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The Structure and Formation Conditions of the Upper Jurassic Succession in the Area of Mount Pakhkal-Kaya (Crimea)

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Abstract—It has been found that the section in Mount Pakhkal-Kaya consists of three structural units separated by almost bedding-plane faults presumably arranged in a normal stratigraphic succession: conglomerate succession (I, ?J_3ox (Oxfordian)), carbonate succession (II, ?J_3km(Kimmeridgian)–tt(Tithonian)), and a conglomerate-breccia unit) (III, J_3km-tt). Each of these successions corresponds to a certain stage of basin evolution, viz., formation of a Gilbert-type delta and the accumulation of a carbonate platform rimmed with a shoal and destruction of the platform margin during its periodic exposures.

Key words: Upper Jurassic, carbonate platform, sedimentology, microfacies, Crimea, Pakhkal-Kaya.

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INTRODUCTION

Mount Pakhkal-Kaya is located in the central part of the First Range of Mountainous

Crimea, 2 km west of the summit of Mount North Demerdzhi (Fig. 1). This mount is often visited by geologists and its structure is often a subject of acute geological debates [Mileev and Baraboshkin, 1999] and, therefore, the purpose of the present publication is refining its structure and the formation conditions of sedimentary units participating in them. Baraboshkin visited this area in 1996 and 2007, but V.K. Piskunov and S.V. Rud'ko examined the area in detail in 2008. They examined structural relations between successions; they constructed sedimentary columns in five sections on different slopes of the mountain, and collected 150 specimens. Microfacies analysis of 120 thin sections of carbonate rocks and their interpretation using Fluegel's techniques was the main purpose of their studies [Fluegel, 2004]. Piskunov examined the thin sections and both authors interpreted the results jointly.

RESULTS

Structural Relations

Structural units separated in Mount Pakhkal-Kaya by bedding-plane faults (Fig. 1) consist of the following rocks (up the section): I, conglomerate succession (dipping at a 245°, angle 30°); II, carbonate succession wedging out eastward (dipping at 255°, angle 25°), and III, conglomerate-breccia succession (355°, angle 15°). The disjunctive discontinuities are the most distinctly displayed at the contacts between conglomerate (I), limestone (II), and conglomerate-breccia (III). This is expressed in the eastern part of the mountain by a brecciated and cataclastic zone (Fig. 2a) with slickensides and a 40-cm vein of columnar calcite (trending 340°–360° and dipping 15°–20°), which is typical of the contacts between tectonic plates [Mileev et al., 2009]. The fault plane (trending 335°–360° and dipping 35°–15°) is split on the southeastern slope of the mountain into two (Fig. 1d) and it separates the lower (I) and upper (III) structural units. Contact between them does not display any evidence of tectonic processes and is expressed by a sharp change in rock composition in units I and III and by presence of calcite filmy veins, which is also typical of tectonic dislocations [Mileev et al., 2009]. The upper surface of the main detachment is located in the southeastern part of the mountain within the upper structural unit III and consists of a vein of columnar calcite with rare slickensides (340°, angle 10°–30°) and of a foliation zone several dozens of centimeters thick.

The detachment surface separating structural units I and II in the hardly accessible southern part of the mountain is recorded by a foliation zone up to 1 m thick with limestone and conglomerate blocks rolled into the crushed matrix (Fig. 2b).

The fault separating structural units III and II was recognized conventionally (Fig. 1d), since a major portion of it is inaccessible and the rest is poorly exposed. A sharp structural discordance between the successions (succession III trends 355° and dips 15° and succession II trends 255° and dips 25°) and calcite veins 2–4 cm thick with slickensides (340°–355°, angle

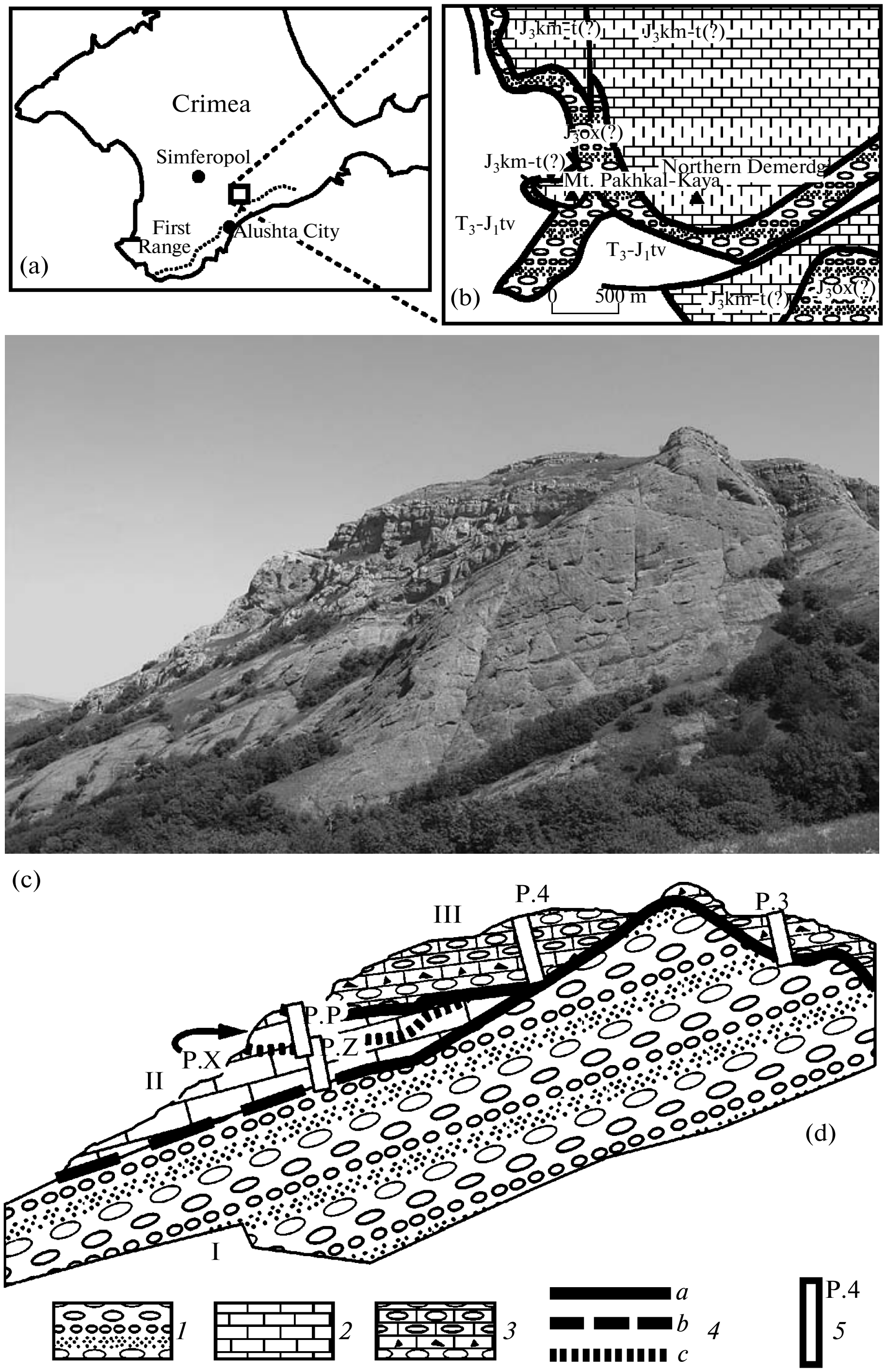

Fig. 1. Mount Pakhkal-Kaya: (a) layout scheme; (b) scheme of principal geological structure, modified after [*Geologicheskaya karta SSSR...*, 1973]. All contacts are tectonic. Southern slope of the Mountain: (c) general view; (d) aerial photograph interpretation scheme; Roman numerals designate structural units. *1*, Conglomerate succession; *2*, carbonate succession; *3*, conglomerate-breccia succession; *4*, faults: *a*, mapped; *b*, inferred; *c*, possible; *5*, location and numbers of principal sections.

10°–15°) typical of contacts between digitations [Mileev et al., 2009] are indirect evidence of disturbances.

We infer the tectonic nature of this boundary.

Thus, Mount Pakhkal-Kaya consists of three structural units separated by reliable and inferred roughly horizontal faults, whose dips suggest southeastward overthrusting of rocks [Mileev et al., 2009]. The over-

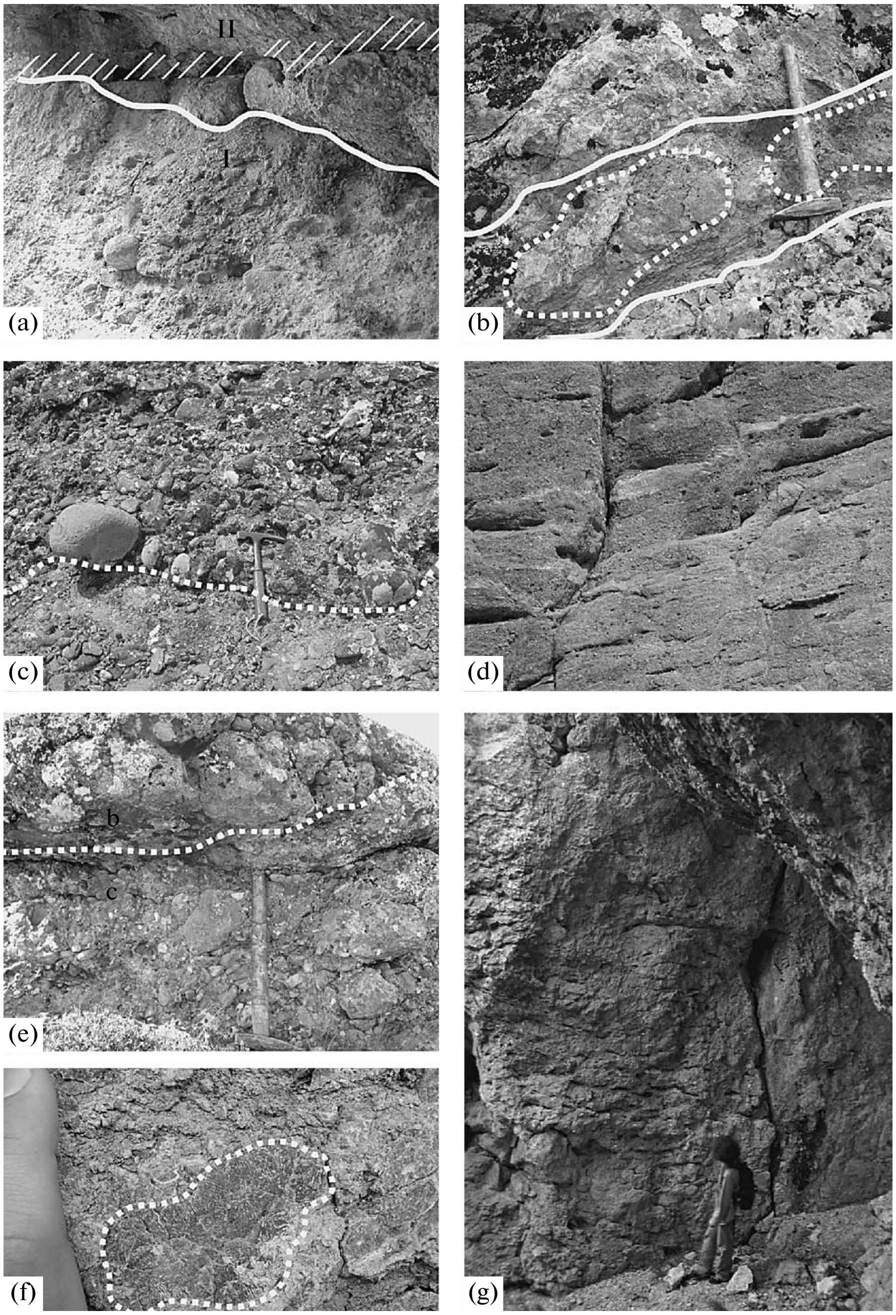

Fig. 2. Details of section structure and relations between different successions in Mt. Pakhkal-Kaya. (a) Is surface of principal detachment in the eastern part of Mt. Pakhkal-Kaya; line shows the boundary, Roman numerals are numbers of structural units, and calcite vein is shaded. (b) Is a fault within structural unit II, dash lines are elongated limestone blocks rolled into loose carbonate matrix, solid line is boundary of tectonized zone. Conglomerate succession (I). (c) Are conglomerates; dashed line shows base of streambed incision. (d) Is large-scale oblique bedding. Conglomerate-breccia succession (III): (e) is a fragment of section ((b) is carbonate breccia, (c) shows conglomerate with angular carbonate fragments and carbonate breccia), dashed line is layer boundary; (f) is a fragment hexacoral; (g) is a massive limestone succession (III).

thrusting amplitude is unknown and, most probably, is not very great.

Age of sediments. No data on the stratigraphy of the succession at Mount Pakhkal-Kaya are available and, therefore, the age of the structural units can be inferred only based on data from adjacent regions. The conglomerate from Mount Southern Demerdzhi, whose age is Oxfordian according to the data of V.G. Chernov [Chernov, 1963, 1971] and M.V. Muratov [Muratov et al, 1969; *Geologicheskaya karta SSSR*..., 1973] is the closest to the conglomerate succession (I). The conglomerate corresponds to the Demerdzhi Formation (upper–middle Oxfordian after Permyakov et al. [1991]. Shnyukov et al. [1990] presented data showing the Oxfordian age of the conglomerate located in the area of Mount Pakhkal-Kaya (in a schematic map).

The carbonate succession (II) and conglomerate-breccia succession (III) are closest to the terrigenous–carbonate sediments of Mount Northern Demerdzhi, whose age is assumed as Kimmeridgian–Tithonian (unpublished data by E.Yu. Baraboshkin). They can be attributed either to the Yalta Formation or to the Lower Subformation of the Tithonian Bedenekyr Formation [Permyakov et al., 1991]. This generally agrees with the opinion found in Muratov et al. [1969] that the Oxfordian conglomerates are overlapped by an angular unconformity of Tithonian limestone. We tentatively refer Succession I to the Oxfordian and Successions II and III to the Kimmeridgian–Tithonian epoch.

Structure of the Section in Mount Pakhkal-Kaya

Sections of structural units were examined on the eastern and southern slopes of Mount Pakhkal-Kaya (Fig. 1d); on other slopes, they are either inaccessible or covered with lichen and vegetation.

Conglomerate succession I consists of yellowish-brown poorly sorted conglomerate (Figs. 2c and 2d) displaying a large-scale trough-related oblique lamination (245°, angle 30°). Clast dimensions vary from pebble sized to boulders (up to 60 cm) and their composition is polymictic: sandstone, quartz, limestone, shale, and basic volcanic rocks. The matrix (15–40%) is gravelly and polymictic. Sedimentation rhythms 1–3 m thick with normal gradational lamination were recorded in the conglomerate; numerous streambed incisions were recorded that are typical of rivers with high stream energy. The apparent thickness exceeds 50 m.

The characteristics of massive carbonate succession (II) are presented based on macroscopic and microscopic examination of rocks accompanied by recognition of standard microfacies (SMFs) in a rimmed carbonate platform [Fluegel, 2004], as described below. Succession II wedges out eastward and consists of coarse-grained limestone (Fig. 2g) enclosing various bioclasts. The following rocks are present in the section:

Gray packstone or wacke-packstone, massive, with fenestrae (SMF-21–16 NLS) or without them (SMF 8–10). The abbreviations LS and NLS designate layered and unlayered structures, which are a determining factor for a number of SMFs. In the rock some rare bioclasts of corals, foraminifers, crinoids, algae, and individual oncolites occur, as well as small quartz and sandstone pebbles. The thickness of the member is 0.9–5.4 m.

Massive gray pack-grainstones (SMF 17) with rare quartz pebbles. The thickness of the member is up to 1.2 m.

Carbonate poorly sorted breccia, indistinctly laminated, with a carbonate matrix. In thin sections, they are usually rudstones containing fragments of SMF 9, SMF 16 NLS, and SMF 17; they locally contain quartz and sandstone pebbles. The thickness is 1.0–3.5 m.

A bed of grayish yellow conglomerate, polymictic, moderately or poorly sorted, with gravelly matrix enclosing pebbles of sandstone, quartz, and limestone. The thickness is 0.7 m.

Bind-packstones (SMF 21–16 NLS) gray in color; they enclose bioclasts of foraminifers, algae, hydrozoans, and crinoids or without the latter. The thickness is 1.7–2.4 m.

Massive gray wacke–packstone and grainstone (SMF 16 NLS, SMF 22). Oncoids and stromatoliths, as well as quartz and sandstone pebbles, occur locally. The thickness is up to 2.2 m.

In the southern part of the mount, a topographic escarpment consists of massive limestone, which was treated during the first practical training as a "reef body." The reef rocks are gray massive pack-bindstone with fenestrae (SMF 21–16 NLS) or without them (SMF 17) enclosing bioclasts of crinoids, corals, sponges, and algae. Stromatoliths are rare; quartz and sandstone pebbles are present, but SMF11 typical of a sandy shoal is lacking. The thickness is 1.5–4.8 m.

The thickness of the massive limestone succession reaches 60 m.

Conglomerate-breccia succession (III) (Fig. 2e) consists of alternating beds (up to 0.5–2.2 m thick) of yellow gray carbonate breccia consisting of poorly rounded and angular limestone blocks (from 0.25 m to 1 m in size) (up to 90%), among which smaller fragments are arranged (10%). The carbonate gravelly matrix gives place down the section to a polymictic matrix (10%). The blocks include rare fragments (6–7 cm) of hexacorals (Fig. 2f) and individual oncoids (up to 3 cm across).

Well-rounded pebbles (2–10 cm) of quartz, more rarely, of sandstones and mafic rocks, are also present and the pebble proportion increases down the section from 5 to 70%. A three-meter interlayer of reddish brown poorly sorted unlayered polymictic conglomerate was traced in the middle portion of the succession. The interlayer is remarkable for the absence of carbonate fragments and is a **correlation benchmark**. At a distance of 7.3 m below this interlayer there is another correlation benchmark of greenish gray gravelstone, consisting of carbonate siliceous lithoclasts and quartz submerged into carbonate cement. The interlayer is 0.2–0.3 m thick. Similar gravelstone makes up a characteristic element in the lower portion of the succession.

Most other beds are not traceable, which is related to different concentrations of carbonate fragments in the beds and, more rarely, to their lenticular shape. The thickness of the conglomerate and limestone succession (III) attains a value of 70 m.

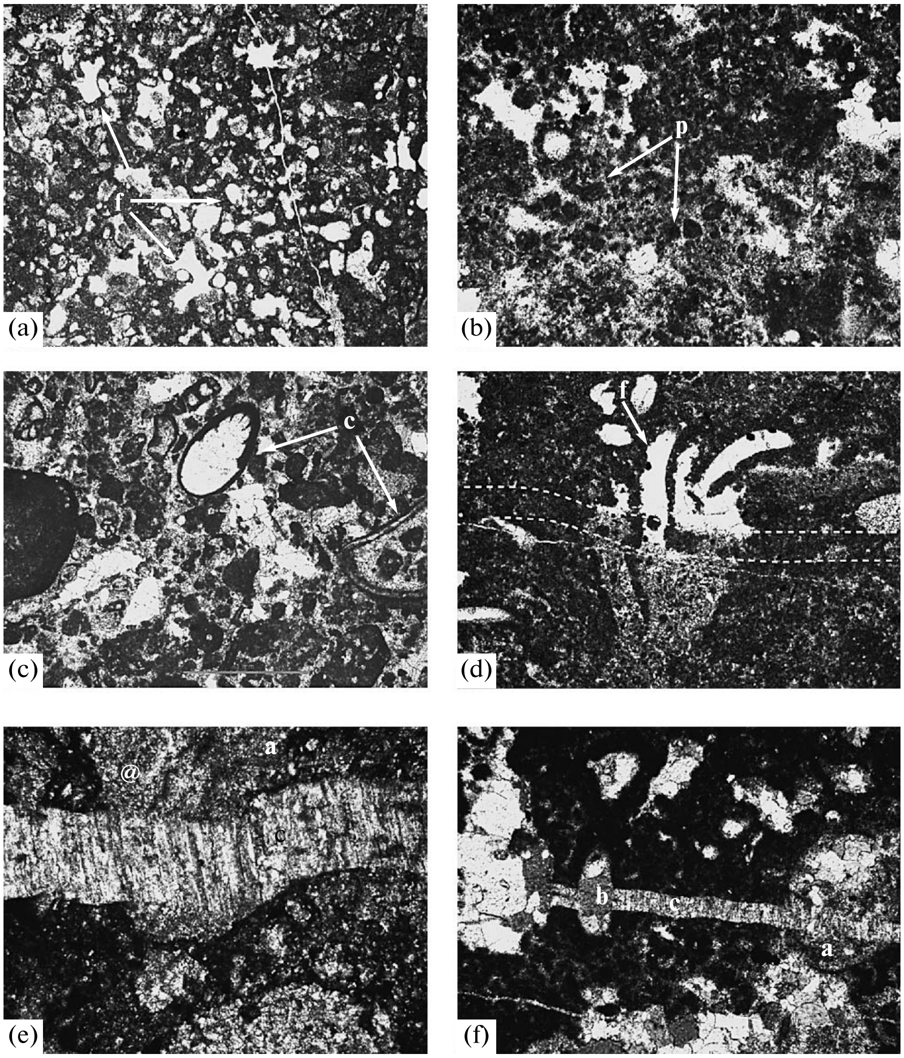

Fig. 3. Principal types of microfacies and diagenesis stages: (a) is SMF 21, fenestral bindstone; f, are fenestrae, thin section PX-27; (b) is SMF 16 NLS, unlayered peloid packstone, p are peloids, thin section PZ-10; (c) is SMF 11, bioclastic grainstone with cortoids (c), thin section PZ-8/1; (d) is SMF 16LS, fenestra (f) in three stages: (1) filling with sediment; (2) formation of crystalline aleurite (a) that inherited bedding (dashed line); (3) formation of blocky cement (b), thin section PX-20 (crossed polarizers); (e) is columnar calcite vein (c) cutting crystalline aleurite (a) and granular cement (g), thin section PX-05 (crossed polarizers); (f) shows relations between (b), columnar calcite vein b and blocky cement; a, and crystalline aleurite, thin section PP-4/1 (crossed polarizers). Measuring scale corresponds in all photographs to 1 mm.

Microfacies of Carbonate Rocks

Standard microfacies (SMFs) are based on a certain type of carbonate structure, and a certain set of microfacies corresponds to each zone of a carbonate platform [Leeder, 1988; Tucker and Wright, 2002; Fluegel, 2004]. The techniques of microfacies analysis was discussed in detail in a fundamental work by Fluegel [2004].

SMF's of a carbonate platform rimmed by shoals were reliably recognized in the examined sections. Information on large reef edifices in the Mt. Ai Petri Area [Muratov et al., 1969] and in other areas was refuted recently [Mileev and Baraboshkin, 1999; Krajewski and Olszewska, 2006; Mileev et al., 2009]. The presence of slope facies within the platform does not allow interpreting it as ramp.

Only the characteristics of the most important lithofacies are presented below because of the limited space of the paper, and those lithofacies will be a basis for interpreting the succession. The SMFs are numbered in accordance with Fluegel's [2004] numbering. Rocks showing indications of several SMFs are designated with a double number.

SMF 21. Fenestral bindstone (Fig. 3a). Bind-packstones and bindstones are massive and yellowish gray rocks. They contain from 20 to 70% micrite, grains consist of peloids (30–80%), stromatolith bioclasts (0–20%), and bioclasts of algae (0–15%), benthic foraminifers (0–10%), sponges (0–5%), and, more rarely, corals, crinoids, and bryozoans. The texture is fenestral, from laminated to chaotic. The fenestrae (25–70%) are presented by cavities (0.05–3 mm) of roundish to complex stromatoid shape and are filled with drusy cement. An ordered arrangement of the fenestrae is typical.

Formation conditions. The fenestrae are of different origins. Spherical and roughly spherical cavities could form, first, within and between algae and stromatoliths and, second, present gas bubbles, a product of organic matter decay. Fenestrae of complex morphology originated because of stromatolith recrystallization, organic remains decayed with the formation of gas bubbles, and, more rarely, because of bioturbation. In exceptional cases their inorganic origin was possible [Fluegel, 2004].

The rock presented originally bacterial and algal mats that created a framework, which subsequently accumulated interlayers of micrite, peloids, and bioclasts [Fluegel, 2004]. The bioclasts of benthic echinoderms, corals, and foraminifers indicate normal marine conditions. This SMF is typical of facies zones in a limited lagoon with variable salinity, while interlayers containing bioclasts of normal marine fauna belong only to the zone of a limited lagoon.

SMF 16 NLS. Unlayered peloid structure (Fig. 3b). It consists of wacke-packstones and packstones. The texture is not layered. Presence of benthic foraminifers (0–10%) and calcispheres (0–5%) is typical.

Formation conditions. Peloids in this microfacies are of microbial (products of stromatolith and algae destruction and microbial vital activity), ooze, and fecal origins. This microfacies is typical of the inner parts of epi-platform shallow-water seas with moderate hydrodynamics (limited lagoon, after [Fluegel, 2004].

SMF 16 LS. Layered peloid pack-bindstone (Fig. 3d). The texture is layered. It consists of alternating pelsparitic and pelmicritic varieties and the layers are usually bent. Presence of fenestrae is typical (0–15%).

Formation conditions. The peloids in this microfacies are of microbial (products of vital activity of incrusting organisms) and, more rarely, ooze origins [Fluegel, 2004]. This SMF is typical of various facies zones but, keeping in mind the absence of SMFs corresponding to reefs and platform slopes, it can correspond only to zones of variable salinity and open sea [Fluegel, 2004].

SMF 11. Bioclastic pack-grainstones with cortoids (Fig. 3c). The pack- and grainstones are massive and yellowish gray. They contain from 0 to 30% micrite. The grains consist of large cortoids (50–80%), which are ooide-like grains covered with a micrite crust, peloids (15–40%), bioclasts (5–20%) of echinoderms, small benthic foraminifers, casts of brachiopods and bivalves, corals, algae, as well as by intraclasts (0–10%) and oncoids (0–10%). The cortoids originated after bioclasts (65–80%) and after grains of uncertain origin (15–33%). The cortoids vary in size from 0.1 to 3 mm. Peloids are roundish and angular in shape (0.02–0.4 mm); large peloids show a weakly pronounced inner structure. The texture of the rock is chaotic.

Formation conditions. The microfacies originated under normal marine conditions during permanent wave impact at the wave base level or higher. The micrite crust occurred due to boring in shallow water. This SMF is typical of the facies zone of a sand bar rimming the platform [Fluegel, 2004].

In addition to the above, the following SMFs were recorded in the section: SMF 23, unlayered homogenous microsparite; SMF 9, bioturbated bioclastic wackestone; SMF 10–8, bioclastic wackestone with abraded and whole micrites; and SMF 22, oncoidal floatstone, as well as other microfacies.

Brief Characteristics of Diagenetic Succession

The pore and basal cement of blocky, drusy, and granular types is typical of the examined rocks, as well as cement in the form of crystalline aleurite and columnar quartz.

Crystalline aleurite (Figs. 3d and 3e; the term by Fluegel [2004]) is matrix consisting of small angular calcite grains several dozens of micrometers in size and of micrite. Its formation proceeded in fenestrae, intra-skeleton cavities, and, more rarely, in intergranular space. The matrix has a lighter color than the primary micrite and consists of microsparite. Darker-colored clots of micrite (over 16 μm) are typically enclosing peloids and are hardly distinguishable from the primary micrite. Crystalline aleurite originates under conditions of meteoric vadose diagenesis in supralittoral zone and is a product of carbonate destruction of primary marine sediment or is altered by microcrystalline cement [Fluegel, 2004].

Drusy cement is typical of intragranular pores and fenestrae. The cement is mosaic and the crystal dimensions grow from the periphery to the pore centers from 10 to several hundreds of micrometers. Its formation is typical of meteoric vadose diagenesis.

Block cement (Figs. 3d and 3f) consists of large (up to several mm in size) acute-angled crystals of chaotic orientation. It is typical in meteoric phreatic and vadose zones. It forms after dissolution of aragonite grains or because of late diagenesis and cement recrystallization.

Granular cement occurs rarely and consists of small isometric calcite crystals measuring from 10 μm to several tenths of a millimeter. It forms in vadose and meteoric phreatic zones.

Columnar calcite (Figs. 3e and 3f) fills veins and fissures related to tectonic activity [Mileev et al., 2009]. Its crystals are perpendicular to the substrate; their width varies from 10 μm to 0.2 mm and their length is determined by the width of the vein.

Relationships between different types of cement Crystalline aleurite fills a portion of the cavity and its boundary with the blocky cement filling the remaining portion of the cavity is parallel to bedding (Fig. 3d). In these cases, formation of crystalline aleurite took place because of diagenesis of primary marine sediment under near-surface conditions of meteoric vadose diagenesis. Growth of the block cement was a second phase of diagenesis that took place in a deeper-seated meteoric vadose or phreatic zone. The relationships between crystalline aleurite, drusy, and granular cement are not clear.

The drusy cement often associates with blocky cement. Its growth toward the center of a cavity is the first stage of meteoric vadose diagenesis and takes place under near-surface conditions. Growth of the blocky cement is the next stage and it takes place under conditions of deeper-seated vadose or phreatic diagenesis.

Thus, the formation of the described types of cement in carbonate rocks occurred, as a minimum, in two stages: (1) during a stage of near-surface vadose diagenesis and (2) during a stage of deeper-seated vadose or phreatic diagenesis.

Columnar calcite veins cut the crystalline aleurite and granular cement but terminate at the boundary with block cement (Figs. 3e and 3f). They were formed later relative to the crystalline aleurite and granular cement but originated earlier than the blocky cement, i.e., before the second stage of vadose or phreatic diagenesis. Relationships between the drusy cement and columnar calcite were not observed.

Inheritance of sedimentary bedding by crystalline aleurite in carbonate fragments indicates that it occurred before redeposition of carbonates as breccia of succession III that formed because of destruction of the margin of carbonate platform. Hence, the carbonate platform underwent early lithification during its exposure at short-term sea-level decline or at maximum ebbs. This is the **first diagenetic stage** and it corresponds to the Kimmeridgian–Tithonian Epoch.

The second stage corresponded to formation of columnar calcite veins that were related to Early Cretaceous nappe formation (late Berriasian?, Valanginian, and early Albian?). **The third stage** of vadose and meteoric phreatic diagenesis, with which blocky cement formation (at least, a portion of it) was related, took place after the nappe formation.

INTERPRETATION AND DISCUSSION OF RESULTS

The described successions are the results of terrigenous (Succession I), carbonate (Succession II), and mixed (Succession III) sedimentation; and a certain stage of sediment accumulation corresponds to each of them.

Conditions of conglomerate succession formation (I) (Fig. 4b) Thick successions of poorly sorted conglomerate with large-scale oblique bedding are typical of Gilbert-type deltas (V.O. Gavrilov (GIN RAN), oral communication, 2008) was the first who noted this phenomenon. Such deltas have a well-expressed steep slope often controlled

by faults where coarse-grained material is accumulated. In this case, the river drains a strongly dissected topography, which explains the coarse-grained composition of sediments [Leeder, 1982; Reding et al., 1990; Breda et al., 2007]. The flowing river stream, whose dynamics is determined by the process of turbulent diffusion, has a density comparable with that of water in the basin. The stream empties with a high velocity gradient into a deep-water brackish-water or fresh water basin [Leder, 1982; Reding et al., 1990; Malartre et al., 2004; Kleinhans, 2005]. In this case, the transportation distance of the dragged material was considerably shorter than that of suspended material and therefore the former accumulated on the delta slope with the formation of large-scale oblique bedding with dip angles of 20°–30° and the latter accumulated on distant parts of the slope or at its rise. These indicators of Gilbert-type deltas are typical of succession I conglomerates, which indicates analogous conditions of its accumulation. The recorded large-scale bedding with typical of delta dip angles of approximately 30°; these dip angles decline westward, which allows us to assume that transportation took place from the east westward. This contradicts Chernov's opinion [Chernov, 1963, 1971] and that of Shnyukov [1990] on southern source of the material and requires verification.

Conditions of carbonate succession formation (II) (Fig. 4b) (Conclusions on its accumulation are based on the results of microfacies analysis.)

The conglomerate interlayer within carbonate breccia and rare quartz and sandstone pebbles in the succession allow us to assume a supply of terrigenous component into the basin. The wedging out conglomerate interlayer was possibly a facies of submarine channel that existed within a carbonate platform. The nature of carbonate breccia in this succession is ambiguous: it may be both sedimentary and be a product of escarpment/cliff destruction [Fluegel, 2004], or be related to submarine channel, or else it could be tectonic.

Overall, the following SMFs were recorded in succession II: 16NLS, 21; 16LS, 17, 11, 10–8, 22, and 9. The most common of them are SMF 16 NLS and 21, unlayered peloid packstone and fenestral bindstone, as well as their transitional varieties. The distribution of recognized SMFs within the rimmed carbonate platform is shown in Fig. 4a, which corresponds to facies zones of variable salinity, limited lagoon, open sea, and sand shoal rimming the platform.

The **facies zone of the sand shoal** is presented only by SMF 11, bioclastic pack- and grainstone enclosing

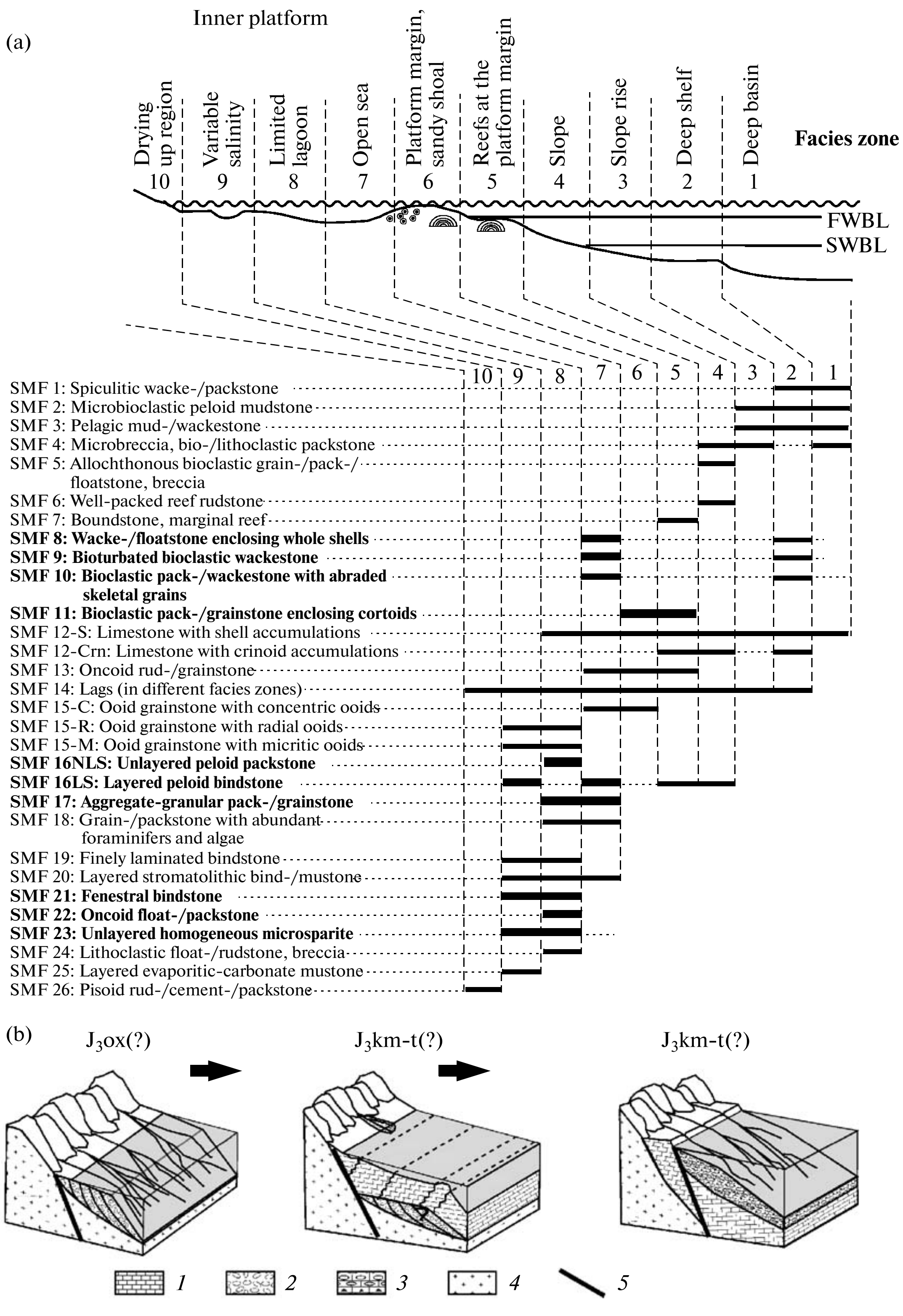

Fig. 4. SMF distribution between facies zones and stages of sediment formation during Late Jurassic at Mount Pakhkal-Kaya: (a) is a scheme of standard microfacies (SMFs) distribution between facies zones within a carbonate platform, modified after [Fluegel, 2004; Tucker and Wright, 2002]. SMFs present in the section are shown and their distribution is shown by thicker lines; wave base level at fair weather (FWBL) and wave base level at stormy weather (SWBL). (b) Shows stages of sediment formation at Mt. Pakhkal-Kaya. *1*, Sediments on carbonate platform; *2*, conglomerates of Gilbert-type delta; *3*, conglomerate-breccia; *4*, country rocks; *5*, growth (synsedimentary) faults. Facies zones in carbonate platform corresponding to such in Fig. 3a.

cortoids, for which formation during the permanent impact of wave action and the presence of organisms capable of microscopic boring is typical. Such facies zones are characterized by extensive shoals, tidal bars and beaches with permanent wave action during good weather within the euphotic zone and by the strong action of tidal currents; such zones form narrow bands along the margin of the platform. They are characterized by saturation of water with oxygen and unfavorable conditions for sessile benthos because of the constant mobility of the substratum [Fluegel, 2004].

The **facies zone of the open sea** is presented by SMF 9, 10–8, 16LS, and 17. Such a zone [Fluegel, 2004] is a flat-topped surface of a platform within a euphotic zone located above the wave erosion base during good weather and is characterized by water salinity and a temperature close to that of oceanic water, as well as by moderate water circulation and a depth from a few meters to several dozens of meters.

The **facies zone of the limited lagoon** is presented by the most common SMFs, 16NLS and 21, and their transitional varieties 16NLS–21 and 21–16 NLS, as well as by SMF 22 and 17, which are typical of the open sea zone. The sedimentation conditions in such zones [Fluegel, 2004] are similar to those in the open sea facies zone but are less connected with the open ocean, which causes great variation in salinity and temperature. The limited lagoon zone belongs to euphotic zone. Tidal regions with fresh-water, saline-water, and hypersaline-water conditions and regions of subaerial exposition are recognized within it, although the composition of the bioclasts indicates normal salinity. The spectrum of other indicators allows us to assume low circulation and small depth.

The **facies zone of variable salinity** is presented by SMF 21 and SMF 16LS, which occur also in other facies zones, and therefore this zone is recognized tentatively. These SMFs are obviously relics of algal marshes typical of such zones and formed on top of supralittoral flat or in small lakes with marine water. Microfacies containing bioclasts can belong to this zone only in the case where they were transported into the supralittoral zone by strong storms [Fluegel, 2004]. Textures typical of tempestites were not found, and therefore such microfacies belong either to the limited lagoon (SMF 21) or the open sea (SMF 16LS) zones.

Thus, the accumulation of carbonate succession II took place within facies zones of limited lagoon, variable salinity, and open sea, as well as on a sand shoal rimming the carbonate platform. Against this background, very insignificant and unsteady terrigenous sedimentation also occurred.

Conditions of Conglomerate-Breccia Succession (III) Accumulation (Fig. 4b)

This succession is characterized by mixed terrigenous accumulation of carbonate breccia and polymictic conglomerates corresponding to two sources. The source of angular and poorly rounded carbonate fragments was located within the sedimentary basin, while the rounded conglomerate pebbles indicate a remote source.

The similarity in pebble composition, their poor sorting, coarse-grained composition of material, and gravelly matrix in successions III and I allow us to assume their genetic similarity.

Conglomerates of succession III accumulated under conditions close to those of a Gilbert-type delta with steep slopes and probably bounded by faults. The large-scale oblique bedding may not show up because of the small size of the accumulation outcrops at the upper margin of avandelta [Breda et al., 2007]. This is indicated by the angular shape of the fragments, which could remain during accumulation below the base of wave action upon the rapid burial of the material.

The standard microfacies found in carbonate fragments from this succession correspond to SMFs in carbonate succession II. The difference lies in the absence of SMF 17 in Succession III and the presence of SMF 23, unlayered homogeneous micrite corresponding to facies zones of variable salinity and limited lagoon where Succession II accumulated. The almost complete identity between SMFs in successions III and II indicate their genetic similarity. We may assume that carbonate breccias and conglomerate fragments in Succession III are products of carbonate redeposition after destruction of Succession II.

The facies variability of beds and variability of sections of conglomerates and carbonate breccias were caused by the periodic collapse of the margin of the carbonate platform and by local bottom currents of clastic carbonates [Tucker and Wright, 2002]. This was obviously accompanied by periodic lithification of limestones at the margin of the platform; this is supported by the near-surface vadose diagenesis caused by exposition of the platform.

The steep slope of the Gilbert-type delta that inherited the slope of the carbonate platform is often dissected by faults [Malartre et al., 2004]. The platform's destruction was probably the result of multiple events and was related to its periodic exposure and tectonic motions along faults.

The conglomerate marker bed 3 m thick and the thin gravelstone interlayers in this succession without carbonate fragments correspond to stages of carbonate platform submergence. Similar gravelstone beds form in Gilbert-type deltas in zones of remote slope or during its rise, which corresponds more to the inner parts of the basin and a greater transgression compared to conditions during conglomerate accumulation [Malartre et al., 2004; Kleinhans, 2005].

Thus, the conglomerate-breccia succession (III) accumulated under conditions of periodic exposure of a carbonate platform and is presented in carbonate succession (II). The platform margin was dissected by faults and was destroyed against the background of general terrigenous sedimentation close to the conditions of a Gilbert-type delta. The conglomerate-breccia was buried below the wave base on the delta slope that inherited the platform slope, while gravelstone was probably buried at the slope rise.

CONCLUSIONS

Three structural units were recognized in the section in Mount Pakhkal-Kaya: conglomerate succession (I), carbonate succession (II), and conglomerate-breccia succession (III).

Three stages in the basin evolution correspond to these structural units (Fig. 4b): (1) ?J_3ox (Oxfordian), formation of Gilbert-type delta on the rift edge (?); (2) ?J_3km, formation of carbonate platform rimmed by shoals; (3) ?J_3km–tt, periodic exposure of the platform, diagenesis of carbonates in vadose zone, destruction of the platform margin, and accumulation of conglomerate-breccia. The sedimentation was controlled by active faults.

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