Vast geophysical experiments in Central Europe

Deep Seismic X-ray

For many years Aleksander Guterch (right) and Marek Grad (left) have been working together to advance our knowledge of the deep structure of the Earth's crust

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The past 7 years have been a time of unprecedented projects in the field of geophysics. Massive seismic experiments have made Central Europe the most thoroughly investigated region in the world. Many scientists believe this is the beginning of a new geology

The future progress of human civilization depends on our gleaning comprehensive knowledge about the structure and evolution of the Earth's whole outer cover, the lithosphere for example. The structure of the continental lithosphere, stretching down to depths of 100-200 km, is extremely complex and inhomogeneous. This is particularly true for its uppermost layer - the Earth's 30-50 km thick crust. For us to be able to forecast earthquakes or pinpoint crucial resources, we must thoroughly know and understand the physical processes taking place in the outer shell of the solid Earth.

Our current knowledge of Earth's lithosphere is far from complete. Humankind has explored the atmosphere and breached the frontier of space, but has not progressed very far in the opposite direction. Deep drillings typically extend only 6-7 km downwards and are tremendously expensive, providing ultimate-quality but essentially one-dimensional data. The alternative is geophysics, offering general insight into the two- and three-dimensional structure of the lithosphere. New geophysical projects to develop accurate, three-dimensional images of the Earth's interior are currently under way in various areas of the globe. Such projects primarily employ the methods provided by geophysics, sometimes supplemented by single deep drillings.

Shaking the ground

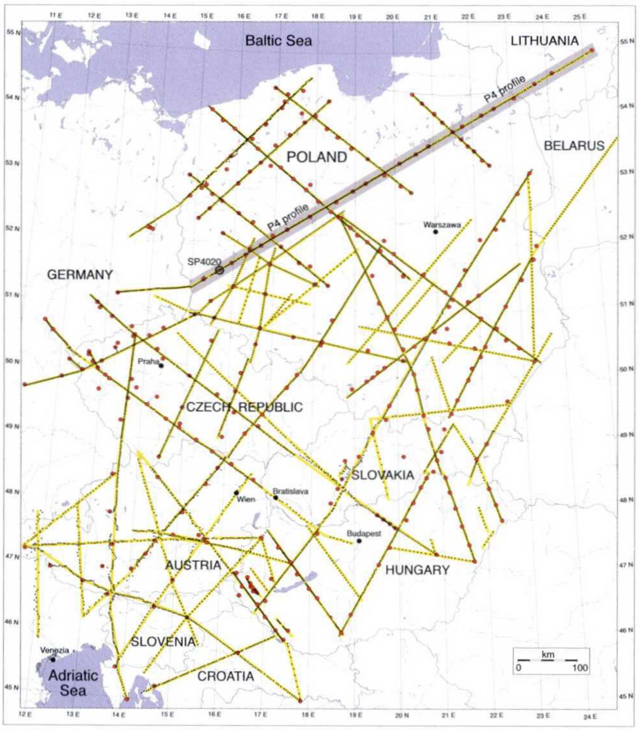
Seismic surveys of the Earth's interior use elastic waves, produced artificially by explosives detonated in boreholes, as research tools. Such waves propagate in the lithosphere at a velocity ranging from 2-3 km/s in near-surface layers to 8.5-8.7 km/s at depths of 100-200 km in the lower lithosphere. Seismic stations deployed along planned profile lines record these seismic waves, usually at a distance of 200-300 km; such waves penetrate the lithosphere down to 30-50 km. When larger amounts of explosives are used, seismic waves can be recorded at a distance of 1000-1500 km, and they may penetrate as deep as 100-150 km.

The speed at which seismic waves propagate depends on the density of the medium. Generally, the deeper we get, the denser the rocks become. However, rocks are virtually incompressible. Density changes are thus discrete, with more or less clear boundaries, reflecting changes in mineral composition. One density boundary that can be observed globally is Moho, separating Earth's crust from its mantle. Over Moho there are igneous, metamorphic and sedimentary rocks of the crust with seismic wave propagation speeds of up to ca. 7 km per second. Below Moho is the upper mantle, with speeds of 8 km/s and more.

Seismic waves do not travel through the lithosphere in straight lines, but are bent and reflected by the boundaries. Knowing the time that elapsed from the explosion to the moment a wave was detected on the surface, it is possible to calculate the depth of a boundary that reflected that wave. Subsequent analysis of all the recorded seismic waves allows us to determine the structure of the lithosphere and its physical properties.

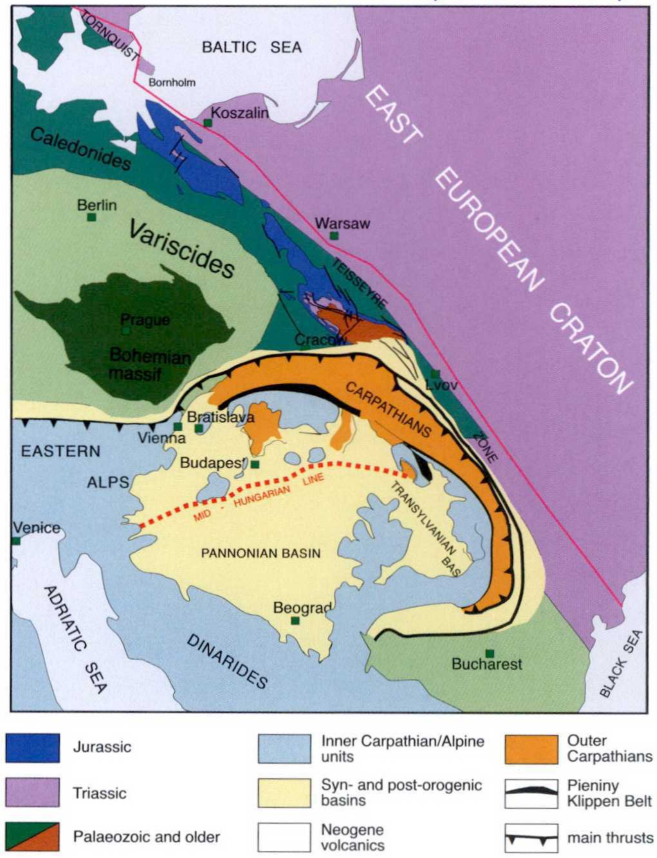
Where the plates meet

In the geological structure of Europe, the area of Poland is of key importance for understan-



Layout of the POLONAISE'97, CELEBRATION 2000, ALP2002 and SUDETES 2003 seismic experiments in Central Europe. Yellow lines show seismic profiles, with about 7,000 seismic receiver positions. Red dots show 295 major shot points. The gray line shows the position of POLONAISE'97 profile P4

Tectonic map of Central Europe



General tectonic map of Central Europe, showing the features targeted by the POLONAISE'97, CELEBRATION 2000, ALP2002 and SUDETES 2003 seismic experiments. The Teisseyre-Tornquist zone is a part of the Trans-European Suture Zone

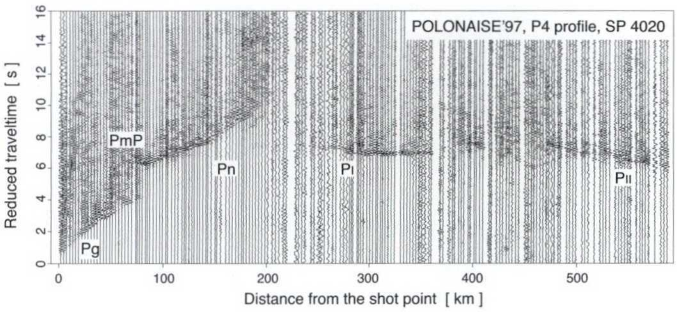
ding the tectonic evolution of the whole continent. Three major European tectonic units meet here: the old Precambrian platform of Eastern Europe, also called the East European Craton (EEC), about one billion years old; the Paleozoic Platform (PP) of Central and Western Europe, about 350 million years old; and the youngest Alpine orogenic belt, represented in Poland by the Carpathians. The contact zone between the EEC and the PP is called the Trans-European Suture Zone (TESZ); this zone is more than 2000 km long and traverses the entire European continent, from the British Isles, across the North Sea, Denmark, North Germany, Poland and Ukraine to the Black Sea.

The TESZ is the most prominent lithospheric boundary in Europe north of the Alpine-Carpathian orogenic front. It is a broad, deep and complex zone, separating the relatively cold and thick ancient crust of the EEC from the warmer and thinner crust of western and southern Europe. Being clearly defined in the whole depth range of the lithosphere, it is a perfect place to study the evolution of continental accretionary processes. The TESZ also has a global aspect, as it supposedly continues on the other side of the Atlantic. In the Appalachian orogenic belt, its closest equivalent seems to be a boundary zone between the Avalon terrane (a microcontinent accreted, or „glued," to a platform) to the south-east, and the North American platform to the north-west.

Since 1997, Central Europe has been covered by an unprecedented network of seismic experiments. These experiments - POLONAISE'97, CELEBRATION 2000, ALP 2002 and SUDETES 2003 - have only been possible due to a massive international cooperation effort. Extending from the Baltic Sea to the Adriatic Sea, the investigations comply with the highest technological and documentation standards. They represent a new generation of seismic experiments, aiming to survey, as accurately as possible, the major lithospheric zones in which the processes of transformation or destruction of the Earth's crust occurred. From the lithosphere, we may learn the history of physical evolution of the planet Earth.

All roads lead to Poland

The seismic survey was conducted in Poland, Slovakia, Hungary, Austria, the Czech Republic, SE Germany, Croatia, Slovenia, and partly in Lithuania, Belarus, and West Russia. Polish scientific institutions initiated and led the experiments dubbed POLONAISE'97, CELEBRATION 2000 and SUDETES 2003, and took part in the ALP 2002 experiment. Thus, the study covered all major geological structures of Central Europe and (partly) Eastern Europe, located between the Baltic and Adriatic Seas. This region, known as the "geotectonic loop of Europe," has an extremely complex geological history and features the greatest contrasts in the lithospheric structure of the European continent. The thickness of the Earth's crust in this area ranges from ca. 22 km in the Pannonian Basin in Hungary to over 50 km in SE Poland.



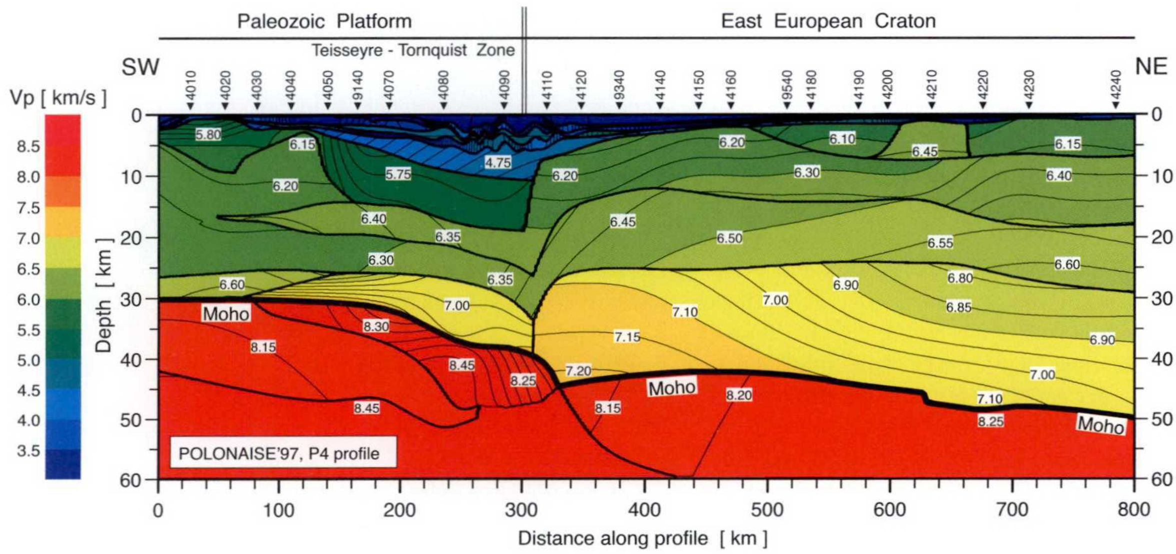
Example of seismic wave section recorded during POLONAISE'97 experiment. Seismic waves from a shot point located close to the Polish-German border were recorded along the P4 profile

The seismic experiments in 1997-2003 involved over 30 institutions from 15 European countries, the USA and Canada. The number of modern seismic recording stations, mainly acquired from the United States and Canada, was the highest ever. In the CELEBRATION 2000 experiment, for example, over 1200 stations were used. About 150 explosive charges were detonated to generate seismic waves. The total length of all seismic profiles reached 9000 km. More than 1000 geophysicists, engineers and technicians participated in this project, carried out from 1 June to 3 July 2000. The CELEBRATION 2000 project, coordinated and led by Polish scientific institutions, proved to be very challenging, literally a logistic mayhem. Despite its massive scale, this experiment, covering the area of eight countries, went very smoothly and was highly prized internationally.

Preparations for the project took more than two years. CELEBRATION 2000 was the largest seismic experiment of this type ever conducted in the world. The use of unique research methods and the record number of seismic instruments involved made it possible to obtain three-dimensional images of the lithosphere for selected geological structures of Central Europe. The process of modeling the deep structures of the Earth's crust and lower lithosphere from seismic data is time-intensive, but some results have already been presented in several reports in international journals.

So what's down there?

The purpose of these massive experiments is to improve our understanding of the processes controlling the formation of the continental lithosphere, including how these processes have varied over time, from its birth up to the present. From the data we determined the thickness of the Earth's crust in



An example of the results: two-dimensional seismic model of the Earth's crust for POLONAISE'97 profile P4. Numbered triangles show shot points

Headquarters of the POLONAISE'97 experiment in Toruń. Programming of 220 RefTek digital seismic stations

A. Guterch

the area under study and the velocity structure of the deep lithosphere across the TESZ [see the profile on the previous page]. The Polish basin, located along the margin of the EEC, is a large structure (ca. 130 km wide) that filled with sediments throughout the Paleozoic and Mesozoic. The thickness of sedimentary strata in this basin reaches an astonishing 15-20 km. The crystalline crust under these strata is only ca. 20 km thick today, indicating that the ancient lithosphere was either thinned drastically or terminated along the northeast margin of the basin. General tectonic models built upon the observed velocity structure imply an abrupt discontinuity in lithospheric structure at the southwest edge of the EEC. This revelation was unexpected by geologists, as it had been believed that the Paleozoic Platform leaned only gently towards the EEC. Seismic discontinuities in the lower lithosphere were also detected as deep as 70, 80 and 90 km in the central part of the TESZ. The results of this study shed much light on the structure and tectonic evolution of the TESZ, providing an objective framework which can be combined with geological evidence to identify and interpret several large-scale tectonic boundaries in Central Europe.

Modern geology and geophysics must overcome the existing technological barriers and significantly increase the range of the detailed penetration of the whole lithosphere, in order to verify all our assumptions about the Earth's interior - many of which are probably false. Such investigations are very expensive and technically demanding, so they have to be carried out under broad international cooperation. The success of all the four seismic experiments in Central Europe was possible owing to excellent cooperation among over 30 institutions from 15 European countries, the United States and Canada. The results provide the basis for research in various branches of earth sciences, and are of utmost strategic importance for both basic and applied research. The ultimate goal is to obtain detailed knowledge about the physical state and dynamical processes within the Earth, and to reconstruct, as precisely as possible, the dramatic history of our planet. At the root of these studies lies a deep belief that we are on our way to a new geology, based on a strict physical foundation on the one hand, and the new reliable results of geological (as well as biological, etc.) research on the other.

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We can expect that the interest in studying the lithosphere will grow in the near future, as this, for us, is the most crucial part of our home planet Earth - the cradle of human civilization, which will probably remain the only place for people to live. Colonizing space, even in the distant future, will be impossible for many reasons. Thus, we should turn our attention to modern deep seismic studies, which constitute a kind of Hubble Space Telescope of geology. ■

Further reading:

Guterch A., Grad M., Thybo H., Keller R. G., and the POLONAISE'97 Working Group. (1999). *POLONAISE'97 - international seismic experiment between Precambrian and Variscan Europe in Poland*. Tectonophysics, 314, 1-3, 101-121.

Guterch A., Grad M., Keller G. R., and CELEBRATION 2000 Organizing Committee and CELEBRATION 2000 Experiment Team. (2001). *Seismologists Celebrate the New Millenium with an Experiment in Central Europe*. Eos, Transactions, American Geophysical Union, 82 (45), 529-535.

Grad M., Jensen S. L., Keller G. R., Guterch A., Thybo H., Janik T., Tiira T., et al. (2003). *Crustal structure of the Trans-European suture zone region along POLONAISE'97 seismic profile P4*. Journal of Geophysical Research, 108 (B11), 2541, doi: 10.1029/2003 JB002426.