OPEN ACCESS

Saudi Journal of Engineering and Technology
Abbreviated Key Title: Saudi J Eng Technol
ISSN 2415-6272 (Print) |ISSN 2415-6264 (Online)
Scholars Middle East Publishers, Dubai, United Arab Emirates
Journal homepage: https://saudijournals.com

Review Article

Origins of Geodynamic Forces and their Importance in the Evolution of the Earth

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DOI: https://doi.org/10.36348/sjet.2025.v10i07.002 | **Received:** 01.06.2025 | **Accepted:** 07.07.2025 | **Published:** 12.07.2025

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Abstract

The article is devoted to one of the main problems of the evolution of the earth's crust, where from the position of the concept of the dynamics of the evolution of the earth's crust (CDEEC) the nature of numerous geological processes is clarified. Including the origin of geodynamic forces and those geotectonic processes that directly occur under the influence of these forces: such as volcanoplutonic; seismotectonic processes; global deep fault networks; divergent and convergent zones; active and passive margins; riftogenic processes; the origin of arc systems, etc. The origin, mechanism of formation, as well as their distribution patterns on the face of the Earth and other characteristic features of these natural processes are clarified from the position of CDEEC. From the position of this concept, geodynamic forces are formed during the rotation of the Earth around its axis and they are distributed on the face of the Earth with certain patterns, which are predetermining factors in the development of geological processes. These geological processes, both in scale and in form of distribution, have their own specific features, which are important in the formation of various genetic types of mineral deposits. Therefore, the study of these processes is one of the priority areas of geological research.

Keywords: tectonics, geodynamic forces, earth's crust, spreading, subduction, volcanic processes, deep faults.

INTRODUCTION

Research into the nature of geological processes—including their origin, formation mechanisms, and modes of distribution—holds not only theoretical but also significant practical importance for the exploration of mineral deposits. This is because the formation of ore mineral deposits directly involves a complex of interconnected geotectonic processes, among which the most important are volcanoplutonic processes. From a theoretical perspective, the main types of valuable components are derived from magmatic masses, which serve as potential sources of useful elements. These masses, originating from the Earth's deep zones (typically the upper mantle), rise to the surface as a result of volcanoplutonic processes and undergo various transformations along the way. In different geotectonic settings, these rising masses experience assimilation, differentiation, contamination, and other geological processes, which result in the release of diverse juvenile products in composition. These products, in essence, serve as the source of various genetic types of endogenous mineral components.

Later, these products participate in the formation of a wide range of mineral deposits within various zones of the Earth's crust (mainly in internal zones and partially on the Earth's surface through effusive processes) [9].

The ascending magmatic masses, while intruding into host environments along their path, are emplaced in different geotectonic settings. From them, gas-liquid products rich in metallogenic elements are released, which form ore components.

These juvenile gas-liquid products essentially represent the primary source of ore components, which are formed through physico-chemical phase transitions [2,4]. These phase transitions occur under the influence of geodynamic forces within the contact zones between the upper mantle and the Earth’s crust [1,3]. Subsequently, the products of these transformations travel a long evolutionary path from their place of formation (the junction zone of the upper mantle and the crust) to the Earth’s surface. In this zone, magmatic melts are subdivided into their constituent parts, and depending on the depth, intrusive and subvolcanic rocks form—often accompanied by characteristic ore accumulations of deposit-type scale.

All these transformations involve large-scale geotectonic processes that occur under the influence of geodynamic forces [2]. Below are the genetic characteristics of certain geotectonic processes from the perspective of the KDÉZK (Concept of Dynamic Evolution of the Earth's Crust). Considering that these grand-scale geotectonic processes occur directly under the influence of geodynamic forces, it is necessary to describe their characteristics from a genetic standpoint.

1. Origin and Distribution Patterns of Geodynamic Forces

The role of geodynamic forces in the evolution of the Earth’s crust is well known [12–28]. However, their forms of manifestation and sources have been interpreted differently by researchers. Some groups of scientists believe that vertical forces dominate in the formation of geotectonic processes [12, 28], while others emphasize horizontal forces. The primary reason for these disagreements lies in the ambiguous explanation of the origin of dynamic forces themselves.

From the perspective of KDÉZK, this issue is explained through the Earth's rotation, which provides a compelling explanation for the nature of geotectonic processes. This concept also outlines the distribution patterns of these forces across the Earth’s surface (Fig. 1). It is noted that the Earth’s rotation around its axis generates geodynamic forces, and all geological processes occur under the influence of these forces. These forces are generated according to the laws of physics by centrifugal forces and are distributed within the Earth’s crust according to specific patterns.

Due to the Earth's rotation, two main groups of geodynamic forces are primarily formed. One group is directed from the Earth’s poles toward its equator. The other—from west to east. The interaction between these forces forms tangential forces, which in the Northern Hemisphere are oriented southeastward, and in the Southern Hemisphere northeastward. From the KDÉZK viewpoint, it is noted that near the Earth’s poles, the dominant geodynamic forces are those directed from the poles toward the equator, while near the equator, the dominant forces are those directed from west to east. This is clearly observed in the distribution patterns of specific types of geotectonic processes.

This is particularly evident in the development of divergent and convergent zones, where various genetic types of deep faults are formed as a result of divergence and convergence. The geometric parameters of these deep faults and the speed of geodynamic forces are of special significance. For this reason, both the scale and other characteristics of such faults are highly variable. This is most evident in the deep faults observed in global oceanic basins—except for the Arctic Ocean, where geotectonic processes are very weakly expressed. In the Arctic Ocean, not only are divergent and convergent processes weakly developed (thus limiting the formation of various genetic deep faults), but other global geotectonic processes related to the intense movement of lithospheric masses are also significantly subdued.

Thus, it can be concluded that the formation of major geotectonic processes is closely linked to the patterns of distribution of geodynamic forces. These distribution patterns, in turn, are directly dependent on the velocity of lithospheric mass movement, which is regulated by changes in the Earth’s radius along planes perpendicular to the axis of the Earth’s rotation [1, 34].

The movement of lithospheric masses—including their velocity—increases regularly between the poles and the equator. At the equator, the velocity of movement reaches its maximum, while toward the poles, it gradually decreases to zero. This variation explains the changing character of geotectonic process development.

2. Origin of Dislocation Processes and Their Significance in Earth’s Evolution

From the standpoint of the KDÉZK concept, dislocation processes are among the most widespread and belong to the fundamental components of global geotectonic processes involved in the evolution of the Earth’s crust. Undoubtedly, they occur directly under the influence of geodynamic forces. These processes participate in the formation of many geotectonic phenomena, such as the development of divergent and convergent zones; the origin and formation mechanisms of global deep faults, which form during the movement of lithospheric masses [3]; the formation of subduction and spreading zones along with many other local processes; the development of active and passive margins and marginal seas and their associated local processes; the origin and mechanisms of riftogenic and island arc systems, among many others.

Dislocation processes generally occur under the influence of global geodynamic forces. However, their specific characteristics, including distribution patterns, are largely dependent on the nature of the development and movement of lithospheric masses and their velocities. The speed of lithospheric mass movement directly depends on the distance from the Earth’s poles or the equator. The largest-scale movements of lithospheric masses take place near the equator, and as these masses move away from the equator, the activity gradually weakens and disappears altogether near the poles—this is a natural pattern. This is most clearly expressed in the activity of volcanoplutonic processes as well as in earthquakes, which often accompany volcanic eruptions, testifying to their genetic connections [9, 12]. Dislocation processes are the primary factors in mountain-building processes, except in those instances where mountains form as a result of volcanic activity. Dislocation processes are involved in one form or another in the origin of all genetic types of mountain structures. Many fold structures owe their formation, at least in part, to dislocation processes [3, 4]. The main components of mountain structures have formed through collisional processes [9]. It should be noted that as a result of collisions, a wide variety of mountain structures have formed, differing both in genetic origin and in shape and scale. This diversity stems from the complexity and variety of collisional processes. There are global and local types of collisions, as well as different genetic variations. Inter-platform types of collision processes are also observed in nature. Naturally, each of these diverse collision processes corresponds to its own distinct type of mountain formation. Global collisional processes take place—though differentially—across the Earth's surface, except at the poles. The most intense dislocations occur near the equatorial zones of the Earth, with slightly less activity near the polar zones. Even within these zones, dislocations occur differentially. Major dislocation processes are accompanied by mountain-building activities and other structural changes. These structural changes are most pronounced in the junction zones between stable and mobile areas, as well as in the wide basins of the world's oceans—except for the Arctic Ocean. A good example is the subduction zones along the western margins of continents such as North and South America and Africa. Second in importance are intracontinental dislocations, which result from the movement of continents. A clear example of this is the Alpine-Himalayan collisional zone.

3. Volcanoplutonic Processes

Volcanoplutonic processes are among the main geotectonic phenomena, whose origin and formation mechanisms are directly tied to geodynamic forces. Their manifestation is expressed in numerous magmatic masses, represented by intrusive magmatic bodies and their effusive equivalents. According to KDÉZK, geodynamic processes originate from the Earth's rotation around its axis. The various geospheres of the Earth respond differently to this rotation. As a result, mass shifts occur between them [5]. Depending on the environment, these shifts cause either compaction or decompression of masses in specific zones of the Earth. Consequently, in solid environments, metamorphism of masses (in this case, rocks) occurs, while in other environments, decompression results in the formation of excess mass. This decompression between the solid Earth's crust and the upper mantle leads to physico-chemical transformations. The products of these transformations are, in terms of substance, undifferentiated magmatic emanations. These products later differentiate and contribute to the formation of various types of rocks. From these products, juvenile substances are released, which serve as sources of ore components [6–7]. When decompression occurs between these geospheres, in the form of physico-chemical phase transformations, the ascending masses undergo differentiation along their path upward, resulting in the formation of various types of rocks. During decompression, enormous surplus energy is generated, which is transferred to the Earth's surface in the form of volcanic eruptions. Thus, between the upper mantle and the Earth's surface, a kind of system (zones in the form of columns) is formed, in which various geological processes—such as assimilation, differentiation, contamination, and others—take place. As a result of these processes, valuable components are formed which, under favorable geotectonic conditions, lead to the formation of endogenous ore deposits. It is important to note that, from the KDÉZK perspective, volcano plutonic processes are geotectonically complex phenomena, in which, along with geodynamic forces, complex magmatogenic processes of a chemical nature occur. These are accompanied by the release of complex juvenile product compositions, which play a significant role in the formation of endogenous ore deposits. From this point of view, exploration work is concentrated in regions of intrusive and subvolcanic body distribution. These zones are undoubtedly among the most promising for the discovery of mineral deposits. As a rule, accumulations of useful components are mainly found in the contact zones of intrusive masses or in crosscutting dikes within these masses. Other promising zones are regions with widespread subvolcanic bodies. The physical characteristics of host rocks located in the contact zones of intrusive and subvolcanic bodies also play a significant role. The distribution of mineral deposit formation zones is not limited to the areas of intrusive and subvolcanic bodies. Effusive formations related to volcano plutonic processes are also associated with various accumulations of useful substances or with the products of the effusive formations themselves, which can be utilized in different sectors of the national economy. Therefore, regions where volcano plutonic processes are widespread are among the most promising for providing the national economy with mineral raw materials.

4. Global Deep Faults

One of the structural elements of the Earth's crust is deep faults of various genetic types and origins. Their formation mechanisms and distribution patterns occur under the influence of geodynamic forces. From the KDÉZK perspective, deep faults collectively form a major component of the Earth's crust. They typically arise due to crustal movements driven by geodynamic forces.

Throughout every stage of crustal evolution, various physical bodies are displaced, creating zones of stress across the entire crust. These stresses can be divergent or convergent in nature and are generally under the influence of geodynamic forces. These forces originate from the continuous development associated with the Earth's rotation, but their evolutionary character—i.e., their changes—largely depends on the structural and morphological features of the crust. In a sense, the global development of geodynamic forces depends heavily on the orientation of the Earth's radii relative to its axis, which determines the characteristics of forces perpendicular to the axis that regulate the speed of lithospheric mass movements.

Within the crust, geodynamic forces act subordinately relative to its structural elements. Therefore, their forms of manifestation, directions of development, and spatial impacts vary depending on their orientation to the Earth's rotational axis.

Consequently, the main geotectonic processes—including the origin, formation mechanisms, and developmental patterns of deep faults—occur under the influence of geodynamic forces, which serve as primary indicators of fault activity. Thus, features such as the intensity and parameter changes of global deep faults directly reflect geodynamic force manifestations. These features are distinctly observed in major divergent and convergent zones, which tend to follow submeridional orientations—such as subduction zones located along the western margins of North and South American and Eurasian continents, as well as Australia, and spreading zones like the Mid-Atlantic Ridge.

Within these structural zones, characteristic deep faults of various genetic types are widespread. Most notably, divergent faults form in spreading centers as parallel lines that stretch across vast distances in the Atlantic and Pacific Oceans—from the edges of Antarctica to the southern margins of the Arctic Ocean. Their subduction-type convergent counterparts differ from divergent faults and are prevalent within global subduction zones, typically manifested as linearly arranged volcanic systems. They often occur in submeridional directions as volcanic features and alternate latitudinally on a global scale.

Regardless of genetic type, the most intense fault activity is observed in mid-latitude zones of the Earth, especially within active tectonic provinces, and is generally accompanied by mountain-building processes. This feature is most pronounced in the Atlantic region [8].

Both divergent and convergent global deep faults develop in submeridional orientations. The evolution of both types is associated with volcanic activity, which contributes to the formation of both volcanic and folded mountain structures. Folded structures are more typical of convergent zones, while volcanic edifices are characteristic of divergent zones.

It is important to note that both types of deep faults are intersected by transform faults, which form part of the global fault network and often contribute to the creation of large bend zones. Transform faults form when lithospheric masses shift along latitudinal paths. Consequently, they run roughly perpendicular to divergent and convergent faults. Transform faults are classified as global, regional, or local. Details on transform faults are available in the author's other works [2–8]. The largest global transform faults are found in the Pacific Ocean, often stretching from one ocean margin to the other. Regional transforms are usually elements within global faults and also feature in major collision zones. They play a key role in forming continental plates and determining the positions of continents. Local transforms, being components of global and regional systems, share similar origins but differ only in scale.

From the KDÉZK perspective, collisional-type deep faults do not exhibit clear common patterns in their development. However, the outlines of large plates are clearly influential in their formation. The geometric parameters of colliding plates are crucial, and thus, unlike divergent and convergent faults, predictable patterns are hard to establish. In addition to global forces, dynamic forces related to individual plate movements - each with its unique developmental trajectory - simultaneously drive fault formation.

5. Active and Passive Margins

From the KDÉZK perspective, active and passive margins refer to the western or eastern margins of continents, while the mid-margin zones are relatively stable. The terms "active" and "passive" are conditional. Under this definition, we consider the western margins of lithospheric plates to be conditionally active, as they lie offshore to advancing geodynamic forces from the west—indeed, lithospheric convergence occurs here. Conversely, eastern margins exhibit divergence, as lithospheric masses move apart. In both cases, geotectonic processes are activated. However, the intensity of this activation largely depends on the geotectonic environment's characteristics, including factors such as the velocity of moving masses (determined by dynamic force intensity), as well as the rigidity and mobility of the Earth's crust.

On the western margins of plates, subduction processes generally develop, while on the eastern margins, divergent processes prevail. All such processes unfold under the influence of systematically developing geodynamic forces. The manifestation of these forces is embodied in the varying speeds of lithospheric mass movements, which exhibit differential intensity.

Active and passive plate margins are essentially the most tectonically dynamic zones of continents (or lithospheric plates, since continents may comprise several plates). Given that lithospheric mass movement does not occur uniformly across the Earth's zones—and that the radii of movement are perpendicular to the Earth's axis of rotation—the intensity of movement depends on the lengths of these radii, which naturally decrease with increasing distance from the equator.

Therefore, the velocity of lithospheric motion decreases as radii shorten. Accordingly, the speed of lithospheric movement changes—and this clearly indicates that, on a global scale, the intensity of geological processes is greatest in equatorial and mid-latitude belts and weaker toward the poles.

Thus, geologically speaking, the activation or passivation of tectonic processes is also tied to location. As noted by KDÉZK, the margins of all major geoblocks on Earth are much more tectonically active than their interior zones. In this respect, all major subduction and spreading zones—as well as their boundary regions—are active zones, characterized by volcanic-tectonic activity and seismicity. A prime example is the eastern margin of the Eurasian continent and the western margins of North and South America.

From KDÉZK's standpoint, the eastern edge of the Eurasian continent—which by conventional division is a passive margin from Kamchatka to eastern Malaya—is actually a typical active divergent zone. Until recently, without understanding its formation mechanism, it was mistakenly classified as a subduction zone. All recorded volcanic activity and earthquakes in the region are linked to this divergent zone.

The most active regions regarding volcanic activity and earthquakes include the western margins of North and South America, which represent classic subduction zones geotectonically. This subduction system is the largest in the world. It developed under the control of west-to-east geodynamic forces. In contrast, pole-to-equator-directed forces are relatively minor here, as the entire western flank lies along the Pacific Ocean and is mostly influenced by Pacific dynamics. Polar-driven forces are only noticeable near the poles, such as in Alaska and the northern fringe of Antarctica, where lithospheric flow columns bend.

It is worth noting that lithospheric mass flows along continental margins contribute to the formation of subduction zones on the eastern margins of the Americas—the Andean–Cordilleran subduction zone, the world's most extensive. A distinctive feature of this subduction zone is that lithospheric flows from continental masses cross the Atlantic—one through the Gulf of Mexico, the other between South America and Antarctica.

6. Origin of ARC Systems

Arc systems form where major geodynamic forces intersect with pole-to-equator directed forces. Their interaction produces tangential geodynamic forces, which are essentially the same physics but act along different orientations. In the Northern Hemisphere, these act in a southeast direction; in the Southern Hemisphere, northeast.

Considering existing data and geodynamic distribution patterns, we conclude that arc systems form most favorably within divergent zones along continental eastern margins—such as equatorial belts near the Pacific, Indian, and Atlantic Oceans.

Arc systems are complex tectonic elements that develop in divergent zones near continental margins, in areas where multiple geodynamic forces intersect, creating intricate interactions. These systems typically form within divergent zones offering the most favorable geotectonic conditions.

Modern arc systems clearly indicate that they form where two main geodynamic forces converge. From the KDÉZK perspective, these are tangential forces generated by the interaction of the two primary forces. These tangential forces are strongest in regions equally influenced by both pole-derived forces. Since tangential directions shift gradually, arc systems take on curved shapes.

According to KDÉZK, volcanic activity and earthquakes are genetically linked to the activity of geodynamic forces, which propagate across the Earth following specific patterns and thus determine all geotectonic processes, including arc systems. In fact, arc systems are a common type of geotectonic process and are distinguished only by their curved geometry from other active zones.

The intensity of geotectonic developments, per the KDÉZK concept, is determined by the interplay of divergent and convergent zones. These intensify in zones of intense compression or tension, while intermediate areas are relatively quiescent in terms of volcanic and seismic activity [8,11–24].

7. Rift Structures and Marginal Seas

From KDÉZK's perspective, continental rift zones and marginal seas are structural elements of the continental crust driven by geodynamic forces. These structures occur wherever geodynamic forces induce crustal divergence, turning regions into active zones prone to further geological phenomena.

These zones typically develop most actively on the eastern margins of continents, due to the differential movement of continental crust. They are best exemplified on the African Plate with the Red Sea rift and several other parallel rift zones forming along the continent's eastern margin in a submeridional direction. These rift zones are Africa's most tectonically active regions and explain volcanic activity in its interior (e.g., Mount Kilimanjaro). Similar rift structures also occur in eastern North and South America and Australia.

As noted, riftogenic structures are characteristic of the eastern margins of major lithospheric plates, where they develop in accordance with geodynamic forces. This correlation is most evident on continents made up of a single major plate—such as southern North America, Africa, and Australia—where rift zones align closely with geodynamic development patterns.

The Eurasian continent is different; it consists of multiple large platform geoplates—such as Central Europe, West and East Siberia, and the Indian and Chinese geoplates—with complex interactions. As a result, numerous rift structures develop, especially along eastern margins, influenced both by geodynamic forces and the geometry of these geoplates.

Thus, in Eurasia, rift zone distribution does not consistently align with general geodynamic force patterns. Among the largest rift zones are the Baikal and Balkhash rifts, whose locations do not conform neatly to geodynamic expectations. This further emphasizes that the geometric parameters of major geoplates determine the largest collisional processes and rift formations.

CONCLUSION

Analysis of the above materials allows the following conclusions to be drawn:

Geodynamic forces are generated by the Earth's rotation around its axis and have a decisive role in the evolution of the Earth's crust.

1. Based on physical, chemical, mechanical, and other natural laws, as well as undisputed geological facts, it has been established that these geodynamic forces are distributed throughout the Earth and its spatial surroundings in a consistent, patterned way. These regularities are reflected at every stage of the geological evolution of the Earth's crust.
2. According to physical-mechanical and other natural laws, geodynamic forces can be divided into two main directional groups. One group acts from west to east, and the other—from the Earth's poles toward the equator. The interaction of these forces gives rise to additional tangential forces, which develop in southeast directions in the Northern Hemisphere and northeast in the Southern Hemisphere. All geological processes, including geotectonic ones, occur under the influence of these forces.
3. The evolution of major geotectonic processes—such as lithospheric mass movements, the formation of divergent and convergent zones, subduction and spreading zones, the formation of global deep fault networks, active and passive margins, the mechanisms of arc system and marginal sea formation, and the emergence of stable and mobile zones—is governed by geodynamic forces. The nature of all these processes is clarified through the regular patterns of geodynamic force distribution. Despite the fact that all these global geotectonic processes are influenced by geodynamic forces, they also develop in close relation to the structural and morphological features of the Earth.
4. From the KDÉZK perspective, the nature of all geological—including global geotectonic—processes can be explained through the interplay between geodynamic force distribution patterns and their behavior, as defined by physical, chemical, and mechanical laws and the Earth's rotational motion.
5. Based on physical-mechanical and chemical laws, it has been determined that geodynamic forces have spatial significance. This is evidenced by the patterned development of volcano-plutonic processes, with which volcanic eruptions and earthquakes are genetically linked.

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