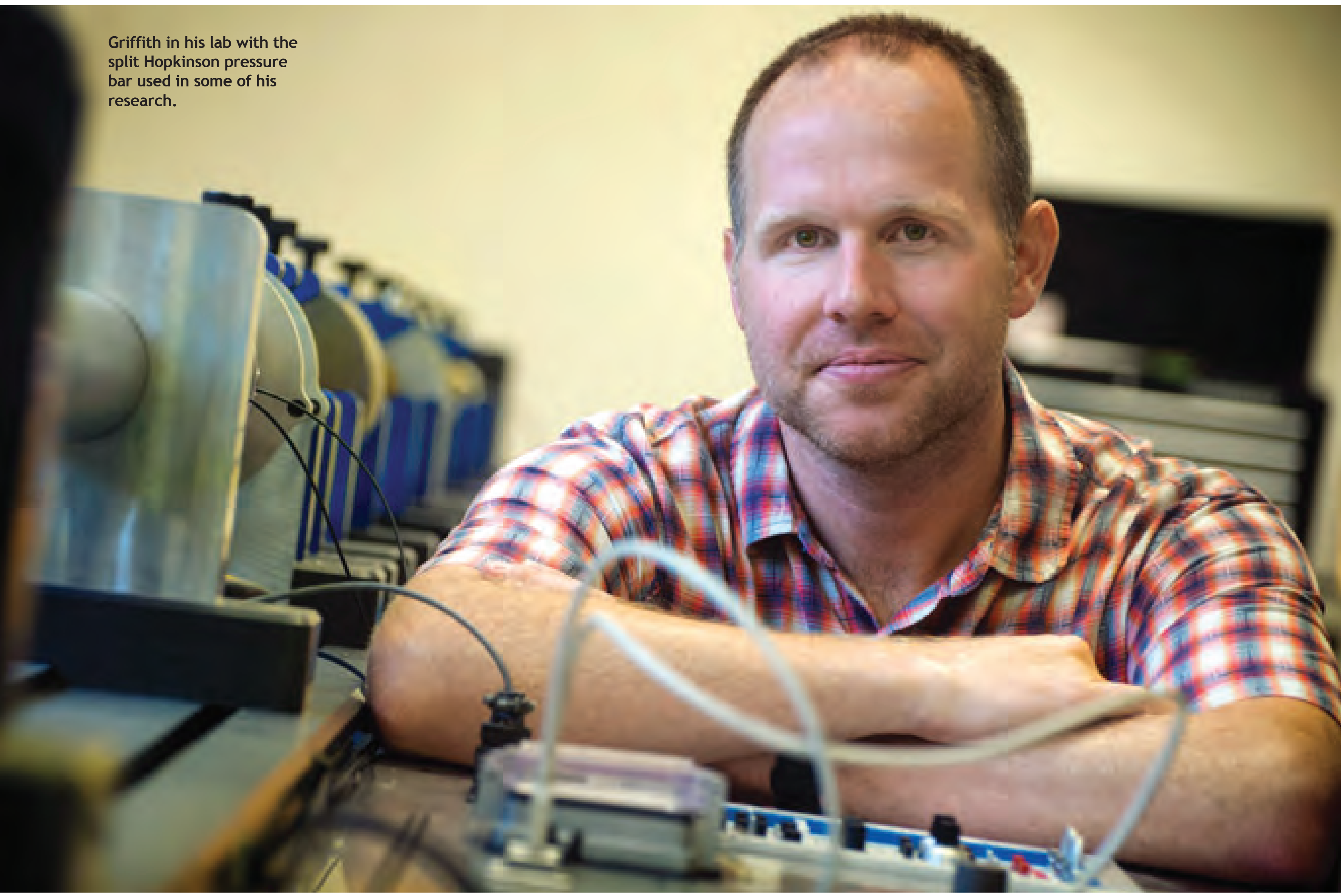
Impulsive Force



Griffith in his lab with the split Hopkinson pressure bar used in some of his research.

Armed with a prestigious CAREER grant from the National Science Foundation, Ashley Griffith is studying what happens to rock when it's exposed to sudden, violent processes at extremely fast speeds.

By Greg Pederson

Geologists and geophysicists know a lot about the havoc that Earth's slow-moving tectonic plates can wreak on rock structures over time. Numerous studies have focused on how this slow movement gradually loads earthquake-generating faults with stress until they fail. This constantly building stress and subsequent failure leads to the "slip" associated with earthquakes and other structural failures.

But what happens to rock structures which are subjected to extremely fast loading rates – rates which characterize the progression of energy found in earthquakes, meteor strikes, explosions or other impacts? Comparatively very little research has focused on understanding the deformation of rocks when they undergo short-lived, but extreme, high loading-rate conditions. That's something that Ashley Griffith is working to change.

Griffith, a UT Arlington assistant professor in earth and environmental sciences, is leading a study of the effects of fast loading rates on the structure of rocks, funded by a $400,000 grant from the National Science Foundation's Faculty Early Career Development (CAREER) Program. CAREER grants are the NSF's most prestigious awards and support junior faculty who exemplify the role of teacher-scholars through outstanding research, excellent education and the integration of education and research within the context of the mission of their organizations.

"Most laboratory research focused on rock failure has been limited to experiments utilizing slow loading rates," Griffith said. "However, many natural processes that pose significant risk for humans – such as earthquakes and extraterrestrial impacts, and risks associated with human activities such as explosions and mine failures – occur at rates which are hundreds to thousands of times faster than are typically simulated in the laboratory.

"As a result, little experimental data exists to confirm or calibrate theoretical models explaining the connection between these dramatic events and the pulverized rocks found in fault zones, impact, or explosion sites. Therefore, I'm undertaking a combined experimental and field investigation of brittle rock failure in both earthquake and impact environments."

The project employs a combination of research methods. Griffith is examining clues left in the "rock record" for the effects of catastrophic events and comparing them to rocks that are deformed under experimental conditions in the lab. One of the instruments Griffith and his students are using in his lab is a split Hopkinson pressure bar which measures how much an object is deformed when a force is rapidly applied to it.

In a split Hopkinson bar, a material sample is positioned between two bars and a "striker" – such as a projectile accelerated by compressed air - strikes the first bar, causing an elastic, longitudinal wave pulse to travel down the bars. This pulse runs through the first bar; part of the pulse is reflected at the bar end, while the other part runs through the material sample into the second bar. Gauges installed on the bars' surfaces measure the strains caused by the elastic wave pulse.

"Our goal is to look at how a rock behaves in response to fast loading rates and relate that behavior to its mineral composition and microscopic structure," Griffith said. "We believe the characteristics are linked. If that proves true, this work could allow scientists to better predict the consequences of earthquakes and impact events based on the rock structure in individual areas and furthermore allow engineers to design more effective structures to withstand the pressures in mining, petroleum and military environments."

In addition to the research portion of the project, the CAREER grant also includes an education component. Griffith is partnering with Teach For America (TFA) – a national program which recruits college graduates to teach for at least two years in secondary schools in economically disadvantaged communities – to create the TFA Rockcorps. The initiative brings area secondary school teachers into Griffith's lab where they participate in research and receive geophysics-based curriculum for their classrooms. Griffith spent two years as a TFA corps member after earning his bachelor's degree, teaching middle school science and U.S. history in Houston. His own positive experiences as a TFA-affiliated teacher led him to incorporate the program as the teaching element of his CAREER proposal.

"This was an incredible period of personal and professional development for me, and I think it was a positive experience for my students as well," Griffith said of his TFA service. "In my opinion, Teach For America does an amazing job of marketing teaching as a career for overachievers, defined in the traditional sense as A-type personalities who do very well in college and go on to have very successful careers in one of a number of select, sought-after professions – for example, doctors, lawyers or investment bankers. In doing so, TFA attracts top-notch talent from pools that would have most likely led to one of these other lines of work typically associated with high achievers."

Griffith, far left, with his students, from left, Monica Barbery, Rene St. Julien, Troy Barber, Cullen Boyd, Chris Borjas, Ciel Elizalde, Doug Tebo, Jennifer Beyer, and postdoctoral researcher Hamed Ghaffari.

"I took my first geology class in college because I couldn't get into a computer science class I needed to take to satisfy science requirements. My first geology class was at 8 a.m. on the first day of my freshman year, and the professor showed up in muddy jeans. Needless to say this was different than what I was used to in high school."

— Ashley Griffith

Griffith noted that one of the problems with this approach is that the recent college graduates that TFA places in classrooms are at a disadvantage compared to their peers who take traditional routes in college to teaching. TFA members receive brief training in basic teaching methods and theory, but they often find that creating innovative lesson plans to teach content to students is challenging, due in large part to their relative lack of experience.

Griffith created the TFA Rockcorps to help alleviate this problem. This summer, Griffith's lab hosted two TFA corps members who teach high school science in the Dallas school district. Griffith and his students helped the teachers develop geophysics-themed curriculum units to teach in their classrooms, and the teachers participated in research related to the CAREER project. Griffith's CAREER grant also provided funds for scientific equipment which the teachers will use to conduct experiments connected to those done in Griffith's lab in their own classrooms. The grant also provides funds to send them to the American Geophysical Union conference in San Francisco in December to share their ideas.

The groundbreaking research, paired with a worthy educational initiative, made Griffith's CAREER grant proposal a winner in the eyes of NSF officials who weigh proposals from thousands of faculty members each year but approve only a small percentage of them.

"NSF CAREER grant recipients like Dr. Griffith are respected for their commitment to excellence in the lab combined with a passion for furthering science education in the community," said James Grover, College of Science associate dean for research and graduate studies. "His research in geophysics is helping add a new dimension to what is known about the Earth's movements. By involving Teach For America educators, he's also ensuring that future scientists get the preparation they need to make their own contributions."

Working with Griffith on the CAREER project are master's student Troy Barber and doctoral student Chris Borjas.

"The damage imparted by fast-loading rates can change the properties of rock," Barber said. "These properties affect the response of the Earth's crust to future loading events, so understanding them has implications for understanding and predicting earthquake mechanics. Moreover, high strain-rate damage in rocks predominantly occurs in the form of fracture, which can have a huge effect on the hydraulic properties affecting fluid flow and storage in subsurface reservoirs."

Barber's role in the project involves quantifying the portion of the energy budget of a loading event responsible for creating new fracture surface area which changes depending on the loading rate.

"Let's take earthquakes, for example. When an earthquake occurs, the elastic energy released is dissipated in a number of ways, including seismic wave propagation, heat due to frictional sliding on the fault(s), and the energy required to create new fracture surfaces in the faulted rocks," Barber said. "Better understanding the not-insignificant fracture damage portion of this energy budget gets us one step closer to understanding the complex processes at play when the earth's plates decide to settle into a more comfortable position."

Among Barber's tasks is to deform rocks at loading rates comparable to natural earthquakes, using the split Hopkinson pressure bar. He will then use various techniques to study the fracture damage characteristics. Next, Barber and Borjas will collect samples from within the damage zone of a fault and try to correlate fracture damage in natural rocks to the damage observed in the lab. The eventual goal is to better constrain the loading and slip history along natural faults, Barber said.

Borjas is also using information gathered from the loading rate experiments to describe the different fracture densities found in the Mojave Desert of California.

"Sections of the San Andreas Fault exposed in the Mojave Desert have multiple types of rocks bordering the fault relatively close to one another," Borjas said. "Each rock features a different fracture density that is due to its proximity to the fault zone. With a better understanding of how each rock experiences high loading rates, we would like to use our experiments to describe more accurately the energy absorption of the rocks as each type will fracture a different amount based on its composition."

Above, Griffith, center, with his postdoctoral supervisor Giulio Di Toro (left) and Ph.D. advisor David Pollard, while doing research of the Lobbia glacier in the Italian Alps in 2006. At left, Griffith, top, and Jose Cembrano, a professor at the University of Chile, conducting research in the Andes Mountains in Chile in December 2014. Photos courtesy of Ashley Griffith (above) and Tom Mitchell (left).

Griffith and his students are also involved in various other research projects, including one which is complementary to his CAREER grant study though the focus of the research differs somewhat. The project, funded by a $357,000 grant from the U.S. Army Research Office, is an experimental investigation of the micromechanics of rock damage during dynamic loading events. On this project Griffith is working with postdoctoral researcher Hamed Ghaffari, who joined Griffith's lab in January after receiving his Ph.D. from the University of Toronto. They are collaborating with Andrew Makeev, a UT Arlington professor of mechanical and aerospace engineering, as well as with the UT Arlington Advanced Materials and Structures Lab. They are using X-ray computed microtomography to create a 3D model of the fracture networks that Griffith's lab produces in rock samples while utilizing the split Hopkinson pressure bar.

"We are interested in defining an energy budget for pulverization of brittle materials," Griffith said. "Understanding of the behavior of geomaterials under different environmental and dynamic loading conditions is a critical need for mobility prediction and as input for projectile penetration prediction to destroy hardened and deeply buried targets."

Another project, funded by the National Science Foundation, focuses on high-speed rock friction. Most earthquakes rupture at depths between about 5 and 15 kilometers below the Earth's surface, Griffith explained. Most experimental devices that are used to study rock friction at fast, earthquake-like sliding rates only work at pressures characteristic of depths that are 2 kilometers or less. The higher the pressure, the faster heat is generated during frictional sliding, so chemical and physical processes that control friction happen much faster at greater pressures, he said. Griffith is co-PI of the study with Vikas Prakash, a professor of mechanical and aerospace engineering at Case Western Reserve University in Cleveland. They will use an apparatus similar to the split Hopkinson bar that operates

Griffith, right, discusses voltage readings from strain gauges on the split Hopkinson bar with Ph.D. student Chris Borjas in Griffith's lab. Borjas is working with Griffith on the NSF-funded CAREER project in which they are studying fast loading rates of rock structures.

based on the propagation of torsional waves, as opposed to longitudinal waves, to simulate earthquake sliding events at depths greater than 5 kilometers.

"This is the first time to our knowledge that frictional behavior of fault materials has ever been directly measured in the laboratory under these conditions," Griffith said.

Born in Denver, Griffith also lived in Idaho, California and Australia while growing up. He graduated from high school in North Canton, Ohio. His father studied engineering in college and "has always been a big science nerd," Griffith says. His grandfather was a metallurgist who worked for a mining company in Idaho, and many other of his relatives were silver miners. In spite of all that, Griffith had his sights set on a history degree when he enrolled as a freshman at the College of William and Mary in Williamsburg, Va.

"I took my first geology class in college because I couldn't get into a computer science class I needed to take to satisfy science requirements," he said. "My first geology class was at 8 a.m. on the first day of my freshman year, and the professor showed up in muddy jeans. Needless to say this was different than what I was used to in high school."

After that class, Griffith signed up for another geology class, then another, and kept doing so because he found them interesting and because, he says, he had great teachers. "By the time I started taking sophomore level classes in geology, I discovered I could get credit for going camping, and I was hooked," he said.

He earned a B.S. in Geology in 1999 and then took the job with Teach For America in Houston. Teaching helped him discover his "inner nerd," Griffith says, and he spent a lot of time re-reading textbooks from physics and math courses he had taken in college.

"I really liked teaching but I wanted to study everything we were covering in more depth, so I started looking at graduate M.S. programs which would allow me to build off of my geology background while beefing up my quantitative abilities," he said. He ended up getting an offer to work with Michele Cooke, a professor at University of Massachusetts in Amherst, Mass., who worked on numerical modeling of fault mechanics.

"She took a chance on me and it all paid off," Griffith says of Cooke. "I probably learned more while earning my M.S. degree than at any other point in my life. It was such a positive experience that I pretty much became committed to a career in academia at that point."

While at UMass, he worked as a teaching assistant and a research assistant, winning an award for his teaching in 2002. After earning an M.S. in Geosciences in 2003, Griffith started work on a Ph.D. at Stanford University, with David Pollard as his faculty advisor. Griffith received his Ph.D. in Geology and Environmental Science in 2008, and won a grant from the NSF as an international postdoctoral scholar at the National Institute of Geophysics and Volcanology in Rome. He, his wife Elizabeth and their 6-month-old daughter packed up and moved to Italy.

"I worked with several scientists there on problems related to studying the frictional behavior of faults during earthquakes," he said. "We learn in introductory physics that materials have a different resistance to sliding, or friction, when they are at rest than they do once they have accelerated and are sliding at fast rates. The frictional behavior of rocks is probably the most important parameter that controls whether earthquakes start, stop, or keep going once they have started."

The frictional behavior of rocks is still an area of research for Griffith.

In 2010, Griffith accepted a position as assistant professor of geology and environmental science at the University of Akron in Akron, Ohio. His wife, who studies chemical oceanography, took a similar position at nearby Kent State University. When the opportunity arose for him and his wife to join the faculty at UT Arlington in 2013, however, Griffith says it was a logical choice.

"I came to UT Arlington because it seemed like a great fit for both me and my wife," he says. "UT Arlington's commitment to building top-notch research facilities was probably the top selling point. Having gone to high school in Canton, I consider northeast Ohio to be home, so it was a difficult move. One of the things that has struck me most since coming here is that unlike many public universities in the country these days where talk is constantly about budget crunches and cutting back on academic aspects of the university which negatively impact teaching and research, UT Arlington definitely has a positive vibe about being on the way up."

Griffith's students say they appreciate his positive vibe as well.

"Dr. Griffith is a stellar mentor," Barber said. "He is incredibly supportive of his students. If one of us has an idea, he is usually willing to invest in it and bring it to fruition. What's more, he is an effective communicator - with choice words he takes high-brow ideas off the top shelf and makes them accessible to everyone in his classes. I've taken one undergraduate course and two graduate courses with Dr. Griffith. These were some of the most enjoyable courses I have taken as a college student, not just because of the content, but because Dr. Griffith is a joy to learn from.

"His biggest strength as a teacher is his passion for science. He becomes nothing short of giddy every time he goes through the process of solving a problem in class. This is rare."

Borjas earned a bachelor's degree in physics and taught high school science in Fort Worth for five years before he decided to change things up and became interested in geology. He started work on his Ph.D. last fall and says Griffith has been an adaptive and engaging teacher.

"Ashley is a driven scientist who always wants to find out more. Working with him has helped me to look deeper into each point and to look everywhere for information that can support what we are doing," Borjas said. "Ashley is someone who likes to use multiple fields of study to support our efforts and build bridges with other disciplines to better understand how geology, and more specifically, how rock fracture mechanics can tie into other work. He has encouraged me to look in engineering, physics, geochemistry and fluid mechanics to obtain a better outlook on what we are discovering."

For his part, Griffith relishes the opportunity to play a role in helping his students succeed and gain confidence in the lab. He also enjoys seeing students soak up knowledge in the classroom and hone their critical-thinking skills. That makes the CAREER grant all the more satisfying, because it incorporates both elements.

"The CAREER proposals are typically reviewed by six or more people, some of whom are from the applicant's field, and some of whom are from the field of education," Griffith said. "So this means a bit more to me than a normal research grant because it acknowledges my ability to contribute to the University and the community as a teacher-scholar, not just as a researcher. In addition to a positive review by experts in both fields, the project was jointly funded by two different NSF disciplinary programs – Geophysics and Tectonics – which shows how interdisciplinary the work is."

Griffith believes that the research from his CAREER project will show that the mechanical behavior of different rock types at fast loading rates depends predictably on the microscopic composition and structure of individual minerals within the rocks.

"If true, this will allow scientists to better predict the consequences of earthquakes and impact events based on the rock structure in individual areas and furthermore allow engineers to design more effective structures to withstand the pressures in mining, petroleum and military environments," he said. "We have a chance to really make an impact with this work." ■