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Stationary Network of Continental Faults and Mobilism

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In discussing the establishment and performance of a stationary network of faults in the moving and rotating continent, the evolution of this network is considered. The hypothesis is supported in that the 4-6 component network of faults observed in the continents is fully complete, and will remain unchanged despite any further modifications in the stress field, displacements, and rotations of the continent.

Study of the distribution of crustal faults, carried out by various investigators with very precise methods including map analysis and interpretation of aerial and satellite photographs, shows that the faults are not randomly oriented but occur at definite angles to one another. As a result of these studies, it has long been concluded that the continents are characterized by four trends of faults spaced 30-60°, 45° in an ideal instance. These four fault systems usually are grouped in pairs, with each paired system consisting of two branches, perpendicular in an ideal instance. One of these trends is closer than the others to the meridional, and its paired system is known as orthogonal, the other as diagonal. Over the vast regions of Eurasia and North America, present displacements on faults of the diagonal system are mainly strike-slips; those on the orthogonal faults are mainly vertical (Suvorov, 1968; Pavoni, 1966; and others). Six trends of faults have been identified in some regions* (Kiselev and Korolev, 1964; Kheraskov, 1977; Chebanenko, 1963; Yakubov et al., 1976).

Inasmuch as this pattern has been identified on different continents, it led to the conclusion that there exists a single global network of faults determined by a steadily oriented field of global stresses (Voronov, 1968; Katterfel'd and Charushin, 1970; Sovorov, 1968; Chebanenko, 1963; Moody, 1966; Sonder, 1947). At the same time, study of the history of displacement on these faults shows that the direction of displacement may change in time, reflecting changes in orientation of the stress field. These changes in the direction of displacement are described for northern Tadzhikistan, Kazakhstan, and other regions (Afonichev and Borovikov, 1975; Virovlyanskiy, 1960; Vol'fson, 1947; Gzovskiy, 1975, Suvorov, 1968; Shakhin, 1960; Illies and Greiner, 1976).

The concept of a single network of faults affecting the entire crust and determined by global stresses is in contradiction to mobilistic views of displacement and rotation for the continental blocks. As such, it is used as an argument against mobilism (Postel'nikov, 1976; Sonder, 1947).

D. Moody (1966) attempted to resolve this contradiction by assuming that crustal blocks are displaced over great distances by using as guides the faults of a discrete global network. In striving to reconcile these displacements with the results of paleomagnetic investigations, V.Ye. Khain (1972, 1975) complemented this idea by supposing that the axis of the Earth's rotation and that its magnetic poles change their position in leaps equivalent to the angular distance between components of the global fault network. Obviously, this mechanism of crustal block movement does not allow for a significant rotation of these blocks, although rotation of the continents and their segments relative to one another is well substantiated by paleomagnetic investigations.

The purpose of the present article is to reconcile the following facts: 1) each continent has a stationary system of faults, with the components trending in 4-6 directions; 2) movements on faults of the stationary system in different continents, during certain definite periods, follow one and the same pattern; and 3) the continents and their segments may rotate at any angle, in the horizontal plane.

CONDITIONS FOR THE EXISTENCE OF A STATIONARY NETWORK OF FAULTS

The questions to be considered are as follows. What would be the result of a change in orientation of the force field, or of rotation of the continent in a steady force field? Would such a rotation continually produce faults with new trends corresponding to each new position of the continent relative to the force field? Information on this question can be obtained from the study of fracturing in ancient rocks affected during different periods by differently oriented forces (Borisova, 1973; Krieger, 1951; Putintseva, 1973; Shul'ts, 1969 and others). As seen in exposures of such rocks, the angle between fault systems always is definite, usually over 20°. It would appear that this rule reflects the physical property of rocks, controlling its shearing deformation. In that

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*Moody and Hill (Moody and Hill, 1960, 1964; Moody, 1966) count eight trends of strike-slip faults. They arrived at this 8-component system by combining on one and the same map the data from several continents. The following exposition shows the error of such an approach.

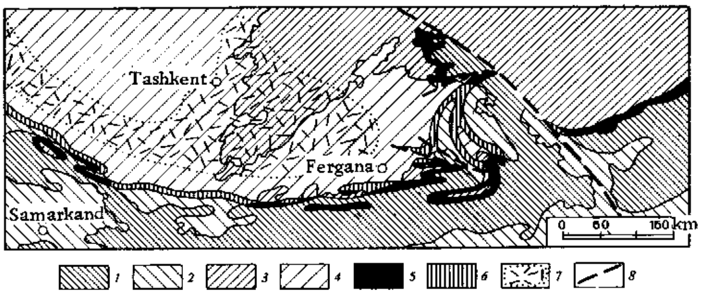

Fig. 1. Oceanic suture in the Paleozoides of the Tien Shan

1–2) rocks of the Alai-Tarim continent: 1) exposed; 2) buried beneath Meso-Cenozoic deposits; 3–4) rock of the Kirghiz continent: 3) exposed; 4) buried beneath Meso-Cenozoic deposits; 5–6) rocks of the Paleozoic oceanic crust, marking the suture of the Turkestan ocean: 5) exposed; 6) beneath Meso-Cenozoic deposits; 7) Late Paleozoic marginal volcanic belt; 8) principal strike-slip faults.

event, as orientation of the force field changes,* rocks would not respond to this type of deformation, over a direction change of 20° and more.

In considering fracturing in dealing with this problem, it must be kept in mind that this conclusion is not exact. To start with, we do not know in what way and how many times the stress field changed its orientation. Secondly, analogy between fractures in rock and faults in the crust is limited because of difference in properties of these media. At the same time, the results are quite acceptable, qualitatively, even though the angle through which the crust is unresponsive to shearing deformation in a variably oriented stress field may be different.

An experimental reproduction of shearing deformations brought about by a changing force field would be of great interest. The author was unable to run across the description of such an experiment. Experimental modeling of recurrent folding was carried out by Ghosh and Ramberg (1968). The smallest angle between the axes of folds produced where the direction of the applied force changed was 30°. This means that the greatest number of possible trends for these folds is six. The minimal angle (γ_{min}) between the faults quite possibly also is 30°. This is in fair agreement with the fact that the maximum number of fault systems known from the continents is six.

The changes in orientation of the force field relative to the continent can come about in two ways. The first variant — that of a gradually changing orientation — takes place under natural conditions when the continent is rotated in a global force field. In that event, the fault systems would originate at angular distances of γ_{min}. With $\gamma_{min}=30°$, the greatest possible number of fault systems is six. In the second variant, orientation of the force field changes by leaps of α°. If $\alpha<\gamma_{min}$, no new fault systems originate. In the special instance of $\alpha=\gamma_{min}=30°$, a 6-component network of faults can develop. If $\alpha>\gamma_{min}=30°$, the number of possible directions is limited to 4–5. Development of a 5-component network is rather improbable because fault systems usually are paired. It may be supposed that a 6-component fault system is produced, as a rule, by the first method; a 4-component system — by the second.

The probability is high that both the 4- and 6-component fault systems are fully complete, i.e. no new systems would originate from further changes in orientation of the force field. Only the direction of displacement on the already existing faults would change. This leads to two conclusions: 1) the existence of a stationary network of faults does not imply a stationary stress field; 2) rotations of the continent relative to the force field, or changes in orientation of the latter, do not lead to a remodeling of a completed fault network in the continent.

HISTORY OF DEVELOPMENT OF THE STATIONARY FAULT NETWORK

Study of geological history reveals that various faults originate during definite stages of the tectonic process, remain active during a certain time period; and then either die down or become inactive, to be reactivated under new tectonic conditions. We now consider which of these structures become the components of a stationary continent fault system, with Paleozoic folding systems for illustration.

The earliest faults existed in rocks of the oceanic crust. Those oceanic structures traces of which are visible on the continents were subsequently closed, joining together their margins, which consist of rocks

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*In all cases considered in the present article, one one of the principal stresses is vertical while the other two, including the maximal, lie in the horizontal plane.

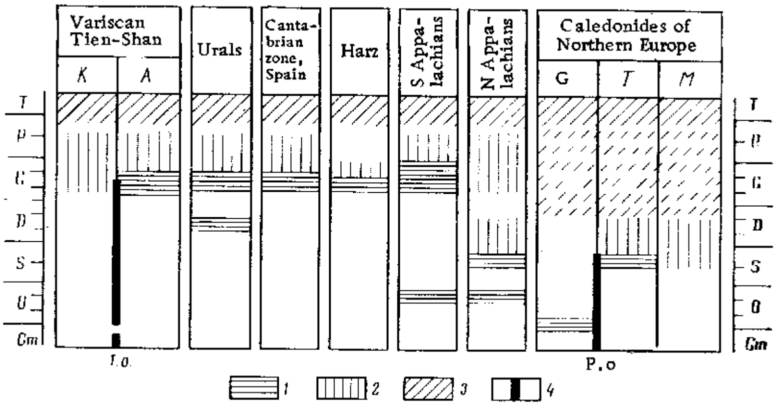

Fig. 2. Deformation stages of the geosynclinal systems.

1) Stage I: development of overthrusts; 2) Stage II: development of reverse and normal faults and folds with vertical axial planes; 3) Stage III: development of strike-slip faults, thrusts, and vertical axis folds; 4) time of existence of oceanic structures (T. o., Turkestan oceanic structure in the Variscides of Tien-Shan; P. o., Protoatlantic oceanic structure in the Caledonides of Northern Europe-Appalachians). Deformation series: K) Kirghiz; A) Alai; G) Grampian; T) Trondheim; M) Moffat.

of the continental crust. In this process of closing of the oceanic structures, the faults in the oceanic crust disappeared along with the crust itself. Traces of the closed oceanic structures persist in the continents as oceanic sutures (Fig. 1). These sutures, however, developed later, during overthrusting. The existence of faults in the closed oceanic structure must be inferred mainly from the principle of uniformity: such faults are numerous in the present oceanic structures. Only the former seismofocal zones have left evidence of their earlier activity in the form of volcanic belts near the former margins of continents and microcontinents. As an example, Fig. 1 shows a Paleozoic marginal volcanic belt in Tien Shan. The site of surface exposure of the seismofocal zone with which this volcanic belt was associated was covered in the Late Paleozoic by a slab of continental crust (Burtman, 1973, 1976).

Within the continents, faults in the folded belts developed when the continental blocks drew together, the oceanic structures were closed up, and the continent so developed was further deformed. Three stages of this process, characterized by different modes of deformation, can be identified (Fig. 2; Burtman, 1976).

The principal structures of Stage 1 are overthrusts. In the Caledonian folded belt, which extends from Northern Europe to the Appalachians, the overthrusts developed in the Ordovician and Silurian. In the Ordovician, these overthrusts emerged at the Canadian margin of the Proto-Atlantic oceanic structure. They are widespread also in the northern and Grampian Highlands of Scotland and in the Northern Appalachians. The Proto-Atlantic ocean closed up in the Late Silurian and the Canadian and Baltic continents joined together. At that time, overthrusts toward the Canadian shield were initiated over the former marginal part of the Canadian continent, in the area of the Northern Appalachians and in Scotland. In Scandinavia, after the closing-up of the Proto-Atlantic ocean rocks of the Canadian continent were thrust over the margin of the Baltic continent, in a multilevel series of overthrusts, overturned in the direction of the Baltic shield.

In the Variscan geosynclinal system, overthrusts developed in Carboniferous time, in connection with a closing-up of Variscan oceanic structures. Such are overthrusts in the European Variscides, the Southern Appalachians, the Urals, and Tien Shan. The Kirghiz and Alai-Tarim continents came together in Tien Shan, following a closing-up of the Turkestan oceanic structure, in the Middle Carboniferous and rocks of the Kirghiz continent were thrust over the Alai-Tarim continent. The multilayered system of overthrusts so formed is like that described in detail from the Scandinavian Caledonides.

All these overthrusts originated, were active, and died down during Stage I of deformation in the geosynclinal system. With rare exceptions, movements on these overthrust surfaces were never renewed. The overthrusts observed within the folded system originated in a peeling-off of the upper part of the oceanic crust and the uppermost part of the continental. The peeling-off and overthrust surfaces did not penetrate deep into the continental crust. In subsequent deformations, they were folded and acquired different dips and orientation. The lines of their surface outcrops are sinuous. The geometry of Stage I faults, and the absence of younger movements, indicate that they did not participate in the development of a stationary system of continental faults.

Stage II of deformations in the geosynclinal system was accompanied by mountain building. This deformation

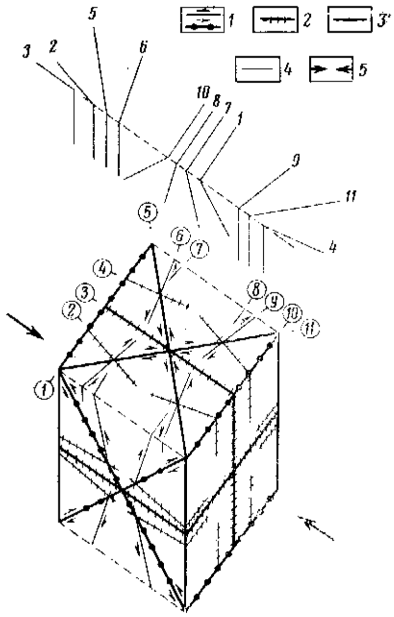

Fig. 5. Fractures that may originate in a geological body as the effect of oriented force.

1) Shearing fractures; 2) tensile fractures; 3) fractures of I category (parent); 4) same II category (derivative); 5) direction of forces.

component of the stationary network takes advantage of fractures of different origin, in different areas. This approach to the problem in question is close to views of Sonder (1956) that faults develop on a template of variously oriented local fractures. The developing faults take advantage of fractures whose directions correspond to the active tectonic stress field. In other words, it is not necessary to look for global factors in setting up such a template, and to conclude, on that basis, that the trend of faults in a stationary network is determined by stresses oriented in the same way over all the continents.

Crustal stresses can be produced by numerous phenomena. We consider here the main sources of oriented stresses affecting the crust of an entire continent or several continents.

1. Fluctuations in the rate of rotation of the Earth lead to periodic weakenings of polar compressive stresses within the geoid. The stresses so originated might have played a role in initiation of a stationary network in one or another continental block.

2. Tendency of the triaxial ellipsoid (a close approximation of the present geoid) to assume a spheroidal form produces equatorial compressive stresses along an axis extending from the Pacific Ocean to the African continent (Voronov, 1968; Katterfel'd, 1962; Magnitskiy, 1948). These stresses are now active. There is no information on the duration of these stresses, nor on the existence of similar stresses in the past.

3. Stresses that originate in a collision of the continents during their movement brought about by mantle convection. Such a collision sets up a strong regional stress field that encompasses the two continents in collision. This stress field remains stable for a long time, because the causes of the movements persist after the collision and maintain the existence of this field.

4. Stresses set up by forces centrifugal from the poles. This stress field is stable, in time, changing but little along the trend, and oriented at any given time in the same way over all the continents.

The last two sources of stresses provide the best explanation for both coincidence and the lack of it in the direction of displacement on faults of the stationary systems in different continents. In the absence of a strong regional stress field, movement on faults probably is controlled by forces centrifugal from the poles and proceeds uniformly over different continents. When continents collide, the direction of displacement on faults within these continents is determined by the force field set up in such a collision. In some instances, these two sources of stresses act in concert: in the same direction. Such was the stress field produced in the Oligocene as a result of collision between the Indian continent and Eurasia. Within this composite stress field, recent movements on faults of the stationary Asian network take place.

CONCLUSIONS

Consideration of the development and activity of a stationary network of faults in the moving and rotating continent leads to the following conclusions.

1. Relative to deformation, the crust of the Earth has the property of breaking along discrete planes. This fundamental property of the crust reflects its capability, within certain limits, to transmit stresses without being deformed and limits the number of possible trends of faults and folds. The least angle between the fold axes is 30°; the angle between the trends of fault systems* is over 20°, possibly approaching 30°.

2. This discrete character of the crust explains the stability of the stationary fault network, in time. A completed network remains unchanged during any changes in the stress field; the changes can lead only to a reversal of displacements on faults of the stationary network. Neither rotation of the continent or of its parts relative to the global force field, or any changes in the force field, nor appearance of regional fields would lead to a remodeling of the stationary fault network. When this network is incomplete (i.e. containing unoccupied trends), the factors cited may lead to a completion of the network by component faults oriented along the unoccupied trends.

3. A stationary network of continental faults is initiated in a crustal block by any stresses affecting this

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*It must be kept in mind that deformation-related properties of a rock differ from those of the crust, as a whole. In speaking of the factors controlling the pattern of crustal deformation, the author refers to deformations that affect a considerable depth of the crust or all of it.

block. Subsequently, the fault network extends to orogens from regions of earlier consolidation.

4. The faults that existed in the geosyncline during the oceanic stage of its development, as well as those of Stage I deformations of the geosynclinal system, do not participate in development of a continental stationary network. Stage II faults do participate in this operation. Stage III is the time of development of a stationary network of faults at the end of orogeny in the folded region. This network remains active during the platform stage of regional development.

5. Direction of movement on faults of the stationary network can be induced by global as well as regional stresses. The most important among the latter are stress fields set up in a collision of continents, effected by movements of the lithosphere plates.

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