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GEOLOGY

Formation Geodynamics of the Infrastructure of the Cretaceous Kongju Sedimentary Basin (South Korea)

V. P. Utkin[a], **Academician of the RAS A. I. Khanchuk**[a],
S. A. Kasatkin[a], **and Lee Dong-Woo**[b]

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It has been established now that strike-slip faulting at the eastern margin of Asia under conditions of lateral compression was accompanied by the formation of their structural parageneses (local extension structures), where sedimentary basins were formed due to subsidences along normal faults. We believe that epicontinental marginal basins of Asia are related to destruction of the crust rather than its subsidence. This concept made it possible to explain periodic processes of volcanism and the delivery of deep mineralized solutions during sedimentation [1]. The infrastructure of most sedimentary basins is characterized, however, by a system of dislocations (folds and fractures) caused by postsedimentary compression of an unknown nature rather than extension, as should be expected. The basins are bordered by strike-slip faults, which isolate the basins from the external influence of regional compression. Consequently, we can assume that the formation of infrastructures of the basins was governed by intrabasin stress fields related to the dynamics of the development of basin-bounding strike-slip faults (hereafter, BB faults) rather than by regional compression.

We attempted to solve the problem formulated above based on study of the evolution geodynamics of the Kongju basin, which is characterized by two essential structural features. First, the basin is distinctly bordered by strike-slip faults, which are usually hidden under sediments and inaccessible for immediate study at the surface in other basins. Second, the BB faults are not coaxial. Their different orientations imply the generation of differently oriented intrabasin stresses, which could produce diverse and, probably, asynchronous dislocations.

The Cretaceous activation period of NE-trending faults in South Korea was marked by sinistral displacements over several tens of kilometers [7, 8] (Fig. 1). The Kongju basin is a structure produced by the syn-

Fig. 1. Main faults and Cretaceous epicontinental basins of the Korean Peninsula (modified after [2, 3]). (*1*) Sedimentary basins: Chonsu (1), Kongju (2), Eumseong (3), Pungam (4), Puyeo (5), Kyokpo (6), Haenam (7), Neungju (8), Naedjensan (9), Jinan (10), Youngdong (11), Kyongsang (12), Youngyang (13); (*2*) Ogcheon Fold Belt (and synonymous strike-slip fault zone); (*3*) main faults and direction of displacements along them; (*4*) direction of displacements of crustal blocks along the Ogcheon strike-slip fault zone; (*5*) direction of regional compression; (*6*) study area.

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[a] *Far East Geological Institute, Far East Division, Russian Academy of Sciences, pr. Stoletiya Vladivostoka 159, Vladivostok, 690022 Russia*
e-mail: stakhor@yandex.ru
[b] *Kongju National University, 182 Shinkwan-dong, Chumgnam, 314-701, Korea*

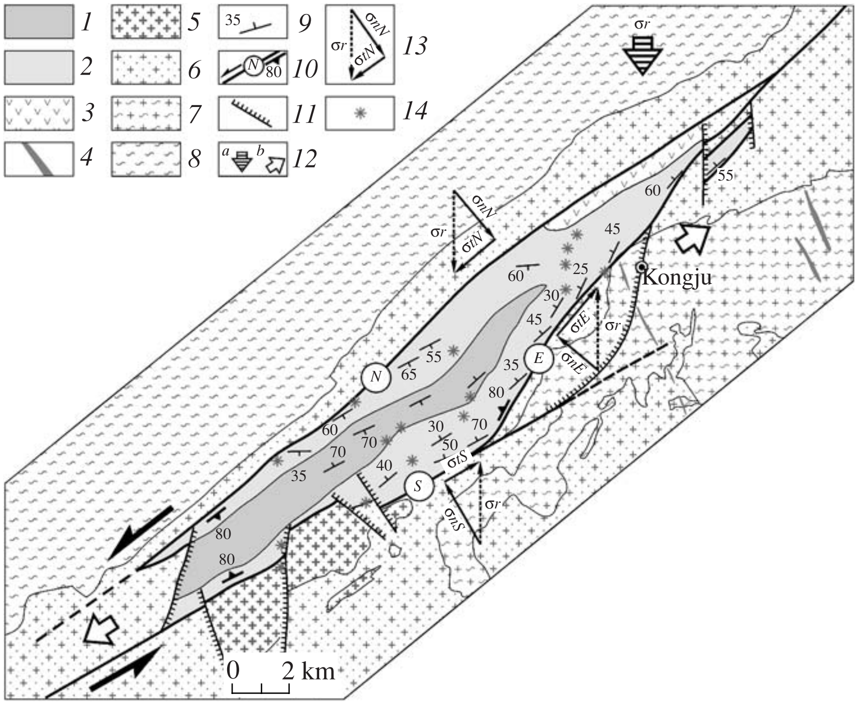

Fig. 2. Geological–structural map of the Kongju basin (modified after [4]) and formation geodynamics of its internal structure. (*1*–*4*) Cretaceous rocks: siltstones (*1*), sandstones and conglomerates (*2*), andesites (*3*), dikes of quartz porphyries (*4*); (*5*) Jurassic granites; (*6*–*8*) Precambrian rocks: porphyroclastic gneissic granites (*6*), micaceous schists (*7*), banded gneisses (*8*); (*9*) bedding attitude elements; (*10*) strike-slip faults bordering the Northern (*N*), Southern (*S*), and Eastern (*E*) basin and their dips; (*11*) normal faults formed under tangential stresses (σtN and σtS); (*12*) general compression (*a*) and synchronous extension (*b*); (*13*) direction of general compression (σr) and its derivatives (normal (σnN) and tangential (σtN)) relative to the Northern (*N*), Southern (*S*), and Eastern (*E*) strike-slip faults; (*14*) original observation points.

faulting (synkinematic) extension of crust in the area of an echelon of NE-trending sinistral strike-slip faults (hereafter, sinistral faults) [6–8] (Figs. 1, 2). According to geophysical data [5], the crystalline basement in this basin is located at a depth of 400–700 m. The basin is bordered by steep (80°) faults (Fig. 2), which represent wide fault zones (450–520 m). The fault planes are often accompanied by mylonites and ultramylonites [6]. The sedimentary beds dip to the northwest and southeast to form a synclinal fold. The northwestern limb of the syncline is steeper (55°–65°) than the southeastern one (30°–40°). One can see facies variation and decrease of grain size toward the fold axis [2] (Fig. 2).

Despite their general northeastern orientation, the BB faults are not parallel to each other (Fig. 2). The difference in their orientation was probably responsible for different-vector (normal and tangential) derivatives of general compression (Fig. 2), which probably governed the intrabasin stress fields that created the infrastructure of the basin. To solve this problem, we have analyzed, together with Korean specialists, mass measurements of orientations of beds, faults with displacement features, and quartz veins that reflect positions of local extension structures. The kinematic characteristics of fault planes were determined by measuring sliding striation and furrows (hereafter, slickensides), as well as accretionary and autochthonous steps. We also studied structural patterns of auxiliary fissures, bends of beds along fault planes, and displacement types (strike-slip, thrust, overthrust, and normal faults) of marker bodies. The dynamic analysis of materials obtained during field works yielded the following results.

Folds (*F*) are oriented at an acute angle to the system of sinistral BB faults (*N*, *S*, and *E*), indicating their synfaulting formation under conditions of intrabasin stress σnF oriented at NW 345° (Fig. 3A). The fracture belt (4) genetically related to folding and compression σnF is poorly expressed (Fig. 3B). The majority of fractures in belts 1 and 2 formed under conditions of compression oriented normally (NW 320°) to the Northern Fault (σnN). These belts demonstrate two prominent maximums (I, II) that reflect the positions of steep (80°) opposite systems of conjugate dextral and sinistral faults (NW 300° and NW 340°, respectively) forming an acute angle (40°) with the bisectrix corresponding to the compression vector σnN. Other maximums in these belts (III–VI) indicate positions of gentler (55°–70°) fault planes that are typical of overthrusts in the same stress field (σnN).

Mass measurements of slickensides (Fig. 3C) characterize the kinematics of differently oriented fractures. In addition to strike-slip faults (maximums I and II),

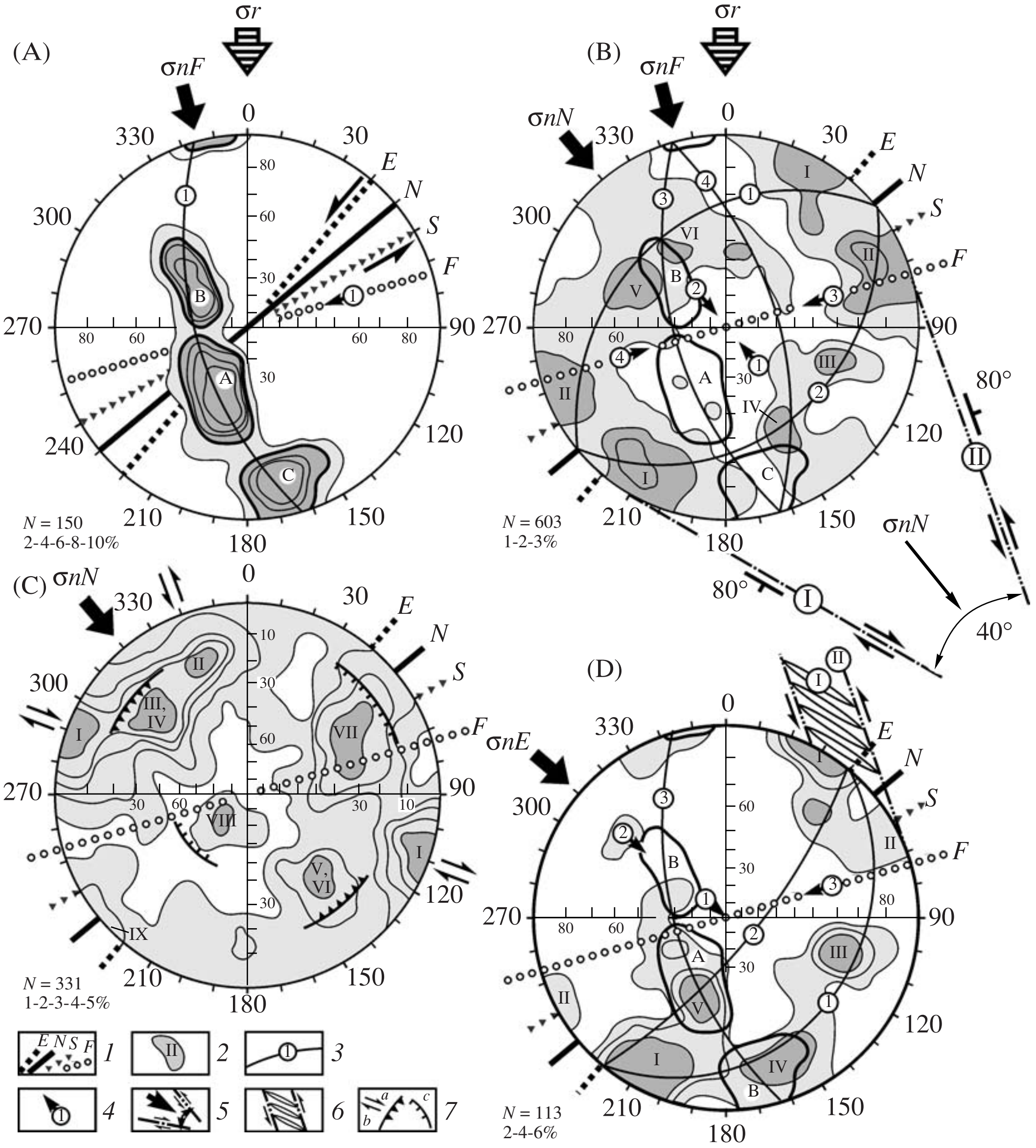

Fig. 3. Diagram and dynamic analysis of mass measurements of bedding (A), fractures (B), slickensides (C), and quartz veins (extension fissures) (D). Wulff net, upper hemisphere. (*1*) Orientation of strike-slip faults bordering the Northern (*N*), Southern (*S*), and Eastern (*E*) basins and orientation of folding (*F*); (*2*) maximums of measurements of bedding, fractures, tectonic striation, quartz veins, and their numbers; (*3*) equators of belts of bedding (A), fractures (B), quartz veins (D), and their numbers; (*4*) axes of belts of bedding (A), fractures (B), quartz veins (D), their numbers, and dip directions (arrow); (*5*) relationships between intrabasin conjugate sinistral and dextral faults in plan view (diagram B); (*6*) opening dynamics of planes of sinistral faults (I) in response to activation of sinistral faults (II) (diagram D); (*7*) direction of main systems of intrabasin strike-slip faults (*a*), main development sectors of upthrust and thrust displacements (*b*), development sectors of normal faults (*c*) according to mass measurements of tectonic striation (diagram C); (σ*r*) direction of general compression; (σ*F*, σ*nN*, σ*nE*) directions of intrabasin compression oriented normally to folds (*nF*) and BB faults (*nN*, *nE*).

one can see sectors with the development of overthrusts and thrusts (maximums III–IV and V–VI), as well as sectors with normal faults (maximums VII and VIII). Localization of maximums of tectonic striation generally corresponds to dynamic laws of the organization of kinematics of differently oriented fractures formed under compression σ*nN*.

Extension fractures (quartz veins) constitute belts 1 and 2 related to σ*nE* (Fig. 3D). The main maximums are concentrated in belt 1, the axis of which is oriented normally to the plane of the Eastern Fault (*E*) and dips to SE 130° at an angle of 15°. The main maximum observed in both belts 1 and 2 reflects the dominant localization of veins in the system of planes of NW-trending (300°) dextral faults (Fig. 3B). In contrast, planes of NW-trending (340°) sinistral faults (maximum II) host rare quartz veins. At the stage of quartz mineralization, sinistral faults were presumably active

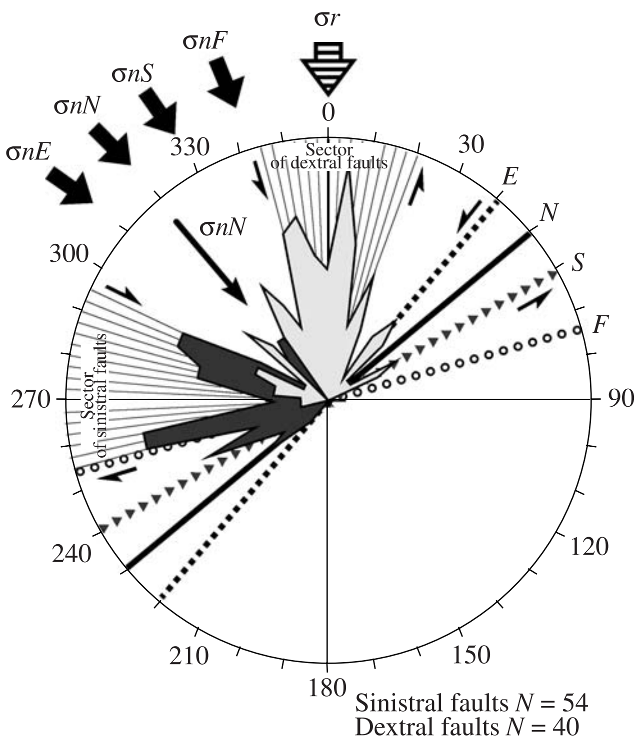

Fig. 4. Orientation of intrabasin systems of dextral and sinistral faults relative to the BB faults (*N*, *S*, *E*) and strike of folding (*F*).

and unfavorable for the injection of hydrothermal solutions with endogenic quartz mineralization, because they represent compression structures. The system of dextral faults (maximum I) obliquely oriented to their sinistral counterparts was transformed into extension structures (Fig. 3D) favorable for the formation of quartz veins. Maximum III reflects the positions of extension fissures oriented normally to beds dipping to the northwest (310°) at an average angle of 30° (maximum B). Maximums IV and V (Fig. 3D) coincide with maximums of bedding orientations A and C, indicating the σ*nE*-mediated exfoliation of these beds and development of conditions favorable for mineralization. The distribution of quartz veins reflects the intrabasin geodynamic setting of the injection of endogenic mineralized solutions synchronously with the formation of the infrastructure of the Kongju basin.

The systems of sinistral and dextral faults represent a dynamic pair (Fig. 4), the formation of which cannot be explained by general compression (σ*r*) or σ*nF*. It resulted from compressions oriented normally to the BB faults, primarily the σ*nN* stress oriented along the bisectrix of the angle between conjugate systems of dextral and sinistral faults (Fig. 4).

The dynamic analysis revealed successive stages in development of the infrastructure of the Kongju basin related to changes in local (intrabasin) geodynamic settings.

The system of NE-trending strike-slip faults of South Korea (Fig. 1) resulted from general meridional compression accompanied by pull-apart displacements of the crust that were responsible for the formation of normal faults and epicontinental sedimentation basins. The Kongju basin was initiated by the synfaulting crustal extension. This process triggered the formation of normal faults, development of the depression, and its simultaneous filling with coarse-debris sediments. After the termination of active extension, the basin was filled with fine-grained facies largely confined to the axial zone of the uncompensated basin. The sediments commonly overlapped the normal faults (Fig. 2).

The subsequent evolution of the infrastructure of the basin can be divided into three stages related to changes in the orientation of intrabasin stresses. The first stage was characterized by plastic deformations with the formation of folds under conditions of the NW-oriented (345°) stress σ*nF* (Fig. 3A). The second (brittle deformation) stage produced regular systems of strike-slip, overthrust, oblique thrust, and normal faults. It should be noted that these fracture systems do not coincide in space with the positions of synorogenic (diagonal and orthogonal) fractures known in structural geology. They reflect an autonomous network of deformations under conditions of the NW-oriented (320°) compression σ*nN* (Fig. 3B). Hence, folded structures and superimposed fractures in the Kongju basin formed successively in fields of differently oriented intrabasin stresses. The third (quartz mineralization) stage was characterized by the transformation of some shear structures and bedding planes of certain orientation into extension structures favorable for the formation of quartz veins under conditions of the NW-directed (310°) compression σ*nE* (Fig. 3D). Synchronous activity of conjugate systems of dextral and sinistral faults (Fig. 3B) at the second stage indicates deformations of the pure strike-slip type. In contrast, only the sinistral fault (NW 340°) system was active at the third stage, which points to the replacement of the pure strike-slip deformations by their simple varieties.

Thus, the infrastructure of the Kongju basin formed under conditions of the replacement of meridional counterclockwise stress by the NW-oriented (310°) one. This replacement occurred in the stepwise manner with stresses always oriented normally to the off-axis BB faults. Stress oriented normally to the Southern Fault (*nS*) is not prominent because the Southern Fault, which is divided by normal faults into separate segments (Fig. 2), lost its continuity and ability to generate significant intrabasin stresses. The most significant stress was generated from the northwestern flank of the basin represented by a steep extended fault (Fig. 2), the σ*nN* stress of which was probably responsible for the formation of not only the main fracture systems, but also asymmetrical folds in the basin. Indeed, the steeper limb of the fold joins the northwestern wall of the basin, probably indicating that this sector was subjected to the strongest compression oriented from the northwest to southeast.

The regularities revealed in the formation of the infrastructure of the Kongju basin in response to the successive reorganization of intrabasin stresses (derivatives of general compression) shed light on the formation of different-rank geodynamic settings and other epicontinental (synfaulting) sedimentary basins at the eastern Asian margin.

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