

## Lithology and petrology of the Ustrem Formation (Lower Triassic) in the Sakar Mountains (SE Bulgaria)

G. A. Čatalov

Geological Institute, Bulgarian Academy of Sciences, 1113 Sofia

(Accepted for publication October 5, 1987)

Г. А. Чаталов — Литология и петрология Устремской свиты (нижний триас) в Сакар-Планине (ЮВ Болгария). Устремская свита (нижний триас) относится к Сакарскому (метаморфическому) типу триаса. Последний вероятно находится в аллохтонном положении. В его состав входят наиболее сильно метаморфизованные триасовые породы в Болгарии (амфиболитовая фация). Устремская свита относится к спятскому ярусу. В мраморах, метакварцитах и амфиболитах установлено значительное количество отпечатков бивальвий. Свита сложена очень разнообразными породами. Их мощность достигает 2250 м. Главные породы — кварц-слюдяные сланцы с порфиробластами биотита, гранат ± ставролит, мраморы и кварц-слюдяные кальцитовые сланцы с порфиробластами биотита. Второстепенные породы — метапесчаники и амфиболиты. Специфические образования представляют марганцево-железные и свинцово-цинковые минерализации. Характерно наличие метаморфических кварцевых жил. Осадочные породы Устремской свиты претерпели региональный динамотермальный метаморфизм средней степени (амфиболитовая фация). Исследование первичных седиментационных условий (протогенезиса) позволяет выделить две главные обстановки — мелководную морскую среду с сильным влиянием суши и мелководную морскую среду, лишенную терригенного влияния. В первой образуются терригенно-карбонатные фации, а во второй вырастает Мраморская карбонатная постройка. Обе обстановки обусловлены специфическими палеогеоморфологическими условиями.

**Abstract.** The Ustrem Formation (Lower Triassic) belongs to the Sakar (metamorphic) Triassic. This Triassic type is probably in allochthonous position. It includes the most strongly metamorphosed Triassic rocks in Bulgaria. The Ustrem Formation belongs to the Spathian. A great number of bivalvia prints have been established in marbles, metaquartzites and amphibolites. It is built up of rather varied rocks. They reach up to 2250 m in thickness. Main rocks are quartz-mica schists with porphyroblasts of biotite, garnet ± staurolite, marbles and quartz-mica calcitic schists with porphyroblasts of biotite. Metasandstones and amphibolites are secondary rocks. Manganese-ferrous and lead-zinc mineralizations are specific formations. The presence of metamorphic quartz veins is characteristic. The Ustrem Formation sediments have undergone regional dynamothermal metamorphism of medium degree (amphibolite facies). The study of the original conditions of sedimentation (protogenesis) allow to be distinguished two main environments — a shallow-water marine environment strongly affected by the dry land and a shallow-water marine environment void of terrigenous influence. Terrigenous-carbonate facies are formed in the first one while the Mramor carbonate buildup grows up in the second one. Both environments are determined by specific paleogeomorphologic conditions.

### Introduction

The Ustrem Formation belongs to the Sakar Triassic. The latter is subdivided in three Formations: Paleokastro Formation (Lower Triassic, lower parts), Ustrem Formation (Lower Triassic, upper parts) and Srem Formation (Middle Triassic). The Sakar Triassic sharply differs from the other Triassic types in Bulgaria (Balkanide, Sub-Balka-

nide, East-Balkan and Strandza types). It is characterized by: vast rock variety, periodic abundance of benthos fauna, very large thickness (up to 2500 m only to the Middle Triassic inclusive), manganese-ferrous and lead-zinc mineralization, restricted acid magmatism and relatively highest degree of metamorphism (to amphibolite facies inclusive).

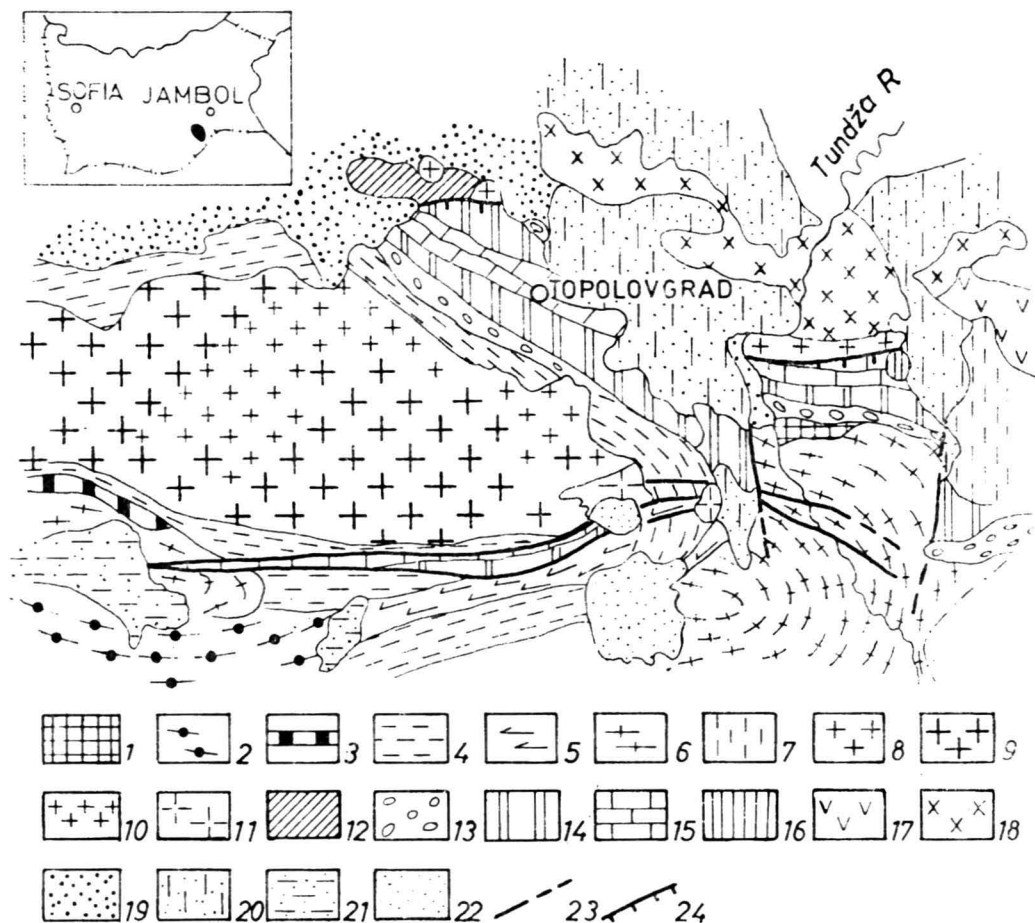


Fig. 1. Geologic map of the Sakar Mountains and the adjacent areas: 1-6 — Pre-Cambrian: 1 — crystalline schists; 2 — Ivanovo Formation (eye gneiss and porphyroblastic migmatites); 3 — Konstantinovo Formation (metaconglomerates); 4 — Mladinovo Formation (gneisses, gneiss schists and amphibolites); 5 — Lisovo Formation (amphibolites); 6 — Lesovo gneiss-granites (metamorphosed granites and granodiorites); 7-11 — Paleozoic: 7 — marble-phyllitic formation — Lower Devonian; 8 — granitoids (undivided); 9 — porphyroidic granites; 10 — medium-grained granites; 11 — aplitoidic granites; 12-15 — Triassic: 12 — Sub-Balkanide Triassic; 13 — Paleokastro Formation (metaconglomerates and metasandstones) — Lower Triassic, lower part; 14 — Ustrem Formation (silicate and silicate-carbonate crystalline schists and marbles) — Lower Triassic, upper part; 15 — Srem Formation (calcitic and dolomitic marbles) — Middle Triassic; 16 — Eastern Thracian Group — Lower and Middle Jurassic; 17-18 — Upper Cretaceous: 17 — volcanogenic and volcanogenic-sedimentary rocks — Senonian; 18 — Upper Cretaceous intrusions; 19-22 — Neozoic: 19 — Marica and Gledačev Formation (sands, marls, limestones, clays, coals) — Miocene; 20 — Elhovo Formation (sands, clays, coals) — Meot-Pliocene; 21 — Ahmatovo Formation (sands, siltstones, clays) — Meot-Pliocene; 22 — Pliocene-Quaternary sediments; 23 — fault; 24 — thrust

Data on Sakar pluton and Pre-Cambrian crystalline schists are after Кожухаров & Кожухарова (1973)

The Ustrem Formation is characterized by the largest rock variety. The lithologic and petrologic investigations of these rocks are few in number (Čatalov, 1961; Боянов et al., 1965; Кожухаров et al., 1966; Кожухарова & Кожухаров, 1978; Čatalov, 1985). The aim of the present paper is to investigate: a) fabric and composition of the rocks; b) their chemical and geochemical characteristics; c) the degree and type of metamorphism; and d) the protogenetic facial peculiarities. A protogenetic sedimentologic model has been the final aim of the lithologic investigations.

The field and laboratory data have been collected for many years and comprise about 100 specimens investigated in polished planes, thin sections, chemically, geochemically (X-ray fluorescent and atom-absorption), X-ray and with microanalyser (Jeol Superprobe 733).

## Stratigraphy

Detailed data on the stratigraphy of the Ustrem Formation were presented during the last years (Čatalov, 1985; Чаталов, 1985). The Formation is built up by an alternation of silicate and silicate-carbonate crystalline schists and marbles. Its lower boundary is positioned in the base of the first layer of quartz-carbonate mica schists with or without biotite porphyroblasts. The upper boundary is drawn in the base of the first layer of gray dolomitic marbles which form a packet in the lower part of the Srem Formation (Figs 2, 3). The Ustrem Formation is subdivided into four Members — Guma, Kerimar, Mramor and Čanaklii (Fig. 2). The Mramor Member is a carbonate buildup which articulates with the terrigenous-carbonate and terrigenous rocks of the Kerimar Member (Fig. 3). It is found only in the region of the village of Mramor (Чаталов, 1985, p. 133, Fig. 2). The Ustrem Formation belongs to the Topolovgrad Group.

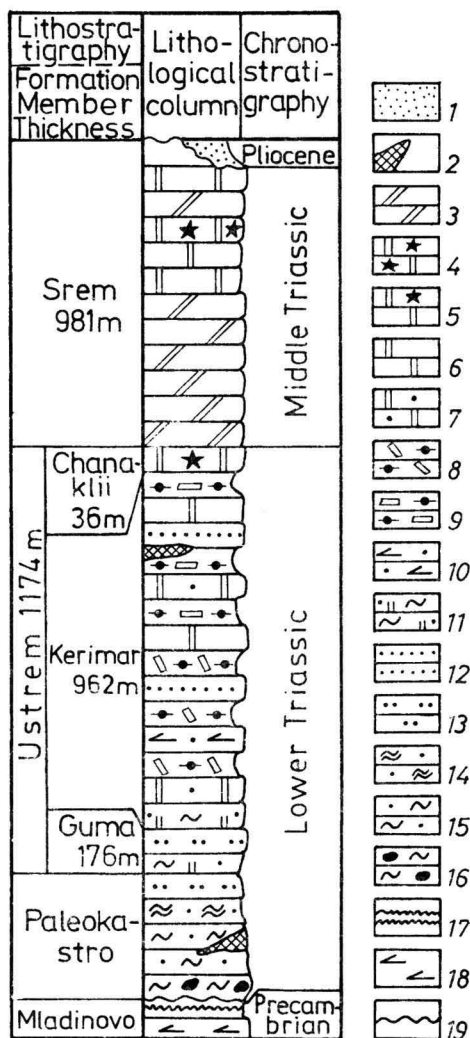


Fig. 2. Column section of the Sakar Triassic at the town of Topolovgrad

1 — Neozeic sediments; 2 — metamorphic (lateral secretion) quartz veins ( $\pm$ feldspar, disthene, muscovite, biotite); 3 — dolomitic marbles; 4 — crinoidal calcitic marbles; 5 — calcitic marbles with crinoids; 6 — calcitic marbles; 7 — quartz-bearing calcitic marbles; 8 — quartz-mica schists with porphyroblasts from staurolite, garnet and biotite; 9 — quartz-mica schists with porphyroblasts from garnet and biotite; 10 — quartz amphibolites; 11 — bimica quartz-calcite schists with biotite porphyroblasts; 12 — quartz metasandstones; 13 — metaarkoses; 14 — bimica quartz schists; 15 — muscovite- or biotite-quartz schists; 16 — metaconglomerates and metagraywackes; 17 — bimica and biotite gneiss-schists; 18 — amphibolites; 19 — paleoerosion boundary

The geological age has been determined on the basis of several specimens from *Cos-tatoria castata* Z e n k e r, *Gervilleia* (*Bekewellia*) cf. *modiola* F r e c h and *Myalina* sp. The fossils are determined by L. R. C o x (British Museum Natural History, London) and L. D. K i p a r i s o v a (VSEGEI, Leningrad). It is agreed that the Formation belongs to the upper parts of the Lower Triassic, probably to the Spathian stage. Bivalvia are presented as prints on a weathered marble and amphibolitic surface (Ч а т а л о в, 1960) (Plate I, Figs 5, 6; Plate II, Figs 1, 2, 3).

The thickness of the Formation reaches up to 2250 m (Fig. 3). It is most widely spread in the Topolovgrad syncline. It is more sparsely found in the Sakar Mountains and the region of the village of Orlov Dol, Svetlina, Gradeč and Madrec (Fig. 1.).

## Lithology and Petrology

### *Fabric and composition*

The Ustrem Formation is built up of alternations of three basic rock groups — silicate rocks (metasandstones and metapelites),\*silicate-carbonate (quartz-mica calcitic schists with or without biotite porphyroblasts) and carbonate (calcitic and dolomitic marbles). Stratification is characterized by an uneven alternations of beds and packets consisting of these rocks. Two main tendencies from the bottom upwards are observed in the section: a) increase of the carbonate rocks at the expense of the silicate ones, and b) gradual disappearance of the metasandstones (up to the middle of the section) and their substitution with metapelites.

Nevertheless the regional metamorphism stratification is preserved since the individual initial layers are preserved, even sharply distinguished from one another. The internal bedding of the layers is however deleted.

The Guma Member is built up of uneven alternation of quartz-mica calcitic schists, metaarkoses, quartz-mica schists and marbles. Almost the same rocks build up the Kerimar Member. The metaarkoses disappear while the amount of the marbles highly increases. Amphibolites and metaquartzites appear. The mica schists contain a considerable amount of porphyroblasts formed of garnet, biotite, and staurolite. The Čanaklii Member is built up only of marbles (calcitic, calcite-dolomitic and dolomite-calcitic). The Mramor Member is also built up only of marbles (calcitic, dolomite-calcitic, calcite-dolomitic and pure dolomitic).

The main rocks of the Formation are quartz-mica schists with porphyroblasts from biotite, garnet±staurolite, marble and quartz-mica calcitic schists with porphyroblasts from biotite. Metasandstones and amphibolites are secondary rocks. Ferrous-manganese (the village of Orešnik, the village of Duganovo) and lead-zink mineralization (the village of Planinovo) are specific formations. The matrix of the quartz-mica schists with porphyroblasts from biotite, garnet and staurolite is lepidogranoblastic. It is built up of quartz, plagioclase, muscovite and biotite measuring from 0.05 up to 0.1 mm. The matrix exhibits a stream-lining round the porphyroblasts (Plate I, Fig. 3). The latter ones have perfectly shaped crystals measuring from 1-2 mm up to 3-4 mm (for biotite and garnet) and up to 1 and rarely up to 2.5 cm (for staurolite). Twins at a right angle (032) or at a slant (232) are often observed. An explicitly expressed sieve-wise texture is characteristic of the porphyroblasts (Plate I, Fig. 4). The amount of the porphyroblasts reaches up to 35%. Also magnesiochlorite (developed along the biotite), apatite, tourmaline and ilmenite are observed under the microscope. The average mineral composition of these rocks shows: quartz (20-30%), muscovite (20-30%), biotite (15-25%), plagioclase (5-10%), garnet (10-20%) and staurolite (0-20%). Quartz, disthene-quartz, and biotite-muscovite-feldspar-quartz veins have been established among these mica schists.

The marbles are gray, brown, reddish, yellow and white. They are medium and thickly layered (30-40 cm up to 90 cm) and massive constructing layers of 2-3 m. Some quartz- and mica-bearing marbles and more rarely pure marbles from the Kerimar Member are rich in prints of bivalvia (Plate I, Figs 5, 6) and more rarely in crinoids (Plate IV, Figs 3, 4). The marble of the Kerimar and Čanaklii Members are of a more varied texture (from homeoblastic up to typical heteroblastic), relatively more coarse-grained (0.1 — 1.2 mm) predominantly calcitic with well-expressed dynamogenic lamellae and they often contain quartz, biotite, muscovite, and pirite (Plate III, Figs 2, 3; Plate V, Figs 2, 3). The marbles building up the Mramor Member are characterized by more uniform textures (homeoblastic isodiametric granoblastic), relatively finer grains (0.06—0.2 mm and 0.1 — 0.3 mm), predominantly dolomitic composition and lack of admixtures (Plate V, Fig. 1). A maximal compact packing of the texture is achieved there. At rectilinear boundaries with an angle of 120° triple contacts are observed quite often (Plate V, Fig. 1). These are mainly distinguished with the dolomitic type of grains — isometric polyhedrons, "rounded" and partially developed rhombohedrons. Similar textures are observed also in the Srem Formation (Plate IV, Figs 5, 6).

Quartz-mica calcitic schists with porphyroblasts from biotite have been formed at the expense of silty-clayey carbonate rocks and their mineral composition is quite varied (Table 1). Biotite blastoporphyric texture is characteristic of them. They are mainly constituted of biotite, muscovite, quartz, and calcite (Plate I, Fig. 2). Sometimes the amount of clinozoisite and ziosite is considerable (up to 11%) (Ч а т а л о в & Г р о з д а н о в, 1978). Plagioclase, pirite, rutile, zircon, tourmaline, and apatite are also established. North of the Paleokastro Peak the following composition is precisely estimated: calcite — 27.7%, quartz — 26.2%, biotite — 17.7%, muscovite — 15.6%, clinozoisite and ziosite — 11.4%, accessories — 1.4%. The average mineral composition of 5 samples is: calcite — 40%, quartz — 30%, biotite — 20% and muscovite — 10%. A particular attention has been paid at biotite and its petrogenic importance. Its crystallochemical formula has been determined:

[K<sub>0.92</sub>, Na<sub>0.05</sub>] 0.97

[Mg<sub>1.40</sub>, Fe<sub>0.62</sub>, Fe<sub>0.34</sub>, Al<sub>0.39</sub>, Ti<sub>0.04</sub>] 2.79

[(Si<sub>2.75</sub>, Al<sub>1.25</sub>), 4.00 O<sub>10</sub>] [OH<sub>1.82</sub>, O<sub>0.67</sub>, F<sub>0.11</sub>] 2.00

Details are given in the work by Č а т а л о в and Г р о з д а н о в (Ч а т а л о в & Г р о з д а н о в, 1978). The metasandstones belong to the group of the quartz sandstones and arkoses (after Ш у т о в, 1967). Quartz metasandstones have homeoblastic isodiametric granoblastic texture with grains measuring from 0.1 to 0.25 m. The texture is strongly tightened. Sometimes they are transformed into metaquartzites (Plate I, Fig. 1). Triple contacts with an angle of almost 120° are often observed which implies a maximum degree of homogenization (Plate III, Fig. 4). The following metasandstones have been distinguished; quartz (90-95%), calcite-quartz (quartz — 60-80%, calcite 20-40%) and muscovite-calcite-quartz (quartz — 70%, calcite — 20%, muscovite — 10%; ± biotite, plagioclase, calcite feldspar; zircon, apatite, rutile, tourmaline and titanite) (Plate III, Fig. 1). Prints of bivalvia have been found in the sandstones.

Feldspar-quartz metasandstones (quartz 75-80%, feldspars 15-20%) and metaarkoses (quartz — 70%, feldspars — 30%) have been found only in the Guma Member. They contain muscovite, biotite and calcite and accessories — zircon, rutile, and apatite. It is typical that the feldspars have undergone degrading recrystallization.

Amphybolitic rocks are in a very small amount and are met as a layer measuring 5-10 cm in thickness rarely up to 20-30 cm. The dimensions of the amphybol crystals are 1-2 × 10-12 mm and rarely reach 3 × 25 mm. They have a strongly expressed sieve-wise texture under the microscope. The An<sub>40-58</sub> plagioclase is mainly non-lamellated. The mineral composition is as follows: amphibole — 30-50%, quartz — 20-40%, plagioclase — 10-30%. According to this composition the quartz amphibolites (pla-

gioclase > 20%) and plagioclase-quartz-amphibolitic schists have been distinguished (plagioclase < 20%). The chemical composition of these rocks is presented in Table 2. A well-preserved bivalvia fauna has been found in amphibolitic rocks (Plate II, Figs 1, 2, 3).

The vertical alterations in the Formation are characterized by an increase of the carbonate rocks at the expense of the silicate ones. The terrigenous-carbonate rocks of the Kerimar Member articulate in horizontal direction with the massive pure carbonates of the Mramor Member (Fig. 3).

### *Chemical and geochemical characteristics*

The following samples: 33-Tp, 34-Tp, 16-Tp, petrographically determined as bimica quartz-calcitic schists with biotite porphyroblasts, are rocks of a very complex composition (Table 1). In the present name albite is not included. Its amount is higher than 5% and reaches up to 10% if there is no paragonite among the white mica. The amount of SiO<sub>2</sub> alters from 22.20 up to 30.80% while that of Al<sub>2</sub>O<sub>3</sub> from 8.40 up to 11.42%. The amount of CaO is from 25.45 up to 30.74% while that of Na<sub>2</sub>O + K<sub>2</sub>O — from 2.88 up to 4%. Fe and Mg are mainly connected with biotite. The chemical composition of this group of rocks corresponds to the mineralogical composition according to data obtained from the microscopic studies. The second conclusion that may be drawn concerns protogenesis or the original lithologic composition, which according to the che-

Table 1

*Chemical composition (%) of rocks from the Ustrem Formation (Lower Triassic)*

| Oxide                          | Sample No |                 |        |                 |        |        |       |       |        |       |       |
|--------------------------------|-----------|-----------------|--------|-----------------|--------|--------|-------|-------|--------|-------|-------|
|                                | 41-A-Tp   | 33-Tp           | 34-Tp  | 16-Tp           | 6-Pl-2 | 42-Tp  | 2-Pl  | 4-Pl  | 4-Pl-1 | 37-Tp | 38-Tp |
| SiO <sub>2</sub>               | 58.40     | 22.20           | 22.67  | 30.80           | 56.50  | 61.40  | 58.16 | 58.36 | 57.75  | 58.30 | 59.49 |
| TiO <sub>2</sub>               | 0.70      | 0.25            | 0.28   | 0.47            | 0.70   | 0.20   | 0.88  | 1.09  | 1.71   | 0.75  | 0.77  |
| Al <sub>2</sub> O <sub>3</sub> | 17.10     | 8.50            | 8.40   | 11.42           | 17.81  | 8.06   | 20.25 | 20.49 | 19.81  | 19.20 | 18.87 |
| Fe <sub>2</sub> O <sub>3</sub> | 3.98      | 1.21            | 1.40   | 2.45            | 1.34   | 0.95   | 3.57  | 3.12  | 2.79   | 4.07  | 4.66  |
| FeO                            |           | 1.40            | 1.20   | 1.83            | 4.62   | 2.00   | 4.06  | 3.98  | 4.83   | 4.03  | 2.45  |
| MnO                            | 0.03      | 0.06            | 0.06   | 0.09            | 0.06   | 0.05   | 0.17  | 0.14  | 0.16   | 0.08  | 0.07  |
| MgO                            | 2.20      | 5.40            | 6.13   | 2.72            | 3.95   | 1.50   | 2.90  | 2.94  | 2.97   | 2.90  | 2.40  |
| CaO                            | 3.98      | 30.74           | 29.06  | 25.45           | 6.70   | 11.92  | 1.67  | 2.72  | 2.71   | 0.96  | 1.10  |
| Na <sub>2</sub> O              | 0.76      | 0.86            | 0.93   | 1.34            | 1.04   | 2.12   | 1.45  | 1.25  | 1.23   | 1.19  | 1.28  |
| K <sub>2</sub> O               | 7.20      | 2.02            | 2.12   | 2.66            | 3.31   | 1.14   | 3.28  | 3.38  | 3.26   | 3.30  | 3.13  |
| P <sub>2</sub> O <sub>5</sub>  | 0.27      | 0.07            | 0.07   | 0.09            | 0.13   | 0.06   | 0.14  | 0.13  | 0.13   | 0.14  | 0.14  |
| S                              |           | 0.07            | 0.01   | 0.07            | 0.01   | 0.01   | 0.02  | 0.02  | 0.01   | 0.01  | 0.01  |
| H <sub>2</sub> O <sup>-</sup>  | 0.20      | 0.14            | 0.10   | 0.30            | 0.26   | 0.22   | 0.38  | 0.15  | 0.27   | 0.29  | 0.63  |
| H <sub>2</sub> O <sup>+</sup>  | —         | 3.73            | 4.71   | 0.27            | 1.93   | 0.65   | 2.42  | 1.99  | 2.23   | 4.40  | 4.39  |
| CO <sub>2</sub>                | —         | 23.52           | 22.89  | 20.25           | 1.61   | 9.93   | 0.18  | 0.22  | 0.09   | 0.10  | 0.21  |
| Heat loss                      | 4.80      |                 |        |                 |        |        |       |       |        |       |       |
| O=S                            |           | 100.17<br>—0.04 |        | 100.19<br>—0.04 |        |        |       |       |        |       |       |
| Sum                            | 99.62     | 100.13          | 100.03 | 100.15          | 99.97  | 100.21 | 99.73 | 99.98 | 100.00 | 99.72 | 99.60 |

Analyzed by: M. Popova, K. Hrilopanova, P. Boneva, N. Filipova, V. Micilkova, E. Asenova; wet analysis; Geological enterprise for laboratory investigations, KG Determination of samples: 41-A-Tp muscovite-biotite-quartz schist; 33-Tp, 34-Tp, 16-Tp bimica quartz-calcitic schists with porphyroblasts: from biotite; 6-Pl-2 calcite-bimica quartz schists with porphyroblasts from biotite; 42-Tp calcite-feldspar-quartz metasandstone; 2-Pl, 4-Pl-1, 37-Tp, 38-Tp bimica plagioclase-quartz schists with porphyroblasts from biotite, garnet and staurolite. The samples marked with Tp are from the Topolovgrad region, while those marked with Pl — from the region of the village of Planinovo.

mical bulk composition corresponds to the marles (О с и п о в а, 1950, after Х в о р о в а, 1958). The second large group of samples (2-Pl, 4-Pl, 4-Pl-1, 37-Tp, 38-Tp) contains  $\text{SiO}_2$  from 57.75 up to 59.49%, while  $\text{Al}_2\text{O}_3$  — from 18.87 up to 20.49% (Table 1). The sum of  $\text{Na}_2\text{O} + \text{K}_2\text{O}$  amounts to 4.41—4.73. The  $\text{Na}_2\text{O}/\text{K}_2\text{O}$  ratio is from 0.37 up to 0.44 while that of  $\text{SiO}_2/\text{Al}_2\text{O}_3$  — from 2.84 up to 3.15. These data as well as the content of Fe and MgO characterize a former clayey rock of a chlorite-hydromica composition. The mica schists analysed in the present paper are more stable with respect to the sums and ratios derived in comparison to the slates of the Vasiljov Formation (Middle Triassic, Sub-Balkanide type). Furthermore, the values of the  $\text{Na}_2\text{O}/\text{K}_2\text{O}$  ratio are considerably higher while those of the  $\text{SiO}_2/\text{Al}_2\text{O}_3$  ratio are smaller. The first one may be explained by the formation of plagioclases while the second one — by the formation of well-individualized aluminosilicates and drawing of  $\text{SiO}_2$  into the quartz veins. The protogenesis of the 41-A-Tp sample is suggested to be clayey sandstone, while that of the 42-Tp — limy feldspar-quartz sandstone (Table 1). The samples (3-Pl, 3-Pl-1, 2/13, 4-Pt-1) marked as quartz amphibolites contain  $\text{SiO}_2$  from 54.80 up to 60.51% (Table 2). The amount of  $\text{Al}_2\text{O}_3$  is from 18.22 up to 20.10%; the amount of  $\text{Na}_2\text{O}$  is higher than that of  $\text{K}_2\text{O}$  except for the 3-Pl-1 sample where biotite is observed. The chemical bulk composition of the samples studied, at a predominantly isochemical metamorphism, allows to be concluded that the protogenesis or the original lithologic composition is connected with the limy-sandy clayey rocks up to limy-clayey sandy ones (but not marls). The samples marked as plagioclase-amphibole-quartz schists (4-Tp-2, 4-Tp-3 and 8-Tp) contain  $\text{SiO}_2$  from 68.81 up to 74.75%. At the same time the amount of  $\text{Al}_2\text{O}_3$  is considerably smaller in comparison with the first group from 10.96 up to

Table 2

Chemical composition (%) of rocks of the Ustrem Formation (Lower Triassic)

| Oxide                   | Sample No |        |        |        |        |        |       |
|-------------------------|-----------|--------|--------|--------|--------|--------|-------|
|                         | 3-Pl      | 3-Pl-1 | 2/13   | 4-Tp-1 | 4-Tp-2 | 4-Tp-3 | 8-Tp  |
| $\text{SiO}_2$          | 54.80     | 56.00  | 59.80  | 60.51  | 68.81  | 71.82  | 74.75 |
| $\text{TiO}_2$          | 0.74      |        | 0.79   | 0.81   | 0.55   | 0.67   | 0.57  |
| $\text{Al}_2\text{O}_3$ | 19.99     | 20.10  | 16.19  | 18.22  | 11.13  | 11.85  | 10.96 |
| $\text{Fe}_2\text{O}_3$ | 2.15      | Σ6.95  | 2.29   | 1.26   | 1.19   | Σ3.00  | Σ3.97 |
| FeO                     | 4.75      |        | 4.41   | 5.22   | 4.01   |        |       |
| MnO                     | 0.29      |        | 0.16   | 0.20   | 0.19   |        |       |
| MgO                     | 2.89      | 2.00   | 3.04   | 1.51   | 2.52   | 1.15   | 1.30  |
| CaO                     | 9.66      | 6.10   | 9.72   | 9.47   | 7.36   | 8.85   | 6.36  |
| $\text{Mg}_2\text{O}$   | 0.60      | 0.53   | 0.89   | 0.60   | 0.50   | 0.20   | 0.51  |
| $\text{K}_2\text{O}$    | 0.47      | 3.55   | 0.28   | 0.21   | 0.16   | 0.13   | 0.14  |
| $\text{P}_2\text{O}_5$  | 0.51      | 0.13   | 0.26   | 00.14  | 0.22   |        |       |
| S                       | 0.09      |        |        | 0.13   | 0.31   |        |       |
| $\text{H}_2\text{O}^-$  | 0.23      |        | 0.57   | 0.19   | 0.23   |        |       |
| $\text{H}_2\text{O}^+$  | 2.68      |        | 1.64   | 1.57   | 2.50   |        |       |
| $\text{CO}_2$           | 0.01      |        |        | 0.03   | 0.01   |        |       |
| Heat loss               |           | 4.00   |        |        |        | 1.95   | 1.20  |
| O≡S                     | 99.82     |        |        | 100.07 | 99.68  |        |       |
|                         | -0.05     |        |        | -0.07  | -0.16  |        |       |
| Sum                     | 99.77     | 99.36  | 100.04 | 100.00 | 99.53  | 99.62  | 99.76 |

Analyzed by: M. Popova, N. Kostadinova, E. Asenova, N. Malinova, V. Micilkova, wet analysis; Geological enterprise for laboratory investigations, KG; S. Kalpakchieva; wet analysis — 2/13; G. Panajotov, M. Levacka; X-ray analysis — 4-Tp-3, 8-Tp; Geological Institute, Bulgarian Acad. Sci. Determination of samples: 3-Pl, 3-Pl-1, 2/13, 4-Tp-1 quartz amphibolites; 4-Tp-2, 4-Tp-3, 8-Tp — plagioclase-amphibole-quartz schists. The samples marked with Tp are from the Topolovgrad region, those marked with Pl — from the region of the village of Planinovo.

11.85%. The content of  $\text{Na}_2\text{O}$  is from 0.20 up to 0.51%. The protogenesis of these rocks was connected with limy-clayey sandy sediments (Table 2). The chemical composition of the carbonate rocks is presented in Table 3.

Most of the element-admixtures studied from the Ustrem Formation are mainly characterized by a content about the clarkie. The metasandstones contain anomalous contents of Sr, Ba, Mn, and Cu (sample 496- $\text{Z}_2$ ). This makes them akin to the metasandstones of the Paleokastro Formation (Table 4). Mica schists and quartz amphibolites exhibit slight anomalous values in the individual samples of Cu (41a-Tp) and Pb (41a-Tp). The marble beds of this Formation have contents mainly about the clarkie for most of the elements (Sr, Zr, Ti, V, Cr, Mn, Cu, Zn, Pb (Table 5)). Ba, Co, and Pb (5-1-Mr) have anomalous values for these rocks. Li, Mn, and Ni have low underclarkie contents. The calcitic and dolomitic marbles of the Mramor Member considerably differ in respect to the Sr content — round the clarkie in the case of the calcitic marbles and under the clarkie in the case of the dolomitic ones (Table 6). The concentrations of Rb, Ba, Co are anomalous and this also concerns Cu and Pb in some samples.

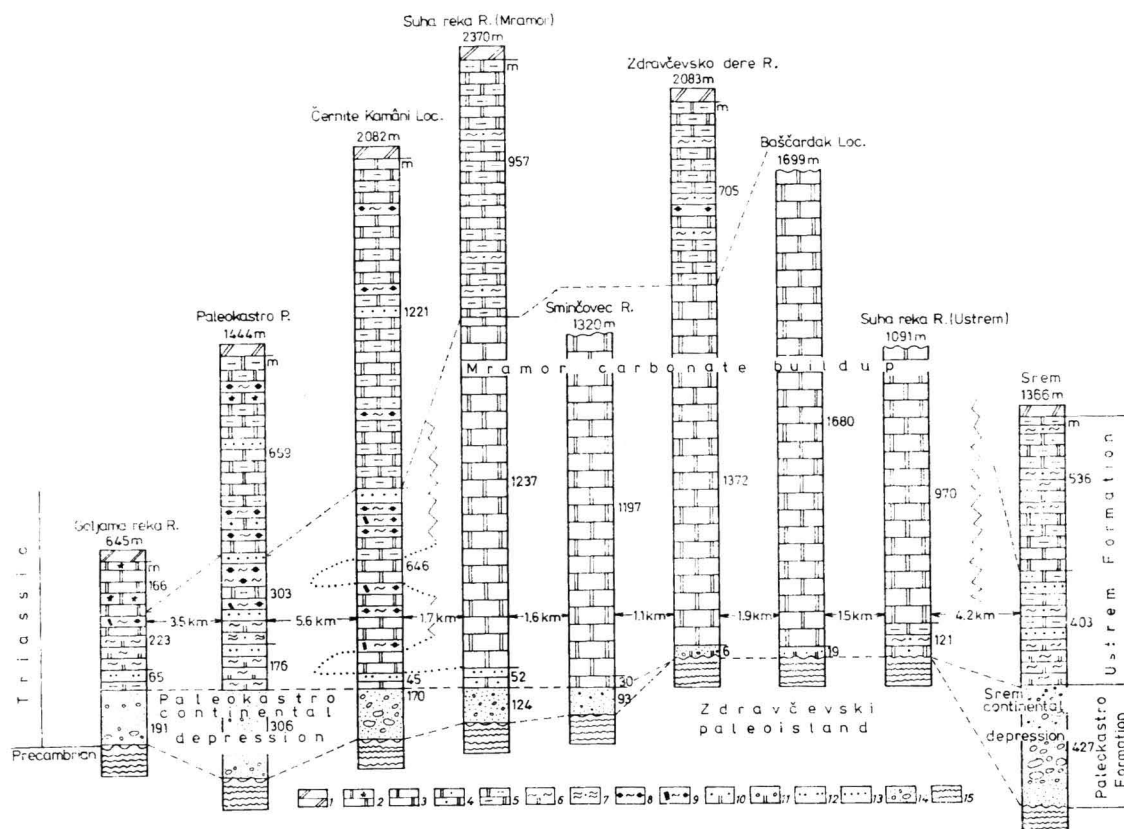


Fig. 3. Column sections of the Paleokastro and Ustrem Formations in the Topolograd Syncline  
1 — dolomitic marbles; 2 — calcite marbles with crinoids; 3 — calcite marbles; 4 — quartz-bearing calcite marbles; 5 — mica-bearing marbles; 6 — quartz-calcite-mica schists ± biotitic porphyroblasts; 7 — quartz-bimica schists; 8 — quartz-mica schists with garnet porphyroblasts; 9 — quartz-mica schists with porphyroblasts from garnet, biotite and staurolite; 10 — metasandstones with calcite cement; 11 — metagavelstones with individual pebble fragments and calcite cement; 12 — metaarkoses; 13 — quartz metasandstones; 14 — metaconglomerates and metasandstones; 15 — gneisses, gneiss-schists and amphibolites

Table 3

Chemical and mineral composition (%) of marbles from the Ustrem Formation (Lower Triassic)

| Sample No | Oxide |       |                   |           | Insoluble residue | Sum    | Oxide            |                                |                                | (Insoluble residue) |                  |                   |                                     | Mineral |        | Sum |
|-----------|-------|-------|-------------------|-----------|-------------------|--------|------------------|--------------------------------|--------------------------------|---------------------|------------------|-------------------|-------------------------------------|---------|--------|-----|
|           | MgO   | CaO   | H <sub>2</sub> O— | heat loss |                   |        | SiO <sub>2</sub> | Al <sub>2</sub> O <sub>3</sub> | Fe <sub>2</sub> O <sub>3</sub> | Na <sub>2</sub> O   | K <sub>2</sub> O | CaCO <sub>3</sub> | CaMg(CO <sub>3</sub> ) <sub>2</sub> |         |        |     |
|           |       |       |                   |           |                   |        |                  |                                |                                |                     |                  |                   |                                     |         |        |     |
| 44-Tp     | 15.50 | 36.30 | 0.30              | 45.50     | 2.00              | 99.60  | 0.70             | 0.90                           | 0.19                           | 0.06                | 0.10             | 26.27             | 70.95                               |         | 99.22  |     |
| 45-Tp     | 8.40  | 43.50 | 0.20              | 43.40     | 4.40              | 99.90  | 2.30             | 1.50                           | 0.32                           | 0.08                | 0.20             | 56.79             | 38.45                               |         | 39.64  |     |
| 5-1-Mr    | 4.50  | 34.00 | 0.30              | 31.80     | 29.48             | 100.08 | 22.00            | 4.80                           | 0.75                           | 0.63                | 1.27             | 49.52             | 20.60                               |         | 99.60  |     |
| 5-2-Mr    | 10.00 | 32.60 | 0.60              | 36.80     | 19.70             | 99.60  | 17.80            | 1.10                           | 0.37                           | 0.19                | 0.20             | 33.36             | 45.77                               |         | 98.83  |     |
| 5-3-Mr    | 2.90  | 47.70 | 0.50              | 40.08     | 7.70              | 99.60  | 4.90             | 1.40                           | 0.96                           | 0.07                | 0.34             | 77.94             | 13.27                               |         | 98.88  |     |
| 5-4-Mr    | 17.90 | 31.60 | 0.30              | 44.40     | 5.60              | 99.80  | 4.40             | 0.70                           | 0.16                           | 0.12                | 0.21             | 11.96             | 81.93                               |         | 99.49  |     |
| 5-5-Mr    | 19.50 | 32.40 | 0.20              | 46.30     | 1.60              | 100.00 | 0.90             | 0.30                           | 0.28                           | 0.06                | 0.03             | 9.41              | 89.26                               |         | 100.27 |     |
| 5-6-Mr    | 18.90 | 32.20 | 0.20              | 46.00     | 2.20              | 99.50  | 0.90             | 1.10                           | 0.14                           | 0.06                | 0.04             | 10.55             | 86.51                               |         | 99.26  |     |
| 4-1-Mr    | 19.30 | 32.20 | 0.20              | 46.50     | 1.40              | 99.60  | 0.90             | 0.30                           | 0.11                           | 0.05                | 0.03             | 9.75              | 88.34                               |         | 99.49  |     |
| 4-2-Mr    | 20.10 | 30.60 | 0.20              | 47.00     | 0.60              | 99.06  | 0.20             | 0.20                           | 0.89                           | 0.03                | 0.01             | 1.98              | 97.04                               |         | 99.62  |     |
| 4-4-Mr    | 0.40  | 43.40 | 0.40              | 34.50     | 21.36             | 100.06 | 18.60            | 1.60                           | 0.66                           | 0.20                | 0.30             | 76.48             | 1.83                                |         | 99.67  |     |

Analyzed by: R. Stojčeva, C. Bičev, E. Stefanova, M. Nikolova; wet analysis; Geological enterprise for laboratory investigations. KG, Deterrmination of the samples: 44-Tp, 5-4-Mr, 5-5-Mr, 5-6-Mr, 4-1-Mr — calcite-dolomitic marbles; 45-Tp, 5-3-Mr — dolomite-calcitic marbles; 5-1-Mr — quartz- and mica-bearing calcite-dolomitic marble; 5-2-Mr — quartz-bearing calcite-dolomitic marble; 4-2-Mr — pure dolomitic marble; 4-4-Mr — quartz-bearing calcitic marble. Quantitative limits at determining the names of the marbles are according to the Rubin's classification (1958) concerning the limy-dolomite-clayey rocks. Samples 44-Tp and 45-Tp are from the Canaklii Member of the Ustrem Formation and are taken from the north-western region of the town of Topolovgrad; all the other samples are from the Mramor Member of the Ustrem Formation and are taken from the south-eastern region of the village of Mramor.

Table 4

Content of rare and dispersed elements (g/t) in rocks from Ustrem Formation (Lower Triassic)

| Sample No                 | Rock                                                 | Li   | Rb  | Sr  | Ba   | Zr  | Ti   | V   | Cr   | Mn   | Co  | Ni  | Cu  | Zn  | Pb |
|---------------------------|------------------------------------------------------|------|-----|-----|------|-----|------|-----|------|------|-----|-----|-----|-----|----|
| 496-Z <sub>1</sub>        | quartz metasediments                                 | 4.5  | 20  | 132 | 70   | 77  | 790  | 20  | 20   | 1902 | 1   | 1   | 7   | 1   | 10 |
| 496-Z <sub>2</sub>        | with calcitic cement                                 | 3    | 73  | 322 | 340  | 66  | 448  | 20  | 20   | 842  | 1   | 1   | 25  | 13  | 20 |
| Clarke of the sandstones* |                                                      |      |     |     |      |     |      |     |      |      |     |     |     |     |    |
|                           |                                                      | 15   | 60  | 20  | XO   | 220 | 1500 | 25  | 35** | XO   | 0.3 | 2** | X   | 15  | 7  |
| 41-Tp                     | bimica quartz schist                                 | 6    | 75  | 420 | 187  | 61  | 1175 | 20  | 20   | 170  | 10  | 4   | 4   | 19  | 10 |
| 41a-Tp                    | bimica quartz schist                                 | 10   | 312 | 746 | 1713 | 277 | 4898 | 80  | 20   | 123  | 4   | 10  | 152 | 104 | 98 |
| 42-Tp                     | feldspar — quartz metasandstone                      | 7.5  | 73  | 109 | 161  | 83  | 1297 | 35  | 20   | 473  | 8   | 9   | 26  | 43  | 60 |
| 36-Tp                     | quartz bimica schists                                | 30   | 195 | 354 | 466  | 158 | 5229 | 134 | 108  | 494  | 18  | 43  | 40  | 32  | 8  |
| 37-Tp                     | with porphyroblast of biotite, garnet and staurolite | 34.5 | 200 | 347 | 637  | 161 | 5593 | 123 | 110  | 509  | 16  | 50  | 40  | 31  | 13 |
| 38-Tp                     |                                                      | 25.5 | 189 | 451 | 657  | 152 | 5212 | 148 | 98   | 469  | 19  | 39  | 41  | 20  | 17 |
| 4-Or                      |                                                      | 31.5 | 163 | 187 | 506  | 169 | 7231 | 136 | 106  | 769  | 8   | 22  | 45  | 40  | 26 |
| 4a-Or                     |                                                      | 28.5 | 133 | 134 | 445  | 189 | 6319 | 111 | 111  | 626  | 8   | 16  | 54  | 108 | 28 |
| 4-Tp-3                    | plagioclase-amphibole                                | 12   | 20  | 662 | 70   | 536 | 3751 | 43  | 24   | 862  | 3   | 19  | 3   | 37  | 20 |
| 8-Tp                      | quartz schists                                       | 12   | 20  | 334 | 70   | 236 | 3374 | 32  | 47   | 1478 | 6   | 22  | 3   | 49  | 25 |
| 3-Pl                      | amphibolite                                          | 12   | 20  | 579 | 70   | 158 | 4692 | 109 | 103  | 1628 | 12  | 45  | 21  | 102 | 17 |
| Clarke of slates*         |                                                      |      |     |     |      |     |      |     |      |      |     |     |     |     |    |
|                           |                                                      | 66   | 140 | 300 | 580  | 160 | 4600 | 130 | 90   | 850  | 19  | 68  | 45  | 95  | 20 |
| Minimum content           |                                                      | 3    | 20  | 104 | 70   | 61  | 448  | 20  | 20   | 123  | 1   | 1   | 3   | 1   | 8  |
| Maximum content           |                                                      | 34.5 | 312 | 746 | 1713 | 536 | 7231 | 148 | 111  | 1902 | 18  | 50  | 152 | 108 | 98 |
| Average content           |                                                      | 17   | 113 | 367 | 415  | 179 | 3847 | 78  | 62   | 796  | 9   | 21  | 35  | 46  | 27 |

Analyzed by: V. Dragostinova, V. Kolarova, T. Nenova (Li, Co, Ni, Cu, Zn, Pb — atom-absorption analysis); G. Panajotova, M. Levacka (Rb, Sr, Ba, Zr, Ti, V, Cr, Mn — X-ray fluorescent analysis); Geological Inst. BAS. The samples are taken from: 496-Z<sub>1</sub>, 496-Z<sub>2</sub> — south of the village of Miramor; 41-Tp, 41a-Tp, 42-Tp, 36-Tp, 37-Tp, 38-Tp, 4-Tp-3, 8-Tp — south-east of the Paleokastro Peak, north-west of the town of Topolovgrad; 4-Or, 4a-Or — south of the village of Orešnik, 3-Pl — west of the village of Planinovo.

\* After Turekian & Wedepohl, 1961 (in Rösler & Lange, 1972).

\*\*X — several g/t; XO — several tens of g/t.

Table 5

Content of rare and dispersed elements (%) in rocks from *Ustrem Formation (Lower Triassic)*

| Sample No               | Rock                                                                   | Li   | Rb  | Sr   | Ba  | Zr  | Ti   | V   | Cr | Mn   | Co  | Ni | Cu  | Zn | Pb  |
|-------------------------|------------------------------------------------------------------------|------|-----|------|-----|-----|------|-----|----|------|-----|----|-----|----|-----|
| 16-Tp                   | quartz-calcitic<br>mica schists with<br>porphyroblasts<br>from biotite | 15.0 | 110 | 748  | 371 | 67  | 2830 | 97  | 38 | 578  | 5   | 16 | 695 | 72 | 22  |
| 16a-Tp                  |                                                                        | 24   | 98  | 1238 | 334 | 74  | 2515 | 48  | 40 | 637  | 5   | 17 | 44  | 62 | 232 |
| 14-Tp                   |                                                                        | 22.5 | 124 | 853  | 357 | 105 | 3178 | 53  | 34 | 348  | 8   | 16 | 16  | 93 | 20  |
| 15-Tp                   |                                                                        | 7.5  | 47  | 422  | 198 | 77  | 1502 | 21  | 26 | 596  | 6   | 11 | 28  | 34 | 34  |
| 33-Tp                   |                                                                        | 7.5  | 101 | 753  | 195 | 68  | 1761 | 61  | 26 | 470  | 7   | 11 | 9   | 46 | 19  |
| 34-Tp                   |                                                                        | 6    | 101 | 745  | 179 | 59  | 1710 | 53  | 33 | 430  | 7   | 9  | 10  | 40 | 16  |
| 35-Tp                   |                                                                        | 9    | 77  | 92   | 140 | 93  | 2266 | 66  | 32 | 293  | 7   | 10 | 20  | 27 | 8   |
| Clarke of slates*       |                                                                        | 66   | 140 | 300  | 580 | 160 | 4600 | 130 | 90 | 850  | 19  | 68 | 45  | 95 | 20  |
| Minimum content         |                                                                        | 6    | 47  | 92   | 140 | 59  | 1502 | 21  | 26 | 293  | 5   | 9  | 9   | 27 | 8   |
| Maximum content         |                                                                        | 24   | 124 | 1238 | 371 | 105 | 3178 | 97  | 40 | 637  | 8   | 18 | 695 | 93 | 232 |
| Average content         |                                                                        | 13   | 94  | 693  | 253 | 78  | 2251 | 57  | 33 | 479  | 6   | 14 | 117 | 53 | 50  |
| 44-Tp calcite-dolomitic |                                                                        | 1.5  | 20  | 556  | 70  | 20  | 110  | 20  | 20 | 84   | 1   | 2  | 4   | 7  | 8   |
| 45-Tp marbles           |                                                                        | 3    | 21  | 607  | 70  | 20  | 246  | 20  | 20 | 85   | 3   | 2  | 3   | 8  | 10  |
| 496 — quartz-bearing    |                                                                        | 1.5  | 20  | 1101 | 70  | 29  | 639  | 20  | 20 | 1483 | 1   | 1  | 10  | 15 | 11  |
| 5-1-Mo marbles          |                                                                        | 1    | 35  | 142  | 101 | 66  | 652  | 20  | 20 | 623  | 10  | 13 | 10  | 35 | 86  |
| Clarke of carbonates*   |                                                                        | 5    | 3   | 610  | 10  | 19  | 400  | 20  | 11 | 1100 | 0.1 | 20 | 4   | 20 | 9   |

Analyzed by: V. Dragostinova, V. Kolarova, T. Nenova (Li, Co, Ni, Cu, Zn, Pb — atom-absorption analysis); G. Panajotov, N. Levačka (Rb, Sr, Ba, Zr, Ti, V, Cr, Mn — X-ray-fluorescent analysis); Geological Institute, BAS. The 496-Z<sub>3</sub> and 5-1-Mr samples are taken from the south region of the village of Mramor, while all the others — from the south-east region of the Paleokastro Peak, north-west of the town of Topolovgrad.

\* After Turekian & Wedepohl, 1961 (in Rösler & Lange, 1972).

Table 6

*Content of rare and dispersed elements (in g/t) in rocks from the Mramor Member of the Ustrem Formation (Lower Triassic)*

| Sample No             | Rock                                    | Li  | Rb | Sr  | Ba | Zr | Ti  | V  | Cr | Mn   | Co  | Ni | Cu | Zn | Pb |
|-----------------------|-----------------------------------------|-----|----|-----|----|----|-----|----|----|------|-----|----|----|----|----|
| 496-Z <sub>5</sub>    | quartz-bearing calcitic marble          | 1.5 | 20 | 155 | 70 | 43 | 148 | 20 | 20 | 412  | 1   | 1  | 13 | 27 | 2  |
| 496-Z <sub>6</sub>    | quartz-bearing dolomite-calcitic marble | 1.5 | 20 | 176 | 70 | 42 | 112 | 20 | 20 | 373  | 1   | 1  | 1  | 15 | 1  |
| 5-2-Mr                | calcite-dolomitic marble                | 1   | 20 | 312 | 70 | 25 | 152 | 20 | 20 | 148  | 1   | 2  | 15 | 26 | 42 |
| 5-3-Mr                | dolomite-calcitic marble                | 12  | 20 | 436 | 70 | 30 | 307 | 20 | 20 | 40   | 5   | 16 | 42 | 39 | 22 |
| 5-4-Mr                | slightly calcite-dolomitic marble       | 1.5 | 20 | 93  | 70 | 39 | 126 | 20 | 20 | 40   | 2   | 4  | 4  | 8  | 21 |
| 5-5-Mr                | "                                       | 1   | 20 | 96  | 70 | 34 | 79  | 20 | 20 | 40   | 1   | 2  | 2  | 4  | 5  |
| 4-1-Mr                | "                                       | 1   | 20 | 83  | 70 | 30 | 17  | 20 | 20 | 40   | 6   | 1  | 13 | 18 | 45 |
| 4-2-Mr                | dolomitic marble                        | 1   | 20 | 88  | 70 | 30 | 67  | 20 | 20 | 40   | 1   | 1  | 3  | 1  | 5  |
| 4-4-Mr                | quartz-bearing calcitic marble          | 1.5 | 21 | 655 | 70 | 30 | 163 | 20 | 20 | 40   | 1   | 1  | 27 | 12 | 13 |
| 4-Mr                  | dolomitic marble                        | 1   | 20 | 20  | 70 | 28 | 98  | 20 | 20 | 40   | 1   | 2  | 10 | 9  | 1  |
| 4a-Mr                 | "                                       | 1   | 20 | 105 | 70 | 33 | 169 | 20 | 20 | 40   | 1   | 1  | 5  | 5  | 9  |
| 5-6-Mr                | slightly calcite-dolomitic marble       | 1.5 | 20 | 108 | 70 | 29 | 72  | 20 | 20 | 40   | 1   | 1  | 14 | 11 | 27 |
| Clarke of carbonates* |                                         | 5   | 3  | 610 | 10 | 19 | 400 | 20 | 11 | 1100 | 0.1 | 20 | 4  | 20 | 9  |
| Minimum content       |                                         | 1   | 20 | 20  | 70 | 25 | 17  | 20 | 20 | 40   | 1   | 1  | 2  | 1  | 1  |
| Maximum content       |                                         | 12  | 21 | 655 | 70 | 43 | 307 | 20 | 20 | 412  | 6   | 16 | 42 | 39 | 45 |
| Average content       |                                         | 2   | 20 | 194 | 70 | 33 | 126 | 20 | 20 | 108  | 2   | 3  | 13 | 14 | 16 |

Analyzed by: V. Dragostinova, V. Kolarova, T. Nenova (Li, Co, Ni, Cu, Zn, Pb — atom-absorption analysis); G. Panajotov, M. Levačka (Rb, Sr, Ba, Zr, Ti, V, Cr, Mn — X-ray-fluorescent analysis); Geological Inst. BAS. The samples are taken from the south region of the village of Mramor.

\* After Turekian & Wedepohl, 1961 (in Rösler & Lange, 1972).

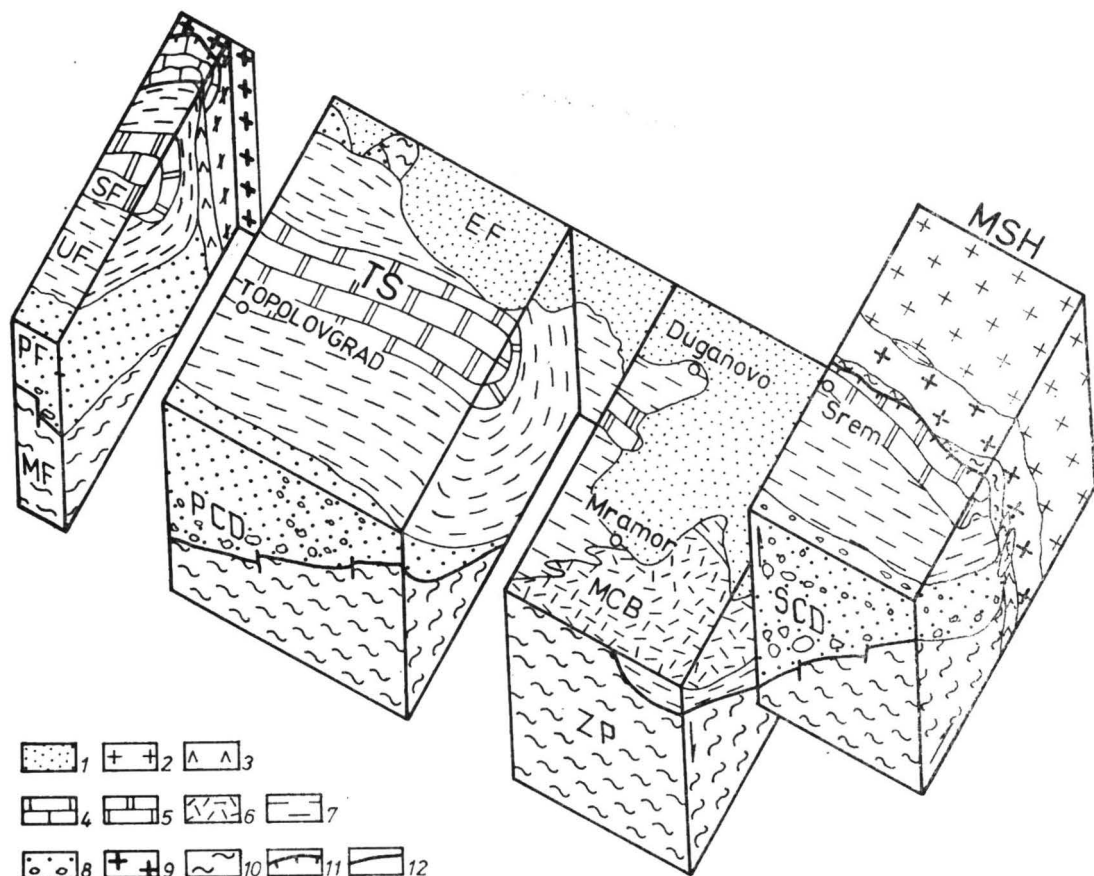


Fig. 4. Block diagram of the Topolovgrad Syncline. The ratio between lithostratigraphic units, basic recent tectonic structures and paleostructure elements

1 — Elhovo Formation (EF) (sands, clays, coals) — Meot-Pliocene; 2 — granites — Upper Cretaceous; 3 — dioritic dyke — Upper Cretaceous; 4 — recrystallized limestones and dolomites — Sub-Balkanide (?) Triassic; 5 — Srem Formation (SF) (calcitic and dolomitic marbles) — Middle Triassic; 6 — Mramor Member of the Ustrem Formation (calcitic and dolomitic marbles) — Lower Triassic; 7 — Ustrem Formation (UF) (silicate and silicate-carbonate crystalline schists and marbles) — Lower Triassic; 8 — Paleokastro Formation (PF) (metaconglomerates and metasandstones) — Lower Triassic; 9 — granites — Paleozoic; 10 — Mladinovo Formation (MF) (gneisses, gneiss schists and amphibolites) — Precambrian; 11 — thrust; 12 — fault; PCD — Paleokastro Continental Depression; SCD — Srem Continental Depression; MCB — Mramor carbonate buildup; ZP — Zdravčevska Paleoisland; TS — Topolovgrad Syncline; MSH — Melnik-Srem Horst.

The vertical and horizontal scales are not equal

#### *Conditions of formation (protogenesis)*

The difficulties with the lithologic investigations or with the protogenetic sedimentologic analysis of metamorphic rocks are well known. The sedimentation of a variegated section consisting of alternating sandstones, clayey and limy sediments, occurred in a shallow, warm marine basin of normal salinity and rather unstable bottom under geosynclinal conditions. Most probably the compensated sinking of the bottom had allowed accumulation only to a part of the Lower Triassic above 2000 m of sediments (Fig. 3). This shows a considerable activity of the tectonic regime. The sea bottom was strongly dismembered. At the beginning of the formation of the sediments south-east of the village of Mramor the so-called Zdravčevska paleoisland existed (Ч а т л о в, 1985),

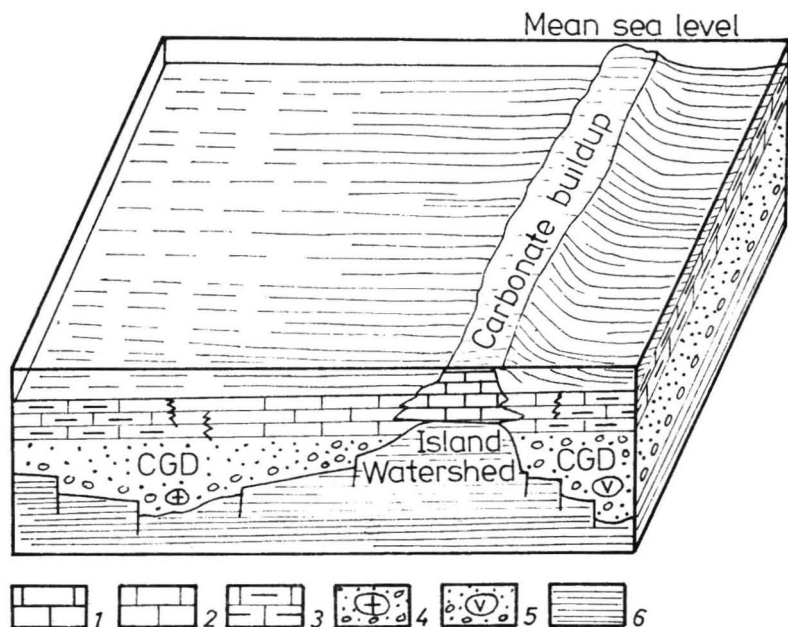


Fig. 5. Model of formation of the continental graben depressions and of the marine carbonate buildup of the Sakar facies type of Triassic 1 — massive limestones; 2 — layered limestones; 3 — clayey layered limestones; 4 — sandstones and conglomerates with individual granitic gravel; 5 — sandstones and conglomerates built up mainly of quartz-porphyrific gravel; 6 — crystalline basement. CGD — continental graben depressions

over which the Mramor carbonate buildup, being a typical reef in terms of shape and size, was formed (Figs 3, 4). Probably the fabric had resulted from an active homogeneous and biogenic sedimentation; it measures up to 1600 m in thickness and about 8 km in length (Fig. 3). A protogenic sedimentologic model on the formation of the Mramor carbonate fabric is presented in Fig. 5. Biogenic processes had been favoured by suitable living conditions during the formation of the Kerimar Member. Organisms were presented by abundant benthos (bivalvia, gastropods, and crinoids). Dry land considerably affected sedimentation. Its influence gradually decreased vertically and at the time of sedimentation of the Čanaklii Member it almost disappeared.

So that two main environments of sedimentation have been distinguished — a shallow marine environment strongly influenced by the dry land and a shallow marine environment void of terrigenous influence characterized by pure warm waters. Terrigenous, terrigenous-carbonate and carbonate sediments precipitated in the first environment, while in the second one a carbonate buildup was formed. The formation of the latter was stimulated by three main factors — increased water temperature, purity of the terrigenous admixtures, and intensively sinking bottom. Both environments existed simultaneously and the facies building them were laterally connected with gradual transition (Fig. 5). Their formation was determined by paleogeomorphologic factors which were the result of particular tectonic conditions.

## Metamorphism

The sediments of the Ustrem Formation have undergone regional dynamothermal metamorphism of medium degree (after the scheme of Winkler, 1974, 1979). The boundary between the low-degree and the medium-degree metamorphism coincides with the incipience of the Eskola amphibolite facies.

The original fabric peculiarities of the rocks of the Ustrem Formation are deleted. The internal bedding of the individual layers is substituted by metamorphic schistose structures. The textures are also altered into metamorphic granoblastic textures exhibiting recrystallization and homogenization of a very high degree. The grains often enter in triple contacts with straight or almost straight boundaries, the angles at the triple points being about  $120^\circ$  or  $120^\circ$  (Plate III, Figs 3, 4; Plate IV, Figs 5, 6; Plate V, Figs 1, 2, 3). This strong tightening and homogenization of the textures are of a great practical importance as to the physicommechanical properties of the carbonate decorative-lining marble.

Metamorphic veins, formed during the metamorphic processes are characteristic. They are built up of quartz. In the region of the village of Planinovo the quartz veins contain a small amount of disthene, biotite, muscovite, and plagioclases. Pure quartz is a particularly valuable raw material.

The first appearance of staurolite in the pelitic rocks from the Topolovgrad district and the Sakar Mountains marks the beginning of the medium-degree metamorphism (=the amphibolite facies). The establishment of parallelly existing staurolite and almandine garnet as contact parageneses determines the presence of staurolite-almandine subfacies in the Topolovgrad Syncline. The establishment of disthene in the region of the village of Planinovo (the Sakar Mountains) existing in paragenesis with muscovite and almandine garnet determines the presence of disthene-almandine-muscovite subfacies. For the time being it is the highest temperature subfacies found out in the Mesozoic (Sakar Triassic) in the Strandža zone. Both subfacies belong to the almandine-amphibolic facies (Винклер, 1969; Тернер & Ферхуген, 1961). The standard disthene-sillimanitic series of metamorphic facies, later becomes popular under the name of facies series of the Barrow type (Винклер, 1969). In the three-membered classification of the barytic types of metamorphism, the facies series of the Barrow type was assigned to the moderate pressures (Миясиро, 1976). The facies series of the Barrow type is characterized by almandine garnet, staurolite and disthene. According to Миясиро (1976) the low-temperature part of the amphibolic facies is characterized by muscovite, biotite, almandine garnet, staurolite and disthene. All these minerals are established in the Sakar Triassic.

On the basis of studies on the mineral composition, the Triassic rocks from the Topolovgrad district and the Sakar Mountains may be related to field IV-D of the mineral facies diagram suggested by Маpакyшeв (1973, Fig. 81)<sup>1</sup>. Biotite-muscovite and staurolitic gneisses and epidotic amphibolites are characteristic of this field. The presence of biotite and common amphibole may be pointed out as a characteristic distinguishing the investigated metamorphites from field III-D, where staurolite is also included. From Marakušev's diagram (Маpакyшeв, 1973) a relative temperature interval, from 450 up to 600 C, and a relative pressure interval, from 1.8 up to 6 sq., are given for the IV-D field.

The temperature values are obtained according to the amphibole-plagioclase and biotite-garnet geothermometer. The initial data ( $X_{Ca} = Ca: (Ca + Na + K)$ ) for the first geothermometer are  $X^{am}$  0.83, 0.84, and 0.84 and  $X^{Pl}$  0.40 — 0.46 respectively for samples 8a-Tr, 4-Tr-1, and 4-Tr-2. The values from the corresponding diagram (Пeпчyк & Pябчиков, 1976, Fig. 82) in the order of the samples are as follows: 525-550, 520-540, and 520-540°C. According to the second geothermometer the initial

<sup>1</sup> Unpublished data obtained by L. Grozdanov and G. Catalon



data — Mg: (Mg+Fe+Mn) — for sample 4-Pl are 0.56 for biotite and 0.14 for garnet. A temperature of 520°C is read from the diagram of the biotite-garnet geothermometer (Перчук & Рябчиков, 1976, Fig. 94).

A diagram of the staurolite stability in the presence of quartz is drawn on the basis of thermodynamic calculations (Перчук & Рябчиков, 1976, Fig. 47). According to this diagram, for temperatures of 520-550°C, the lower stability limit of the staurolite+quartz paragenesis is a pressure of 2.5—3 sq., while the upper stability limit — about 9 sq.

## Conclusion

1. The Ustrem Formation has the largest rock variety with respect to the mineral composition and the largest thickness in comparison with the other Formations building up the Sakar Triassic. Due to this fact it is the most suitable Formation for studies with respect both to the initial sedimentary (protogenetic) conditions and to the degree of metamorphism.

2. The sediments of this formation were formed in the course of marine transgression which was advancing over a continental alluvial plain.

3. Two main environments of sedimentation are distinguished — a shallow-water marine environment strongly influenced by the dry land and a shallow-water marine environment void of terrigenous influence in which the Mramor carbonate buildup grows.

4. The geochemical peculiarities of the rocks are expressed into anomalous (more than 3-4 times higher than the Clarke) concentrations of Rb, Ba, Co and in some samples of Cu and Pb.

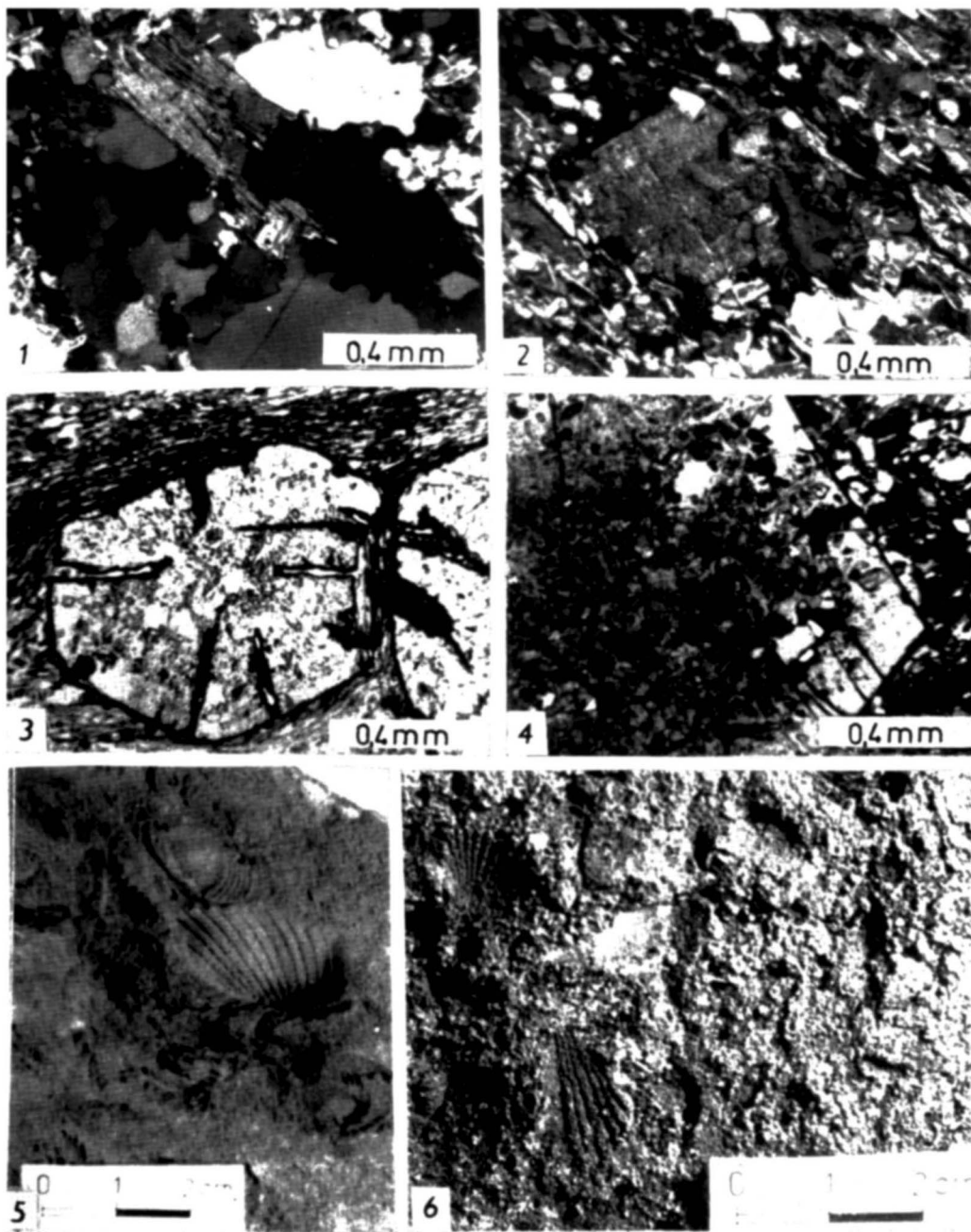
5. The Ustrem Formation sediments have undergone a regional medium-degree dynamothermal metamorphism. Temperatures from 520 up to 550°C are obtained on the amphibole-plagioclase and biotite-garnet geothermometer. The pressure limits (P) are determined within a very wide range — from 3 up to 9 sq.

## References

- Čatalov, G. 1961. Triassische kristalline Schiefer und Magmageschiebe zwischen Haskovo und Dimitrograd. — *C. R. Acad. bulg. Sci.* 14, 5; 503—506.
- Čatalov, G. A. 1985. Notes on the stratigraphy of the Sakar (metamorphic) type of Triassic (South-Eastern Bulgaria). — *C. R. Acad. Bulg. Sci.*, 38, 6; 711—714.
- Folk, L. R. 1968. *Petrology of Sedimentary Rocks*. Austin, Texas, Hemphills'; 170 pp.
- Miyashiro, A. 1961. Evolution of metamorphic belts. — *Journ. Petrol.*, 2; 277—311.
- Rösler, H. J., Lange, H. 1972. *Geochemical Tables*. Amsterdam—London—New York, Elsevier; 466 pp.
- Winkler, H. G. F. 1974. *Petrogenesis of Metamorphic Rocks*. New York—Heidelberg—Berlin, Springer-Verl.; 320 pp.
- Winkler, H. G. F. 1979. *Petrogenesis of Metamorphic Rocks* (5th Edit.). New York—Heidelberg—Berlin, Springer-Verl.; 348 pp.
- Боянов, И., Кожухаров, Д., Савов, С. 1965. Геоложки строеж на южния склон на Сакар планина между селата Радовец и Костур. — *Сп. Бълг. геол. д-во*, 26, 2; 121—134.
- Винклер, Г. 1969. *Генезис метаморфических пород*. М., Мир. 246 с.
- Кожухаров, Д., Боянов, И., Савов, С. 1968. Геология на областта между селата Клокотница и град Марица, Хасковско. — *Геол. инст. БАН и Ком. геол. Юбилеен геол. сборн.*, 37—50.
- Кожухарова, Е., Кожухаров, Д. 1973. Стратиграфия и петрология на докамбийските метаморфни скали от Сакар планина. — *Изв. Геол. инст. Сер. геохим., минер. и петрол.*, 22; 193—213.
- Кожухарова, Е., Кожухаров, Д. 1978. Бележки върху триаския кварц-порфиров магматизъм между с. Клокотница и гр. Марица, Хасковско. — *Сп. Сп. Бълг. геол. д-во*, 39, 3; 335—341.

- М а р а к у ш е в, А. А. 1973. *Петрология метаморфических горных пород*. М., Моск. Унив.; 322 с.
- М и я с и р о, А. 1976. *Метаморфизм и метаморфические пояса* (перевод с англ.), М., Мир; 535 с.
- П е р ч у к, Л. Л., Р я б ч и к о в, И. Д. 1976. *Фазовое соответствие в минеральных системах*. М., Недра; 286 с.
- П е т р о в, Б. 1984. Типизация и физико-механични свойства на естествените декоративно-облицовъчни скали у нас. I. Метаморфни скали. — *Строит. матер. и силикат. пром.*, 9; 15—18.
- Т е о д о р о в и ч, Г. К. 1958. *Учение об осадочных породах*. М.—Л., Гостоптехиздат.
- Т е р н е р, Ф., Ф е р х у г е н, Д ж. 1961. *Петрология изверженных и метаморфических пород*. М., Иностран. лит.; 592 с.
- Х в о р о в а, И. В. 1958. *Атлас карбонатных пород среднего и верхнего карбона Русской платформы*. М., Изд. АН СССР; 169 с.
- Ч а т а л о в, Г. 1970. Строежни части на варовиците. — *Изв. Геол. инст. Сер. стратигр. и литол.*, 19; 137—172.
- Ч а т а л о в, Г. А. 1971. Схеми за големините на строежните елементи при карбонатните скали. — *Сп. Бълг. геол. д-во*, 32, 3; 347—377.
- Ч а т а л о в, Г. А. 1985. Принос към стратиграфията и литологията на Сакарския тип триас (Сакар планина, Югоизточна България). — *Сп. Бълг. геол. д-во*, 44, 2; 127—143.
- Ч а т а л о в, Г. А., Г р о з д а н о в, Л. 1978. Върху петрологията на триаските епидот-калцит-слюдени шисти от Сакар планина и генетичното значение на биотита в тях. — *Геохим., минер. и петрол.*, 9; 80—88.
- Ш у т о в, В. Д. 1967. Класификация песчаников. — *Литол. и пол. ископ.*, 5; 86—102.

PLATE I



## EXPLANATION OF PLATE I

Fig. 1. Metaquartzite with subporphyritic biotite and fine-sclaly muscovite. Texture is quartzite-wise, heteroblastic, granoblastic, strongly packed with rectilinear or microstylolitic jagged contacts between the minerals. Ustrem Formation, Lower Triassic; north of the Paleokastro Peak, north-west of the town of Topolovgrad; thin section 1-Tp, +N,  $\times 50$

Fig. 2. Quartz-muscovite-calcitic schists with porphyroblasts from biotite (in the middle) located at a slant with its basal planes to the main schistosity. The matrix is lepidogranoblastic. Besides the minerals mentioned above, also albite zoisite, zircon, tourmaline, titanite, rutile, apatite, and hematite are present. Ustrem Formation, Guma Member, Lower Triassic; north of the Paleokastro Peak, north-west of the town of Topolovgrad; thin section 1x —K/A,  $\times 50$

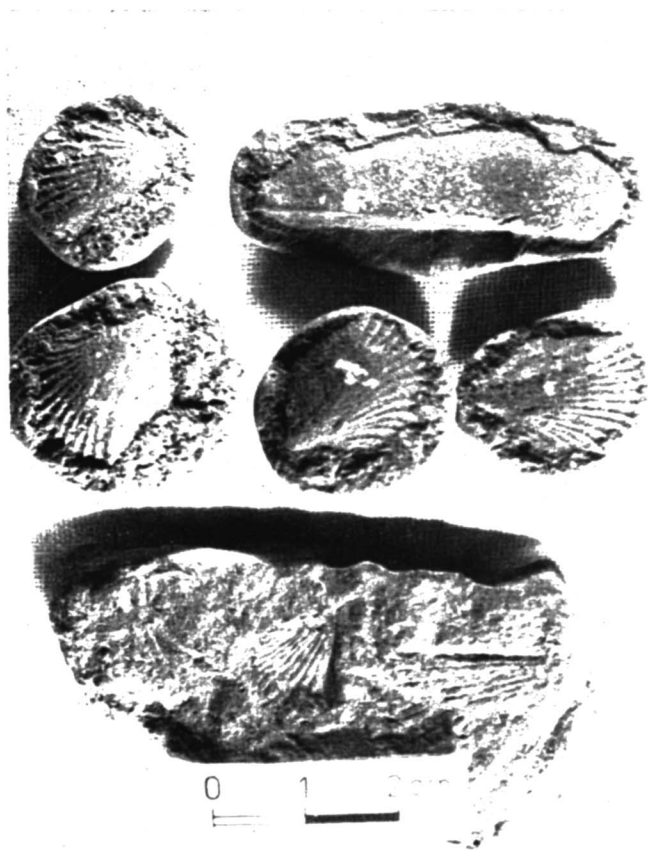
Fig. 3. Rotary garnet porphyroblasts with lining of the matrix, radially cracked, comparatively poor sieve-wise texture due to inclusions of fine-grained drop-wise quartz. Muscovite-quartz schist with porphyroblast from garnet and staurolite. Mineral composition: quartz 45%, muscovite 35%, staurolite 10%, garnet 5%, biotite (subporphyritic), tourmaline and ilmenite, Ustrem Formation, Kerimar Member; Lower Triassic; north of the Paleokastro Peak, north-west of the town of Topolovgrad; thin section 2x — Tp, +N,  $\times 50$

Fig. 4. The same thin section and magnification. Part of a staurolitic porphyroblast of sievewise texture due to abundant quartz and ore mineral inclusions

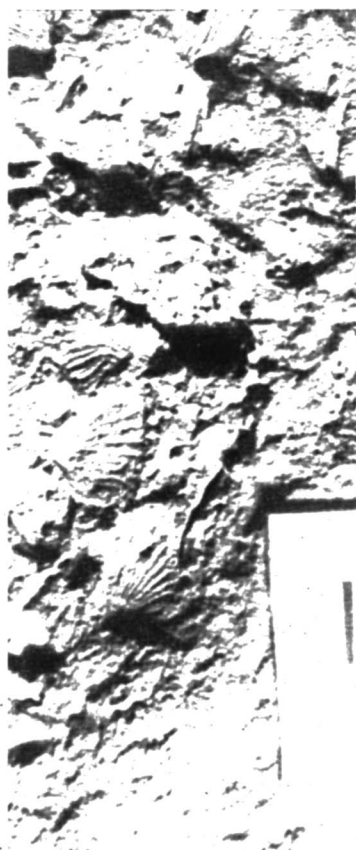
Fig. 5. Bivalvia prints of weathered surface in fine-grained marble. Ustrem Formation, Kerimar Member, Lower Triassic; the locality of Sv. Ivan, south of the town of Topolovgrad

Fig. 6. Weathering surface of quartz-bearing coarse-grained marble with bivalvia prints. Ustrem Formation, Kerimar Member; Lower Triassic; the locality of Sv. Ivan, south of the town of Topolovgrad

PLATE II



1



2



3

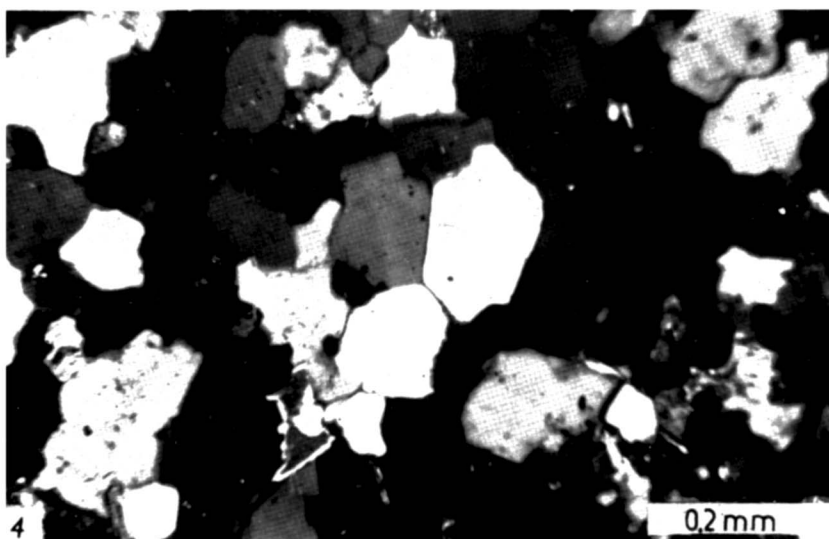
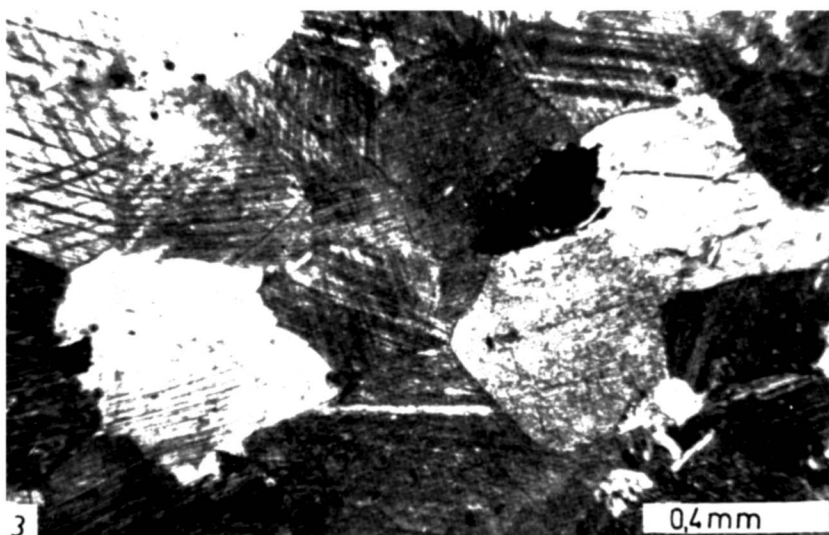
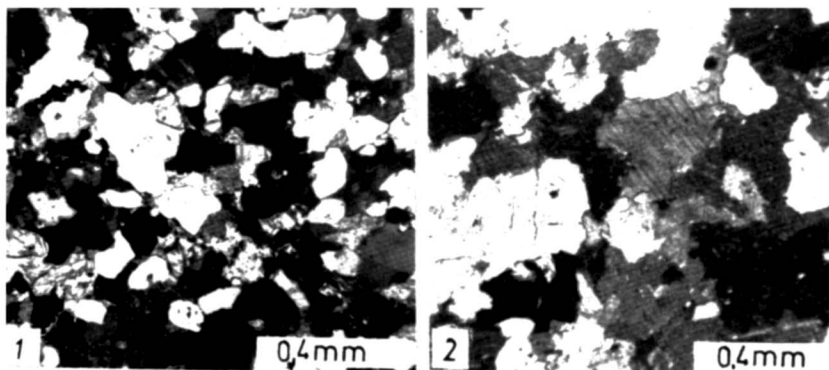
## EXPLANATION OF PLATE II

Fig. 1. Plasticine prints of *Myalina* (at top, in the right) and *Myophoria costata* (Z e n k e r) made on a weathered relictorganogenic surface of quartz amphibolite (the other four samples). Determinations were carried out by Prof. L. R. C o x (British Museum, Natural History, London). Weathering surface of a fragment of quartz amphibolite with relict negative prints of bivalvia (at the bottom). Bivalvia ribs are well expressed also on amphybolic crystals. The most important conclusions that can be drawn concerning this figure are that actual metamorphic reactions proceed in a solid state and that migration of substances is performed at atom distances or at distances not larger than the crystal sizes. Ustrem Formation, Kerimar Member; Lower Triassic; the locality of Sv. Ivan, south of the town of Topolovgrad

Fig. 2. Weathering relictorganogenic surface of quartz amphibolite. The same deposit

Fig. 3. Fresh surface of the same amphibolites

PLATE III



## EXPLANATION OF PLATE III

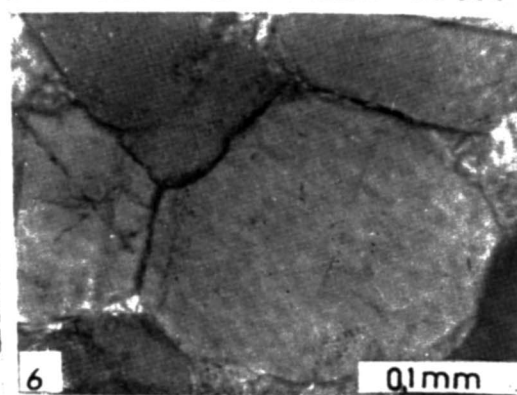
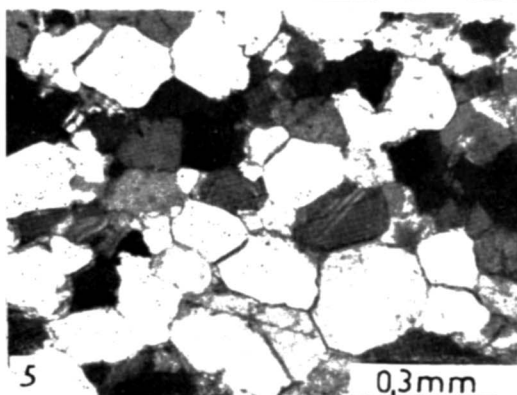
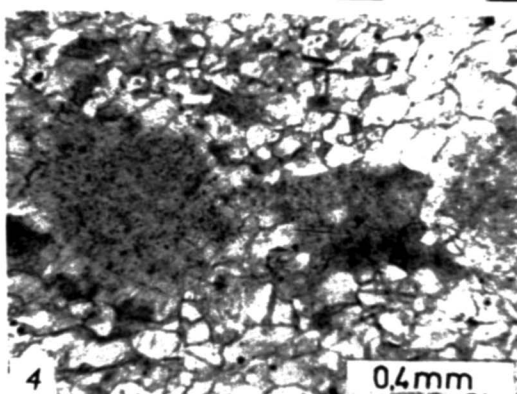
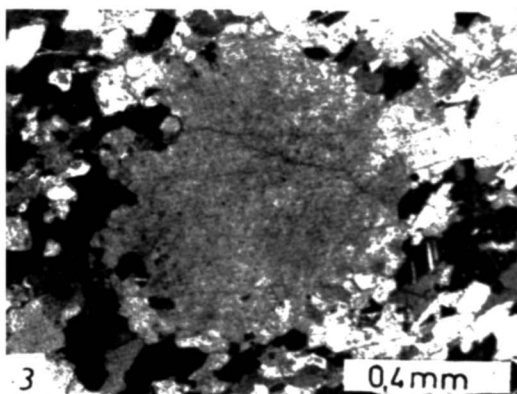
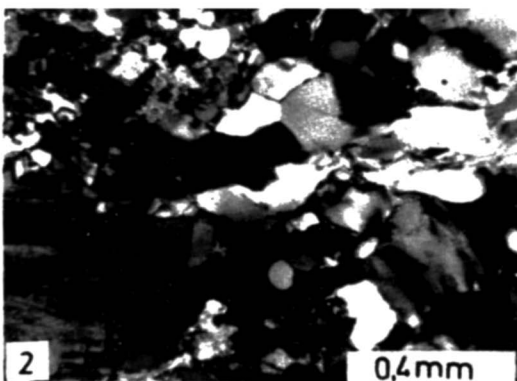
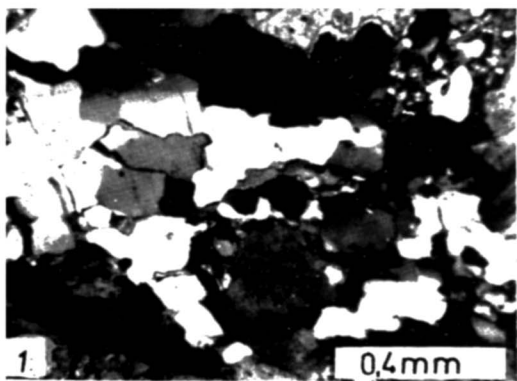
Fig. 1. Fine-grained calcite-quartz metasandstone (0.1—0.25 mm). The former calcitic cement has recrystallized in a way so that calcite grains, as large as the quartz grains, are formed. In this way a biminerall homeoblastic isodiametric granoblastic mosaic is formed. Homogenization and tightening are so well expressed that triple contacts ( $120^\circ$ ) between the calcite and quartz grains are observed. Mineral composition: quartz 55%, calcite 40%, muscovite, biotite, plagioclase, potassium feldspar, zircon, tourmaline, apatite and rutile. Ustrem Formation, Kerimar Member; Lower Triassic; right east of the town of Topolovgrad; thin section t. 15,  $\perp$ N,  $\times 50$

Fig. 2. Medium-up to coarse-grained calcitic marble (0.2—1.5 mm; Ч а т а л о в, 1970) of complex heteroblastic, slightly anisodiametric granoblastic texture. The varieties at the borders between the grains are typical — jagged, incorporational, and conformable. This texture is rarely met under the conditions of this metamorphism and its origin has not been adequately explained. Ustrem Formation, Kerimar Member; Lower Triassic; north of the Paleokastro Peak; thin section 69-Tp,  $\perp$ N,  $\times 50$

Fig. 3. Coarse-grained calcitic marbles (0.5—0.6 mm). Complete homogenization — homeoblastic isodiametric granoblastic texture, strongly tightened with triple contacts between the grains ( $\sim 120^\circ$ ) at rectilinear and slightly curved boundaries. Well-expressed dynamogenic lamellae are also typical. Ustrem Formation, Kerimar Member; Lower Triassic; north of the Paleokastro Peak, north-west of the town of Topolovgrad; thin section 3-Tp,  $\perp$ N,  $\times 63$

Fig. 4. Metaquartzite of homeoblastic isodiametric granoblastic texture. Elements of the most compact packing with triple contacts ( $120^\circ$ ) at rectilinear boundaries (in the middle) are typical. Bivalvia prints have been established in these rocks. Ustrem Formation, Kerimar Member; Lower Triassic; north-east of the Paleokastro Peak, thin section 67a-Tp,  $\perp$ N,  $\times 125$

PLATE IV



## EXPLANATION OF PLATE IV

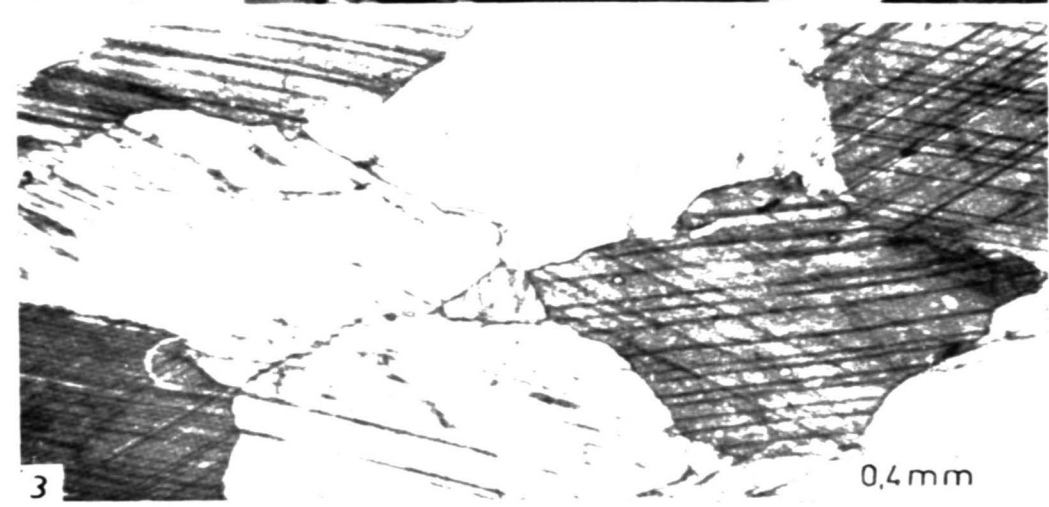
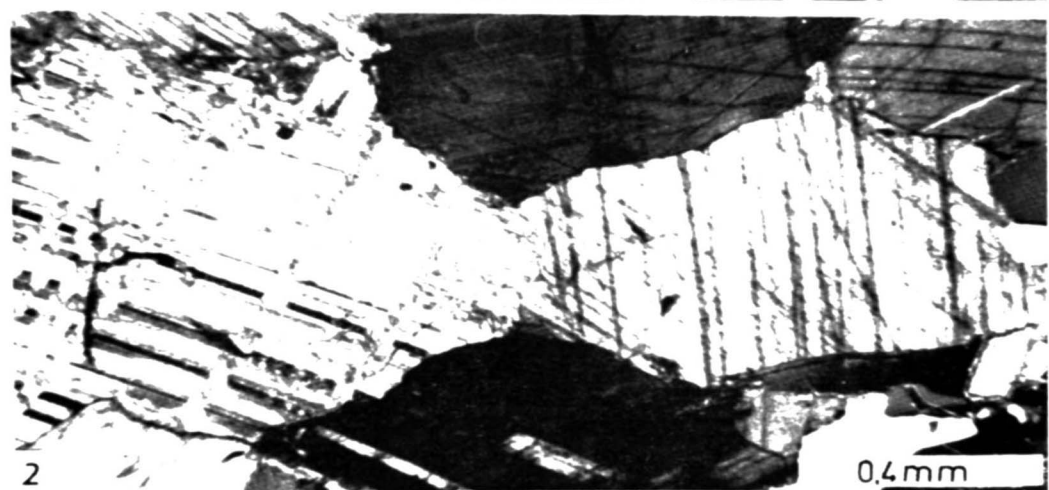
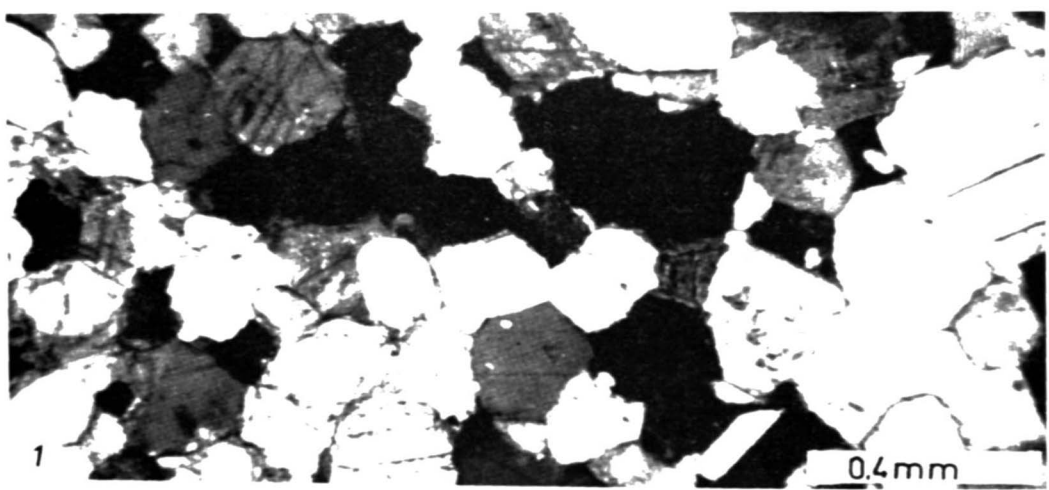
Fig. 1. Medium- and very coarse-grained calcite-quartz metasandstones (0.2—1.2 mm; after F o l k, 1963) of heteroblastic granoblastic texture. The quartz grains form a complex strongly tightened mosaic with varied contacts between the grains — rectilinear, incorporational and jagged. Ustrem Formation, Kerimar Member (transgressive carbonate-terrigenous layers); Lower Triassic; the Zdravčevsko Dere River, south-east of the village of Mramor; thin section 494<sup>1</sup>-Tp, +N,  $\times 50$

Fig. 2. Fine- up to very coarse-grained calcite-quartz metasandstone of heteroblastic granoblastic texture. The metasandstone is characterized by a microcline which is preserved here and by triple contacts ( $120^\circ$ ) at rectilinear boundaries between the quartz grains (at top, in the right). Ustrem Formation, Kerimar Member; Lower Triassic; (transgressive carbonate-terrigenous layers); the Zdravčevsko Dere River, south-east of the village of Mramor; thin section 496<sup>5</sup>-Tp, +N,  $\times 50$

Figs 3, 4. Fine-grained calcitic marble with relics of crinoid fragments. The marginal areas of the crinoid monocrystal are of a fabric quite close to the fabric of quartz grains under tension, affected by degrading recrystallization. In the case, presented here, it is assumed that this texture is a result of the attacking recrystallization of the former micritic matrix. The crinoid monocrystal shows the same resistance, as well as during the processes of dolomitization (Ч а т а л о в, 1970). Ustrem Formation, Mramor Member, Lower Triassic; the Zdravčevsko Dere River, south-east of the village of Mramor; thin section 496-7, +N,  $\times 50$

Fig. 5. Fine-grained slightly calcitic dolomitic marble of homeoblastic isodiametric granoblastic texture. A maximum compact packing of isodiametric polyhedrals with frequent triple contacts ( $120^\circ$ ) characterizes the texture. The dynamogenic lamellae are comparatively poorly expressed. Srem Formation; Middle Triassic; the locality of Karaibrjajmova Češma, north-west of the town of Topolovgrad; thin section 46-Tp, +N,  $\times 63$

Fig. 6. A detail of the same thin section (Fig. 5). A maximum compact packing with triple contacts and almost hexagonal sections is presented,  $\times 200$



## EXPLANATION OF PLATE V

Fig. 1. Fine-grained slightly calcitic dolomitic marble (0.1—0.3) (Т е о д о р о в и ч, 1958). The texture is strongly tightened homeoblastic isodiametric granoblastic. The grains are "rounded" in a different degree; they are polyhedral and rarely rhombohedral. Dynamogenic lamellae are thin stripes and are rarely met. Triple contacts ( $120^\circ$  or  $\sim 120^\circ$ ) are usual. The dolomitic marbles of the Mramor Member, used as decorative-venetting rocks, are of the hardest dolomites in Bulgaria (И т р о в, 1984). Ustrem Formation, Mramor Member; Lower Triassic; the locality of Drănci Dupka, south-east of the village of Mramor; thin section 5-5-Mr,  $\perp N$ ,  $\times 63$

Fig. 2. Quartz-bearing, medium- up to coarse-grained calcitic marble (0.4—2 mm; Ч а т а л о в, 1971). Homeoblastic texture, almost isodiametric, complete homogenization and extremely large grains. The most intensively developed dynamogenic lamellae in the Triassic in the region of Topolovgrad are also observed here. During recrystallization silicates "push out" one another and recrystallize in the interspaces, mainly round the triple contacts (at the bottom, in the right) and in some rare cases they are inserted poikilitically into the marginal parts of the calcitic crystals. They are presented by quartz (5%) and by single crystals of albite, potassium feldspar and muscovite. Ustrem Formation, Kerimar Member (right above the basaltic transgressive layer); Lower Triassic; the Zdravčevsko Dere River; south-east of the village of Mramor; thin section 496 —  $Z_3$ ,  $\perp N$ ,  $\times 63$

Fig. 3. The same thin section and magnification. Well-expressed triple contacts ( $\sim 120^\circ$ ) are presented. They are with almost erect walls and strongly developed dynamogenic lamellae. The presence of a triangular prism in the centre is an expression of a maximum tightening as well