REPORT of researches of 2018
“Orogenesis of Alpine-Himalayan Folded Belt on the base of the researches of Crimean Mountain/Orogen System: geological history and reconstruction of hydrodynamic conditions”

INTRODUCTION

Reconstruction of the geological history of the Earth is possible based on research of orogeneses which determine relief of the surface, sequence of successive facies and distribution of the fauna in the deposits of the orogen system and surrounding area. Planetary character of the orogeneses indicates global character of the forces producing the orogeneses. Movements of the water masses initiated by tectonic activity result to erosion, transport and sedimentation of the sediments. Research of the present-day geomorphology of the orogen systems, reconstruction of the paleorelief, research of the erosive structures and corresponding sediments, and reconstruction of paleohydraulic conditions allows revealing of the history of the developing of the regions.

Crimean-Caucasus Orogen System is part of Alpine-Himalayan Folded Belt (AHFB) extended over thousands of kilometers from South-East Asia to the Pyrenees in the West Europe. Based on the published articles and monographs, also as on own previous researches (Upper Jurassic conglomerates, flysch sequence, carbonate deposits) it is possible to make detail paleohydraulic reconstruction and refoundation of the geological history of Crimean Orogenesis, surrounding Black Sea territories and AHFB as a whole.

The widest extended is orogenesis of Alpine fold and mountain-building Epoch. It is well displayed in Alpine-Himalayan and the Cordilleran-Ands Highlands, Siberia (Trans-Baikalian region), northeastern Eurasia (Chukot) and Urals Mountain System. In 2018 small but very informative part of AHFB – Crimean peninsula was studied.

Crimean Orogen has key position in geological structure of south-eastern Europe and north-western Middle East. Characteristics of studied region as a part of AHFB reflect geological processes which had place in whole Belt. The orogen system is well-displayed and accessible for investigation. It is possible to use results of numerous previous geological researches and to make field investigations for reconstruction of the paleofacial and hydrodynamic conditions during the orogenesis.

1. GEOLOGICAL STRUCTURE OF CRIMEAN OROGENE SYSTEM AND SURROUNDING AREA

Crimean orogen has several structural floors (fig.1):

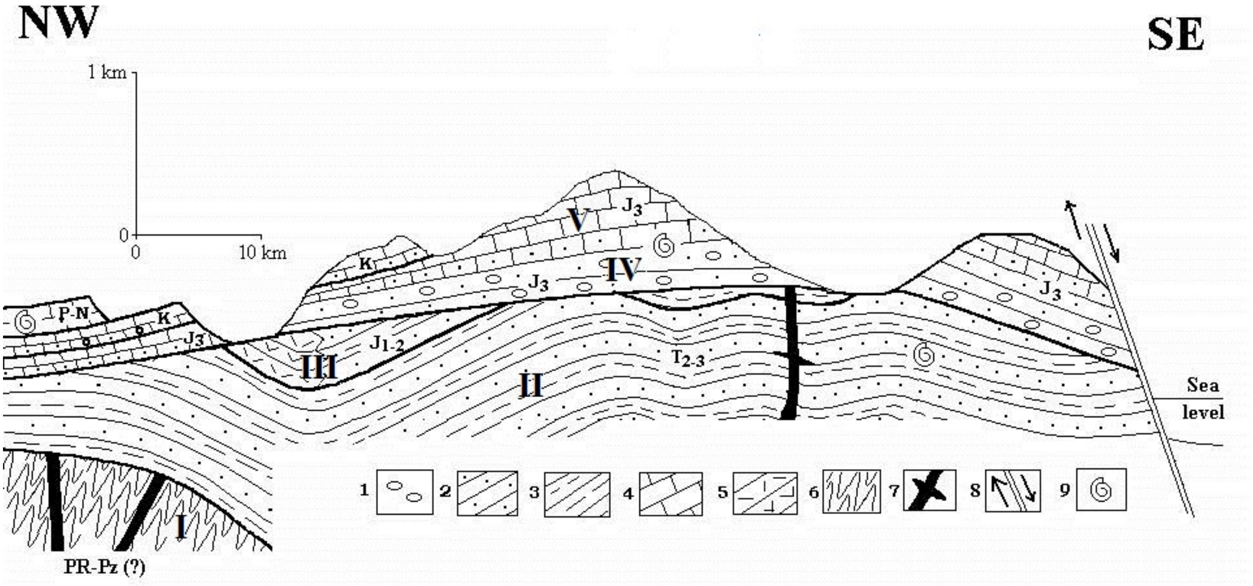

Fig.1. Schematic cross-section of Crimea anticline. Legend: 1. Conglomerate, 2. Sandstone, 3. Shale, 4. Limestone, 5. Volcanic rocks, 6. Metamorphosed shales and limestones, 7. Diabase dikes, 8. Fault and direction of the block movement, 9. Fossils.
Structural floors: I. PR-Pz(?): Proterozoic (?) and Paleozoic strata; II – T_{2-3}: Tavrick Formation; III – J_{1-2}: Eskiordian Formation; IV – J_3: Upper Jurassic conglomerates and sandstones; V – Cretaceous, Paleogene and Neogene carbonate sequence.

I. Metamorphic basement that consists of Paleozoic (partly Pre-Cambrian ?) terrigeneous-carbonate sequence with volcanic rocks and small intrusions of which had been folded in apparently in Hyrcinian Fold Event. This deposit is available northern from Crimea mountains in the area of steppe Crimea by drilling only.

II. Middle-Upper Triassic Tavrick Formation. Intensively folded, faulted and moderate metamorphed flysch deposits (alteration of the layers of sandstones, siltstones and shales) of Tavrick Formation. Researchers estimate total thickness of the Formation more than 2.5–4.0 km (Logvinenko and Karpova, 1961). Whole thickness is unknown: deepest drilling whole of 2250 m near the Yalta did not cross the lower border of Tavrick Formation. Upper surface of the formation is eroded.

The Flysch Formation is deformed by folding into a series of synclines and anticlines. The amplitude of folding ranges from several meters to kilometers. Small folds occur as a result of the slumping of unconsolidated deposits, whereas large ones are associated with large-scale tectonic movements, accompanied by faulting and intrusion of igneous dikes.

Fig.2. Flysch sequence of Tavrick Formation .

The flysch formation has many interesting sedimentary features, such as dragging grooves, erosion grooves, cross beds and trace fossils, which aid interpretation of its origin.

Fig.3. Dragging grooves on the surface of the sandstones.

Dragging grooves (or their casts) formed from dragging trees or stones over the sediment-water interface by the current (Figure 3). These have widths between 1 and 2 cm, lengths between 50 and 100 cm, and penetration into the rock between 0.5 and 1 cm. These marks are evidence of deposition of stratified sediments under conditions of high current velocity. Preservation of these marks is also evidence of rapid burial.

Fig.4. Erosion grooves indicate high velocity of the bottom currents.

Erosion groove has been defined as “a sedimentary structure formed by closely spaced lines of straight-sided scour marks. The scouring may be initially concentrated by a pre-existing groove.” These structures (or their casts) are common on the surface of the sandstone and siltstone beds (Figure 4). They reach 10–20 cm in width, 50–100 cm in length, and 5–10 cm penetration into the rock. Another evidence of vigorous erosion is the absence of part of the upper (shale) beds in the flysch sequence in the older normal flysch member. The presence of erosion grooves strongly suggests that these strata were deposited under conditions of vigorous water current.

III. Terrigeneous-volcanogenic sequence with laccolites and small intrusive dykes (*Eskiordinian Formation*). Terrigeneous member has flysch-like character. This sequence is distributed locally; it associates with depressions and faults of underlying flysch deposits. Usually it has erosion surface with underlying flysch sequence but sometimes it has concordant continuous changing, so the interrupt of sedimentation had local character, therefore some researchers join Tavrick and Eskiordinian Formation in one Tavrick series. Thickness reaches 400–600 m.

The volcano structure Kara-Dag is known in the east part of Crimean mountains. Several volcano-igneous bodies (the most well-known is Aiu-Dag - Bear Mountain) and numerous volcanic dykes locates in mountain part and south coast.

Fig.5. Laccolite Aiu-Dag on the south coast of Crimea.

One more significant feature of the Eskiordian Formation is presence of large and giant (from few tens to hundred meters long) exotic blocks of Paleozouc carbonate rocks mainly on the northern slope of Crimean Ridge.

Fig.6 Giant exotic block of limestone (dated as Carboniferous) in Lower Jurassic Eskiordinian Formation.

IV. Formation of Upper Jurassic conglomerates and sandstones (UJCS), overlying floors 2 and 3 with erosion surface and angular unconformity. The formation was studied in detail, result were published in Lithology and Mineral Resources in 2007 (Lalomov, 2007). Everywhere it has intensively eroded contact with underlying formations. The conglomerate contains pebbles and boulders of Pre-Cambrian granite which apparently were transported from Ukrainian 400 km to the north (Geologiya …, 1969). Cross-bed series also indicates that the flows had north-northeastern to south-southwestern direction. The Formation has lenses structure: the most thick conglomerate sequence of 850 m on the distance of 5-10 km laterally changes to limestones. Deposition of the Formation is concerning with series of the troughs (channels) of 10-20 km width. Largest boulders reach 0.8 m in diameter.

In the upper part of the Formation the sediments became finer: the conglomerate change by small pebble with sand matrix and sandstones. Upper border of the Formation is not obvious: the coarse sediments have gradual transition into carbonate sandstones, marls and limestones.

Fig.7. Upper Jurassic conglomerate and sandstone on the southern slope of Demerji mount.

Fig.8. Pebble of the granite, apparently transported from Ukrainian Shield.

V. The upper structural floor of Crimea Orogen is carbonate sequence which consists of the reef buildings in the lower part of the Formation and stratified carbonate layers in the upper part which are inclined in the mountain area and sub-horizontal in the surrounding plains. The limestones have abundant organic fossils.

Fig. 8. Upper Jurassic – Cretaceous reef buildings up to 500 m thick (Sokol Mount, Novy Svet Bay).

Structure of Crimean sequence, constitution and textures of the deposits, distribution and transporting evidences of fossils allows carrying out detail paleofacial and paleohydraulic reconstruction of the history of the Crimean peninsula.

2. INTERPRETATION OF THE GEOLGICAL PROCESSES OF FORMATION OF CRIMEAN OROGENE STRUCTURE

Studied geological structure and lithological constitution of Crimean mountain system allow determination of the geological history and interpretation of the processes of the region.

It is possible distinguishing four phases of development of the Crimean orogenesis (do not taking into account formation of Hyrcinian basement of the orogenic system).

A. Formation of the flysch sequence in the trough depression of the basement (stage A, fig.10). There are few points of view on formation of the flysch which is typical component of orogenic systems. Initially geologists believe that such sequence is the result of successive deposition of the layers of the sandstone-siltstone-shale cycle in conditions of oscillatory tectonic movements of the land around the sedimentary basin: rising of the land result to deposition of sand, in the time of stagnation the shale layers are formed. Later the flysch deposits began connected with avalanche-like mudflows which periodically drop the coastal sediments to the lower part of continental slope and abyssal plain through the system of submarine canyons (Potter and Pettijohn, 1963).

The third point of view is that such stratified deposits form as result of separation of the heterogranular sand-silt mixes in conditions of lateral water current (Julien et al., 1998; Berthault, 2002). In this case the sequence forms both in vertical and lateral directions simultaneously. Research of the internal structures of the natural flysch layers and comparison with experimental data indicates that flysch layers were formed in the current conditions according to the model proposed by P. Julien and G. Berthault.

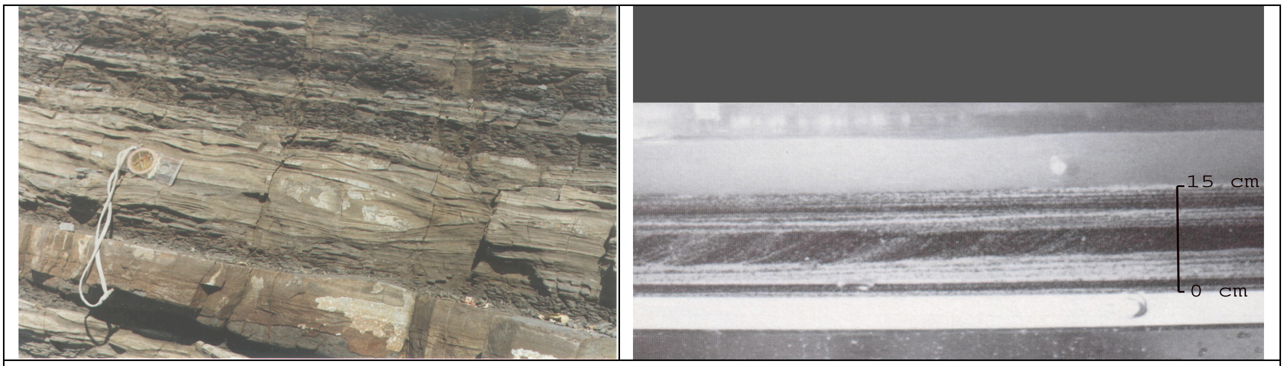

Fig.9. Internal structures of the flysch layers of Crimea and structure of experimental deposits in the flume as result of separation and eposition of heterogranular sand-silt mix in condition of water current (Berthault, 2002).

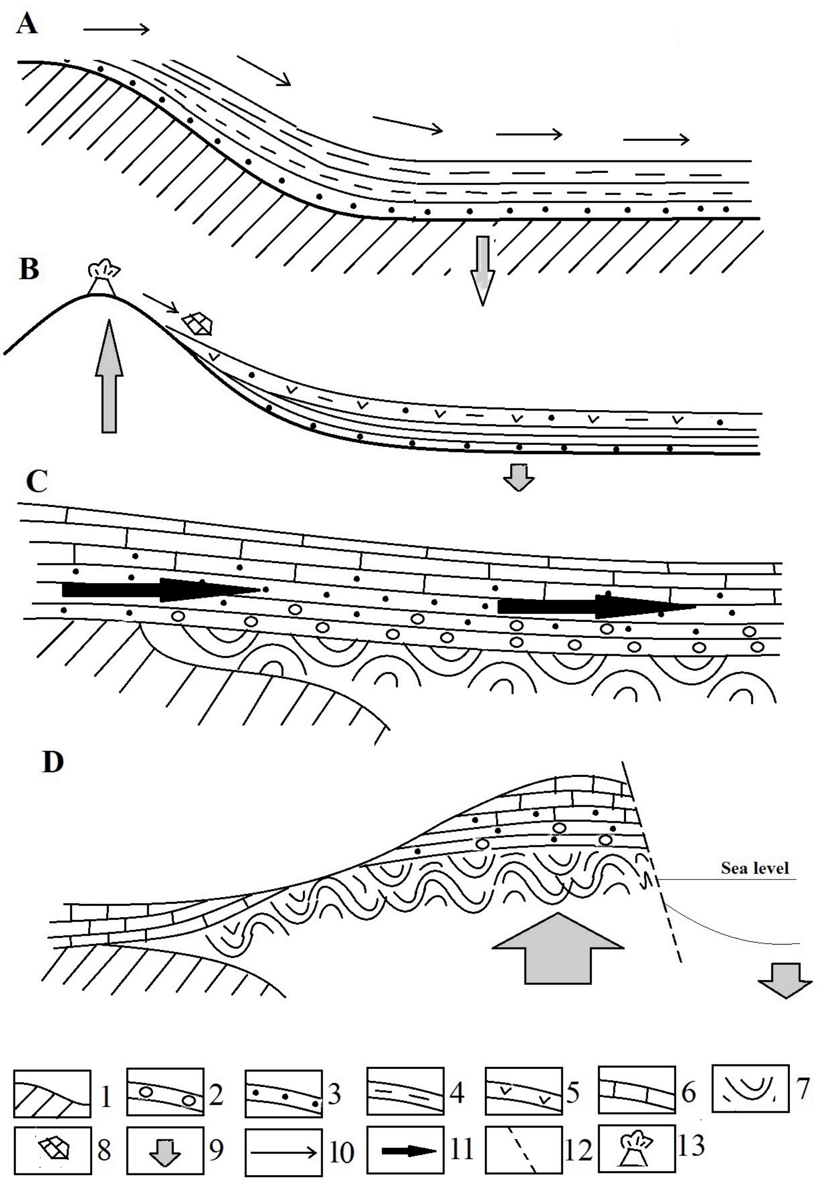

Fig.10. Stages of development of the Crimean Orogen System.

1 – Paleozoic-Precambrian highly metamorphic basement; 2 – conglomerate; 3 – sandstone; 4 – siltstone and shales; 5 – volcanic rocks; 6 – carbonates (marl and limestone); 7 – intensively folded flysch; 8 – exotic blocks of Paleozoic carbonates; 9 – tectonic movements; 10 – direction of currents; 11 – direction of mudflows; 12 – faults; 13 – volcanoes.

A – deposition of flysch in the trough of Paleozoic-Precambrian basement;

B – deposition of Eskiorian sedimentary-volcanogenic Formation with giant exotic blocks; with followed tectonic folding of the strata;

C – erosion of folded Tavrick-Eskiordian complex by catastrophic flow and deposition of Upper Jurassic conglomerates and sandstones; followed decreasing of hydrodynamic activity with deposition of sand-marl-limestone Formation;

D – mountain-building rising of the Crimean mountains and formation of the Black Sea depression bordering by the system of sub-vertical faults.

The mudflow model of turbidity formation by Kuenen (1950) supposes very fast sedimentation of the turbidity cycle (sand-silt-clay) with very long (thousands years) interrupts between sedimentary events. In this case, upper surface of the cycle should have numerous trace fossils of bottom marine organisms. In reality, we see a few short traces of the fossil movement that indicates short interrupts between sedimentation of successive cycles (fig.11).

Fig.11. Short fossil traces on the surface of the upper layer of the turbidity cycle.

2. Sedimentary-volcanogenic stage and tectonic event

The next stage (Eskiordian) was significant by appearance of the volcanic activity (stage B, fig.10), contrast relief and intensive tectonic impact on the Tavrick-Eskiordian sequence.

The volcanic structures are known on the border parts of the sedimentary trough. Giant exotic carbonate blocks dated as Paleozoic are observed mainly near the north border. Apparently, positive tectonic movements on the flank area of the trough result to appearance of steep slopes. The Paleozoic rocks of the basement formed the coastal land which was intensively eroded, and the blocks of the consolidated limestones had downward sliding into Eskiordian basin.

The stage was completed by intensive tectonic folding and faulting of the Tavrick and Eskiordian layers. Character of folds also reveals information about the geological history of the FF. Detailed observation of small folds indicates that there was not a long period of time between deposition and folding. During folding, it appears that sedimentary beds were soft and plastic; therefore deposition of strata and folding probably occurred within a short time of each other, not over a long geological period (fig. 12).

Figure 12. Small folds indicating plastic consistence of the layers during the deformation.

Well-known Russian sedimentologist Prof. Nicolas Logvinenko wrote about the conditions of deposition of the Tavrick-Eskiordian Formations:

"*The presence of dragging grooves with lengths more than 50–100 cm, widths 1–2 cm, depths 0.5–1 cm and erosion grooves with lengths up to 50 cm, widths 10–15 cm and depths up to 5 cm, often S-shaped, bear witness to high-velocity, turbulent currents*" (Logvinenko, 1961, here and below translated from Russian by A. Lalomov).

"*The preservation of mechanically generated textures such as erosion grooves and ripple marks is evidence of considerable rate of sedimentation*" (Logvinenko and Karpova, 1961, p. 27).

"*Invariability of the mineral associations is evidence of a single and complex source of detritus for all of the Crimean peninsula and adjacent territories during flysch deposition*" (Logvinenko and Karpova, 1961, p. 134).

"*The S-shaped form of sills with thickness up to 10 m is evidence of a pre-fold age of intrusives. Penetration of these sills into non-solidified sediments has been confirmed by the inviolate character of contacts and alteration of plagioclase near the contacts by steam*" (Logvinenko and Karpova, 1961, p. 199).

“*Sedimentation occurred under conditions of high hydrodynamic activity and instability of the sediment… Conditions for the existence of marine organisms were unfavorable*” (Logvinenko and Karpova, 1961, p. 258).

“*The amount of arriving detritus was tremendous: there was much mud not only near the shoreline, but also very far from the coast… The black color of the flysch rocks is evidence of a large amount of plant detritus and organic material arriving into the sedimentary basin*” (Logvinenko and Karpova, 1961, p. 260).

Thus, high-energy hydrodynamic conditions during deposition of the flysch formation, very intensive rate of sedimentation, short intervals between sedimentary episodes and followed intrusion of dykes, also as folded process are confirmed by present researches and previously published investigations.

3. Upper Jurassic intensive hydrodynamic event

The Upper Jurassic stage began with intensive hydrodynamic event which eroded folded Tavrich-Eskiordian strata and deposited series of conglomerate above the erosion surface (stage C, fig.10). Detail description of the strata and interpretation of the event is possible to see in the article “Lalomov A.V. Reconstruction of paleohydrodynamic conditions during the formation of Upper Jurassic Conglomerates of the Crimean Peninsula // Lithology and Mineral Resources, 2007, Vol. 42, No. 3, pp. 268–280”.

It is necessary to note that main part of the conglomerate consists of local underlying sandstone. It is evidence that before erosion episode the sandstones underwent metamorphism after that the sandstones became much more solid up to quartzite. Apparently, folding process was associated with significant pressure and thermal flow from the dip that result to quartzitisation of the sandstones. On the other hand, the surface below the conglomerate has evidence of mechanic erosion only, without long interrupt of sedimentation, paleosoils and weathering crusts.

The flow has various rheological characteristics: while in the beginning of the erosion event the medium has a character of debris flow, middle and upper members have features of aquatic transportation by dragging and in suspension. Velocity of the current decreases gradually from 7 – 9 m/s for lower member to 5 – 6.5 for upper member of the conglomerate formation.

Followed (Cretaceous, Paleogene and Neogene) carbonate sequence (sandy limestone, marl and organic limestone) overlie the conglomerate concordantly with gradual transition and local erosion surfaces within the sequence. Thus, final sedimentation episode began with high hydrodynamic energy event (erosion and deposition of the conglomerate), after that the velocity gradually decreases to calm water basin.

The final geological event was tectonic rising (assigned to the Miocene-Pliocene) and forming of the mountain system with present-day relief (stage D, fig. 10). Very significant feature of Crimean relief is inconsistency between the scale of the valleys (kilometers in width and hundreds meters of depth) and small water discharge of the streams: from few cubic meters per second per 1 m width in short spring flood period to approximately zero in the end of summer and autumn. Apparently, the valleys is result not of present-day streams erosion ability, but were formed in conditions of the flows much more powerful than present-day springs and small rivers. Erosion resistance of solid limestone and dolomiteis very large: the flow of 20-25 m/s did not erode the samples of soli rocks; some erosion was observer for semi-solid rocks (Berthault et al., 2010), so addition factor of fast erosion could be concerning with soft non-lithified condition of the carbonate rocks of Crimea Mountains during stage D.

3. DETERNINATION OF HYDRAULIC CONDITIONS OF THE CRIMEAN SEDIMENTARY BASINS

Two main sedimentary episodes can be determined for Crimea Orogenesis: (1) deposition of Tavrich-Eskiordian formation and (2) conglomerate-sandstone-carbonate sequence. It is possible to estimate intensity of hydrodynamic processes for these stages.

(1) The presence of erosion grooves in flysch sequence strongly suggests that these strata were deposited under conditions of significant water current. These marks also enable researchers to determine the direction and velocity of the paleocurrent. Erosion grooves demonstrate that the paleocurrent velocity exceeded the initial erosion threshold for clay particles (Potter and Pettijohn, 1963). Erosion grooves are commonly formed on the sediment surface during brief bursts of abrasion under fastflowing water conditions (Allen, 1984). Thus, it is possible to estimate the paleocurrent velocity from the Hjulström diagram (Hjulström, 1935). For clay particles the paleocurrent velocity probably exceeded 1.0 m/s.

The cross beds are generated as a result of the sand moving as waves. The thickness of the cross beds is up to 0.8 m. Because erosion has removed the top of each sand wave, the true height of each sand wave could have been double the present cross bed thickness (Austin, 1994, p. 34). Inasmuch as the sand-wave height is approximately one-fifth of the water depth (Austin, 1994, p. 34), the depth of the sedimentary basin that timemay be estimated as not more than 10 m. Using the Rubin and McCulloch diagram (Rubin and McCulloch, 1980, p. 214), the velocity of the paleocurrent may be estimated between 0.8–1.2 m/s. Such velocities are observed now in mountain rivers (such as Colorado) or in conditions of intensive bottom currents of the oceans.

(2) Hydraulic parameters of the Upper Jurassic basin during conglomerate-sandstone sedimentation episode were described in detail in the article (Lalomov, 2007). That research indicated that velocity of the flow changed from 7.1–9.3 m/s in during deposition of the Lower Member (conglomerate) to 5.1–6.4 m/s in the Upper Member (pebble sandstone). At the same time specific discharge of debris vary from 11–22 m^2/s to 0.4–1.7 m^2/s. Comparison of the calculated hydrodynamic parameters of paleoflows involved in the Formation with the cited data of natural observations shows that velocity and specific discharge of debris in paleoflows are significantly higher than those in recent mountainous alluvial channels and are compatible with the recorded recent catastrophic mudflows. For the Upper Member of the sequence mainly represented by sandsized sediments, the minimum flow parameters are close to those for recent mountainous rivers. Followed carbonate sequence was deposited in conditions of shallow sea similar to present-day tropical marine basins. Estimated duration of deposition is not more than 40 years.

4. CONCLUSIONS

Thus, geology of Crimea Orogen provides information about several geological episodes:

- deposition of flysch sequence in conditions of unidirectional water flow of approximately 1-1.2 m/s speed. Whereas sedimentation of the flysch cycles was very fast (from days and months to a year), and the interrupts of sedimentation between two flysch cycles was correlated with duration of sedimentation. As the flysch sequence has approximately 2500–4000 cycles, total duration of deposition can be estimated as 2500-4000 years;

- volcanic and tectonic activity that result to formation volcanic-sedimentary sequence, sliding down of exotic carbonate blocks from rising surrounding mountains;

- tectonic compression of the basin sediments with forming of folding and faulting structures, intrusion of dykes and laccolites;

- catastrophic hydrodynamic event resulting to erosion of folding strata and deposition of boulder conglomerates above the erosion surface; followed decreasing of hydrodynamic activity with deposition of pebble, sand and carbonate; total duration of sedimentation of the Conglomerate and Sandstone Formation is calculated as 10–40 years. At the same time, growth of the reef buildings which reach 500-800 m height, was certainly long: taking into account registered present-day velocity of the reef growth 1-3 cm/year, duration of the reef formation was not less than 20000 years;

- tectonic rising of the complex with forming of the present-day relief.

Thus, it is possible distinguishing of the episodes of different intensity and duration of the geological objects formation: the periods of fast geological events sometimes alternated with relatively slowly moving processes.

But, in any case, both “fast” and “slowly” events occupied the time interval that are many times less than periods assigned with conventional geological time-scale. The difference varies from 0.0002% for conglomerates and 0.01% for flysch to 0.1% for reefs.

Thus, this research provides the reason for the revision of conventional geological time-scale, but the uniform compression of the scale is not applicable. For each geological object and time interval it is necessary to find the coefficients of proportionality.

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