3D strength and thermal model of intraplate Europe

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Abstract

The construction of the first 3D strength cube of the European lithosphere has lead to an improved understanding of the dynamics of intra-lithospheric deformation processes. The 3D strength model is constructed using a first order 3D geometrical model of Europe's lithosphere and consists of several regions, representing areas of different composition, tectonic and/or thermal history. The depths of the different interfaces of the layers are distinguished on the base of deep seismic reflection and refraction or surface wave dispersion studies. The base of the crust is detected using a recently compiled European Moho map. Further constraints on the thermal lithospheric structure are obtained from heat flow studies and upper mantle seismic tomography.

The first results show that the European lithosphere is characterized by major spatial mechanical strength variations, with a pronounced contrast between the strong lithosphere of the East-European Platform east of the Tesseyre-Tornquist line and the relatively weak lithosphere of Western Europe. Within the Alpine foreland, pronounced north-west-southeast trending weak zones are recognized that coincide with major structures, such as the Rhine Rift System and the North Danish-Polish Trough, that are separated by the high strength North German Basin. Moreover, a broad zone of weak lithosphere characterizes the Massif Central and surrounding areas. A pronounced contrast in strength can also be noticed between the strong Adriatic indenter and the weak Pannonian Basin area and between the Fennoscandia, characterized by a relatively high strength, and the North Sea rift system corresponding to a zone of weakened lithosphere.

The next approach to realize a 3D European strength map consists of a refinement of the previous thermal model in order to obtain more detailed temperature distributions, which will be subsequently used as input parameter in the calculation of the integrated strength.

The new model under development consists of one 3D block limited on the top by the topography reconstructed using GTOPO30 data and on the bottom by the lithosphere-astenosphere boundary, defined using tomography data. This 3D block is divided in a number of layers depending on the number of discontinuities detected in the crust and mantle lithosphere by seismic reflection and tomography data. Two main layers are defined in every part of the model (crust and lithospheric mantle layer), while the others (e.g. sedimentary and lower crust layer) are only specified in the areas where they are observed. In order to generate the temperature distribution in our model we used the steady state conditions to solve the heat conduction equation. In tectonically active regions, affected by uplift and erosion, the velocity of the rocks inside the crust with respect to top free surface is taken in account. The model is constrained at the top by surface temperatures corrected for latitude and altitude effects and at the bottom by temperatures obtained by the inversion of tomography data. Sensitivity tests will be made to check the influence on the model of the approach chosen to calculate the heat production, density and thermal conductivity variation and of the boundary conditions used.

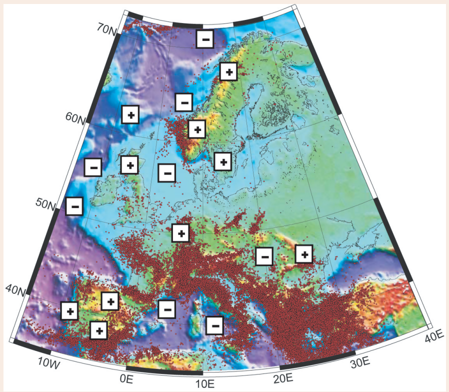

Fig.1

Fig. 1. Seismicity and Topographic map of Europe, illustrating present-day active intraplate deformation and areas of Late-Neogene uplift (rectangular with plus symbols) and subsidence (rectangular with minus symbols). Background elevation images are extracted from the ETOPO2 data set. Earthquake epicenters are from the NEIC data center, and are shown as red dots. The identification of intraplate areas that are mechanically weaker or stronger than neighbouring areas helps to understand the observed spatial variation in the response of the European lithosphere to large scale plate tectonic and thermal loading. The construction of the first 3D strength cube of the European lithosphere lead to a significant understanding of the dynamics of intra-lithospheric deformation processes, allowing to analyse the variation of rock strength with depth in 2D and 3D.

Fig.2. The 3D strength model is constructed using a first order 3D geometrical model of Europe's lithosphere and consists of several regions, representing areas of different composition, tectonic and/or thermal history. For continental realms, a 3D multi-layer compositional model are constructed, consisting of one mantle layer, two crustal layers and an overlying sedimentary cover layer, whereas for oceanic areas a one-layer model is adopted. The depth of the different interfaces several regional or European-scale compilations are distinguished on the base of deep seismic reflection and refraction or surface wave dispersion studies. The base of the crust is detected using a recently compiled European Moho map (Dezes and Ziegler, 2004). More constraints on the thermal lithospheric structure are obtained from heat flow studies and upper mantle seismic tomography. This model is developed in two principal steps: 1) construction of a 3D compositional model and 2) calculating a 3D thermal cube The final 3D strength cube is obtained by calculating 1D strength envelopes for each lattice point (x,y) of a regular grid covering Europe. For each lattice-point the appropriate input values are obtained from the 3D compositional and thermal cube. Grass 5.4 software package is used as reference for the construction of the input model.

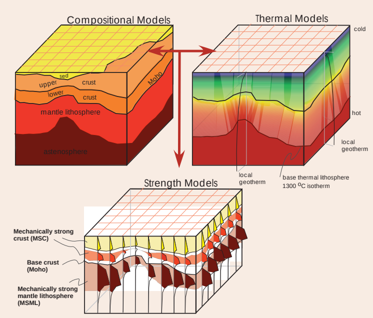

Fig.2

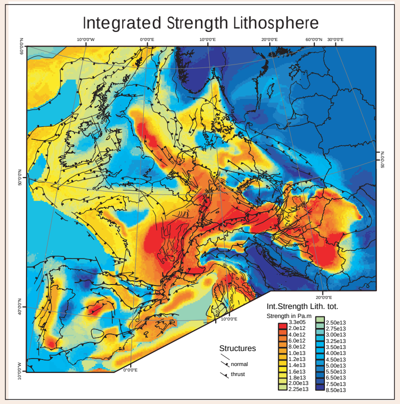

Fig.3a

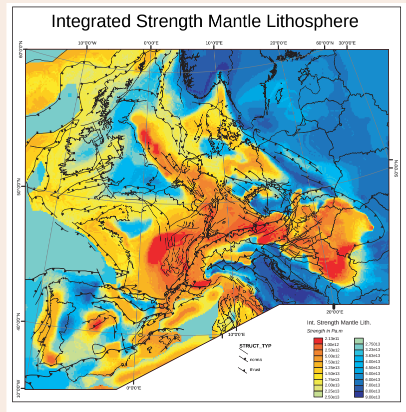

Fig.3b

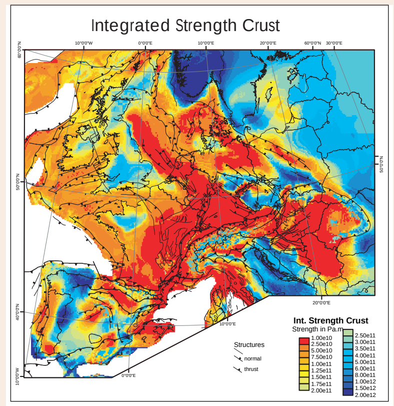

Fig.3c

Figs. 3a-c. Integrated strength maps for intraplate Europe. Adopted composition for upper crust, lower crust and mantle is based on a wet quartzite, diorite and dry olivine composition, respectively. Rheological rock parameters are from Tsenn and Carter (1987). The adopted bulk strain-rate is 10-16/s. Contours represent integrated strength in compression for (a) total lithosphere, (b) mantle and (c) crust. The main structural features of Europe are superimposed on the maps (Ziegler, 1988; Dezes et al., 2004).

The European lithosphere is characterized by major spatial mechanical strength variations, with a pronounced contrast between the strong lithosphere of the East-European Platform east of the Tesseyre-Tornquist line and the relatively weak lithosphere of Western Europe (Cloetingh et al., 2005). Within the Alpine foreland, pronounced north-west-southeast trending weak zones are recognized that coincide with major structures, such as the Rhine Rift System and the North Danish-Polish Trough, that are separated by the high strength North German Basin. Moreover, a broad zone of weak lithosphere characterizes the Massif Central and surrounding areas. A pronounced contrast in strength can also be noticed between the strong Adriatic indenter and the weak Pannonian Basin area and between the Fennoscandia, characterized by a relatively high strength, and the North Sea rift system corresponding to a zone of weakened lithosphere.

The comparison between Figs. 3a–c reveals that the lateral strength variations of Europe's intraplate lithosphere are primarily caused by variations in the mechanical strength of the mantle–lithosphere, whereas variations in crustal strength appear to be much more modest. The variations in mantle–lithospheric strength are primarily related to variations in the thermal structure of the lithosphere, reflecting thermal upper mantle perturbations imaged by seismic tomography, with lateral changes in crustal thickness playing a secondary role, apart from Alpine domains which are characterized by deep crustal roots. For instance, the strong lithosphere of the East-European Platform, the Bohemian Massif, the London–Brabant Massif and the Fenno-Scandian Shield can be explained by the presence of old, cold thermal lithosphere, whereas the European Cenozoic Rift System coincides with a major axis of weakened lithosphere in the Northwest European Platform. Similarly, the weakening of the lithosphere of southern France can be attributed to the presence of tomographically imaged plumes rising up under the Massif Central (Granet et al., 1995; Wilson and Patterson, 2001).

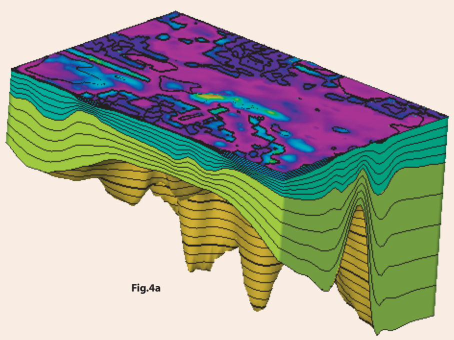

Fig.4a

Fig. 4a. Example of a 3D model used as input for the thermal model.

Figs. 4b-c. Example of a 3D thermal model obtained using the steady state condition to solve the heat equation. The model shows the temperature distribution within the lithosphere. The top of the model represent the temperature at the base of the sediments (Fig. 4b) and at the base of the Moho (Fig. 4c), respectively.

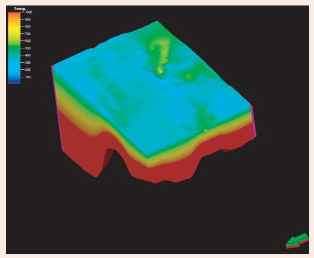

Fig.4b

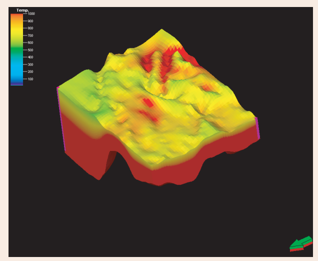

Fig.4c