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Jurassic transgressions and regressions in the Caucasus (northern Neotethys Ocean) and their influences on the marine biodiversity

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Abstract

In the Jurassic, the Caucasus, presently located in the southwest of Russia, Georgia, Armenia and Azerbaijan, was located on the northern active margin of the Neotethys Ocean. Facies interpretation in all 62 areas, distinguished by differences in facies, allows to semi-quantitatively evaluate Jurassic regional transgressions and regressions for this region. Major transgressive regressive cycles took place in the Hettangian–Aalenian, Bajocian–Bathonian and Callovian–Tithonian. Each transgression was more extensive than the previous. The same cycles are established in the Greater Caucasus Basin. Deep-marine environments were common in the Pliensbachian, late Aalenian and late Bathonian, whereas they were very restricted in the Late Jurassic. The Jurassic transgressions and regressions in the Caucasus coincided with the proposed global eustatic changes. However, some differences were caused by the regional tectonic activity. Although transgressions and regressions cause some changes in marine biodiversity, it seems that only ammonites might have been directly influenced by them. Diversity of bivalves, brachiopods and belemnites was driven by other factors. However, global changes in marine biodiversity were more closely related to the eustatic fluctuations than it was documented on a regional scale.

Keywords: Transgression; Regression; Eustasy; Biodiversity; Jurassic; Caucasus

1. Introduction

Global sea level fluctuated strongly during the Jurassic (Hallam, 1978; Haq et al., 1987; Hallam, 1988, 1992, 2001; Haq and Al-Qahtani, 2005). Special attention has been paid to the intriguing question of how these changes as well as regional transgressions and regressions influenced marine biodiversity (Wiedman, 1973; Hallam, 1975, 1977; Jablonski, 1980; Lehmann, 1981; Gygi, 1986; Hallam, 1987; McRoberts and Aberhan, 1997; Hallam and Wignall, 1999; O'Dogherty et al., 2000; Sandoval et al., 2001a,b; Smith, 2001; Sarti, 2003; Ruban, 2004; Aberhan et al., 2005; Ruban and Tyszka, 2005; Ruban, 2006a). However, this question is not yet fully answered, and the influence is still poorly understood.

In this paper, I will focus on Jurassic transgressions and regressions in the Caucasus, a large region, stretching along the southern periphery of the Russian Platform and embracing the territory of southwestern Russia, Georgia, Armenia and Azerbaijan (Fig. 1). The few previous studies addressed to regional transgressions and regressions suggested that they were somewhat different from those observed globally and elsewhere in Europe

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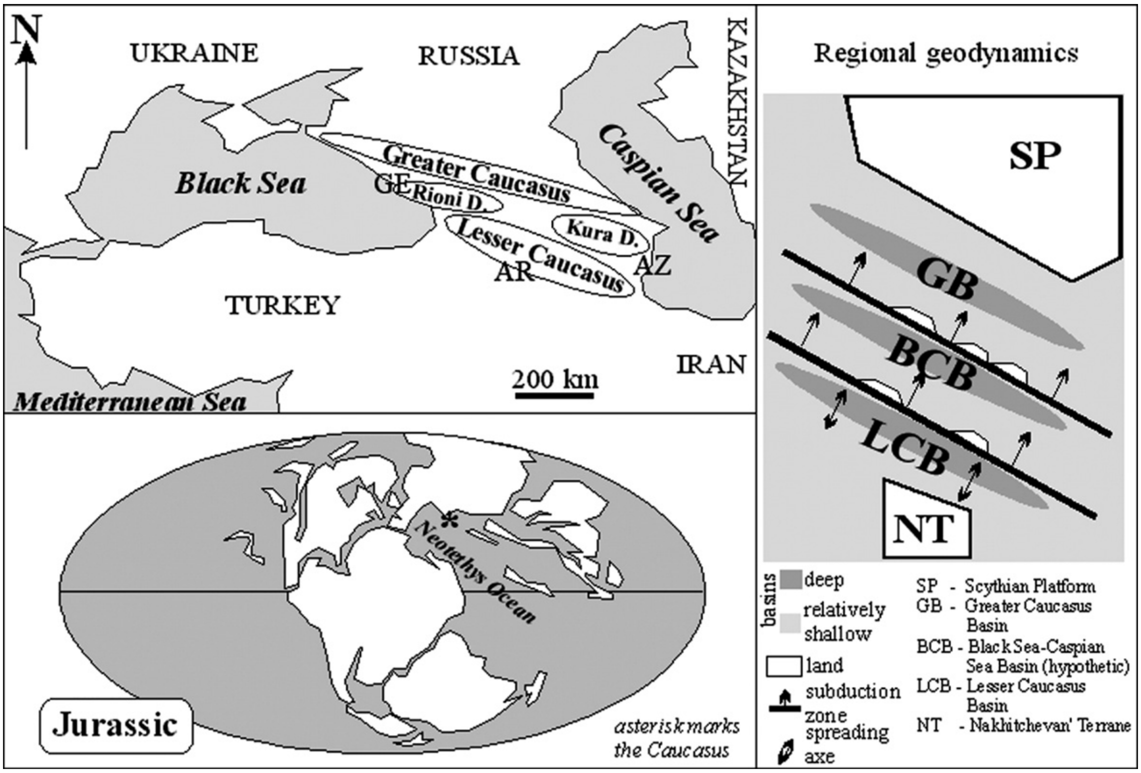

Fig. 1. Geographical location of the studied region. GE — Georgia, AR — Armenia, AZ — Azerbaijan. Palaeogeographical map is simplified after Scotese (2004). Geodynamic sketch is modified from Lordkipanidze et al. (1984), who used the geological and palaeomagnetic evidences.

(Ruban, 2004; Ruban and Tyszka, 2005; Ruban, 2006a). The Late Jurassic history of the Caucasus is marked by two remarkable events — the development of a carbonate platform with the growth of carbonate buildups (Rostovtsev et al., 1992; Kuznetsov, 1993; Martin-Garin et al., 2002; Akhmedov et al., 2003; Ruban, 2005a, 2006a; Tawadros et al., 2006) and a salinity crisis (Jasamanov, 1978; Kuznetsov, 1993; Ruban, 2006a; Tawadros et al., 2006). These events are interpreted as controlled by the basin dynamics and climate, and to document their relationships with transgressions and/or regressions is intriguing.

In this paper, an attempt is made to detail and to semi-quantitatively evaluate Jurassic transgressions and regressions in the Caucasus. The study area may serve as a test region to investigate their influences on the marine biodiversity. Previous studies have suggested that sea-level changes did not cause mass extinction among brachiopods (Ruban, 2004) and foraminifers (Ruban and Tyszka, 2005), and they did not control bivalve diversity (Ruban, 2006a). Here the influences of the Jurassic transgressions and regressions on ammonites, bivalves, brachiopods and belemnites are considered.

2. Geological setting

The Caucasus is a large elongated region consisting of three principal segments, the Greater Caucasus, the Transcaucasian depressions (the Kura Depression and the Rioni Depression), and the Lesser Caucasus (Fig. 1). During the Jurassic, the Caucasus was located on the northern margin of the Neotethys Ocean (Gamkrelidze, 1986; Dercourt et al., 2000; Stampfli and Borel, 2002; Golonka, 2004; Tawadros et al., 2006; Ruban, 2006d). Accretion of minor terranes along the southern margin of the Russian Platform (also known as the Scythian Platform) resulted in the development of several marine basins, separated by island arcs (Lordkipanidze et al., 1984; Ershov et al., 2003; Efendiyeva and Ruban, 2005; Tawadros et al., 2006; Ruban, 2006d) (Fig. 1). The geometry of these basins changed during the Jurassic (Ruban, 2006d), but the evaluation of the changes and their precise delineation have not yet been realized.

The Jurassic stratigraphy of the Caucasus was comprehensively presented by Prosorovskaya (1979) and Rostovtsev et al. (1985, 1992). Ruban (2003, 2006b) and Ruban and Pugatchev (2006) revised the regional stratigraphy of the Western Caucasus and proposed a new framework (Fig. 2), incorporating recent developments in Jurassic chronostratigraphy (Gradstein et al., 2004; Gradstein and Ogg, 2005, 2006), including the ratification of the Sinemurian, Aalenian and Bajocian Global Standard Sections and Points (Pavia and Enay, 1997; Cresta et al., 2001; Bloos and Page, 2002), and biostratigraphy (Cariou and Hantzpergue, 1997). The Callovian Stage in the Caucasus is traditionally ascribed to the Upper Jurassic (Rostovtsev et al., 1992; Ali-Zadeh, 2004) which contradicts to the present International Stratigraphic Chart (Gradstein et al., 2004). The palynological study of Gaetani et al. (2005) suggested a late Bathonian age for the lower part of the Kamennomostskaja Formation. If so, the termination of the major Bathonian hiatus should be reconsidered throughout the

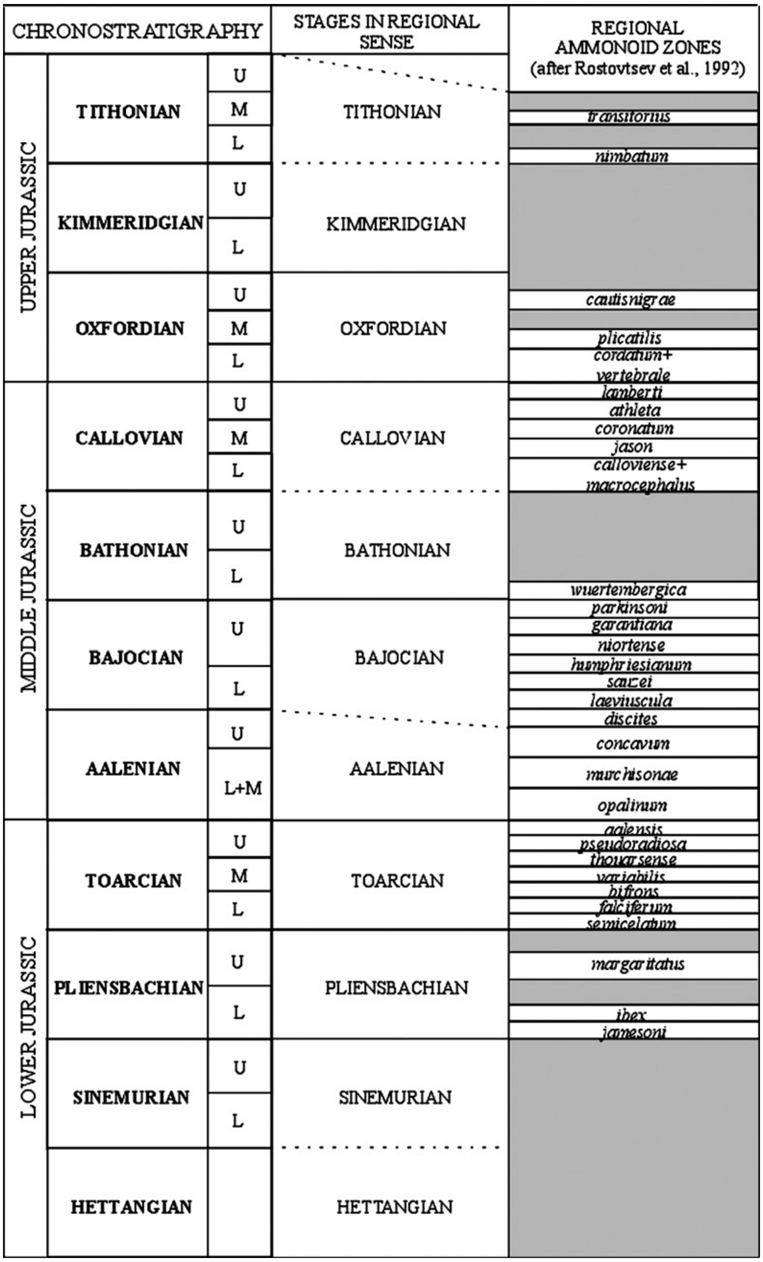

Fig. 2. Stratigraphic scale of the Jurassic used in the Caucasus (after Ruban, 2006d). Abbreviations: L — Lower, M — Middle, U — Upper. Unzoned intervals are shaded as gray. Dashed line marks uncertainty in the boundary definition. Regional ammonite zonation does not correspond at this scale to the showed chronostratigraphy (it seems to be impossible to correlate them at now), but only to the stages in regional sense.

entire Caucasus, which may lead to a significant revision of the Middle Jurassic stratigraphy of the region. However, in this paper I prefer the widely accepted early–middle Callovian age of the Kamennomostskaja Formation, an age supported by ammonites, bivalves and belemnites (Prosorovskaya, 1979; Rostovtsev et al., 1992; Ruban, 2005b).

The Jurassic deposits, lithologically quite variable, outcrop in hundreds, if not thousands, of sections across the Caucasus. The territory of the Caucasus is subdivided into several dozen areas which are traditionally called "zones" (Rostovtsev et al., 1992) distinguished by differences in facies (Fig. 3). However, the term "zone" should be abandoned to avoid confusion with biostratigraphic zones.

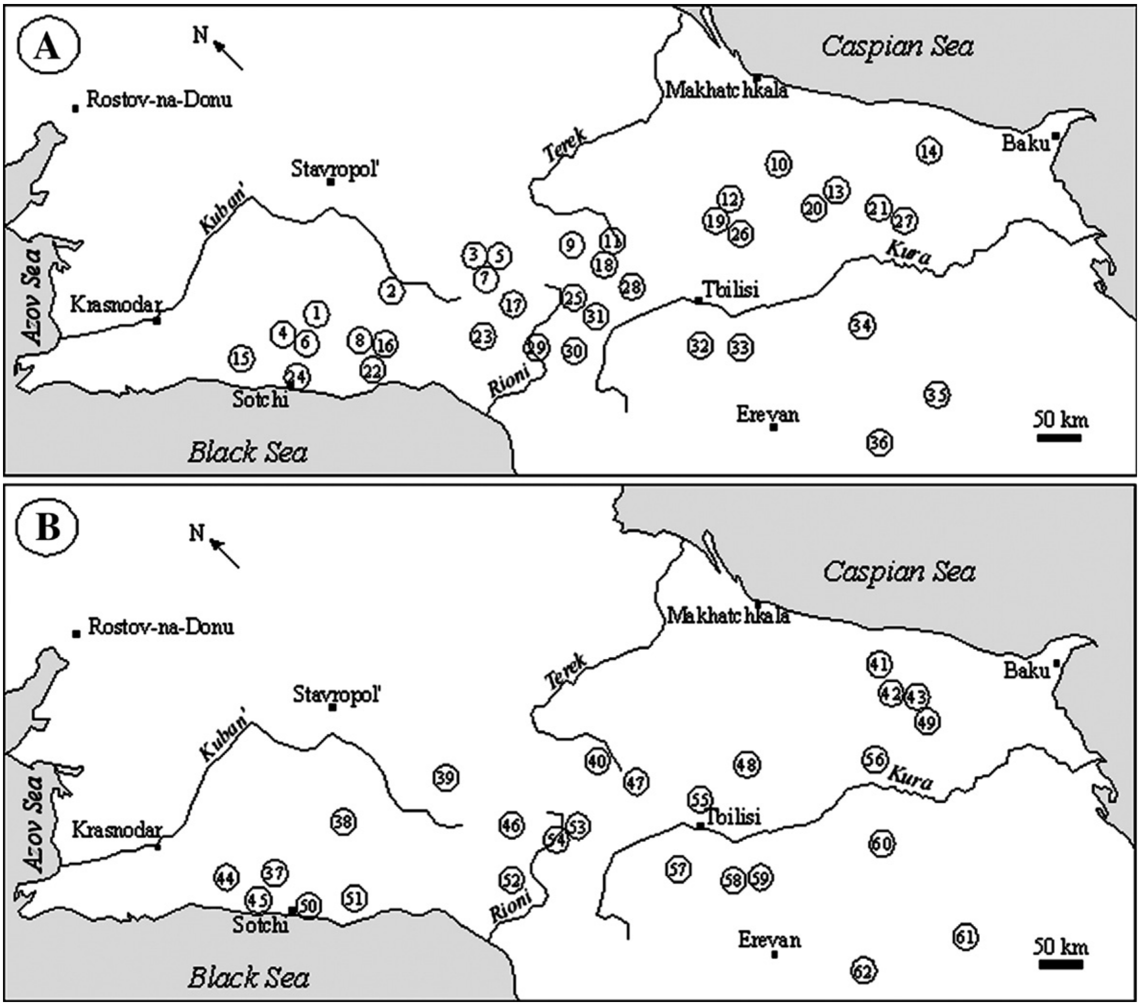

Fig. 3. Location of the Jurassic areas (marked by circles) in the Caucasus (after Rostovtsev et al., 1992). A — Hettangian–Bathonian areas (1–36), B — Callovian–Tithonian areas (37–62). Areas ("subzones" and "regions" of Rostovtsev et al. (1992) are mentioned here as areas): 1 — Western Labino–Malkinskaja, 2 — Central Labino–Malkinskaja, 3 — Eastern Labino–Malkinskaja, 4 — Western Pshikish–Tyrnyauzskaja, 5 — Eastern Pshikish–Tyrnyauzskaja, 6 — Northern Arkhyz–Guzeripl'skaja, 7 — Eastern Arkhyz–Guzeripl'skaja, 8 — Southern Arkhyz–Guzeripl'skaja, 9 — Digoro–Osetinskaja, 10 — Agwali–Khivskaja, 11 — Western Bokovogo Khrebta, 12 — Central Bokovogo Khrebta, 13 — Eastern Bokovogo Khrebta, 14 — Southeastern Bokovogo Khrebta, 15 — Gojtkhsko–Atchishkhinskaja, 16 — Severoabkhazskaja, 17 — Svanetskaja, 18 — Western Glavnogo Khrebta, 19 — Central Glavnogo Khrebta, 20 — Tfanskaja, 21 — Durudzhinskaja, 22 — Western Gagra–Dzhavskaja, 23 — Eastern Gagra–Dzhavskaja, 24 — Amuksko–Lazarevskaja, 25 — Sakaojskaja, 26 — Shakrianskaja, 27 — Vandamskaja, 28 — Kakhetino–Letchkhumskaja, 29 — Tskhenistskali–Okribskaja, 30 — Southwestern Dzirul'skaja, 31 — Northeastern Dzirul'skaja, 32 — Loksko–Khramskaja, 33 — Alaverdskaja, 34 — Shamkhorsko–Karabakhskaja, 35 — Kafanskaja, 36 — Araksinskaja; 37 — Lago–Nakskaja, 38 — Labinskaja, 39 — Malkinskaja, 40 — Kabardino–Dagestanskaja, 41 — Jugo–Vostotchnogo Dagestana, 42 — Sudurskaja, 43 — Shakhdagskaja, 44 — Abino–Gunajskaja, 45 — Novorossijsko–Lazarevskaja, 46 — Svanetsko–Verkhneratchinskaja, 47 — Liakhvi–Aragvinskaja, 48 — Kakhetinskaja, 49 — Dibrarskaja, 50 — Akhtsu–Katsyrkha, 51 — Dzhirkhva–Akhibokhskaja, 52 — Tkvartcheli–Okribskaja, 53 — Ratchinskaja, 54 — Tsessi–Kortinskaja, 55 — Iori–Tsitelitskarojskaja, 56 — Vandamskaja, 57 — Khramskaja, 58 — Lalvarskaja, 59 — Idzhevanskaja, 60 — Dashkesano–Karabakhskaja, 61 — Kafanskaja, 62 — Nakhitchevanskaja.

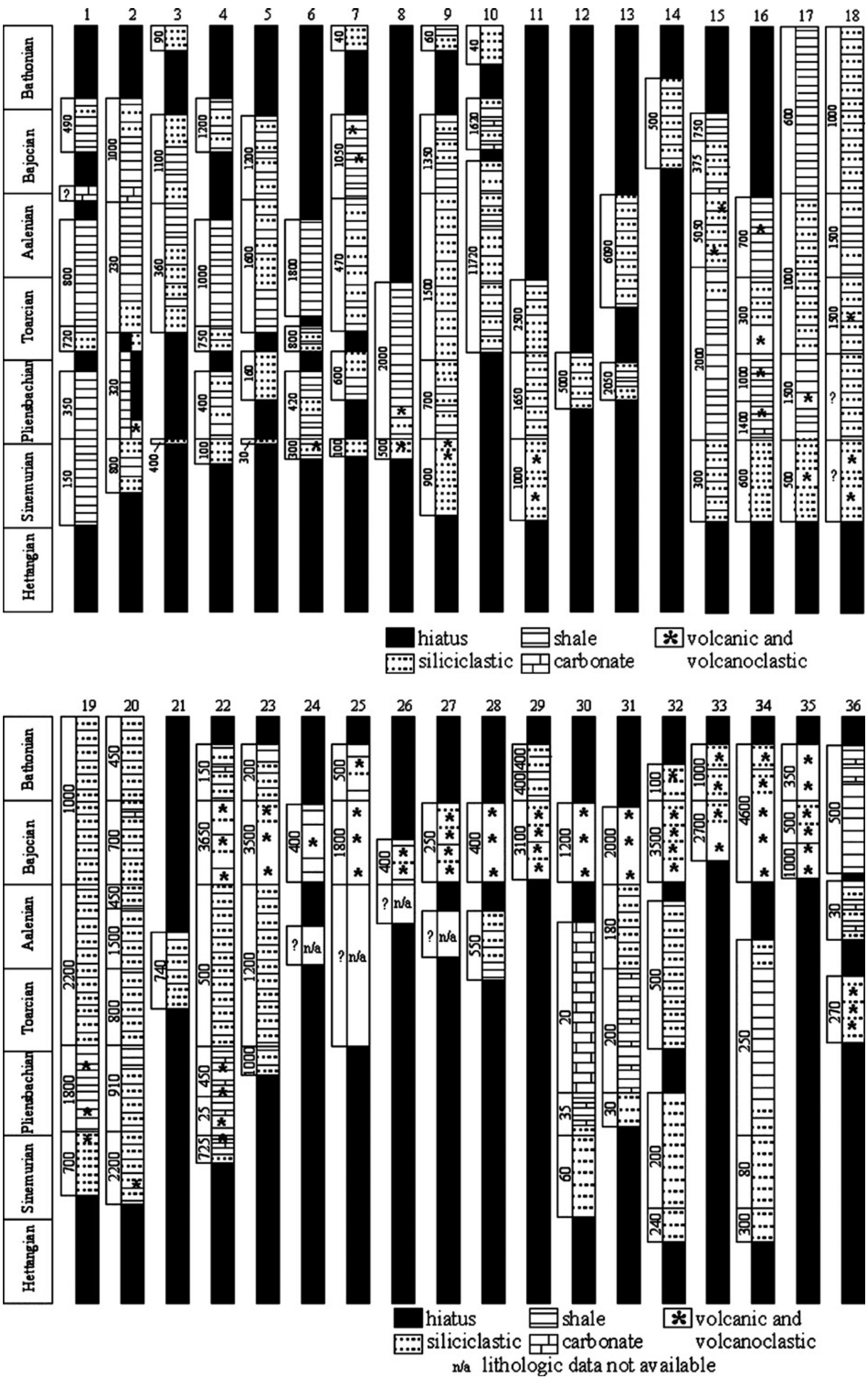

Fig. 4. Composite lithologic sections of the Caucasian areas: Hettangian–Bathonian (based on field observations and data of Rostovtsev et al., 1992). Location of areas — see Fig. 3. Dominating sedimentary rocks are shown. Maximum thickness (meters) is indicated to the left of each column.

I propose therefore to use the usual term “area”. Composite lithologic sections have been drawn for each of these areas (Figs. 4, 5). In general, siliciclastics (up to 10,000 m thick) dominate the Lower–Middle Jurassic successions, whereas carbonates (up to 3000 m thick) prevail in the Upper Jurassic succession (Tsejsler, 1977; Prosorovskaya,

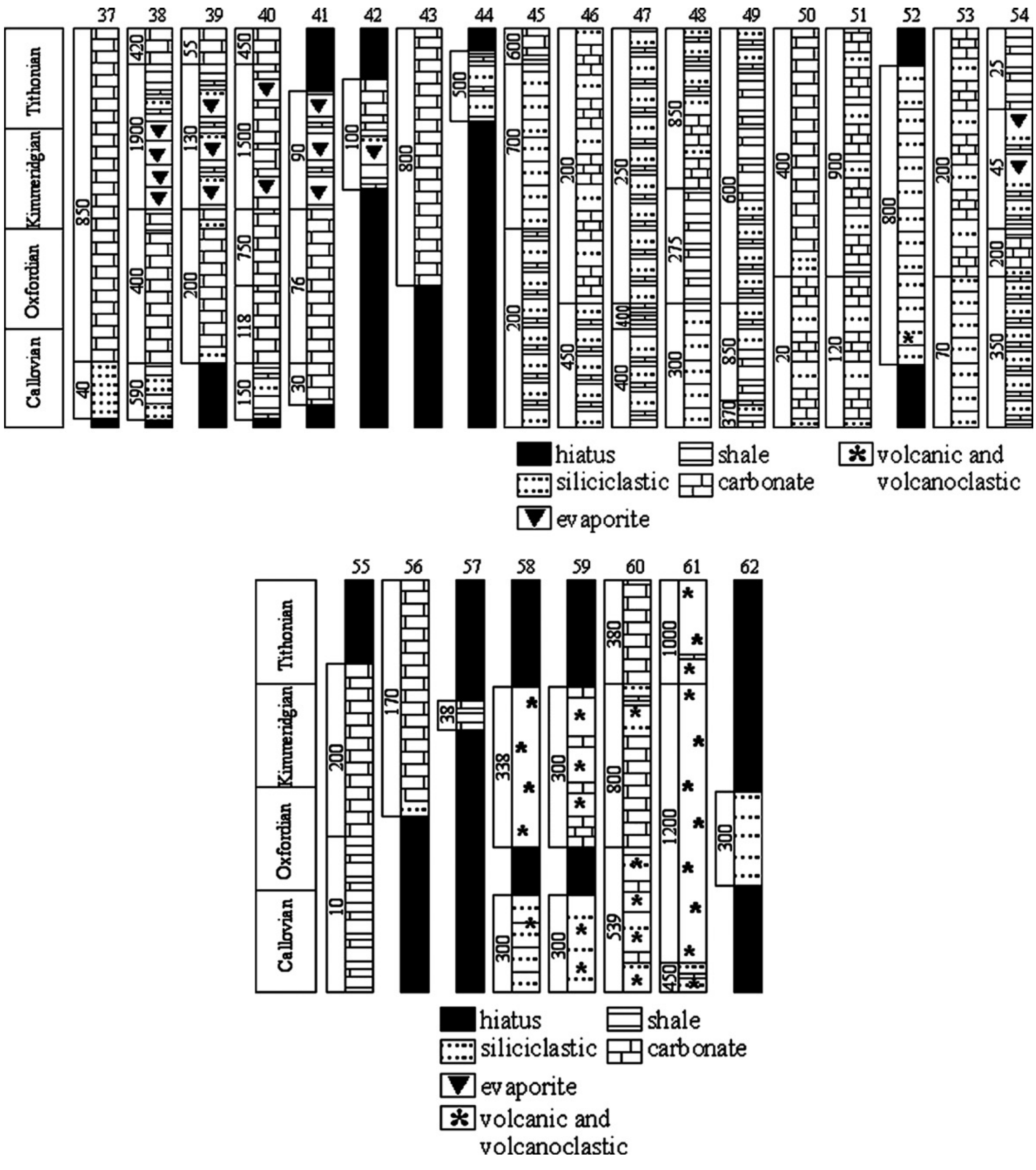

Fig. 5. Composite lithologic sections of the Caucasian areas: Callovian–Tithonian (based on field observations and data of Rostovtsev et al., 1992). Location of areas — see Fig. 3. Dominating sedimentary rocks are shown. Maximum thickness (meters) is indicated to the left of each column.

1979; Rostovtsev et al., 1992; Tawadros et al., 2006). In the Lesser Caucasus, volcanics and volcanoclastics are abundant (Prosorovskaya, 1979; Rostovtsev et al., 1985, 1992). Palaeobiogeographically, the Caucasus belonged to the Tethyan Subrealm until the Middle Jurassic, when it became a part of the Tethyan Realm (Westermann, 2000).

3. Materials and methods

The method of transgression and regression evaluation used in this study is somewhat similar to that proposed by Ruban (2006a,b,c) and earlier by Hallam and Wignall (1999), Peters and Foote (2001), Smith (2001), and Crampton et al. (2003). Transgressions and regressions

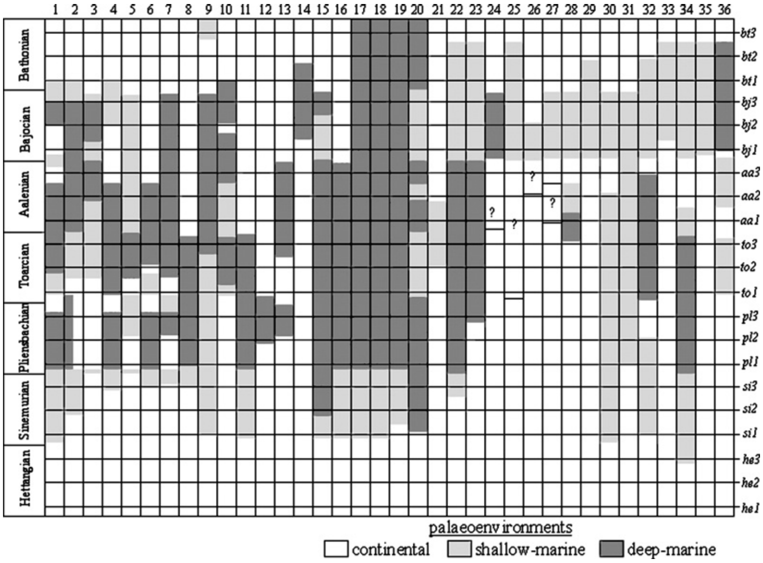

Fig. 6. Interpreted palaeoenvironments of the Hettangian–Bathonian. Location of areas — see Fig. 3. Time slices used to evaluate sea-level changes are shown by horizontal lines and indexes from the right side.

are defined as land- and seaward migrations of the shorelines respectively (Catuneanu, 2006; cf. Veeken, 2006). They should be distinguished from deepenings and shallowings, which describe water depth in the basin.

The first step in my study is to interpret the facies for each area, based on information from Rostovtsev et al. (1992) and personal field observations (Figs. 6, 7). Interpretations made earlier by Ruban (2006a) were verified and slightly revised. Three main types of palaeoenvironments were defined: continental, shallow-marine and deep-marine. Continental palaeoenvironments are marked by a hiatus or rarely by continental deposits usually comprising sandstones and shales with abundant floral remains and lacking any marine fauna. Shallow-marine palaeoenvironments are dominated by siliciclastics or carbonates with benthonic shelfal fauna. Deep-marine palaeoenvironments are marked by laminated dark-coloured shales and turbidites common with submarine slumps.

The second step is to calculate the number of areas with a particular type of palaeoenvironments for each of the time slices. In this paper I consider three time slices for each stage (Figs. 6, 7) rather than the single time slice per stage used by Ruban (2006a).

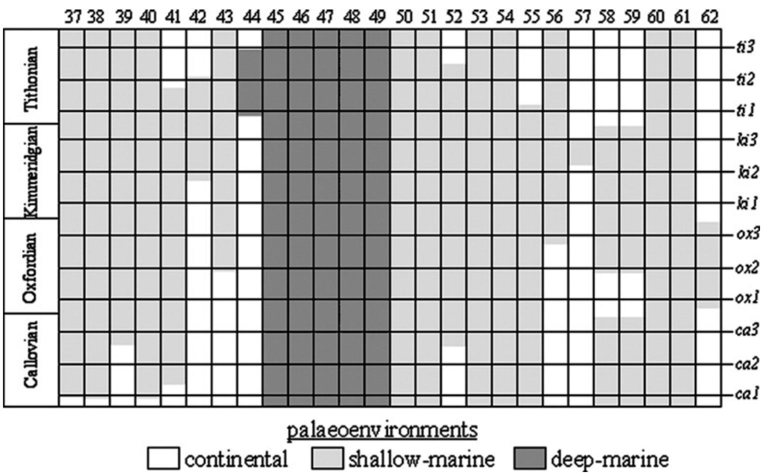

Fig. 7. Interpreted palaeoenvironments of the Callovian–Tithonian. Location of areas — see Fig. 3. Time slices used to evaluate sea-level changes are shown by horizontal lines and indices from the right side.

The third step was to evaluate semi-quantitatively the transgressions and regressions with TR-index (named ISL by Ruban, 2006a):

$$TR = (s + d)/c,$$

where s, d, and c are the number of areas for each time slice with shallow-marine, deep-marine and continental palaeoenvironments respectively. Lower values of this index indicate regression, whereas higher values indicate transgression.

Additionally, the semi-quantitative evaluation of changes in the average basin slope angle, DS-index is attempted:

$$DS = d/s.$$

However, this index cannot be used to document changes of the maximum water depth of the basin. The latter may be recorded by the appearance of deep-marine palaeoenvironments even in the unique area. The DS-index characterizes the extent of deep-marine palaeoenvironments in palaeogeographical space in relation to the extent of shallow-marine environments. Lower values of the index do not indicate that the basin was shallower at this time interval than previously when values were higher. Rather, they indicate that the deep-marine palaeoenvironments became restricted in a little amount of areas. The DS-index measures the average basin slope angle. Therefore, it is necessary to take into consideration another curve, which demonstrates the maximum water depth of the basin. This was not made herein since the Sinemurian deep-marine palaeoenvironments existed at least in one area of the Caucasus.

The regional tectonic processes were perhaps the principal control of the regional transgressions and regressions. In the Jurassic, the Caucasus consisted of several basins different from one another in origin, tectonic regime, and general “geometry” (Lordkipanidze et al., 1984; Ershov et al., 2003; Efendiyeva and Ruban, 2005; Tawadros et al., 2006; Ruban, 2006d). This makes difficult an interpretation of the constrained TR- and DS-curves, as they are attributed to the entire Caucasus. With the suggestions by Rostovtsev et al. (1992) and Ruban (2006d) it is possible to establish the areas, which belong to the Greater Caucasus Basin in the Jurassic. This permits to calculate TR-index and DS-index for this particular basin. Unfortunately, our knowledge on the other Caucasian basins remains limited, and we cannot attempt the same for them.

The absolute age and duration of stages mentioned in this paper are based on the time scale of Gradstein et al. (2004).

4. Regional transgressions and regressions

Three Jurassic transgressive–regressive cycles are recognized in the Caucasus (Fig. 8). The first Jurassic transgressive–regressive cycle embraced the Hettangian–Aalenian interval, lasting 28 m.y. After major Hettangian hiatus, which can be traced across the entire Caucasus, a gradual transgression began. In the early Toarcian, a small regressive episode is known in the Caucasus, which was followed by a significant transgression. A remarkable, but short-term, regional regression occurred in the Aalenian. The second transgressive–regressive cycle was shorter and it embraced the Bajocian–Bathonian interval, lasting 6.9 m.y. The sea rapidly transgressed at the beginning of the Bajocian and reached a maximum territory in the middle–late Bajocian. In the Bathonian, the marine basin was restricted to a size similar to that of the Sinemurian, and at the end of the Bathonian, sedimentation was terminated within most areas of the Caucasus. This time interval corresponded to the second major regional hiatus. The third transgressive–regressive cycle embraced the Callovian–Tithonian interval, lasting 19.2 m.y. A gradual transgression took place during the Callovian and Oxfordian, and minor regressive episode was documented in the early Oxfordian. The peak of transgression took place in the late Oxfordian–Kimmeridgian. A significant short-term regression occurred in the early Kimmeridgian, but during the middle and late Kimmeridgian the sea had the same extent as in the late Oxfordian. A gradual regression occurred in the Tithonian, although the sea still covered a large region at the end of the Tithonian. The Callovian–Late Jurassic transgression explains the development of the wide carbonate rimmed shelf with the growth of carbonate buildups (Rostovtsev et al., 1992; Kuznetsov, 1993; Martin-Garin et al., 2002; Akhmedov et al., 2003; Ruban, 2005a, 2006a; Tawadros et al., 2006). Very shallow lagoonal environments were common in the Kimmeridgian–early Tithonian, where evaporties or varicoloured shales were deposited (Tsejsler, 1977; Jasamanov, 1978; Rostovtsev et al., 1992; Kuznetsov, 1993), which corresponded to the beginning of the end-Jurassic regression. In the Andean region, Late Jurassic evaporitic deposition also occurred during a regressive episode (Legaretta and Uliana, 1996; Hallam, 2001). The same event took place in Northeastern Africa (Tawadros, 2001, pers. comm. 2006), Arabia (Sharland et al., 2001) and Germany (Stratigraphische Tabelle von Deutschland, 2002).

In the Greater Caucasus basin, the same transgressive–regressive cycles have been established (Fig. 8). Only minor differences in the TR-pattern between the entire Caucasus and the Greater Caucasus Basin are found. The Late Plienbachian transgression was larger

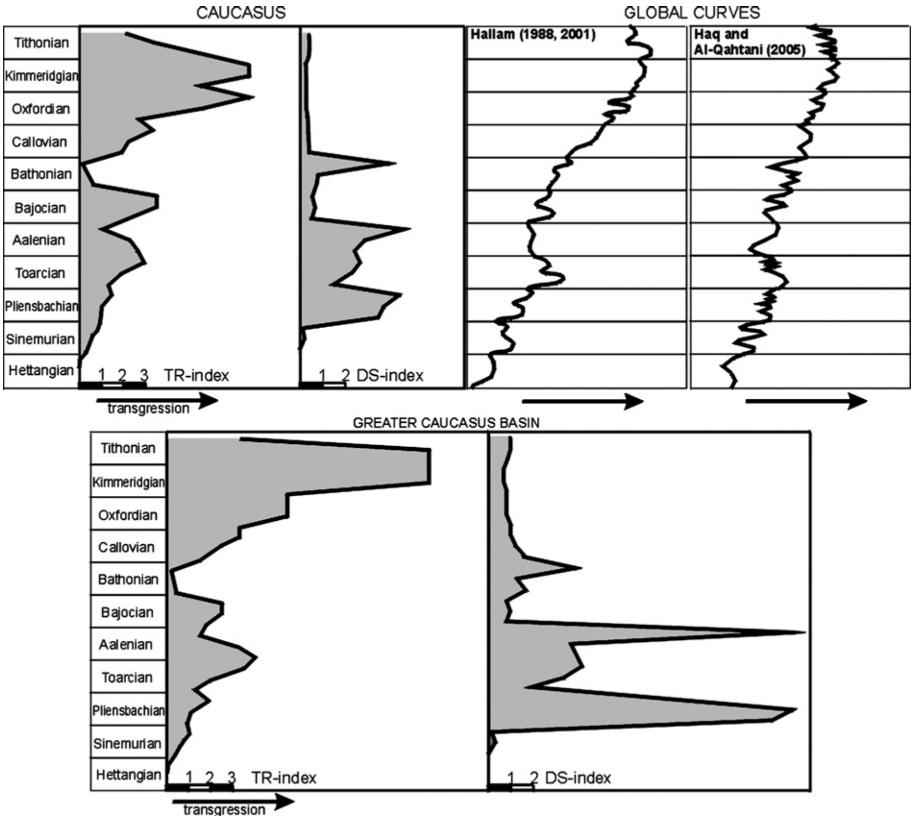

Fig. 8. Regional transgressions and regressions and the global Jurassic curves.

in the latter, whereas the Bajocian transgression was less. Also the regressions in the early Oxfordian and the early Kimmeridgian were not present within the Greater Caucasus Basin.

In contrast to the transgressive–regressive pattern, the changes in the average basin slope angle appeared as few short-term pulses both in the entire Caucasus and in the Greater Caucasus Basin (Fig. 8). The first pulse occurred in the Pliensbachian, the second pulse in the late Aalenian, and the last in the late Bathonian. During the Late Jurassic the Caucasus was characterized by the relatively small number of areas with deep-marine palaeoenvironments in contrast to the Early and Middle Jurassic.

The regionally documented shoreline migrations might have been controlled by both global eustatic fluctuations and regional tectonics as deduced from the present sequence stratigraphic models (Catuneanu, 2006). The eustatic changes in the Jurassic might have been caused by plate tectonics, plume activity and glacioeustasy (Hallam, 1992, 2001; Veeken, 2006). A comparison of the curve by Hallam (1988), updated in Hallam (2001), and the curve of Haq et al. (1987), updated recently by Haq and Al-Qahtani (2005), with the curve of the Caucasian transgressions and regressions (Fig. 8), suggests that their general trends correspond quite well. However, nothing major appeared globally in the Bathonian, when a major regression took place in the Caucasus. The relationships between the global eustatic fluctuations and the regionally documented transgressions and regressions were always complicated because the eustasy is not a unique factor of the regional shoreline migrations. McGowran (2005) even questions how trustable are our global sea-level reconstructions based on the regional studies.

The regional tectonic activity was potentially the main factor, which controlled the Jurassic transgressions and regressions in the Caucasus. The opening and extension of the new marine basins, originated in the beginning of the Jurassic, dominated until the early Aalenian (Ershov et al., 2003), provoked a regional transgression. At the same time, a subsidence of the southern margin of the Russian Platform (Ershov et al., 2003) additionally contributed to the latter. The late Aalenian regression might have been a result of the “orogeny” hypothesized by Ershov et al. (2003). The Bajocian transgression had the same mechanism as that in the Early Jurassic. The major Bathonian regression was a result of the other phase of the mid-Jurassic “orogeny” (Ershov et al., 2003) or it

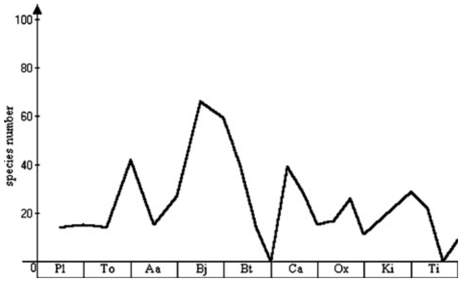

Fig. 9. Ammonite diversity dynamics in the Caucasus (data from Rostovtsev et al., 1992).

was a consequence of the arc–arc collision proposed by Ruban (2006d). The Callovian–Late Jurassic transgression was so large because of continuing basin extension and subsidence of its margins (Ershov et al., 2003). As for the end-Jurassic regression, it may be linked to the regional compressional event and partial uplift of basin margins (Ershov et al., 2003).

5. Transgressions and regressions and marine biodiversity in the Caucasus

Transgressions and regressions might have been an important factor which drove the changes in taxonomic diversity of the marine fauna. Four fossil groups are considered here: ammonites, bivalves, brachiopods and belemnites as they were the principal contributors to the marine biodiversity. The total number of species exceeds 1200 (see review papers by Makridin and Kamyshan, 1964; Prosorovskaya, 1993a,b; Rostovtsev et al., 1992; Topchishvili et al., 2005; Ruban, 2004, 2005b, 2006a,c). Below, a comparison between the changes of the total species number (Figs. 9–12), and transgressions and regressions (Fig. 8) is shown for each of these groups.

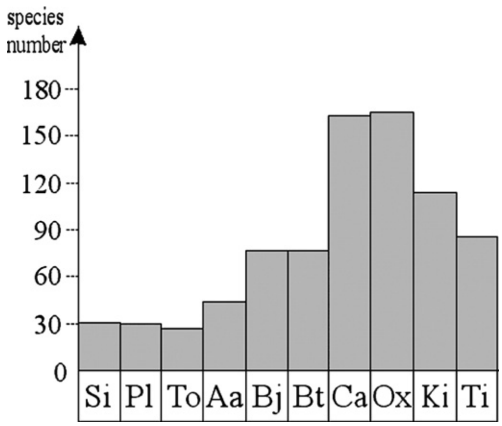

Fig. 10. Bivalve diversity dynamics in the Caucasus (after Ruban, 2006a).

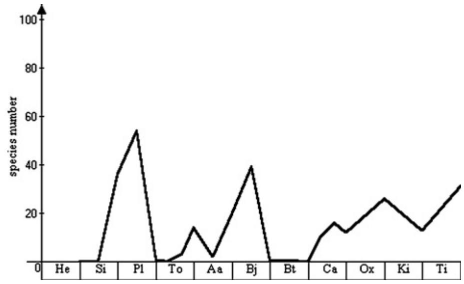

Fig. 11. Brachiopod diversity dynamics in the Northern Caucasus (data from Makridin and Kamyshan, 1964; Rostovtsev et al., 1992; Prosorovskaya, 1993a,b; Ruban, 2004, 2006c). The data and curve are attributed to the Northern Caucasus only, but they seem to be representative for the entire Caucasus.

5.1. Ammonites

The taxonomic diversity of the Caucasian ammonites fluctuated strongly during the Jurassic (Fig. 9). An absolute maximum was reached in the Bajocian, while the early Aalenian, Bathonian, late Callovian, late Oxfordian and middle Tithonian are characterized by significant diversity drops. Overall, a slight decline in ammonite diversity can be documented between the Early–Middle Jurassic and the Late Jurassic.

The ammonite diversity changes (Fig. 9) coincided with the transgressions and regressions (Fig. 8). Diversity rises corresponded to transgressive episodes, and falls to regressions. However, the coincidence of the overall transgression, documented for the entire Jurassic, contrasts with the long-term, slight species decline. This may be explained by the abrupt change from basins with a wide distribution of deep-marine conditions in the Early–Middle Jurassic to shallow-marine in the Late Jurassic. Ammonites were stenotypic organisms (Sandoval et al., 2001a). However, the other explanation of the Late Jurassic diversity decline may be related to the restriction of connection between the boreal and

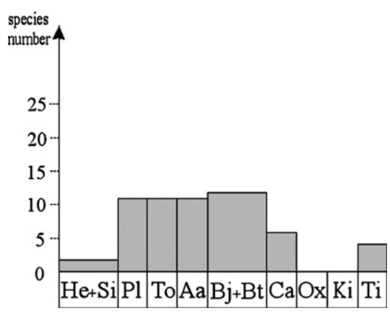

Fig. 12. Belemnite diversity dynamics in the Caucasus (data from Rostovtsev et al., 1992; Topchishvili et al., 2005; Ruban, 2005b).

temperate–tropical realms through the Russian Platform (Dercourt et al., 2000; Rogov et al., 2006).

5.2. Bivalves

The taxonomic diversity of the Caucasian bivalves was low in the Early Jurassic (Fig. 10). After a small decline in the Toarcian, it increased rapidly and a maximum was reached in the Callovian–Oxfordian. Then a gradual diversity drop took place, but the total species number in the Tithonian was greater than in Bajocian–Bathonian.

There are no direct relations between the regional bivalves diversity (Fig. 10) and transgressions and regressions (Fig. 8) (Ruban, 2006a). For example, the total species number rose both in the Callovian, when transgression began, in the Aalenian, when regression took place, and it did not fall in the Bathonian, when major regression occurred. However, the bivalve diversity was much higher during that time interval when shallow-marine conditions dominated. Thus, it is difficult to consider transgressions and regressions as a factor which influenced bivalve diversity, and many other factors were at least as significant.

5.3. Brachiopods

The taxonomic diversity of the North Caucasian brachiopods changed rapidly during the Jurassic (Fig. 11). Peaks occurred in the early Pliensbachian, early Bajocian, Oxfordian and Tithonian, while significant drops took place in the late Pliensbachian–early Toarcian, early Aalenian, late Bajocian–Bathonian and Kimmeridgian. No overall changes in the total species number are found.

There are no direct links between the changes of the brachiopod diversity (Fig. 11) and sea level (Fig. 8). For example, both the early Pliensbachian diversification and the late Pliensbachian decline occurred during gradual transgression. Only the regression in the Bathonian led to the demise of brachiopods. But even in this case, there is uncertainty: the diversity decline began in the late Bajocian, slightly before the regional regression had begun. The brachiopod diversity in the Northern Caucasus was controlled by other factors than transgressions and regressions.

5.4. Belemnites

The taxonomic diversity of the Caucasian belemnites did not change significantly during the Jurassic (Fig. 12). It remained at the same level during the Pliensbachian–Bathonian. A remarkable disappearance of belemnites occurred in the Oxfordian–Kimmeridgian interval. The same disappearance is also known in the English Kimmeridgian (Wignall, pers. comm. 2006). The observed patterns (Fig. 12) cannot be explained by transgressions and regressions (Fig. 8), and it seems that other factors were at least as important. The dominance of shallow-marine conditions does not explain the total absence of belemnites in the Oxfordian–Kimmeridgian because there were some deep-marine areas during this time interval.

5.5. Brief synthesis

Comparison between regional transgressions and regressions and diversity dynamics of four fossil groups suggests that only ammonites were influenced directly by the former, although even for this fossil group other factors might have been even more important (see above). These other factors were more significant for bivalves, brachiopods and belemnites. A detailed study of ammonite diversity and sea-level changes in the Cordillera Bética (south of Spain) suggests that they were correlated (O'Dogherty et al., 2000; Sandoval et al., 2001a,b). The same conclusion was reached with the Caucasian data.

6. Discussion

6.1. Jurassic transgressions and regressions in the Caucasus and selected Peri-Tethyan and Neotethyan regions

Jurassic transgressions and regressions, reconstructed in the Caucasus, are compared to those established in some Peri-Tethyan and Neotethyan regions. In Western Europe, two major transgressive–regressive cycles are established in the Jurassic (Jacquin and de Graciansky, 1998; Jacquin et al., 1998). The first was the Ligure Cycle which started in the Late Triassic, and the peak was reached in the middle Toarcian, when a rapid regression occurred. The Aalenian–Bajocian transition is marked by a widespread unconformity. The succeeding North Sea Cycle started in the Bajocian, and the stepwise transgression reached its maximum in the Kimmeridgian. However, minor regressive episodes occurred in the Bathonian and Oxfordian. Since the Tithonian, a regression took place, and this cycle ended in the beginning of the Early Cretaceous. Although transgression and regressions in the basins of the Western Europe are rather similar to those of the Caucasus (Fig. 8), significant differences are evident. There is no such difference between the Hettangian–Bathonian and Callovian–Tithonian intervals in Western Europe as it is found in the Caucasus. The principal boundary between cycles in Western Europe is the regional unconformity at the Aalenian–Bajocian transition, while in the Caucasus the most remarkable hiatus occurred in the Bathonian. The latest Triassic–earliest Jurassic transgression was rapid in Western Europe, while it appeared later and more gradually in the Caucasus. The peak of the Early Jurassic transgression was reached a little later in the Caucasus.

Smith (2001) measured the outcrop area of the terrestrial/fluviatile, marine unfossiliferous and marine fossiliferous sedimentary rocks which outcrop in England and France and concluded that the sea transgressed from the Late Triassic until the Middle Jurassic. A minor regressive episode was established in the Aalenian. The second transgression occurred in the Bajocian–Bathonian although a regression took place in the Callovian. After the next transgression in the Late Jurassic, a remarkable regression occurred in the Berriasian. Such changes in England and France only partly correspond to the changes recorded in the Caucasus (Fig. 8). The Hettangian–Aalenian records are similar, while the Bathonian regression, which took place in the Caucasus, is not recovered in England and France, and the Callovian regression, though not so large as the Bathonian regression in the Caucasus, has no analogue in England and France.

Wignall et al. (2005) reported the earliest Toarcian regression in Western Europe, which is comparable to that in the Caucasus.

Guillocheau et al. (2000) recognized Carnian–Toarcian, Aalenian–lower Bathonian, lower Bathonian–Oxfordian, and Kimmeridgian–lower/upper Berriasian boundary cycles in the Paris Basin. These cycles are difficult to trace in the Caucasus at all.

The Stratigraphische Tabelle von Deutschland (2002) presents a detailed overview of the Jurassic formations and facies established in Germany. Shallow-marine facies dominated in the German basins during the Jurassic, and no pelagic facies have been identified. Regressive episodes, documented by the high number and wider extent of local hiatuses, occurred in the Hettangian, late Sinemurian, middle Toarcian, late Aalenian–middle Bajocian, Bathonian–early Callovian, late Callovian, and Kimmeridgian–Tithonian. Only the first of these has an analogue in the Caucasus. Some other regressions in the German basins, such as late Aalenian–middle Bajocian, Bathonian–early Callovian, Kimmeridgian–Tithonian, only partly corresponded to the regressions documented in the Caucasus (Fig. 8).

Surlyk (2003) developed a curve for East Greenland, which demonstrates the shoreline migration. Thus, this is essentially a transgressive–regressive curve. According to it, a general weak-regressive trend in the Toarcian–Bajocian changed to the prominent transgressive trend in the Bathonian–Kimmeridgian. Among the second-order events, the most remarkable were the early Bathonian, middle Callovian–early Oxfordian, and Kimmeridgian transgressions as well as the regressions at the Toarcian–Aalenian transition, in the late Bajocian, and in the mid-Oxfordian. The general trends documented in East Greenland are analogous to those in the Caucasus (Fig. 8). However, the second-order events appear to be incomparable, except the Kimmeridgian transgression, which is evident both in East Greenland and the Caucasus.

On the Arabian Plate, transgressions occurred in the early–middle Toarcian, early Bajocian, early Bathonian, Callovian–Oxfordian, middle Kimmeridgian, and late Tithonian with a maximum in the Early Cretaceous, while regressions took place in the late Toarcian, late Bajocian, late Bathonian, late Oxfordian–early Kimmeridgian, and late Kimmeridgian–middle Tithonian (Sharland et al., 2001). Only a few of these episodes had direct analogues in the Caucasus (Fig. 8). Therefore, transgressions and regressions documented in the latter and in Arabia differed somewhat.

Available data and their interpretations (Schandelmeier and Reynolds, 1997; Tawadros, 2001, pers. comm. 2006; Guiraud et al., 2005) allow recognition of chronology of transgressions and regressions in northern and northeastern Africa. Transgression occurred during the Early Jurassic. The Toarcian–Aalenian transition is marked by an unconformity which seems to be a result of regression. Then sea transgressed, although the late Callovian and late Tithonian are marked by regressive episodes. The peak of transgression was reached in the Kimmeridgian. Such sea-level changes in northern Africa do not correspond well to the changes documented in the Caucasus (Fig. 8).

Consequently, Jurassic transgressions and regressions in the Caucasus were only partly similar to those recorded in other regions. This may be explained by differences in the tectonic history of those regions.

6.2. Global changes in the Jurassic biodiversity and sea level

A problem is the low resolution of the Jurassic global marine biodiversity curve. The most reliable data of Peters and Foote (2001) provide the maximum and minimum numbers of marine genera for the Early, Middle and Late Jurassic, but even these would allow recognition of the links with the eustatic changes. A biodiversity curve of Newman (2001) is a bit more detailed. The average number of Early Jurassic marine genera is 1046. It increased up to 1425 genera in the Middle Jurassic, and then slightly rose again up to 1446 genera in the Late Jurassic. Comparison of these numbers with the global sea-level changes (Haq et al., 1987; Hallam, 1988, 2001; Haq and Al-Qahtani, 2005) (Fig. 8) shows that global marine biodiversity increased together with eustatic rises during the Jurassic.

A comparison of the global generic diversity dynamics of Jurassic bivalves (Miller and Sepkoski, 1988) with the eustatic changes (Haq et al., 1987; Hallam, 1988, 2001; Haq and Al-Qahtani, 2005) suggests a close relation. A rapid eustatic rise in the Early Jurassic provoked a significant radiation of bivalves. The next radiation, which occurred in the late Middle Jurassic, evidently coincided with the Bajocian–Callovian transgression. The diversity peak was reached in the Late Jurassic at the same time when sea level was the highest. The Tithonian eustatic fall resulted in a bivalve decline. Earlier, Hallam (1977) also found that eustatic changes significantly controlled the global bivalve diversity.

A comparison between the global belemnite diversity changes (Doyle and Bennett, 1995) and sea-level fluctuations (Haq et al., 1987; Hallam, 1988, 2001; Haq and Al-Qahtani, 2005) suggests that all three increases in diversity of belemnites, occurring in the Pliensbachian–Toarcian, Bajocian and Callovian–Oxfordian, corresponded to global eustatic rises. However, belemnites declined in a stepwise pattern during the Jurassic while sea level rose. Therefore, the links between the Jurassic sea-level changes, global marine biodiversity and diversity of particular fossil groups are evident on a global scale.

7. Conclusions

Three transgressive–regressive cycles have been established in the entire Caucasus, namely the Hettangian–Aalenian, Bajocian–Bathonian and Callovian–Tithonian cycles. Each transgression was more extensive than the previous. The same cycles have been established for the Greater Caucasus Basin. The Jurassic transgressions and regressions documented in the Caucasus correspond generally to the global eustatic fluctuations recorded by Haq et al. (1987), Hallam (1988, 2001), and Haq and Al-Qahtani (2005). The regional tectonic activity was another important control of the regional transgressions and regressions. The Caucasian transgressions and regressions only partly corresponded to those established in some Peri-Tethyan and Neotethyan regions.

Jurassic transgressions and regressions influenced the marine biodiversity in the Caucasus. However, direct relationships between them are obvious for the ammonites only, in contrast to bivalves, brachiopods and belemnites. On a global scale, marine biodiversity corresponded well to the eustatic changes.

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