The European Geotraverse Project:
a major European scientific venture

R. Freeman and St. Mueller, Zurich
(Institut für Geophysik, ETH) *

Part II

In Part I, published in the June 1987 issue of *Europhysics News*, the aims and organization of the “EGT” were described and an introduction given to seismic research methods.

Another application of refraction seismic data is to map the depth to the Moho as shown in Fig. 3b. The data for this figure have been gathered from many small experiments over the last twenty years ³) and the position of this profile was drawn to coincide with a nearly north-south 1000 km profile from Kiel to Genoa (the EUGEMI experiment) that was recorded in September-October 1986. This experiment was a success, involving more than 20 large explosions and over 200 operators; the data are still being processed. The new results, however, do not alter the general features shown in Fig. 3 which illustrates a relatively “flat” Moho under much of central Europe and a relatively deep Moho under the Alps. Changes in the depth to Moho are also mirrored in changes in the long-wavelength gravity anomalies ⁴) (gravity methods will be discussed in more detail below). On comparing Figs. 3a and b, a parallel thickening of the upper crust and downward trend in the gravity anomaly curve is clearly evident. Both these effects are due to the large mass of crustal material of the Alps (see also Fig. 5 where this profile is continued). A slight upward bulge in the Moho near Kassel (Federal Republic of Germany) at 400-500 km along the profile is not apparent in the gravity profile. To explain this it is useful to remember that gravity is a potential field, integrating density effects over a wide three-dimensional area whereas refraction seismics measures travel times of the “velocity field” along a two-dimensional profile. Seismic data are directly affected by the discontinuous nature of the materials through which the signal passes, whereas the potential field of gravity is continuous at all points. Short wavelength gravity effects are sensitive to “nearby” crustal anomalies which are difficult to resolve with the large-scale refraction seismic method. But the density effects of these crustal anomalies can mask the Moho topography as in Fig. 3a. In contrast, the crustal anomalies are “transparent” to the refraction seismic experiments that provided the data for Fig. 3b and resolved km-scale variations in the depth to the Moho.

With increased resolution through either reflection seismic profiles or denser station spacing in refraction experiments, the crustal density anomalies apparent in the gravity profiles can also be seismically determined. Indeed, recent seismic profiles from the southern and central parts of the Federal Republic of Germany that cross each other yield a 3-dimensional picture indicating widespread lateral heterogeneity within the crust. Other seismic results from different regions demonstrate that indeed heterogeneity characterizes much of the crust beneath central Europe.

Electromagnetic Methods

Electromagnetic surveys measure natural or artificially generated electrical fields at or near the Earth's surface. These fields are strongly influenced by the presence of conductive layers in the crust. Although electromagnetic surveys are commonly used to detect mineral resources or ground water occurrence, sensitive instruments with large arrays and complex analytical methods can also detect deeper-lying conductive layers in the crust and to depths of over 400 km in the mantle.

There are three principal methods to measure fluctuations in the Earth's electromagnetic field: magnetometer arrays or magnetovariational sounding (MV), magnetotelluric profiles (MT), and frequency soundings (FS). In MV techniques, three orthogonal components of the time-varying magnetic field are recorded by magnetometers arranged in a two-dimensional array. Sources for the magnetic field are currents in the magnetosphere and ionosphere with field strengths ranging from a few to several thousand nT and periods from 1 min to 1 day. MV arrays of up to a thousand km length yield information about the areal distribution of electrical conductivity and delineate crustal and upper mantle conductivity anomalies.

Natural fluctuations in currents that run through the Earth are utilized in the magnetotelluric (from Latin *tellus* = earth) method (MT). The horizontal component of the electric field and the horizontal and vertical components of the magnetic field are measured simultaneously as a function of frequency.
Analysis of the results yields impedance as a function of frequency which is then inverted to give resistivity as a function of depth.

FS methods use powerful magnetohydrodynamic generators as electromagnetic signal sources. One such generator, located on Rybachy Island off the northern shore of the Kola Peninsula, feeds a current pulse of 10-20 kA or several subsequent pulses of 0.5-1.2 kA via a 7 km long cable into the Barents Sea. Since the current tends to flow around the island, both magnetic and electric dipole fields are generated. Telluric and associated magnetic fields have been measured at distances of 350-500 km from the source and have been used to estimate conductivity structures in the Baltic Shield.

In the crust high-conductivity layers may indicate the presence of aqueous fluids (water as ions or solutes) or conductive material (graphite, magnetic and hydrated minerals, sulphur in combination with other volatiles, or iron). Porosity of rocks and salinity of fluids are also factors that affect resistivity in the crust, although usually to a lesser degree than those just mentioned. Zones of high conductivity are normally interpreted either as mineralised layers produced by precipitation after fluid flow in fractured rock or as fluids present along major thrusts or fractures.

Beneath the crust, in the upper mantle, temperature and fluid phases in association with partial melting are the critical parameters. Temperature is related to conductivity both theoretically (through the semiconduction equation) and practically (in the correlation of conductivity with heat flow as found by surveys in the central European rift system). The transition from the lithosphere to the asthenosphere is poorly understood; it is neither a simple chemical change (as at the Moho) nor a density transition (as the 440 km boundary), but rather a temperature effect. One consequence of this temperature difference is that the lithosphere is cooler and therefore much harder than the underlying asthenosphere.

Fig. 4 shows the results of a magnetotelluric study 6) carried out in the region of the central segment of the EGT which illustrates some of the information attainable by MT methods. This profile crosses a clearly defined geological division between two zones of the Hercynian (Variscan) mountain system. Called the Rhehercynian and Saxothuringian zones (labeled RH and SX in Fig. 4), these regions are well-known from surface exposures, but little is understood about their significance in the evolution of the European lithosphere. Interest in the nature of these zones is high and several methods are now being focussed on their properties at depth. The zones with pattern in Fig. 4 are regions of low resistivity (ca. 10 Ωm), the white areas have high resistivity (ca. 1000 Ωm). There are three conducting layers:

1) at about 10 km depth (i.e. beneath Münsterland),
2) in the upper/middle crystalline crust (the irregular band at about 20 km depth), and
3) the layer below 50 km depth.

The shallowest layer confirms the presence of widespread and thick sedimentary basins over much of northern Ger-

---

**University of Bristol**

**Faculty of Engineering**

**Department of Engineering Mathematics**

**Post-Doctoral Research Assistant in Electrohydrodynamics**

(Temporary position: Twelve months duration)

Applications are invited for the post of Post-Doctoral Research Assistant in Electrohydrodynamics to be based in the Department of Engineering Mathematics in a multi-disciplinary and multi-national team. Investigations currently under way involve experimental and theoretical analysis of the augmentation by means of DC electrical fields of single phase heat transfer in dielectric liquids. The project necessarily involves working with groups in the Laboratoire d’électrostatique et de matériaux diélectriques, CNRS, Grenoble, France and the Departamento de Electricidad y Electronica, Universidad de Sevilla, Spain and forms part of work sponsored by the European Economic Community under its Stimulation Action Programme.

The investigation will involve the construction of theoretical models of finite amplitude fluid convection in the presence of both thermal and electrical charge gradients. A numerical treatment of these models will it is hoped provide an insight into the intricate interactions that lead to the significant increases in the heat transferred. It is thought that candidates who already possess or are about to submit for a Doctoral qualification and who have some experience in fluid dynamics and an interest in the numerical treatment of nonlinear dynamical systems of an interdisciplinary nature would be ideally suited to the post. An ability to speak English and French or Spanish would be an advantage. Salary according to age and experience will be within the range £9305 – £11015 (£9865 – £11680 from 1st March, 1989) of the 1A scale for British Universities Research Staff. For more details of the project and terms of employment please write to one of the following:

Dr. A.T. Richardson, Department of Engineering Mathematics, Queens Building, University Walk, Bristol, England BS8 1TR.

Dr. P. Atten, Laboratoire d’électrostatique et de matériaux diélectriques, CNRS, 25 rue des Martyrs, 166-38042 Grenoble Cedex, France.

Professor A. Castellanos, Departamento de Electricidad y Electronica, Universidad de Sevilla, Avenida Reina Mercedes, 41012 Sevilla, España.

Applications to be forwarded as soon as possible.
many. Sediments are usually channels for ground water and this characteristic is reflected by the low-resistivity of layer 1. Of particular interest are the two deeper layers which coincide in depth and extend with seismic low-velocity zones that have been found in this region. If associated with fluids, the zone should indicate low seismic velocity; if associated with mineralised layers or high-pressure metamorphism, the zone may be seismically detected as high-velocity layers. As mentioned above, some high-velocity seismic reflectors in the upper crust have been proposed as mineralised or mylonite layers along which large blocks of the continental crust may have moved. Thus detection of zones of high conductivity through magnetotelluric methods not only supports the seismic identification of these layers, it also provides confirmation of their geologic significance. The deepest zone of low-resistivity (layer 3) is usually called the "conductosphere" and may correspond to the asthenosphere which is expected at this depth. Seismic results have not yet penetrated to this depth; it is hoped that, as for FENNOLORA, the forthcoming EUGEMI results may provide information on upper mantle velocities to compare with the electromagnetic data.

In addition to the horizontal differentiation, another important observation from the data of Fig. 4 is the clear evidence for a deep-seated vertical boundary beneath the surficial exposure of the Rhenohercynian/Saxothuringian boundary. Vertical reflectors are notoriously difficult to resolve through seismic methods. The confirmation by electromagnetics of the importance of this geologic boundary is itself a valuable result; that it appears to continue through the "conductosphere" (asthenosphere) is an unexpected discovery that awaits data from other sources better to understand it.

Gravimetric and Geodetic Methods

Gravity measurements provide another important parameter that reveals information about the deep density structure of the crust and upper mantle. After correction for topography (normally calculated to a radius of 187 km from the measurement site using an average density of crustal material of 2670 kg/m³), for elevation ("free air" correction), and for the effect of earth tides (since gravity measurements are now accurate to better than ±10 µgal [100 nm/s²] and maximum amplitudes of earth tides are about 250 µgal), the resultant gravity measurements are compared to a standard reference model and called "Bouguer anomalies". Large negative Bouguer anomalies indicate missing mass at depth, large positive Bouguer anomalies indicate the presence of a deep, extra-dense mass. Negative Bouguer anomalies are in a region with normal crustal densities indicate that crustal rocks must continue to abnormal depths as was seen in Fig. 3a in the region of the Alps.

The wavelength of the Bouguer anomaly curve along a given profile is proportional to the depths of the anomaly source. Short and intermediate wavelength Bouguer anomalies provide information about the upper crust (i.e. sedimentary basins and density variations in the depth range 1-5 km). Large wavelength gravity anomalies usually reflect changes in depth to the Moho. As stated in the discussion of Fig. 3a, gravity is a potential field and gravity data integrate density effects over a wide region. Long wavelength Bouguer anomalies can be corrected for surficial densities where these are known or estimated and data so corrected are called "residual" gravity. The residual gravity provides information on effects of anomalous bodies located in the lower crust and upper mantle.

Fig. 5 illustrates the gravity behaviour under the southern segment of the EGT. This north-south profile is an extension to the south of Fig. 3. The top line shows the topography of the crystalline base-
basis for Fig. 5 yield evidence for a deep density anomaly dipping into the atmosphere. In Fig. 5b, the lower thin and broken thick lines are the observed and modelled Bouguer anomaly (BG) curves and the upper thin line is the residual gravity (RG) curve. The residual gravity was produced by taking into account all known near-surface effects, such as the sediments of the Molasse Basin to the north of the Alps and of the Po Plain south of the Alps. Seismic refraction and reflection data, information from boreholes, and results of geoelectric soundings were used to define the geometry and the density distributions of these near-surface structures. After the crustal effects were eliminated, a large, long-wavelength positive anomaly is evidenced by the residual gravity curve in Fig. 5b. Three-dimensional modelling and a least-squares inversion technique were applied to this data and the result indicates a deeply buried, dense body in the upper mantle under the southern margin of the Alps. One model of this structure is shown in the lower part of Fig. 5a. The centre of this dense body lies southwards of the maximum topography and the minimum Bouguer values due to the Alps and their crustal root. Although this model is still very primitive, lacking independent data from other sources (seismic tomography, precise geodetic levelling, and heat flow among others), it appears that this deep, dense body is a slab of continental lithosphere, partially subducted in the African-European plate collision, which is now lying in a near-vertical position under the southern Alps.

Further south, the EGT crosses Corsica and Sardinia. These two pieces of old (Hercynian) European continent have provided clues to a very dynamic and, in a geological sense, recent past. Similarity of rocks on Corsica and Sardinia with those from southern France supports the view that these islands were once part of the European continent. About 21 Ma ago, they began rift away from Europe. Magnetic anomalies charted by airborne surveys and the findings of palaeomagnetism (a method based on the record of the direction of the Earth's ancient magnetic field which is contained in some rocks and can be used to reconstruct the movements of parts of the Earth's crust) indicate that first Corsica alone, then Corsica and Sardinia together, rotated counterclockwise at a relatively fast rate of 30 mm/a. Fig. 6 illustrates this process. Rifting had ceased by 18 Ma ago when Corsica and Sardinia arrived at their present position leaving the Provençal Basin in their wake. This move-

The Faculty of Science of the University of FRIBOURG, Switzerland has an opening for a

Full Professor in Theoretical Physics

The successful candidate will be head of the Institute of Theoretical Physics and in charge of the teaching activities of the basic courses in theoretical physics, which are given in French and/or German.

It would be desirable if the new professor were in a position to interact with the three research groups in experimental physics. Two of these groups perform experiments at SIN and LEAR, one does research in solid state physics.

Qualified applicants should submit their curriculum vitae, a statement of current research interests, a list of publications and the names of three professional references.

Applications should be sent to the:
Dean of the Faculty of Science, University of Fribourg, Pérolles, CH - 1700 FRIBOURG / Switzerland by October 15, 1987.

The Svedberg Laboratory, Uppsala University

Post-Doctoral Fellowship in Experimental Physics

The Svedberg Laboratory is a newly established national laboratory built around three accelerators, a 6 MV tandem accelerator, a K = 200 cyclotron for light and heavy ions and a storage and cooler ring (CELSIUS) for proton energies up to 1360 MeV and corresponding energies for heavy ions, e.g., about 400 MeV/nucleon for fully stripped ions with A ≤ 40. The tandem accelerator has been in operation since 1970. The cyclotron is under reconstruction and the first external beam was delivered on May 29, 1987. The CELSIUS ring is expected to become operational in 1988.

A one-year post-doctoral fellowship is open for applicants within three years after their Ph.D. (or corresponding) examination. The applicant should qualify in experimental nuclear or elementary-particle physics or in accelerator physics. It is expected that he/she will use the facilities around the cyclotron or the CELSIUS ring. The fellowship can be extended to maximum two years and amounts to SEK 80 000 per year (free of tax) plus travel to Uppsala and back. Applications with curriculum vitae, publication list and three letters of reference before October 15, 1987 to:
Prof. Arne Johansson, The Svedberg Laboratory, P.O. Box 533, S-751 21 Uppsala, Sweden.
Both aeromagnetic and geochronologically-dated palaeomagnetic results were used to constrain the timing and extent of movement of ocean basins where mantle material is close to the surface. Geochemistry is important in gaining direct knowledge of the composition of the lower crust and upper mantle through chemical analysis of xenoliths, mantle and deep crustal material brought up in volcanoes. Geochronology, which uses precise analyses of ratios between radioactive isotopes and known decay rates for age dating, can help piece together the puzzle of superposed mountain building events. There are several cases where rocks of ancient mountains have been weathered down and the resistant minerals redeposited as sediments only to become involved again in younger mountain building events. One example of this is shown in Pb-U isotope data from zircons (a very hard zirconium silicate oxide) that were originally formed in mountain building 3700 Ma ago, subsequently eroded, and then redeposited in sediments which were caught up in the Hercynian orogeny dating from 400-230 Ma ago.

Geological field studies, aeromagnetics, geothermics, and palaeomagnetism combined to provide the crucial evidence for the rotation of Corsica and Sardinia. Although this rotation is now an accepted part of the geological evolution of the western Mediterranean, this result and others have created more questions than they have answered. How and when did the lifting from the European continent take place? What processes in the asthenosphere and lithosphere trigger lifting and drive the mechanism of plate movement? What is the nature of the layers and zones detected by the electromagnetic and seismic methods? What keeps the Alps rising when a deep density anomaly lies below their roots? The present EGTM programme will not be able to answer these difficult questions, but the large amount of data obtained from many different methods, the organisational structures, and the human resources for evaluating, analysing, and integrating these data into a unified whole, together provide a fertile ground out of which answers may one day arise.

BIBLIOGRAPHY