A subduction model for the Alps derived from geophysical results

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There are abundant physical, geochemical and geophysical data about the Eastern Alps for which a tectonic synthesis may be tried from a geophysical point of view.

It is geologically clear that the crust of the Eastern Alps has been shortened but this shortening is not reflected in the total crustal thickness indicated by seismic data. The average thickness of the crust does not exceed 35 to 40 km. This is in contrast with the 65 to 80 km thickness which would have resulted if all of a mixed continental and oceanic crust has been compressed and shortened by a factor of 2.5 or 3. Therefore, there is good reason to postulate that crustal material has disappeared. We have two models for such a process, AMPFERER's " Verschluckung " or plate-tectonic subduction of a lithospheric plate. It is difficult to determine which model better fits the geological facts and the known physical data because only the very last orogenic events are presently observable. There is no active Benioff zone in the Eastern Alps today — but a gravity high south of the Alps — and, although there is evidence of andesitic volcanism in the Southern Alps, this evidence is not sufficient to define a classical subduction model.

In the non-folded molasse trough of the foreland of the Alps there are numerous east-west striking faults which are downthrown towards south. They may be an effect of a bending of the crust down towards the Alps.

Nearly 55 km north of the border of the Alps, the iso-surfaces of seismic velocity in the crust start dipping southwards. In contrast, below and south of the Peri-Adriatic (or Insubric) line up to a depth of more than 30 km the iso-surfaces are practically horizontal. Consequently, there is a remarkable geophysical asymmetry of the Alpine region between the northern and southern molasse troughs.

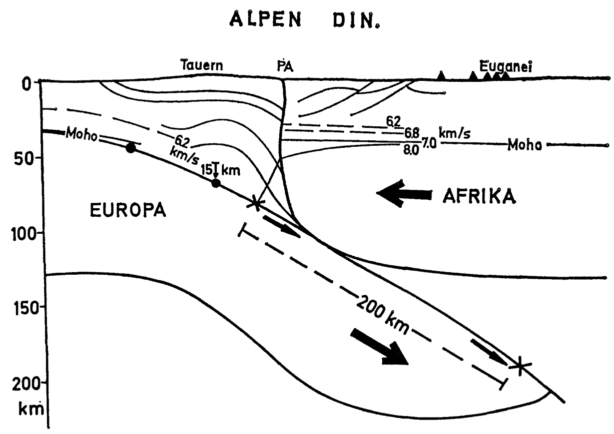

FIG. 1. : A cross section of the Eastern Alps about 20 million years b.P. Below the Tauern the Moho at that time is shown about 15 km deeper than calculated from recent refraction crustal investigations. A minimum figure for the subduction seems to be 200 km. PA = Periadriatic lineament. South of PA the results of recent seismic crustal studies are used.

Rapp. Comm. int. Mer Médit., **23**, 4a, pp. 55-57, 1 fig., (1975).

Exposed in the Tauern window are rocks which have been metamorphosed twice (MORTEANI). The first metamorphism was mainly an Alpine high-pressure phase (average of 6-8 Kbar) followed somewhat later by a phase with higher temperatures (500 to 600° C) (MORTEANI, FRIEDRICHSEN). The time delay between these two events is typical for a subducted plate. Radiometric age determinations on rocks exposed in the central part of the Tauern window give K/Ar cooling ages between 10 and 20 million years (KREUZER). This, together with the metamorphic history of these rocks, indicated that the crust-mantle boundary below the window must have been at a depth of about 70 km during the tertiary main orogeny. There is no evidence that the Moho south of the Insubric line ever was so deep. This pronounced asymmetry and the asymmetry of the distribution of seismic velocities favour a plate tectonic interpretation with subduction along a paleo-Benioff zone dipping to the south (see Figure 1).

Below the Eastern, Central and Western Alps is a low-velocity channel in the crust. In the Eastern Alps, the depth of the lowest velocities (less than 5.6 km/s) is about 20 km. These low velocity values indicate temperatures on the order of 600 to 700° C, temperatures which usually occur about 20 km deeper in normal continental crust. Because the heat flow is normal (when corrections for isostatic uplift are applied) (HÄNEL), it appears that the low velocity layer in the Alpine crust is a mass containing relict heat which is being or was up to subrecent time uplifted (at an average rate of about 1 mm/yr) and was buried much deeper in the past.

Geophysical measurements show that the electrical conductivity and, consequently, also to some extent the porosity of the sediments below the Calcareous Alps are similar to those of layers outside of the Alps (BERKTOLD). A relatively quick process of over- or underthrusting during which pore fluids could only be partially driven out could explain these observations. Such an explanation is most consistent with a plate-tectonic subduction model.

In addition to the nappe formation and the extraordinarily deep subsidence of the crustal material in the early and main phases of orogeny of the Alps, there also was perhaps partly quick uplift in a later phase. This well-known process has been attributed mainly to isostatic effects. However, the diapir-like uplift of the crust north of the Insubric line and in the Tauern window could also have been caused by increasing bouyancy resulting from the ever increasing subduction of at least partly continental material when continents collide during that subduction. In this case, the hot upper crust of the subducting plate which is subject to an overburden pressure in the order of 6 to 8 Kbar and considerable tangential overpressure, has the tendency to be forced upwards to form a type of megadiapir such as we can see in a cross-section of the Tauern window. Similar considerations can be made for the Ivrea body.

In summary, geophysical evidence presently seems to favour a plate-tectonic subduction model over a " Verschluckung " model for the Alps.

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Interventions

K. Hsü — I congratulate Prof. CLOSS for his interesting model constructed on the basis of geophysical evidence. We geologists working on alpine synthesis also speculated on a south-dipping subduction during the Tertiary (e.g. HSÜ & SCHLANGER, 1972).

The subductions may have continued till Pliocene and may have accounted for the crustal shortening under the Jura, as my colleague TRÜMPY believes.

D.C. Krause — CLOSS has indicated low velocity layers deep in the crust. These must be weak zones if they represent elevated temperatures. Could these have existed during the period of subduction so that they acted as zones where the upper crust could " peel " off from the lower crust, thereby allowing the lower plate to slip into the mantle under conditions of reduced friction?

Réponse — We now see that under the Ivrea-body the reduction of the crustal velocity is more pronounced in greater depths. Therefore the idea of the speaker is a very reasonable one.

P. Baïssas — Comment expliquez-vous, à la lumière de cette notion de subduction profonde, le rétrocharriage de la zone briançonnaise et piémontaise des Alpes occidentales?

Réponse — Le modèle que je propose est uniquement théorique, et il reste aux géologues à le confirmer ou l'infirmer à l'aide de leurs observations.
J. Makris — How does your model account for the not existing deep located earthquakes?
Réponse — The model which I have presented in fig. 1 demonstrates an idea of the situation about 20 million years ago. Today we do not have any evidence of an active Benioff-zone under the Alps, only in the foreland of the Alps we have perhaps evidence of some tangential overpressure. But this fact does not exclude a paleo-Benioff — zone which was active from the Lower Cretaceous to the Upper Tertiary.
D.H. Matthews — Are there any deep focus earthquakes to substantiate the pver-ridden European slab, and if not, why not?
Réponse — As explained the Benioff-zone which I tried to derive from a number of physical data has lost its activity since the Upper Tertiary. The driving forces seem to have stopped possibly as a consequence of a bouyancy equilibrium because too much continental crust might have been involved in the late period of tectonism, or perhaps because the continental blocs stopped moving. The absence of deep focus earthquakes can demonstrate that also along the lower part of a possible paleo-Benioff-zone all movements have stopped now and even no deeper part of a slab is moving downward as a separate unit.

It is difficult to have an idea about the maximum length of the slab, because the width of the Penninic and Flysch troughs are unknown.

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