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# Palaeotemperatures of the Jurassic and Early Cretaceous of Bulgaria according to the Isotopic Oxygen Composition of Belemnites Guards

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*Р. В. Тейс, Д. П. Найдин, М. Стоянова-Вергилова — Юрские и раннемеловые палеотемпературы Болгарии по данным изотопного состава кислорода в рострах белемнитов.* Проведены палеотемпературные исследования по изотопам кислорода в рострах юрских и нижнемеловых белемнитов из Болгарии. Подсчитанные палеотемпературы для различных юрских веков подтверждают представление о том, что юрский период отличался теплым климатом с периодами похолодания, приуроченными к позднему байосу и бату. Исключительно высокие „палеотемпературы" для тоарса и раннего байоса (25—39,9°С), соответствующие данным, полученным по Швабской Юре и Сибири, объясняются эвентуально какой-то еще неизвестной глобальной особенностью водного фона морей Евразии в тоарсаалене.

Палеотемпературы раннего мела в Болгарии ниже и равномернее юрских. Более устойчивое понижение температур, но с незначительной средней амплитудой, выявляется в апте. Эти результаты указывают на значительное сходство температурных условий в раннемеловом бассейне Северо-Восточной Болгарии в течение отдельных веков. Бассейн и примыкавшая суша находились в зоне умеренного климата.

*Abstract*. Oxygen isotope palaeotemperature measurements of Jurassic and Lower Cretaceous belemnite rostra from Bulgaria have been carried out. The palaeotemperatures calculated for various ages of the Jurassic come to confirm the conception for the existence of warm climate in the Jurassic period, alternating with periods of cooling in the Late Bajocian and Bathonian. The estimations for the Toarcian and the Early Bajocian extremely high "palaeotemperatures" (25°-39.9°C), which agree with data on the Schwabian Jurassic and on Siberia, may get a probable explanation with certain global peculiarity, still unknown, of the water background of the seas in Eurasia during the Toarcian - Aalenian.

The values of the palaeotemperatures of the Early Cretaceous in Bulgaria are lower and more constant than those for the Jurassic. A more stable decrease is outlined in the Aptian which however has a lower average amplitude. These results indicate that temperatures in the basin of North-Eastern Bulgaria were very similar in the different ages of the Early Cretaceous and that the corresponding zone may be referred to the moderate climate zone.

Temperature measurements of the water in marine basins of the geological past are of great importance for a number of palaeogeographic and palaeoclimatic conclusions. Without underrating the part played by biological and other indices in that respect, the attention of researchers is directed towards getting results by other means, too, physico-chemical in particular, in recent years. That is how the method of oxygen isotope palaeothermometry and other chemical-analytical methods have been developed. This paper reports the results from isotope palaeotemperature measurements on material originating from Bulgaria. This in point of fact is the first attempt to interpret on this basis the palaeotemperature conditions in the basins of this country's territory in the Jurassic and the Early Cretaceous.

The theoretical basis of the method of isotope palaeothermometry, evolved by Urey et al. (1954), as well as the results obtained from its application in the past twenty years, are put forward in detail by Bowen (1966) and by Тейс & Найдин (1973). The oxygen isotope composition of the carbonates is analyzed and the rostra of the Mesozoic belemnites proved to be the most favourable for this purpose. Belemnites, owing to the compactness of their rostra, retain the initial oxygen isotope composition for a long while. The results from the measurements, effected with a mass-spectrometer, are determined in the promilies of the equation:

$$\delta O^{18} = \frac{R \text{ of the sample} - R \text{ of the standard}}{R \text{ of the standard}} \; 1000, \text{ where } R = 0^{18}/0^{16}.$$

$O^{18}$ distribution between the water and the carbonate, deposited from it, depends on the temperature: the lower the temperature is, the greater the significance of $\delta O^{18}$. In addition to the temperature, however, the $O^{18}$ concentration in organogenic carbonates is also determined by the so-called aquatic background — the oxygen isotope composition of the water, determined by various factors. The aquatic background alters with the inflow of fresh water, with the mixing of the ground water and in the case of evaporation. In many cases, the results are affected also by diagenetic changes in the rostra.

The isotope palaeotemperature analyses used here have been carried out in the Laboratory for Stable Isotopes at the Institute of Geochemistry and Analytical Chemistry, jointly with the Moscow State University. Rostra from the collection of Jurassic and Lower Cretaceous belemnites, arranged systematically in the Higher Mining and Geological Institute in Sofia, were studied. The material was obtained from Western Bulgaria, some areas of the Fore-Balkan, the eastern part of the Stara Planina Range and from Central and North-Eastern Bulgaria, They are of Pliensbachian, Toarcian, Bajocian, Bathonian, Callovian, Tithonian, Valanginian, Hauterivian, Barremian, Aptian and Albian age. Owing to the lack of material that has been systematically arranged, no measurements have been made from Sinemurian, Oxfordian, Kimmeridgian and Berriasian belemnites, while from Bajocian, Valanginian and Albian measurements, which are sparse and insufficient, no exact interpretations are possible.

## Results from Analyses of Jurassic Belemnites

The measurement of $\delta O^{18}$ in a *Catateuthis apicicurvata* (Bl.) rostrum from the Lower Pliensbachian in Western Bulgaria (Zabărdé) made it possible to calculate the mean annual palaeotemperature of the water, in which the rostrum was formed — 23.0°C, and in the rostra of *Passaloteuthis* sp., 23.4° and 23°C. Rostra have been found in sandy organogenic crystalline limestones having leptochloritic oölites filled with remains of ammonites (genus *Androgynoceras*), bivalva, brachiopods, etc. The rostra are elongated and tapering towards the apex and belonged probably to animals inhabiting surface shallow waters of the sublittoral zone. The relatively high palaeotemperatures in this case could be due to the fact that the rostra were formed in warm, well insolated waters.

The palaeotemperatures of the Late Pliensbachian have been studied by rostra taken from four localities: in the Western Stara Planina Range (the villages of Ginci and Zimevica, District of Sofia), in Western Bulgaria (the village of Bukorovci, District of Sofia) and in the Eastern Stara Planina Range (the village of Tărnak, area of Aytos).

In the first three localities the belemnites were obtained from marls, which alternate with aleurolitic and clayey limestones and contain small phosphoritic concretions. They have been formed in a depression of the neritic zone. The rostra analyzed (representatives of the genus *Passaloteuthis*) are nectonic and lived probably in deeper waters too. In spite of this, however, the values of $\delta O^{18}$ obtained are lower in comparison with those of the Early Pliensbachian. Thus, from *Passaloteuthis rudis* Liss. and from *P. laevis* (Simps.) from the village of Ginci, District of Sofia, the mean annual palaeotemperatures have been calculated: 26.5° and 28.9°C, respectively, and from *Passaloteuthis* sp. and from *P.* cf. *ridgensis* Lang from the village of Zimevica, 33.5° and 25.4° C, respectively. *P. bruguieriana* (d'Orb.) specimens from Western Bulgaria (the village of Bukorovci) show a $\delta O^{18}$ isotope composition of —2.13 and —0.33‰, which corresponds to palaeotemperatures of 25.1° and 16°C, or 20.5°C on an average. The species has a large, solid guard with a rounded apex and a nekto-benthonic way of life may be assumed for it.

From the Upper Pliensbachian rostra from the village of Tărnak, area o Aytos (Начев et al., 1967, ascribe an olistostrome origin to these outcrops), have been calculated palaeotemperatures of 24.1° C from *P. striolata* (Phill.), of 32.5° C from *P. rudis* Liss., and of 27.7° C from *Orthobelus rudis* (Phill.). They have been obtained from the layers constituting a frequent and continuous alternation of thin intercalations of organogenic limestones (crynoids and brachiopods) with sandy marls. In this locality the rostra are accumulated in a vast amount, both in the limy and marly intercalations, and represent genuine "battle fields" In all probability a warm current passed there.

Significant temperature differences (16°, 25° and 33.5°C) have been obtained for the Late Pliensbachian in general. In comparison with the palaeotemperatures for the Early Pliensbachian, there they manifest a considerable rise, particularly when the relatively deeper water nature of the sediments, from which the rostra have been obtained, is taken into account.

The exceptionally low $\delta O^{18}$ values have been obtained from Toarcian rostra. Analyses have been made on belemnites from three localities: the town of Teteven, the village of Polaten (area of Teteven) and the village of Bov (District of Sofia). A palaeotemperature of 25.5°C, the lowest for the Toarcian, has been calculated from the Lower Toarcian near the town of Teteven (from the Tenuicostatum Zone to the Bifrons Zone) from *Dactyloteuthis* aff. *irregularis* (Schloth.). This species possesses short solid guards with a blunt apex, adapted probably for a nekto-benthonic way of life. The rest of the guards manifest considerably higher "palaeotemperatures": above 30°C, e.g. *Acrocoelites quenstedti* (Oppel), 33.2⁰C and *Mesoteuthis janenschi* (Ernst), 34.0⁰C. All of them have been found in marly layers containing thin limy layers and leptochloritic oölites in the Vărbančovec locality. Along with the belemnites, numerous ammonites (*Hildoceras, Harpoceras*) and almost no benthonic fauna, are found in them.

From *M. conoidea* (Oppel) in the lithologically similar layers near the village of Polaten, the lower part of the Upper Toarcian (Thouarsense Zone; I. Sapunov — a verbal communication) also a low value of $\delta O^{18}$ (— 3.51), corresponding to 33.2$^0$C, has been obtained.

The lowest $\delta O^{18}$ values are those of the belemnite guards from the Upper Toarcian (Levesquei — Moorei Zones) near the village of Bov, District of Sofia, included in the dark marls, having more limy intercalations and lenses. The highest "palaeotemperatures" have been measured from *M.* cf. *inornata* (Phill.) — 38.4$^0$C, and from *Acrocoelites subtriscissus* Kolb, 39.9$^0$ C.

These exceptionally high values of the "palaeotemperatures" of the Toarcian, measured from rostra of deep-water, normally saline sediments, raise doubts concerning their authenticity (Fig. 3). Owing to the considerable interest in this question, it will be examined in greater detail further on.

Low $\delta O^{18}$ values have been established also from analyses of guards from the Lower and Middle Bajocian [Aalenian is not used as an independent stage in Bulgaria. It corresponds to the Lower Bajocian Substage, which embraces the interval from the Opalinum Zone to the Concavum Zone (Sapunov & Stephanov, 1964)]. The number of the measurements (one each for the three substages of the Bajocian) is not sufficient to formulate well-grounded conclusions, yet a certain trend is at hand. Thus, for instance, from *Holcobelus blainvillei* (Voltz) from the dark argillites of the Lower Bajocian near Teteven (Concavum Zone), a palaeotemperature of 30.1$^0$ C ($\delta O^{18}$=—3.17) has been measured. From *Megateuthis elliptica* (Mill.) a palaeotemperature of — 34.8$^0$ C ($\delta O^{18}$=—3.76‰) has been measured for the Middle Bajocian in Etropolé (Sowerbyi Zone). These guards possess a morphology of good swimmers and the dark Bajocian argillites are the most deep-water formation in the Middle Jurassic in general. Owing to this, these "palaeotemperatures" are higher than the expected ones for the corresponding conditions under which the belemnites deposited the limy substance of their rostra.

A leap in the change of $\delta O^{18}$ values is at hand barely in the Late Bajocian, when the value —0.29 has been obtained from *Belemnopsis* sp., corresponding to a temperature of 16$^0$C. The guard is solid, possibly a representative of the nektobenthos found in the deep-water marly sediments near the village of Belotinci, area of Belogradčik. The low palaeotemperature of the Late Bajocian remains distinct for those of the Early and Middle Bajocian in Bulgaria, but is in agreement with the low values obtained for the Late Bajocian in other countries.

A somewhat higher palaeotemperature (20.1$^0$C) is calculated from *Belemnopsis parallelus* (Phill.), originating from the Upper Bathonian marly layers in the village of Belotinci, area of Belogradčik.

By measuring the $\delta O^{18}$ in the calcite of guards from the Middle Callovian and the Tithonian, again a decrease in their values is established. From *Hibolites hastatus* (Bl.) of the Middle Callovian near the village of Gaganica, District of Mihaylovgrad, a value of —1.25 (25.8$^0$C) has been obtained for $\delta O^{18}$, and from *Conobelus strangulatus* (Opp.) from the Tithonian near the village of Plešivec, District of Vidin, —1.87‰ (23.6$^0$C). This rise in the mean annual palaeotemperatures coincides with the formation of the compact limestones of the Upper Jurassic carbonate complex, which constitute facies of the open sea.

Table 1

*$\delta O^{18}$ Values and Palaeotemperatures Measured from Belemnites of the Jurassic in Bulgaria*

| Sample No. | Species | Locality | Age | $\delta O^{18}$ ‰ Non-heated | Heated | ‰ Difference | T°C |
|---|---|---|---|---|---|---|---|
| 327 | *Catateuthis apicicurvata* (Bl.) | Berendé-Izvor, near Sofia | Lower Pliensbachian | —1.79 | —1.74 | +0.05 | 23.0 |
| 328 | *Passaloteuthis* sp. | Berendé-Izvor | » | —1.78 | —1.82 | —0.04 | 23.4 |
| 329 | *Passaloteuthis* sp. | Berendé-Izvor | » | —1.87 | —1.76 | +0.11 | 23.0 |
| 313 | *Passaloteuthis rudis* Liss. | Ginci, near Sofia | Upper Pliensbachian | —1.96 | —2.80 | —0.84 | 28.9 |
| 314 | *P. laevis* (Simp.) | Ginci | | —2.30 | —2.40 | —0.10 | 26.5 |
| 318 | *P. rudis* Liss. | Trănak, near Aytos | | —2.71 | —3.38 | —0.67 | 32.5 |
| 316 | *Orthobelus rudis* (Phill.) | Trănak | | —2.56 | —2.60 | —0.04 | 27.7 |
| 317 | *P. striolata* (Phill.) | Trănak | | —1.81 | —1.96 | —0.15 | 24.1 |
| 300 | *P. bruguieriana* (d'Orb.) | Bukorovci, near Sofia | | —1.94 | —2.13 | —0.19 | 25.1 |
| 301 | *P. bruguieriana* (d'Orb.) | Bukorovci | | —0.11 | —0.33 | —0.22 | 16.0 |
| 302 | *Passaloteuthis* sp. | Zimevica, near Sofia | | —3.49 | —3.55 | —0.12 | 33.5 |
| 315 | *P.* cf. *ridgensis* Lang. | Zimevica | | —1.83 | —2.27 | —0.44 | 25.4 |
| 322 | *M. janenschi* (Ernst) | Teteven | Lower Toarcian | —3.33 | —3.63 | —0.30 | 34.0 |
| 319 | *Megateuthis coniformis* Ernst. | Teteven | | —3.06 | —3.33 | —0.27 | 32.2 |
| 320 | *Acrocoelites quenstedti* (Oppel) | Teteven | | —3.09 | —3.51 | —0.42 | 33.2 |
| 321 | *Salpingoteuthis* aff. *blomenhofensis* Kolb | Teteven | | —3.02 | —3.43 | —0.41 | 32.8 |
| 330 | *Dactyloteuthis* aff. *irregularis* (Schloth) | Teteven | | —2.90 | —2.40 | +0.50 | 25.5 |
| 323 | *Mesoteuthis conoidea* (Oppel) | Polaten, near Teteven | Lower part of Upper Toarcian | —2.87 | —3.51 | —0.67 | 33.2 |
| 324 | *Acrocoelites triscissus* (Yane) | Bov, near Sofia | Upper Toarcian | —4.86 | 3.82 | +1.04 | 35.2 |
| 325 | *A. subtriscissus* Kolb. | Bov | » | —4.72 | —4.48 | +0.22 | 39.9 |
| 326 | *Mesoteuthis* cf. *inornata* (Phill.) | Bov | » | —4.13 | —4.29 | —0.16 | 38.4 |
| 312 | *Holcobelus blainvillei* (Voltz) | Teteven | Lower Bajocian | —2.73 | —3.17 | —0.44 | 30.1 |
| 303 | *Megateuthis* cf. *elliptica* (Mill) | Etropolé | Middle Bajocian | —2.85 | —3.76 | —0.91 | 34.8 |
| 300 | *Belemnopsis* sp. | Belotinci, near Vidin | Upper Bajocian | —0.11 | —0.29 | —0.18 | 16.0 |
| 301 | *Belemnopsis parallelus* (Phill.) | Belotinci | Upper Bathonian | —0.64 | —1.18 | —0.54 | 20.1 |
| 398 | *Hibolites hastatus* (Bl.) | Gaganica, near Mihaylovgrad | Middle Callovian | —1.74 | —2.25 | —0.51 | 25.8 |
| 311 | *Conobelus strangulatus* (Oppel) | Pleševec, near Vidin | Tithonian | —1.57 | —1.87 | —0.30 | 23.6 |

## Results from Analyses of the Lower Cretaceous Rostra

Figures which are of low value and are very different have been obtained for $\delta O^{18}$ from two Valanginian rostra of *Duvalia lata* (Bl). From guards of the Lower Valanginian aleurolitic marls, alternating with the thick-layer sandstones near the village of Gorno Šipkovo, area of Troyan, a $\delta O^{18}$=—2.29‰ has been obtained, and by the same manner, from the flyschoid formation in the area of Veliko Tărnovo, —3.76 (temperatures of 25.9° and 34.7° C, respectively). These rostra proved to be in the deep-water sediments in the thanatocoenosis, but still one of these values, possibly the higher one, should be accepted as a random one.

Belemnite guards in sediments, formed from the Hauterivian up to the Aptian, yielded relatively high $\delta O^{18}$ values, while the mean annual palaeotemperatures are lower.

Two rostra of *Pseudoduvalia polygonalis* (Bl.) have been analyzed from the Lower Hauterivian glauconite clayey-carbonate rocks, having rare phosphoritic concretions (Cultrata Zone) near Teké-Deré in Šumen. The palaeotemperatures calculated are 20.2° and 17.7°C or the mean of two measurements is 18.9°C. Similar values have been obtained also from two *D. dilatata* (Bl.) rostra, originating from a slightly higher level (the lower part of the Upper Hauterivian Sayni Zone)— 17.3° and 21.1°C, or 19.2°C on an average. These rostra possess the morphological characters of good swimmers and could have lived doubtlessly in somewhat deeper water, but the temperatures measured are typical of surface waters of a quite warm sea.

The oxygen isotopes of 13 guards belonging to different species have been analyzed from the Barremian clayey marls and slightly limy clays in North-Eastern Bulgaria. From a short and thick guard of *Curtohibolites oosteri* St.-Verg. and from a small and thin guard of *Hibolites mirificus* St.-Verg. from the Lower Barremian near the village of Podgorica, the mean annual palaeotemperatures have been calculated, 19.6° and 21.9°C, respectively. In analyzing the calcite of three specimens *D. binervia* (Rasp.) from the Lower Barremian in the town of Tărgovišté (Emerici Zone) palaeotemperatures of 15.6°, 18.6° and 20.9°C, or 18.3°C on an average, have been calculated. These guards could be found in the deep-water Barremian marls likewise only in the thanatocoenosis, since they resemble passively-swimming forms by their morphological characters. The palaeotemperatures obtained in this case seem to be feasible.

The temperatures calculated from the guards coming from Barremian layers that have not been exactly dated (possibly the very base of the Upper Barremian) near the villages of Svetlen, Zaraevo and Golyamo Novo, District of Tărgovišté, are within the 18°-21.6°C range. For instance, palaeotemperatures of 17.8° and 21.6°C, or 19.7°C on an average, have been measured from two specimens of *Mesohibolites varians* (Schw.) 18.6° C from *M.* cf. *shaoriensis* (Hetch.), etc.

From two specimens of *M. beskidensis* (Uhlig.) from the Upper Barremian in the villages of Podgorica and Golyamo Novo, District of Tărgovišté, $\delta O^{18}$ values = —1.09 and —0.40‰ have been obtained, which correspond to temperatures of 19.6° and 16.3° C, and from a *D. grasiana* (Duv.-Jouve) —1.57, or a mean annual palaeotemperature of 22.2°C.

Obviously, the $\delta O^{18}$ values for the Barremian are limited within a not very wide range, from —0.73 to —1.55‰, or to temperatures from 18.2° to 21.9°C, respectively, excluding the lowest values from —0.26 and —0.40‰, which are

Table 2

*δO¹⁸ Values and Palaeotemperatures Measured from Belemnites of the Lower Cretaceous in Bulgaria*

| Sample No. | Species | Locality | Age | δO¹⁸, ‰ Non-heated | ‰ Heated | ‰ Difference | T°C |
|---|---|---|---|---|---|---|---|
| 530 | *Duvalia lata* (Bl.) | Yovkovci, near Veliko Tărnovo | Valanginian | —3.76 | —3.76 | 0.00 | 33.8 |
| 533 | *Duvalia lata* (Bl.) | Troyan area | „ | —2.13 | —2.29 | —0.16 | 25.9 |
| 521 | *D. polygonalis* (Bl.) | Teké-Deré, Šumen | Lower Hauterivian | —0.67 | —1.22 | —0.55 | 20.2 |
| 522 | *D. polygonalis* (Bl.) | Teké-Deré | „ | —0.71 | 0.71 | 0.00 | 17.7 |
| 527 | *D. dilatata* (Bl.) | Teké-Deré | The lower part of the Upper Hauterivian | —0.84 | —0.61 | +0.23 | 17.3 |
| 528 | *D. dilatata* (Bl.) | Teké Deré | „ | —0.45 | —1.39 | —0.94 | 21.1 |
| 503 | *Curtohibolites oosteri* St.-Verg. | Podgorica, near Tărgovište | Lower Barremian | —0.85 | —1.10 | —0.25 | 19.6 |
| 532 | *Hibolites mirificus* St.-Verg. | Podgorica | | —1.24 | —1.55 | —0.31 | 21.9 |
| 509 | *D. binervia* (Rasp.) | Tărgovishté | „ | —0.58 | —1.35 | —0.83 | 20.9 |
| 510 | *D. binervia* (Rasp.) | Tărgovište | „ | —0.99 | —0.26 | +0.73 | 15.6 |
| 511 | *D. binervia* (Rasp.) | Tărgovište | „ | —1.09 | —0.88 | +0.20 | 18.6 |
| 507 | *Mesohibolites tzankovi* St.-Verg. | Svetlen, near Tărgovište | Barremian | —0.20 | —0.84 | —0.64 | 18.4 |
| 525 | *M. varians* (Schw.) | Svetlen | | —0.81 | —0.73 | +0.08 | 17.8 |
| 526 | *M. varians* (Schw.) | Svetlen | | —1.47 | —1.47 | 0.00 | 21.6 |
| 523 | *M. elegantoides* St.-Verg. | Zaraevo, near Tărgovište | „ | —0.89 | —0.92 | —0.03 | 18.7 |
| 501 | *M.* cf. *schaoriensis* (Hetch.) | Golyamo Novo, near Tărgovište | „ | —0.00 | —0.90 | —0.90 | 18.6 |
| 531 | *M. beskidensis* (Uhl.) | Podgorica, near Tărgovište | Upper Barremian | —0.06 | —1.09 | +1.03 | 19.6 |
| 502 | *M. beskidensis* (Uhl.) | Golyamo Novo, near Tărgovište | | —0 08 | —0.40 | —0.32 | 16.3 |
| 1013 | *Duvalia grasiana* (Duv.-Jouve) | Golyamo Novo | | —1.57 | —1.59 | —0.02 | 22.2 |
| 504 | *M. beskidensis* (Uhl.) | Polski Trămbeš, near Veliko Tărnovo | Lower Aptian | —0.38 | —0.69 | —0.31 | 17.5 |
| 505 | *D. grasiana* (Duv.-Jouve) | Varana, near Pleven | | — | —0.51 | — | 16.8 |
| 506 | *Neohibolites* sp. | Varana | „ | —0.14 | —0.94 | —0.80 | 18.8 |
| 524 | *M.* cf. *falauxi* (Uhl.) | Zaraevo, near Tărgovište | „ | —0.34 | —0.20 | +0.14 | 15.4 |
| 512 | *N. clava* Stoll. | Kozar-Belené, near Pleven | Upper Aptian (Clansay) | —0.06 | —0.06 | 0.00 | 14.8 |
| 513 | *N. clava* Stoll. | Krivina, near Rusé | | —0.66 | —0.96 | —0.30 | 18.9 |
| 514 | *N. wollemanni* Stoll. | Kozar-Belené, near Pleven | | —0.68 | —1.47 | —0.79 | 21.6 |
| 515 | *N. wollemanni* Stoll. | Kozar Belené | | —0.14 | —0.70 | —0.56 | 17.7 |
| 516 | *N. moderatus* (Schw.) | Kozar Belené | | —0.23 | —1.36 | —1.13 | 21.0 |
| 517 | *N. moderatus* (Schw.) | Kozar Belené | | —0.23 | —0.27 | —0.04 | 15.8 |
| 518 | *N. clansayense* St.-Verg. | Batin, near Rusé | „ | —0.57 | —0.65 | —0.08 | 17.4 |
| 519 | *N. clansayense* St. Verg. | Batin | „ | —0.74 | —1.00 | —0.26 | 19.2 |
| 520 | *N. clansayense* St. Verg. | Batin | „ | —0.23 | —0.20 | +0.03 | 15.4 |
| 508 | *N. minimus* (Miller) | Virovsko, near Vraca | Middle Albian | —0.15 | —0.27 | —0.12 | 15.7 |

only two of a total of 13 measurements. In comparison with the Hauterivian, no significant changes in the temperature of the water in the basins is established.

The palaeotemperatures of the Lower Aptian may be judged from the values of $\delta O^{18}$ obtained from the analyses made of four guards from different localities. From *M. beskidensis* (Uhl.) in the Lower Aptian marls near the village of Polski Trămbeš, District of Veliko Tărnovo, a value of —0.69‰ has been obtained, or a mean annual palaeotemperature of 17.5° C. From *D. grasiana* (Duv.-Jouve) and *Neohibolites* sp. from the village of Varana, District of Pleven, the palaeotemperatures calculated are 16.8° and 18.8° C, respectively, and from *M.* cf. *falauxi* (Uhl.) in the village of Zaraevo, 15.4° C. In this case the most shallow-water formations are the Lower Aptian sandy marls, alternating with impure limestones near the village of Varana, District of Pleven, and those from the deepest water ones, the clayey marls near the village of Zaraevo, District of Tărgovište. The palaeotemperatures obtained correspond to a greater or lesser extent to the conditions of the respective environment inhabited by the belemnites.

The $\delta O^{18}$ values obtained for the Upper Aptian (Clansaysian) from nine specimens from three localities range from —1.47 to —0.20, and also with a measurement of —0.06 (14.5°C). From three guards of *Neohibolites clansayense* St.-Verg. from the village of Batin, District of Rusé, the mean $\delta O^{18}$ value is —0.62, corresponding to a mean palaeotemperature of 17.5°C. From two *N. wollemanni* Stoll. guards in the village of Kozar-Belené, District of Pleven, which showed an average of —1.08 for $\delta O^{18}$, a mean palaeotemperature of 19.5°C has been calculated, and from two *N. moderatus* (Schw.) rostra, a temperature of 18.4° C .The Clansaysian sediments near the village of Batin, District of Rusé, are represented by sandy marls, including a large amount of glauconite containing numerous belemnites, probably brought over by a current. Near the village of Kozar-Belené, the Clansaysian layers are siltstone clays intercalated by limy siltstones and red limy concretions. If compared proportionally, the sediments near the village of Batin, District of Rusé, are formed under shallow-water conditions and the somewhat lower palaeotemperatures obtained from them could be possibly explained by the abundant development of the glauconite in the Clanysaysian marls (Imlay, 1957).

In comparison with the Barremian, the Aptian $\delta O^{18}$ values are somewhat higher and the palaeotemperatures calculated from them demonstrate a slight decrease, which is not conditioned by the differences in the conditions under which the belemnites lived (Fig. 4).

Only one rostrum of *N. minimus* (Mill.) from the Albian in the village of Virovsko, District of Vraca, has been analyzed. A high $\delta O^{18}$ value, —0.21, has been obtained, corresponding to a palaeotemperature of 15.7°C. No well-founded conclusions may be drawn from this single measurement.

## Comparison of the Jurassic and Early Cretaceous Palaeotemperatures in Bulgaria and other Countries

The Jurassic and Early Cretaceous palaeotemperatures obtained by measuring the $\delta O^{18}$ from belemnite guards in Bulgaria may be compared with available data on isotope palaeotemperatures in other European countries. These data have been summed up and analyzed by Bowen (1961, 1966) and Тейс & Найдин (1973). The Jurassic temperatures in Bulgaria may be compared above all by results obtained for the Schwabian Jurassic in the southern part of the Federal Republic of Germany (Bowen & Fritz, 1963; Fritz, 1965), for Bavaria (Bowen, 1963), for Switzerland and France (Bowen & Fontes, 1963), for England (Bowen, 1961b) and for the northern part of the German Democratic Republic (Kunz, 1973). For the Late Jurassic in particular our measurements are insufficient, but as many of them as are available they may be compared with those for Germany and Poland (Bowen, 1961c; Тейс et al., 1968).

Owing to the similar and exceedingly high values for the isotope palaeotemperatures of the Early and a part of the Middle Jurassic in the southern part of the Federal Republic of Germany and Bulgaria (Fig. 2), they will be discussed in greater detail in the conclusion of this paper. Isotope palaeotemperatures in France, according to the Pliensbachian and the Toarcian, vary between 24.6$^0$ and 24.9$^0$C and they are somewhat lower (20.1$^0$ to 21.8$^0$C) for the Bajocian and the Bathonian. In England the data are valid only for the Toarcian, where palaeotemperature values are high; they range from 23.8$^0$ to 31.7$^0$C, or 27.7$^0$C on an average, which brings them closer to those in Bulgaria.

Kunz (1973) published data on measurements of palaeotemperatures from belemnite guards from the Jurassic sediments in the northern part of the German Democratic Republic. The highest values of palaeotemperatures there are also calculated from Toarcian rostra (25.2$^0$—26.6$^0$C), but they are lower by 10 and more degrees than those in Bulgaria. The minimum mean seasonal temperatures (13$^0$C) have been established for the Middle and Late Bajocian and for the early part of the Late Bathonian. As of the Late Callovian, an increase in the palaeotemperatures in Northern Germany is observed, as the onset of a new warm period during the Oxfordian and the Kimmeridgian.

Palaeotemperatures from the Upper Jurassic rostra in Poland, where the belemnites are of a Mediterranean nature, have been established by Bowen (1961c) near Lubaczov, which vary from 27.0$^0$ to 28.8$^0$C. The palaeotemperatures obtained by Тейс et al. (1968) for the Middle and Late Jurassic in Poland vary within different but much lower limits than those. In comparison with these for Bulgaria, they are by about 5-8$^0$ C lower on an average. Considerably high palaeotemperatures have been established for Eastern Greenland from the Bajocian to the Early Portlandian (14.1$^0$ and 19.4$^0$, 22.9$^0$C on an average), which Тейс et al. (1968) relate to the presence of a warm current towards the Arctic.

Considerably greater is the difference in the calculated mean annual palaeotemperatures for the Bathonian and the Middle Callovian in the European part of the USSR (the Ryazan area) and Bulgaria. A palaeotemperature of 14.5$^0$ C has been determined for the Late Bathonian by *Cylindroteuthis spathi* Sachs et Naln. as compared with 20$^0$C for the Upper Bathonian in North-Western Bulgaria from *Belemnopsis parallelus* (Phill.). The values for the Middle Callovian range from 10.3$^0$-14.1$^0$ C to 18.4$^0$ C from different representatives of the genera *Acroteuthis* and *Cylindroteuthis* as compared with 25.8$^0$ C from *Hibolites hastatus* (Bl.) in North-Western Bulgaria.

Data available on the palaeotemperatures for the Cretaceous in different countries are valid mainly for the Post-Aptian and Late Cretaceous periods. Most suitable for comparison with the results obtained for Bulgaria are the palaeotemperatures for the Early Cretaceous, obtained from French material (Bowen, 1961a; Bowen & Fontes, 1963; Bowen, 1966). The results for the palaeotemperature measurements (dep. Hautes Alpes, Devolui) have manifested regular changes with a trend towards a gradual decrease from the Berriasian towards the Barremian. Thus, from 20.0⁰-22.8⁰ C for the Berriasian, the temperatures fall to 17.0⁰-20.5⁰ C for the Barremian (Bowen & Fontes, 1963). Somewhat higher palaeotemperatures — from 19.2⁰C near Bedule to 23.7⁰C near Vissant, for the Early Aptian have been established for the Aptian and the Albian, and 20.5⁰ and 21.0⁰C for the Late Aptian near Vaucluse and Clansay (Bowen, 1961a). The values of the palaeotemperatures for the Albian in France are higher. Near Pas-de-Callais they range from 22.7⁰ to 25.1⁰C. From Albian rostra from the Hautes Alpes 27.7⁰ and 28.1⁰ C have been obtained, which are the highest palaeotemperatures for the Cretaceous in France. These values agree with the opinions put forward by certain researchers on the presence of an Albian temperature maximum in Western Europe (Bowen, 1961a; Lowenstam & Epstein, 1954).

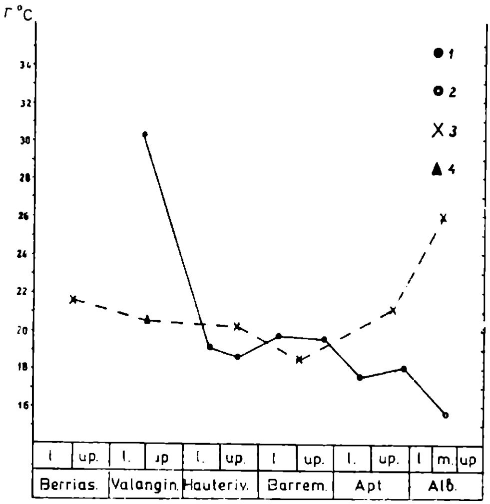


Fig. 1. Early Cretaceous oxygen isotope temperatures in Bulgaria and in France

*1* — mean values by substages for Bulgaria; *2* — single measurements for Bulgaria; *3* — mean values by stages for France; *4*—single measurements for France (Bowen, 1961, 1963; Bowen & Fontes, 1963)

The general picture of the changes in the Early Cretaceous palaeotemperatures in France indicate that they vary for the different ages between 17⁰ and 22.8⁰ C, i.e. they have an amplitude of about 6⁰ C. If certain single measurements are excluded, which have manifested lower values, the general trend in the changes in Early Cretaceous palaeotemperatures in Bulgaria is a similar one. Only, a more distinct decrease in the values in this case is outlined during the Aptian, and not in the Barremian, as it is in France (Fig. 1).

Data on Early Cretaceous palaeotemperatures outside the Thetys area are known from the "Neocomian" near Braunschweig in Germany, which change from 18.7⁰ to 21.2⁰ C (Bowen, 1961c). The term "Neocomian" embraces a large stratigraphic range and if it is judged by the locality in Braunschweig, in that case mainly Aptian sediments (Gargasian and Claynsaysian) occur there. In such a case these palaeotemperatures are fully within the limits of the fluctuations for the Late Aptian in Bulgaria.

## Interpretation of Some Anomalous Palaeotemperatures

In analyzing the results obtained from the isotopic investigations of the Jurassic and Cretaceous Belemnites guards in Bulgaria, the high "palaeotemperatures" for the Toarcian, Early and Middle Bajocian are distinctly obvious in particular. These values reaching up to 38.4⁰ C and 39.9⁰C are the highest for all data on other European and non-European countries known so far. They exceed the temperatures of the surface waters of the seas in the subtropical and tropical areas and evidently call for a more special explanation.

The $\delta O^{18}$ values obtained for the Toarcian are of great interest since they fully agree with the results published for the Federal Republic of Germany (Fritz, 1964), and those obtained by R. V Teis and D. P. Naidin for Siberia (the data are being prepared for publication). Bowen & Fritz (1963) established particularly low $\delta O^{18}$ values for rostra of Toarcian belemnites in Western Europe. P. Fritz (1964) showed that the low $\delta O^{18}$ values are typical also for the Aalenian in the southern part of the Federal Republic of Germany. Hence if from these $\delta O^{18}$ values the temperatures are calculated, then they will be very high, distinctly higher than the possible actual values. The data on Bulgaria, quoted above, also show that the lowest $\delta O^{18}$ values are typical of belemnite rostra taken from border sediments between the Lower and the Middle Jurassic (Toarcian and Lower Bajocian). The data on the Federal Republic of Germany and Bulgaria are presented in Table 3.

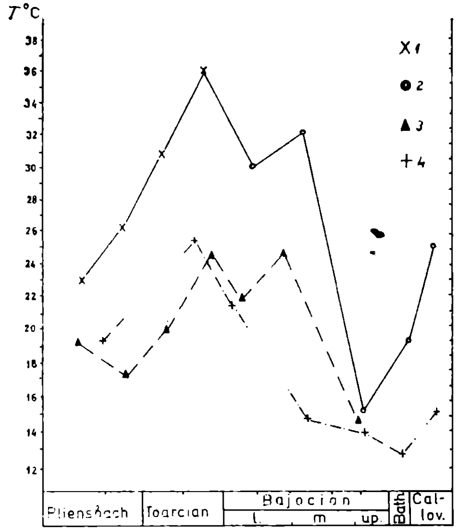


Fig. 2. Jurassic oxygen isotope temperatures in Bulgaria, the southern part of the Federal Republic of Germany and the northern part of the German Democratic Republic

*1* — mean values by substages for Bulgaria; *2*—single measurements for Bulgaria; *3* — mean values for the southern part of the Federal Republic of Germany (Bowen & Fritz, 1963; Fritz, 1965); *4* — mean values for the northern part of the German Democratic Republic (Kunz, 1973)

As is seen, the $\delta O^{18}$ values for the Toarcian-Aalenian in the Federal Republic of Germany and the Toarcian-Bajocian in Bulgaria differ considerably from the values for the Pliensbachian and very markedly from the Bajocian for the Federal Republic of Germany and the Late Bajocian for Bulgaria. For the sake of comparison, we shall cite data on the $\delta O^{18}$ values for organogenic carbonates of different ages (Тейс & Найдин, 1973): the mean $\delta O^{18}$ values calculated from Upper Jurassic belemnites in Siberia and the Russian Platform are of the —0.55 to —0.60 order (from 130 measurements of an average); according to Upper Cretaceous belemnites from the Russian Platform: +0.01 (an average for 240 measurements).

On the basis of the measurement of the oxygen isotope composition in the calcite in rostra from Lower Jurassic belemnites in Western Europe (the Federal Republic of Germany, Switzerland, France and England), Bowen suggests the existence of warmer conditions in the Lias in Western Europe in comparison with other epochs of the Jurassic Period. This suggestion is in contradiction with the longstanding ideas, based on lithological and palaeonthological data, about cooler climatic conditions during the Lias as compared with the Middle and Late Jurassic.

Fritz (1965) interprets the $\delta O^{18}$ values with greater care. He believes that the $O^{18}/O^{16}$ ratio in the rostra of Toarcian and Aalenian belemnites in the southern part of the Federal Republic of Germany do not entirely reflect temperature conditions. In his opinion, the aquatic background of the basins in Western Europe at the boundary between the Early and the Middle Jurassic could be under the influence of river water inflow poor in $O^{18}$. In that case it seems that the interpretation of isotope measurements from the Toarcian in Western Europe, as suggested by Fritz, is closer to reality than that put forward by Bowen.

Of particular interest are the data on the Toarcian also owing to the fact that in the mass-spectrometric study of material from Siberia (the collection of

Table 3

*$\delta O^{18}$ values (heated) from Belemnite guards in sediments on the boundary between the Lower and Middle Jurassic in the Federal Republic of Germany and Bulgaria*

| Area | Pliensbachian | | Toarcian | | Aalenian | Bajocian | Bathonian |
|---|---|---|---|---|---|---|---|
| | Lower | Upper | Lower | Upper | | | |
| Southern part of the Federal Republic of Germany*** | —0.86 (13) | | | —2.76 (2) | —2.67 (1) | +0.12 (6) | |
| | —1.02 (10) | —0.31 (3) | | | | | |
| Southern part of the Federal Republic of Germany**** | —1.26 (4) | | —1.64 (15) | | —1.94 (11) | —0.04 (7) | —0.51 (2) |
| | | | —1.08 (5) | —1.93 (10) | | | |
| Bulgaria | —2.73(12) | | —3.60 (9) | | —3.46 (2)* | —0.29 (1)** | —1.18 (1) |
| | —1.77 (3) | —2.38 (9) | —3.26 (5) | —4.02 (4) | | | |

Note. For the Pliensbachian and the Toarcian on the upper line — the mean values for the stage, on the lower line — the mean values for the substages: the number of measurements are given in brackets; * — for the Lower and the Middle Bajocian: ** — for the Upper Bajocian; *** — Bowen & Fritz (1963); **** — Fritz (1964)

V. I. Saks), in that area also from Toarcian rostranamely the lowest $\delta O^{18}$ values have been established (of the —4.5 order on an average). The low $\delta O^{18}$ values for the Toarcian-Aalenian in Europe and Siberia could be explained by the action of the following three factors:

(a) the $\delta O^{18}$ values obtained reflect the diagenetic changes in the initial $O^{18}/O^{16}$ ratio;

(b) the temperatures of the sea water during the Toarcian and the Aalenian (of the lower Bajocian in Bulgaria, respectively) have been higher than during the other ages of the Jurassic Period;

(c) in the Toarcian-Aalenian the isotopic aquatic background was different from the aquatic background during the other ages of the Jurassic and the Cretaceous.

If the low $\delta O^{18}$ values are determined by diagenetic changes in the primary $O^{18}/O^{16}$ ratio, there arises the question why these changes are manifested only in Toarcian-Aalenian rostra and why have they proceeded similarly in the three areas, so much distant from each other: Western Europe (the Federal Republic of Germany mainly), Bulgaria and Siberia. It is hardly possible, however, that such selective processes of the diagenesis in the primary oxygen isotope composition could have been possible.

The $\delta O^{18}$ values, higher than —2.8 to —3.0 (which corresponds to the calculated temperatures of 29-30°C) may possibly be viewed as initial values reflecting the real temperatures.

And finally, the third possible explanation for the low $\delta O^{18}$ values for the Toarcian-Aalenian could be related to disturbances in the isotope aquatic background of the seas in Euroasia at the boundary of the Early and the Middle Jurassic. The most feasible explanation, as already stated above, is the one suggested by Fritz: the flow of river waters, poor in $O^{18}$ The inflow of river waters is a local phenomenon, hence it should be assumed in such a case that the entire material on the Toarcian-Aalenian, studied so far, originates from sediments that have formed under the effect of fresh waters (in bays, for instance). Naturally, it would be strange to believe that the Toarcian-Aalenian rostra come from bays, while the rostra of other stratigraphic subdivisions of the Jurassic and the Cretaceous, from normally saline basins. For this reason it is possible that the low $\delta O^{18}$ values for the Toarcian-Aalenian could be related with a certain global feature of the aquatic background of seas in Euroasia, unknown to us.

## Conclusion

The results from the isotope measurements of belemnites guards from the other ages of the Jurassic and the Cretaceous seem to be of a more normal nature. Clayton & Stevens (1968) accept as valid only the minimal values of the isotope palaeotemperatures, being the only least altered carbonates. According to the data obtained by us that opinion is unacceptable since only one result shows 16°C ($\delta O^{18}$ —0.33) from Pliensbachian guards for example as compared with eight measurements above 24°C ($\delta O^{18}$ from —1.96 to —3.35), or from Toarcian only one measurement of 25.5°C ($\delta O^{18}$ —2.48) as compared with eight having values above 32.2°C ($\delta O^{18}$ —3.33 to —4.48‰). Generally, taking into account what has been stated above about the slightly raised values of the belemnite palaeotemperatures (Берлин et al., 1966; Тейс et al., 1968), the conception about the prevalence of a warm (subtropical) climate in Bulgaria during the Jurassic may be maintained, based on lithological and other indices (Начев, 1973; Nachev, 1967). At the same time, however, there are indications that the climate has not been the same throughout the whole Jurassic (somewhat warmer during the Pliensbachian — Middle Bajocian interval and the Late Jurassic, and possibly cooler during the Upper Bajocian and the Bathonian) (Fig. 3). A differentiation of this type has been established from isotope measurements also in the northern parts of the USSR (Берлин et al., 1966).

The $\delta O^{18}$ values established from the Lower Cretaceous are higher and the values of the palaeotemperatures calculated are correspondingly lower and more uniform than the Jurassic ones. They range from —0.73 to —1.59‰ (18.2° to 22.2°C) for the different ages.

If the palaeotemperatures for the Valanginian are accepted as random ones, in that case there are no markedly expressed maxima. The Albian temperature maximum shown in other countries, to which many authors lend a global nature, cannot be confirmed. A more stable decrease in the palaeotemperatures is observed during the Aptian, yet having a weak average amplitude: 2-3°C (Fig. 4).

The general results from isotope measurements are in agreement with the conclusions made by Горанов (1966) that sedimentation conditions in the Lower Cretaceous basin in North-Eastern Bulgaria were almost the same during the ages and that the basin and the adjoining land coincided with the zone of the moderate humid climate.

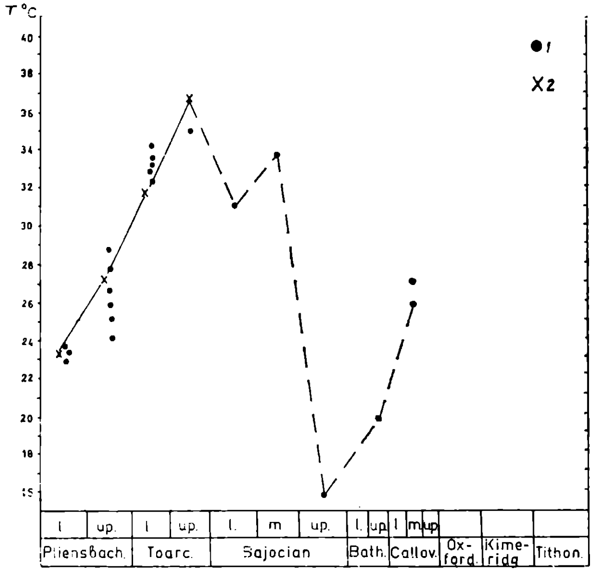


Fig. 3. Oxygen isotope palaeotemperatures of the Jurassic in Bulgaria

*1* — mean annual palaeotemperatures; *2* — mean values of palaeotemperatures by substages

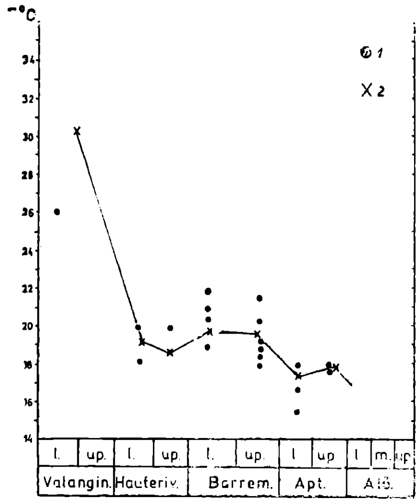


Fig.4. Oxygen isotope palaeotemperatures of the Lower Cretaceous in Bulgaria

*1* — mean annual palaeotemperatures; *2* — mean values of palaeotemperatures by substages

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