A Global Perspective on Crustal Structure and Evolution based on A New Crustal Classification

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Knowledge of the crustal structure is the key for understanding physical and chemical conditions of its formation and later modification by geodynamic processes. It has long been recognized that crustal structure is controlled by tectonic settings, and that the crustal thickness is one of the most important parameters that reflects the geodynamic origin of the crust. A long tectonic life of continental crust leads to its significant reworking by plate tectonics processes and crust-mantle interaction, which include mechanical extension, delamination, relamination, magmatic intra- and underplating, metamorphic reactions, sedimentation and erosion. As result, thickness of the entire crust and thicknesses of its internal layers may change significantly. In extreme cases some crustal layers can be entirely missing, as for example in the Variscan Western Europe where the lower crust is nearly absent.

A broad development of controlled-source crustal seismology in 1960-1970-ies, followed by systematic studies of the crust on regional and global scales, led to recognition of broad global correlations between crustal structure and tectonic settings (Meissner, 1986; Beloussov et al., 1992). This led to models of crustal typization by 1D crustal columns based on absolute thicknesses of crustal layers and the Moho depth, and has led to models of crustal typization, which formed basis for global crustal models starting with CRUST5.1 (Mooney et al., 1998). In these models, the Moho depth is a major parameter, and the proposed crustal tectonic types typically show broad regional variations, making such typization highly non-unique (Fig. 1). We demonstrate that "classical" 1D typizations are not efficient in recognizing different crustal types (Fig. 1).

Novelty and Rational

We propose a fundamentally different approach to typify the crust and geodynamic models of crustal evolution (Artemieva and Shulgin, 2019) (Fig. 2).

(1) While recognizing that the crustal thickness is a very important parameter that characterizes the crust, including the fundamental difference between continental and oceanic crust, we remove this parameter from our classification.
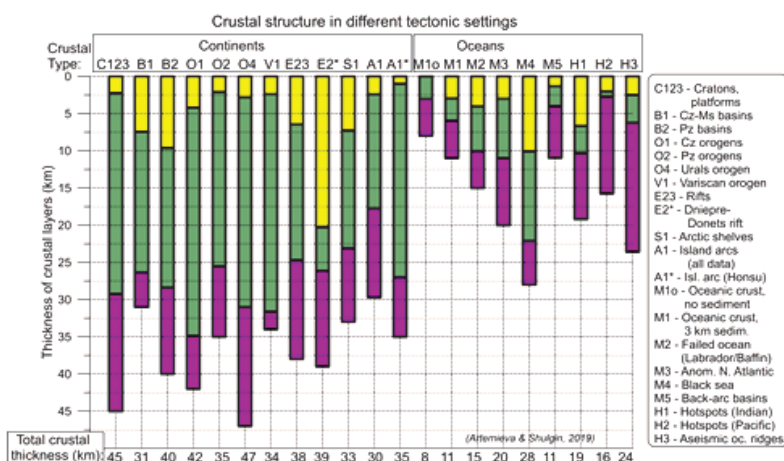

Fig. 1. "Traditional" 1D typization of the crust in Eurasia and oceans globally, based on absolute thicknesses of three major crustal layers is not efficient in distinguishing different crustal types (from Artemieva and Shulgin, 2019).

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(2) We focus on the relative thicknesses of the principal crustal layers, instead of using their absolute thicknesses, as in all crustal studies. Therefore, the total crustal thickness is included in our analysis indirectly, for conversion of the absolute thicknesses to relative thicknesses.

The role of relative contributions of the major crustal layers has been completely overlooked in the previous studies that focused on crustal types, so that until now the total crustal thickness is considered as an important parameter in crustal typization. Yet a regional analysis of the relative thicknesses of just two crustal layers demonstrated that they provide an efficient indicator of crustal tectonic origin and an extent of crustal reworking (Artemieva and Thybo, 2013). For example, in Europe, the thickness of the granitic-intermediate layer normalized by the thickness of the crystalline basement is: < 0.3 for oceanic crust, 0.3 to 0.5 for transitional crust, 0.5 to 0.7–0.8 for crust of stable platforms, and > 0.8 for extended continental crust.

Data on the crustal structure

We selected ca. 70 tectonic provinces to represent as many different tectonic settings as possible in continental and oceanic domains of the northern Eurasia and in oceans globally. Only regions with a high density of seismic profiles, and therefore with a well-known crustal structure are included into the analysis.

We subdivided major tectonic types into 24 sub-types, depending on geodynamic settings (Fig. 1). Although for some structures (e.g. the Black Sea) the tectonic classification is non-unique, our results and conclusions are independent of the choice of the tectonic type. Instead they provide a new basis for tectonic regionalization based on the fundamental differences in the internal crustal structure in different geodynamic settings.

The following tectonic provinces are selected for the crustal structure analysis (Figs. 1–4):

(1) Precambrian cratons (types C1, C2, C3), including shields and platforms (Baltic Shield, Russian platform, Ukrainian Shield, Voronezh Massif, Siberian craton);

(2) Sedimentary basins (types B1, B2), including Cenozoic (Pannonian) and Meso–Paleozoic basins (Polish-German, North Caspian, Pechora, West Siberia);

(3) Orogens (types O1–O4), including Cenozoic (Alps, Caucasus, Carpathians) and Paleozoic (North Appalachians, Norwegian Caledonides, Caledonides of UK and Ireland, Timan ridge, Urals, Anti-Atlas/Atlas mountains, Svalbard) orogens,

(4) Variscan orogen (type V1), including the Gondwana massifs (Iberian, Bohemian, Armorican, Brabant);

(5) Large igneous provinces (LIPs) (type E1), including Paleozoic (the Siberian LIP) and Mesozoic (the North Atlantic Igneous Province in Eastern Greenland);

(6) Extended continental crust (types E2–E4), including active rifts (Rhine Graben, Baikal), Meso-Paleozoic paleorifts (the Central Graben of the North Sea, Oslo and Dnieper–Donets rifts in Europe, and Ob, Khatanga and Viluy rifts in Siberia), and Proterozoic rifts (aulacogens) of the East European Craton;

(7) Continental shelves and margins (type S1), including shelves of the Arctic Ocean (Barents and Kara) and the Voring margin of the North Atlantic Ocean (off-shore Norway);

(8) Oceans (types M1–M3), including "normal" oceanic crust (with a different thickness of sediments) and anomalous oceanic crust (ocean plateau) that does not fit the age-bathymetry predictions (the Labrador and Baffin seas, the North Atlantic Ocean around Iceland, the Jan Mayen block, and the Iceland–Faroe region);

(9) Off-shore back-arc basins (types M4, M5), including Western Pacific (the Japan Sea and the Lau Basin) and the Black Sea; the latter may have been formed as a Cretaceous back-arc basin (e.g. Zonenshain and Pichon, 1986), note that its crustal structure is not well constrained by seismic studies; the back-arcs of the Mediterranean are excluded because of their small size and the lack of seismic data on the inner structure of the crust;

(10) Volcanic island arcs (type A1), including the Kurils, Japan, and the Izu-Bonin arcs;

(11) Ocean hotspots and volcanic provinces (types H1, H2), including the Hawaii and Louisville hotspots in the Pacific Ocean and the Reunion, Laccadive and Laxmi
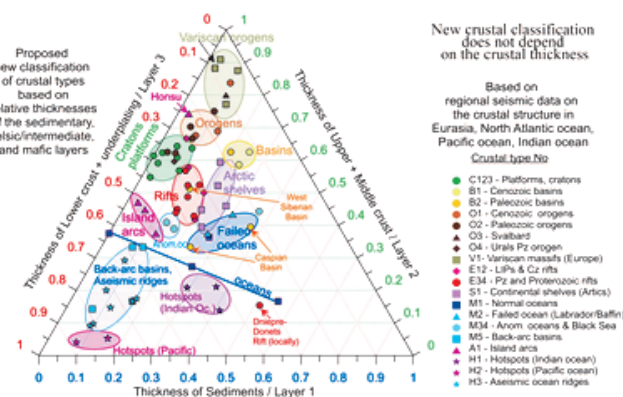

Fig. 2. New crustal typization illustrated by a ternary diagram for relative thicknesses of three major crustal layers in various crustal provinces of Eurasia and oceans globally (modified from Artemieva and Shulgin, 2019).

Various crustal types cluster in tight groups. Few outliers (e.g. the Caspian Basin) clearly illustrate that their traditional tectonic interpretation is incorrect.
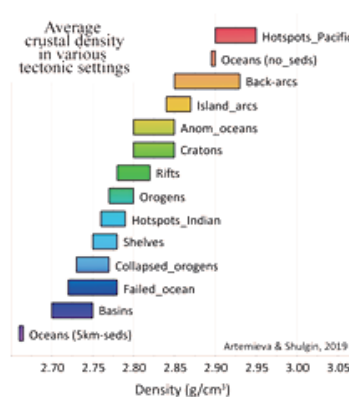

Fig. 3. Average crustal density (including sediments) in various crustal provinces based on figs. 2 and 7 (Artemieva and Shulgin, 2019).
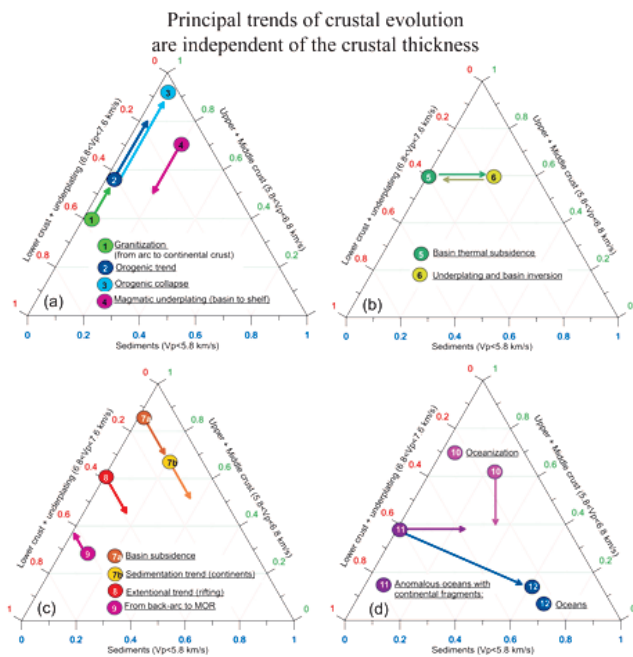
Fig. 4. Principal trends of crustal evolution, preserving relative thickness of one of crustal layers unchanged (a, b, c), and some trends for oceans (d) (modified from Artemieva and Shulgin, 2019).

volcanic provinces in the Indian Ocean;

(12) Aaseismic ocean ridges (type H3), including the Cocos, Walwis, Bonin, and the Ninety-East ridges.

The crustal layers (sediments, upper crust, middle crust, lower crust and high-Vp lowermost crustal layer) for the continental crust are defined by seismic velocities with the boundary values of Vp of 5.8 km/s, 6.4 km/s, 6.8 km/s and 7.2 km/s. Therefore, the results are presented as ternary diagrams for 3 principal crustal layers normalized by the total crustal thickness and defined as:

Sediments (Vp < 5.8 km/s) or Layer 1 for oceans;

Felsic-intermediate crust (5.8 < Vp < 6.8 km/s) or Layer 2 for oceans;

Mafic continental crust (6.8 < Vp < 7.4 km/s) or Layer 3 for oceans.

However, when seismic surveys included reflection data and other geophysical information, the boundaries between the crustal layers were accepted as interpreted in the original publications.

Major results listed below.

(1) The relative ratio of the thicknesses of three principal crustal layers (sedimentary/felsic-intermediate/ mafic in continents and Layer1/Layer2/Layer3 in oceans) is a fundamental characteristic of the crust (Fig. 2).

(2) The relative ratio uniquely specifies the crustal structure in different tectonic settings and is independent of the absolute values of thickness of the crustal layers and the Moho depth (Fig. 2).

(3) Due to different composition of three principal crustal layers, and therefore, their different typical densities, our classification predicts typical crustal densities in various tectonic settings (Artemieva and Shulgin, 2019) (Fig. 3).

(4) Changes in the relative thicknesses of three principal

crustal layers define principal trends in crustal evolution, such as granitization and formation of continental crust in the arc settings, orogenesis, orogenic collapse, magmatic underplating (Fig. 4a), basin subsidence and basin inversion (Fig. 4b), rifting, back-arc extension, initiation of ocean spreading (Fig. 4c), and oceanization (Fig. 4d).

Key words: crustal delamination, granitization, basin subsidence, orogenic processes, continental rifting, hotspots, continental shelves, failed oceans, oceanic crust

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