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DISTRIBUTION AND VOLUME OF ROCKS IN SEDIMENTARY BASINS – UNUSUAL CASE OF THE SOUTH CASPIAN BASIN

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Abstract

The article gives a brief overview of the sedimentary cover of the Earth and summarizes volumes and mass of sediments contained in the Earth sedimentary layer (stratisphere). Using available data authors show unique nature of the South Caspian Basin and other rapidly subsiding basins with large amount of sediments and attenuated crust. Sedimentary, crustal and lithospheric thickness correlations are discussed.

Keywords:

Sedimentary basins;
South Caspian basin;
Sediment volumes;
Lithosphere.

Introduction

Knowledge about temporal and geographic distribution of sedimentary rocks on Earth comes from compilations made by Alexander Borisovich Ronov and Viktor Yefimovich Khain at the Vernadski Institute of Geochemistry at the academy of sciences of USSR in Moscow. The compilation started in 1947 and included data on areas, volumes and masses of all continents, except Antarctica and also from ocean basins. Thickness of the sedimentary basins of the world have been counted many times since that period most famously by Ronov (1993) [1]. Southam and Hay (1981) [2], Kunin (1987) [3] and Berry and Wilkinson (1994) [4]. Most recent data estimation was summarized by Hay (2004) [5]. Hay (2004) gives an extensive review of distribution of mass-age of sediments on the continental blocks and additional data sediment that lies on the ocean floor, based on the data by Ronov (1993) and Hay (1994).

Our recent estimate sits very well within the range of the previous and we use the data from various open sources to demonstrate the match. Our estimate is derived from 2 open sources – digitized sediment thickness maps from Earthbyte project [6] and CGG Robertson and Earthbyte basin shapes digitized from publicly available maps. Some of more subregional or localized maps were accumulated from other sources, including maps by Abdullayev et. al [7]. By using the technique of estimating mean thickness from area and sediment volumes under area we arrive to best fit trend and then we point to most of the anomalies observed in a number of basins, most importantly South Caspian Basin. South Caspian Basin is unique in that it has much larger average and maximum average than others (13 km) and standing apart in any distributions.

Sedimentary and crustal thicknesses

Most of the World's sediment cover is in the sedimentary basins (and there are around more than 65000 of them), however there are also sediments on the oceanic crust. Sedimentary basins are regions of Earth of long-term subsidence creating accommodation space for infilling by sediments. The subsidence in the basins can result from crustal stretching, sedimentary, and tectonic loading, and changes in the thickness or density of adjacent lithosphere.

Sedimentary basins are where the products or erosion of the related reliefs accumulate. They create the possibility of quantifying the fluxes coming into the basins from the rivers. Some basins are not subjected to compressive deformation; others are not active. They are mostly located at the periphery of mountain ranges and collect detrital material eroded during the mountain building process. Basins can experience long periods of average stability and therefore carry very long sedimentary records. It is then possible to determine the volume that accumulated in these basins and therefore calculate mass fluxes resulting from erosion of a growing mountain range during its tectonic build-up. It should then be possible to place constraints on the mechanical processes taking place upstream in a basin drainage area.

Figure 1 shows sediment thickness map of the world taken from this compilation by Gabi Laske in UCSD [8]. The largest sedimentary sinks have an average of 15 to 20 km sedimentary thickness. They

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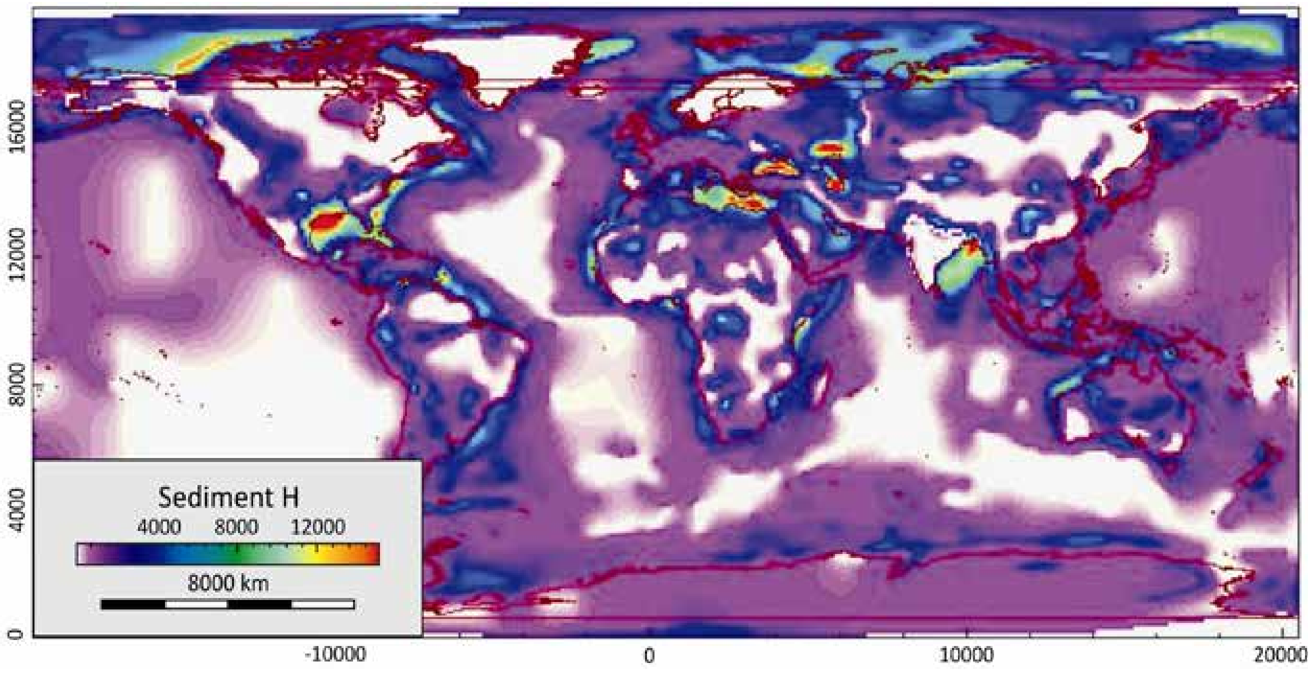

Fig.1. World's sedimentary thickness map

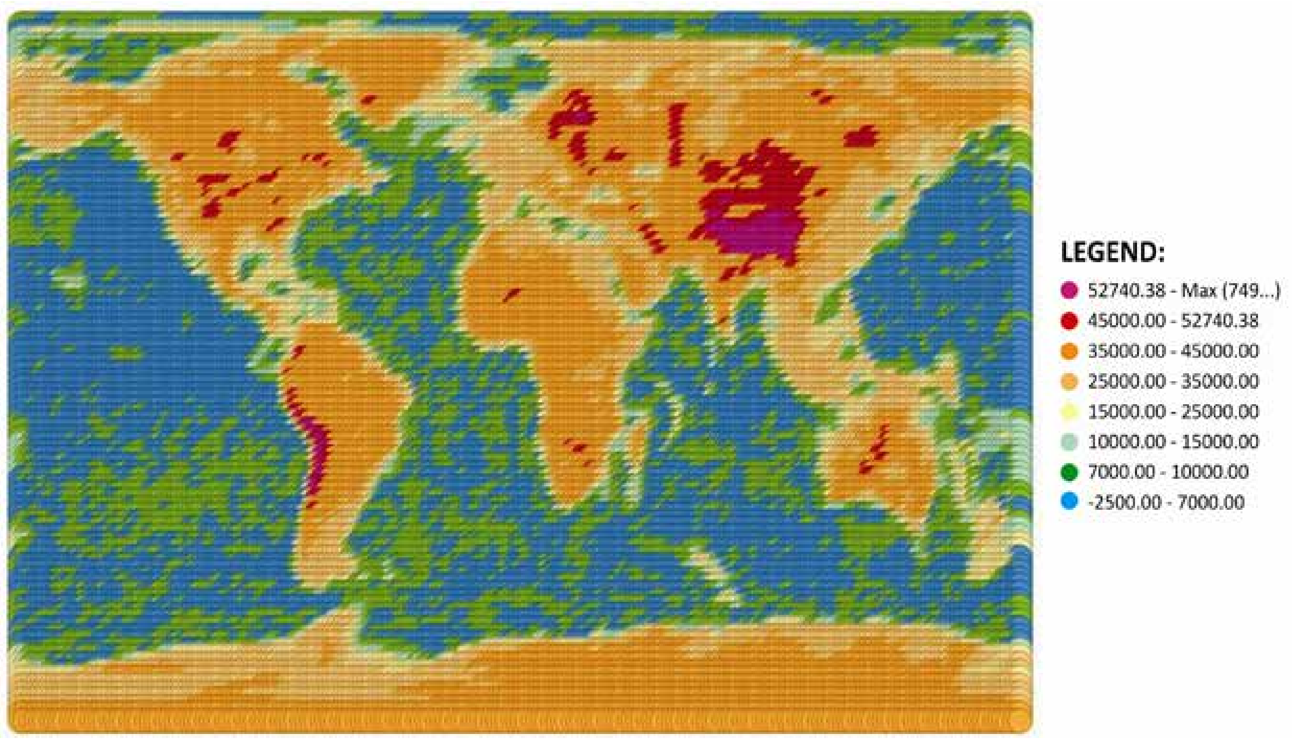

Fig.2. Crustal thickness (with sediment thickness excluded) in meters of the World's basins

are concentrated only in few areas. This includes South Caspian, Pre-Caspian, Mediterranean, Bengal Fan in Eurasia and Gulf of Mexico in America. There are also some Arctic basins. Except very unusual sedimentary thickness of Paleozoic Pre-Caspian Basin most of these sedimentary sinks are Cenozoic.

Crustal thickness across the world (fig. 2) on the continents is around 35 km on average; while for the oceans it is around 10 km (fig. 3a and b). Worldwide crustal thicknesses in the world can be shown on figure 3a to match a bimodal distribution where the oceanic crust sits at one end of the distribution (less than 10 km) and continental crust sits at another end with an equal occurrence. Thickest sedimentary sinks are mostly associated with regions above a continental crust, except few examples like South Caspian Basin, Black Sea, Gulf of Mexico which are located over attenuated oceanic-type crust.

Another interesting observation is that relationship between sedimentary thickness and crustal thickness can be described in a bell-shape of a Gaussian fit (fig. 3b). South Caspian sits on the upper end of this curve, together with Pre-Caspian Basin. These two basins are quite unique and stand apart from the trend, having an attenuated crust below thick sediment pile.

Earth's lithosphere includes the crust and the uppermost mantle, which constitute the hard and rigid outer layer of the Earth. Oceanic lithosphere is typically about 50-140 km thick (but beneath the mid-ocean ridges is no thicker than the crust), while continental lithosphere has a range in thickness from about 40 km to 240 km with an average of 150 km or so. Linear relationship exists between lithospheric thickness and crustal thickness for both oceanic and continental lithosphere as shown on figure 3c. Sedimentary basins with a thick cover are developed on continental lithosphere that ranges between 100 to 220 km in thickness.

The ratio of sedimentary thickness to non-sedimentary crustal thickness is mostly below 1.0 and exceeds 1.0 only in few basins. These basins are South Caspian, Pre-Caspian, Bengal Fan, Amazon Fan, West Black Sea, East Mediterranean, Gulf of Mexico and Canadian Beaufort Basins. Figure 4 shows the concentration of these basins most of these basins are in the margins of the continents, except of the Pre-Caspian (interior continental sag). South Caspian and Black Sea are unique in being basins with attenuated oceanic crust trapped between colliding continents.

Sediment volumes in basins of the world

We have measured close to 900 sedimentary basins in the world and identified the relationships between the basin sedimentary thickness, areas and sediment volumes in these basins (fig. 5). Most of sedimentary basins are located on passive, active or rifted margins of the continents and interior of the continents such as cratonic sags, aulacogens or failed rifts. Most of the sediments are located in Eurasia (almost 45%), followed by sediments in North America (25%), Africa, South America and Australia (Antarctica is excluded) (fig. 6). Most of sediments accumulated during Phanerozoic were in mudstones and almost equally distributed in Paleozoic, Mesozoic and Cenozoic (around 1/3 each). 16% of sediment volumes in the basin are of chemogenic nature (carbonates) and around 8% are sandstones. Large sediment sink of the World is associated with continental drainages and large mountain belts like Himalayas, that is why Eurasia predominates.

Ronov (1993) compared four estimates of the total global mass of sedimentary rocks obtained using different data and methods [1]. His estimate (113E+21 kg or 11.8+18 km^3) coincided within 5% to that of Southam and Hay (1981; 111.5E+21 kg) [2] and of Khain et al. (1982; 110.4E+21 kg) [9]. Only Kunin's (1987) estimate (97.0 x 1021 kg) [3], based on extrapolation of geophysical data on Eurasia to other continents differed from other estimates. Our estimates are within 70% of the Ronov's estimates for basins away oceans.

There is a clear relationship between volumes and area of basins; their correlations are well defined by a logarithmic regression function and can be shown on figure 5. These two functions (1) and (2) are shown below.

$$\text{(1)}\quad \text{Area}(X) \text{ and Volume } (X)/\log_{10}(y) = = 4.11 + (0.65 \cdot \log_{10}(x)\text{R2} = 0.75$$

$$\text{(2)}\quad \text{Mean Thickness}(Y) \text{ and Volume}(X)/Y = = 0.28 + ((43.54 - 0.28)/1.00 - 100.32 \cdot (18.55\text{-}\log_{10}(x)))$$

Best basins that follow the trends are Cenozoic-age passive margins. Basins that are mostly not following the trends are foreland basins. This is because foreland basins are most affected by flexure and experience tectonic shortening, whereas passive margins experience only tectonic subsidence and sediment loading.

South Caspian deviates significantly from all other basins in a correlation of mean thickness to sediment volume (figs. 5, 6). It shows that with an average thickness of 13 km and a maximum of 26 km SCB dominates all other sedimentary basins and does not fit equation (2) easily. The expected value of mean thickness for the sediment volume and the area is around 4 km if South Caspian was a passive margin. Most of this sediment pile accumulated in the last 4Ma in the Pliocene age Productive Series after a significant base-level fall [7]. This base level fall was a result of isolation of the South Caspian from Black Sea, evaporation of the water volume and integration of sediment drainage into the South Caspian Basin as a result. More than 4-5 km of sediments accumulated during a very short period of time. An anomalous subsidence of this kind is explained by sediment loading on unusually thin but dense crustal thickness below the basin as outlined by [7]. About 4km of sediments can be accounted for during is unusual episode bringing the Caspian closer to the trend fit. Furthermore, as there was a significant shortening resulting on subduction of the South Caspian Plate under the Absheron Ridge the SCB might have been geographically more extensive. We estimate that in order to make SCB consistent to the passive margin best fit trend on figure 6, the sediment thickness might be reduced by further 4 km and geographical area increased from 172,000 to around 400,000 (around 2 times). This might indicate a large geographical area of the SCB that has been underthrust below the Absheron Ridge and Caucasus and has not been consumed.

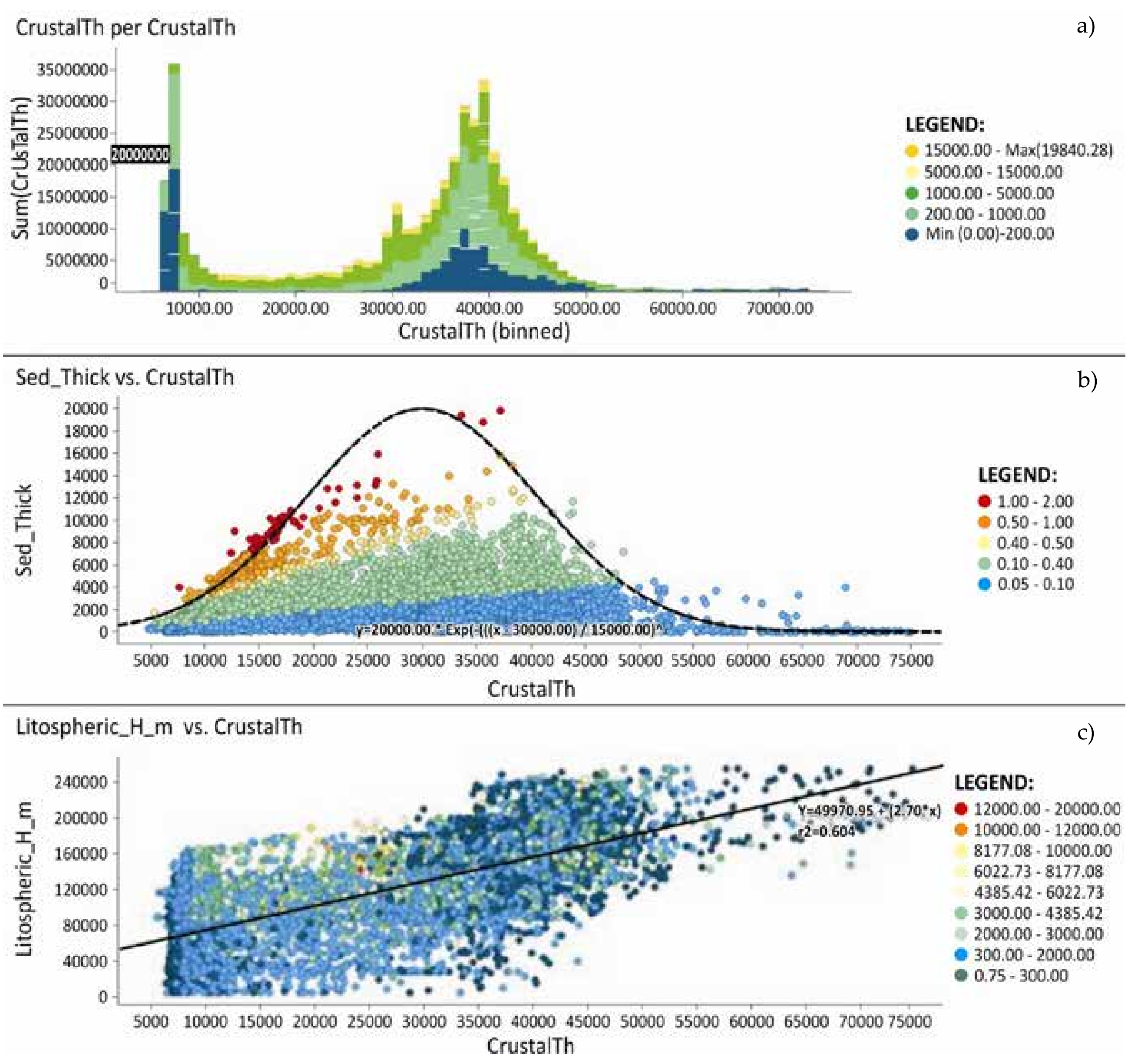

Fig.3. Sedimentary thickness and crustal thickness distributions: a) crustal thickness distribution graph; b) sediment thickness/crustal thickness ratio; c) Lithospheric thickness compared to crustal thickness

Conclusions

Earth's crust has volumetrically significant but variable sediment cover. This sediment cover (stratisphere) receives unequal contribution from different geological eras, periods and geographies. The sediment volumes come largely from passive margins or from continental interiors and are subject to relationships with areas and thicknesses of these basins. Most of the basins follow very obvious correlation patterns which is probably caused by similar basin formation of those evolution. This is especially evident with passive margin and rift basins. South Caspian Basin, however, is very unique amongst all basins in the world – it shows significant increase in its thickness compared to its rather small area. It is probably one of the most unusual examples of the oceanic crust overlain by a very thick sedimentary cover. This allows for anomalous basin subsidence caused by sediment loading as was shown by Abdullayev et al (2015) [7], which creates the basin shape we see today.

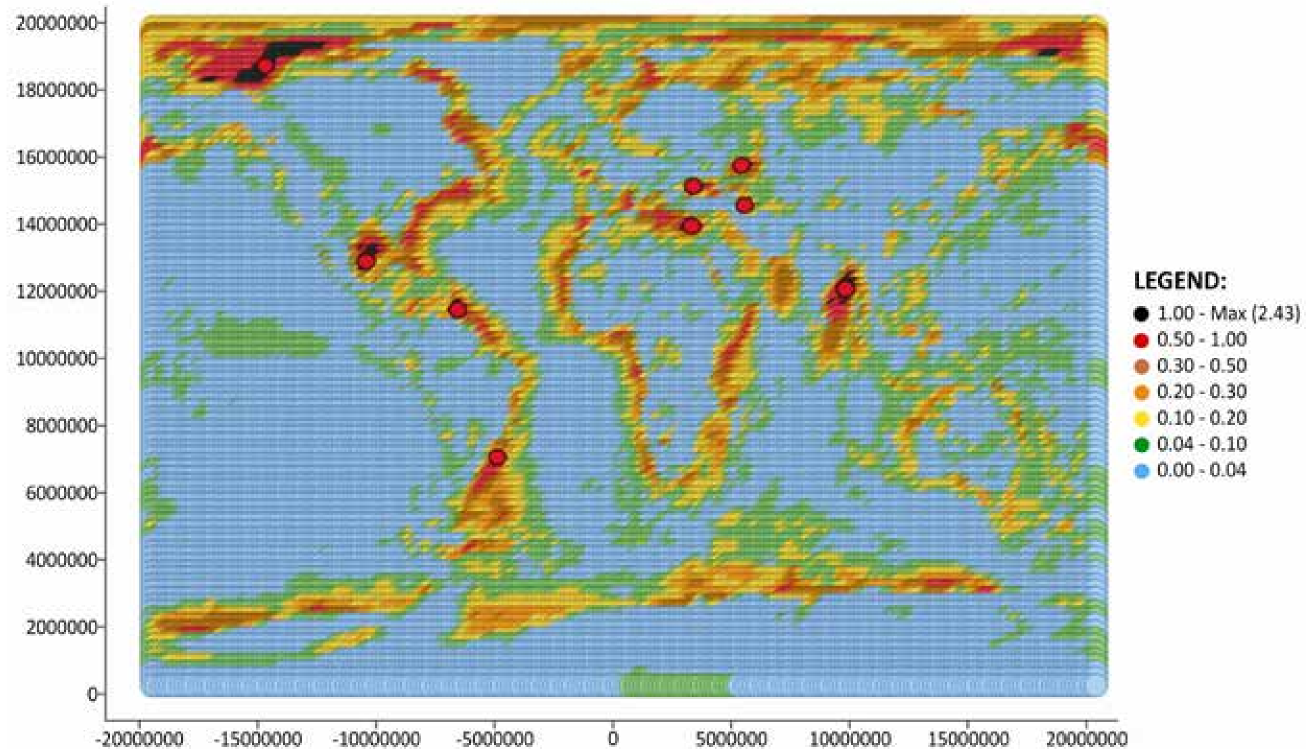

Fig.4. Ratio of sedimentary thickness to non-sedimentary crustal thickness. Regions of low ratio denote little sedimentation

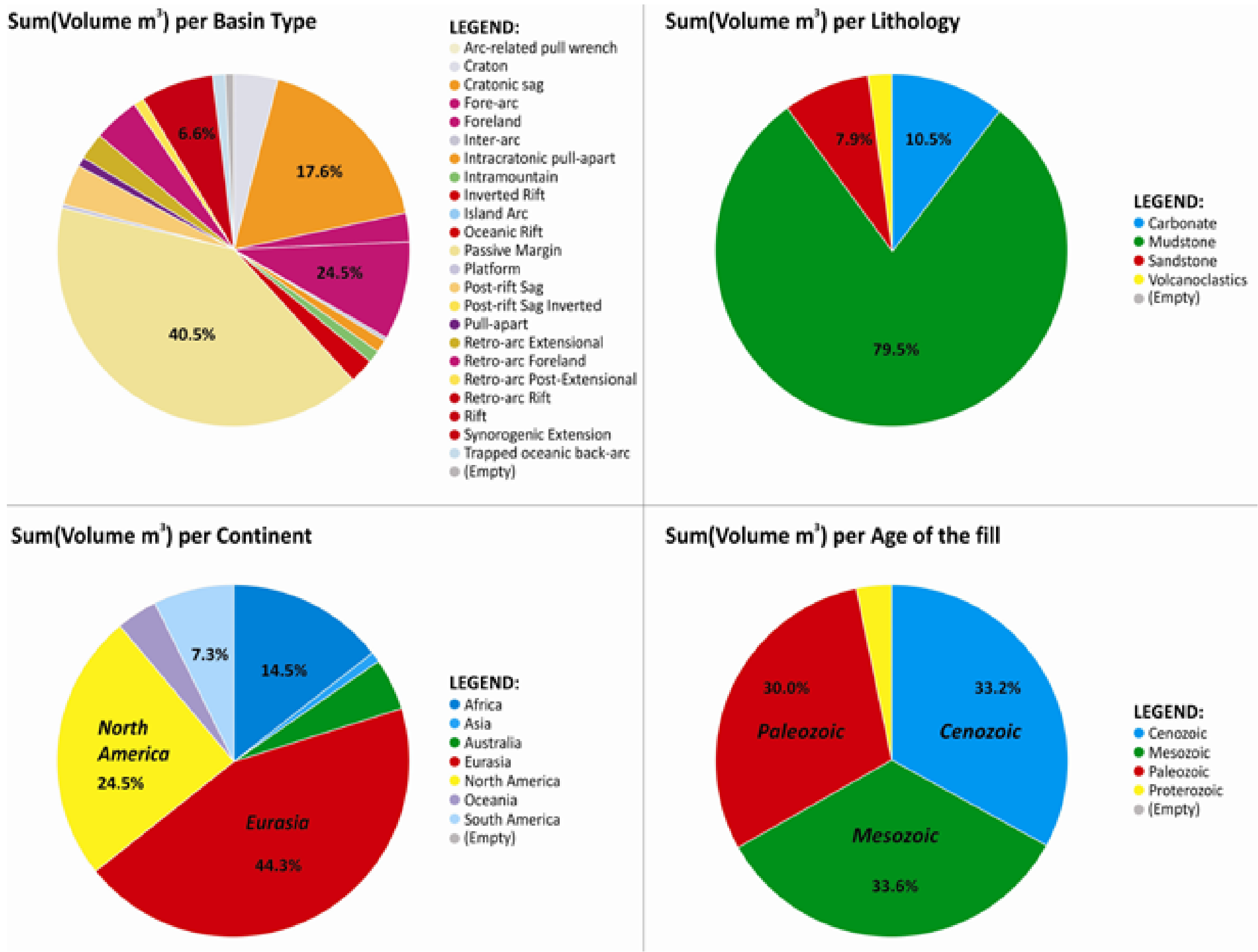

Fig.5. Pie charts of basin type, continents, era of the fill and lithology

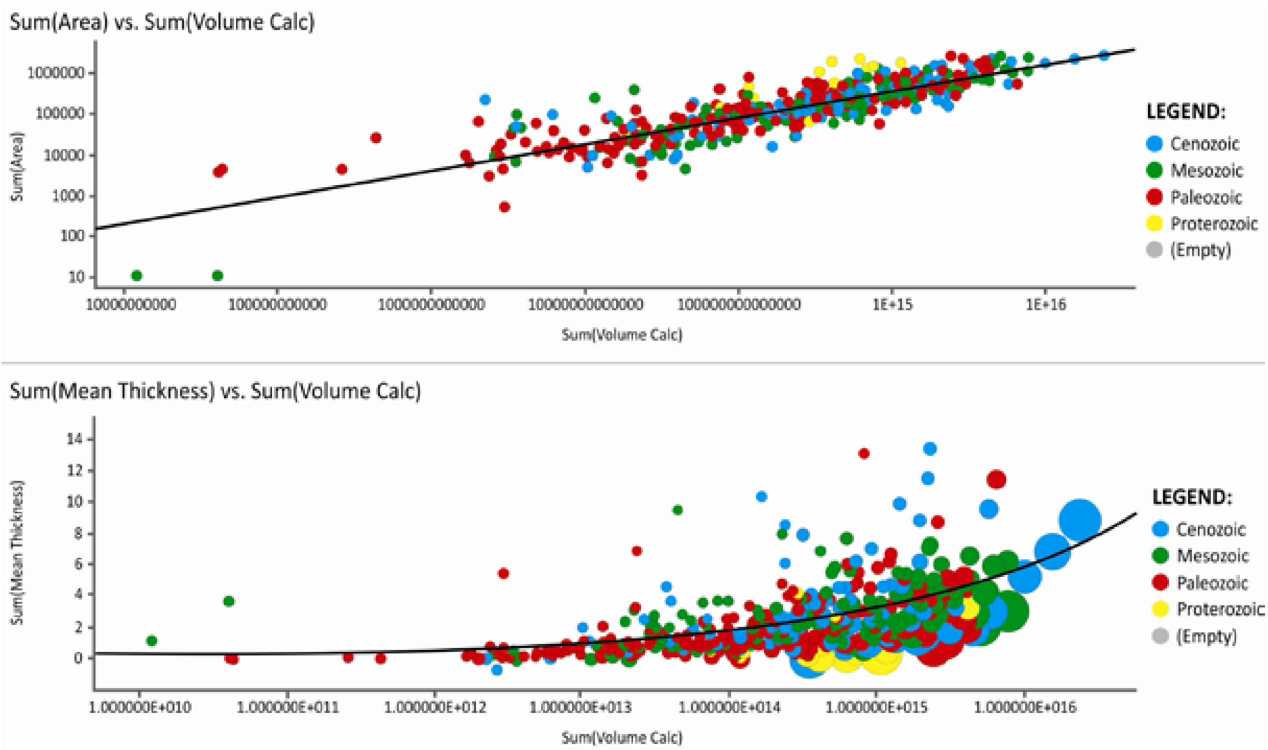

Fig.6. Worldwide basin trends – log/log trend area vs volume and average thickness vs volume (km^3)

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Объем и распределение пород в осадочных бассейнах - уникальность Южно-Каспийского бассейна

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Реферат

В статье дается краткий обзор осадочного слоя (стратисферы), оценка объема и массы осадочного чехла Земли. На основе имеющихся данных показана уникальная природа Южно-Каспийского бассейна и других быстро погружающихся бассейнов с большим количеством осадков и малой мощностью земной коры. В статье обсуждаются также взаимозависимости мощностей осадочных пород, коры и литосферы.

Ключевые слова: осадочные бассейны; Южно-Каспийский бассейн; объем осадков; литосфера.

Çöküntü hövzələrində süxurların həcmi və paylanması - Cənubi Xəzər hövzəsinin unikallığı

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Xülasə

Meqalədə Yerin çöküntü örtüyünün qısa təsviri verilmiş və çöküntü qatının (stratisferin) həcmi və kütləsi qiymətləndirilmişdir. Mövcud olan məlumatlar əsasında Cənubi Xəzər hövzəsinin və digər sürətlə gömülən böyük çöküntü həcminə və nazik yer təkinə malik olan hövzələrin unikal xarakteri göstərilmişdir. Məqalədə həmçinin çökmə süxurların, yer qabığının və litosferin qalınlıqları arasında olan asılılıqlar müzakirə edilmişdir.

Açar sözlər: çöküntü hövzələri; Cənubi Xəzər hövzəsi; çöküntülərin həcmi; litosfer.