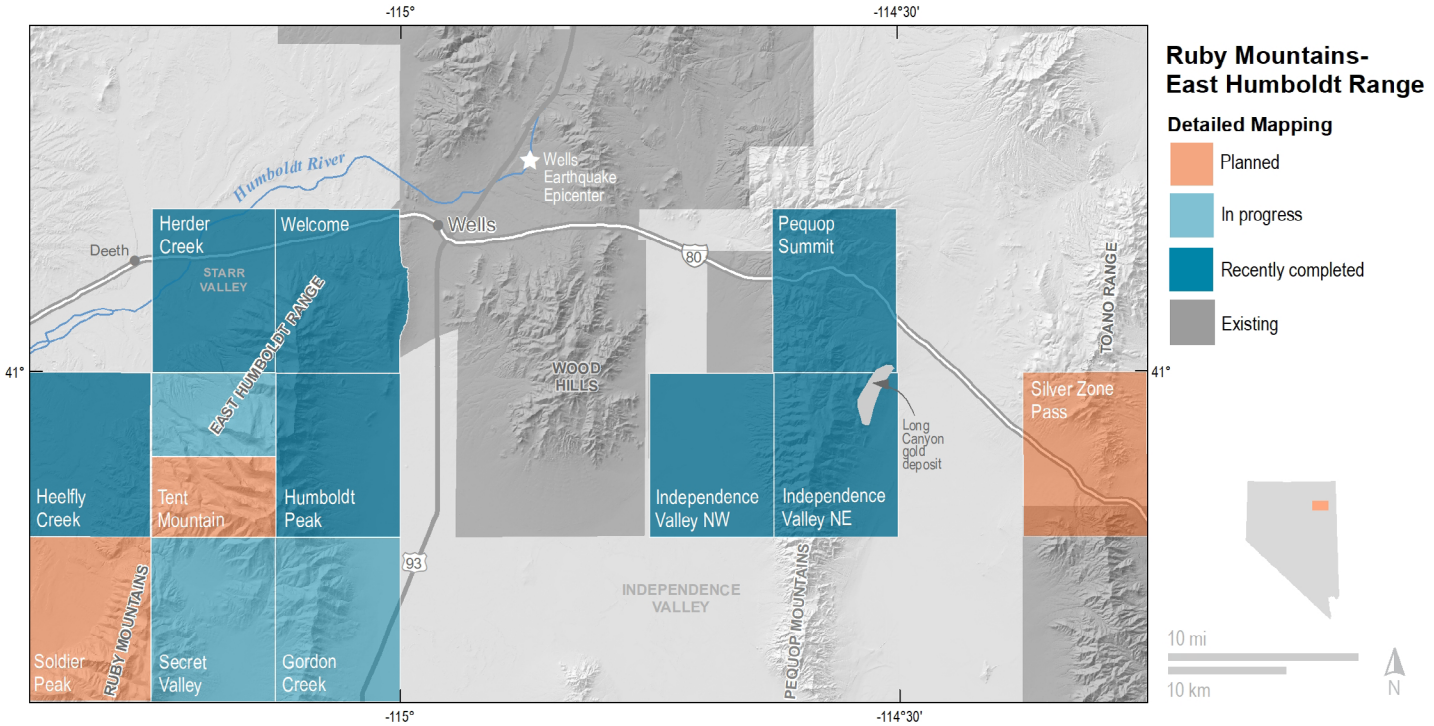
The study area includes several recently identified gold deposits with active exploration and production. This includes the Long Canyon deposit with 557,132 ounces of gold production through 2019. In 2018–2019, NBMG scientists collaborated with exploration geologists from the Newmont Mining Corporation in the production of two new geologic maps of the Pequop Mountains, which host the gold deposit.

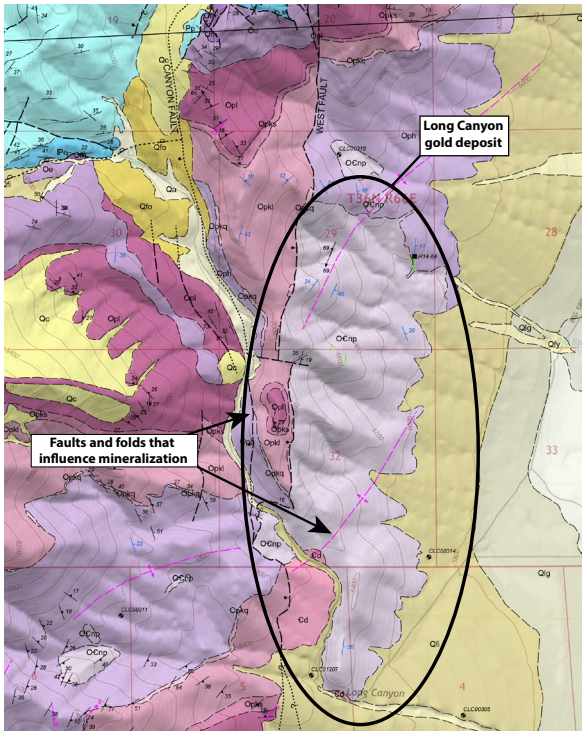
The most concerted petroleum exploration effort in Nevada in decades was also recently conducted just west of the Ruby Mountains–East Humboldt Range.

Although two geothermal power plants already reside in northeast Nevada, the full geothermal energy potential of the region has not been tapped, and further development is possible in many areas.

NBMG RESEARCH HIGHLIGHT

Geologic Framework of the Ruby Mountains–East Humboldt Range Area, Northeast Nevada (cont.)





(Top) Recently completed geologic maps in the Ruby Mountains–East Humboldt Range study area, east of Elko.

(Left) The recently published Geologic Map of the Independence Valley NE 7.5′ quadrangle depicts the complex geology surrounding the Long Canyon gold deposit. Mapping was performed collaboratively with geologists from Newmont Mining Corporation.

Zuza, A.V., Henry, C.D., Ressel, M.W., Thorman, C., Dee, S., and Blackmon, J.E., 2018, Preliminary geologic map of the Independence Valley NE quadrangle, Elko County, Nevada: Nevada Bureau of Mines and Geology Open-File Report 18-4, scale 1:24,000, 11 p.

Zuza, A.V., Dee, S., Henry, C.D., Ressel, M.W., and Thorman, C., 2019, Geologic map of the Independence Valley NW quadrangle, Elko County, Nevada: Nevada Bureau of Mines and Geology Open-File Report 19-3, scale 1:24,000, 18 p.

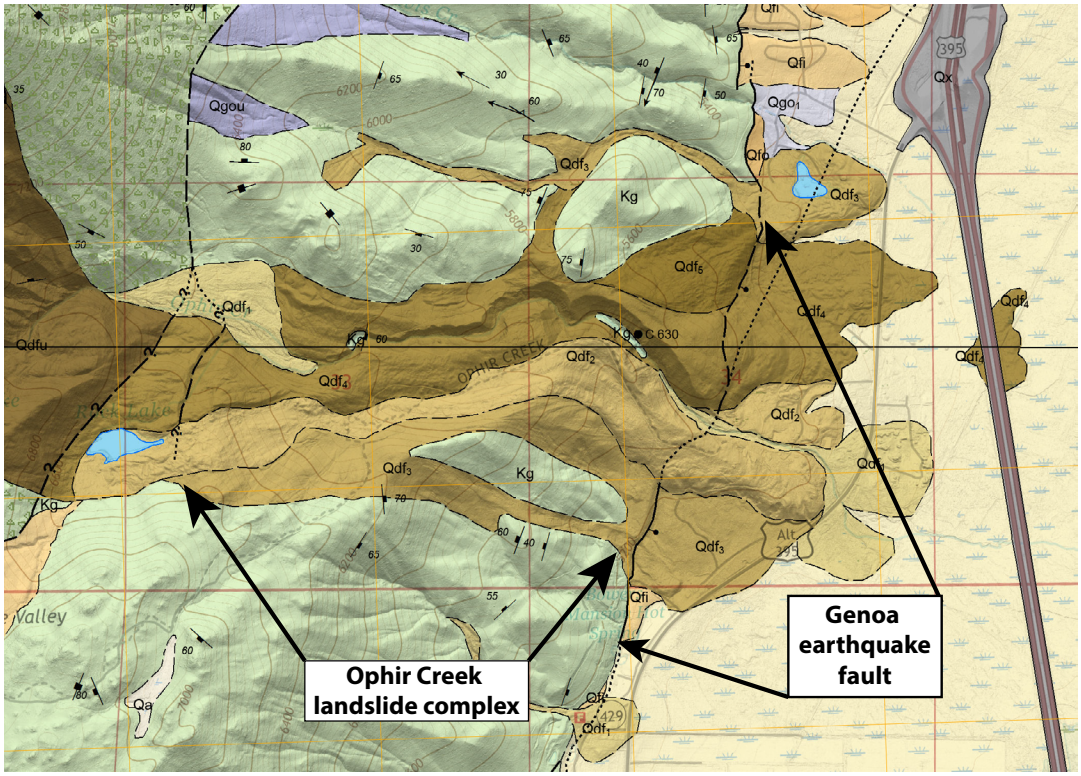
NBMG RESEARCH HIGHLIGHT

Geologic Mapping in the Carson Range, Reno, Nevada

NBMG has conducted recent geologic mapping in the Carson Range, west of Reno and Carson City. Mapping in the area has revealed numerous landslide deposits in the recent geologic past and potentially hazardous earthquake faults. The maps have also addressed several research questions regarding the history in the area of volcanic eruptions from 2 to 15 million years ago and the timing of uplift of the Sierra Nevada in the last several million years.

The dynamic landscape of the Carson Range, Washoe County. *Photographer*: Alan Ramelli

A portion of the recently published geologic map of the Washoe City quadrangle. The map shows the geology immediately west of Washoe Lake, between Carson City and Reno, Nevada. The mapping reveals the recent geologic history of landslides and surface rupturing earthquakes along the Genoa fault.



Hinz, N.H., Ramelli, A.R., and Henry, C.D., 2018, Preliminary geologic map of the Mount Rose NW quadrangle, Washoe County, Nevada: Nevada Bureau of Mines and Geology Open-File Report 18-3, scale 1:24,000, 4 p.

Carlson, C.W., Koehler, R.D., and Henry, C.D., 2019, Geologic map of the Washoe City quadrangle, Washoe County, Nevada: Nevada Bureau of Mines and Geology Open-File Report 19-4, scale 1:24,000, 6 p.

Find additional information on geologic mapping at
http://www.nbmg.unr.edu/Research/GeologicMapping.html

Mineral Resources and Economic Geology

by John Muntean

In both 2018 and 2019, Nevada led the nation in the value of its non-fuel production. In 2018, the value was $8.12 billion, with gold accounting for $7.08 billion. In 2019, the value was $7.78 billion, with gold accounting for $6.78 billion. In 2019, Nevada produced $4.87 million ounces of gold, a 13.7% drop from 2018. Despite the drop, Nevada was the sixth largest producer of gold in the world after China, Australia, Russia, Indonesia, and Canada. Besides gold, Nevada also produced significant amounts of copper, silver, barite, gypsum, diatomite, and lithium, along with other mineral commodities in 2018 and 2019.

NBMG plays a key role in providing information and carrying out research on Nevada mineral resources, which helps to spur mineral exploration and development. The research results and information that NBMG collects on mineral resources are vital to companies that come to Nevada to explore. It saves these companies time and resources in tracking down and compiling data, especially for smaller companies. Much of this information comes from mineral industry reports that NBMG publishes annually. NBMG also maintains an online archive of historic mining and exploration records, reports, and maps that go back to the 1800s. In addition, NBMG conducts a biennial survey of mineral and energy exploration companies, focused on expenditures, employment numbers, and factors that impact exploration in Nevada. Such surveys have demonstrated that exploration spending is not dominated by a few large companies, and that small "junior" companies have accounted for nearly half of the exploration expenditures in some years.

NBMG also plays an important role in helping federal, state, and local government officials and agencies make informed decisions regarding land use by assessing mineral potential, mainly on federally managed lands in Nevada. Mineral assessments are required in many cases before federally managed lands can be removed from mineral entry. In 2019, in collaboration with the Nevada Division of Minerals, NBMG began developing a web-based mineral exploration database so that companies can view and download data pertinent to mineral exploration in Nevada, while also allowing government agencies to utilize the data to make informed land use decisions.

In addition to compiling and releasing information, NBMG carries out both applied and basic research on Nevada mineral deposits. This research discipline in the geosciences is known as "economic geology." Applied research in economic geology includes mapping and describing in detail the geology of mineral deposits, which allows identification of the geologic controls on ore formation from micron to crustal scales, which facilitates both mineral exploration and efficient mining of ore. Basic research in economic geology focuses on identifying the geologic and physiochemical processes that were responsible for the deposition of metals and other economic minerals. Products that result from this research are maps, reports, and publications in scientific journals. The more geologists understand about the geology, processes, and controls on ore formation, the better equipped they are to predict where ore bodies form. Important maps that NBMG released in 2018 and 2019 that had applications to economic geology included the Ravens Nest geologic map in the northern Piñon Range (Ressel and Dee, 2018) and several geologic maps in and around Pequop Mountains (Zuza et al., 2018, 2019), where the Long Canyon gold deposit is located.

John Muntean along with CREG graduate students from the Yerington mapping course in 2017.

Most NBMG research in the field of economic geology has been on gold deposits in Nevada. The large basins with relatively recent alluvial sediments cover half of Nevada. Recent research focusing on the "footprint" of known ore deposits, including patterns of hydrothermal alteration and metal zoning, will help companies vector into ore deposits with fewer drill holes and lower costs when exploring in these basins.

Much of this research is carried out by the Ralph J. Roberts Center for Research in Economic Geology, known as CREG, which has been housed in NBMG since 2013. CREG is a partnership between the Mackay School of Earth Sciences and Engineering, the Nevada mining and mineral exploration industry, and the U.S. Geological Survey. These partners pool their resources to fund graduate students to carry out research. Typically, ~5–10 students are funded by CREG at any given time. The goals of CREG are to 1) prepare well-educated professionals for careers in the mining industry or in economic geology research by exposing them to a wealth of expertise within UNR, UNLV, industry, and U.S. Geological Survey, and 2) produce and publish high-quality research results on topics of critical interest to the Nevada mining industry. In 2018 and 2019, companies and individuals donated totals of $151,000 and $203,490, respectively. Three CREG students received their Master's degrees in 2018 and 2019, and all three are employed in the in Nevada mineral industry, as are most past CREG graduates.

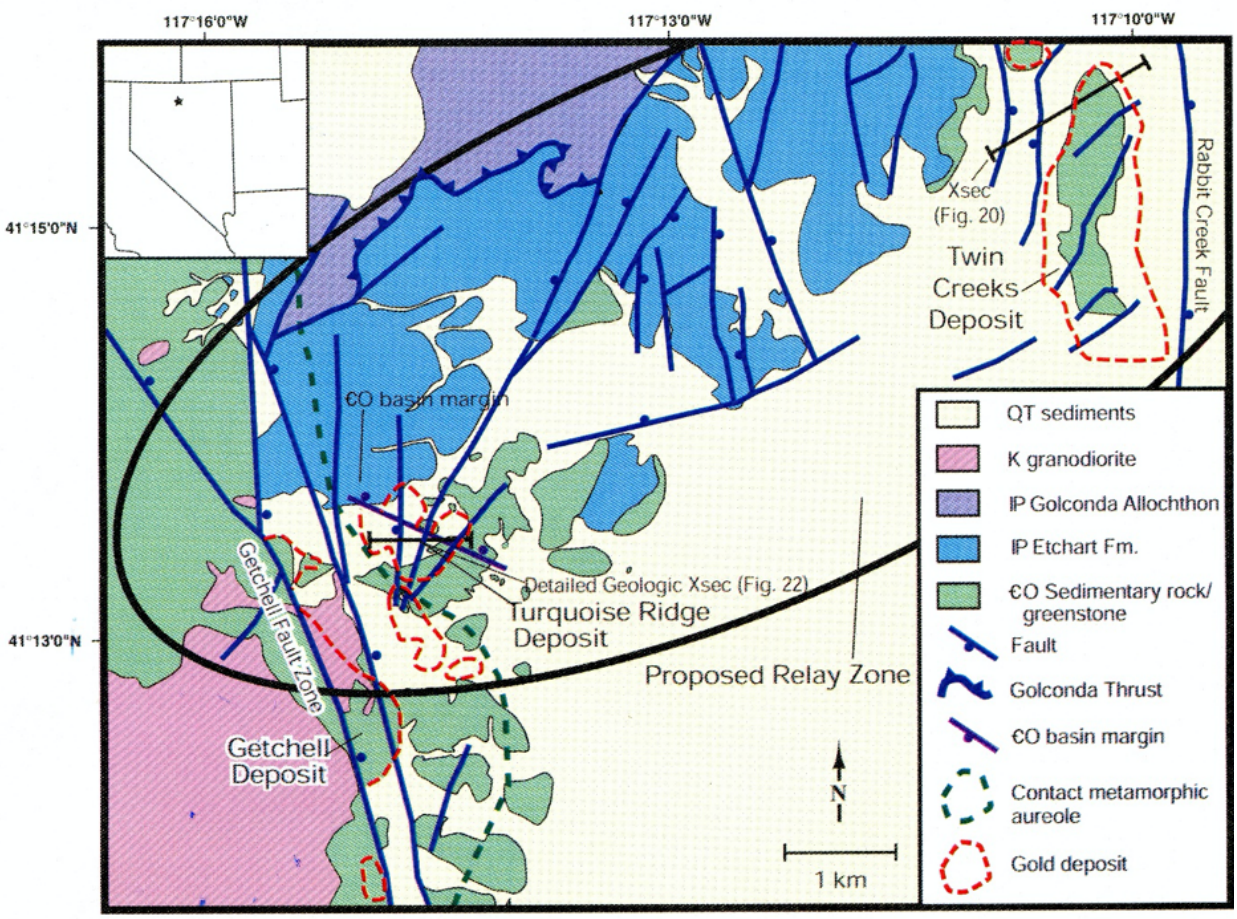
Top photo: CREG students on Society of Economic Geologists-sponsored student field trip to Kyushu, Japan. The group was fortunate to witness an eruption of ash from Mount Sakurajima volcano. Bottom photo: Group photo of CREG student and our Japanese hosts in traditional dress.

Future research will likely include studies of critical minerals. Federal Executive Order 13817 was released in December of 2017 and prescribes "A Federal Strategy to ensure secure and reliable supplies of critical minerals." Of the 35 critical minerals listed in the Executive Order, Nevada produces, has produced, or has the potential to produce lithium, barite, magnesium, tungsten, arsenic, mercury, antimony, fluorite, vanadium, and cobalt. Very few of the thousands of old mines, including tailing and non-ore waste piles in Nevada, have been analyzed for their potential to contain critical elements, including cobalt, rhenium, tellurium, gallium, scandium, and indium. Though NBMG will still research gold, silver, copper and other metallic deposits, an increasing portion of the research will be focused on critical minerals. The U.S. Geological Survey, through its Earth Mineral Resources Initiative program (Earth MRI), is funding state geological surveys, like NBMG, to carry out field research on critical mineral deposits in their states.

NBMG RESEARCH HIGHLIGHT

Society of Economic Geologists Reviews in Economic Geology Volume: Diversity of Carlin-Style Gold Deposits

Important journal publications in this biennium include two papers in the Volume series of the Society of Economic Geologists Reviews in Economic Geology. The volume was entitled Diversity of Carlin-Style Gold Deposits. The volume included papers on Nevada's Carlin-style gold deposits and other deposits in the world, including deposits in Iran, Macedonia, Indonesia, Malaysia, and China. The most notable NBMG paper was a comprehensive review of Carlin-type gold deposits in which a mineral-systems approach to exploring for these important gold deposits in Nevada was laid out in detail. Critical processes for formation of Carlin-type deposits, were converted into a practical exploration system in which specific targeting criteria were described at different scales, ranging from regional to district to drill target scales. Below is an excerpt from this paper showing how a relay ramp in normal-fault systems appears to have localized the formation of the giant Twin Creeks and Turquoise Ridge Carlin-type gold deposits. There is significant resource potential between the two deposits.



Simplified geologic map of the Getchell-Twin Creeks area, based mostly on mapping by Hotz and Willden (1964) and unpublished mapping by Placer Dome geologists. The oval outlines a proposed faulted relay ramp, composed of a mesh of north-south and northeast faults that is transferring extension from the Getchell fault zone to the Rabbit Creek fault on the east side of the Twin Creeks deposit. Note how the Turquoise Ridge deposit straddles the edge of the metamorphic contact aureole associated with the Cretaceous Osgood stock (pink body). Modified from Muntean et al. (2007).

NBMG RESEARCH HIGHLIGHTS

The Nevada Mineral Industry 2018

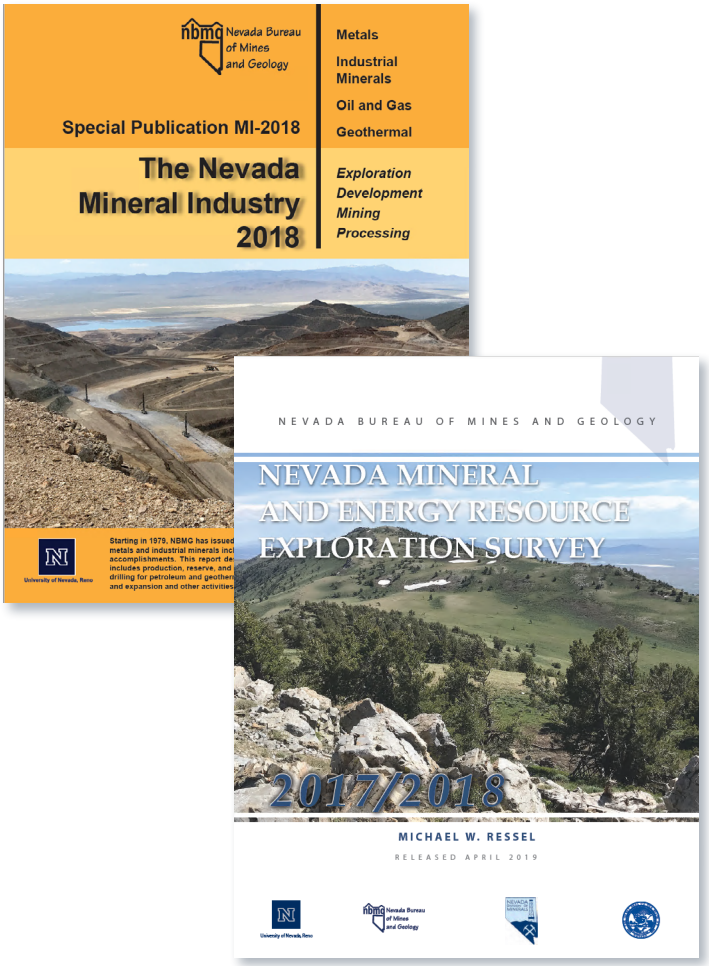
Starting in 1979, NBMG has issued annual reports that describe the mineral (metals and industrial minerals), geothermal, and oil and gas activities and accomplishments. Information on production, reserve and resource statistics, exploration and development, including drilling and new discoveries, is summarized. These reports are available free on the NBMG website (https://pubs.nbmg.unr.edu/The-NV-mineral-industry-2018-p/mi2018.htm), and print copies are also available for purchase.

Special Publication MI-2018, 222 pages
https://pubs.nbmg.unr.edu/The-NV-mineral-industry-2018-p/mi2018.htm

Nevada Mineral and Energy Resource Exploration Survey 2017/2018

NBMG carried out an online survey of companies exploring for new metal, industrial mineral, and geothermal resources in Nevada. Exploration success is imperative for the continued well-being and sustainability of natural resource industries in Nevada. The results of the survey were published in a Bureau report that is available for free on the NBMG website (https://pubs.nbmg.unr.edu/NV-exploration-survey-2018-p/es2018.htm). Printed copies are also available for purchase.

Exploration Survey ES-2018, 20 pages
https://pubs.nbmg.unr.edu/NV-exploration-survey-2018-p/es2018.htm



Find additional reports and data on Nevada's mineral industry at http://nbmg.unr.edu/Research/MineralResources.html

NOTABLE PUBLICATIONS (PAPERS AND MAPS)

DeMull, T.J., Davis, D.A., Patterson, L.M., and Lenz, J., 2018, Opportunities for precious metals toll processing and copper concentrate processing in Nevada: Nevada Bureau of Mines and Geology Report 57, 44 p.

Muntean, J. L., 2018, The Carlin gold system: Applications to exploration in Nevada and elsewhere: in Muntean J.L. (ed.), Diversity of Carlin-Style Gold Deposits, Society of Economic Geologists Reviews in Economic Geology, v. 20, p. 39-88.

Muntean, J.L., and Davis, D.A., 2019, Nevada active mines and energy producers: Nevada Bureau of Mines and Geology Open-File Report 19-1, compilation scale 1:1,000,000

Muntean, J.L., Davis, D.A., and Ayling, B., 2018, The Nevada mineral industry 2017, Nevada Bureau of Mines and Geology Special Publication MI-2017, 212 p.

Muntean, J.L., Davis, D.A., and Ayling, B., 2019, The Nevada mineral industry 2018, Nevada Bureau of Mines and Geology Special Publication MI-2018, 222 p.

Perry, R. and Visher, M., 2018, Major mines of Nevada 2017—mineral industries in Nevada's economy: Nevada Bureau of Mines and Geology Special Publication P-29, 28 p.

Perry, R. and Visher, M., 2019, Major mines of Nevada 2018—mineral industries in Nevada's economy: Nevada Bureau of Mines and Geology Special Publication P-30, 28 p.

Ressel, M.W., 2018, Nevada mineral and energy resource exploration survey 2017/2018, Exploration Survey ES-2018, 20 p.

Ressel, M.W., and Dee, S., 2018, Preliminary geologic map of the Ravens Nest quadrangle, Elko and Eureka counties, Nevada Bureau of Mines and Geology Open-File Report 2018-05, scale 1:24,000, 20 p.

Zuza, A.V., Henry, C.D., Ressel, M.W., Thorman, C.H., Dee, S. and Blackmon, J.E., 2018, Preliminary geologic map of the Independence Valley NE quadrangle, Elko County, Nevada: Nevada Bureau of Mines and Geology Open-File Report 2018-04, scale 1:24,000, 12 p.

Zuza, A.V., Dee, S., Henry, C.D., Ressel, M.W., and Thorman, C.H., 2019, Geologic map of the Independence Valley NW quadrangle, Elko County, Nevada: Nevada Bureau of Mines and Geology Open-File Report 2019-03, scale, 1:24,000, 18 p.

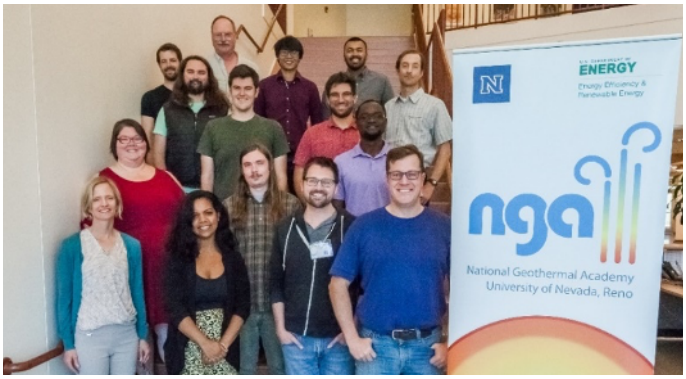
Geothermal

by Bridget Ayling and James Faulds

Nevada has more geothermal resources than any other state and currently is second (after California) in the production of geothermal energy. At present, Nevada has ~768 MWe of installed electricity generation capacity, but all studies indicate vast untapped geothermal potential in the region. One MWe provides enough electricity for ~700–1,000 homes. In 2018–2019, geothermal electricity generation increased with the commissioning of the McGinness Hills Phase 3 plant and the re-powering of the Soda Lake plant.

The geothermal team at the Great Basin Center for Geothermal Energy (GBCGE) in NBMG was very productive in 2018 and 2019, with 1) completion of several major research projects funded by the U.S. Department of Energy, 2) supervision of multiple graduate students at UNR, with two M.S. theses and one dissertation completed during this period, 3) new publications, 4) successful offerings of the National Geothermal Academy training program in both summers (Resource Conceptual Modeling, Geothermal Geophysics and Geothermal Geostatistics modules (photos below and top right)), and 5) outreach activities. The GBCGE team includes Professor Bridget Ayling (GBCGE director), Professor James Faulds (NBMG director), Elijah Mlawsky (geothermal data manager), Dr. Cary Lindsey (post-doctoral scholar) and Rozena Brecke (administrative assistant).

GREAT BASIN CENTER FOR
Geothermal Energy



Instructors and attendees of the Geothermal Geostatistics module of the 2019 National Geothermal Academy, held at the University of Nevada, Reno, Redfield campus in south Reno, June 2019.

Participants on a geothermal fieldtrip to Dixie Valley led by Professor David Blackwell (blue shirt – center) as part of the 2019 National Geothermal Academy. Dr. Blackwell points out geothermal features beside one of the shut-in geothermal wells in the valley.

RESEARCH PRIORITIES

Research priorities of the team broadly relate to addressing the key geothermal exploration and development challenges in Nevada that include the following:

1. Identifying and locating hidden (blind) geothermal systems that have no active thermal expression at the surface (e.g., hot springs or fumaroles);
2. Finding the permeability 'sweet spot' or 'play fairway'. High temperatures are relatively easy to find at depth in Nevada, but an important challenge for geothermal development is achieving sufficient fluid flow in geothermal wells (related to permeability). Permeability is usually controlled by faults and fractures, which results in localized zones of permeability that can be difficult to target with drilling.
3. Optimizing the placement of geothermal injection and production wells to ensure resource sustainability (i.e., to minimize thermal or pressure drawdown of the resource).

To address these challenges, the GBCGE/NBMG geothermal team conducts innovative, applied research in the following areas:

- Investigation of the geological factors that control where geothermal resources are located in Nevada;
- Development of new approaches for geothermal exploration to facilitate discovery of 'blind'/hidden geothermal systems; and

- Subsurface characterization to optimize the development and sustainable management of geothermal reservoirs (both conventional and Engineered Geothermal Systems or "EGS"). EGS are those that have insufficient permeability to allow commercial rates of fluid production, and require reservoir stimulation to create new fractures and thus new fluid pathways.

The GBCGE/NBMG geothermal team worked on several projects in 2018 and 2019 that were funded through the U.S. Department of Energy Geothermal Technologies Office (DOE-GTO), including 1) the Nevada Play Fairway Project (Phase 3), 2) the Fallon Frontier Observatory for Research in Geothermal Energy (FORGE) Phase 2 Project, 3) the Hawthorne Deep-Direct-Use Project, 4) Applications of Ambient Seismic Noise Interferometry to characterize the subsurface in Dixie Valley, and 5) the Nevada Machine Learning Project. Additionally, work continued on a major project funded by the U.S. Department of State that focuses on building geothermal capacity in foreign countries with geothermal potential via training, country exchanges, and collaborative research with foreign government partners. In 2018–2019, we engaged with researchers from the Argentine Geological Survey (Servicio Geológico Minero Argentino) and the Peruvian Geological Survey (Instituto Geológico Minero y Metalúrgico) (photo, top right).

GBCGE/NBMG representatives Dr. Bridget Ayling and Dr. James Faulds (4th and 3rd from the left, respectively) in Lima, Peru with partners from the Instituto Geológico Minero y Metalúrgico, November 2019.

Terra-Gen Power's Dixie Valley geothermal power plant, Churchill County, Nev. *Photographer: Jack Hursh*

NBMG RESEARCH HIGHLIGHT

Nevada Play Fairway Project: Phases 1, 2, and 3 (April 2015–March 2019)

The primary goal of this project is to develop a methodology that will predict the locations of potential blind hydrothermal geothermal systems (i.e. systems with no surface hot springs or steam vents) and distinguish the most promising systems for development. This project has been funded by the U.S. Department of Energy, with $500,000, $825,000, and $1,500,000 provided for Phases 1, 2, and 3, respectively. In Phase 1 of the Nevada play fairway project, an extensive suite of existing geological, geophysical, and geochemical data were compiled and evaluated, in support of locating new areas with geothermal potential and developing a workflow to reduce geothermal exploration risk. A detailed geothermal potential map was produced for 96,000 km^2 of Nevada in Phase 1. In Phase 2, five sites were selected for more detailed characterization: southern Gabbs Valley, Sou Hills, Granite Springs Valley, Crescent Valley, and Steptoe Valley. Key activities in Phase 2 included additional data collection such as shallow temperature surveys, more detailed geological mapping, acquisition and evaluation of geophysical data, geological modeling, and water sampling for geochemical analysis. Phase 3 aims to validate the play fairway workflow developed in Phases 1 and 2 via confirmation (thermal gradient) drilling and more detailed geophysical surveys. Two locations were prioritized for Phase 3 work: southeastern Gabbs Valley (in Mineral County) and northern Granite Springs Valley in Pershing County.

As part of the Nevada play fairway project, six temperature gradient holes were drilled in southeastern Gabbs Valley and led to the discovery of a hidden geothermal system.

NBMG graduate student, Jason Craig presents important findings while co-leading a field trip to southeastern Gabbs Valley for the Annual Meeting of the Geothermal Resources Council in October 2018. Jason's M.S. thesis focused on Gabbs Valley and was critical for the discovery of the hidden geothermal system.

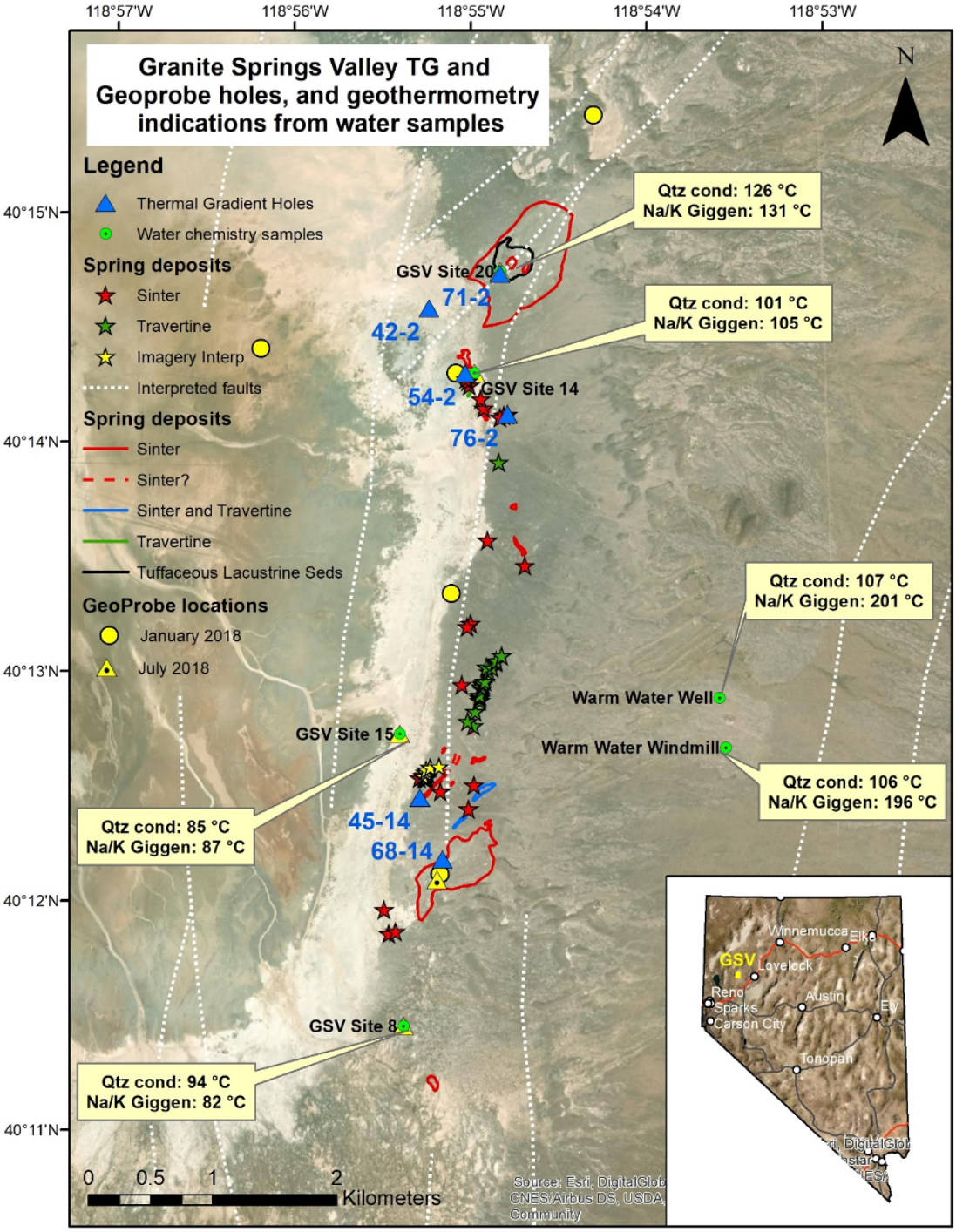
Earney, T.E., Schermerhorn, W.D., Glen, J.M., Peacock, J., Craig, J.W., Faulds, J.E., Hinz, N.H., Siler, D., 2018, Geophysical investigations of a blind geothermal system in southern Gabbs Valley, Nevada: Geothermal Resources Council Transactions, Vol. 42.

Faulds, J.E., Craig, J.W., Hinz, N.H., Coolbaugh, M.F., Glen, J.M., Earney, T.E., Schermerhorn, W.D., Peacock, J., DeOreo, S., Siler, D.L., 2018, Discovery of a blind geothermal system in southern Gabbs Valley, western Nevada, through application of the play fairway analysis at multiple scales: Geothermal Resources Council Transactions, v. 42, 14 p.

Faulds, J.E., Hinz, N.H., Coolbaugh, M.F., Ramelli, A., Glen, J.M., Ayling, B.F., Wannamaker, P.E., DeOreo, S., Siler, D.L., Craig, J.W., 2019, Vectoring into potential blind geothermal systems in the Granite Springs Valley area, western Nevada: application of the play fairway analysis at multiple scales *in* Proceedings of the 44th workshop on geothermal reservoir engineering, Stanford Geothermal Workshop, Palo Alto, CA: Stanford University. SGP-TR-214, 11 p.

NBMG RESEARCH HIGHLIGHT

Nevada Play Fairway Project: Phases 1, 2, and 3 (April 2015–March 2019) (cont.)



Location of thermal gradient (TG) and Geoprobe holes drilled in Granite Springs Valley during Phase 3 of the Nevada Play Fairway project. Inset: location of Granite Springs Valley (GSV) in Nevada.

NBMG RESEARCH HIGHLIGHT

Fallon Frontier Observatory for Research in Geothermal Energy (FORGE): Phase 2b (June 2017–September 2018)

Phase 1 of the Fallon FORGE project began in 2016, and Phase 2b was completed in mid-2018. The goal of this project was to select and demonstrate site viability to host the FORGE field research laboratory, where the scientific and engineering communities can conduct research and test technologies to make Engineered Geothermal Systems (EGS) commercially viable. The Fallon site was a semi-finalist for FORGE. Sandia National Laboratories was the lead on the entire Fallon FORGE project, and NBMG led the development of geological models for the site in collaboration with several other organizations, including the U.S. Geological Survey, Navy Geothermal Program Office, and Ormat Nevada, Inc. Phase 1 of the project involved extensive data compilation and review to determine the suitability of the site to host FORGE. In Phase 2, key activities included 1) securing additional environmental permits and initiating an Environmental Assessment (EA); 2) extensive outreach; 3) preparing an induced seismicity mitigation plan (ISMP); 4) acquisition of seismologic and geodetic baseline datasets; 5) reprocessing and reinterpretation of preexisting seismic reflection profiles; 6) acquisition of new geophysical data; 7) refining the 3D geological model of the site produced in Phase 1, 8) geomechanical and reservoir modeling; and 9) siting and drilling a deep well to provide additional certainty that the target reservoir has low permeability and is suitable for FORGE experiments (Faulds et al., 2018). Activities in early 2018 were focused on drilling a deep observation well (21-31) into the proposed reservoir formations (Ayling and Blankenship, 2018; Kraal and Ayling, 2019; above). The well was drilled in record time to 2481 m (8,140 ft) deep using advances in drilling technology, such as PDC (polycrystalline diamond compact) drill bits (photos on next page). Three injection tests were completed in well 21-31 in early 2018 to evaluate the permeability of the site, and all indicated that the well was non-productive and could not produce economically feasible rates of fluid flow, thus meeting the criteria for an EGS test site. After submitting the final project report to the DOE-GTO for the Fallon site, the site was ultimately not selected to move forward as the FORGE field laboratory. The Milford site in Utah was instead selected.

GBCGE faculty and students visit the rig site for Fallon FORGE well 21-31 in March 2018.

NBMG RESEARCH HIGHLIGHT

Fallon Frontier Observatory for Research in Geothermal Energy (FORGE): Phase 2b (June 2017–September 2018) (cont.)

One of the PDC (polycrystalline diamond compact) drill bits that was used to drill Fallon FORGE well 21-31 to 2481 m (8,140 ft) depth in 55 days.

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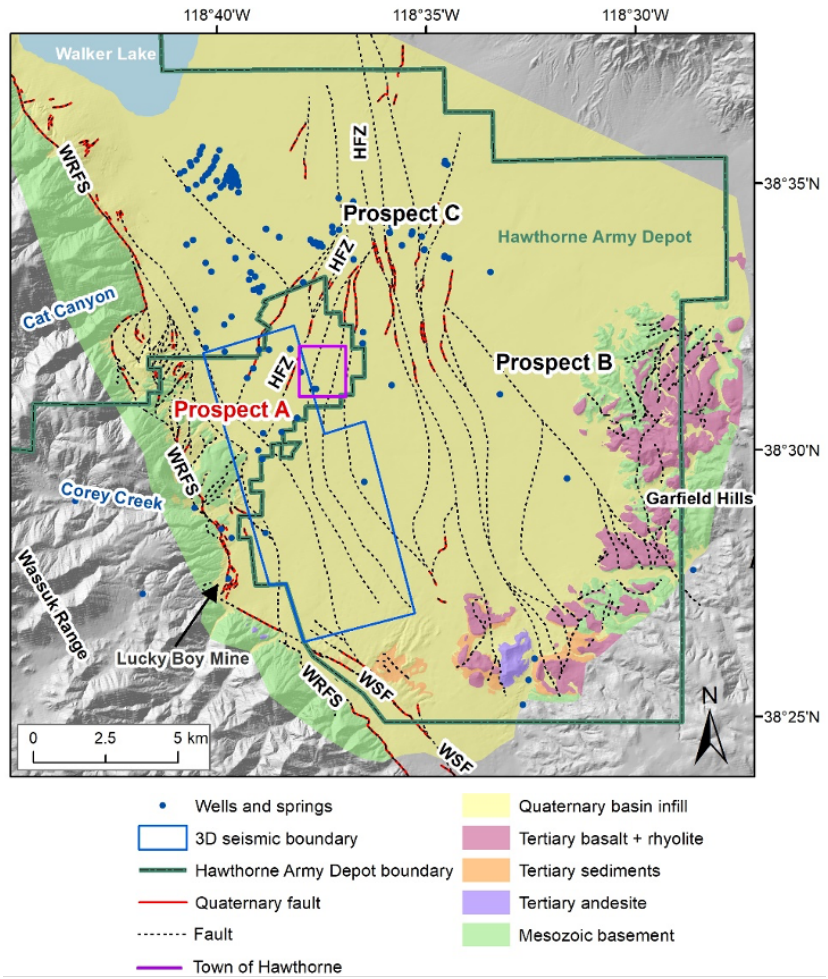
Faulds, J.E., Hinz, N.H., Siler, D.L., Glen, J.M., Fortuna, M.A., Queen, J.H., Blake, K., and Fallon FORGE team, 2018, Update on the stratigraphic and structural framework of the proposed Fallon FORGE site, Nevada: Geothermal Resources Council Transactions, v. 42, p. 1026–1046.

Kraal, K., and Ayling, B.F., 2019, Hyperspectral characterization of Fallon FORGE well 21-31—new data and technology applications *in* Proceedings of the 44th workshop on geothermal reservoir engineering, Stanford Geothermal Workshop, Palo Alto, CA: Stanford University. SGP-TR-214, 15 p.

NBMG RESEARCH HIGHLIGHT

Hawthorne Deep-Direct-Use Geothermal Project: September 2017–December 2019

The goal of this project was to develop a multi-disciplinary, three-tiered analysis approach to assess the geothermal resource and determine the feasibility of implementing a geothermal direct-use (heating and cooling) facility for the Hawthorne Army Depot (HAD) as well as the town and Mineral County facilities in Hawthorne, Nevada (e.g., library, town hall, and other public buildings). Led by Sandia National Laboratories, the three-tiered approach linked a production side analysis (PSA) and a demand side analysis (DSA) into a whole-system analysis (WSA) to provide an integrated assessment of the geothermal resource and the probability of delivering economically viable direct-use energy to the Hawthorne area (Arguello et al., 2018; Sabin et al., 2018). The GBCGE-NBMG team members were responsible for evaluating the resource potential of one of three blind geothermal prospects in the Hawthorne area, Prospect A (figure, right). Key findings from this effort included the identification of two separate geothermal targets, including a deeper fluid (~120°C [248°F]) and a shallower fluid (~100°C [212°F]) that is encountered in several shallow wells in the Walker Lake basin. Estimated resource capacities of these two low-temperature systems were 7 MWe and 1.6 MWe, respectively (Ayling and Hinz, 2020). To evaluate the overall performance of proposed heating and cooling systems at Hawthorne, the GEOPHIRES software tool was used to model over 100 geothermal resource development scenarios. These were compared to the thermal demand of HAD and the community to calculate the levelized cost of heat (LCOH), return on investment (ROI), and carbon offset associated with developing the geothermal resources at Hawthorne. The study found that there is ample heat in the system to serve the HAD and the community of Hawthorne for 30–50 years. For scenarios that met all the heating demands of the priority buildings at the HAD and for the city and county, the LCOH was ≤ 4 ¢/kWh (Lowry et al., 2020).



Location of the three blind geothermal prospects in the Hawthorne area, including prospect A that was evaluated in detail for the Hawthorne deep direct-use project.

Arguello, R., Schwendig, J., Lowry, T., Sabin, A., Blake, K., Lazaro, M., Anderson, S., Ayling, B.F., Tiedeman, A., Hinz, N.H. 2018, Deep direct-use geothermal—development of a demand side model for the Hawthorne, Nevada area: Geothermal Resources Council Transactions, v. 42.

Ayling, B.F., and Hinz, N.H., 2020, Developing a conceptual model and power capacity estimates for a low-temperature geothermal prospect with two chemically and thermally distinct reservoir compartments, Hawthorne, Nevada, USA: Geothermics, v. 87. https://doi.org/10.1016/j.geothermics.2020.101870

Lowry, T.S., Ayling, B., Hinz, N., Sabin, A., Arguello, R., Blake, K., Tiedeman, A., 2020, Deep direct-use geothermal feasibility study for Hawthorne NV: Sandia National Lab Technical report SAND2020-3210, https://doi.org/10.2172/1606296 .

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Find additional information on geothermal energy at
http://nbmg.unr.edu/Research/GeothermalEnergy.html
https://gbcge.org/

Geologic Hazards

by Rich Koehler, Seth Dee, and Craig dePolo

Geologic hazards occur throughout Nevada and pose potential risks to public safety and critical transportation, power, and water infrastructure. Hazards are related to a wide variety of processes including earthquakes, liquefaction, floods, landslides, debris flows, volcanoes, subsidence, and expansive soils, among others. NBMG scientists provide information on these hazards to the public through research and outreach focused on hazard planning and preparedness.

The state of Nevada lies within the tectonic province known as the Basin and Range, which contains hundreds of active faults. In addition, the Walker Lane cuts through the western part of the state and accommodates ~20% of the relative motion (~1 cm/yr) between the Pacific and North American plates. Over 10,000 earthquakes occur in the state every year. Historically, there have been over 20 strong earthquakes (magnitude ≥ 6) in the last ~160 years, including several major events (magnitude ≥7). Although earthquakes can occur anywhere in the state, the major population centers (Reno–Carson City and Las Vegas) are proximal to multiple fault sources capable of generating damaging earthquakes.

NBMG fault studies in the Reno area have focused on mapping the locations of active faults and better understanding their relative behavior. During 2018 and 2019, NBMG conducted work on several projects in the Reno area funded by grants from the U.S. Geological Survey Earthquake Hazards Program (EHP). Several projects initiated in the last biennium were completed in 2018–2019, including fault trenching, analyses, and reporting along the Fred's Mountain, Warm Springs Valley, and Petersen Mountain faults directly north of Reno. New projects initiated in 2018-2019 focused on active faults include studies along the Bonham Ranch fault north of Reno and the Dog Valley fault located directly west of the state line in California. The Dog Valley fault has the potential to impact several major water storage dams, posing a flood hazard along the Truckee River corridor through Reno. These projects utilize trench excavations to expose geologically young soils to then develop information on the number and frequency of prehistoric earthquakes. This information provides important input parameters for seismic hazards assessments and building code improvements.

Inside the Warm Springs Valley fault trench study area, Washoe County, Nev. *Photographer: Colin Chupik*

Characterization of the earthquake hazard in the Las Vegas metropolitan area continued as a NBMG priority during the 2018–2019 biennium. Funding from the USGS EHP and Clark County supported two fault trenching studies in the Las Vegas area, including projects along the Eglington and Frenchman Mountain faults. Significant progress was also made on a multi-year project funded by Clark County to systematically evaluate the seismic potential of the Las Vegas Valley fault system. This study is designed to develop new information on the relative activity and age of prehistoric earthquakes based on mapping and geochronological analyses of potentially faulted deposits. New insights have been gained on the local faults and how they accommodate offset of the ground during relatively short episodes of activity separated by long periods of relative quiescence. Highlights of some of the projects involved in this study are described in greater detail in the next few pages.

NBMG also began a new EHP project to update the database of Quaternary (period of time extending from 2.6 million years ago to present) active faults for the state. This effort will result in a user-friendly web-based platform to display fault data and map references and will be an important resource for engineers, researchers, and earthquake risk reduction planners. Additionally, NBMG was funded by the Nevada Division of Emergency

NBMG field reconnaissance team inspecting damage along the Trona railway due to surface rupture during the 2019 Ridgecrest, CA earthquakes.

Management (NDEM) to design a post-earthquake technical clearinghouse web site and operations plan that will streamline state agency coordination for earthquake response and recovery after a damaging event.

The NBMG hazards group maintains collaborations with federal, state, and local agencies as well as other departments at UNR. NBMG scientists have held active roles in the Western States Seismic Policy Council, the Nevada Resilience Advisory Committee, the Nevada Earthquake Safety Council, the Basin and Range Province Earthquake Working Group, and several workshops on Quaternary fault parameters and seismic hazards. These efforts involved collaboration with geologists and engineers throughout the region and resulted in the development of policy statements and research plans focused on seismic risk reduction. As part of the teaching mission at UNR, NBMG staff taught classes in field geology, engineering geology, and fault trenching techniques providing training for the next generation of geologic hazard practitioners. New geologic mapping of fault traces and landslides was conducted by NBMG hazards personnel for several geologic maps funded by the U.S. Geological Survey STATEMAP program (described in the 'Geologic Mapping' section of this biennial report).

NBMG staff participated in the rapid response field surveys of the Ridgecrest, California earthquakes that occurred on July 4th and 5th, 2019. The earthquakes (magnitude 6.4 and 7.1) generated strong ground shaking in southern Nevada and provided a sobering reminder of the hazards posed by earthquakes within the state. The multi-agency response team included staff from the U.S. Geological Survey, California Geological Survey, NBMG, and graduate students from UNR, as well as emergency management personnel. Coordination with these agencies resulted in the establishment of response protocols that will be valuable should a future large earthquake occur in Nevada. A field trip and lecture on the results of this investigation were presented at an Association of Engineering Geologist meeting (Las Vegas Chapter).

NBMG has also continued to produce and maintain broad hazard assessments and mitigation plans. An update to the Nevada Hazard Mitigation Plan was completed in 2018 and is available through the NBMG website. Nevadans can obtain the most recent hazard information and maps from the NBMG MyHazards- Nevada website (https://gisweb.unr.edu/MyHAZARDS/), which includes data on earthquake hazards, risk modelling estimates (HAZUS), radon potential, and other hazards.

NBMG RESEARCH HIGHLIGHT

Earthquake Hazards Studies in the Reno Area

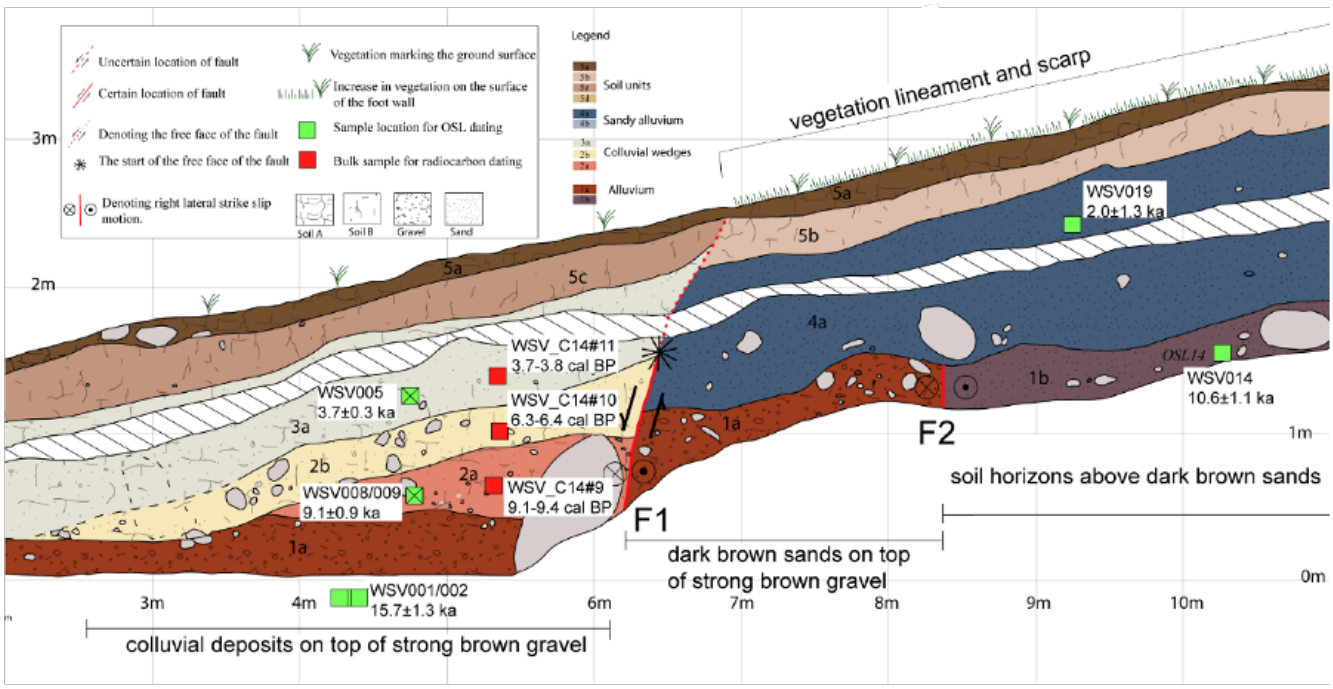
The Reno area is geographically situated within a zone of tectonic transition between the Basin and Range Province and Walker Lane to the east and Sierra Nevada to the west. This transition results in a complex array of active faults, including normal faults (vertical movement) and strike-slip faults (horizontal movement). Although the locations of these faults are relatively well-documented, little information is available on their paleoearthquake history and relative rates of activity (slip rate). This paucity of data has limited the understanding of their potential to generate large earthquakes and resulted in large uncertainties in estimates of ground shaking hazards (e.g., National Seismic Hazards Map). NBMG earthquake studies in the Reno area have generated new data that will contribute toward more robust seismic hazards estimates and risk reduction planning for this rapidly evolving region. Trenching and estimates of the age of faulted deposits along the Warm Springs Valley fault indicate that the fault has generated at least three surface rupturing earthquakes in the last 10,000 years. Results from our investigations along the Petersen Mountain fault indicate that earthquakes are characterized by both normal and strike-slip movement and long inter-event times (time between earthquakes). The Fred's Mountain fault

NBMG RESEARCH HIGHLIGHT

Earthquake Hazard Studies in Reno (cont.)

has generated four earthquakes since the late Pleistocene (<30,000 years). All of these faults pose surface rupture and ground shaking hazards to the greater Reno area and in particular to the North Valleys communities, which are currently experiencing significant residential development. Studies along other hazardous faults in the Reno area are in the planning stages and will likely occur in conjunction with NBMG STATEMAP efforts.

A

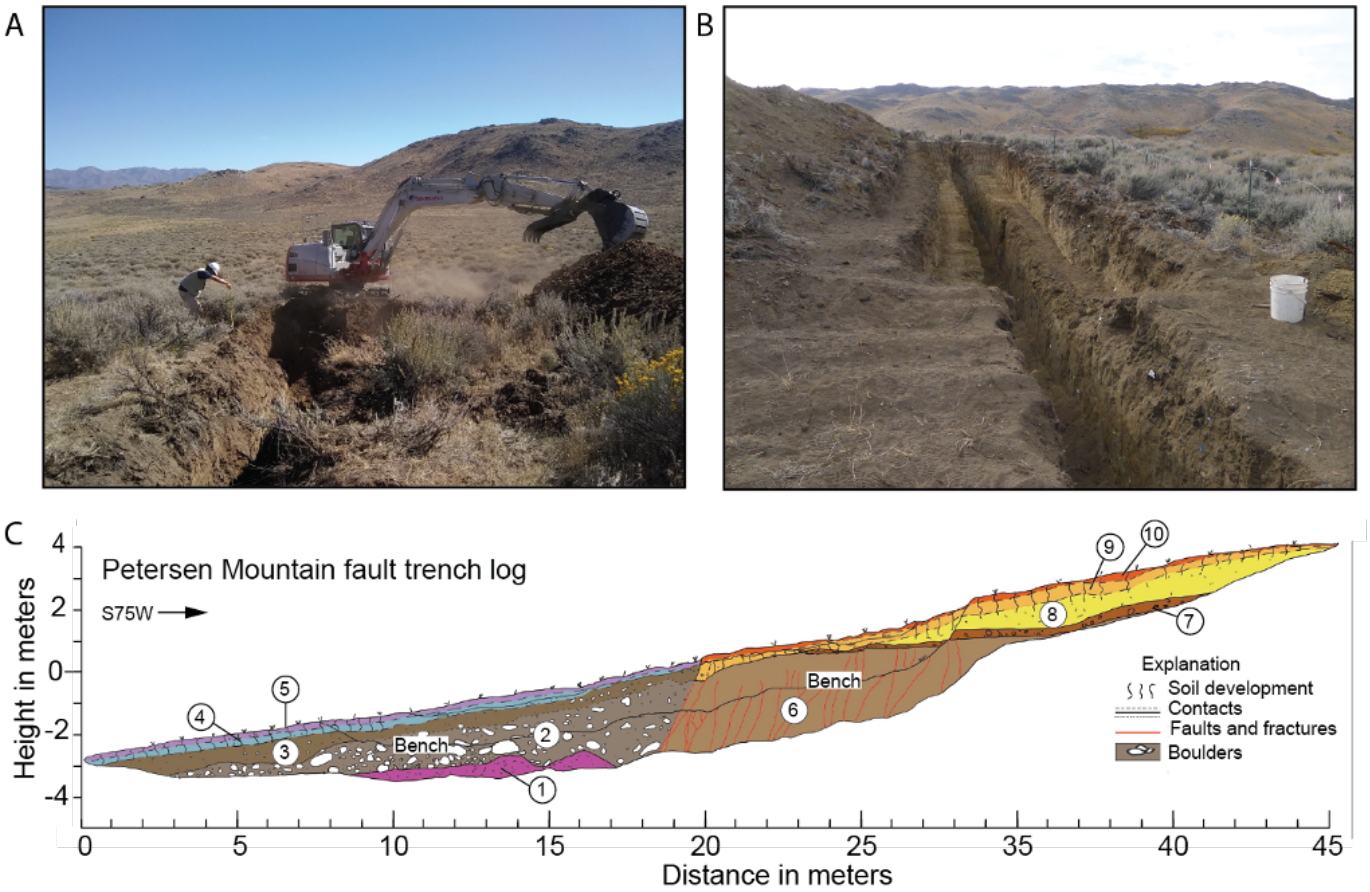


B

(A) Log of a trench exposure along the Warm Springs Valley fault showing displaced alluvial-fan sediments. Thin layers on the left side of the exposure represent colluvial deposits generated by erosion of the fault scarp (vertically broken surface) after each earthquake, providing evidence for three earthquakes. **(B)** Drone photograph of the trench site.

NBMG RESEARCH HIGHLIGHT

Earthquake Hazard Studies in Reno (cont.)



(A and B) Photographs of the paleoseismic trench excavation along the Petersen Mountain fault. **(C)** Trench log showing stratigraphic relations in the exposure. A clear juxtaposition of bedrock on the right (light brown) and boulder alluvium on the left (dark brown) across the fault provides evidence for at least one earthquake in the last 30,000 years.

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Koehler, R.D., De Masi, C., and Dee, S., 2019, New lidar mapping and paleoseismic characterization of the Petersen Mountain fault zone, north of Reno, NV, Final Technical Report: U.S. Geological Survey National Earthquake Hazards Reduction Program, 26 p.

Koehler, R.D., and Chupik, C., 2019, Development of earthquake chronology, recurrence and slip rate data for the northern Warm Springs Valley Fault—Using trenching and high-resolution UAV photography, Washoe County, Nevada, Final Technical Report, U.S. Geological Survey National Earthquake Hazards Reduction Program, 46 p.

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NBMG RESEARCH HIGHLIGHT

Earthquake Hazard Studies in Las Vegas Valley

NBMG, in conjunction with UNLV and U.S. Geological Survey is investigating the earthquake potential of Quaternary faults in Las Vegas Valley by measuring offset across fault scarps and fault escarpments and remapping the surficial geology within the valley. Fault offsets are used in earthquake hazard analysis to determine how fast faults are moving and to provide insight into the origin of the fault scarps, earthquakes, and how differential compaction might affect scarps. A pre-development topographic map was prepared using 1965 aerial photography as the base map for the offset measurements. Over 470 elevation profiles were constructed, interpreted, and measured for offsets. These data were projected along the fault to define offset patterns and to develop fault slip rates (fault slip rates are used to estimate how often earthquakes occur). Prior geologic mapping in the valley assigned broad geologic ages to deposits. New dates collected by the NBMG and U.S. Geological Survey indicate that the surficial sediments are latest Pleistocene or on the younger side of the original age range. Mapping also revealed extinct hot spring clay and opal deposits in northern Las Vegas Valley, an indication of conduits for fluid flow along faults that extend to the bedrock below the basin, likely related to tectonism.

NBMG Director Dr. James Faulds in the foreground and NBMG scientist Seth Dee examining the clay and opal deposits of the hot spring site along Cheyenne Boulevard. Opal mineralization indicates subsurface water temperatures were at least 180°C (356°F). The paleo-hot spring deposit is located along the Valley View fault zone, and movement along this fault may have provided the conduit for the hot water from the basement rocks below.

Dee, S., dePolo, C.M., Taylor, W.J., and Mahan, S., 2018, New paleoseismic data from the Frenchman Mountain fault, Las Vegas *in* Koehler, R.D., and Anderson, J.G., editors, 2018 working group on Nevada seismic hazards—summary and recommendations of the workshop, February 5-6, 2018: Nevada Bureau of Mines and Geology Open-File Report 19-2, 44 p.

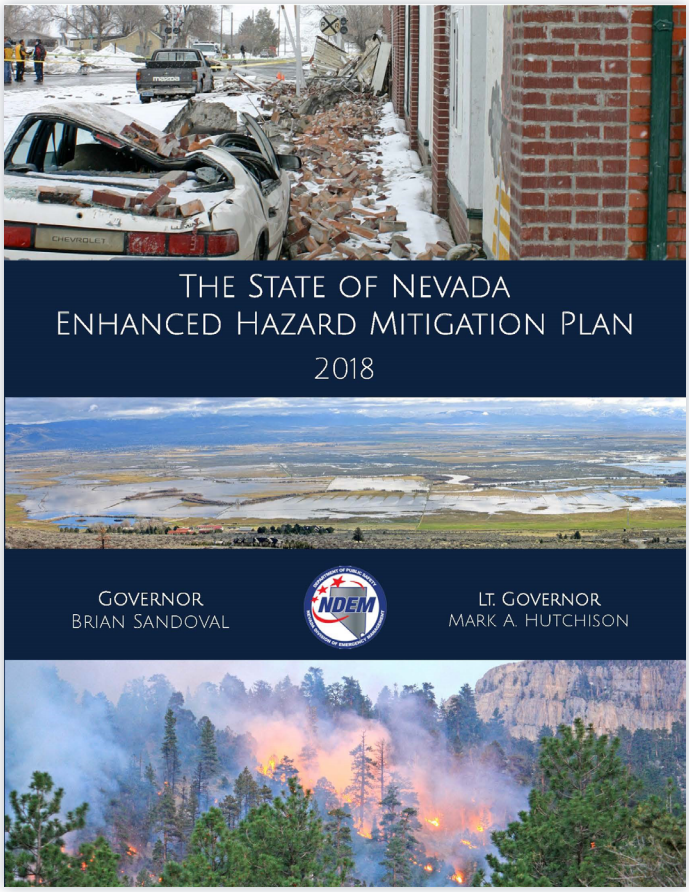
Dee, S., dePolo, C.M., and Koehler, R.D., 2019, Paleoseismic investigation of the Eglington fault, Clark County, Nevada, Final Technical Report, U.S. Geological Survey National Earthquake Hazards Reduction Program, 21 p.

GEOLOGIC HAZARDS AND PUBLIC SAFETY: STATE HAZARD MITIGATION PLAN

In 2018, NBMG published an update to the Nevada Enhanced Hazard Mitigation Plan (EHMP) through funding from the Nevada Division of Emergency Management (DEM). The revised 1,135-page document includes updates to the landslides, expansive soils, earthquakes, volcanoes, lake tsunami, and naturally occurring asbestos sections. The plan describes the various geologic hazards that can potentially impact Nevada citizens and infrastructure and outlines mitigation strategies for reducing risk exposure and economic losses. The "enhanced" status of the EHMP ensures that funds will be available to the state for the mitigation of natural disasters. The existence of the plan helps secure funding for both pre- and post-disaster activities and allows for "state of emergency" declarations to be obtained.

The Nevada EHMP helps to identify strategies for risk reduction and builds partnerships with other state, regional, local, and tribal entities, as well as the private sector and general public. It represents a comprehensive resource on natural hazard mitigation and contributes toward a better understanding of hazards and vulnerabilities applicable to more effective preparedness. The plan is especially useful as a hazard education and outreach tool for local communities that may not have the technical expertise to develop local mitigation plans.

https://data.nbmg.unr.edu/Public/NEHMP/StateOfNevadaEnhancedHazardMitigationPlan2018.pdf



Cover of the 2018 State Enhanced Hazard Mitigation Plan. The cover shows the top three natural hazards in Nevada: earthquake, flood, and wildfire.

Find additional information on geologic hazards in Nevada at
http://nbmg.unr.edu/Research/GeologicHazards.html

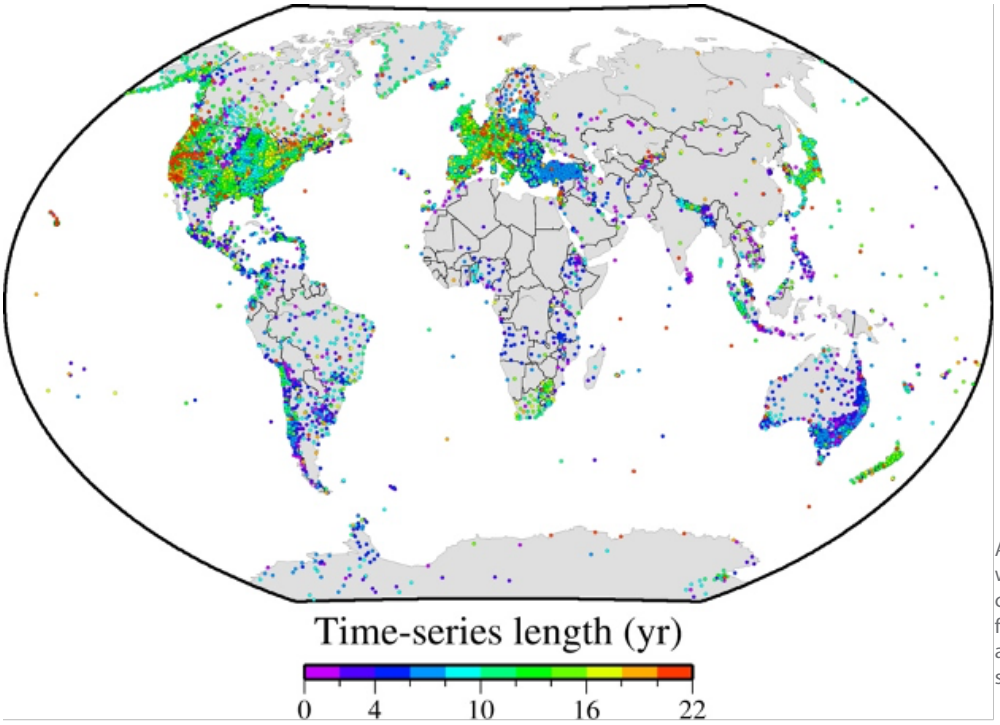
Nevada Geodetic Laboratory

by Geoffrey Blewitt, William C. Hammond, and Corné Kreemer

The Nevada Geodetic Laboratory (NGL) conducts research in the field of space geodesy to study scientific problems that have local, regional, and global significance. The NGL is located within NBMG and interacts closely with the Department of Geological Sciences and Engineering, the Nevada Seismological Laboratory, and the Physics Department at the University of Nevada, Reno.

Research at NGL uses extremely precise measurements from the Global Positioning System (GPS) and Interferometric Synthetic Aperture Radar (InSAR) to study active Earth movement. Scientific studies cover a wide range of topics that relate to Earth deformation from natural and human-driven processes. Past and ongoing studies have elucidated Nevada's natural hazards from active faults, earthquakes, and volcanism and have supported Nevada's push for clean energy by monitoring surface deformation associated with geothermal development. More recent research is focusing on vertical movements, how they relate to hydrological conditions in mountains and aquifers, and what these movements may mean for active mountain growth, water resources, and climate change in Nevada. NGL is internationally recognized in its role of pushing forward the science of global geodesy, including patterns of surface mass loading and global-scale plate tectonics.

Research faculty within the NGL at NBMG are Professors Geoffrey Blewitt, William Hammond, and Corné Kreemer, all of whom participate in undergraduate and graduate education at UNR by teaching courses and advising graduate students. The following research highlights summarize some of the major efforts by NGL in 2018–2019, including (1) an overview of NGL's comprehensive GPS data analysis system that processes all geodetic GPS data in the world from over 18,000 stations and provides scientific products to researchers around the globe; (2) an analysis of GPS, seismic, gravity, and climate data that led to NGL's discovery of connections between drought, mountain uplift, and magmatic activity in eastern California; and (3) NGL's discovery of connections between seasonal crustal deformation detected by GPS and measured seismicity in California and Nevada.



A map of all GPS geodetic stations in the world that are processed routinely by NGL, color coded by duration of operation. Data from these stations are used to generate a variety of products for the international scientific community.

NBMG RESEARCH HIGHLIGHT

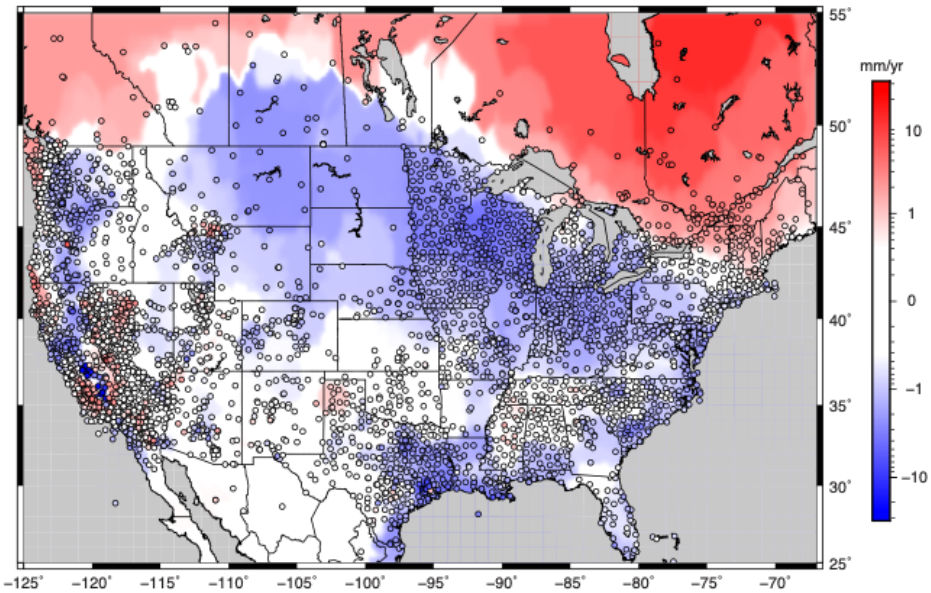
Harnessing the GPS Data Explosion for Science

In work published in 2018 and 2019, NGL described how it makes a variety of useful data products freely available online to the international science community—products that result from a comprehensive analysis of all the geodetic GPS data in the world from 1994 to the present. The data products include the global coordinates of over 18,000 GPS stations every 5 minutes, as well as tropospheric delay and atmospheric water vapor content. These products are then used by other scientists as well as NGL for a variety of research topics, such as those detailed in the other research highlights that follow in this section.

Long before GPS positioning devices appeared in our hands, scientists had already realized that by applying signal processing techniques, GPS could be used to measure how the ground underneath our feet is moving with millimeter-level precision. The data system that NGL has developed builds on that foundation and represents a culmination of the advances made in high-precision positioning, Earth modeling, and the science of geodesy over the last three decades. As such, the system is state-of-the-art, delivering the highest precision products for consumption by the regional, national, and international science community.

The quantity of data handled by the system is now growing toward 100 TB. The data are processed by a cluster of 10 computers, each with up to 64 CPU cores, running custom cluster control software. The analysis software uses fully automated algorithms to manage any problems that may arise in the data, based on decades of the team's experience. At the heart of the data analysis is the GIPSY precise positioning software created by the NASA Jet Propulsion Laboratory, of which NGL Professor Blewitt is a co-author.

This endeavor highlights NGL's commitment to open community data access and depends critically on the same commitment by the international geodetic community to share GPS station data. This is facilitated through the International Association of Geodesy, an organization that NGL has long served by volunteering as board and committee members, and in leadership positions. The outcome is that NGL data products can be used in ways that were never conceived at the outset, raising new opportunities for interested scientists at and beyond NBMG, commonly in interdisciplinary fields.



Map of North America showing uplift (red) and subsidence (blue) as inferred by NGL's GPS data products. The map shows a color contrast with Canada moving upward, and USA moving downward. This is caused by glacial isostatic adjustment—the response of the Earth's mantle to the removal of ice sheets over Canada from the last Ice Age. Superimposed on this are many GPS signals, including subsidence of California's Great Valley.

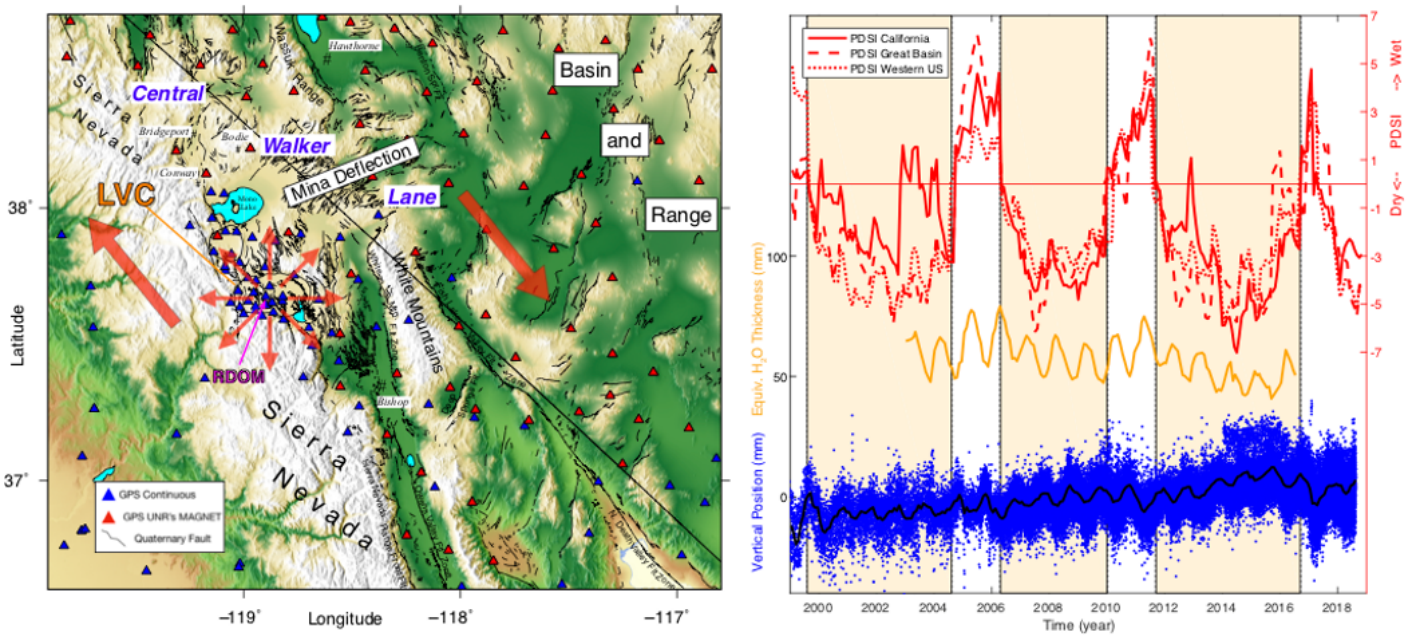
Blewitt, G., Hammond, W.C., and Kreemer, C., 2019, Harnessing the GPS data explosion for interdisciplinary science (print version): Eos, v. 100, no. 3, p. 19–22.

Blewitt, G., Hammond, W.C., and Kreemer, C., 2018, Harnessing the GPS data explosion for interdisciplinary science (online version): Eos, v. 99, https://doi.org/10.1029/2018EO104623.

NBMG RESEARCH HIGHLIGHT

Climatic Control on Long Valley Caldera Deformation

In work published in 2019, NGL described their discovery of connections between the recent drought in California, changes in uplift rate of the Sierra Nevada, and inflation of the magmatic system at the Long Valley Caldera near Mammoth, CA. The team analyzed GPS, seismic, gravity, and climate data to show that the speed of Sierra Nevada uplift is sensitive to broad-scale changes in surface and groundwater (e.g., the cumulative weight of snow, streams, lakes, and aquifers) and that these changes correlate with movements deep within the plumbing system of the large volcano. This occurs because the weight of snow and water loads the surface and increases pressure deep in the Earth. Conversely, droughts reduce the mass of water loading the Earth surface, resulting in uplift and reduced pressure on the magmatic system. While the exact physical mechanism is not yet clear, we hypothesize that this allows magmatic fluids to rise or expand more easily. When that occurs, it provides an outward horizontal push on the crust, influencing small- to moderate-sized earthquakes up to 60 km away. We showed where and when these changes occurred and specific earthquakes that may have been triggered by this inflation. The work was done in collaboration with the Department of Mathematics and Statistics in the UNR College of Science.



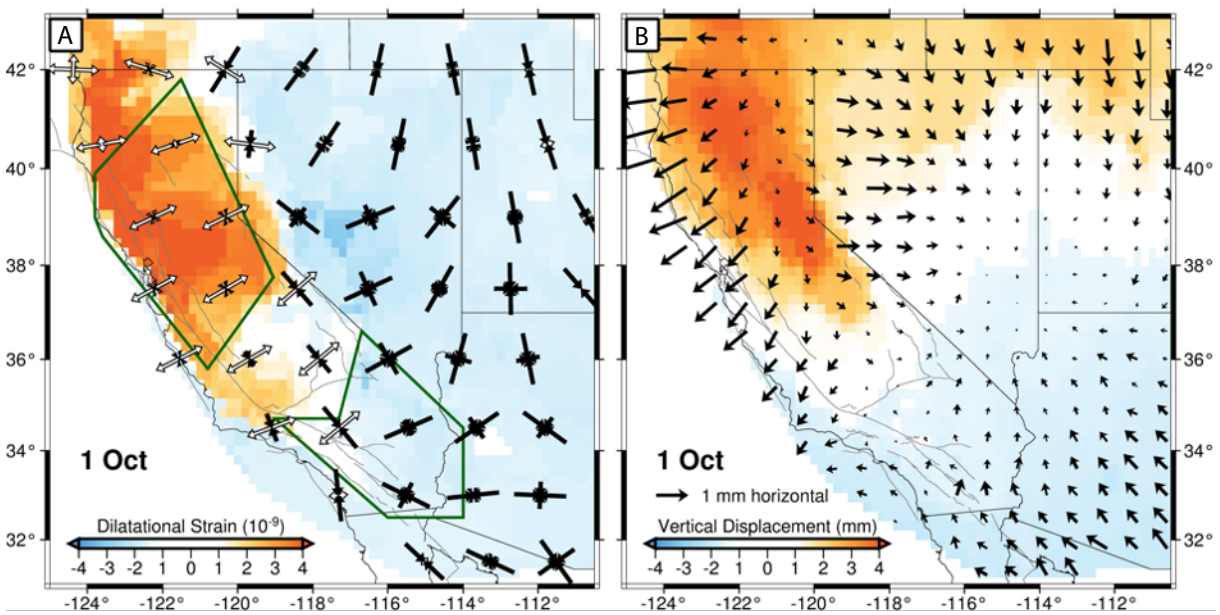
A) Map of border region between Nevada and California where the Long Valley caldera (LVC) sits at the boundary between the Sierra Nevada front and Great Basin. Red arrows indicate the sense of motion of active tectonic deformation in the central Walker Lane (northwest/southeast motion) and active radial extension of the surface above the inflating LVC magmatic system. Triangles indicate locations of GPS stations including NBMG's MAGNET network (red) and other regional continuous GPS stations (blue). **B)** Time series show relationship between climate, gravity and geodetic data. Red time series indicate the Palmer Drought Severity Index (PDSI, red), which indicates overall tendency toward wet or drought conditions. Orange time series shows equivalent water height from the GRACE gravity satellite, and blue indicates vertical position of GPS time series for station RDOM, which sits directly on top of the LVC magmatic system.

Hammond, W.C., Kreemer, C., Zaliapin, I., and Blewitt, G., 2019, Drought-triggered magmatic inflation, crustal strain, and seismicity near the Long Valley caldera, central Walker Lane: Journal of Geophysical Research—Solid Earth, v. 124, p. 6072–6091, https://doi.org/10.1029/2019JB017354.

NBMG RESEARCH HIGHLIGHT

Seasonal Deformation and Seismicity in California & Nevada

In 2018, NGL's Corné Kreemer and Ilya Zaliapin of UNR's Department of Mathematics and Statistics published how ~1200 GPS station motions track how the land in California and Nevada moves up and down and simultaneously extends and contracts horizontally throughout the seasons. This seasonal deformation pattern is most likely caused by the imposition (in winter) and removal (in summer) of snow/water on the Earth's surface, but the horizontal component had previously not been estimated. For the latter, this study used a new strain mapping technique ('MELD'), which NGL had published earlier in the year. The biggest seasonal signal is in northern California, where the land moves down up to ~5 mm and horizontally contracts in the winter/spring, and the reverse occurs in summer/fall. The seasonal variation in horizontal strain is oriented orthogonal to the San Andreas fault system, and this causes small variations in the stresses that keep the fault clamped with less clamping expected in the summer/fall. They found that there are more (small) earthquakes during that period than other times of the year. This correlation between seasonal strain and seismicity is not present in southern California, probably in part because the seasonal strain is small and the fault is not aligned as favorably as in northern California. In both areas, the proportion of larger earthquakes are in-phase and the aftershock productivity out-of-phase with the seasonal strain. These observations suggest that a seasonal increase in fault-normal extension may or may not trigger mainshocks, but when an earthquake happens in the summer/fall they grow larger than they otherwise would, which would cause a larger stress reduction and result in fewer aftershocks. Correlation with earthquakes in Nevada were not evaluated due to lack of enough events.



A) Colors show dilatational strain on October 1 derived from horizontal variation in GPS station time-series, and vectors show direction and style of strain tensor; red/blue colors and open/white vectors imply extension/compression, respectively. **B)** Colors show vertical motion, and vectors show gridded horizontal motion on October 1 from seasonal variation in GPS time-series. In northern California, land moves up in summer/fall as water has been removed from the surface. Simultaneously, the land there extends at that time.

Kreemer, C., and Zaliapin, I., 2018, Spatio-temporal correlation between seasonal variations in seismicity and horizontal dilatational strain in California: Geophysical Research Letters, v. 45, p. 9559–9568, https://doi.org/10.1029/2018GL079536.

Kreemer, C., Hammond, W.C., and Blewitt, G., 2018, A robust estimation of the 3D intraplate deformation of the North American plate from GPS: Journal of Geophysical Research—Solid Earth, v. 123, p. 4388–4412, https://doi.org/10.1029/2017JB015257.

Find additional information on the Nevada Geodetic Laboratory at
http://geodesy.unr.edu
http://www.nbmg.unr.edu/Research/Geodesy.html

Cartography & GIS

by Jennifer Vlcan

Rachel Micander teaching grade school students about minerals. *Photographer: Jennifer Vlcan.*

The NBMG Cartography and GIS program is a largely soft-funded operation that consists of dedicated cartographers, graphic designers, and geographic information systems (GIS) analysts, who also have experience in publications design and web development. The strong mix of artistic talent and technical skills results in the production of user-friendly, visually appealing, and innovative products that continue to receive national attention and even earned the group a Special Achievement in GIS award in 2014.

The Cartography and GIS team supports all NBMG programs and, as requested, other internal UNR departments (e.g., Geological Sciences, Cooperative Extension, DeLaMare Library, etc.) as well as external organizations in Nevada and beyond (e.g., other state agencies, UNLV, U.S. Geological Survey, other state geological surveys, etc.).

The team assists research scientists with geologic-map production, web GIS, publications, figures, and scientific illustrations for journal articles and reports, in addition to general GIS support. They also routinely assist the NBMG sales office and Great Basin Science Sample and Records Library (GBSSRL) with publication and data dissemination as well as collaborate with the GBSSRL staff on new publication and data initiatives.

The Cartography and GIS team also serves a major role in the NBMG education and outreach mission. Members of the team regularly give K-12 classroom presentations, teach at Nevada Mining Association teacher workshops, give community presentations and demonstrations, and provide for activities during Earth Science Week each October. They also produce the highly informative and educational Nevada Geology Calendar every year in addition to developing many other educational products about geology.

The Cartography and GIS team also plays an important role in the educational mission of NBMG and UNR. They mentor and support graduate students from the geology program during their research and production of geologic maps for their theses and dissertations. The team works closely with graduate students, who opt to publish their maps through NBMG, and provides the students with information and support to bring maps to publication status, ensuring that publication standards are followed. Furthermore, undergraduate students from the geography, geology, and other programs at UNR are commonly employed by the Cartography and GIS team to gain hands-on GIS experience critical to a successful future in the GIS and/or geoscience industries.

2018 AND 2019 HIGHLIGHTS

A total of 12 new maps, 14 reports, and 2 calendars were published in 2018–2019, as well as a major update to one publication in 2019. During this period, various other maps and publications were also in progress for future publication, GIS and web support was provided for numerous research and public service projects, and a major effort to improve ADA compliance of NBMG web content was also in progress. In addition to these accomplishments, highlights during 2018 and 2019 include the following:

2018 Nevada State Enhanced Hazard Mitigation Plan published: The NBMG Cartography and GIS team was contracted by the Nevada Division of Emergency Management (NDEM) to assist in updating the Nevada State Hazard Mitigation Plan. Updating the state plan was critical to ensure Nevada's eligibility of receiving FEMA support in the event of a natural disaster declaration in the

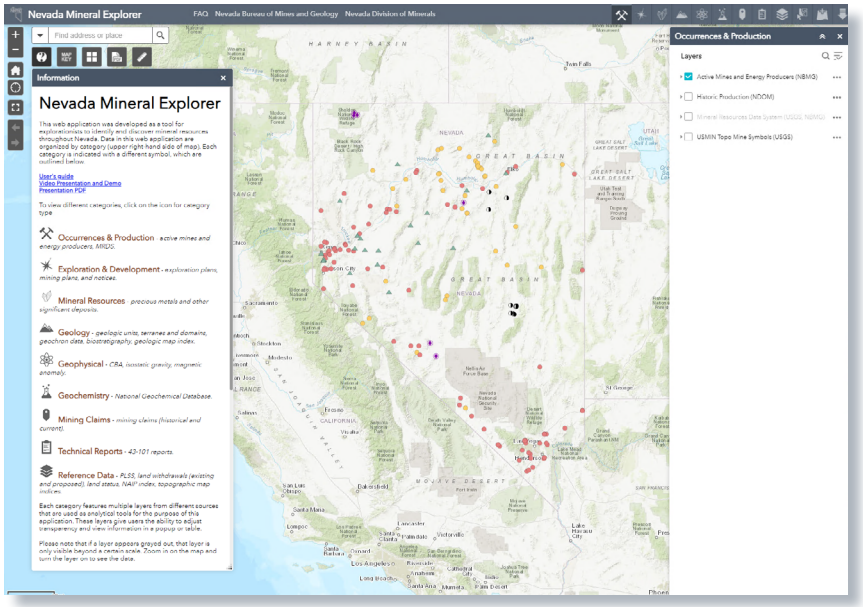
state. The multi-year effort to update the plan was completed in 2018 with delivery of the plan to NDEM and FEMA, followed by adoption of the plan. The bulk of updating the 1000+ page document and project management was primarily handled by the Cartography & GIS team.

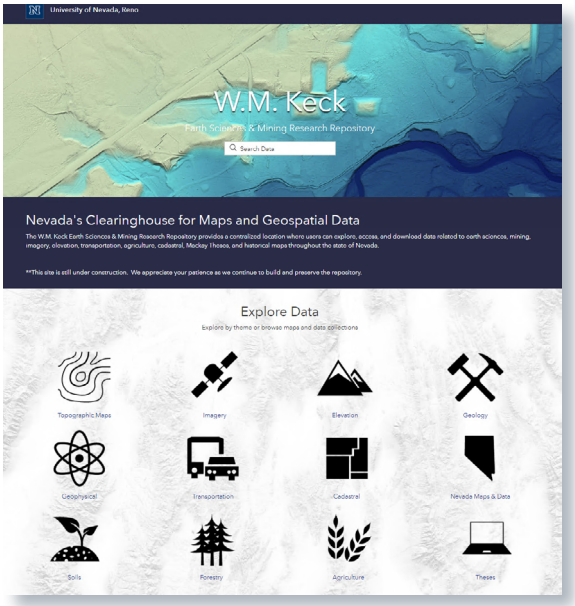
Support for earthquake hazards research and web tools: The team also provided significant GIS support to the Las Vegas Valley earthquake study in 2018–2019. Production of the geologic map for this study was in full force with ongoing fieldwork and GIS assistance needed throughout various stages of the mapping. In addition to other GIS support, numerous elevation profiles were generated by the team to support the research efforts of the study during this period. The team also provided technical support to other hazards projects in production, such as an update to the online Quaternary faults viewer and development of an earthquake clearinghouse website.

Nevada Mineral Explorer web application development: A major effort was underway in 2019 to develop a new tool for exploration geologists to locate and virtually explore natural resources in Nevada through an interactive web application with stacked layers and other special features to allow for querying, exporting, downloading, and printing. This was a joint project between NBMG and the Nevada Division of Minerals, with the Cartographic and GIS team leading the effort for a planned Spring 2020 release.

Keck website overhaul: The Cartographic and GIS team, NBMG Data Manager, and UNR Libraries collaborated on a major update to the W.M. Keck Earth Sciences and Mining Research website. The front end was migrated to a user-friendly and ADA compliant Open Data site and was launched September 2019. As part of this effort, a new web application for NAIP (aerial imagery) was also made available.

Geologic Map Schema (GeMS) initiative: NBMG kicked off a move to the new data model for geologic mapping developed by the U.S. Geological Survey called GeMS. The Cartographic and GIS team led the effort by setting up new mapping projects in GeMS for geologists and cartographers alike to learn the format prior to the future U.S. Geological Survey requirement that all geologic map deliverables use the format. Ongoing work and training with GeMS occurred during 2018–2019 with funding from STATEMAP and Earth MRI projects.





The NBMG cartographic staff play a major role in creating and maintaining web application sites, giving the public easy access to information on geohazards, mining and renewable resources in Nevada, and geologic maps.

Find additional information on Cartography and GIS at
http://nbmg.unr.edu/

Great Basin Science Sample and Records Library

by Emily O'Dean, Charlotte Stock, and David Davis

The Great Basin Science Sample and Records Library (GBSSRL), located at 2175 Raggio Parkway in Reno, is the Publication Sales and Information Office for the NBMG, as well as a public repository for geologic information for Nevada. This collection includes over 35,000 mining and geologic samples and records and at least 250,000 historical aerial photographs. Archiving these records and materials is also one of the duties of the NBMG as noted in NRS 514.040.

In 2018 and 2019, the GBSSRL staff accessioned over 1,000 mining district files, a new collection of Nevada aerial photographs donated by the U.S. Geological Survey, and a very large submission of geothermal core and cuttings from Ormat Technologies, Inc. These samples included 33,236 feet of core from 3,435 boxes representing 25 geothermal wells throughout the state. GBSSRL has a state mandate to store geothermal well samples.

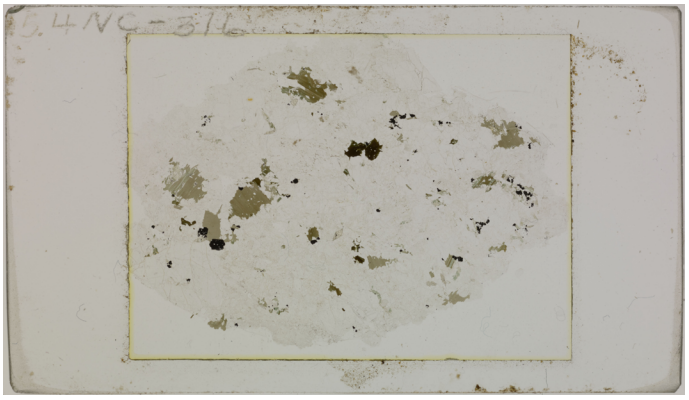
Additionally, the GBSSRL staff were active in digitization activities, including creating metadata and scanning approximately 800 mining district files and making them available on the Bureau's Open Data website (https://gisweb.unr.edu/MiningDistricts/). The GBSSRL also accessions, scans, and disseminates well exploration permits, logs, and related materials on an annual basis.

This unique facility preserves the results of hundreds of millions of dollars of mineral and energy exploration and drilling in locations across Nevada, including some that are no longer accessible. The ability of current and future generations to reanalyze these archived samples is exceedingly valuable and has resulted in enhanced exploration that otherwise could not have been conducted.

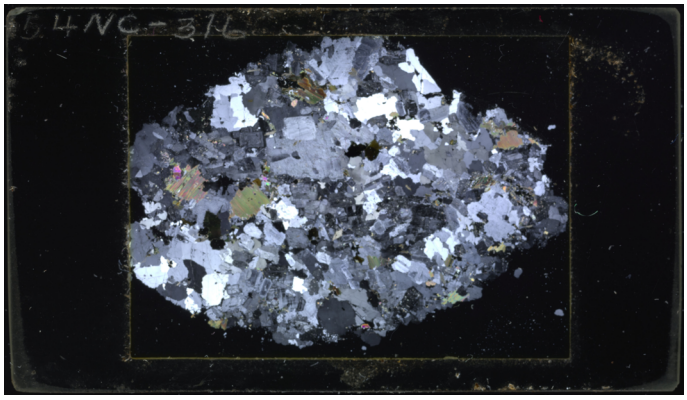
The following resources are available from the Publication Sales and Information Office at the GBSSRL: NBMG and USGS maps and publications; aerial photographs; general geologic and mining information; and cuttings, core, and well records for oil, gas, geothermal, and mineral-exploration drill holes.

Many of the publications and collections at the GBSSRL are now accessible online through the NBMG website. In 2018 and 2019, the publications website was accessed by 46,576 users in every state and many countries worldwide, which demonstrates the high value of the information stored at and disseminated through the GBSSRL. Data at the GBSSRL are critical for public safety, including research on geologic hazards, and for the mineral, geothermal, geotechnical, and petroleum industries.

The GBSSRL also began digitizing thin sections in 2018, funded by the USGS National Geological and Geophysical Data Preservation Program. This project was spearheaded by Emily O'Dean and David A. Davis at the GBSSRL.



Left: An image from Robert Coats Thin Section Collection, 54NC316, quartz monzonite, **with unpolarized light**.



Right: The same sample **with polarized light**, showing minerals not visible with unpolarized light.

NBMG RESEARCH HIGHLIGHT

BEFORE

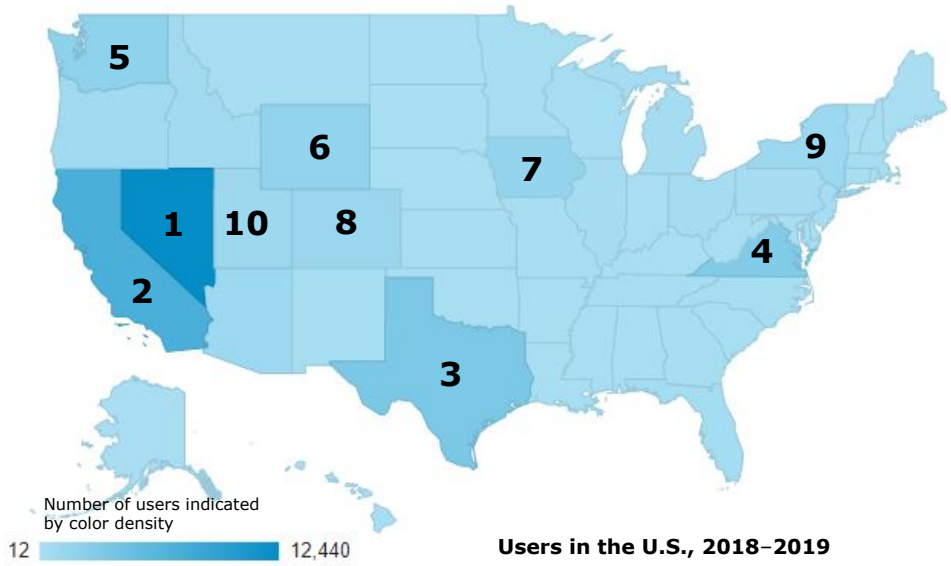
Bridget Ayling, Director of the Great Basin Center for Geothermal Energy at NBMG, received a large shipment containing 33,236 feet of geothermal core from 25 geothermal wells in Nevada from Ormat Technologies, Inc.

AFTER

Bret Pecoraro, Development Technician at NBMG, performed the Herculean tasks of making space and shelving all 3,435 boxes of the geothermal core shipment in the GBSSRL warehouse.

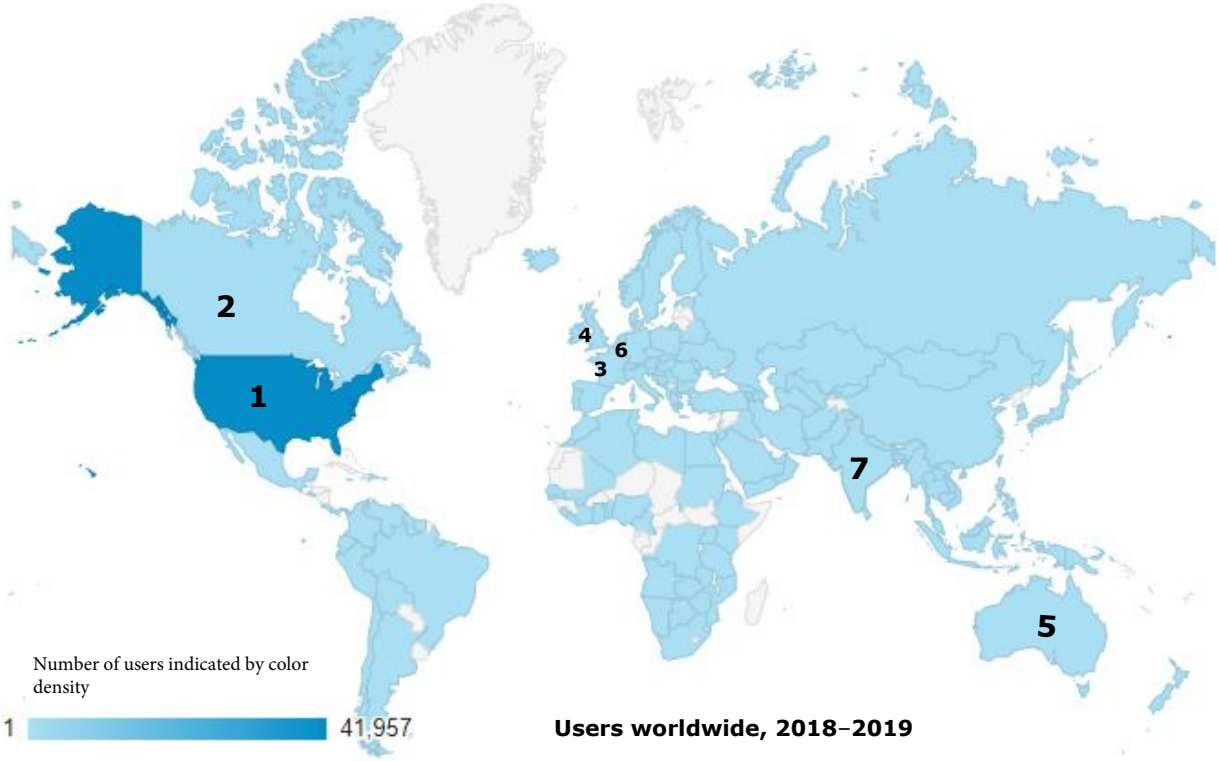
AND NOW AVAILABLE FOR PUBLIC RESEARCH

NBMG USER ENGAGEMENT



Users in the U.S., 2018–2019

Two years of activity from January 1, 2018 through December 31, 2019 on the NBMG publications website, which averaged about 650 sessions per week. Users from all states and countries shown in blue accessed the website during this period. Users in the U.S. account for about 90 percent of the website traffic. The top 10 states in descending order were Nevada, California, Texas, Virginia, Washington, Wyoming, Iowa, Colorado, New York, and Utah. The top 7 countries were the USA, Canada, France, United Kingdom, Australia, Germany, and India.



Users worldwide, 2018–2019

Find additional information about the GBSSRL (aka the "Gold Building:) at
http://pubs.nbmg.unr.edu

Open Data

by Rachel Micander

As Nevada's state geological survey, the production of map services and datasets has been an important part of NBMG modernization and organization. Many of these datasets are freely available, and in an effort to better disseminate these data, NBMG staff developed and launched an open data website in 2017. Features of this website include

- Data search: allows the public to search and download GIS data (https://data-nbmg.opendata.arcgis.com/).
- Web applications: interactive web maps that allow GIS users to view and query different layers and to make educated decisions based on these data.
- Story maps: interactive stories that engage and inspire people through maps, places, locations, and geography.
- Publications: maps, reports, and other products available from NBMG.
- Other GIS data: data available from other state and federal agencies as well as Nevada county GIS—where available.

Open Data can be freely used and reused by anyone and provides users with a single location to source these data. NBMG GIS datasets can be searched for and downloaded in various digital formats, including Excel spreadsheets, KML (Google Earth) files, or ESRI shapefiles within the NBMG Open Data site. Since it was implemented, the amount of data hosted on the NBMG Open Data site increased from 50 datasets (when the site was first launched in August 2017) to 63 datasets by the end of 2017. The Open Data site is a rapidly evolving resource, and NBMG staff are continuing to make datasets more easily accessible to the public, contractors, and companies alike in order to further collaboration with other agencies, industry, and scientific research. The NBMG Open Data site reflects the most recent and up-to-date data and web applications that are publicly available from the Bureau. Some of these datasets include earthquakes, Quaternary faults (young, earthquake-prone faults), flood data, Nevada geology, data related to geothermal energy, mineral exploration, and topographic maps and indices.

Education and Outreach

by Andrew Zuza and Rachel Micander

NBMG staff are involved in a variety of teaching and outreach missions that enrich geology education at UNR and the entire state. The faculty are involved in teaching core courses for the Geology program at UNR, including economic geology, field methods, and the capstone summer field class. Instruction in economic geology is provided by NBMG through the Ralph J. Roberts Center for Research in Economic Geology (CREG). Roughly one-third of the Geology graduate students are advised by NBMG faculty, and these students are focused on a variety of diverse topics, including geothermal research, regional tectonics, fault studies, and economic geology. NBMG also offers field trips, teacher workshops, and other outreach opportunities.

Undergraduate students on UNR's 2018 Summer Field Camp, a capstone summer course, pose in Owens Valley.

Undergraduate Geology at UNR and Summer Field Camp

NBMG faculty teach core curriculum classes in the Geology program at UNR. In 2018–2019, 5 undergraduate geology courses were taught by NBMG faculty. NBMG faculty teach different levels of field methods courses, such as Geol-450 (Advanced Geologic Mapping, Rich Koehler). Andrew Zuza is Director of the required capstone "Summer Field Course," which is a 6-unit, 5.5 week field-intensive geologic mapping course that is based in eastern Nevada. The class involves themed exercises that train undergraduate students in geologic mapping, field interpretations, and effective report writing. John Muntean and Mike Ressel of NBMG and the CREG program teach the economic geology courses. In addition, exciting extracurricular courses on geothermal energy are taught by NBMG faculty Bridget Ayling and Jim Faulds.

Graduate Education

A variety of practical and specialized graduate-level courses are offered by NBMG faculty to train Masters and Doctorate students. Some courses include Geothermal and Ore Exploration, Advanced Structural Geology, Paleoseismic Trenching, Global Geophysics and Geodynamics, Geophysical Geodesy, and Economic Geology. In 2018–2019, 10 graduate courses were taught by NBMG faculty, and 7 Masters and 1 Ph.D. were completed by students advised by these faculty.

Graduate students in an Advanced Structural Geology course taught by Prof. Zuza conduct fieldwork in the northern White Pine Range of eastern Nevada.

Earth Science Week

The NBMG hosts field trips each year near or during the National Earth Science Week (second full week of October). These field trips are free and open to the public. They encourage people of all ages to explore the natural world and learn about the geosciences. Participants learn how geologists use geologic maps to unravel the history of Nevada geology, assess geologic hazards including flood impacts and earthquake hazards from evidence of recent faulting, evaluate the potential for mineral and geothermal resources, and learn how landscapes are formed. Participants are given the opportunity to collect mineral and rock specimens during these field trips. The 2018 field trip took participants on a tour of the Lahontan Valley, where earthquake faults, flood mitigation infrastructure, a geothermal system with an operating power plant, and volcanic maars were visited and discussed. In 2019, participants toured the Steamboat geothermal plant on the south side of Reno and old mining features on the

Comstock in Virginia City. A field trip guide is published each year by NBMG and given to the field trip participants. Field trip guides from past trips are available for free on the NBMG website in the Educational Series listings http://pubs.nbmg.unr.edu/Educational-Series/1856.htm.

dePolo, C.M., Henry, C.D., Zuza, A.V., Micander, R., and Faulds, J.E., 2018, Sparkling or still? A tour of geology from Soda Lakes to Stillwater Marsh, Nevada (Guide for the Earth Science Week Field Trip, October 13, 2018): Nevada Bureau of Mines and Geology Educational Series 63, 25 p.

Ressel, M., Micander, R., Hursh, J., Russell, S., and Sophy, M., 2019, Lode and behold! Geology and natural resources of the Truckee Meadows and Virginia City (Guide for the Earth Science Week Field Trip, October 12, 2019): Nevada Bureau of Mines and Geology Educational Series 65, 25 p.

NBMG geologist Craig dePolo shares information about earthquake faults east of the Lahontan Valley during the 2018 Earth Science Week field trip.

2019 Earth Science Week field trip participants learn about mining activities on the Comstock during the 1800s and early 1900s. *Photographer: Jack Hursh.*

Teacher Workshops

NBMG staff participate in the highly effective and popular Mineral Education Workshops that are jointly sponsored by the Nevada Mining Association and the Nevada Division of Minerals. These workshops occur twice a year—one in northern Nevada and one in southern Nevada—and are open to all K-12 teachers, free of charge. The 2018 Northern Nevada workshop was held in Reno and hosted teachers from across northern Nevada. The 2019 Northern Nevada workshop was held in Carson City, again with teachers attending from all over northern Nevada. Both the 2018 and 2019 southern Nevada workshops took place in Las Vegas. These workshops aim to educate K-12 teachers about rocks, minerals, mining, renewable resources, and Earth sciences. In addition to hands-on classroom activities, the teachers attend half-day field trips to various mine sites, museums, national recreation areas, or other Earth-science related locations. The goal is to provide teachers with Nevada standards-based science lessons to take back to their classrooms to teach their students about geology, rocks, minerals, and natural resources in Nevada. Teachers can receive continuing education credit for attending these workshops.

Rachel Micander interacting with teachers at the 2019 northern Nevada teacher workshop in Carson City. *Photographer: Drew McGregor, Nevada Mining Association*

Find additional information on education and outreach at
http://www.nbmg.unr.edu/ScienceEducation/ScienceEducation.html

Classroom Presentations

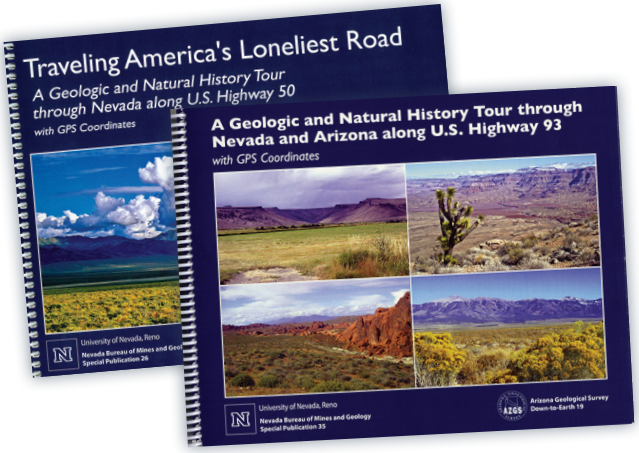
In addition to teaching during the Mineral Education Workshops, NBMG staff also conduct classroom presentations in K-12 schools. These classroom presentations aim to share information about rocks and minerals with Nevada students and assist teachers in their lesson plans by providing detailed geologic information based on grade level.

Community Presentations

Several presentations on rocks, minerals, mining and geothermal activities occurring in the state were also given by NBMG staff at various assisted living centers in both Reno and Fernley during the 2018–2019 biennium.

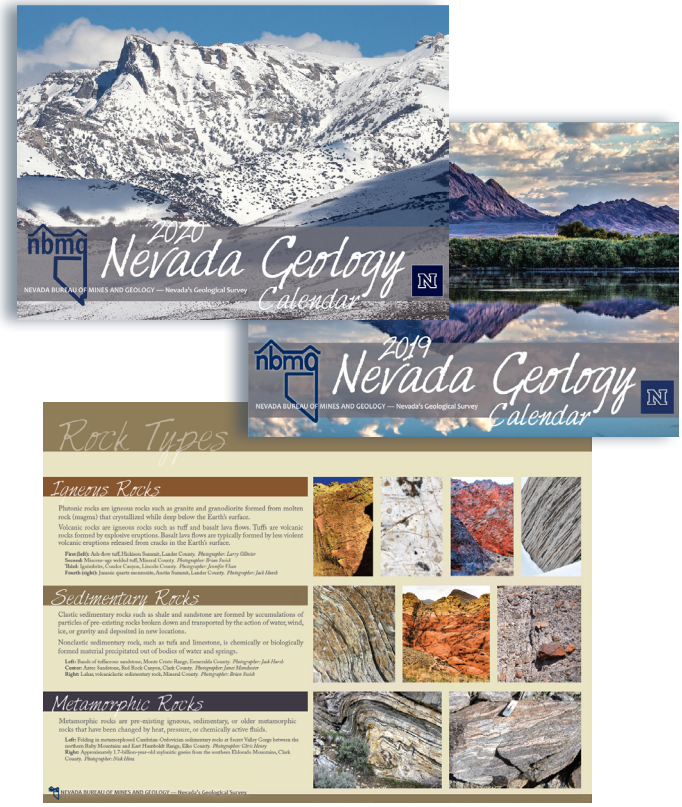
Geologic Tour Guide Book Series

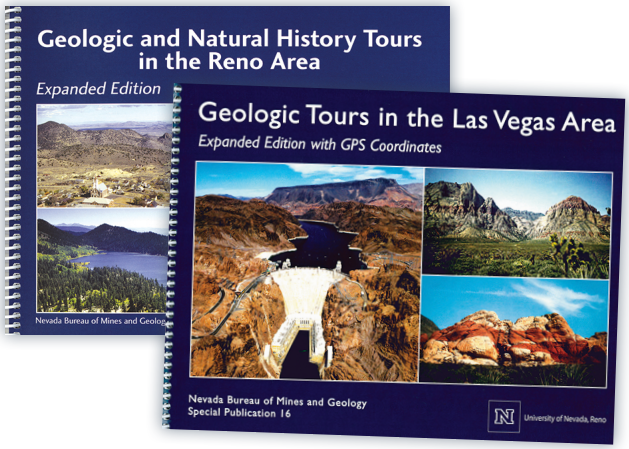
NBMG also produces publications specifically for the general public, such as our popular field guides on the geology and natural history of U.S. Highways 50 and 93, Reno-Carson City-Lake Tahoe, and Las Vegas regions.



Nevada Geology Calendar

NBMG publishes a calendar packed with information on the geology of Nevada. This 12-month calendar is full of beautiful photos highlighting Nevada's scenic wonders and features a different geologic topic each month.





Find additional information about NBMG's tour guide books and the Nevada geology calendars at https://pubs.nbmg.unr.edu/

NBMG ACTIVITIES BY THE NUMBERS 2018–2019

PUBLICATIONS

30
Total number of NBMG publications produced

94
Total number of scientific journals, conference proceedings, guidebooks, and other external publications

42
Number of separate journals, conferences, and books, where NBMG personnel have published

GRANTS

~$5.08M
Grant expenditures in fiscal years 2018 and 2019

75+
Number of active research grants

24
Number of organizations from which grants were received

EDUCATION

33
Graduate and undergraduate students advised

65
Graduate and undergraduate classes taught

ACCOLADES

5
NBMG personnel who serve as Directors of centers/labs at UNR

6
Individual honors and awards earned

COMMUNITY ENGAGEMENT

13
Public presentations by NBMG personnel

21
Field trips led by NBMG personnel

MEDIA

14
Television or Radio appearances/broadcasts

16
Online, magazines, or newspaper article features

PRESENTATIONS

178
Total number of professional presentations given

189
Presentations, abstracts, contract reports, and websites

16
Total number of invited international presentations

ONLINE

230
Posts on the NBMG blog

>22,000
Number of U.S. visitors to NBMG website in one year

60%
Percentage of NBMG website visitors from Nevada

Publications, Reports, Maps, and Books by NBMG in 2018

Bolded names indicate NBMG authors, * indicates first author is a student

*Carlson, C.W., 2018, Geologic map of the Terrill Mountains quadrangle, Churchill and Mineral counties, Nevada: Nevada Bureau of Mines and Geology Map 187, scale 1:24,000, 16 p.

DeMull, T.J., **Davis, D.A.**, Patterson, L.M., and Lenz, J., 2018, Opportunities for precious metals toll processing and copper concentrate processing in Nevada: Nevada Bureau of Mines and Geology Report 57, 44 p.

dePolo, C.M., **Henry, C.D.**, **Zuza, A.V.**, **Micander, R.**, and **Faulds, J.E.**, 2018, Sparkling or still? A tour of geology from Soda Lakes to Stillwater Marsh, Nevada (Guide for the NBMG Earth Science Week Field Trip, October 13, 2018): Nevada Bureau of Mines and Geology Educational Series 63, 25 p.

Faulds, J.E., 2018, Biennial report of the Nevada Bureau of Mines and Geology, 2016–2017: Nevada Bureau of Mines and Geology Open-File Report 18-8, 52 p.

Hinz, N.H., Ramelli, A.R., and **Henry, C.D.**, 2018, Preliminary geologic map of the Mount Rose NW quadrangle, Washoe County, Nevada: Nevada Bureau of Mines and Geology Open-File Report 18-3, scale 1:24,000, 4 p.

Hursh, J.P., **Vlcan, J.M.**, and **Henry, C.D.**, 2018, Nevada geology calendar 2019: Nevada Bureau of Mines and Geology.

Koehler, R., and **Chupik, C.**, 2018, Subsurface trenching investigation in support of the Barrick Goldstrike N. Carlin Trend Structure Project: Nevada Bureau of Mines and Geology Open-File Report 18-2, 18 p.

*Laravie, J.A., 2018, Preliminary geologic map of the Kelly Creek area, Humboldt, Elko, and Lander counties, Nevada: Nevada Bureau of Mines and Geology Open-File Report 18-6, 2 plates, scale 1:24,000, 10 p.

Muntean, J.L., **Davis, D.**, and **Ayling, B.F.**, 2018, The Nevada mineral industry 2017: Nevada Bureau of Mines and Geology Special Publication MI-2017, 212 p.

*McGrew, A., 2018, Geologic map of the Humboldt Peak quadrangle, Elko County, Nevada: Nevada Bureau of Mines and Geology Map 186, scale 1:24,000, 23 p.

Perry, R., and **Visher, M.**, 2018, Major mines of Nevada 2017—mineral industries in Nevada's economy: Nevada Bureau of Mines and Geology Special Publication P-29, 28 p.

*Price, J.G., Price, E.M., and Bryan, D.P., 2018, Scavenger hunt for rocks used to build the Stewart Indian School: Nevada Bureau of Mines and Geology Educational Series 62, 6 p.

Ressel, M.W., and **Dee, S.**, 2018, Preliminary geologic map of the Ravens Nest quadrangle, Elko and Eureka counties, Nevada: Nevada Bureau of Mines and Geology Open-File Report 18-5, scale 1:24,000, 11 p.

Seelye, I.M., Bishop, B.L., **Micander, R.E.**, **Wilson, S.**, 2018, Updated assessment of risks and vulnerability to flood hazards in Nevada [online version]: Nevada Bureau of Mines and Geology Open-File Report 18-1, 16 pages, plus 103 linked pages.

*Wyld, S.J., Nutaitis, J.R., and Wright, J.E., 2018, Preliminary geologic map of the central East Range, Pershing County, Nevada: Nevada Bureau of Mines and Geology Open-File Report 18-7, scale 1:24,000, 14 p.

Zuza, A.V., **Henry, C.D.**, **Ressel, M.W.**, Thorman, C., **Dee, S.**, and Blackmon, J.E., 2018, Preliminary geologic map of the Independence Valley NE quadrangle, Elko County, Nevada: Nevada Bureau of Mines and Geology Open-File Report 18-4, scale 1:24,000, 11 p.

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Bryan, D.P., Pease, R., and **Henry, C.D.**, 2019, Mining history and geology, northern Sierra Nevada: Geological Society of Nevada 2019 Spring field trip guidebook, Special Publication No. 67, 71 p.

Carlson, C., **Koehler, R.D.**, and **Henry, C.D.**, 2019, Preliminary geologic map of the Washoe City quadrangle, Washoe County Nevada: Nevada Bureau of Mines and Geology Open-File Report 19-4, scale 1:24,000, 7 p.

Dee, S., 2019, Geologic map of the Granite Peak quadrangle, Washoe County, Nevada: Nevada Bureau of Mines and Geology Open-File Report 19-2, scale 1:24,000, 3 p.

dePolo, C.M., Pohll, G.M., Carroll, R.W.H., Ryan, K., Rasmussen, B.P., and Malone, P.O., 2019, Flood hazard and mitigation potential for irrigation ditches: Nevada Bureau of Mines and Geology Open-File Report 19-6, 34 p.

Hursh, J.P., **Vlcan, J.M.**, and **Henry, C.D.**, 2019, Nevada geology calendar 2020: Nevada Bureau of Mines and Geology.

Koehler, R.D., and Anderson, J.G., 2019, 2018 working group on Nevada seismic hazards—summary and recommendations of the workshop: Nevada Bureau of Mines and Geology Open-File Report 19-2, 44 p.

Muntean, J.L., and **Davis, D.A.**, 2019, Nevada active mines and energy producers: Nevada Bureau of Mines and Geology Open-File Report 19-1, compilation scale 1:1,000,000.

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Papke, K.G., **Davis, D.A.**, Ross, C., Pedersen, R., **Micander, R.**, and Robison, N., 2019, Mining claim procedures for Nevada prospectors and miners (sixth edition): Nevada Bureau of Mines and Geology Special Publication 6, 73 p.

Perry, R., and **Visher, M.**, 2019, Major mines of Nevada 2018—mineral industries in Nevada's economy: Nevada Bureau of Mines and Geology Special Publication P-30, 28 p.

Ressel, M., **Micander, R.**, **Hursh, J.**, Russell, S., and Sophy, M., 2019, Lode and behold! Geology and natural resources of the Truckee Meadows and Virginia City (Guide for the Earth Science Week Field Trip, October 12, 2019): Nevada Bureau of Mines and Geology Educational Series 65, 25 p.

Ressel, M.W., 2019, Nevada mineral and energy resource exploration survey 2017/2018: Nevada Bureau of Mines and Geology Exploration Survey ES-2018, 20 p.

Zuza, A.V., **Dee, S.**, **Henry, C.D.**, **Ressel, M.W.**, and Thorman, C., 2019, Geologic map of the Independence Valley NW quadrangle, Elko County, Nevada: Nevada Bureau of Mines and Geology Open-File Report 19-3, scale 1:24,000, 18 p.

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Arguello, R., Schwendig, J., Lowry, T., Sabin, A., Blake, K., Lazaro, M., Anderson, S., **Ayling, B.F.**, Tiedeman, A., and **Hinz, N.H.**, 2018, Deep direct-use geothermal—development of a demand side model for the Hawthorne, Nevada area: Geothermal Resources Council Transactions, Davis, CA, v. 42, 7 p., https://www.geothermal-library.org/index.php?mode=pubs&action=view&record=1033977.

Ayling, B.F., Blankenship, D., Sullivan, P., Kennedy, M., Majer, E., Villavert, M., Sonnenthal, E., Tang, J., Dobson, P., **Hinz, N.**, **Faulds, J.**, **Hammond, W.**, Mlawsky, E., Blake, K., Tiedeman, A., Sabin, A., Lazaro, M., Akerley, J., Nordquist, J., Sophy, M., Siler, D., Kaven, J.O., Phelps, G., Hickman, S., Glen, J., Williams, C., Robertson-Tait, A., Hackett, L., Pettitt, W., Riahi, A., Blanksma, D., Damjanac, B., Hazzard, J., Eneva, M., Witter, J. B., Queen, J., and Fortuna, M., 2018, Phase 2 update for the Fallon FORGE site, Nevada, USA in Proceedings of the 43rd workshop on geothermal reservoir engineering, Stanford Geothermal Workshop, Palo Alto, CA: Stanford University SGP-TR-213, 13 p., https://pangea.stanford.edu/ERE/pdf/IGAstandard/SGW/2018/Ayling.pdf.

Blewitt, G., 2018, GPS imaging of Earth's flex and flow: NASA Earth Surface and Interior Focus Area Progress Report.

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Blewitt, G., **Hammond, W.C.**, and **Kreemer, C.W.**, 2018, Harnessing the GPS data explosion for interdisciplinary science: Eos, v. 99, https://doi.org/10.1029/2018EO104623.

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Colgan, J.P., John, D.A., **Henry, C.D.**, and Watts, K.E., 2018, Insights into the emplacement of upper-crustal plutons and their relationships to large silicic calderas, from field relationships, geochronology, and zircon trace element geochemistry in the Stillwater-Clan Alpine caldera complex, western Nevada, USA: Journal of Volcanology and Geothermal Research, v. 349, p. 163–176.

Cousens, B.L., **Henry, C.D.**, Stevens, C., Varve, S., Wetmore, S., and John, D.A., Igneous rocks in the Fish Creek Mountains and environs, Battle Mountain area, north-central Nevada—a microcosm of Cenozoic igneous activity in the northern Great Basin: Earth Science Reviews, v. 192, p. 403–444.

Dee, S., Ramelli, A.R., and **Koehler, R.D.**, 2018, Pilot paleoseismic investigation of faults in the North Valleys, Reno, NV: Final Technical Report to the U.S. Geological Survey National Earthquake Hazards Reduction Program, USGS External Award #G16AP00060.

dePolo, C.M., Blakely, M., Ghan, T., Hellmer, W., Stolyarov, G., and West, K., 2018, Final Report of the Unreinforced Masonry Building Committee of the Nevada Earthquake Safety Council, 21 p.

Earney, T.E., Schermerhorn, W.D., Glen, J.M., Peacock, J., Craig, J.W., **Faulds, J.E.**, **Hinz, N.H.**, and Siler, D., 2018, Geophysical investigations of a potential blind geothermal system in southern Gabbs Valley, Nevada: Geothermal Resources Council Transactions, v. 42, p. 1369–1382.

Faulds, J.E., Craig, J.W., Coolbaugh, M.F., **Hinz, N.H.**, Glen, J.M., Deoreo, S., 2018, Searching for blind geothermal systems utilizing play fairway analysis, western Nevada: Geothermal Resources Council Bulletin, v. 47, p. 34–42.

Faulds, J.E., Craig, J.W., **Hinz, N.H.**, Coolbaugh, M.F., Glen, J.M, Earney, T.E., Schermerhorn, W.D., Peacock, J., Deoreo, S.B., and Siler, D.L., 2018, Discovery of a blind geothermal system in southern Gabbs Valley, western Nevada, through application of the play fairway analysis at multiple scales: Geothermal Resources Council Transactions, v. 42, p. 452–465.

Faulds, J.E., **Hinz, N.**, Siler, D., Glen, J., **Ayling, B**., **Mlawsky, E.**, and the Fallon FORGE team, 2018, Conceptual geologic model of the Fallon FORGE site: Department of Energy Final report for Phase 2 of FORGE, 174 p. (and multiple appendices).

Faulds, J.E., **Hinz, N.H.**, Siler, D.L., Glen, J.M., Fortuna, M.A., Queen, J.H., Blake, K., and Fallon FORGE team, 2018, Update on the stratigraphic and structural framework of the proposed Fallon FORGE site, Nevada: Geothermal Resources Council Transactions, v. 42, p. 1026–1046.

Husson, L., Bodin, T., Spada, G., Choblet, G., and **Kreemer, C.W.**, 2018, Bayesian surface reconstruction of geodetic uplift rates—mapping the global fingerprint of glacial isostatic adjustment: Journal of Geodynamics, 122, p. 25–40.

Koehler, R.D., 2018, Active faulting in the North Valleys region of Reno, Nevada—a distributed zone within the northern Walker Lane:

Geomorphology, v. 326, p. 38–53, https://doi.org/10.1016/j.geomorph.2018.09.015.

*Kraal, K., **Ayling, B.F.**, Calvin, W.M., Browning, D., 2018, Comparison of a portable field spectrometer and automated imaging on geothermal drill core—a pilot study: Geothermal Resources Council Transactions, Davis, CA, v. 42, 13 p., https://www.geothermal-library.org/index.php?mode=pubs&action=view&record=1034001.

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Roberts, B., **Blewitt, G.**, Dailey, C., Derevianko, A., 2018, Search for transient ultralight dark matter signatures with networks of precision measurement devices using a Bayesian statistics method: Physical Review D, v. 97 (083009), no. 8, 20 p., https://doi.org/10.1103/PhysRevD.97.083009.

Robertson-Tait, A., Camacho-Lopez, T., Sullivan, P., Villavert, M., Tang, J., Blankenship, D., Kennedy, M., Majer, E., Nordquist, J., Akerley, J., **Ayling, B.F.**, **Faulds, J.E.**, and Roque-Rivera, R., 2018, Communications and outreach for public acceptance of complex technical projects—experience from the Fallon FORGE project in Proceedings of the 43rd workshop on geothermal reservoir engineering, Stanford Geothermal Workshop, Palo Alto, CA: Stanford University SGP-TR-213, 10 p., https://pangea.stanford.edu/ERE/pdf/IGAstandard/SGW/2018/Robertsontait.pdf.

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Siler, D.L., **Faulds, J.E.**, Glen, J.M., **Hinz, N.H.**, Witter, J.B., and Fallon FORGE team, 2018, New data yield new geologic insights at the Fallon FORGE site, Carson Sink region, Nevada: Geothermal Resources Council Transactions, v. 42, p. 1173–1183.

Siler, D.L., **Hinz, N.H.**, and **Faulds, J.E.**, 2018, Stress concentrations at structural discontinuities in active fault zones in the western United States—implications for permeability and fluid flow in geothermal fields: Geological Society of America Bulletin, v. 130, no. 7-8, p. 1273–1288, https://doi.org/10.1130/B31729.1.

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Faulds, J.E., invited talk (keynote address), Refining exploration strategies for geothermal systems in extensional to transtensional settings—lessons learned from the Great Basin region, western USA: Keynote address for Montana Mining and Mineral Symposium, Butte, Montana, October 10, 2019.

Faulds, J.E., invited talk, Geothermal potential in the Fallon Range Training Complex (FRTC) land withdrawal areas, Nevada: Nevada Governor's Office of Energy, Carson City, April 26, 2019.

Faulds, J.E., invited talk, Nevada is in more hot water—technological advances for characterization and development of geothermal systems in the Great Basin region, western U.S.: Talk given as part of duties for serving on panel on "Characterization and Management of the Subsurface" for National Academy of Sciences Committee on Earth Resources, October 8, 2019, Washington, DC.

Faulds, J.E., invited, served on Mining/Renewable Energy Panel at the Annual Meeting of the Nevada Mining Association—discussed potential synergies between the mining and renewable energy industries—provided brief summary and took questions from a moderate and the audience (September 7, 2019). Reported in Nevada Independent on September 10.

Hammond, W.C., **Kreemer, C.W.**, Zaliapin, I., **Blewitt, G.**, 2019, Drought-triggered magmatic inflation, crustal strain, and seismicity near the Long Valley Caldera, central Walker Lane: Journal of Geophysical Research, v. 124, https://doi.org/10.1029/2019JB017354.

*Kraal, K.O., and **Ayling, B.F.**, 2019, Hyperspectral characterization of Fallon FORGE Well 21-31—new data and technology applications in Proceedings of the 44th workshop on geothermal reservoir engineering, Stanford Geothermal Workshop, Palo Alto, CA: Stanford University SGP-TR-214, 15 p. https://pangea.stanford.edu/ERE/pdf/IGAstandard/SGW/2019/Kraal.pdf

Murray, J., Bartlow, N., Bock, Y., Brooks, B.A., Foster, J., Freymueller, J., **Hammond, W.C.**, Hodgkinson, K., Johanson, I., Lopez-Venegas, A., Mann, D., Mattioli, G.S., Melbourne, T., Mencin, D., Montgomery-Brown, E., Murray, M.H., Smalley, R., and Thomas, V., 2019, Regional global navigation satellite system networks: Seismological Research Letters, v. 91, no. 2A, p. 552–572, https://doi.org/10.1785/0220190113.

Sandwell, D.T., Bettadpuri, S., **Blewitt, G.**, Braun, J.J., Cazenave, A., Glenn, N., Larson, K., Nerem, R.S., Sneed, M., and Velicogna, I., 2019, Evolving the geodetic infrastructure to meet new scientific needs: The National Academies Press, 169 p.

Siler, D.L., Burns, E.R., and **Faulds, J.E.**, 2019, Can geologic factors be predictive for distinguishing between productive and non-productive wells?:

Geothermal Resources Council Transactions, v. 43, p. 884–901.

Siler, D.L., **Faulds, J.E.**, Glen, J.M.G., Hinz, N.H., Witter, J.B., Blake, K., Queen, J., and Fortuna, M., 2019, Three-dimensional geologic map of the southern Carson Sink, Nevada, including the Fallon FORGE area: U.S. Geological Survey Scientific Investigations Map 3437, pamphlet 22 p. (includes video), https://doi.org/10.3133/sim3437.

Siler, D.L., **Faulds, J.E.**, **Hinz, N.H.**, Dering, G.M., Edwards, J.H., and Mayhew, B., 2019, Three-dimensional geologic mapping to assess geothermal potential—examples from Nevada and Oregon: Geothermal Energy, v.7, no. 2, 32 p., https://doi.org/10.1186/s40517-018-0117-0.

Wannamaker, P., **Faulds, J.**, Kennedy, B.M., Maris, V., Siler, D., Ulrich, C., and Moore, J., 2019, Integrating magnetotellurics, soil gas geochemistry, and structural analysis to identify hidden, high enthalpy, extensional geothermal systems in Proceedings of the 44th workshop on geothermal reservoir engineering, Stanford Geothermal Workshop, Palo Alto, CA: Stanford University SGP-TR-214, p. 191–209.

Zuza, A.V., Cao, W., **Hinz, N.H.**, DesOrmeau, J., Odlum, M., Stockli, D.F., 2019, Footwall rotation in a regional detachment fault system—evidence for horizontal-axis rotational flow in the Miocene Searchlight pluton, NV: Tectonics, v. 38, no. 7, p. 2506–2539.

Research Grants Active in 2018 and 2019

Clark County Building Department: Earthquake fault analysis of Las Vegas Valley, 8/16–3/21, $1,714,704, **dePolo, C.M.**, **Dee, S.**, Taylor, W.J., and **Faulds, J.E.**

Department of Energy: Applications of machine learning techniques to geothermal play fairway analysis in the Great Basin region, Nevada: 8/19–7/21, $499,980, **Faulds, J.**

Department of Energy: Discovering blind geothermal systems in the Great Basin region—an integrated geologic and geophysical approach for establishing geothermal play fairways—phase 3: 10/17–9/19, $1,500,000, **Faulds, J.E.**, **Hinz, N.**

Department of Energy: Frontier Observatory for Research in Geothermal Energy (FORGE)—Fallon, Nevada, Phase 2B, 3/17–9/19, $8,500,000, **Faulds, J.E.**, **Ayling, B.**, **Hinz, N.**, Sandia National Laboratories.

Department of Energy: Poroelastic tomography by adjoint inverse modeling of data from seismology, geodesy, and hydrology, 10/1, $65,154, **Kreemer, C.W.**

Federal Emergency Management Agency: University of Nevada, Reno, Earthquake Hazards and Consequences in Nye County, $50,404, **dePolo, C.M.**

Idaho National Laboratory: Geodetic analysis for Idaho National Lab SSHAC L3 project: 9/19–6/20, $54,269, **Hammond, W.C.**

NASA ROSES: Earth Surface and Interior, GPS imaging of solid Earth's flex and flow, 7/16–6/19, $416,949, **Blewitt, G.**, **Hammond, W.C.**, **Kreemer, C.W.**

NASA ROSES: Earth Surface and Interior, GPS imaging of time-variable Earth deformation for multi-disciplinary science, 7/19–6/22, $477,585, **Blewitt, G.**, **Hammond, W.C.**, **Kreemer, C.W.**

NASA Sea Level Change Team: Global interconnections of cryosphere and solid Earth, sea-level change and ice mass balance, 10/17–12/20, $203,876, **Blewitt, G.**, **Hammond, W.C.**

NASA Sea Level Change Team: Using satellite measurements to improve regional estimates of the impacts of sea level change, 8/17–4/20, $225,520, **Hammond, W.C.**, **Blewitt, G.**

NASA, Jet Propulsion Laboratory: Global interconnections of cryosphere and solid Earth, sea-level change and ice mass balance, 3/18–3/21, $203,875, **Blewitt, G.**, **Hammond, B.C.**

NASA: Earth Surface and Interior, GPS imaging of solid Earth's flex and flow, 7/16–6/19 $416,950, **Kreemer, C.W.**, **Blewitt, G.**, **Hammond, B.C.**

NASA: Earth Surface and Interior, GPS imaging of time-variable Earth deformation for multi-disciplinary science, 7/19–6/22, $477,585, **Kreemer, C.W.**, **Blewitt, G.**, **Hammond, B.C.**

National Science Foundation Earthscope, Collaborative Research: Using GPS to unravel the long-term kinematics and dynamics of the American southwest from an ever-changing deformation field, 6/16–11/20, $246,500, **Kreemer, C.W.**, Bennett, R.A., **Blewitt, G.**

National Science Foundation Physics: Topological dark matter search - REU, 8/18–7/19, $5,000, **Blewitt, G.**

National Science Foundation Tectonics: Using structural fabrics and thermochronology to document extensional footwall rotation—insights from the tilted Miocene Searchlight pluton, NV, 8/18, $186,406, **Zuza, A.V.**, Cao, W.

National Science Foundation, RAPID: Collaborative: Response to the Searles Valley earthquake sequence, 8/18–7/20, $19,000 (UNR portion). **Hammond, W.C.**

National Science Foundation: Dark matter search with atomic clocks onboard GPS satellites and networks of precision measurement devices, 8/18–8/21, $439,997, **Blewitt, G.**, Derevianko, A.

National Science Foundation: Neotectonics and structural development of the northern Walker Lane, 7/14–8/18, $456,220, Wesnousky, S., **Faulds, J.E.**

Nevada Division of Emergency Management and Federal Emergency Management Agency: Predisaster Mitigation 2018—Nevada enhanced hazard mitigation plan update, 5/18–10/18, $53,334, **dePolo, C.M.**, **Faulds, J.E.**, **Vlcan, J.**

Nevada Division of Minerals: NBMG sample curation, MI reports, and special projects (Special projects include mineral resources database

and geothermal structural settings database), 7/19–6/21, $180,000, **Faulds, J.E.**

Nevada Division of Minerals: NBMG sample curation, MI reports, and special projects, 8/17–6/19, $170,000, **Faulds, J.E.**

Nevada Office of Nuclear Projects: Assessment of previous seismic hazard studies, Yucca Mountain, Nevada— scoping report on applications of new technologies to reduce critical data gaps, 11/19–6/21, $100,000, **Faulds, J.E.**, **Koehler, R.D.**, **dePolo, C.**, **Hammond, B.**, and **Kreemer, C.**

Raser Power Systems, LLC: Structural assessment and play fairway analysis of the Desert Queen geothermal area, Churchill County, Nevada, 8/19–7/21, $100,255, **Faulds, J.E.**

U.S. Department of Energy: Deep direct-use feasibility study for the Hawthorne Nevada Army Depot and surrounding community, 10/17–9/19, $560,000, **Ayling, B.F.**, Lowry, T., Sabin, A., Arguello, R., **Hinz, N.H.**

U.S. Department of Energy: Fallon FORGE project, phase 2, 9/16–12/18, $690,000, **Ayling, B.F.**, **Faulds, J.E.**, **Hinz, N.H.**

U.S. Department of Energy: National Geothermal Academy 2019, 12/18, $50,000, **Ayling, B.F.**

U.S. Department of State: Strengthening the capacity of foreign countries to develop their geothermal energy resource base, 10/17–9/20, $1,199,822, **Ayling, B.F.**, **Hinz, N.H.**

U.S. General Services Administration and National Science Foundation, AGeS2 Proposal: Prelude to the 'plano'—assessing the contribution of Jurassic crustal thickening to growth of the Cretaceous Nevadaplano, 4/19, $10,000, *Levy, D.A., **Zuza, A.V.**

U.S. Geological Survey EDMAP, Reconstructing the Last Chance thrust system, eastern CA—implications for the Paleozoic evolution of the western margin of North America, 4/18, $17,350, **Zuza, A.V.**

U.S. Geological Survey Geodetic Networks: University of Nevada, Reno, supplement—western Great Basin geodetic network operations, 2015–2020, 9/18–2/20, $94,227, **Hammond, W.C.**

U.S. Geological Survey, Earthquake Direct State Assistance Grant: Development of a Nevada specific post-earthquake technical clearinghouse web site and operations plan, 11/19–12/20, $45,000, **Koehler, R.D.**

U.S. Geological Survey, Geodetic Networks program: Second supplemental funding for MAGNET GPS network to address deferred maintenance of GPS receivers, 9/19–2/20, $145,000, **Hammond, W.C.**

U.S. Geological Survey, Geodetic Networks program: Western Great Basin geodetic network operations, MAGNET 2020–2025, 03/20–2/25, $361,196, **Hammond, W.C.**, **Blewitt, G.**

U.S. Geological Survey, National Earthquake Hazards Reduction Program: Fault trace mapping and paleoseismic investigation of earthquake history and recurrence along the Bonham Ranch fault zone, north of Reno, Nevada, 11/19–12/20, $64,602, **Koehler, R.D.**, **Dee, S.**

U.S. Geological Survey, National Earthquake Hazards Reduction Program: Nevada Quaternary fault database—a new publically accessible web-based resource, 11/18, $58,490, **Koehler, R.D.**, **Vlcan, J.**

U.S. Geological Survey, National Earthquake Hazards Reduction Program: New lidar mapping and paleoseismic characterization of the Petersen Mountain fault zone, 1/18–12/18, $60,607, **Dee, S.**

U.S. Geological Survey, National Earthquake Hazards Reduction Program: Paleoearthquake trenching investigation of the Dog Valley fault, $68,537, Pierce, I., Wesnousky, S., **Koehler, R.D.**

U.S. Geological Survey, National Earthquake Hazards Reduction Program: Paleoseismic investigation of the Eglington fault, Clark County, NV, 1/18–12/18, $40,000, **Dee, S.**

U.S. Geological Survey, National Earthquake Hazards Reduction Program: Pilot paleoseismic investigation of faults in the North Valleys, Reno, NV, 3/16–6/18, $59,375, **Dee, S.**

U.S. Geological Survey, National Earthquake Hazards Reduction Program: University of Nevada, Reno, On the relationship between seismicity and geodetic strain rates in the central and eastern U.S., 1/18–12/18, $79,983, **Kreemer, C.W.**, Zaliapin, I.

U.S. Geological Survey, National Earthquake Hazards Reduction Program: Western Great Basin geodetic network operations cooperative agreement 2015–2020, 3/15–2/20, $327,854, **Hammond, W.C.**, **Blewitt, G.**

U.S. Geological Survey, National Geological and Geophysical Data Preservation Program: NBMG 2019 data preservation and critical minerals studies, 9/19–8/20, $71,239.77, **dePolo, C.M.**, **Davis, D.**

U.S. Geological Survey, National Geological and Geophysical Data Preservation Program: Preservation of mining documents and thin sections, 9/18–8/19, $35,407, **dePolo, C.M.**, **Davis, D.**

U.S. Geological Survey, STATEMAP 2018, 7/18–7/19, $164,518, **Dee, S.**

U.S. Geological Survey: Earth MRI geologic mapping assessment cooperative agreement, 10/19–9/21, $400,000, **Faulds, J.E.**

U.S. Geological Survey: Geologic mapping in the Mountain Pass REE focus area, USGS Earth MRI Initiative, 10/19–9/21, $100,000, **Dee, S.**, **Faulds, J.E.**

U.S. Geological Survey: Investigating unrecognized earthquake faults in the Carson domain, Walker Lane, 9/18, $40,499, **Zuza, A.V.**

U.S. Geological Survey: STATEMAP 2019, 9/19–9/20, $157,631. **Dee, S.**

University of Nevada, Reno, Office of the Provost: UNR faculty international activities grant, 7/18–5/19, $1,400, **Hammond, W.C.**

NBMG Honors, Awards, and Special Appointments in 2018 and 2019

Ayling, B.F., Board of Directors, Geothermal Resources Council.

Ayling, B.F., Committee Member, National Academy of Sciences, Engineering and Medicine: Earth Resources Board.

Ayling, B.F., Study Committee Member, Future directions for the U.S. Geological Survey's Energy Resources Program, National Academy of Sciences, Engineering and Medicine.

Blewitt, G., Committee Member, GGOS Committee on Essential Geodetic Variables.

Blewitt, G., Committee Member, IAG Resolutions Committee for the 27th International Union of Geodesy and Geophysics General Assembly.

Blewitt, G., Committee Member, National Academy of Sciences Committee on Evolving the Geodetic Infrastructure to Meet New Scientific Needs.

dePolo, C.M., Chairman, Nevada Hazard Mitigation and Planning Committee

dePolo, C.M., Chairman, Unreinforced Masonry Building Committee (2016–2018).

dePolo, C.M., Commission Member, Nevada Resilience Commission.

dePolo, C.M., Commission Member, Nevada Resilience Commission.

dePolo, C.M., Committee Member, Nevada Earthquake Safety Council.

dePolo, C.M., Geological Society of America Fellow, 2019.

Faulds, J.E., Chair, Geothermal Resources Council (GRC) Annual Meeting Field Trip, 2020 Annual Meeting of GRC.

Faulds, J.E., Erskine Visiting Teaching Fellowship from the University of Canterbury (UC) in Christchurch, New Zealand.

Hammond, W.C., Committee Member, National Academy of Science, Board on Earth Science and Resources.

Micander, R., **Seelye, I.**, Ryan, K., and Johnson, G., 1st Place "Artographic" category for cartographic work on MyHAZARDS-NEVADA: using the web map to identify hazards from earthquakes, floods, fires, and other natural hazards, Nevada Geographic Information Society, 2018

Micander, R., **Seelye, I.**, Ryan, K., and Johnson, G., 1st Place "People's Choice" category for cartographic work on MyHAZARDS-NEVADA: using the web map to identify hazards from earthquakes, floods, fires, and other natural hazards, Nevada Geographic Information Society, 2018

Micander, R., Nevada State Representative, National States Geographic Information Council (NSGIC).

Micander, R., Nevada State Representative, National States Geographic Information Council (NSGIC).

Seelye, I., and McGrew, A., 1st Place "Cartographic" category, Geologic Map of the Humboldt Peak Quadrangle, Nevada Geographic Information Society, 2018.

Vlcan, J., Board Member, Nevada Geographic Information Society (2015–2018).

Zuza, A.V., Exceptional Reviewer, Lithosphere journal from Geological Society of American.

Masters Theses and Dissertations in 2018 and 2019

ADVISOR: Faulds, J.E.

Craig, Jason W., 2018, Discovery and analysis of a blind geothermal system in southeastern Gabbs Valley, western Nevada [M.S. Thesis]: University of Nevada, Reno.

McConville, Emma G., 2018, Detailed analysis of geothermal potential in Crescent Valley, north-central Nevada [M.S. Thesis]: University of Nevada, Reno.

McLachlan, Holly S., 2018, Stratigraphy, structure, and fluid flow at the Soda Lake geothermal field, western Nevada [Ph.D. Dissertation]: University of Nevada, Reno.

ADVISOR: Ressel, M.W.

Aliaga, Gabriel E., 2018, Igneous geology of the keystone window, simpson park mountains, Eureka County, Nevada: Age, distribution, composition, and relationship to Carlin-style gold mineralization [M.S. Thesis]: University of Nevada, Reno.

Freedman, David J., 2018, Igneous and hydrothermal geology of the Central Cherry Creek range, White Pine County, Nevada [M.S. Thesis]: University of Nevada, Reno.

Claypoole, Micah N., 2018, Mineral ridge: A late cretaceous orogenic gold system in the Miocene Silver Peak-Ione Mountain metamorphic core complex [M.S. Thesis]: University of Nevada, Reno.

ADVISOR: Muntean, J.L.

Bonner, W.M., 2019, Spatial and temporal relationships between Carlin-style gold and polymetallic mineralization at the deep cove gold-silver deposit, Lander County, Nevada [M.S. Thesis]: University of Nevada, Reno.

ADVISOR: Koehler, R.

Chupik, C.M., 2019, Quaternary mapping and paleoseismic assessment of the Warm Springs Valley fault in the northern Walker Lane, Nevada [M.S. Thesis]: University of Nevada, Reno.

Selected Media Reports in 2018 and 2019

Gold Fever: The Last Prospectors, Tahoe Quarterly, (February 2018). https://tahoequarterly.com/best-of-tahoe-2018/the-last-prospectors

Energy wells plugged as Hawaii's volcano sends lava nearby, Physics.Org, (May 22, 2018). https://phys.org/news/2018-05-lava-hawaii-power.html

Are Nevada's gold mines near the end of the rainbow?, Mining Quarterly-Elko Daily Free Press, (August 1, 2018).

https://elkodaily.com/opinion/editorial/editorial-are-nevada-s-gold-mines-near-the-end-of-the-rainbow/article_e4fa561e-38f9-5e42-b412-e078e11bb0bb.html

Engineered geothermal systems have wide potential as a renewable energy source, Physics Today, (September 2018). https://physicstoday.scitation.org/doi/10.1063/PT.3.4017

IndyMatters Episode 69: State Geologist Jim Faulds talks geothermal and the chaotic origin story of minerals in Nevada, The Nevada Independent, (September 25, 2018). https://thenevadaindependent.com/podcast/indymatters-episode-69-state-geologist-jim-faulds-talks-geothermal-and-the-chaotic-origin-story-of-minerals-in-nevada

Move over, San Andreas: There's an ominous new fault in town, Wired Magazine, (April 18, 2019). https://www.wired.com/story/walker-lane-move-over-san-andreas-fault/

KNPR interview (public radio station in Las Vegas): Interviewed on theory that Walker Lane may be heir apparent to the San Andreas fault, (April 29, 2019).

Nevada in More Hot Water: Geothermal Industry Gets a Boost with Discoveries of 'Blind Systems', Nevada Today, (May 21, 2019). https://www.unr.edu/nevada-today/news/2019/geothermal-success

Seismic Nevada: Sequence of 60 earthquakes in Sun Valley, Washoe Valley, College of Science leads effort to monitor, research, assess earthquake hazards, Nevada Today, (June 17, 2019).

Earth's Heat Gives States Another Option for Clean Energy Goals", Bloomberg Environment and Energy, (July 15, 2019). https://news.bloomberglaw.com/environment-and-energy/earths-heat-gives-states-another-option-for-clean-energy-goals

"Indy Environment: Earthquakes, Yucca Mountain and Why Everyone is Talking about Walker Lane, The Nevada Independent, (July 25, 2019). https://thenevadaindependent.com/article/indy-environment-earthquakes-yucca-mountain-and-why-everyone-is-talking-about-walker-lane

Nevada's First Recorded Earthquake Death? This Could Be It, Caused by Ridgecrest Temblors, Los Angeles Times, (August 6, 2019). https://www.latimes.com/california/story/2019-08-06/ridgecrest-earthquakes-nevada-pahrump-man

Panel considers benefits—and challenges—of placing solar projects on mine sites, The Nevada Independent, (September 10, 2019). https://thenevadaindependent.com/article/panel-considers-benefits-and-challenges-of-placing-solar-projects-on-mine-sites

Geologist gets national attention for plate tectonics theory, KOLO (Channel 8-Reno), (September 16, 2019). https://www.kolotv.com/content/news/Geologist-gets-national-attention-for-plate-tectonics-theory--560520191.html

Blue Dot 159: A New Plate Boundary In The Making? The Walker Lane, North State Public Radio, (September 20, 2019). https://www.mynspr.org/post/blue-dot-159-new-plate-boundary-making-walker-lane#stream/0

Biggest-Ever BLM Geothermal Lease Sale Reaps $638,000 in Nevada, California Energy Markets, (September 20, 2019). https://www.newsdata.com/california_energy_markets/southwest/biggest-ever-blm-geothermal-lease-sale-reaps-638-000-in-nevada/article_eda840a8-dbfa-11e9-b9d1-c708fb447f3c.html

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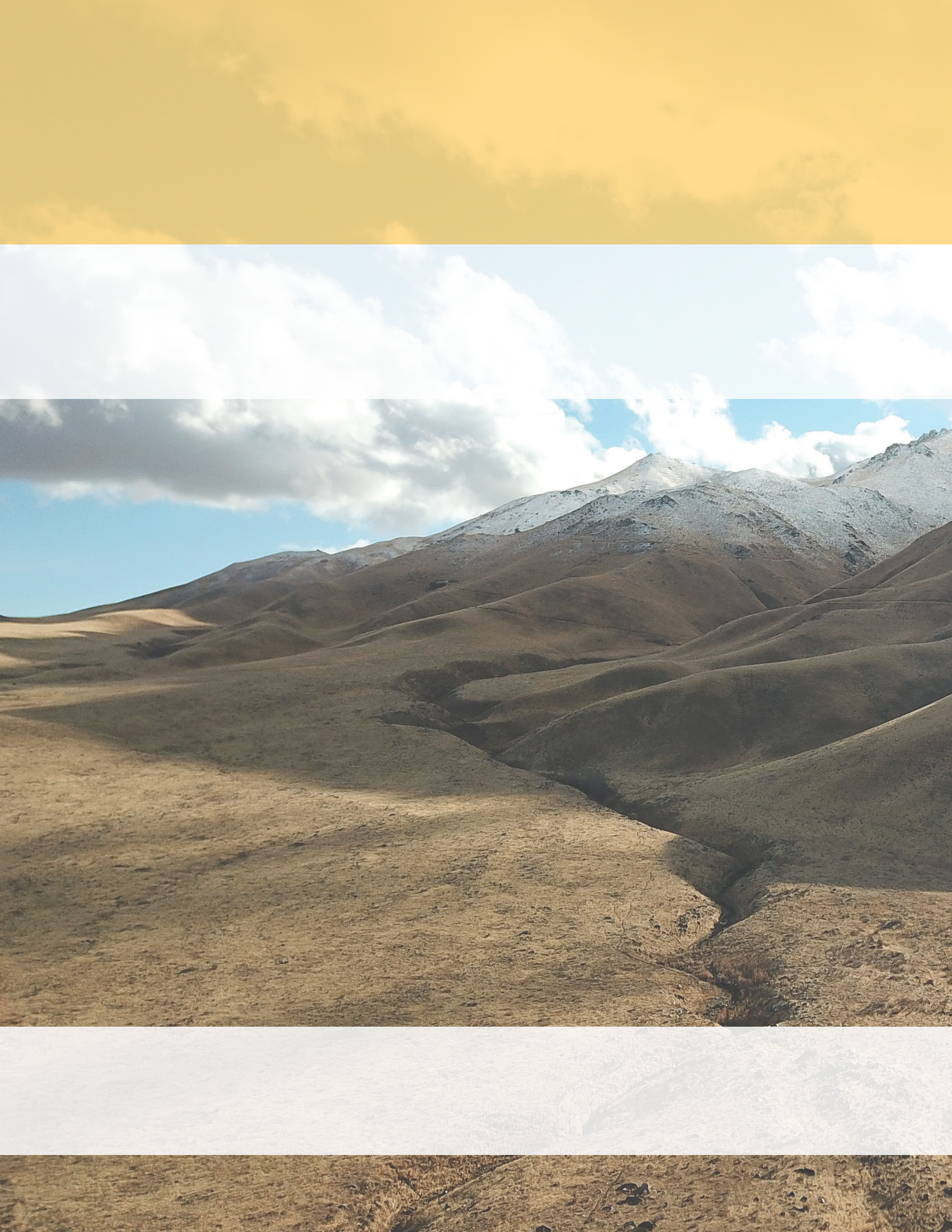
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