The TRANSALP Project: Concept and Main Goals

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1 INTRODUCTION

TRANSALP is a multidisciplinary and international research programme for investigating the deep structure and evolution of the Eastern Alps as a paradigmatic example for mountain building by continent-continent collision.

The Alps as the youngest and highest mountain range in Europe have always been a challenge for geoscientists, and have played a key role in the development of new concepts and theories of mountain building (e.g. Termier, 1904; Ampferer, 1906; Dewey & Bird, 1970; Oxburgh 1972). While our former understanding was mainly based on geology and low resolution geophysical methods such as refraction seismics and gravimetry, more recently remarkable progress has been gained in the Western Alps and elsewhere by applying the high resolution technology of deep seismic reflection profiling DSRP (Roure *et al.*, 1990; Pfiffner *et al.*, 1997). The combination of the seismic reflectivity image with depth extrapolations from surface geology led to a new concept, the key structure of which is a wedge-shaped indenter of Adriatic lower crust and upper mantle splitting up the European crust, peeling and folding its upper part, and overriding and pushing its lower part down into the mantle. This model has been eagerly taken up and adapted to the Eastern Alps, although conspicuous west-east differences like the existence of the Austroalpine mega-nappe and the northward offset of the Periadriatic Lineament (PL) suggest the necessity of modifications or even basically different processes in the east. In any case, it became obvious that for validation, extension or improvement of the model deep seismic reflection profiling (DSRP) is also in the Eastern Alps an indispensable prerequisite.

This insight has given new impetus to the many years standing plan of connecting the deep seismic reflection networks of DEKORP in Germany and CROP in Italy by a transect through the Eastern Alps, and at the same time motivated the formation of the related OECORP group in Austria. Based on preparatory work of the national groups, representatives from Austria, Germany and Italy initiated the "East-Alpine Reflection Seismic Traverse" as a joint priority programme, later shortly termed TRANSALP. Its primary objectives can be outlined by the following questions:

- Where is the boundary between the European and the Adriatic/African plates at depth?
- Is there an unilateral subduction of one plate beneath the other (the European beneath the Adriatic or vice versa)?
- Or is there a more symmetric sub-vertical subduction of both lithospheric plates?
- Or created continental collision a complex imbrication and wedging pattern of lithospheric scale?
- Are there basic differences in the deep structure of the Western an Eastern Alps?
- Are the structural constraints provided by DSRP strong enough to control retro-deformation of East Alpine orogeny from surface geology?

More specific targets related to these questions concern (a) the geometry and reflectivity of the Moho and lower crust of both plates, (b) the depth of the crystalline basement beneath the Northern and Southern Calcareous Alps, (c) the possibility and extent of overthrusted younger, potentially hydrocarbon bearing sediments beneath the Calcareous Alps, (d) the deep structure of the crystalline Tauern Window, (e) the dip direction and significance of the PL, and (f) possible relationships between seismic structure and seismicity of the Eastern Alps.

These challenging problems and possibilities to their solution have been discussed at various international meetings and workshops from May 1994 to February 1998. The final research programme was worked out by the TRANSALP Steering Committee in cooperation with the TRANSALP Technical Committee, both comprising members from the CROP, OECORP and DECORP groups, and in close contact with colleagues from the Swiss NFP20 project.

2 TRANSALP SUB-PROJECTS

The TRANSALP programme focuses on a 300 km long and 40 km wide north-south transect approx. between Muenchen and Venice. The transect has been located at the meridian where the north-south width of the Alps is maximum and where the indentation of the Adriatic into the European plate, marked by the Periadriatic Lineament (PL), reaches furthest to the north (Fig. 1) indicating maximum north-south compression. Organizationally TRANSALP is subdivided in two main parts: (1) seismic and seismological projects, and (2) complementary geophysical, geological and petrological projects. The first part is coordinated by the Steering Committee, the second part by an additional Geoscience Committee.

2.1 SEISMIC AND SEISMOLOGICAL SUB-PROJECTS

The very centre of the first part and of the whole TRANSALP project is formed by a deep seismic near-vertical reflection profile, jointly financed by the Austrian, Italian and German partners. It has been designed for high resolution in the upper crust as well as deep penetration into the lithosphere by combining high-fold vibration with high energy but low-fold explosion seismics. The details of the programme have been worked out by the TRANSALP Technical Committee. Although the data acquisition was splitted up in three different campaigns between autumn 1998 and winter 1999, it provided for the first time a coherent, homogeneously measured, and thereby fully migratable section through the complete orogene and parts of its molasses foredeeps (see Fig.1, and Lueschen *et al.*, 2003).

The observation of the 300km long main line has been combined with a variety of complementary seismic and seismological experiments aimed at the control of 3D effects, at improving our knowledge of the seismic velocity distribution, and at the acquisition of informations about subcrustal depth ranges, which are inaccessible to active reflection seismics, but may nevertheless be of crucial importance for a comprehensive understanding of the orogenic processes.

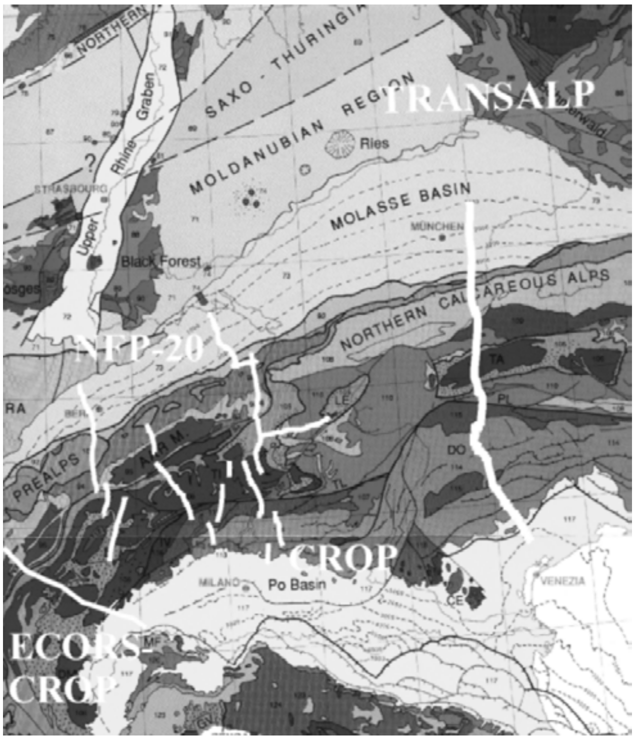

Fig. 1 – Location of the TRANSALP main line in the Eastern Alps and of earlier deep seismic reflection lines in the Western Alps (tectonic base map from Blundell *et al.* 1992). TA: Tauern Window, PL: Periadriatic Lineament, DO: Dolomite Mountains.

3D control was realized by 7 stationary cross-lines of 20 km length each at a mutual distance of about 30 km recording all vibrations and shotpoints on the main line in between the neighbouring cross-lines, and thus providing single-fold 3D coverage in a 10 km wide strip around the main line. This concept turned out to be economical and efficient. Clear evidence on seismic anisotropy of the upper crust in the central Eastern Alps was an extra bonus obtained from the cross-line observations.

Seismic reflection imaging requires reliable velocities which, for the deeper crust, cannot be extracted from reflections alone. Therefore TRANSALP has made special efforts to acquire complementary refraction and wide-angle reflection data for improving previous velocity models, which mainly stem from refraction experiments in the 1960s and 70s (Miller *et al.,* 1977; Scarascia & Cassinis, 1997). To this purpose on the one hand additional remote shots have been fired at the reflection spread, and on the other hand a mobile array and a wide-spread stationary network of continuously recording 3-component station (up to 128) have been deployed to register all explosions and, as far as possible, also the vibrations of the reflection programme to greater distances. Remarkably, vibrations could be recorded and processed at well placed single stations up to a distance of 80 km and provided a large amount of overlapping travel-time data which could be inverted, together with the explosion data, by tomography to an improved velocity model (Bleibinhaus, 2003).

The stationary 3-component network, part of which was maintained operational for up to 9 months, was also used to gather data for multiple seismological purposes, e.g.

(a) seismotectonics as reflected by focal mechanisms of local earthquakes,

(b) study of velocity anomalies in the subcrustal lithosphere and astenosphere by local and teleseismic earthquake tomography (Lippitsch *et al.*, 2002),

(c) imaging lithospheric and upper mantle discontinuities by means of teleseismic receiver functions (Kummerow *et al.*, 2001).

The seismological investigations have been carried out by an extended working group including amongst others also partners from Switzerland (ETH Zurich). The various seismological results gained until now clearly confirm that the East Alpine tectonics is not restricted to the lithosphere but reaches deep into the upper mantle.

2.2 COMPLEMENTARY SUB-PROJECTS

Deep seismic reflection profiling is undoubtedly the most powerful tool to unravel the deep structure of mountain belts, especially when supported by accompanying seismological investigations as outlined in the last section. But even then some fundamental interpretational problems may remain, which can only be solved in combination with other methods.

One of these problem concerns the integrated interpretation of seismic sections and surface geology being often impeded by the poor resolution of the reflection method near to the Earth surface. In the Alps this problem is partly decreased due to deeply exposed outcrops enabling extrapolation of surface geology to greater depth. On the other hand significant tectonic boundaries may be concealed by glacial blankets or by alluvial valley deposits making a surface consistent interpretation of the reflection seismic results difficult. In one of the complementary projects (Thomas *et al.*, 2003) show convincingly how such problems can be solved by small-scale high resolution reflection seismics compensating the near-surface drawbacks of DSRP.

Other accompanying projects are aimed at the re-evaluation of the density structure and isostatic state of the Eastern Alps in the light of the new reflection seismic and tomographic results (e.g. Ebbing *et al.*, 2001; Ebbing, 2002). It turned out that the spacing and quality of the initially available gravity data were to inhomogenous in crucial areas of the Southern Alps for discriminating between competing seismic models. This caused the TRANSALP Steering Committee to commission the acquisition of some other 250 gravity stations in autumn 2001; the extended data set is deemed now more adequate to solve the open problems (Bernabini *et al.*, 2003; Ebbing & Goetze, 2003).

Besides seismic structure and density distribution the actual temperature field is amongst the most important boundary conditions constraining the tectonic and petrogenetic evolution of the Alps. Surprisingly, in spite of only few reliable heat flow data in the Eastern Alps and uncertainty about the heat production rate in the middle crust, Vosteen *et al.* (2003) were able by steady-state forward and inverse simulation of the conductive heat transport to estimate relatively sharp bounds on the temperature distribution, e.g. 900°C +- 30% at 55 km beneath the PL. This implies at least partial anatexis in the deepest parts of the European crust and offers explanations for the seismic trans-parency in that depth range as well as for the origin of young periadriatic igneous intrusions.

In addition TRANSALP is accompanied by a wealth of complementary geologic and petrologic research projects aimed at incorporating the seismic results as constraints and/or at providing support to their integrated interpretation. They include specific field-works as well as various (petrophysical, geochemical, chronometrical) laboratory investigations and modelling-supported reconstructions of the East-Alpine evolution.

3 SUMMARY OF THE SEISMIC RESULTS

First DRSP results have been published in TRANSALP Working Group (2002) and will be presented in more details at this conference. Interpretations should be based on the entirety of the seismic sections (vibroseis and explosions, stack sections, time- and depth-migrated sections). But even then, some correlations and conclusions may depend also on the personal experience and conception of the interpreter, and it is therefore not surprising that different models are under discussion so far. The following structural properties, however, are beyond doubt:

The Eastern Alps display an thickened crust related to convergent and slightly asymmetric dips of both, the European and the Adriatic plate. Using the Moho (defined in reflection seismics as the base of the reflective lower crust) as marker horizon, the European Moho can be traced over a distance off 160 km from 30 km depth under the northern Molasse foreland to about 55 km depth south of the Alpine main crest, where it disappears in a transparent zone below the PL. Remarkably, the low frequency receiver functions derived from teleseismics (Kummerow *et al.*, 2003) indicate a limited continuation to south of the PL. The Adriatic Moho is less pronounced, but dips steeper than the European Moho; it disappears as well at 55 km depth in the transparent zone below the PL. Distinct differences in the crustal reflectivity pattern give good chances to delimit the two plates: A thin European lower crust is confronted with a very thick Adriatic lower crust. A prominent transcrustal reflecting zone dipping from the Inn valley to the south separates a northern domain with moderate subparallel reflectivity from a southern domain of strong and complex reflectivity with a conspicuous bi-verging pattern (Lueschen *et al.*, 2003) which bifurcates beneath the PL. The PL proper, often supposed to be a key structure for the understan-ding and reconstruction of Alpine orogeny, cannot be clearly identified in the seismic sections, most likely because of subvertical inclination. Also the successful processing of the neighbouring crosslines has not provi-ded evidence for a northward or southward dip of the PL, which would imply quite different collisional scena-rios.

The seismic sections contain many new and hard constraints, which must be taken into account in any evolutionary models of the Eastern Alps. Naturally, they are still to wide to enforce an unambiguous interpretation, and thus again emphasize the necessity of close interdisciplinary cooperation.

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