processes increases in the given order: the Hellenic arc being the youngest and the Carpathian arc being the oldest (evolved) version. Finally, a very noteworthy result is that - for all three arcs - the migration patterns associated with the inferred lateral migration of slab detachment appear to originate in the region of the present-day Alps.

de Jonge, M., Wortel, M., and Spakman, W., 1993. From tectonic reconstruction to upper mantle model: an application to the Alpine-Mediterranean region. Tectonophysics, 223, 53-65.

de Jonge, M., Wortel, M., and Spakman, W., 1994. Regional scale tectonic evolution and the seismic velocity structure of the lithosphere and upper mantle: the Mediterranean region. J. Geophys. Res., 99, 12091-12108.

Spakman,W., 1988. Upper mantle delay time tomography, Ph.D. Thesis, Geologica Ultraiectina, 53, 200 pp.

Spakman, W., 1991. Delay time tomography of the upper mantle below Europe, the Mediterranean, and Asia Minor. Geophys. J. Int., 107, 309-332.

Spakman, W., van der Lee, S., and van der Hilst, R., 1993. Travel-time tomography of the European-Mediterranean mantle down to 1400 km. Phys. Earth Planet. Int., 79, 3-74.

Wortel, M., and Spakman, W., 1992. Structure and dynamics of subducted lithosphere in the Mediterranean region. Proceedings Koninklijke Nederlandse Akademie van Wetenschappen, 95, 325-347.

Wortel, M., and Spakman, W., 1993. The dynamic evolution of the Apenninic-Calabrian, Hellenic and Carpathian arcs: a unifying approach. Terra Abstracts (EUG VII, Strasbourg), sup. to Terra Nova, 5, 97.

Yoshioka, S., and Wortel, M., 1995. Three-dimensional modeling of detachment of subducted lithosphere. J. Geophys. Res., 100, 20223-20244.

The complex evolution of the Western Outer Carpathians: implications of flexure- and gravity modelling

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Vertical movements in the Western Outer Carpathian foreland system are investigated by lithospheric flexure- and gravity- models carried out along 5 profiles crossing the foredeep and thrust belt. Special attention is paid to the possible influence of pre- and post- orogenic processes on the deflection of the foredeep and thrust belt.

In the west the Neogene foredeep, resulting from the SE underthrusting or subduction of the North European plate under the Carpathian mountain belt, is very steep and narrow. This implies weak lithosphere and high bending stresses. Seismic observations of nearly horizontal Moho are explained with two possible scenarios: (1) a post- orogenic process of slab detachment and (2) the subduction of thinned lithosphere (pre-orogenic passive margin). Furthermore, post-orogenic regional scale uplift, about 150 to 300 m, is proposed for profiles crossing the Western and Central Carpathian foreland, in order to explain erosional surface, elevated distal foreland deposits and the low amplitude of the Bouguer gravity anomaly. A possible thermal uplift, associated with the Pannonian basin evolution is ruled out as possible explanation. Such uplift would imply a negative contribution to the gravity anomaly.

In the eastern part, the foredeep becomes more wider. Although the lithosphere is proposed to be slightly stronger, the effect of widening is explained by the interference of the East European plate, underthrusting or subducting the Carpathians to the SW.

Jointing in the Polish Outer Carpathians: hints for stress field reorientation

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The Polish segment of the Outer Carpathian fold-and-thrust belt is composed of a number of north-verging nappes. Studies of joint pattern within the different lithostratigraphical units of these nappes, as well as within the discordantly overlying younger strata, enable one to constrain the Late Cretaceous through Pliocene stress field of that region.

In the medial segment of the area studied, joints have been analyzed in several nappes, most of the data coming from the Magura nappe. In the last one, joint pattern reveals a clockwise rotation of the reconstructed maximum stress axis (s1) from the Late Cretaceous through the Middle Miocene strata. The maximum stress axis, inferred from the position of the acute bisector between conjugate Coulomb-shear or hybrid-shear fractures, is oriented N-S within the Turonian-Campanian strata, NNE-SSW in the Maastrichtian strata, ENE-WSW within the Palaeocene strata, and NNW-SSE within the Eocene through Middle Miocene strata. This gives 150° of clockwise rotation of s1 in the time-span considered. The maximum stress axes reconstructed for post-Cretaceous strata of other nappes are oriented NNE-SSW to NE-SW, being nearly perpendicular to fold axes.

On the other hand, the Pliocene molasses of the Podhale region display joint pattern indicating the N30-40°E oriented s1. This suggests a further clockwise rotation of the maximum stress axis by

60°. This orientation of s1 (NE-SW) coincides with that in the eastern segment of the Polish Outer Carpathians, both in the Palaeogene strata of Dukla and Silesian nappes and in the unconfortably overlying Middle Miocene molasses, as well as with the orientation of the present-day maximum horizontal stress axis, detected by breakout analysis.

Summing up, the stress field associated with jointing in the Magura nappe in the medial sector of the Polish Outer Carpathians has undergone clockwise rotation since the Late Cretaceous. The bulk of this rotation (130°) occurred during Palaeogene times, whereas Neogene rotation amounted to some 60°. No traces of this rotation have been found within other nappes.

The Miocene strata of the Carpathian Foredeep near Kraków display another picture. These strata are cut by four sets of joints and one set of gypsum veins. These structures appear to result from four successive deformation stages, including N-S extension of Langhian age, and three stages of subsequent compression (N-S, NE-SW and NW-SE). The last compressional episode appears to have been active during Pliocene-Quaternary times.

Jointing in the Skiba (Skole) Unit, Ukrainian Carpathians: preliminary results

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The Skiba (Skole) nappe is one of the outermost flysch nappes in the Outer Ukrainian Carpathians fold-and-thrust belt. The nappe is composed of a number of imbricated slices thrust one upon another in the middle-late Miocene times. In a SW-NE oriented profile, these are Slavsko, Rozhanka, Zelemianka, Parashka, Skole, Orovska and marginal slices, whose lithostratigraphic inventory includes: Upper Cretaceous thin- to medium-bedded Stryi beds, Palaeocene thick-bedded Jamna sandstones, Palaeocene-Eocene variegated shales and thin- to medium-bedded turbidites of Maniava, Pasiechna, Vyhoda and Bystritsa beds, Oligocene Menilitic beds and calcareous Holovets beds, as well as Oligocene-Miocene thin- to medium-bedded sandstone-shale complexes of Verkhovina beds. Joints and shear/hybrid shear fractures have been measured at some 40 localities equally spaced throughout all but the marginal slices of the Skiba nappe along the Opir river section.

The fractures are mostly kathetal and cluster into two to three cross-fold sets. The axes of maximum compression associated with jointing usually trend NE-SW to W-E, as far as Paleogene and Miocene strata are concerned, being subperpendicular to the overall strike of thrusts and fold axes. In the Upper Cretaceous strata, however, the axes in question strike N-S to NNE-SSW. These results are fairly coincident with those obtained by microtectonic studies of Kopyst'iansky and Kryzhevich (1985) on orientation of optical axes of deformed quartz crystals, and suggest that jointing must have been coeval with folding and thrusting of the rocks studied.

Kopyst'iansky R. S. and Kryzhevich V. L. 1985. Microstructural analysis of flysch deposits of the Carpathians and its significance for oil geology (in Russian). AN USSR, Inst. Geol. Geoch. of Fossil Fuels, 28 pp., Lvov.

The Outer Eastern Carpathians record continuous convergence since the late Cretaceous.

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Convergence and resulting folding and nappe stacking of the Eastern Carpathian Moldavides nappe complex have traditionally (e.g. Sandulescu 1984) been interpreted to have occurred in two main phases: in late Cretaceous and in Miocene times. This separation was enforced by the previous view of the internally conformable Maastrichtian to Eggenburgian Gura Beliei unit as the sedimentary cover of the folded, but not yet stacked area of the future Teleajen and Macla nappes in the front of the Ceahlau nappe complex. Strong deformation of the base of the Gura Beliei unit (Maastrichtian Gura Beliei Marls) suggests that large parts of this unit represent an out-of-sequence nappe. Its emplacement age is constrained to be Eggenburgian to Ottnangian, because lower Eggenburgian strata are a conformable member of the pile (Sandulescu et al. 1981) and the Ottnangian-Karpatian Doftana Molasse (Stefanescu & Marunteanu 1980) covers the folded pile sedimentary. This re-interpretation allows foreland propagating, in-sequence emplacement of the Teleajen, Macla, and Audia nappes between the Senonian (youngest sediments in Teleajen nappe) and the Lower Miocene (sedimentary onlap of the later folded Doftana Molasse on an already deformed nappe edifice). The progressive eastward shift of sedimentary