Study of interrelation between faults and folded structures in the hinterland of NW Caucasus based on strain value estimations

Fedor YAKOVLEV[1]

[1]O. Schmidt's Institute of Physics of the Earth RAS, Moscow, Russian Federation; *yak@ifz.ru*

Defining the main geometric parameters of a folded structure at large depth is one of the ongoing issues of tectonics. The multirank strain analysis, developed in the last years (YAKOVLEV 2008), has allowed solving a number of problems in this field. Input data for this analysis are detailed structural sections, which were constructed during specific field works (GIORGOBIANI & ZAKARAYA 1989; SHOLPO et *al.* 1993).

Calculation of the position of basement tops. Exact knowledge of the structure of folding and of measured main parameters of its deformation allows restoring a pre-folded state of a section. In the beginning, the structural section is split into numerous domains (0.5–2 km wide), which are aggregating folds with an almost equal morphology. Three parameters are estimated in each domain, i.e. axial plane dip, envelope folds plane dip, and shortening value of folds in a direction perpendicular to the axial plane. Thus, the description of deformation of this domain (YAKOVLEV 2009) is equal to the determination of the strain ellipsoid (ellipse). Kinematic procedures of rotation, simple horizontal shearing, elongation regarding these parameters, and segment of section line allow restoring the initial length and inclination of the segment of the section line to horizontal bedding. The fault plane is considered as the boundary of the domain and its dip is estimated. The pre-folded inclination of the fault plane is restored by the same three procedures. Each domain has exact positions of bedding in the sedimentary succession. The difference of position of bedding on the opposite sides of the pre-folded fault plane gives the vertical displacement. Horizontal displacement is calculated based on the vertical displacement and on the fault plane dip. The total pre-folded structure is obtained by the aggregation of the pre-folded states of domains including fault displacements. The next step was the aggregation of several sets of domains into structural cells (pre-folded width of the cell is approximately equal to the total sedimentary cover thickness). For NW Caucasus we studied 11 sections, 244 do-

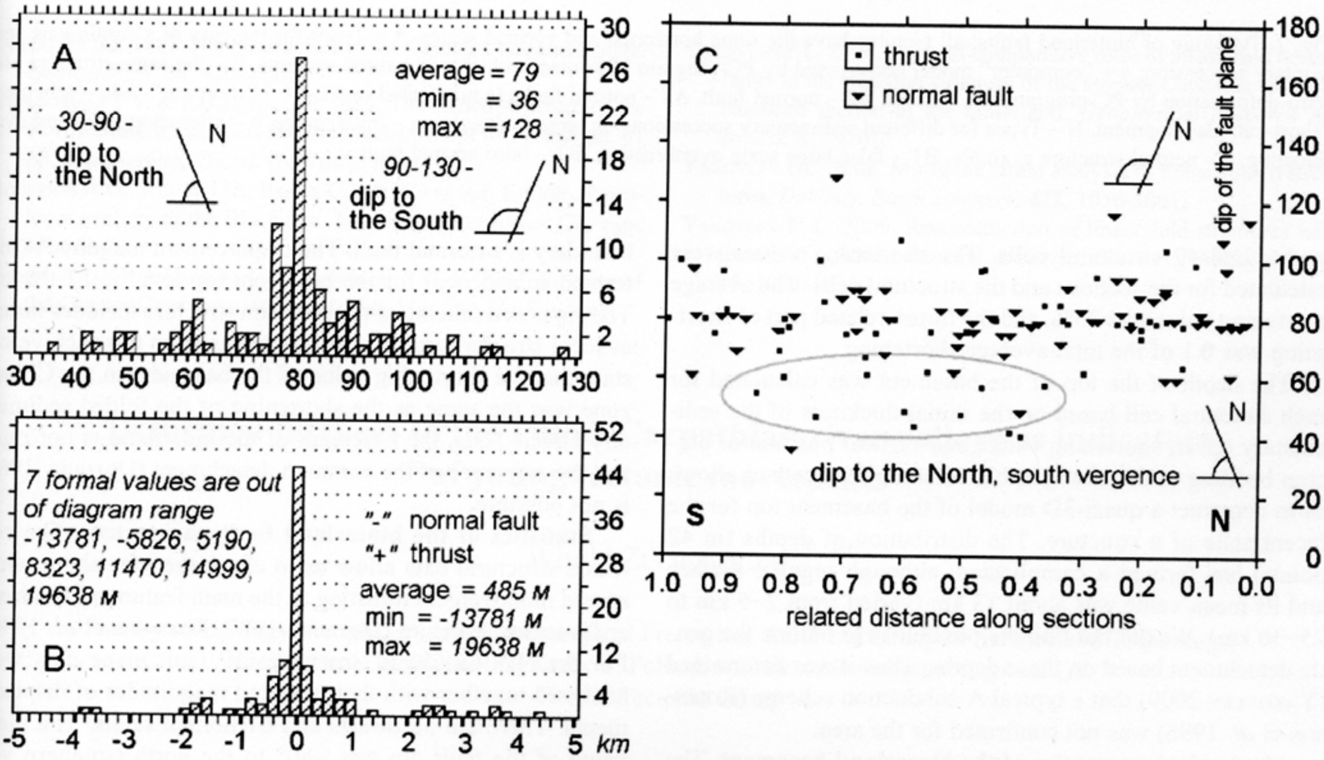

Fig. 1. Statistic diagrams of fault parameters. A – Histogram of fault plane dips, B – Histogram of fault displacement magnitudes; some values are out of range, C – Diagram of distribution of fault plane dips across the structure (along sections); the grey ellipse shows part of faults that have a southern vergence. The structure with monovergent thrusts should show only thrusts and only in the area around the grey ellipse

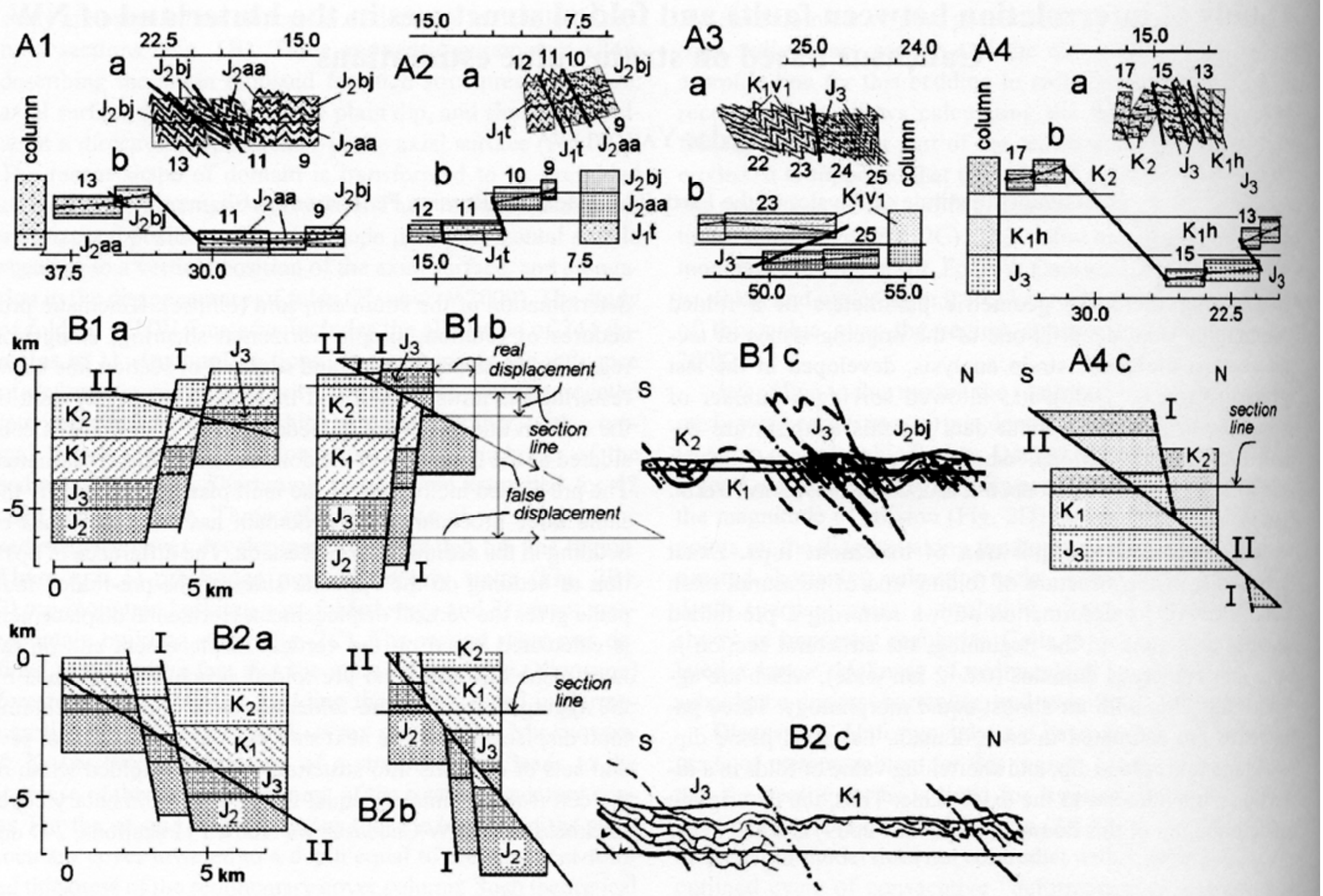

Fig. 2. Typology of hinterland faults; all pictures have the same horizontal and vertical scales. A – Types for the case of a continuous sedimentary succession; a – "computer" model constructed by PC-program after measurements in natural sections, b – the same structure after retro-deformation by PC-program. A1 – thrust, A2 – normal fault, A3 – normal faults (complicated case), A4 – "short-cut", A4c – scheme of "short-cut" development. B – Types for different sedimentary successions on large fault sides; a – initial stage, b – after shortening and overthrusting, c – natural structure example. B1 – false large scale overthrusting, B2 – false normal fault

mains, and 42 structural cells. The shortening values were calculated for the sections and the structural cells. The average shortening value was 35%, and the thrust-related part of shortening was 0.1 of the total average shortening.

The depth of the top of the basement was calculated for each structural cell based on the initial thickness of the sedimentary cover, shortening value, and vertical position of outcrop bedding in the stratigraphic column. The method allows us to construct a quazi-3D model of the basement top for the recent state of a structure. The distribution of depths (in 42 points) has formed a complicated, although regular, surface and its mean value was about 13 km (varied from 2–5 km to 25–30 km). We did not find the possibility to outline the gentle detachment based on these depths. Thus it was determined (Yakovlev 2009) that a typical A-subduction scheme (Robinson et *al*. 1996) was not confirmed for the area.

Mechanical properties of the hinterland basement. The structure of the transition zone (Transcaucasian Massif/Greater Caucasus) was studied based on structural materials of the Chiauri zone (South Ossetia) using the same method (Yakovlev 2006). It was shown that the Racha-Lechkumi fault on this boundary is a normal fault. The displacement magnitude (hinterland subsidence) for the basement top level is 12–15 km. The supposed scheme of the common structure includes thrusts as local structures in its upper part. Based on this fact we can state that the shortening value of the basement in the Chiauri zone was the same as the shortening of the folded sedimentary cover. Thus, the basement of the hinterland is not rigid, and the existence of the common detachment (Dotduev 1987) is not possible.

Statistics of the hinterland fault parameters. The collected structural data allow us to check the idea about widespread monovergent thrusting as the main feature of the Greater Caucasus structure (Dotduev 1987; Robinson et *al*. 1996). For the NW Caucasus structure, 119 fault plane dips were analyzed together with their restored magnitudes of displacements. There are 58 thrusts and 61 normal faults. The mean value of the fault dip was ~80° to the north (southern vergence). However, the distribution of dips was normal and symmetric around this value (Fig. 1A). One fifth of the faults (10 thrusts and 13 normal faults) have dips to the south. The mean value of the magnitudes of horizontal displacements was

~1838 m for thrusts and ~788 m for normal faults (Fig. 1B). The distribution of dips of fault planes across the total structure shows a weak divergence (Fig. 1C). A few thrusts having maximal displacements belong to the central and southern parts of the structure. Thus, the monovergence of thrusting is not confirmed by statistics.

Hinterland faults typology. The experience of restoration of faults allows us to suppose several main types of faults for cases of identical and different sedimentary successions in adjacent domains. The simplest structures for the constant sedimentary cover succession are thrusts and normal faults. They are restored for domains with subvertical axial planes by the difference in depths of beds on the opposite sides of the fault (Fig. 2A1, 2A2). A more complicated case occurs when the dip of the fault plane is steeper than the inclination of the axial plane. In this case, a formal thrust (older sediments in hanging wall) can be restored as a real normal fault (Fig. 2A3). Well-known «shortcut» structures also occur in multi-scale folded structures (Fig. 2A4). In the first stage under extensional regime, a normal fault develops with a dip about 70°. In the second stage during shortening, a thrust develops as a new plane with a dip about 45°. This thrust penetrates from the hanging wall to the footwall and cuts a wedge, which has the length of about several kilometres along the section line.

A complicated structure appears if the fault occurs at the boundary of a sharp change in the thickness of units of the sedimentary cover. Let us assume that in the northern block during the initial stage, Upper Jurassic beds are 3 km higher than beds of the same age in the southern block, because the Cretaceous and Palaeogene units have different thicknesses. In the case of gentle thrusting to the south, the Upper Jurassic is in contact with the Upper Cretaceous. We may calculate the magnitude of displacement based on the level of the northern unit (this is correct), or on the level of the southern unit (Fig. 2B1). The magnitude will be about 2 km in the first case and almost 15 km in the second case (this is an error). Another situation occurs if the block having a larger thickness of the sedimentary succession was overthrusted. Thrusting from the north to the south leads to the contact of the Lower Cretaceous (hanging wall) with the Middle Jurassic (Fig. 2B2). Formal analysis of the structure based on the ages of beds gives us the erroneous solution of the "normal fault". In the analysis of such complex cases, we offer to use exact stratigraphic successions with numerical indications of the depths of particular beds. Thus, based on the differences of depths the vertical and horizontal displacements can be found easily. The ages of beds will be ignored in this case.

Conclusions. The presented special studies of folded structures using estimation of fold-related shortening allow us to determine the real properties of fault structures. The results can confirm or disprove widespread opinions on these complicated objects.

REFERENCES

Dotduyev S.I. 1987. Nappe structure of the Greater Caucasus Range. *Geotectonics*, **20**, 420-430.

Giorgobiani T.V. & Zakaraya D.P. 1989. The folded structure of the North-Western Caucasus and the Mechanism of its Formation, 61 pp. *Metsniereba*; Tbilisi. [*In Russian*]

Robinson A.G., Rudat J.H., Banks C.J. & Wiles R.L.F. 1996. Petroleum geology of the Black Sea. *Marine and Petroleum Geology*, **13**, 195-223.

Sholpo V.N., Rogozhin E.A. & Goncharov M.A. 1993. Folding of the Greater Caucasus, 192 pp. *Nauka*; Moscow. [*In Russian*]

Yakovlev F.L. 2006. Study of comparative roles of thrusts and normal faults in the collision structure of the Greater Caucasus based on balanced section of the hinterland. *Geophysical Research Abstracts*, **8**, 09201.

Yakovlev F.L. 2008. Multirank strain analysis of linear folded structures. *Doklady, Earth Sciences*, **422**, 1056-1061.

Yakovlev F. L. 2009. Reconstruction of linear fold structures with the use of volume balancing. *Izvestiya, Physics of the Solid Earth*, **45**, 1023-1034.

Deformed terraces in the Polish Carpathian river valleys as indicators of young tectonic movements

Witold Zuchiewicz[1,2]

[1]Faculty of Geology, Geophysics and Environmental Protection, AGH University of Science and Technology,
Mickiewicza 30, PL-30-059 Kraków, Poland; *witoldzuchiewicz@geol.agh.edu.pl*
[2]Galicia Tectonic Group

In the Pliocene and Quaternary the Polish Carpathians witnessed differential vertical and some remnant horizontal movements, resulting in the formation of elevated and subsided areas. Evidence for Quaternary faulting in the Polish Carpathians is far from sufficient. Few examples have been documented, more or less convincingly, from the Orawa–Nowy Targ Basin, Podhale region, Pieniny Klippen Belt, Jeleśnia Basin, NW margin of the Nowy Sącz Basin, southern part of the