Sinking ocean plate stays out of sight

Deep below the Carpathian Mountains in Romania the earth quakes and shakes. The reason for this tectonic violence is a mystery that is difficult to unravel even with the latest measuring techniques and seismic and tomographical research.

Tomas van Dijk

With a look on his face that hints at despair Professor Boudewijn Ambrosius studies a map of the Carpathian Mountains. Forty or so white arrows indicate the deformations that affect the area. In some places the arrows indicate shifts of five millimetres, but most are much less, say one or two millimetres per year. They look as if they are rotating around the end of the mountain range like a very slow whirlpool. The area, about two hundred kilometres north of Bucharest, is notorious for its earthquakes. “This stress map is still incomplete,” the professor says. “Some things have changed since our last measuring campaign. Our measuring rig was damaged during the construction of a windmill in that location, so we don’t have sufficient data to draw conclusions.”

What the professor of DEOS (Department of Earth Observation and Space Systems), a department of the aerospace engineering faculty, is indicating is the result of a major measuring programme using GPS equipment to map the stresses building up in the Carpathians in Romania. He hopes to use the results to find out more about the plate tectonics deep below the mountain range.

Six years ago the remote sensing expert set up a network of dozens of GPS receivers to detect vertical and horizontal shifts. Each summer he would travel to Romania to collect the data, assisted by students of Bucharest University. The network covers an area of 350 square kilometres and extends down to the Black Sea. »»
Ambrosius hopes eventually to be able to make predictions about the risk of major earthquakes in the future. “The research contains a clear-cut socio-economic component,” he says, “although predicting earthquakes will probably always remains a thousand times more difficult as forecasting the weather.” One small area in the Romanian province of Vrancea in particular is ravaged by earthquakes on a fairly regular basis. And these aren’t minor quakes either. In 1977 an earthquake measuring 7.4 on the Richter scale resulted in the death of over 1,500 people. On average the area is affected by earthquakes of this magnitude or worse once every fifty years. “The epicentre area is sparsely populated,” Ambrosius explains, “but beyond Vrancea lies an extended area covered by a layer of sediment from the mountains that is many kilometres thick. The whole lot shakes like a jelly pudding, making earthquakes felt as far away as Bucharest.”

Mystery
The research is also particularly interesting from a fundamental science point of view. For decades scientists have been racking their brains about what exactly is going on in the region. Several million years ago this was the place where the bottom of the Sea of Thetys, the ocean that once lay between the paleocontinents of Gondwana and Laurasia, disappeared under the European continental plate. The Carpathians were created as a result of the violent tectonics involved. Although the Thetys plate is no longer moving westwards, peace and quiet have still not returned to the area. Why these earthquakes are still occurring is a mystery as is why they are concentrated in an area of only a few hundred square kilometres. Perhaps even more remarkable is the fact that the epicentres of most of the earthquakes are located at such enormous depths of between seventy and two hundred kilometres.

Ambrosius: “Such deep earthquakes are exceptional for a continental area. Continental earthquakes usually occur within the upper thirty kilometres, i.e. within the earth’s crust, and sometimes at the transition between the crust and the lithosphere. Deeper earthquakes normally occur at the edges of continental plates, for example along the coasts of Chile or Japan, where oceanic plates are sliding under the continental plates.”

GPS measurements are not the only data to offer insight into the processes involved. Ambrosius conducts his tectonic research together with geologists from the Vrije VU University Amsterdam and geophysicists from the University of Utrecht. The VU University Amsterdam scientists conducted seismic tests of strata down to a depth of approximately fifty kilometres, and their colleagues from Utrecht collected tomographical data and did model research. The research project as a whole is conducted under the auspices of ISES (Netherlands Research Centre for Integrated Solid Earth Science), one of the six national Research Centres.

One theory that might help explain the mysteriously deep earthquakes is that somewhere under Vrancea a piece of plate of several hundred kilometres length is sinking vertically. At a depth of around fifty kilometres the plate would tear loose under its own weight. This would cause the earth above it to spring back. This is one of the theories proposed by Professor Dr. Wim Spakman and Professor Dr. Rinus Wortel of the University of Utrecht, which they base on seismic tomography data. Seismic tomography involves constructing three-dimensional images of the earth’s interior based on information gleaned from earthquake tremors. The differences in the arrival times of shock waves enable the scientists to deduce which types of rock the waves encountered in their path, and where these types of rock are located within the earth’s interior.

In addition to the slab detachment theory, Spakman explains there is also the delamination theory, that is the possibility that the plate is shedding flakes so that sections on the underside become unstuck and sink into the depths, while the upper parts can still spring back. “It’s only now that we have an almost complete set of data for the Carpathians,” Spakman explains. “We are on the verge of processing the data using a geophysical model method. We have two different models based on different stress fields. Analysing the data is bound to make this an exciting year.”

Hard to measure
For the time being however, the area remains an enigma. The researchers expect to find that the region around Vrancea is rising, but there is no evidence of that yet. “With hindsight we can say that the Carpathians form one of the hardest areas to collect data in,” Ambrosius says. “Indonesia moves several centimetres each year, and so does Greece, but in Romania we’re talking only a few millimetres a year. That’s close to becoming impossible to measure.” Spakman adds: “Actually it’s remarkable that the lack of movement at the surface obscures the fact that here we have one of the most seismically active zones in Europe.”

The GPS receivers installed by Ambrosius should normally be capable of measuring vertical movement with an accuracy of four to eight millimetre per year, and for horizontal movements the equipment is even more sensitive, being capable of detecting shifts of one or two millimetres. However, this requires the experiments to be carried out in ideal conditions.

“We need stable datum points,” Ambrosius explains. “We can’t do any measuring in a bog. Suitable locations are few and far between. We thought we had found a first-class datum point on a hotel sitting against the side of a mountain. It was an open location, allowing the receiver to communicate freely with the satellites. We had set up a permanent field station that performed measurements throughout the year. In the end our
location turned out to move three to four times as fast as other locations around it, and on top of that it was moving in exactly the opposite direction. This was probably the result of a local landslide. We’re not interested in those.”

There are five more permanent field stations. One of them is located at a meteorological station, and another is housed at a seismic station. To collect the remaining data, the researchers had to spend their summers trekking through the Romanian wilderness to install GPS equipment at spots marked by metal tubes. At each of these points students from Bucharest University erected tents and spent three days in pairs collecting the data.

Unfortunately they did not use exactly the same equipment at each of the points as the year before. The position of the minute dielectric elements that make up the aerials of the measuring device can vary between individual instruments. This does not make interpreting the data any easier. “Fortunately we do know which types of aerial were used where,” Ambrosius says, “and that is the good news. We are now in the process of recalibrating the receivers on the roof of NMi, the Dutch national measuring standards institute here in Delft, to enable us to interpret the data better.”

The satellite expert would love to be able to install more permanent field stations. “Alas, that’s not so easy,” he says, “since we’re dealing with a wooded area that is difficult to negotiate, and there are lots of wild animals, including bears. Permanent field stations require large solar panels to provide enough power to the receivers. In the wilderness there is every chance that the panels wouldn’t survive.”

Seismic image
The fact that Vrancea is probably rising, or that it has been doing so for the past couple of million years, is demonstrated a little more clearly by the results of seismic research conducted by Dr. Randell Stephenson of VU University Amsterdam, together with Romanian researcher Ionela Panea, who recently completed her doctoral research under the supervision of the rector of TU Delft, Professor Dr. Ir. Jacob Fokkema. Stephenson and Panea completed a seismic image by setting off a series of dynamite charges of 28 kilogrammes each in boreholes at a depth of 20 metres along a line 130 kilometres long. By measuring the resulting vibrations, they were able to draw up an image showing a sediment-filled depression in the earth’s crust just to the east of the earthquake area. The researchers can reconstruct the geological dynamics of the area on the basis of the various layers of sediment. “From the data you could deduce that Vrancea had risen, but it is not very clear,” Stephenson admits.

But the researcher has more exciting news to offer. “There are magma flows up to a depth of five kilometres,” he says, “or at least, that is what one of my doctoral students thinks he can deduce from his magnetic research of the area. He is still working on it. Such magma flows could indicate that an oceanic plate is indeed breaking away. The resulting space would then be filling with magma.”

Ambrosius will soon be submitting a new research proposal to ISES. “We would like to increase the scope of our research area to enable us to see how the stress field around the Carpathians fits into the larger European situation,” he explains. “Sooner or later another major earthquake will strike Romania, and then our measurements will provide us with the perfect basis for mapping the major shifts that will then occur. Satellite measuring involves waiting for mother nature to do her work.”

Slab detachment:

Slab delamination: