

# Seismic forecasting

PROFESSOR CORNÉ KREEMER

**Professor Corné Kreemer** is using geodetic data from GPS stations to refine the measurement of strain rates between tectonic plates. His technique has become an invaluable tool for geophysical researchers



## What first attracted you to the field of geodetics?

My interest in geography was largely inspired by my fascination for maps and topography, while my subsequent studies were in geophysics, which seemed like an ideal combination of physics and geography. So when it was time to choose a graduate study, it was an easy choice for me to go to Stony Brook University, New York, to create a map that would emphasise the deformation in plate boundary zones.

**Known as the Global Strain Rate Map, this tool has been invaluable to the research community. Why is it so important for**

## determining seismic activity, and can it be used to accurately predict earthquakes in all areas of the Pacific-North America plate?

In places on the Earth's surface where tectonic plates meet, as they do at the Pacific-North America plate boundary, it is expected that almost all of the relative plate motion will be released seismically. Over large areas seismicity follows a Gutenberg-Richter (GR) relationship, which means that earthquakes at magnitude 5 are around 100 more likely than a magnitude 7 event, while magnitude 6 are 10 times more likely. As a result of this relationship, knowing the plate motion gives a good approximation of how many earthquakes of which size to expect in any given time interval. Because

## Defining boundaries

Researchers at the **University of Nevada, Reno**, are unravelling the tectonic activity of the Colorado Plateau, a unique geological area that is still poorly understood despite its important role in activity at the Pacific-North America plate boundary

**PLATE TECTONICS INVOLVES** the study of the large, slowly moving plates that make up the Earth's surface. The majority of seismic activity occurs at the edges of these crustal plates as they collide with other formations floating on the Earth's mantle. The advent of the global positioning system (GPS) has allowed scientists to see tectonic plates moving in what amounts to 'real time', while the relatively low cost of these devices means many more locations can now be covered to build up a more comprehensive picture of tectonic movements.

One area of particular interest to geophysicists is the Colorado Plateau, a distinct mass of continental crust in the US Southwest, which has managed to remain structurally intact for

more than 500 million years. Bounded by the Rocky Mountains to the east and the Basin and Range Province to the west, the role of the Colorado Plateau in the geological evolution of the Pacific-North America plate boundary zone has been somewhat unclear to date. The area is unusual in that it has no active faults, although when earthquakes do occur they tend to be large. Researchers from several universities are now uncovering the secrets of this enigmatic 'micro-plate' and their work promises improved predictions of seismic hazards in the region.

### MODELLING SEISMICITY

Based at the University of Nevada, Reno, USA, Professor Corné Kreemer is Principal

Investigator of the collaborative research project 'Geodetic Constraints on the Kinematics of the Colorado Plateau and its Western and Southern Margin'. With funding from the US National Science Foundation (NSF), it started in July 2010 and runs until June 2015. Part of Kreemer's work focuses on the global modelling of seismic hazards, but this inevitably overlaps with his other field of research: the Global Strain Rate Model. "The extent to which global forecasts are applicable to the Pacific-North America plate boundary depends mostly on whether seismicity truly follows a Gutenberg-Richter (GR) relationship in all parts of the boundary, that there is no significant aseismic deformation, and that we know the thickness of the crustal area that



we can now use the global positioning system (GPS) to map the detailed spatial distribution of the relative plate motion over the roughly 1,500 km-wide Pacific-North America plate boundary, we are now trying to make these 'forecasts' much more spatially relevant. We work on a global scale because that allows us to best determine some empirical factors that go into this analysis.

**While GPS can measure plate movement in real time, it is not able to directly infer the reasons for deformation. How do you explore the causes of deformation?**

There are various ways. Some people construct models of mantle flow that predict surface motions and can be compared with GPS velocities. Personally, I work with others to compare the geodetically inferred deformation (ie. the strain rate tensor) with stress orientations that are due to either plate motion or the fact that thick crust wants to spread out towards adjacent thin crust. In one particular study, we looked at the Pacific-North America plate boundary and identified the areas that grow

geodetically and found corresponding areas that shrink. From associating these regions with each other, we determined that the southern Cascadia subduction zone must act as a 'window of escape' for the Basin and Range to flow towards.

**Do any theories exist to explain earthquakes occurring within the Colorado Plateau 'micro-plate'? What, if any, are their shortcomings?**

The earthquakes within the Colorado Plateau seem to have two origins. In the western part they seem to suggest east-west extension as a result of the Basin and Range encroaching into the Plateau. The earthquakes in the more central part of the Plateau also show extension, but along a northeast-southwest direction. We showed that this is the same direction as you would expect from the spreading of the thick crust towards the thin crust in Southwestern Arizona. What is puzzling is that the actual extension measured with GPS is in an east-west direction. This suggests additional forces are responsible in driving the deformation, but why do these earthquakes not show that?

**Why are aseismic creep events not well documented?**

Creep has so far only been documented geodetically where faults slip fast and where there is good GPS coverage. Examples are some segments of subduction zones and parts of the San Andreas Fault system. It is much more difficult to detect creep on faults that have slip rates less than 1 mm per year, which is the case for most faults in the American southwest.

**What is the value of outreach to the long-term impact of your research?**

Most people recognise the seismic hazard along major fault zones, but are unaware of the significant hazard that exists in places like the Basin and Range and Colorado Plateau. This is easily understood, given the low seismic activity rate. The goal of our work is to quantify the very low strain accumulation that will likely be released in future earthquakes, and, through outreach, make the general public and policy makers aware of the non-zero hazard in areas that many believe to be tectonically stable.

hosts the earthquakes; there are admittedly a lot of unknowns," he explains.

Kreemer and co-Principal Investigator Professor Rick Bennett of the University of Arizona use highly accurate GPS measurements to record the horizontal velocity of the Colorado Plateau. This can demonstrate whether the area is moving as a coherent mass or is undergoing internal deformation that could lead to seismic activity.

### GPS STATIONS

In conjunction with NSF's Earthscope programme, Kreemer and his team have deployed 33 GPS stations across Arizona, southern Utah and Southeastern Nevada, which lies on the edge of their chosen study area. "Our GPS stations are installed with the explicit goal of complementing Earthscope's Plate Boundary Observatory, which is rather sparse in the slower deforming parts of the plate boundary zone," Kreemer elucidates. The project's GPS stations also present a cheaper alternative to the expensive stations employed by Earthscope.

Many of the project's data collection stations are situated in US national parks across the

Colorado Plateau, such as Zion National Park and Petrified Forest National Park. This is of considerable benefit as it allows the researchers to provide park rangers and visitors with information about the tectonic activity in these areas. These areas of outstanding natural beauty often appear to be static, but they are in fact in a state of constant flux and evolution due to the geological processes taking place underground.

### TAKING THE STRAIN

In his graduate work, Kreemer brought together GPS data from plate boundary zones in the Western US, the Mediterranean and central Asia into a consistent formulation of plate tectonics that included the deformation field of the plate boundary zones as well as the motion of tectonic plates. This resulted in the Global Strain Rate Map, in which strain rate is a measure of deformation rate. "This map has become a logical extension of the theory of plate tectonics," notes Kreemer.

The relative velocities of GPS stations in plate boundary zones can be used to measure the strain rate that is building up between tectonic plates: this energy will ultimately be released as

earthquakes. Hence, the greater the strain rate measured between tectonic plates, the greater the likelihood – or the greater the magnitude – of an earthquake in a given location. However, using strain rate as a proxy for seismic activity is not always precise. In Arizona, for instance, the team's geodetic readings have highlighted a small but steady deformation that is greater than can be explained by the levels of seismic activity in the area. Also, there are no known active faults in the Colorado Plateau.

### ASEISMIC CREEP

Kreemer sees three possible reasons for this discrepancy. First, the deformation measured using geodetic information could be aseismic: that is, the deformation relates to tectonic plate creep rather than earthquakes. Aseismic creep is a rare phenomenon on continental faults. Second, the deformation might relate to rare large events, or earthquakes that only occur once every 100,000 years. Such an event was last recorded south of Tucson in northern Mexico in 1887: with a magnitude of 7.5, this was the largest earthquake ever recorded in the US Southwest outside of the San Andreas Fault, and yet it occurred in a region that did not

## INTELLIGENCE

### GEODETTIC CONSTRAINTS ON THE KINEMATICS OF THE COLORADO PLATEAU AND ITS WESTERN AND SOUTHERN MARGIN

#### OBJECTIVES

- To establish how the crust of the Colorado Plateau moves relative to stable North America
- To assess whether the earthquake activity can be related to the deformation measured in this project or whether they are due to other processes, such as gravitational collapse

#### KEY COLLABORATORS

**Dr Richard Bennett**, co-Principal Investigator, University of Arizona

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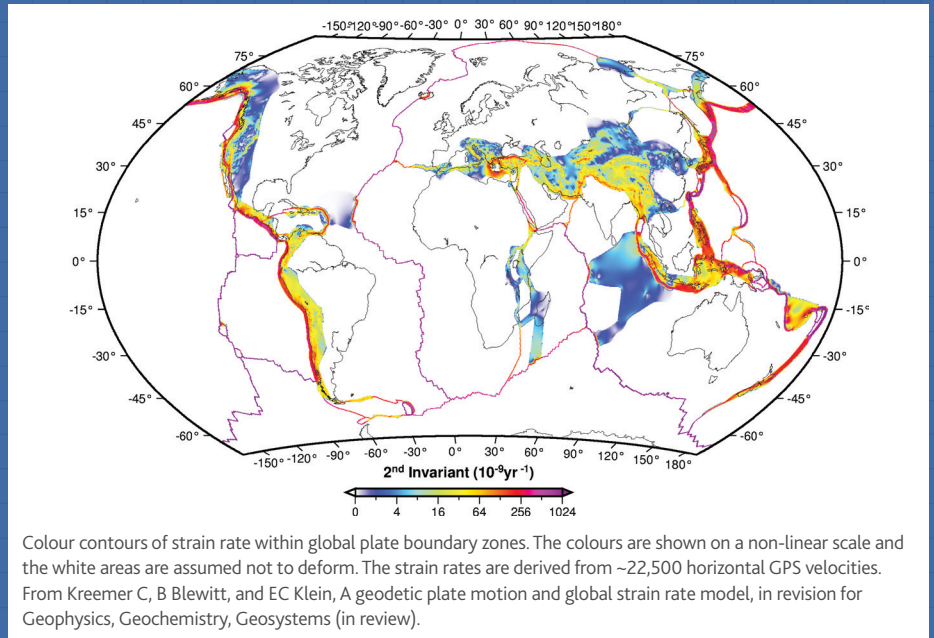
#### CONTACT

**Professor Corné Kreemer**  
Research Associate Professor

Nevada Geodetic Laboratory  
Nevada Bureau of Mines and Geology  
Nevada Seismological Laboratory  
The University of Nevada, Reno  
Reno, Nevada 89557-0178  
USA

T +1 775 582 8780  
E kreemer@unr.edu

**CORNÉ KREEMER** graduated from Utrecht University in The Netherlands with an MSc in Geophysics in 1997. In 2001, he completed his PhD in Earth and Space Sciences from Stony Brook University in New York, US. Kreemer has authored or co-authored over 100 papers. In 2010 he was honoured for his contributions with the Geodesy Section Award of the American Geophysical Union and in 2011 with the Mackey Faculty Achievement Award from the University of Nevada, Reno. As Research Associate Professor, he mainly uses space-geodesy to investigate crustal deformation, tectonics and geodynamics. He is particularly interested in global plate kinematics, lithospheric dynamics, natural hazards and the seismic cycle.



Colour contours of strain rate within global plate boundary zones. The colours are shown on a non-linear scale and the white areas are assumed not to deform. The strain rates are derived from ~22,500 horizontal GPS velocities. From Kreemer C, B Blewitt, and EC Klein, A geodetic plate motion and global strain rate model, in revision for Geophysics, Geochemistry, Geosystems (in review).

otherwise show any seismic activity. The final possibility is that the geodetic velocities being recorded are not necessarily representative of the average earthquake time scales. From their work so far, the Nevada team has hints that this could indeed be the case, as all of their GPS stations appeared to have changed velocity after the 7.2 magnitude earthquake that occurred along the San Andreas Fault south of the US-Mexican border in 2010. As Kreemer reveals: "This was probably due to the visco-elastic relaxation of the mantle that makes it hard to place our observation in the context of long-term crustal deformation".

#### HURDLES AND OPPORTUNITIES

The 2010 event appears to have dissipated the stress generated by the earthquake into the deeper crust and upper mantle of the Colorado Plateau, thereby affecting the movement of the team's GPS stations. This suggests seismic events on the San Andreas Fault could be affecting, or even dictating, the distribution and accumulation of stress across Arizona. This

slight detour in the team's work has had some positive outcomes, as it has presented them with an opportunity to carry out further research into Earth's visco-elastic properties.

Meanwhile, Kreemer's development of the Global Strain Rate Map has provided a tool for researchers to more accurately assess seismic hazards around the world. "My work on creating and improving the strain rate field in the Southwestern US is part of a larger effort for all the Earth's plate boundary zones," he clarifies.

Over the longer term, Kreemer and his colleagues will utilise their GPS data to build more accurate seismic hazard models for the Southwestern US. Aside from improving understanding of geological formations that are hundreds of millions of years old, the work has very real implications on a human scale, as it will allow scientists to more accurately assess the seismic risks faced by urban areas in the region.

