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Variscan Structural Evolution of Central Kazakhstan

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ABSTRACT: The Variscan orogeny started in Central Kazakhstan in Middle Devonian. Beginning from middle Visean until the end of the Variscan orogeny in Early Triassic, various structural associations were developed in the environment of increasing compression. Recumbent fold–nappes of the Spassky Nappe Belt appeared during the first stage in a wide zone of sinistral strike–slip faulting along the boundary of the median massif and enveloped the Zhungar–Balqash Foldbelt. The second stage deformations occurred throughout Zhungar–Balqash Foldbelt. During this stage the E–trending cleavage folds, thrusts, strike–slip, and normal faults were formed. The deformation became younger northwestward, towards the median massif; sedimentary cover of the latter was deformed later, at the end of Carboniferous and in Early Permian. An arcuate shape of the regional–scale structures of the second stage is not primary, but is the result of their bending during the third stage of deformation. Folds of the third stage are of the NW strike. The fourth stage (from middle Visean to Early Triassic) is characterized by the formation of volcanoplutonic belt. The Formation of the NW–striking folds was continued during this stage. Strike–slip faults were typical structures of the fifth stage (Early Triassic).

INTRODUCTION

The geology of Central Kazakhstan has been discussed in many papers (Voznesensky, 1978; Patalakha and Slepykh, 1974; Patalakha and Smirnov, 1978; Chitalin, 1985, 1988, 1991) and maps of different scales compiled in 1960's–1970's by N.A.Afonichev, A.A.Abdulin, and Yu.A.Zaitsev. The main tectonic features of Kazakhstan are summarized in Figs. 1 and 2.

The Variscan orogeny started in Middle Devonian with formation of black–shale troughs in the Zhungar–Balqash Foldbelt. These troughs inherited those of Caledonian age or were overprinted on the late Caledonian ("Telbes orogeny" of Central Kazakhstan) folded basement. In the Kazakhstan–North Tien Shan Caledonian Median Massif they were overprinted on the basement or inherited more ancient molasse troughs. In Famennian and at the beginning of Early Carboniferous shale, chert, and carbonate rocks were deposited in the riftlike troughs showing sedimentary environments contrasted with those of shallow–water shelf carbonate rocks in the adjacent areas (Kabanov et al., 1993; Weimarn and Milanovsky, 1993).

Beginning from the middle Visean Saur orogeny (Middle Asian analogue of the Sudetian orogenic phase of the western Europe) and until the end of the Variscan orogeny in Early Triassic, various structural paragenesis were developed. In the following text author uses the term *"structural paragenesis"* as a combination of various structures formed simultaneously or subsequently in the same stress field as a result of progressive deformation. A combination of structural paragenesis resulted from the stress field changes is called here as *"structural association"*. The main objectives of this paper are to discuss structural evolution of the area during the Variscan orogeny with special reference to formation of strike–slip faults during it latest stages.

STAGES OF STRUCTURAL EVOLUTION

The First Stage of Deformation

Recumbent fold–nappes of the Spassky Nappe Belt were formed during the first stage (middle Visean) as the result of approximately N–S compression in a zone of sinistral strike–slip fault at the boundary of the post–Caledonian median massif and the Variscan Zhungar–

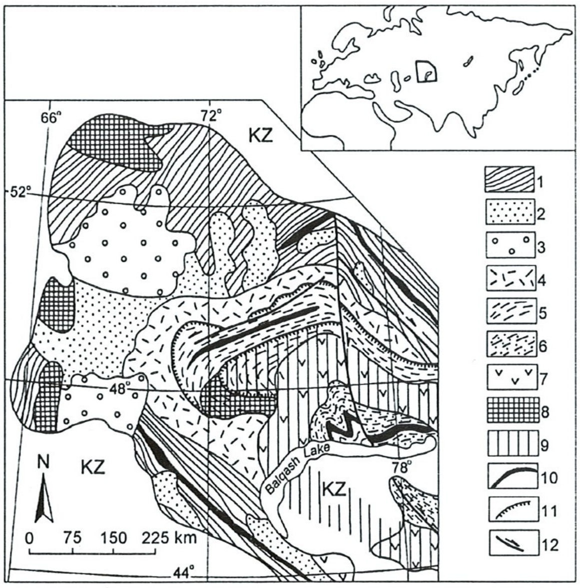

Fig. 1. Tectonic map of Central Kazakhstan.
1 — post–Caledonian median massif; 2 — Devonian–Carboniferous sedimentary cover of the median massif; 3 — late Paleozoic basins; 4 — Devonian volcanoplutonic belt; 5 — early Variscan structures of the Zhungar–Balqash Foldbelt; 6 — late Variscan structures of the Zhungar–Balqash Foldbelt; 7 — late Paleozoic volcanoplutonic belt; 8 — Precambrian block; 9 — hypothetical deep–buried Precambrian block; 10 — ophiolitic zone; 11 — nappe belt and shear zone; 12 —late Variscan strike–slip fault. KZ — Cenozoic.

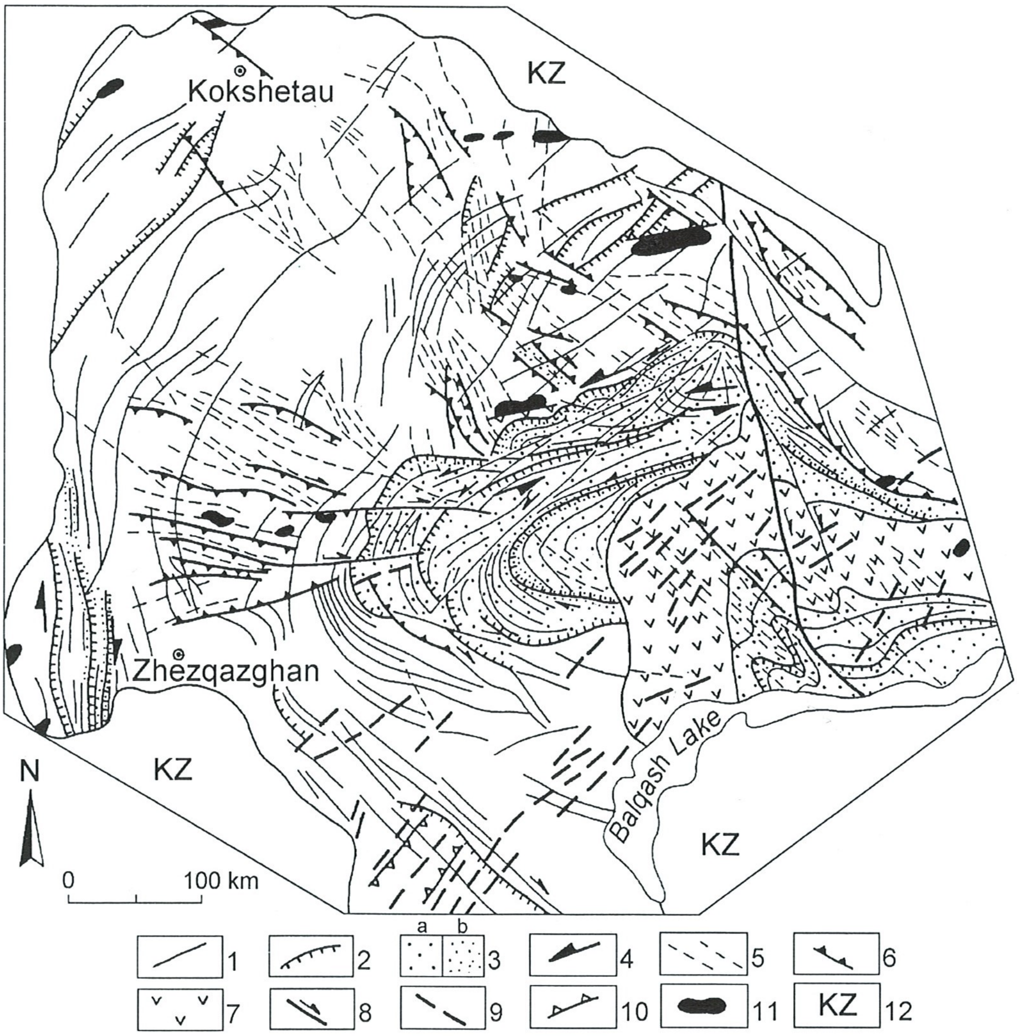

Fig. 2. Late Paleozoic and early Mesozoic structures of Central Kazakhstan.
1–4 — *Variscan structures of the first and second deformation stages:* 1 — fold, 2 — nappe and thrust, 3 — cleavage (a) and schistosity (b), 4 — shear zone; 5–7 — *structures of the third and fourth deformation stages:* 5 — fold, 6 — thrust, 7 — late Paleozoic volcanoplutonic belt; 8 — strike–slip fault of the fifth deformation stage; 9–11 — *Kimmerian structures:* 9 — fold, 10 — thrust, 11 — Triassic–Jurassic syncline; 12 — Cenozoic basin.

Balqash Foldbelt (Fig. 3) (Chitalin, 1988). Inclined and overturned folds of the NW vergency, thrusts and reverse faults of the N strike (Figs. 4 and 5) are typical of the southernmost parts of the area. The tectonic style was inherited from the Middle Devonian Telbes orogeny structures. During the first stage of the Variscan orogeny the Caledonian nappes continued to develop in the Teqturmas Ophiolite Zone (Yakubchuk et al., 1989).

The Second Stage of Deformation

The second stage deformation structures were widespread throughout Zhungar–Balqash Foldbelt (Figs. 2, 6). During this stage N– to NE–trending *en echelon* cleavage folds in a strike–slip and thrust zone of the Variscan and Caledonian structures conjunction have been formed. These structures are accompanied by thrusts and ductile shear zones with some transverse strike–slip and normal faults. The formation of cleavage and schistosity took place before the formation of faults that had similar kinematic features. Steep normal faults are transverse to cleavage and are conjugated with subhorizontal fractures with displacement direction along the second stage fold axes. Normal faults were formed before strike–slip faults or simultaneously with them (Chitalin, 1985).

In the northeastern area of the Zhungar–Balqash Foldbelt (Qarasor Synclinorium) distribution of the second stage folds has a fanlike shape in plan. In cross–section they are convergent and overprinted on the Ordabai Syncline formed during the first stage (Fig. 7). Folds are complicated by listric thrusts. Fanlike geometry of folds, decreasing of folding intensity, and the absence of cleavage in the synclinorium core indicate the northward displacement of the Qarasor thrust wedge against the rigid Caledonian massif. Geometry and, therefore, origin of this structure seem to be similar to those studied by the physical modelling (Patalakha, 1970). It implies that the N–trending extensional structures intruded by numerous Middle to Late Carboniferous trachyrhyolitic and trachydacitic rocks has been formed during the compression.

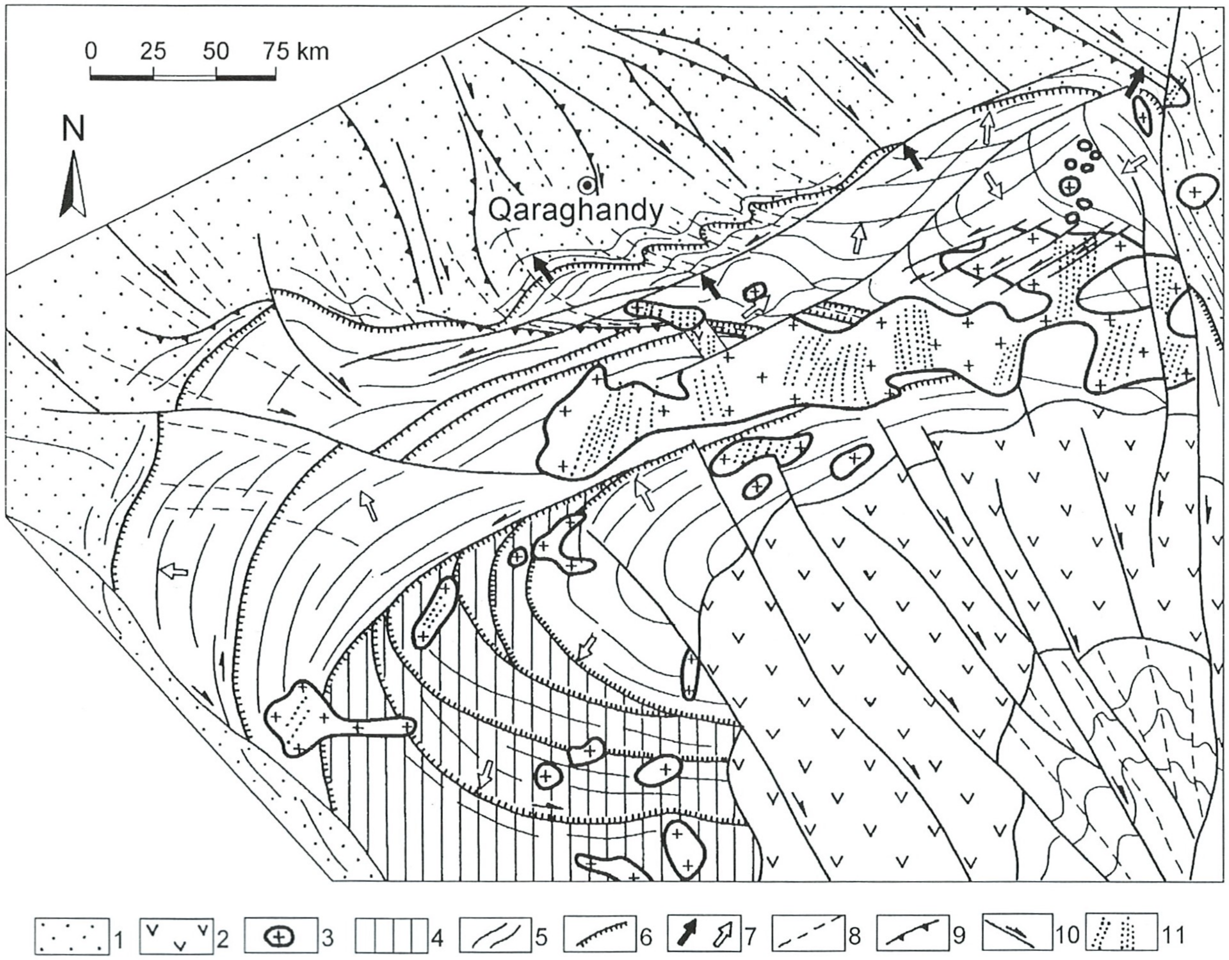

Fig. 3. Variscan tectonics of the northern segment of the Zhungar–Balqash Foldbelt and its framework.
1 — post–Caledonian median massif; 2 — late Paleozoic volcanoplutonic belt; 3 — late Paleozoic granitic intrusion; 4 — Precambrian massif; 5–7 — *structures of the first and second deformation stages:* 5 — fold, 6 — nappe and thrust, 7 — vergency of fold; 8–11 — *structures of the third and fourth deformation stages:* 8 — fold, 9 — thrust, 10 — strike–slip fault of the fifth deformation stage, 11 — late Paleozoic dike swarm and isolated dike.

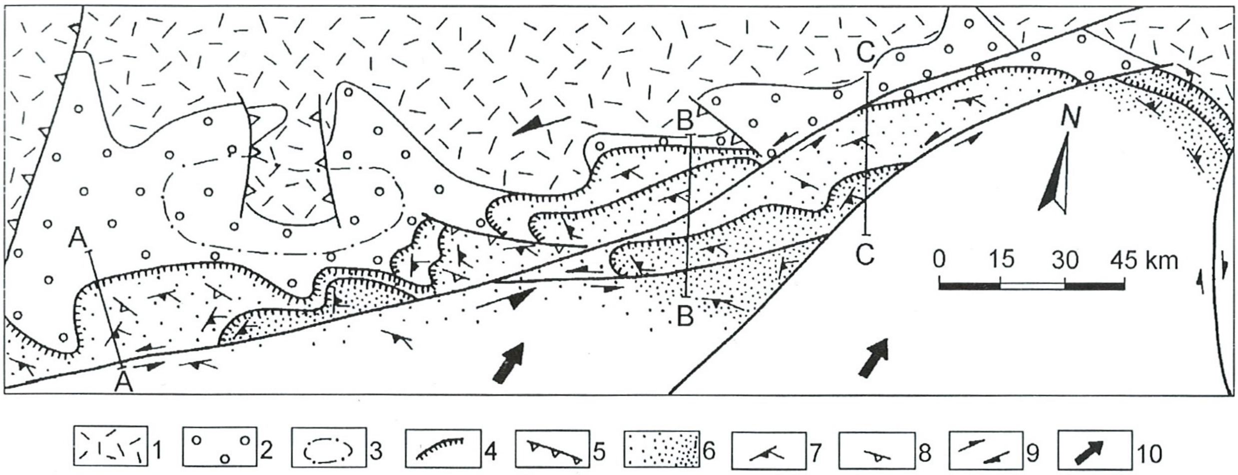

Fig. 4. Structural map of the Spassky Nappe Belt.
1 — Devonian volcanoplutonic belt; 2 — Qaraghandy Synclinorium; 3 — contour of the overprinted Triassic–Jurassic syncline; 4 — nappes of the first and second deformation stages; 5 — thrusts of the third and fourth deformation stages; 6 — greenschist metamorphism; 7 — cleavage, schistosity, and deformation lineation of the second deformation stage; 8 — cleavage of the third deformation stage; 9 — shear zone; 10 — regional stress.

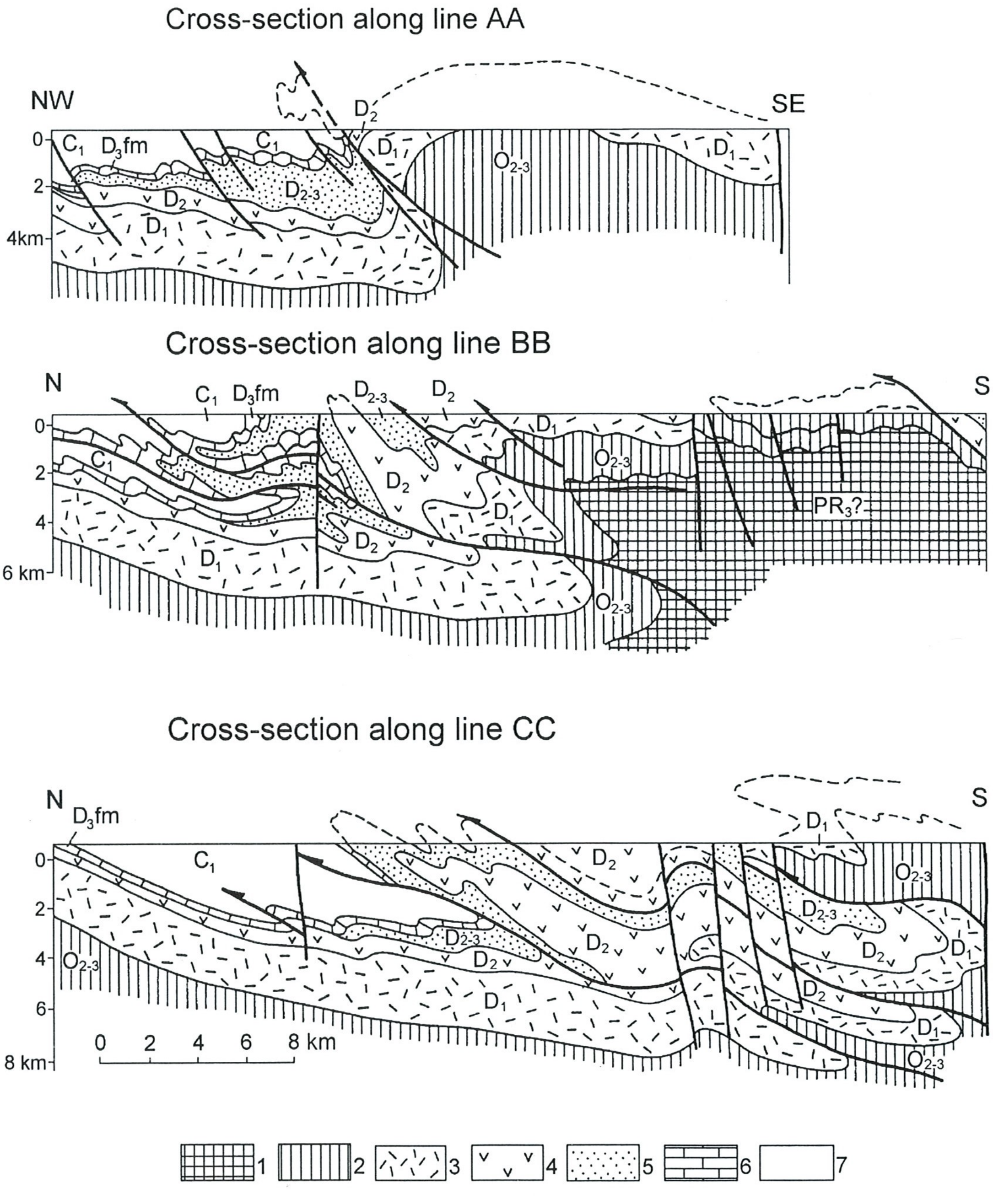

Fig. 5. Cross–sections AA, BB, and CC through the Spassky Nappe Belt (see location in Fig. 4).
1 — Upper Proterozoic (?) metamorphosed volcanic–sedimentary units; 2 — Middle–Late Ordovician island–arc volcanics; 3 — Lower Devonian volcanic–sedimentary units; 4 — Middle Devonian volcanic–sedimentary units; 5 — Middle–Upper Devonian terrigenous units; 6 — Famennian shale–carbonate units; 7 — Lower Carboniferous terrigenous units.

The age of the second stage deformation becomes younger towards the median massif. Thus, similar structural paragenesis in the sedimentary cover of the massif were formed at the end of Carboniferous and in Early Permian (Fig. 8). Disharmonic folding occurred mostly clearly at the base of the cover, and the folding did not affect central parts of the late Paleozoic Zhezqazghan and Teniz basins.

The schistosity zones along strike–slip faults analogous to those of early Variscan age in the Zhungar–Balqash Foldbelt are traced to the west of the Zhezqazghan City (Zaitsev, 1961). *En echelon* geometry of folds indicates presence of strike–slip zones that seems to be an inherited from the faults in the basement. It is important to note a non–cleavage type of the second stage folds in the sedimentary cover of the median massif, except the above mentioned zones. It is possibly caused by a higher total viscosity of the sedimentary units in the cover of the "cold" and passive median massif as compared with the "hot" and active Zhungar–Balqash Foldbelt. On the other hand, absence of cleavage may be also explained by a more late involving of the median massif in the deformation, i.e. after the cleavage flow stage, but before the buckling.

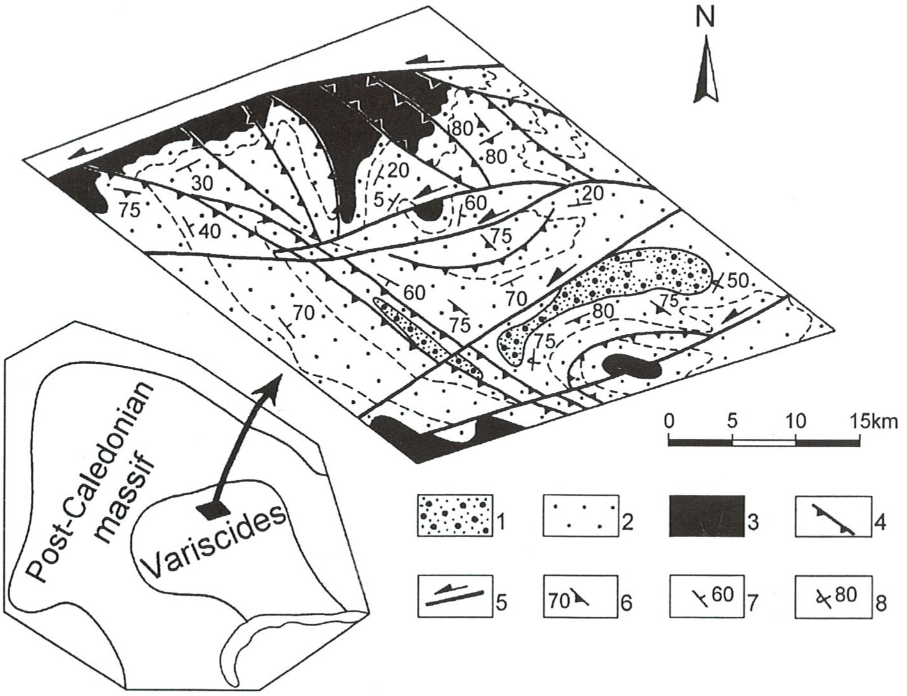

Fig. 6. Interference folds of the central part of the Nura Synclinorium.
1 — Givetian–Frasnian red sandstone and conglomerate; 2 — Lower Devonian volcanic–terrigenous and terrigenous units; 3 — Upper Silurian greywacke flyschoid; 4 — thrust; 5 — strike–slip fault; 6 — cleavage and schistosity; 7 — normal bedding; 8 — overturned bedding.

The Third Stage of Deformation

The regional–scale structures of the third stage have an arclike shape (Figs. 2, 3). This structural feature appears to be not primary, but resulted from the formation of arcs during the bending of previously formed structures. Some gradual northward displacement and compression of ductile deformed masses with sinistral strike–slip displacement and anti–clockwise rotation of numerous ancient continental blocks (microcontinents) also can be assumed. These microcontinents, passively moving within a tectonic flow, were deformed themselves and affected their ductile framework.

Curvature radius of the third stage structural arcs regularly decreases southeastward, towards the internal parts of the Zhungar–Balqash Foldbelt, where the crustal shortening was the highest. Large horizontal sigmoid folds deformed the North Balqash Ophiolite Belt have been formed. These sigmoids are similar to the well–known Fergana sigmoid of the third stage of the Variscan orogeny in the Tien Shan (Burtman, 1976) that implies their synchronous origin. NW–striking linear folds and thrusts have been overprinted on the folds during the final stage of the structural arc formation. In the Spassky Nappe Belt they are represented by synform and antiform folds, bending pre–existed nappes, and folds of the first and second stages. On the contrary, in the Nura Synclinorium and Teqturmas Belt they inherited folds of the second stage that become more flattening with formation of transverse extensional fractures filled with quartz and calcite veinlets and veins. The veins became more thick and long eastward along fold axes strike up to 1–5 m and 1000–3000 m respectively. Structural pattern of the Zhungar–Balqash Foldbelt is very similar to the structure of the Cantabryia Zone in the Variscan Asturian Arc of the northern Spain. In the latter area folds have been also formed during three stages of deformation.

The well–known "block" folds and grabens (Zavrazhnov, 1993) of the Sarysu–Teniz Watershed are similar to structures in the northern side of the Qaraghandy Synclinorium and have been formed at the end of the third stage. The field study of these structures and analysis of the large–scale geological maps allow to conclude that all these structures have been formed due to horizontal compression as it was supposed by Zonenshain et al. (1990) but not due to keylike vertical displacement of rigid blocks and bending of beds, as proposed by Zaitsev (1961). Basins developed in grabens represent cores of interferenced folds formed during the second and third stages (Fig. 8).

The Fourth Stage of Deformation

The strong flattening of the Zhungar–Balqash Foldbelt and the effect of hypothetical mantle plume promoted, possibly, a melting of lower crust and formation of the vast Balqash–Ili Volcanic Belt. The formation of polyphase volcanoplutonic complexes took place during the fourth stage of deformation and their setting was controlled by previously formed faults and zones of penetrative deformations as well as by local extension zones (Besstrashnov et al., 1991). The youngest Late Permian–Early Triassic leucogranitic plutons intrude both the Variscan and post–Caledonian structures.

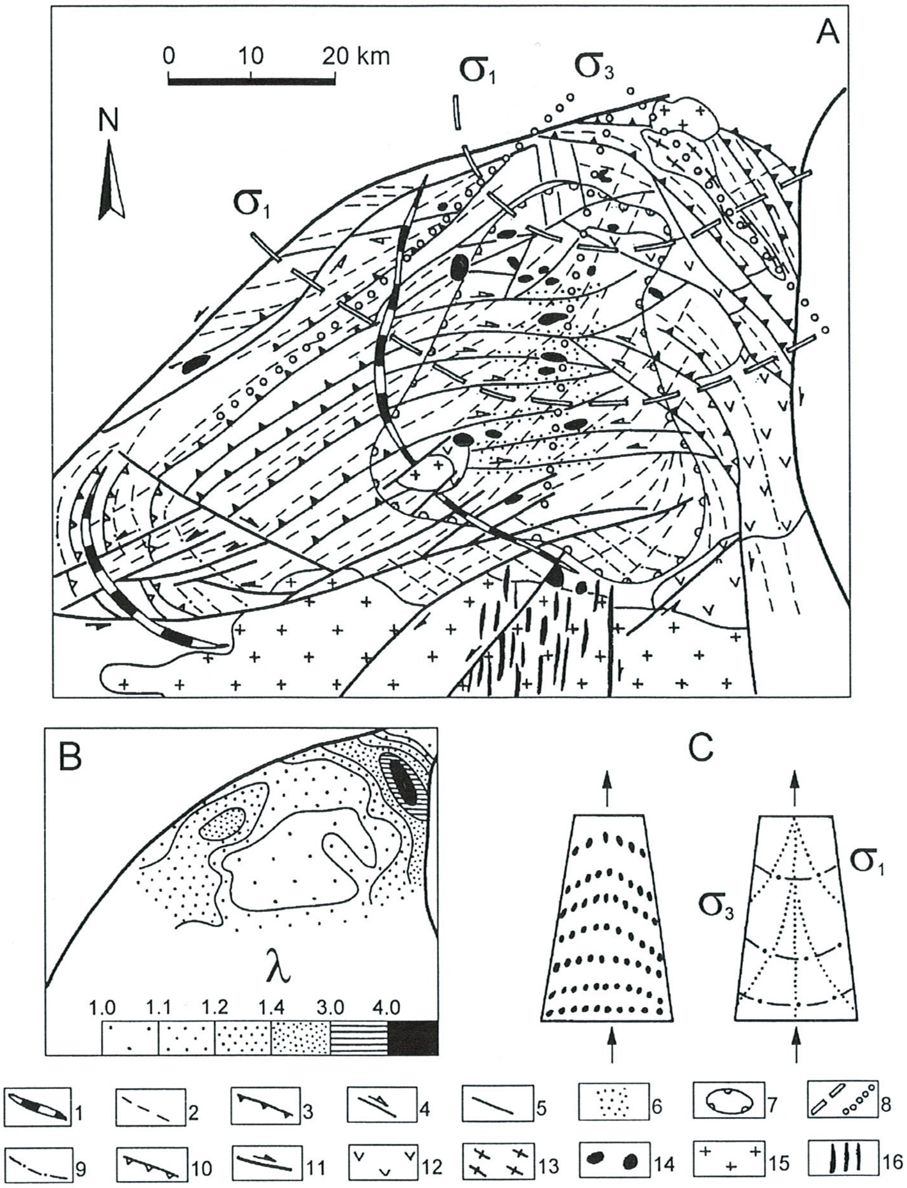

Fig. 7. Structure of the Qarasor Synclinorium.
A — structural scheme; B — contour map of the bed's elongation coefficient; C —stress and strain patterns in the physical model of Patalakha (1970).
1 — fold of the first stage of deformation; 2–8 — *structures of the second stage of deformation:* 2 — fold, 3 — thrust, 4 — strike–slip fault, 5 — normal fault, 6 —fault-related breccia and extensional stockwork, 7 — area devoid of the cleavage, 8 — axes of the main normal stresses (compression σ1, extension σ3) reconstructed using synfold fractures or shear structures of the third and fourth deformation stages; 9 — folds of the third and fourth stages of deformation; 10 — thrust; 11 — strike–slips of the fifth stage of deformation; 12 — late Paleozoic volcanics; 13 — Early Carboniferous synkinematic granitic plutons; 14 — Middle Carboniferous subvolcanic felsic alkaline intrusion; 15 — Middle Carboniferous–Early Permian granitic pluton; 16 — dikes within the intrusion.

These granitic rocks have been originated from a residual magmatic melt in a continuously developed late Paleozoic magma chamber of the areal extent (Zaitsev, 1984). This deep magma chamber has probably initiated an intense heating of the Zhungar–Balqash Foldbelt. As a result, the viscosity of sedimentary units was reduced, and these rocks were underwent an intense deformation during the first three stages of the Variscan orogeny. Filtration of synfolding hydrothermal solutions in the Spassk–Teqturmas region caused the formation of synkinematic ore veins of the second and third stages prior to intrusion of the Middle Carboniferous post-folding granitic plutons.

The Fifth Stage of Deformation

During the fifth stage of deformation (Late Permian–Early Triassic) the crust was cut by strike–slip faults of various magnitude formed as the result of N–S compression and transverse extension. These deformations occurred after emplacement of plutons, complete consolidation and cooling of the crust.

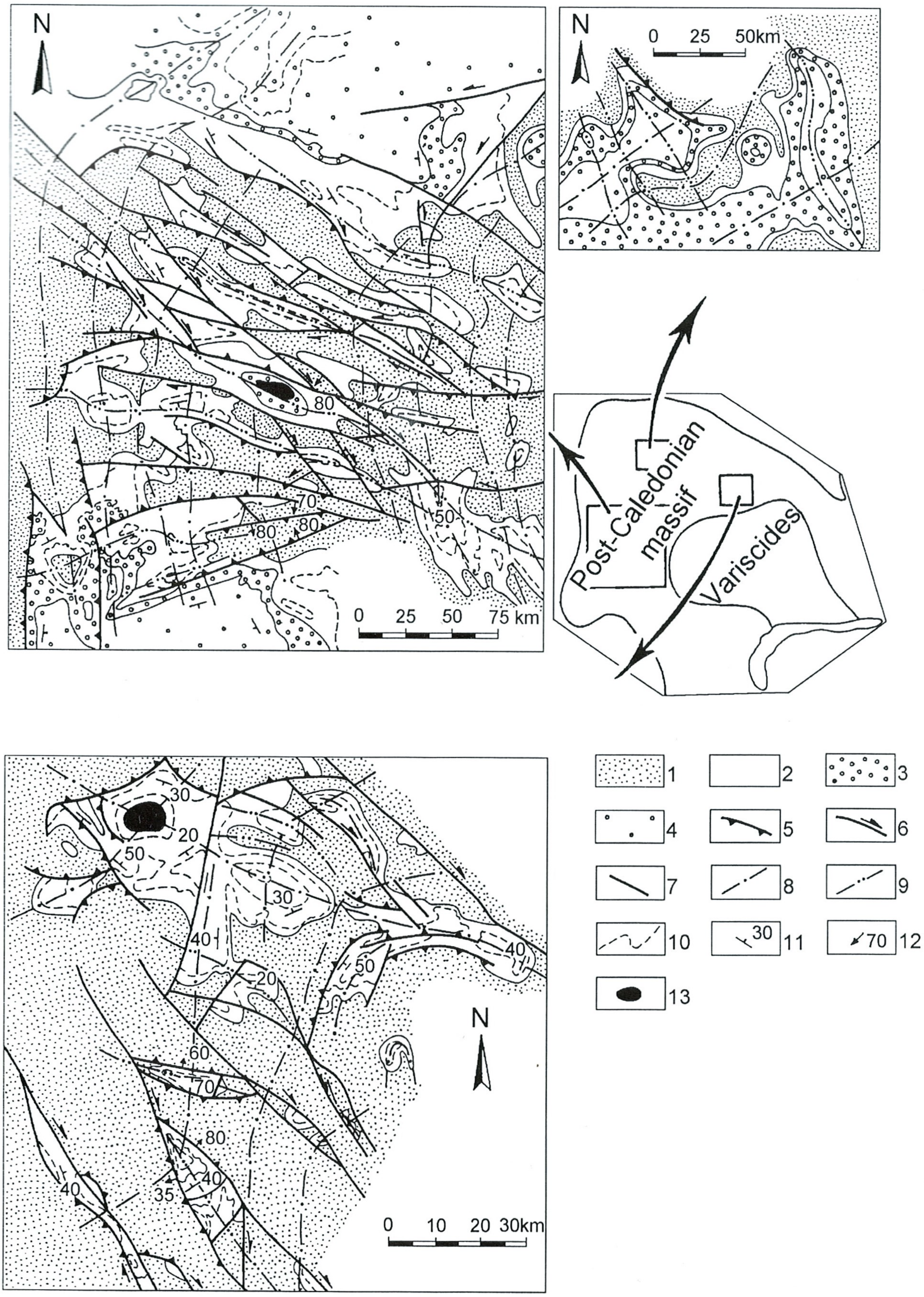

Fig. 8. Interference Variscan folds in the cover of the median massif.
1 — pre–Famennian units; 2 — Famennian–Lower Carboniferous; 3 — Middle and Upper Carboniferous; 4 — Permian; 5 — thrust; 6 — strike–slip fault; 7 — normal fault; 8 — fold axes of the first and second deformation stages; 9 — fold axes of the third and fourth deformation stages; 10 — marker beds; 11 — bedding strike and dip; 12 — dipping of fault planes as inferred from the drilling and geophysical data; 13 — Triassic–Jurassic synclines.

The latest Variscan strike–slip faults in the tectonic structure of Central Kazakhstan have a significant role and distort initial shape of structural zones. Strike–slip faults are subdivided into four sets related to NE–SW compression and NW–SE extension. Some local folds, faults, and volcanoplutonic structures appear to be connected with strike–slip faults (Trifonov, 1967; Suvorov, 1968, 1975; Koshkin, 1969; Shcherba, 1973; Samygin, 1974; Mikhailov, 1980; Chitalin, 1985, 1988, 1991; Filatov and Bogin, 1988; Yakubchuk et al., 1989).

Dextral and sinistral strike–slip faults are conjugated and form several generations. Some of them inherit large faults of long–term development.

The youngest are numerous faults of small magnitude (1–5 km) that are grouped within wide (up to 200 km) and long (more than 800 km) zones of NNW–NW and ENE strikes (Fig. 9–A). Faults have mainly strike–slip kinematics but reverse and normal faults also occur. NW–trending shear zones are dextral, whereas those of NE strike are sinistral, both coupled in a giant conjugated structure.

The crossed zones form a giant net overprinted on the Paleozoic concentric structural patterns of Central Kazakhstan. This net appears to be extended far outside of the area. Large width of deformation zones is possibly caused by a ductile state of lower crust preserved at some depth after the early Variscan deformation.

Thus, small–magnitude latest Variscan strike–slip faults were developed in the upper parts of residual two-layer ductile zones. Their orientation and kinematics were controlled by the regional NNE–SSW compression of the crust.

Structural style of the median–magnitude (5–10 km) faults was significantly different, although it was also related to the same compressional field (Fig. 9–B). Almost all faults of this group have the NW strike and dextral shear sense, sometimes with a small vertical displacement. They are of *en echelon* geometry and are located within a wide (500 km) NE–striking zone being approximately normal to it boundaries. According to the results of modelling, the formation of such faults take place either in the brittle and thick crust or in the viscous crust at a low deformation rate, when extension axis is approximately orthogonal to the forming strike–slip fault (Bokun, 1988). The lithosphere deformation rate was apparently increased (progressive deformation) during the evolution of strike–slip faults in Kazakhstan with simultaneous increasing of viscosity in its upper part due to cooling. The penetration depth of the median–magnitude faults appears to be of some kilometers, and it is certainly more than penetration depth of small–magnitude faults. It is quite possible that the median–magnitude faults were formed somewhat later than small–magnitude faults, although in the same stress field. This assumption does not contradict to results of modelling of strike–slip zones made by Sherman et al. (1983). In this model faults and fractures have been appeared after ductile deformation, then most of them dye out and only rare, but large faults continue to develop up to formation of the main strike–slip fault.

Large–magnitude (10–20 km) and giant–magnitude (50–100 km) strike–slip faults (Fig. 9–C) appeared somewhat later than median– and small–magnitude faults (they are always in cross–cut relationships) also under NNE-SSW compression, but in a more viscous crust. Ductile flow is suggested to take place only in the upper mantle, where, according to geophysical data, all largest faults disappear downward, significantly changing dip angle at a depth of 50–70 km. Large strike–slip faults have not been traced deeper than 10–20 km and do not affect the Conrad discontinuity (Bekzhanov et al., 1975). Some strike–slips are curved in plan, revealing a significant normal fault or thrust displacement (Trifonov, 1967; Belyaev and Yunakovskaya, 1972). An anomalous curvature and kinematics of strike–slip faults are caused by their deformation during Mesozoic. Large strike–slip faults are commonly splitted near termination into a fan of median– and small–magnitude strike–slip faults with summary magnitude being approximately equal to the magnitude of the main strike–slip fault (Chitalin, 1985). In some cases, thrusts or local pull-apart structures compensated strike–slip movement have been formed at the termination of strike–slip faults.

Giant–magnitude NW–trending dextral strike–slip faults and thrusts with some strike–slip displacement of *en echelon* and arclike geometry are predominant in Central Kazakhstan. They have been formed under transverse shortening of the belt and dextral transpressional shearing along it with a small anti–clockwise rotation of the blocks. A similar kinematics of the late Paleozoic movements along strike–slip faults was described for the European Variscan belts (Matte, 1986).

An approximate estimation shows that related to strike–slips transverse shortening of the Central Kazakhstan sector of the Uralian–Mongolian Mobile Belt was not more than 30% (Chitalin, 1991).

Thus, faults of progressively augmented magnitude were formed in the response of the crust hardening as follows from the failure mechanics. Appearance and development of faults of each magnitude took place under a gradual increase of viscosity and brittleness of the upper lithosphere and gradual deepening of the roof of its lower viscous–ductile layer. A residual slip flow still existed in the latter. The upper boundary of this layer was located in the upper mantle during the giant strike–slip fault formation. The proposed evolution of deformation processes and the sequence of the fault formation do not contradict the results of tectonophysical modelling.

The width of a zone of dynamic influence of strike–slip fault (Sherman et al., 1983), where strike–slip deformations are predominant, is not more then 1.1% of it initial length and not more then 12.5% of it magnitude. The results of these deformations are represented in the sigmoid bends of the early Variscan folds, in the formation of small *en echelon* drag folds deformed cleavage, schistosity, and Alpine veins with ore mineralization, in the reorientation and rotation of the early Variscan synfold fractures and in the opening of these fractures with formation of barren veins and veinlets.

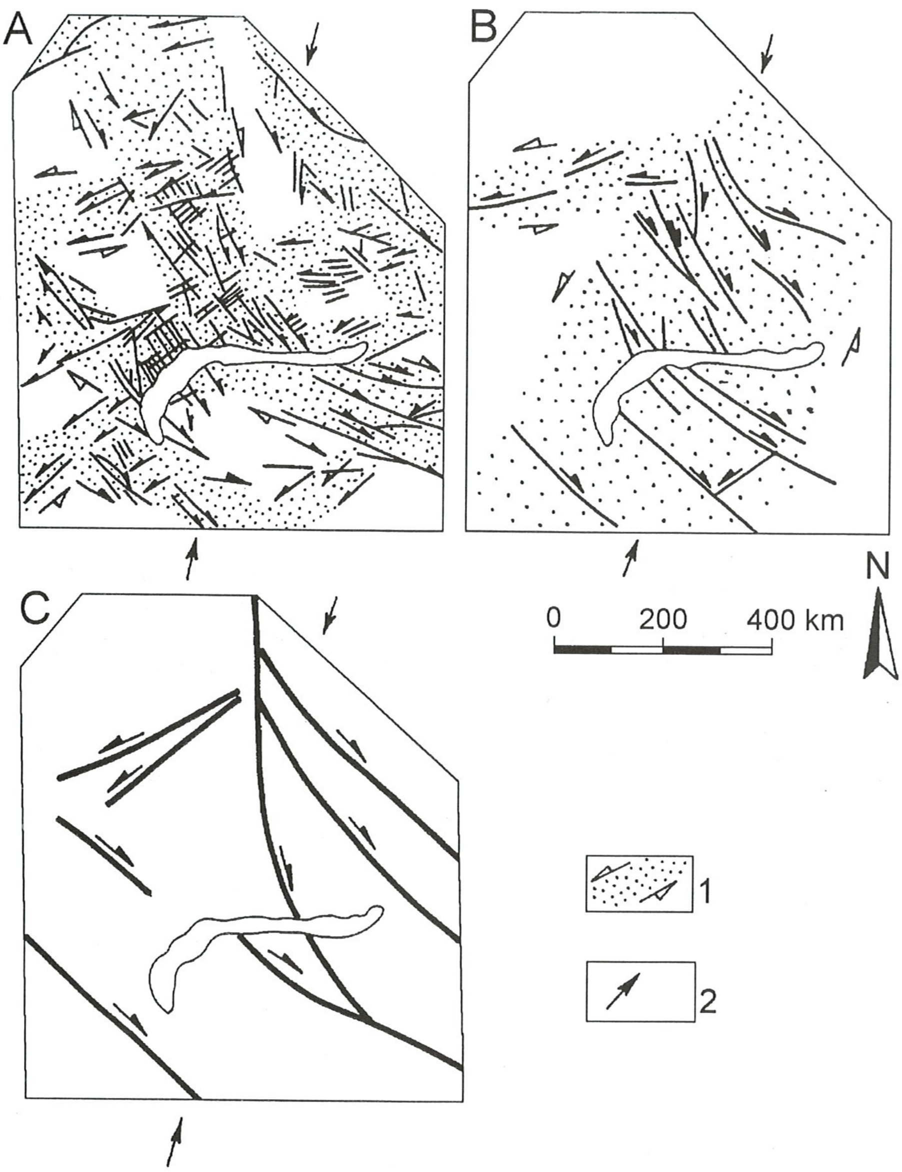

Fig. 9. Sequence of the strike–slips during the fifth deformation stage.
A —small–magnitude strike–slips of the first substage; B —median–magnitude transverse strike–slips of the second deformation substage; C —large– and giant–magnitude strike–slips of the third substage.
1 — zones of assumed viscous shear flow in the lower lithosphere; 2 — direction of regional compression.

POST–VARISCAN TECTONICS

The local post–Variscan structural paragenesis are represented by the Kimmerian overprinted or, rarely, inherited brachysynclines, occasionally complicated by the E– to NE–trending thrusts. Some open folds in volcanic rocks of the Balqash–Ili Foldbelt were also developed (Fig. 2).

Newly formed Alpine structures are absent, but some ancient faults have been slightly reactivated.

CONCLUSION

Five stages of Variscan deformations are established based on the cross–cutting structural relationships. Ductile deformation resulted in cleavage folds, shear zones, and thrusts was widespread during the early stages. The cooling and hardening of crust led to brittle deformation at later stages. Strike–slip faults of different magnitude, varying from 1 km to more than 100 km, were formed during the latest (fifth) stage. The Variscan structural paragenesis are widespread throughout Central Kazakhstan and were formed during a long–term continuous deformation event caused by movements of cratons in framework of the Uralian–Mongolian Mobile Belt and by intralithospheric material flows within this belt.

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