Geophysical fields and geodynamic model of the Verkhoyansk–Kolyma orogen (North-East Russia)

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The Verkhoyansk-Kolyma orogen (VKO) is located in northeast Russia and bounded by the Verkhoyansk and Sette–Daban Ranges to the west and Moma Range to the east. The VKO is reflected in the low-frequency component of the gravity field as a negative Bouguer anomaly (up to 100 mGal) of a size of 1100x1200 km. The average heat flow in the VKO is about 65 mW/m², with values as high as 100 mW/m² in the Suntar–Khayata Range and 88 mW/m² in the Tas–Kystabyt Range. The earthquakes of this region belong to the Arctic-Asia seismic belt being located in the areas of the Kharaulakh Range and the Chersky mountain system. Variations in the VKO crustal thickness from 35 to 45 km (average thickness is about 37 km) were established using seismic wave travel time data obtained for regional seismic events (Mackey et al. 1998). The result of combined investigations conducted by the authors was a model of the VKO deep structure. The velocity of P-waves in the upper mantle was computed from the velocity-density correlation and data of deep seismic investigations of the Europe–East Siberia transect (Pavlenkova 1997).

The supposed model of the VKO structure (to a depth of 200 km) has four layers. The upper layer of the Earth's crust (0–15 km) has a density of 2.65–2.75 $g.cm^{-3}$ and consists mainly of terrigenous–carbonate sedimentary rocks. The middle layer of the Earth's crust (15-25 km) has a density of 2.75–2.85 $g.cm^{-3}$ and the low layer (25–37 km) 2.90–3.0 $g.cm^{-3}$. According to the model, the density of the upper layer of the mantle (37–200 km) varies from 3.24 to 3.40 $g.cm^{-3}$. A low density (σ = 3.24 $g.cm^{-3}$) lens-like body (asthenolith?) is supposed to exist at a depth of 37–120 km in the mantle. The formation of the low density plume seems to have occurred in the Late Proterozoic. This generated the development of rift-related structures and aulacogens with a subsequent formation of a sedimentary basin within the passive margin of the North Asia craton. The ascent of the cooling asthenolith at the 37 km level during Mesozoic-Cenozoic times caused the development of an orogen due to the change of extensional stresses into compressional ones. Movements of the crystalline basement blocks within the upper and middle crustal layers were responsible for the formation of small rift-related structures, among them pull-apart basins, and causing high seismicity in the region.

The work was supported by the program "University of Russia" (99-9-1244)

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Late extension in the Western internal Alps inferred from converging brittle tectonic, geodetic and seismotectonic analyses

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To the SE of the Pelvoux massif, in the Briançonnais Zone of the Western Alps, a late alpine normal fault network overprints at every scales all the alpine compressive structures: pile of Briançonnais nappes, folds, and associated schistosities. Two main faults families trending NNW–SSE (longitudinal to the belt) and WSW–ENE (transverse to the belt) acted synchronously to forms this fault network. Some neotectonic indications have been found along these faults, showing a Quaternary activity. This normal faults network has partly been reactivated by strike-slip motions, longitudinal (right-lateral) and transverse (left-lateral) to the belt. Paleostress inversion of associated microtectonic data shows that both normal and strike-slip faulting correspond to a single late-Alpine tectonic event with permutation of the stress axes. This multi-scale brittle deformation is particularly well developed close to the Frontal Penninic Thrust, the crustal boundary between Internal and External Zones (Sue and Tricart 1999). Normal faults branch this Oligocene Thrust at depth, suggesting its extensional reactivation.

The present day activity of this area, which belongs to the Briançonnais seismic arc, has been inferred from seismotectonic analysis, using the Sismalp (Grenoble) and IGG (Genova) database. It is also extensive, and implies the same fault network. Several active faults have been recognised, especially along the High Durance fault zone. The roughly E–W extension deduced from fault plane solutions analysis has been confirmed by a geodetic study showing rapid tectonic motions in the alpine context (Sue et al. 2000). Seismotectonic cross-sections show that the seismic activity is located above the Frontal Penninic Thrust, and that active normal faults are linked to the former Thrust: it is currently inverted as a crustal-scale detachment.

The seismotectonic analysis of the Western Alpine arc as a whole, from the Argentera massif up to the Aar massif, 300 km along the belt, establishes that extensional tectonics affects the most part of the internal zones. Active extension spreads out to the North up to the Aar massif, and to the East in the Piemont Zone, along the Piémont seismic arc, which corresponds to the western side of the Ivrea Body. Thus, the recent and still active extensional tectonic regime reactivates the main crustal structures at the scale of the Western Alpine belt: the Frontal Penninic Thrust and the western side of Ivrea body. The current stress field, inferred from inversion of focal mechanisms, presents extensive stress axes perpendicular to the belt's arcuate geometry in the whole internal zones (Sue et al. 1999). The analysis of the GeoFrance3D database (using a temporary dense seismic network) confirms the extensional stress field to the south of the belt. Nevertheless, transpressive and compressive tectonic regimes are found to the front of the belt and in the Pô plain respectively. The core of the western Alps is thus undergoing extensional tectonics, while the alpine collision seems to be still active.

This major tectonic contrast asks for an accurate dynamic model. A competition between boundary forces at the limits of the belt (Europe–Apulia collision and Apulia counterclockwise rotation) and buoyancy forces in the alpine lithospheric root could control the present-day tectonic contrast in the Western Alps. We propose two dynamic models in which extension may be explained by the detachment or the roll-back of a continental slab in the alpine lithospheric root.

Intracontinental tectonics in the Atlas ranges of Morocco

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The Atlas ranges of northern Africa are belts of localized deformation in the foreland of the Rif–Tell plate-boundary orogen. Characteristics that are often cited for the Atlas mountains are high topography (summits above 4000 m) but moderate orogenic shortening, and lack of crustal roots in seismic refraction studies. In addition to these features, the absence of flexural basins in the periphery of the ranges is also striking .

A new balanced cross-section has been constructed through the central High Atlas of Morocco, between the localities of Midelt and Errachidia, parallel to the existing seismic refraction traverse. The section describes well the upper crustal structure and basement/cover interactions. As documented by previous works, the range derives from the inversion of a Triassic–Jurassic E–W trough, in whose former evolution extensional and strike-slip faults played a debated role. However, the process of fault reactivation during alpine shortening is perhaps less widespread than hitherto assumed. The margins of the Atlas range are formed by outward verging basement-involved thrusts, some of them deriving from inversion of Jurassic faults but others not. Towards the center of the range, large-scale buckle folding of basement and cover alike is recognized. Basement is downwarped in wide sinclinal areas to ca. 3000 m below sea level, but it is exposed at the surface outside of the range in the undeformed High Plateau to the north (Zaida area) and the Saharan platform to