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The Growth Rate of Salt Structures

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Masses of salt if they are of sufficient thickness and purity in the areas of tectonic activation experience plastic deformation to form the salt anticlines and diapirs. The growth rates of salt structures and mass transfer of salt per unit of time can be calculated for each of the salt-dome areas. In this paper, such calculations for the areas of recent activation such as the South-Western Hissar (Tien Shan) and the Afghan-Tajik Depression.

Key words: Salt formations, Salt-dome structures, Growth rates, Diapirs, Salt congelations.

The growth of salt structures is due to the interaction of several factors such as lithologic one (it is required a salt formation, and the stratum of rock salt should be sufficiently thick and clean at that, not "reinforced" with seams of insoluble formations); tectonic one (the manifestation of subsalt fractures and the shifts of block-benches of the subsalt substrate); and gravity ones (the presence of a strong covering mass of rocks, and the more contrast the overlying rock mass distribution, the more contrast the manifestation of salt tectonic generation). In the particular case, the gravitational contrast may be due to very deep linear erosional cuts. The combined effect of these factors leads to unusual effects as salt tectonics, indicated by the salt structures of various morphology and size. We have attempted to estimate the growth rate of them and the rate of "salt outing", a way of mobilizing the plastic material coming from the deep-lying horizons of sedimentary cover to the day surface on the example of the South-Eastern Turkmenistan and Tajikistan relating to the epi-platformal orogenic area. A large salt-dome region is allocated here, covering the southern part of the Turan plate, epi-platformal dislocations of the South-western Hissar and the Afghan-Tajik Depression. The occurrence of salt structures within this tectonically heterogeneous region is associated with the deformations of salt strata of Upper Jurassic age during the Alpine orogeny.

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METHODS

Since in many parts of the world the largest deposits of hydrocarbons, brimstone and other minerals are associated with the salt-dome structures, this fact determines the constant interest in the study of the mechanism of salt tectonics and peculiarities of its dynamics [Baikov A.A., 1981; Baikov A.A., 2004; Baikov A.A. and Sedletskii V.I., 2001; Belelovskii M.L., Sedletskii V.I. and Korobka V.S., 1971; Belenitskaia G.A., 1998]. In the Peri-Caspian Depression, the area of Golf Costa, the Northern German and the Dnieper-

Donets Depressions and other salt-dome regions of the world it is established an important pattern of the growth of salt structures consisting in the fact that the most intense climbs of salt cores occurred abruptly coinciding with the regional tectonic phases [Belenitskaia G.A., 2004, 2008; Boyko N.I., 1998; Vinsent S.J., 2013]. The South-western Hissar is an alpine mountain-folded structure, where along with the actual tectonic forms – the system of submeridional pronounced anticlines and synclines, forming a meganticline – there are developed salt folds of various types. They are also characteristic for the alpine Afghan-Tajik Depression. In connection with multiple shifts of Neogene period and their precise dating on the example of some folds of the South-western Hissar and the Afghan-Tajik Depression, it is possible to show the relationship in the time of fold-forming movements and direct salt tectonics and to calculate the growth rate of the salt core folds [Gavrilov V.P., 1990; Capet A., 2013; Holbouty M.G. and Hardin D.K., 1961].

The Main Body

The section of the South-western Hissar meganticline is divided into three structural stages. The ground stage covering rocks of Precambrian-Paleozoic age (Hercynian basement) comes to the day surface in the northern part of the nuclei folds of this meganticline. The middle stage is composed of three lithologic and stratigraphic complexes corresponding to the platform stage (Triassic-Oligocene), the subsalt one (siltstones, mudstones, sandstones, limestones, 1000-1400 m), the saliferous one (600-800 m) and above-salt one (mainly clay, siltstone and sandstone, 3000-3500 m). The saliferous complex is represented by anhydrites (160-420 m) and rock salt with layers of potassium salts (Kimmeridgian-Tithonian age). The thickness of salt rent reaches 410 m, but to the south and west, in the direction of immersion folded structures, it increases to 800 m and more. In 300-350 m above the base of the above-salt complex, the Lower Cretaceous strata of rock salt (up to 120 m) is locally distributed, but it does not form the independent forms of salt tectonics [Levorsen A., 1970; McBride C., 1998; Perrodon A., 1994; Richter-Bernburg G. and Schott B., 1961].

The Oligocene-Neogene-Quaternary terrigenous complex, corresponding to the upper structural stage, accumulated under conditions of sharp tectonic activation in the region, distributed in the deep synclines and along the periphery of the meganticline, where his thickness ranges from 2,000 to 3,000 m. The disarticulation of the complex on formations and strata, clarifying the nature of their occurence and age allowed in some cases to date the formation of the individual non-salt folds and structures that have arisen as a result of salt tectonic genesis [Richter-Bernburg G. and Schott B., 1961; Robin S. Pilcher and Raleign D., 1998; Rowan M., Ratiff R., Trudjill B. and Duart J., 2001; Sassen R., Sweet S.T., Milkov A.V. and others, 2001; Walliser O.H., 1995].

The submeridional folding of the recent history was imposed on the large sublatitudinal block-benches of the basement, which is much less pronounced in the sedimentary cover. However, during the platform stage of development the latitudinal tectonic zonation dominated, subject to the same orientation of Paleozoic morphostructures and faults. The location of the block-benches at various hypsometric levels relative to each other and their development under syn-depositional conditions defined regional characteristics in change of thickness of Mesozoic and Cenozoic sediments, including sulfate-halogen rocks. The block-benches joints on the sites of the regional diastrophisms, some of which are well expressed on the ground. Most of these faults can be traced within the Afghan-Tajik Depression. A very active salt tectonic genesis up to diapirs of the breached type is linked with some of them.

Processes and concrete manifestations of salt tectonics within the South-western Hissar meganticline described by many researchers, but the question of duration of the growth of salt structures virtually are not considered. For a long time it was believed that salt folds are very widely distributed. In particular, these include the Repetek group, with more than 11 salt anticlines and diapirs, the origin of which is explained by action of the gravitational factor. The authors of this hypothesis associated the rise of salt folds with very deep (up to 1000 m) Middle Pliocene erosion by the pre-Amu Darya of the above-salt rocks along the fault. The salt folds of the Repetek zone were formed by the beginning of the filling of erosional incision by alluvium of the Amu Darya.

The studies of recent decades found that salt tectonics here has a much smaller scale than anticipated before, and the salt structures out of alignment with the deformation of the subsalt complex are absent. The salt deposits are observed only in the structures associated with the major zones of Hercynian faults, which have experienced the latest activation.

The diapirs of this zone are represented as structures with a complex history of development. A very deep erosional incision of the pre-Amu Darya valley, which was arisen most likely at the beginning of the Middle Pliocene, was preceded by a sharp recovery of the fault associated with the tectonic shifts that covered vast areas of the Central Asia, including the South-western Hissar and the Afghan-Tajik Depression. At the same time base levels of the basins of rivers draining into the Caspian Sea changed very sharply. A chain of narrow anticlines occurred along the fault formed in sediments of the above-salt and subsalt complexes.

In the areas of the highest dynamic activity of the fault rock salt was transferred to a plastic state, and rushed up, having broken pre-Middle Pliocene complex of rocks of an anticline fold occurred into the fault zone. This is evidenced by a steep occurrence of the Cretaceous strata below the Middle Pliocene incision and on other salt structures of the Turan plate. By the beginning of filling of the erosional incision by sediments a gypsum cap rock has formed in the core of the diapir.

During Pliocene the growth of salt stocks did not occur. The breakthrough of poorly compacted sediments of Pliocene was accomplished at the edge of Neocene and Quaternary periods. Gypsum of the cap rock and lying on them Pliocene clays and silts were occured to breed to the day surface, and then almost completely covered with alluvium of the Amu Darya. Increase in salt stocks exceeded 600 m.

The above-mentioned data indicate that in the formation of diapirs were two distinct periods, pre-Middle Pliocene and post-Pliocene (pre-Middle Quaternary) ones. To determine the rate of growth of the salt core at each stage it is necessary to determine the height of the salt pillar corresponding to the actual growth phase structure and the duration of the process.

The growth of diapirs took place in two phases: during pre-upper Sarmatian and proper pre-Middle Pliocene ones. The maximum duration of these two phases (upper Sarmatian - Lower Pliocene, if we assume that the salt was pressed continuously) is about 7 million years. The minimal growth rate of a diapir was 3100 m: 7 million yrs = 440 mm / 1000 years. If we assume that the salt stock was formed for a single phase, pre-Middle Pliocene one, time of its growth is not more than 1 million years, and the growth rate, which in this case is maximal, reaches 3100 m : 1 million yrs = 3100 mm / 1000 years.

There are unique materials for calculation of the growth rate of salt structures on the Afghan-Tajik Depression. The structure of the sedimentary cover of the Depression is not fundamentally differed from the South-western Hissar meganticline. But within the Depression, except for its cutoff parts, complete sections of Upper Jurassic and Cretaceous sediments were not opened by drilling. Thickness of the above-salt layer is estimated as 4500-5000 m, of which only Cretaceous formations is of 2000 m.

Salt domes are located on the axis of linearly elongated in the north-eastern direction narrow anticlinal zones, usually accompanied by large faults. The morphological type of salt structures has the following specific features: high (several kilometers) and narrow salt stock cutting through the zone of faulting on the entire above-salt rock stratum; mushroom-shaped top of the salt massif outbred to the day surface, or located at a shallow depth; relatively small (tens of meters) thickness of the cap rock composed mainly of gypsum and anhydrite. Salt outputs form a positive form of the relief: the large dome-shaped, rounded in plan swells in the valley of the Yakhsu and Kyzylsu rivers. One of these swells is salt mountain Khojamumyn of 55 km^2 in area towering over the river valley at 880 m and 1334 m of absolute elevation. The dome of Hajasartis has relative elevation above the plain of about 400 m. As to the height of elevation of their salt stocks over a modern erosion surface, these domes are among the most significant ones in the world. The formation by salt massifs of larger positive landforms is observed in the salt-dome regions of Iran (Qu'n'Namak mountain) and the Dead Sea (Djebel Uzdum mountain).

A peculiar mushroom-shaped top of the

salt massifs arose due to the spreading of salt at its exit points to the surface. At that the thickness of produced salt cover can reach many hundreds of meters, and the distance from the edges to the centre of the salt stock is usually a few kilometers. The spread mass of salt overlay sediments of various ages: from Lower Quaternary to Paleogene. This allows calculating not only the growth rate of the salt diapir, but weight of rock salt supplied to the surface for a certain period of time (Table 1).

Table 1. Growth rates and salt masses of congelations in the salt structures of the South-Western Hissar and the Afgan-Tajik Depression

Parameters	Dongugsyrt	Aktar	Saiat	Hojamumyn
Thickness of the above-salt sediments, m	4000-4500	-	-	-
The height of salt stock, pre-Middle Pliocene, m	2800-3100	-	-	-
Duration of salt stock growth, pre-Middle Pliocene, million years	7 (or 1)	-	-	-
The growth rate of salt stock, pre-Middle Pliocene, mm/1000 yrs	444 (or 3100)	-	-	-
The height of salt stock, pre-Middle Pliocene, m	-	-	2000	4500-5000
Duration of salt stock growth (Middle Pliocene – Early Pleistocene) (?), million years	-	-	3.47	3.47
The growth rate of salt stock, Middle Pliocene – Early Pleistocene (?), mm/1000 yrs	-	-	600*a*($V_{min.}$)	1440($V_{min.}$)
The height of salt stock, pre-Middle Pleistocene, m	618(increase saltto the stock, pre-Middle Pliocene)	500-600	2000	4500-5000
Duration of salt stock growth, pre-Middle Pleistocene (Lower Pleistocene ?), million years	0.69 (?)	0.69 (?)	0.69 (?)	0.69 (?)
The growth rate of salt stock, pre-Middle Pleistocene, mm/1000 yrs	900	720-870	3000($V_{<0E}$)	7200($V_{<0E}$)
Salt weight of the cap, million tons	-	-	79320	26160
Duration of cap forming (Early Pleistocene ?), million years	-	-	0.69 (?)	0.69 (?)
Salt weight: tons/yr million tons /1000 yrs	-	-	115000115	3800038
The height of rise of the salt stock for 1000 yrs, mm	-	-	600*(min.)*	-
Increase of salt weight in the stock: tons/yr million tons/1000 yrs	-	-	62506.35	-
The height of rise of the salt stock for 1000 yrs, mm	-	-	300*(<0E.)*	-
Increase of salt weight in the stock:tons/yr million tons/1000 yrs	-	-	3125031.25	-

CONCLUSIONS

The presented calculations and obtained figures of the growth rates of salt stocks and salt bodies at the day surface can hardly be mechanically transplanted to salt structures of other regions without regard to their originality. Our findings are based on the geological features of the area of the most powerful Neogene-Quaternary activation, within of which salt tectonic genesis was limited to a narrow range of time: from the turn of Early-Middle Pliocene until the turn of Early-Middle Pleistocene. Approaching with caution to the available facts, we consider that the growth rates of salt stocks and salt masses entered the salt caps per time unit was underestimated. This should be taken into account in further research in this area and comparison of the results. The most impartial figures should be recognized those of the growth rates of salt stocks, increase of which occurred in pre-Pleistocene time at the Donguzsyrt diapir and the Aktag structure. They were, respectively, 900 mm / 1000 years and 720-870 mm / 1000 years, i.e. they were almost equal. The growth rate of salt stocks of the Middle Pliocene – Early Pleistocene activation may vary, according to our calculations, from 600-1440 to 3000-7200 mm / 1000 years and more.

In fact, the accepted technique gives the lower limit of the growth rate of salt structures and salt masses coming to the surface per time unit. As described phenomena are discrete in nature, the upper limit of the growth rate remains unknown. To define it, it requires different approaches.

The supply of huge masses of easely soluble salts to the day surface (38-115 million tons/ 1000 years) can not but affect the sedimentation processes in the salt-dome regions even of arid climate, where insufficient moisture prevents the massive dissolution of salts. However, until now researchers do not pay attention this to opportunity.

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