PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY A MATHEMATICAL, PHYSICAL & ENGINEERING SCIENCES

Main Fault Systems of the Soviet Far East

B. A. Natal'in, L. M. Parfenov, A. A. Vrublevsky, L. P. Karsakov and V. V. Yushmanov

Phil. Trans. R. Soc. Lond. A 1986 **317**, 267-275
doi: 10.1098/rsta.1986.0035

Phil. Trans. R. Soc. Lond. A **317**, 267–275 (1986) [267]
Printed in Great Britain

Main fault systems of the Soviet Far East

By B. A. Natal'in[1], L. M. Parfenov[2], A. A. Vrublevsky[1], L. P. Karsakov[1] and V. V. Yushmanov[1]

[1] *Institute of Tectonics and Geophysics, Academy of Sciences U.S.S.R., Khabarovsk, U.S.S.R.*
[2] *Geological Institute, Siberian Branch, Academy of Sciences U.S.S.R., Yakutsk, U.S.S.R.*

The analysis of the distribution of thrusts, normal faults and strike-slip faults of various ages has allowed us to determine the character of lithospheric block displacements in the Soviet Far East. The early Mesozoic, late Mesozoic and Cainozoic kinematics were each essentially different.

The Early Mesozoic Dzhagdinsk fault system appeared as a result of the collision of the Bureinsk–Khankaisk microcontinent with the Siberian continent. The largest faults of the system are neither longstanding nor deep but were formed during the latest stage of the structural evolution. The multistage formation of the faults of the Dzhagdinsk system is conditioned by its position at the margin of the continent. The late Mesozoic faults are mainly strike-slip faults caused by the subduction of the oceanic crust at an acute angle with respect to the strike of the active continental margin. The Cainozoic faults were formed under compression on the boundary between the Siberian platform and the Bureinsk massif, but under tension in the east of the region.

1. Introduction

In most of the current interpretations of Far Eastern tectonics special significance is attributed to longstanding deep faults that control magmatism, sedimentary zones and ore distribution. The faults are believed to have been characterized by vertical displacements that were not correlated within the region as a whole, nor with displacements along conjugate faults.

Recent studies indicate that horizontal displacements along Mesozoic faults have made the main contribution to the formation of the region's present structure. The analysis of the coeval strike-slip faults, thrusts, normal and reverse faults suggests a pattern of horizontal movements of lithospheric blocks within the continent, and their possible correlation with the plate movements in the adjacent part of the Pacific. The kinematics of lithospheric blocks can be shown to be quite specific for the early and late Mesozoic and Cainozoic times.

2. Main tectonic units

The Lano–Aldansk block of the Siberian platform, the early Precambrian Stanovoy foldbelt, the Bureinsk and Khankaisk median massifs and two Mesozoic foldbelts, the Mongolo–Okhotsk and Sikhote–Alinsk, are the principle tectonic units of the region (figure 1).

Both the basement of the Siberian platform and the Stanovoy foldbelt consist of early Precambrian metamorphic complexes. The age of the oldest is 3500 Ma. Within the Leno–Aldansk block they are overlain by a cover of Riphean and Vedean–Cambrian quartzose sandstones and carbonate rocks, and Jurassic–Lower Cretaceous terrigenous coal-bearing deposits. Along the Stanovoy foldbelt – a large arch in Mesozoic time – stretches a belt of polyphase granodiorite plutons, whose K–Ar ages are from 200 to 70 Ma. The belt lies along the strike of the Triassic–Neocomian Udsko–Murgalsk island arc (Parfenov *et al.* 1979) and apparently marks the active continental margin of a Cordillerian type. The fore-arc region of the margin was the Mongolo–Okhotsk geosyncline.

The Mongolo–Okhotsk foldbelt stretches sublatitudinally from the Sea of Okhotsk into Mongolia. Between the Siberian platform and the Bureinsk massif its width is minimal and the dislocations here are extremely complex. The foldbelt consists of Palaeozoic and Upper Triassic–Middle Jurassic terrains that have regional schistosity and which are metamorphosed to greenschist and locally to glaucophane schist facies. Palaeozoic basalts and spilites, ribbon cherts, tectonic lenses of banded gabbroic and ultrabasic rocks may be relics of oceanic crust. Mesozoic turbidites with volcanic material admixture may be considered as deposits formed in fore-arc basins.

Early Precambrian complexes, younger than those on the Siberian platform, make up the basement of the Bureinsk and Khankaisk massifs. They are metamorphosed to amphibolite and lower granulite facies. Late Precambrian and early Palaeozoic complexes of variable compositions and thicknesses are also present. Locally, they are metamorphosed to greenschist and epidote–amphibolite facies. The main feature of the Bureinsk massif is well developed Palaeozoic granitoids, constituting up to 90% of the basement. In Mesozoic time the Bureinsk and Khankaisk massifs were part of a common continental plate (Parfenov *et al.* 1979).

The Sikhote–Alinsk foldbelt frames the Bureinsk and Khankaisk massifs on the east. It consists of late Palaeozoic and Mesozoic (pre-Senonian) eugeosynclinal complexes. Palaeozoic faunas are found, as a rule, in olistoliths of Mesozoic olistostromes and in tectonic mélange blocks. Along the Sea of Japan coast stretches the Senonian–Palaeogene East Sikhote–Alinsk volcanic belt formed during the development of the active continental margin.

3. Early mesozoic faults

The Dzhagdinsk fault system coincides with the narrowest part of the Mongolo–Okhotsk foldbelt pressed between the Bureinsk massif and the Siberian platform (figure 1). The North Tukuringrsk, Lansk and South Tukuringrsk faults are believed to have controlled the development of the eugeosynclinal trough and the multistage magmatism in the Palaeozoic and Mesozoic (Kirillova & Turbin 1979). However, a structural analysis of the dislocations indicates that in the structural evolution these faults are the youngest. They were formed after intensive ductile deformation (Natal'in *et al.* 1985). This deformation is represented by isoclinal folds with northern vergence (F_2) and by faults parallel to their axial surfaces (S_2). In the largest, northern, part of the foldbelt the fault planes, the axial surfaces of folds and the schistosity parallel to them dip at a low angle, forming open folds F_4. Southwards, the faults S_2 and the axial planes of folds F_2 gradually acquire stable southerly dips. Steep dips occur in the vicinity of the South Tukuringrsk fault (figure 2). The contrasting lithostratigraphic members allow us to delineate large recumbent folds F_2. These folds testify to considerable mass displacements northwards onto the early Precambrian complexes of the Stanovoy foldbelt. The roots of the nappes associated with the folds appear to be in the south, in the region of steeply dipping schistosity.

Folds F_4, the synchronous cleavage and the faults are superimposed on folds F_2. The vergence of folds F_4, the orientation of cleavage S_4 and the faults indicate mass transport from north to south in the direction opposite to that of the previous stage. Only after these events did folds

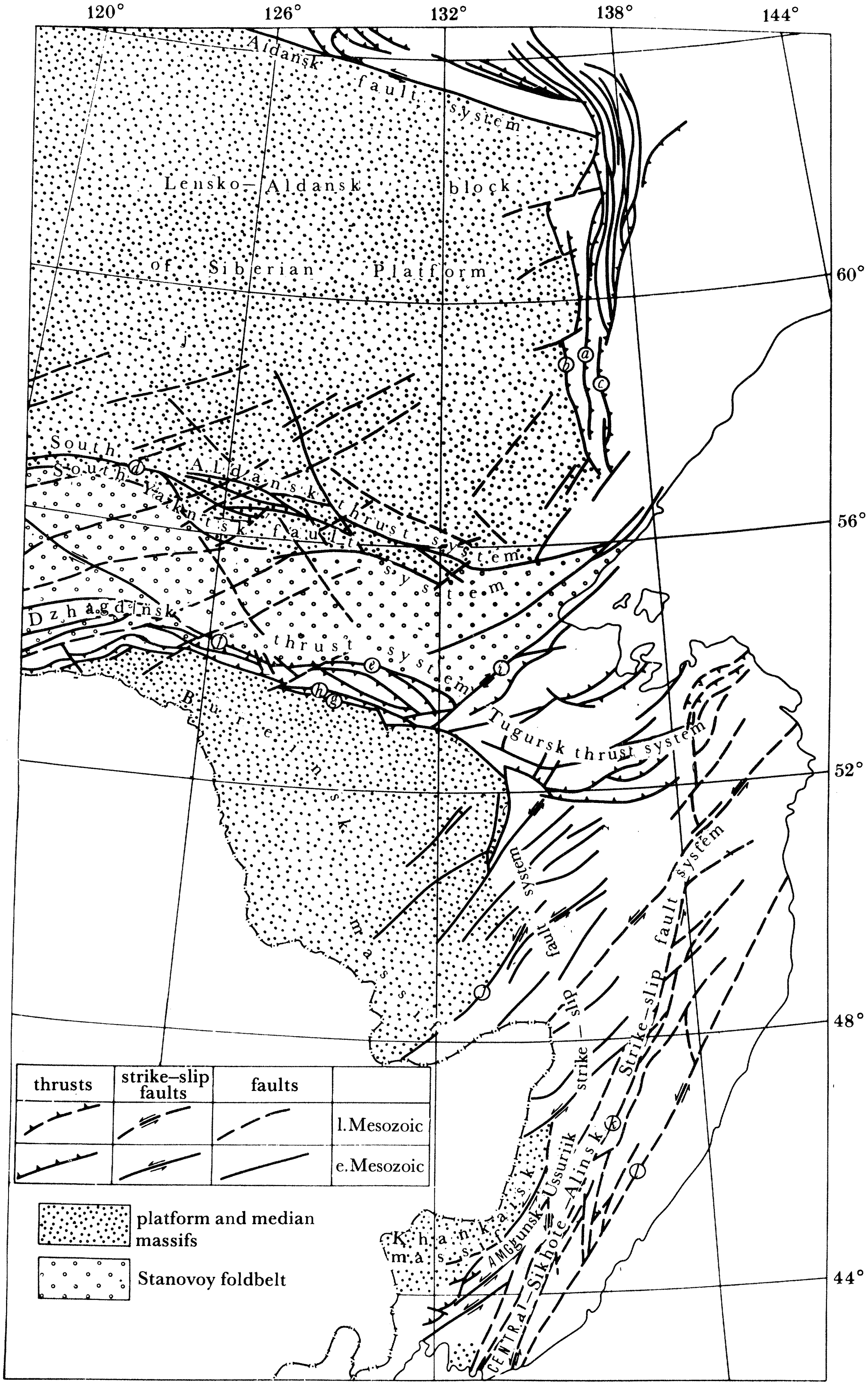

Figure 1. Main fault systems in the Soviet Far East. Main faults: (*a*) Nel'kansk; (*b*) Guvindinsk; (*c*) Chelatsk; (*d*) Chul'mansk; (*e*) Lansk; (*f*) North Tukuringrsk; (*g*) Nini–Sagayansk; (*h*) South Tukuringrsk; (*i*) Uligdansk; (*j*) Kukansk; (*k*) Central Sikhote–Alinsk; (*l*) East Sikhote–Alinsk.

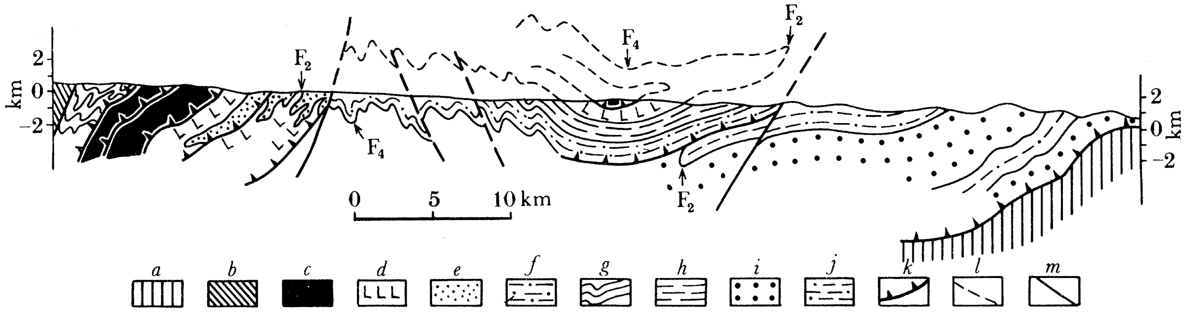

FIGURE 2. Cross section of the Mongolo–Okhotsk foldbelt and the relation of faults of various ages in the Dzhagdinsk system. (*a*) Aldano–Stanovoy block; (*b*) Bureinsk massif; (*c*) banded gabbros and hyperbasic rocks; (*d*) metavolcanites and microquartzites; (*e*) green schists and microquartzites; (*f*) phyllites and sandstones; (*g*) shale; (*h*) phyllites; (*i*) proximal turbidites; (*j*) distal turbidites, (*k*) faults S_2; (*l*) faults S_4; (*m*) faults S_5.

F_5 appear, which conforms with the orientation of the North Tukuringrsk, Lansk and South Tukuringrsk fault planes. The faults of this stage were formed in the course of brittle deformations. This marks them as different from earlier ones. The cataclasis of these faults is superimposed on the schistosity S_2 and the cleavage S_4. The orientation of the faults and of the folds F_5 again indicate a mass transport from south to north.

The folds F_2, F_4 and F_5 are coaxial. The synchronous faults have similar strikes but their planes dip in various directions. The structural evolution was completed by the formation of the folds F_7 with northeast trending axes. After its formation the cleavage S_7 was disturbed by northeast trending left-lateral strike-slip faults. Northwest trending shears conjugate with them are also widely spread in the Stanovoy foldbelt (figure 1).

All the above dislocations were the result of the collision of the Bureinsk–Khankaisk microcontinent with the active continental margin of the Siberian platform. The collision started at the end of the Middle or the beginning of the Upper Jurassic and was completed at the end of the early Cretaceous. Structures resulting from the subduction are rare on the Dzhagdinsk, but are dense in the Tugursk part of the Mongolo–Okhotsk system which was only slightly affected by the collision deformation.

Multistage deformations of the Dzhagdinsk system are not the result of the evolution of deep faults anchored in the mantle. Each stage of deformation has its specific structural pattern corresponding to a particular stage of the development of the continental plate margin.

In the course of its development, the active margin of the Siberian platform had at its rear the Lensko–Aldansk block moving eastwards along the sublatitudinal South Yakutsk and Aldansk systems of strike-slip faults (figure 1). The South Yakutsk system (20–30 km in width) is represented by en echelon faults. A belt of granodiorite plutons of the Stanovoy Range is conjugate with the southern flank of the system. From magnetic data (Zablotsky & Sytina 1974), the plutons are fractured bodies whose roots are traced down to 10 km. They form a system of northwest trending echelons lying at an angle of 40°–60° to the general trend of the South Yakutsk faults. Granitoids apparently intruded along tension fissures formed by large right-lateral shifts in the South Yakutsk fault system.

The Aldansk strike-slip fault system is 75–80 km across. It is distinctly seen on small-scale air photographs. Dislocations are represented by left-lateral strike-slip faults and conjugate thrusts. Displacements along some strike-slip faults reach 10 km.

The displacement of typical sublongitudinal magnetic anomalies suggests that the overall

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY A MATHEMATICAL, PHYSICAL & ENGINEERING SCIENCES

displacement on the Aldansk strike-slip fault system may reach 300 km (Sitnikov & Spektor 1978).

The eastward movement of the Lensko–Aldansk block was achieved by underthrusting beneath the folded structures of the South Verkhoyanye and the formation of the Settedabansk system of imbricate thrusts (figure 1).

The thrusts are gently dipping (10°–50°) in the western part of the system close to the Siberian platform (Nel'kansk thrust). To the east they become steeper (Guvindinsk and Chelatsk thrusts and others). Stavtsev (1971) noticed that the thrusts are not distinctly expressed on gravity maps, even though they separate blocks with different thicknesses of Upper Precambrian and Palaeozoic (up to 3–4 km). He explains it by the fact that the thrusts do not affect the Archaean basement but flatten out with depth. United, they form a gently dipping thrust zone apparently confined to Upper Precambrian argillites. This argument is confirmed by gently dipping thrusts parallel to bedding and by rootless folds observed in outcrops. The Aldansk fault system has no continuation in the Sittedabansk uplift.

The collision of the Bureinsk–Khankaisk plate with the Siberian platform might have resulted in the formation of the Amgunsk–Ussuriisk fault system along the eastern margins of the Bureinsk and Khankaisk median massifs. The system consists of numerous northeast trending faults that stretch from several tens to several thousands of kilometres (such as the Kukansk fault). Because of these faults the eastern margins of the massifs are left-laterally displaced (figure 1).

To the east of the Khankaisk massif the faults of the Amgunsk–Ussuriisk system are truncated by northnortheastern and longitudinal (also left-lateral) strike-slip faults of the late Mesozoic Central Sikhote–Alinsk system. These strike-slip faults are discussed below.

The Tugursk thrust system forms an arc convex to the south. The system can be interpreted as a compression zone compensating mass transport along the faults of the Amgunsk–Ussuriisk system. It includes post-folding thrusts with the amplitude of horizontal displacements up to 5 km. These displacements involve Paleozoic and Mesozoic deposits of the Mongolo–Okhotsk system.

4. Late Mesozoic faults

The main strike-slip faults of the Central Sikhote–Alinsk system (Central and Eastern) have been discussed in a number of works (Ivanov 1972; Bersenev *et al.* 1977; Utkin 1980). The amplitude of the left-lateral Central strike–slip fault is determined from the displacement of the Upper Permian and Lower Cretaceous facies zones as 150–200 km. From the separation of late Cretaceous granitoid plutons it is 60 to 100 km, and along the Eastern left-lateral strike-slip fault the minimum amplitude is 20–30 km. Southwards the amplitude increases because of sequential joining of secondary strike-slip faults.

The movements along the Sikhote–Alinsk faults occurred in the early Cretaceous through to the Palaeogene, reaching their maximum in the late Cretaceous. Oceanwards the 'rejuvenation' of the strike-slip fault activity is observed. Displacements along the strike-slip faults of the Central Alinsk system are compensated by formation of folds and thrusts. In the Lower Amur-river a complete compensation of the displacement effect along the strike-slip fault system apparently takes place. Eastnortheast striking thrusts are established in this region (figure 1).

FIGURE 3. Cainozoic faults of the Aldan–Stanovoy and Tukuringra–Dzhagdinsk regions: (*a*) normal faults; (*b*) thrusts; (*c*) strike-slip faults; (*d*) extension zones; (*e*) faults not defined more exactly.

5. Cainozoic faults

The systems of Cainozoic faults differ essentially in the northwestern and eastern parts of the region.

In the Tukurigra–Dzhagdinsk and Aldano–Stanovoy areas a system of sublatitudinally and sublongitudinally trending faults is observed. It is easily seen on small-scale photographs and distinctly expressed in the relief (figure 3). They are traced by rectilinear scarps, river valleys and graben-like lows. In the central part of the Aldansk–Stanovoy arch and within the Tukuringra–Dzhagdinsk uplift a concentration of sublatitudinal faults is observed. Westwards and eastwards the topographic expression of the faults clearly decreases, and they have a fan-like pattern. The accompanying distinct system of sublongitudinal disturbances vanishes.

Parallel to the sublatitudinal faults are Cainozoic warping folds represented by uplifts and depressions. We think that the Cainozoid faults and folds of the Aldano–Stanovoy and Tukurigra–Dzhagdinsk uplifts were formed in conditions of southwest to northeast compression.

The Ussuriisk–Lower Amursk system of rift-like basins stretches as far as 1400 km from the Bay of Peter the Great (Sea of Japan) in the south, up to the Tugursk Bay (Sea of Okhotsk) in the north. The basins are filled with Palaeogene, Neogene and Cretaceous continental deposits (Varnavsky 1971; Shevchenko 1979). From geophysical data, the depth of the basement in some depressions is about 5 km. In the Lower Amur-river vast flood plains coincide with basins, testifying that the process of downwarping continues to the present. Sedimentation was accompanied by the eruption of Miocene and Pliocene–early Quaternary alkali basalts. Sublatitudinal faults transecting the general longitudinal trend of the depressions are typical for the region. The formation of the Ussuriisk–Lower Amursk fault system is undoubtedly related to sublatitudinally oriented tension processes.

6. A relation between continental lithosphere blocks, horizontal displacements, and the adjacent oceanic plate movements

The northward mass movements in the Far East in the Mesozoic is consistent with the displacement of the oceanic plates of the Tethys and of the Mesozoic Pacific Ocean (figure 4*d*) (Hilde *et al.* 1977; Larson & Chase 1972). In early Mesozoic time the Bureinsk–Khankaisk and the Okhotomorsk microcontinents were apparently part of the Kula plate (figure 4*a*). The northward movement of the Kula plate was compensated in the active southeastern margin framing the Siberian continent (Parfenov & Natal'in 1977; Parfenov *et al.* 1979). At that time imbricate thrusts (the earliest faults in the Tugursk system) were formed in the accretion wedge related to the magmatic arc of the Stanovoy Range. A consistent increase of the amount of magmatic rocks within the arc caused its isostatic rise and fragmentation, which caused northerly mass transport and the origination of the South Aldansk thrust system (figure 1).

The collision of the Bureinsk–Khankaisk microcontinent with the Siberian continent caused the formation of a suture zone between them. As a result of the Bureinsk–Khankaisk plate obduction, nappes, recumbent folds with regionally developed schistosity and transpositional structures were formed. Compressional conditions were preserved there later, mostly with a similar mass movement.

After the collision of the Bureinsk–Khankaisk microcontinent, the eastern part of the Kula

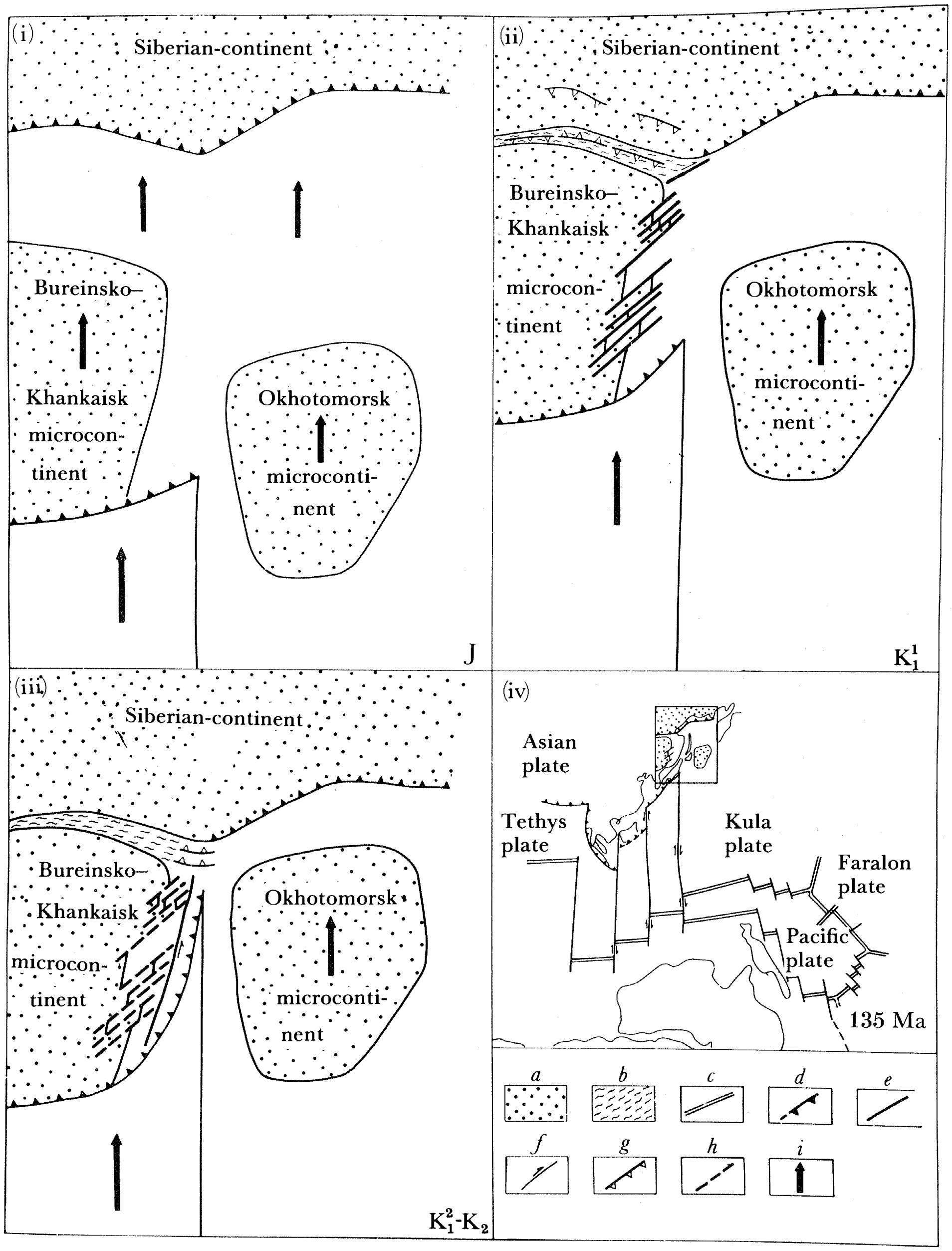

FIGURE 4. Model of the formation of main Mesozoic fault systems in the Soviet Far East. Palaeotectonics of the Pacific and Indian oceans according to Hilde *et al.* (1977): (*a*) continents and microcontinents; (*b*) foldbelts; (*c*) median oceanic ridges; (*d*) active continental margin; (*e*) transform faults; (*f*) large strike-slip faults; (*g*) thrusts; (*h*) faults whose formation was finished at the previous stage; (*i*) direction of lithosphere plates movement (the size of the arrow is directly proportional to the movement rate).

plate continued its migration northwards. It is indicated by the processes of magmatism, continuing in the Udsko–Murgalsk island arc and later in the Okhotsk–Chukotsk volcanic belt (Parfenov & Natal'in 1977; Parfenov *et al.* 1979). The suggested kinematic pattern accounts for the formation of the Amgunsk–Ussuriisk strike-slip fault system. A gliding between the Bureinsk–Khankaisk microcontinent and the eastern part of the Kula plate occurred there (figure 4*b*). With time the main displacements were shifted to the east. They did not cease after the Sikhote–Alinsk island arc formation in the Aptian–Albian. The oceanic crust was submerged beneath this arc as well as beneath the island arcs of Japan at an acute angle (Uyeda & Miyashiro 1974, figure 4*c*). Fitch (1972) proved that with such geometry large strike-slip faults must appear in the back-arc region. It appears that the Central Sikhote–Alinsk strike-slip fault system was formed that way.

In the Cainozoic, the orientation of the block movements was greatly changed. New fault systems appeared. The formation of the Ussuriisk–Lower Amursk system of rift-like basins may be related to the extension processes that originated the Sea of Japan. The compression that was preserved in the Tukuringrsk–Dzhagdinsk and Aldano–Stanovoy regions till the Cainozoic, might have been caused by the inertial northward movement of the Bureinsk–Khankaisk megablock.

The authors thank their colleagues G. Kirillova, V. Pilatsky, V. Utkin, F. Onukhov for valuable discussions. Mrs Kucheryavenko R. helped to prepare the English version of the paper.

References

Bersenev, I. I., Kulinich, R. G., Oleynik, Yu. N., Pushchin, I. K. & Utkin, V. P. 1977 Primorye. In *Faults and horizontal movements of mountain structures of the U.S.S.R.* (136 pages.) Moscow: Nauka. (In Russian.)

Fitch, T. J. 1972 Plate convergence, transcurrent faults and internal deformation adjacent to south east Asia, the Western Pacific. *J. geophys. Res.* **77**, 4432–4461.

Hilde, T. W. C., Uyeda, S. & Kroenke, L. 1977 Evolution of the Western Pacific and its margin. *Tectonophysics*, **38**, 145–166.

Ivanov, B. A. 1972 Central Sikhote–Alinsk fault. (116 pages.) Vladivostok Publishing House. Branch of the U.S.S.R. Academy of Sciences. (In Russian.)

Kirillova, G. L. & Turbin, M. T. 1979 Formations and tectonics of the Dzhagdinsk zone of the Mongolo–Okhotsk foldbelt. (114 pages.) Moscow: Nauka. (In Russian.)

Larson, R. L. & Chase, C. G. 1972 Late Mesozoic evolution of the Western Pacific. *Bull. Am. geol. Soc.* **23**, 3645–3662.

Natal'in, B. A., Popeko, L. I. & Chobotov, S. A. 1985 Tectonics of Western Dzhagdinsk zone of Mongolo–Okhotsk folded system. *Tikhookeanskaya Geologia*, no. 2, pp. 49–64.

Parfenov, L. M. & Natal'in, B. A. 1977 Tectonic evolution of northeast Asia in the Mesozoic and Cenozoic. *Dokl. Akad. Nauk SSSR.* **235**, 1132–1135. (In Russian.)

Parfenov, L. M., Voinova, I. P., Natal'in, B. A. & Semenov, D. F. 1979 Geodynamics of northeastern Asia in the Mesozoic and Cenozoic and the nature of the volcanic belt. *J. Phys. Earth.* **26** (supplement), pp. S503–S526.

Schevchenko, V. K. 1979 Tectonic nature of intermontane basins of the Lower Priamrye and of the Western Priokhotye. *Geotectonics* no. 4, pp. 104–112. (In Russian.)

Sitnikov, V. S. & Spector, V. B. 1978 Viluysko–Aldansk system of dislocations. In *Geophysical investigations in Yakutiya.* (127 pages.) Yakutski. (In Russian.)

Stavtsev, A. L. 1971 Mechanism of the formation of folded and rupture structures in the Southern Verkhoyan'e. *Dokl. Akad. Nauk SSSR* **200**, 1411–1415. (In Russian.)

Utkin, V. P. 1980 *Strike-slip fault dislocations and methods of studying them.* (144 pages.) Moscow: Nauka. (In Russian.)

Uyeda, S. & Miyashiro, A. 1974 Plate tectonics and the Japanese Islands: a synthesis. *Bull. Am. Geol. Soc.* **85**, 1159–1170.

Varnavsky, V. G. 1971 *Paleogene and Neogene sediments of the Sredne–Amursk basin.* (159 pages.) Moscow: Nauka. (In Russian.)

Zablotsky, Ye. M. & Sytina, N. M. 1974 The structure of the Tyndinsk massif of granitoids (Stanovoy Range) by geologo-geophysical data. *Geol. Geophys.* no. 11, pp. 82–90. (In Russian.)

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY A MATHEMATICAL, PHYSICAL & ENGINEERING SCIENCES