Reconstruction of volcanic structures: examples from Kazakhstan and Egypt

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Abstract. The existing hypotheses and paradigms about the structure of the Earth’s crust and its parts, where igneous rocks are present, do not always show facial connections of rocks and explain the reasons for their formation, as well as the genetic connection of ore deposits. These issues can be solved with the help of paleovolcanic reconstruction of the territory. This paper explains the stages of formation of paleovolcanic structure in aid for their reconstruction. Such structures represent the main units of territories with existence of igneous rocks. Examples of reconstruction of certain territories of Kazakhstan and Egypt are given. These structures are tensely related to large metallic ore deposits of Mo, Cu, Zn, Au, Ag, Ni, Co, etc. These structures have various ages of formation and degree of development. Paleovolcanic structure has many similar features to recent well-preserved structures. Our model reset on the lithostatigraphic study of contributing units around oldest complexes and their geochronological sequence, spatial distribution and pattern fault systems and dykes. These researches have not only theoretical interest for science, but also practical. Reconstruction of such structures allows to allocate the most prospective areas for search the overlapped endogenous mineralization (porphyry copper-gold, copper-sulphide, poly-metallic deposits, etc.).

1. Introduction
Professional geologists and even people who are interested in geology know that the huge masses of igneous rocks have been accumulated on the surface of the Earth into different volcanic structures (volcanoes). The largest example of modern volcanic structure on Earth’s surface reaches a height of 10 km with a base diameter of up to 300 km and more (for example, Tamu Massif, located in the northwestern Pacific Ocean [1]). The largest volcanic structure recorded on Mars is Mount Olympus, 27 km high with a base diameter of 500 km [2].
Manifestations of intense magmatic activity from the Upper Proterozoic to the present day have been concentrated in regional volcanic belts located within and between platforms. In Russia, the most well studied is the Ural-Mongolo-Okhotsk belt, which connected the East European, Siberian, Tarim and Chinese platforms into a single Eurasian continent.
Our research investigated Ural, Kazakhstan, Siberia. Also, we have studied to a lesser extent volcanic structures in the Russian segment of the Pacific Fire Ring and the Alpine Belt (Caucasus, Transcaucasia and Central Asia). Within the above-mentioned regional structures, we have identified paleovolcanic structures, of varying degrees of preservation, their average base diameters vary from 100 km or more. As a result of long-term research, a unique factual material has been accumulated, the analysis of which allowed us to create a universal model of paleovolcanic structures.

For areas with a cover of igneous rocks, the basic structural unit is a volcano or paleovolcanic structures. Paleovolcanic structure consists of pyroclastic, lava and volcanic-sedimentary, sedimentary and intrusive rocks. Combination of rocks forms facies. Each of the facies takes its spatial position and accumulates on the entire time interval of the structure. Facies are classified: vent; slope; distant or far distant (see Fig. 1).

Figure 1. Allocation scheme of paleovolcanic facies (by Dyakonov V.V.; Kotelnikov A.E., 2011).

Legend: 1-10 - facies of paleovolcano: 1-7 - facies of the second stage of development (1- vent, 2- vent and near the vent, 3- pyroclastic slopes, 4 – effusive slopes, 5 - ignimbrite slopes, 6 - reef (carbonate), 7 – distant); 8-10 - facies of the first development stage: (8- vent, 9- effusive-pyroclastic slopes, 10 – distant); 11 - bedrock of the volcano; 12 - intrusive; 13 – hypabyssal (or subvolcanic) rocks; 14 - tectonic faults.

The formation of Paleovolcano occurs in two periods, including three consecutive stages (Table 1):

| Periods  | Stages | Structural elements                        | Composition     | Time interval (Ma) |
|----------|--------|--------------------------------------------|-----------------|--------------------|
| Intrusive| 3 stage| lopolith, laccolith, etc.                  | mafic-felsic    | ~10                |
| Volcanic | 2 stage| stratovolcano                              | intermediate-felsic | ~50                |
| Volcanic | 1 stage| shield volcano                             | mafic-intermediate | ~70                |

**First period** – volcanic period – is characterized by extrusive (or effusive) structures development. Volcanic period includes two stages. First stage – eruption of effusive products of basic chemical composition, leads to the creation of a shield volcano; Second stage – the subsequent eruptions of effusive rocks of acidic composition, out of the same magmatic channel, lead to the creation of stratovolcano. Formation of a stratovolcano associated to the same volcanic pipe (conduit), so stratovolcano forms on shield volcanoes, this is due to the change of the chemical composition of the magma at a significant time interval (more than 100 million years). Hypabyssal (or subvolcanic) rocks
are formed predominantly within vent from end of first stage to end third stage. Third – the third stage is the formation of intrusive bodies within the paleovolcano.

Second period – Intrusive period - is characterized by intrusive (or post-volcanic) structures development. Intrusive period includes third stage. During this stage, intrusive bodies (lopolith, laccolith, etc.) introduced into border of shield volcano and stratovolcano. During volcanic period in each stages can distinguish three structural-facies zones: vent, slope and distant. The rocks of this zones form a terrigenous-volcanic-plutonic association reflecting homodromous direction of magmatism (from mafic to felsic).

The theoretical concept is presented in detailed articles by authors [3, 4].

2. Kazakhstan paleovolcanic structure

The first given example presents the reconnaissance paleovolcanic routes within the volcanic center in Kazakhstan. It was possible to identify the remnants of a large paleovolcanic structure. In the stratigraphic sequence, the oldest rock units are basaltic lavas and their differentiates. The stratification of acidic lavas and their tuffs over basic volcanics are recorded everywhere.

The central part of the structure (caldera) with a diameter of 16-18 km. (Fig. 2), filled with rocks corresponding to the vent facies. Tuffaceous volcanic bombs ranging in size from few centimeters to several meters are widely represented (Fig. 3-a-d). Among the debris, there are both rock compositions; basic, as well as acidic, cementing mass of tuffaceous lava of intermediate-acidic composition. In addition to effusive rocks, numerous subvolcanic bodies of rhyolite (Fig. 3-e) and numerous ring and radial dikes of diabases, rhyolites, trachydaces, and dacite (Fig. 4) are widely developed.

![Figure 2. 3-D image of the central part of the paleovolcanic structure.](image-url)
Figure 3. Rock species of the vent facies: a- Volcanic breccia of rhyolitic composition; b- Volcanic breccia of dacitic composition with fragments of basalts, etc.; c- large-block of bombed tuffs; d- medium-grained acid tuffs; e- Different rhyolite species in the area.

Slope facies. Outside the development area of the ventral facies, rocks are confidently mapped to the slope facies. The area of their development reaches 100 km in diameter. These rocks are represented by numerous lava flows, massive, and lapilli tuffs, and often ignimbrites. In the stratigraphic sequence, the oldest rocks are basaltic lavas and their differentiates. In numerous outcrops, the occurrence of acidic lavas and their tuffs covering basic volcanics is recorded. For the rocks of the sloping facies, their periclinar occurrence is noted relative to the center of the structure with an average angle of incidence not exceeding 15 degrees. The subvolcanic facies are represented by arc and radial zones of dikes of acidic composition, small stocks, and extrusive domes. The ring structure of the slope part of the paleovolcanic structure is emphasized by the shape of the individual and a series of acidic subvolcanic bodies, dykes of quartz porphyry confined to radial and annular cracks developing around the volcanic center.

Distant facies. The volcanic rocks of the remote zone of the paleovolcanic structure are represented by tuffaceous conglomerates, sandstones, and siltstones. Rocks build up rhythmic strata of volcanic-sedimentary rocks that accumulate at the lower parts (foot) of the volcano. According to the petrographic description, the rocks are products of the destruction of a volcanic structure that has fallen into sediment without changing the structure of the debris. A characteristic feature of the rocks of the remote zone is a pronounced lamination, expressed by the alternation of different grain-sized, and multi-colored horizons with a certain fixed rhythm in the sequence of accumulation. Thickness of rhythms up to 30 meters. The rhythm begins with either coarse-fragmented tuffites or coarse-grained tuffs, up the section is replaced by more fine-grained tuffite to tuffaceous silts or even to siltstone. Apparently, the rhythms correspond to individual volcanic eruptions, differing in intensity. The initial eruptions were the most powerful, as evidenced by the decrease in the grain size of the rhythms up the section.
Figure 4. Ring-shaped and radial fault systems control the paleovolcanic structure with 1 – major tectonic faults; 2 – fissures and dikes; 3 – facial boundary.

It should be noted that the time of formation of volcanic structures in volcanic belts corresponds to the length of the main epochs of tectonomagmatic activations (Cadomian, Sardian, Caledonian, Hercynian, Cimmerian, Alpine). The duration of tectonomagmatic epochs in different regions varies, sometimes significantly. Within the continents, the reconstruction of paleovolcanic structures faces considerable difficulties like the presence of a thick platform cover. For example, within the Russian territory, the continental Phanerozoic volcanic - a polar Ural where Upper Proterozoic and Lower Paleozoic igneous rocks occur directly on the old metamorphic basement (Archaean-Proterozoic) submitted various gneiss and schists (Harbeyesky anticlinorium), typical of the continental crust [5].

3. Egyptian paleovolcanic structure (Maetiq)
The territory of the Red Sea Hills (Eastern Desert of Egypt) within the Arabian-Nubian Shield turned out to be relatively favorable for the reconstructions paleovolcanic structure. Here it was possible to identify a huge Archean-Neoproterozoic paleovolcanic structure with the center in the area of the Meatiq massif (Fig. 5).

The basement complex of the central Eastern Desert (CED) can be divided into two major tectonostratigraphic units [6, 7, 8]. The lower structure unit, or infrastructure, is composed of gneisses and migmatites that crop out in domed-structures, such as the Hafafit, Meatiq, and Sibai, domes. The overlying unit, the suprastructure, was constructed on three stages, a) Older Metavolcanics related to ophiolitic nappes, b) Younger Metavolcanic and metasedimentary rocks, c) Dokhan volcanics.

The stratigraphic sequence of the CED stratified basement rocks (Fig. 6) is adapted in the following order from [9, 10, 11, 12]. The oldest rock unit is represented by the metamorphic rocks of Meatiq dome which called 1) Meatiq formation and composed of two units a) Umm Baanib granitic gneiss, and b) Abu Fannani metasediments which composed of different types of quartz-feldspar and pelitic schists reach several hundred meters thick. Meatiq rocks are exposed on an area measuring about 20 * 15 km. (see fig. 6) in the form of an eroded dome. This metamorphosed rocks represent the old eruption center. The metamorphic sheet is followed by 2) "Volcanogenic-sedimentary formation"
located along the outer contour of the Meatiq dome forming oval shape (60 * 30 km.) elongated in NW-SE direction. The visible thickness is no more than a few hundred meters. According to [9], it is predicted to 3000 meters. In the north-west, fine-grained types predominate, while in the south-east, coarse-grained clastic to conglomerates are the main types. Transitions between different units are gradual. At the base of the stratum, a basal horizon of a conglomerate is recorded everywhere. This unit represent the development area of old platform cover of the paleovolcanic structure. The volcano-sedimentary rocks is followed by 3) Metavolcanics formation which is composed of two sheets a) The lower mafic metavolcanics, which is related to ophiolitic sequence (called Older Metavolcanics by Stern [13] and followed by b) The upper intermediate and acidic metavolcanic sheet (called Younger Metavolcanics [13]. This unit represent the development area of both distant and slope facies.

![Figure 5. Stratigraphic sequence of the Eastern Desert basement complex, intruded by serpentinite (oil green), Older Granite (orange), and Younger Granite (red).](image-url)
All the above mentioned formations represent "Geosynclinal formations" according to Sabet [9] which uncomfortably covered by a second phase of tectonomagmatic activation beginning with 4) Dokhan volcanics formation, comprise two main rock suites: (a) Lower minor intermediate volcanic suite, composed of lower basaltic andesite, andesite, dacite sheet, and their associated pyroclastic rocks; and (b) Upper felsic volcanic suite composed of rhyolite and rhyolitic tuffs [11]. The Dokhan volcanics are uncomfortably covered by 5) Hammamat formation which composed of non-metamorphosed clastic "molasses-type" sediments range from conglomerate to siltstone. The time relation between Hammamat formation and the Dokhan volcanics is debated. El-Gaby et al. [9] and Akaad [14] established that the deposition of the hammamat sediments was after the eruption of the Dokhan volcanics. Moghazi [15] concluded that the Hammamat sediments and Dokhan volcanics were formed contemporaneously. Early Phanerozoic volcanism produced some small exposures as 6) Atalla felsite formation occur in close association to older metavolcanics and 7) Post-Hammamat felsite group. This proposed stratigraphic sequence rests on serpentinites and ophiolite complexes; in many places ophiolites thrust over this sequence. Most of these units are intruded by different granitic massifs, gabbro-diorite-granodiorite complexes [16, 17, 18, 19, 20, 21]. The Dokhan volcanics and the emergence of the granitic plutons extremely with long periods of deformation history intubated the Meatiq paleovolcanic structure and hide many its features. The study of the lithostratigraphic sequence of units with their spatial distribution, age and field relations success to construct this proposed model.

4. Conclusion
The presented research results suggest that the paleovolcanic structures of the old continents are similar to those of the recent volcanic belts. This similarity is represented by 1- The same structure of volcanic rhythms - from the eruption of basic volcanics at the first stage to the acidic at the second stage, 2- Ring-shaped occurrence of magmatism products around the central vent, 3- the concentric facies zones, 4- the introduction of intrusive arrays after the completion of the effusive rhythm. The annular structure of the paleovolcanic structure is emphasized by various dikes and cracks, which clear the radial structure of the structures. The development of the paleovolcanic structures is directly affected by their life time. If the structures of the belts were formed during a tectonomagmatic cycle (an average of 100 million years), then on the platform, the formation time consistently includes several epochs of activation, dragging on for several hundred million years. The paleovolcanic structure that we studied in Egypt was formed from the Late Proterozoic to the Middle Paleozoic, and only due to the conditions of intense erosion in the continental conditions, only relatively well-preserved products of the Proterozoic-Early Paleozoic time remained, and from the subsequent ones, different fragments were preserved. Moreover, what is interesting is that the younger they are, the less volume they are presented.

Over the past few years, such investigations have been conducted in Kazakhstan on the territory of more than 10 thousand sq. km. As a result, the allocation of perspective areas and plots. The drilling works carried out on some of them confirmed the presence of copper-porphyrific mineralization. In the future, it is planned to conduct research on the territory of Egypt and Russia in order to discover new zones of ore mineralization in territories with developed mining infrastructure.

5. References
[1] William W S, Jinchang Z, Jun K, Takashi S, Anthony A P K, Mike W and John J M 2013 An immense shield volcano within the Shatsky Rise oceanic plateau, northwest Pacific Ocean Nature Geoscience vol 6 pp 976–981
[2] Fabio VittorioDe Blasio 2012 Conceptual model for the origin of the Olympus Mons cliffs, Mars: An essential influence of water? Planetary and Space Science Volume 69, Issue 1 pp 105-110
[3] Dyakonov V V 2011 Phanerozoic paleovolcanic structures and ore mineralization of copper-molybdenum porphyritic type (Doctoral dissertation). Retrieved from Russian State Library (Storage location OD 71 12-4/3) (In Russian)
[4] Kotelnikov A E 2013 Mednogorsky paleovolcanic structure and prospects of its ore potential (PhD dissertation). Retrieved from Russian State Library (Storage location OD 61 13-4/54) (In Russian)

[5] Galiullin I Z and Remizov D N 2009 Geological-Mineragenetic Mapping (GMM) of scale 1:200000 of the sheets Q-41-XVI, XVII, XXI, XXII (East-Voykar area) (Labytnangi, JSC “Polyarno-Uralskoe GGP”) (Storage location: Moscow, “Russian Federal Geological Fund”, rfgf.ru, accession number 494311)

[6] El-Gaby S, List F K, Tehrani R 1988 Geology, evolution and metallogenesis of the Pan-African Belt in Egypt The Pan-African Belt of Northeast Africa and Adjacent Areas ed El Gaby S and Greiling R O (Vieweg & Sons, Braunschweig/Wiesbaden) pp 17–68

[7] Abdeen, M M, Greiling R O 2005 A quantitative structural study of late PanAfrican compressional deformation in the Central Eastern Desert (Egypt) during Gondwana assembly. Gondwana Research 8 457–471

[8] Abd El-Wahed M A and Kamh S Z 2010 Pan African dextral transpressive duplex and flower structure, Central Eastern Desert, Egypt Gondwana Reserch p 22

[9] Sabet A H, Bykov B A, Berezin Y P 1977 Geological setting and ore deposits of the Bir Umm Fawakhir sheet Internal report EGSMa p 57

[10] Coral Conoco 1987 Geological map of Egypt, scale 1:500,000 (The Egyptian General Petroleum Corporation, Cairo, Egypt)

[11] Mohamed F H, Moghazy A M Hassanen M A 1999 Petrogenesis of late Proterozoic granitoids in the Ras Gharib magmatic province, northern Eastern Desert, Egypt: petrological and geochemical constraints Neues Jahrbuch Fur Mineralogie-Abhandlungen 174 319–353.

[12] Ali K A, Stern R J, Manton W I, Kimura J-I, Khamees H A 2009 Geochemistry, Nd isotopes and U–Pb SHRIMP zircon dating of Neoproterozoic volcanic rocks from the Central Eastern Desert of Egypt: New insights into the ~750Ma crust-forming event Precambrian Research 171 1–22

[13] Stern R J 1979 Late Precambrian ensimatic volcanism in the Central Eastern Desert of Egypt Ph.D thesis (University of California, San Diego, USA)

[14] Akaad M K 1996 Rock succession of the basement: An autobiography and assessment The Geological Survey of Egypt 71 p 78

[15] Moghazi A M, Andersen T, Oweiss G A, El-Bouseily A M 1998 Geochemical and Sr–Nd–Pb isotopic data bearing on the origin of Pan-African granitoids in the Kid area, southeast Sinai, Egypt J Geol Soc London 155 697–710

[16] El Ramly M F 1972 A new geologic map of the Eastern and South-Western Deserts of Egypt. Scale 1:1000.000 Annals Geological Survey of Egypt 12 1–18

[17] Stern R J 1981 Petrogenesis and tectonic setting of Late Precambrian ensimatic volcanic rocks, Central Eastern Desert of Egypt Precambrian Research 16 195–230

[18] Gass I G 1981 Pan-African (Upper Proterozoic) plate tectonics of the Arabian Nubian Shield Precambrian Plate Tectonics ed A Kroner (Amsterdam: Elsevier) pp 387-405

[19] Vail J R 1985 Pan-African (Late Precambrian) tectonic terrains and the reconstruction of the Arabian–Nubian shield J. Geol. 13 839–842

[20] Abdel-Rahman A M and Doig R 1987 The Rb–Sr geochronological evolution of the Ras Gharib segment of the Northern Nubian Shield J. Geol. Soc. Lond. 144 577–586

[21] Mohamed M A 2012 Geochemistry and fluid evolution of the peralkaline rare-metal granite, Gabal Gharib, Eastern Desert of Egypt Arab. J. Geosci. 5 697–712