Trabajos de Geología, Univ. de Oviedo, 27 : 19-27 (2007)

A new hypothesis on the position of the Greater Caucasus Terrane in the Late Palaeozoic-Early Mesozoic based on palaeontologic and lithologic data

Dmitry A. Ruban[1], Henrique Zerfass[2] and Wan Yang[3]

[1] *Department of Geology, University of Pretoria, Pretoria 0002, South Africa (corresponding author) contact address: Tchistopolskaja st., H. 3, App. 10, Rostov-na-Donu, 344032, Russia. E-mail address: ruban-d@mail.ru, ruban-d@rambler.ru*

[2] *Geological Survey of Brazil (CPRM), Rua Banco da Província, 105, CEP 90840-030, Porto Alegre, RS, Brazil. E-mail address: henrique_zerfass@yahoo.com.br, zerfass@pa.cprm.gov.br*

[3] *Department of Geology, Wichita State University, Wichita, KS, 67260, USA E-mail address: wan.yang@wichita.edu*

Abstract: The Greater Caucasus Terrane (GCT) is the core of the Greater Caucasus, where Palaeozoic rocks crop out. Ludlow and the earliest Devonian fauna assemblages and Late Carboniferous flora assemblages contain some taxa typical for the Hunic counterpart and adjacent areas in Europe. The Palaeozoic sedimentary succession of the GCT resembles that of the Carnic Alps. Both palaeontologic and lithologic evidence suggests a similarity between the GCT and European Hunic and adjacent terranes. We hypothesize that the GCT was located close to the Carnic Alps in the Silurian-Permian time. This interpretation implies that this terrane derived from Gondwana as a part of the Hun Superterrane in the Silurian. Later, it was docked to the northern margin of the Palaeotethys Ocean together with other European Hunic Terranes. After Middle Triassic, the GCT was displaced to its present position due to sinistral movements along a major shear zone, which was active on the northern Palaeotethyan margin during the Late Palaeozoic-Early Mesozoic.

Keywords: terrane, shear zone, Palaeozoic, Triassic, Gondwana, Greater Caucasus.

Resumen: El terreno del Gran Cáucaso (GCT) es el núcleo del Gran Cáucaso y en el afloran rocas de edad Paleozoica. Las asociaciones faunísticas del Ludloviense y del Devónico inferior y las asociaciones de flora del Carbonífero superior encontradas en este terreo contienen taxones típicos de la zona Húnica y áreas adyacentes en Europa. La sucesión sedimentaria paleozoica del GCT es semejante a la de los Alpes Cárnicos. Tanto las evidencias paleontológicas como litológicas sugieren que hay similitud entre el GCT y los terrenos europeos Húnicos y zonas adyacentes. En este artículo se sugiere que durante el Silúrico-Pérmico el GCT estaba situado en una zona próxima a los Alpes Cárnicos. Esta interpretación implica que, durante el Silúrico, este terreno provino de Gondwana como parte del superterreno Húnico. Posteriormente, este terreno, junto con otros terrenos europeos Húnicos, fue accrecionado al margen septentrional del océano Paleotethys. Con posterioridad al Triásico medio, el GCT se desplazó hasta su posición actual debido a un movimiento sinistro que tuvo lugar a lo largo de una gran zona de cizalla que, durante el Paleozoico superior y el Mesozoico inferior, era activa en el margen septentrional del océano Paleotethys.

Palabras clave: terreno, zona de cizalla, Paleozoico, Triásico, Gondwana, Gran Cáucaso.

Global plate positions before the Jurassic (200 Ma) are still quite uncertain, especially for the Silurian-Devonian and Triassic times (Scotese, 2004). Thus, much more efforts are needed to improve the palaeotectonic reconstructions. Special attention should be paid to those regions, where tectonic evolution is poorly known and/or was interpreted on the basis of old tectonic theories.

The Greater Caucasus is a large region, connecting the European and Asiatic structures (Fig. 1). It is a long and narrow mountain chain between the Black Sea and the Caspian Sea. The northern slopes of this chain are exposed in Russia, whereas the southern slopes belong to Georgia and Azerbaijan. The Greater Caucasus formed in the Cenozoic, when it was deformed and subsequently uplifted (Ershov et al., 2003), together with other Alpine orogens. At the present, the Greater Caucasus remains an active region. Previous interpretations of the Palaeozoic geodynamics of the Greater Caucasus (Laz'ko, 1975; Belousov, 1978; Milanovskij et al., 1984) may not be valid any more, because they are based on old tectonic concepts (including the geosyncline paradigm), that cannot be incorporated into the new global plate tectonic models. Moreover, there are some facts that cannot be well explained by the traditional tectonic models. For example, a palaeomagnetic study by Shevljagin (1986) suggests that the polar wander paths of the northern Greater Caucasus and the Russian Platform are different before the end of the Palaeozoic. The tectonic history of the Greater Caucasus needs to be re-interpreted within a global palaeotectonic framework (Stampfli and Borel, 2002; Stampfli et al., 2002; von Raumer et al., 2003) to understand the evolution of the adjacent domains of Europe and Middle East. In this paper, basic evidence and concepts are presented to introduce a new terrane hypothesis, which was proposed previously by Tawadros et al. (2006) and Ruban (2007 a, 2007 b), but without a presentation of detailed analysis and interpretation. This work intends to serve as a foundation for future, more detailed studies of the tectonic history of the Greater Caucasus.

Geological setting

The Greater Caucasus is one of the main regions of the Caucasus, which comprises the Lesser Caucasus, the Transcaucasian depressions (the Kura and Rioni depressions), and some foredeeps (Fig. 1). A variety of Palaeozoic sedimentary complexes are exposed in the central part of the Greater Caucasus, where the Greater Caucasus Terrane (GCT) was identified by Gamkrelidze (1997), Tawadros et al. (2006) and Ruban et al. (2007 a) (Fig. 1). The Palaeozoic sedimentary complexes were described by Paffengolts (1959, 1965), Robinson (1965), Miklukho-Maklaj and Miklukho-Maklaj (1966), Zhamojda (1968), Kizeval'ter and Robinson (1973), Zanina and Likharev (1975), Kotlyar (1977), Kotlyar et al. (1999, 2004), Obut et al. (1988), Davydov and Leven (2003), Valentseva et al. (2006) and Ruban (2006, 2007 a, 2007 b). These authors established a general lithostratigraphy for the northern GCT (Fig. 2).

The Cambrian-Lower Ordovician deposits of the entire GCT contain quartzites, shales, volcanoclastics, and carbonates and are 2600 m thick; they were accumulated in a marine basin (Paffengolts, 1959, 1965; Zhamojda, 1968; Ruban, 2006, 2007 a). A major regional hiatus spans the middle part of the Ordovician (Ruban, 2006, 2007 b). The Silurian-Devonian deposits (up to 5000 m thick) are shales, arenites, volcanoclastics and carbonates (Obut et al., 1988; Robinson, 1965; Ruban, 2006,

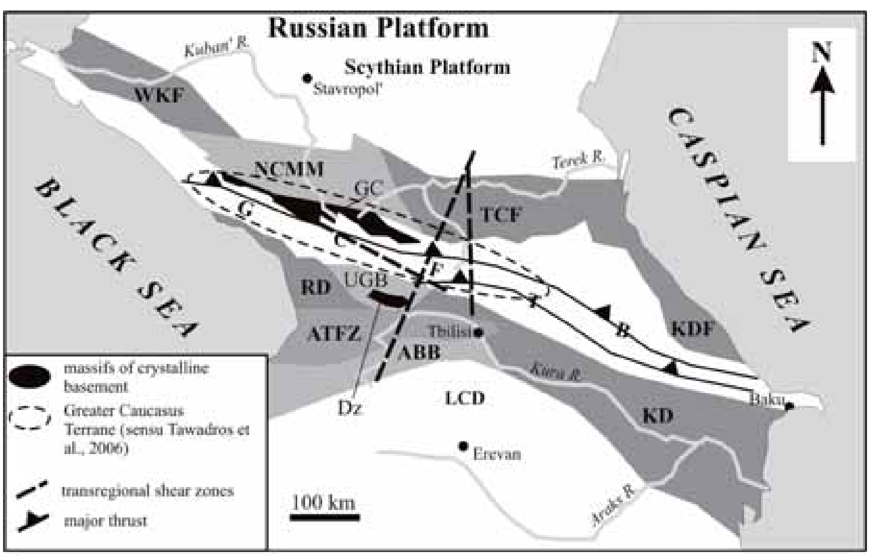

Figure 1. Principal structural units of the Caucasus (modified after Gamkrelidze, 1986, 1997). Abbreviations: ABB - Arthvin-Bolnisi Block, ATFZ - Adjara-Thrialethian Fold Zone, Dz - Dzirula Massif, GC - Greater Caucasian Massif, GCFTB - Greater Caucasian Fold and Thrust Belt, KD - Kura Depression, KDF - Kusar-Divichian Foredeep, LCD - Lesser Caucasus Domain, NCMM - North Caucasian Marginal Massif, RD - Rioni Depression, TCF - Terek-Caspian Foredeep, UGB - Uplifted Georgian Block, WKF - West Kubanian Foredeep. Different patterns are used to differentiate the units.

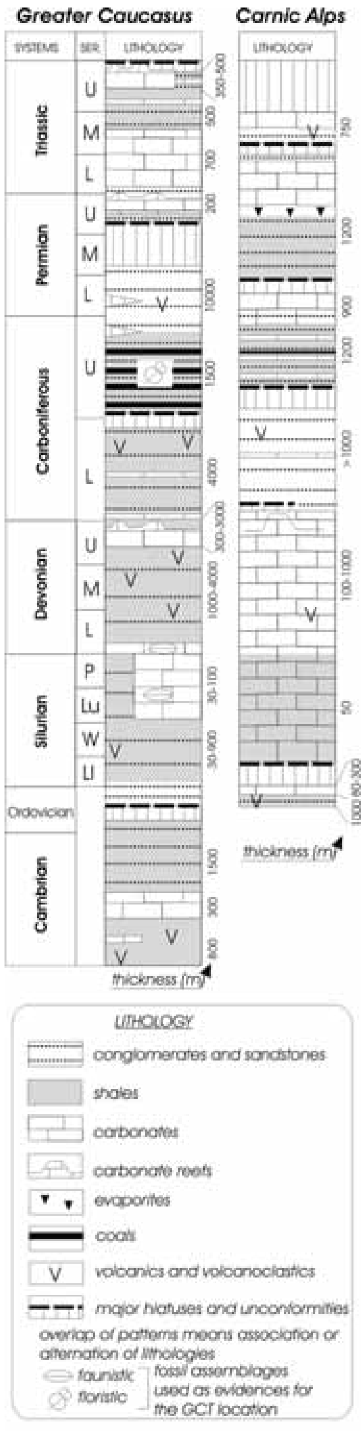

Figure 2. Generalized stratigraphic sections of the Palaeozoic-Triassic strata of the northern part of the GCT (modified after Ruban, 2006) and the Carnic Alps (after Venturini, 1990, 2002; Wenzel, 1997; Schönlaub and Histon, 1999; Krainer, 1989, 1993a,b, 1996; Kříž et al., 2003). Chronostratigraphy after Gradstein et al. (2004) and following the recommendations of the International Commission on Stratigraphy (www.stratigraphy.org). Abbreviations: L - Lower, M - Middle, U - Upper; Silurian series: Ll - Llandovery, W - Wenlock, Lu - Ludlow, P - Pridoli. Thickness is approximate.

2007 a). Until the earliest Devonian, marine environments dominated, whereas a volcanic island existed from the Early Devonian to the latest Devonian (Ruban, 2007). The uppermost Devonian deposits are dominantly carbonates up to 3000 m thick, which were accumulated on a rimmed shelf (Paffengolts, 1959; Zhamojda, 1968; Kizeva'ter and Robinson, 1973; Zanina and Likharev, 1975; Ruban, 2005, 2006, 2007 a). The Lower Carboniferous deposits are interbedded siliciclastics, shales, carbonates and volcanoclastics with a total thickness of 4000 m; they were accumulated in a possibly deep marine basin (Paffengolts, 1959; Zhamojda, 1968; Kotlyar, 1977; Ruban, 2006, 2007 a). The Upper Carboniferous strata are thick (up to 1500 m) coal-bearing siliciclastic deposits (Paffengolts, 1959; Zhamojda, 1968; Kotlyar, 1977; Ruban, 2006, 2007 a). They are overlain by molassic siliciclastics-dominated deposits of Lower-Middle Permian age, with a thickness more than 10000 m (Paffengolts, 1959; Miklukho-Maklaj and Miklukho-Maklaj,1966; Zhamojda, 1968; Kotlyar, 1977; Davydov and Levin, 2003; Ruban, 2006, 2007 a; Valentseva et al., 2006). In the southern part of the GCT, marine Upper Carboniferous-Permian deposits are present, but are not observed in its northern part (Miklukho-Maklaj and Miklukho-Maklaj,1966; Kotlyar, 1977). A major regional hiatus spans the middle part of the Permian (Ruban, 2006, 2007 b). During a short marine incursion in the latest Permian, approximately 200 m of sandstone, shale and carbonate (including reefal limestones) were deposited (Miklukho-Maklaj and Miklukho-Maklaj,1966; Kotlyar, 1977; Kotlyar et al., 1999, 2004; Ruban, 2006, 2007 a). Volcanic and volcanoclastic rocks are common in the entire Palaeozoic sedimentary succession.

The structural setting of the Greater Caucasus is far from being understood completely. The most appropriate tectonic framework was proposed by Gamkrelidze (1986, 1997) and Ershov et al. (2003), who interpreted this domain as a thrust and fold belt oriented NW-SE. Major trans-regional shear zones with strike-slip displacements are present across the central part of the Greater Caucasus (Fig. 1). They shear off the fold and thrust belt at different angles. The present structure of the Greater Caucasus was created in the Cenozoic (Ershov et al., 2003). A collision between the Arabian and Eurasian plates initiated an orogeny in the Oligocene. This resulted in both folding and faulting. The orogenic activity culminated in the late Miocene-Pliocene, which was accompanied by a rapid uplift that lasted to the present. Compressional phases during the Palaeozoic and the Mesozoic were also interpreted (Laz'ko, 1975; Belousov, 1978; Milanovskij et al., 1984; Ershov et al., 2003). However, major uncertainties in the interpretation of the tectonic architecture of the Greater Caucasus do not allow to conclude whether these compressional phases occurred or not. For example, a mid-Jurassic unconformity was interpreted as caused by a local orogeny (Ershov et al., 2003), but it might have been formed by a sea-level fall (Ruban, 2007 b). Unconformities are also known within the Carboniferous sequence (Paffengolts, 1959; Davydov and Leven, 2003).

In the GCT, two episodes of Palaeozoic tectonic activity are recognized, namely the Middle Ordovician and the Carboniferous-Permian. They correlate with the Sardic phase (e.g., Stille, 1939; Leone et al., 1991) and the Variscan orogenic cycle (e.g., Matte, 1986, 1991; Franke et al., 2000) respectively. The Palaeozoic sedimentary complexes exhibit intense folding, cleavage, and metamorphism, and contain many magmatic bodies (Paffengolts, 1959; Laz'ko, 1975), which suggest deformation in a deep domain. According to the geosyncline models, the Palaeozoic structures of the Caucasus and their evolution are related to the southern margin of the Russian Platform (e.g., Laz'ko, 1975; Belousov, 1978; Milanovskij et al., 1984). An alternative hypothetic model is presented below.

Evidence for the location of the Greater Caucasus Terrane in the Middle-Late Palaeozoic

Unlike the traditional models that link the GCT to the southern margin of the Russian Platform, the palaeontologic and lithologic evidence presented below suggests a number of similarities between the GCT and the European Hunic terranes (sensu Stampfli and Borel, 2002) and adjacent regions of Europe. We focus on the Carnic Alps - a representative Hunic terrane, which was comprehensively characterized by Krainer (1989, 1993a,b, 1996), Venturini (1990, 2002), and Schönlaub and Histon (1999), but also discuss some other European regions such as Bohemia or the Rotliegend type area.

Palaeontologic evidence

The palaeontological record of the GCT is generally poor. The only informative fossil assemblages are those from the Ludlow-lowermost Devonian carbonates and from the Upper Carboniferous non-marine coal-bearing strata (Fig. 2). The rich reefal communities from the uppermost Permian are not useful for this study, because they are dominated by taxa common to the entire Palaeotethys (Kotlyar et al., 1999, 2004).

The fossil assemblage from the Ludlow carbonate deposits of the GCT contains *Cardiola, Lunulicardium, Antipleura, Silurina, Vlasta, Slava, Orthoceras, Michelinoceras, Plagiostomoceras, Parakinoceras, Arionoceras, Geisonoceras, and Cheirurus*. It is similar to that from some structural units in the Carnic Alps, Bohemia and Sardinia (Robinson, 1965; Zhamojda, 1968; Bogolepova, 1997; Bogolepova and Holland, 1995).

A great similarity between the earliest Devonian bivalve assemblage from the central Greater Caucasus and Bohemia (Kříž et al., 2003) is observed. The Caucasian assemblage includes *Antipleura (Dualina), Cardiola, Hercynella, Lunulacardium, Mila, Neclania, Praecardium, and Vlasta* (Obut et al., 1988).

The Late Carboniferous plants from the coal-bearing strata of the northern GCT include a number of Western-Central European characteristic and even endemic taxa (Anisimova, 1977, 1979). Among these taxa are *Lepidodendron* cf. *haidingeri* Ettigshausen, *L. brevifolium* Ettingshausen, *Lepidophloios macrolepidotus* Goldenberg, *Calamites goeppertii* Weiss, *Macrostachya infundibuliformis var. solmsii* Weiss, *Cingularia typica* Weiss, *Rhacopteris asplenites* Gutbier, *R. busseana Stur, Sphenopteris lanceolata* (Gutbier), *Sph. haidingeri* Ettingshausen, *Sph. coemansi* Andrae, *Sph. corifolia* Kidston, *Sph. ovata* Lillie, *Sph. pecopteroides* Kidston, *Linopteris weigeli* Sterzel, *Neuropteris subauriculata* Sterzel, *Odontopteris alpina* Geinitz, *Corinepteris erosa* Gutbier, *"Triphyllopteris" rhomboidea* Ettingshausen, *Lonchopteris silesiaca* Gothan, *Calamites cf. discifer* Weiss, *Asterophyllites jubatus* Lindley et Hutton, *Calamostachys discifer Legg et* Schonefeld, *C. superba* Weiss, *Zeilleria delicatula* (Sternberg), *Diplotmema geniculatum var. erectum* Bell, *D. zeilleri Stur, Cordaicarpus areolatus* (Boulay), *and Rhabdocarpus sublunicatus* Grand'Eury.

Most of these species are not found in the Upper Carboniferous deposits of the Donbass -a large Late Palaeozoic basin located on the southern margin of the Russian Platform (see flora review by Novik, 1974). This observation requires an explanation, because the Donbass is nowadays close to the Greater Caucasus.

Lithologic evidence

Some lithological similarities between the Silurian-Triassic sedimentary successions of the GCT (Robinson, 1965; Zhamojda, 1968; Kizeval'ter and Robinson, 1973; Kotlyar, 1977; Obut et al. 1988; Ruban, 2006) and those of the Carnic Alps (Krainer, 1989, 1993a, 1993b, 1996; Venturini, 1990, 2002; Wenzel, 1997; Schönlaub and Histon, 1999; K?í? et al., 2003) are observed (Fig. 2).

The older deposits are not considered, because of their uncertain composition in these regions.

In both the GCT and the Carnic Alps, the Silurian interval includes graptolite shales and carbonates. In the Carnic Alps, however, the graptolite shales are restricted to the Bischofalm and the Findenig facies (Kříž et al., 2003). It appears that both deep-marine and shallow-marine environments existed in both regions during the Silurian (Schönlaub and Histon, 1999; Kříž et al., 2003; Ruban, 2007 a).

The Devonian succession, except for its lowermost and uppermost parts, differs between the two regions. In contrast to the carbonate sedimentation in a subsiding basin in the Carnic Alps (Schönlaub and Histon, 1999), a thick succession up to 4000 m, composed of volcanic and volcanoclastic rocks, was formed in the GCT, which was an island mass (Ruban, 2007 b). However, the Upper Devonian reefal carbonates are typical for both the Carnic Alps and the GCT.

The Carboniferous sequences are similar in both regions. Thus, the Lower Carboniferous flysch, accumulated in a slope environment, and the terrestrial Upper Carboniferous coal-bearing sedimentary complexes crop out in both the Carnic Alps and the GCT (Paffengolts, 1959; Zhamojda, 1968; Kotlyar, 1977; Krainer, 1989; Schönlaub and Histon, 1999). The major mid-Carboniferous unconformity within the Carnic Alps has a counterpart analogue in the GCT (Paffengolts, 1959; Davydov and Leven, 2003) (Fig. 2).

Some lithological dissimilarities between the GCT and the Carnic Alps are observed in the Permian succession (Fig. 2). However, the thick (up to 10 km) Permian non-marine molassic deposits of the GCT (Miklukho-Maklay and Miklukho-Maklay,1966; Kotlyar, 1977; Davydov and Leven, 2003; Valentseva et al., 2006) are similar to those of the Rotliegend (Holub and Kozur, 1981; Kozur, 1989; Glennie, 1997; Schneider, 2001; Stratigraphische Tabelle, 2002; Menning et al., 2006) and crop out in most parts of Western and Central Europe. The lower part of Permian non-marine deposits in the GCT includes the 1250 m thick Aksautskaja Formation (uppermost Carboniferous-lowermost Permian) composed dominantly of conglomerates, sandstones, siltstones, and shales, overlying conformably and, in some places, unconformably the Carboniferous coal-bearing strata and older Palaeozoic deposits. The middle part is formed by the 800 m thick Kishkitskaja Formation (Lower Permian) composed of volcanoclastic and clastic deposits. The upper part consists of the 10 km thick Bol'shelabinskaja Formation (Lower-Middle Permian (?)) composed of red conglomerates, sandstones, and siltstones, with a disconformable or locally conformable base and an angularly-unconformable top, overlain by Upper Permian marine deposits. The Lower Rotliegend (sensu Glennie, 1997) correlates with the Aksautskaja and Kishkitskaja formations, whereas the Upper Rotliegend-1 (sensu Glennie, 1997) correlates with the Bol'shelabinskaja Formation. The lower part of the Rotliegend deposits of Europe are grey-coloured, whereas the upper part is red-coloured (Menning et al., 2006). The same colours are observed in the Greater Caucasus (Miklukho-Maklay and Miklukho-Maklay,1966). The deposition of the Upper Permian marine carbonates with *Bellerophon* gastropod began synchronously in the GCT (Miklukho-Maklaj and Miklukho-Maklaj, 1966) and in the Carnic Alps (Krainer, 1993b), on a shelf with shallow-water, transgressive environments (Krainer, 1993a; Schönlaub and Histon, 1999; Ruban, 2007 a).

The youngest stratigraphic interval with similar lithologies between the GCT and the Carnic Alps is the Lower Triassic, when episodes of carbonate accumulation took place in both regions (Fig. 2).

The Palaeozoic deposits of the Greater Caucasus differ from those of the Donbass, although both regions are located closely at present. In the Donbass, the stratigraphy of the pre-Devonian succession is unclear, and the Middle-Upper Devonian is dominated by shallow-marine to terrestrial clastic deposits with a total thickness up to 1400 m (Laz'ko, 1975). This contrasts with the Greater Caucasus, where a carbonate platform existed (Ruban, 2005, 2007 a). In the Donbass, the Carboniferous deposits are much thicker (up to 10000 m) than those of the GCT and the coal-bearing interval is characterized by the presence of abundant limestones (Laz'ko, 1975). These strata are mostly shallow-marine, whereas the Carboniferous of the Greater Caucasus represents a transition from slope to terrestrial environments (Laz'ko, 1975). The Permian-Triassic deposits of the Donbass are non-marine clastics with a thickness of about 1800 m (Laz'ko, 1975). The Permian beds have some similarities to those of the Greater Caucasus, but evaporites (not found in Permian of the Greater Caucasus) are common in the Donbass (Laz'ko, 1975). The Triassic deposits of the Donbass and the Greater Caucasus are extremely different because they are marine carbonates in the latter (Ruban, 2007 b).

Terrane motions

The aforementioned evidence is used to establish a new terrane hypothesis to explain the geodynamics of the GCT during the Palaeozoic (Fig. 3). We speculate that, in the Middle-Late Palaeozoic, the GCT was part of the

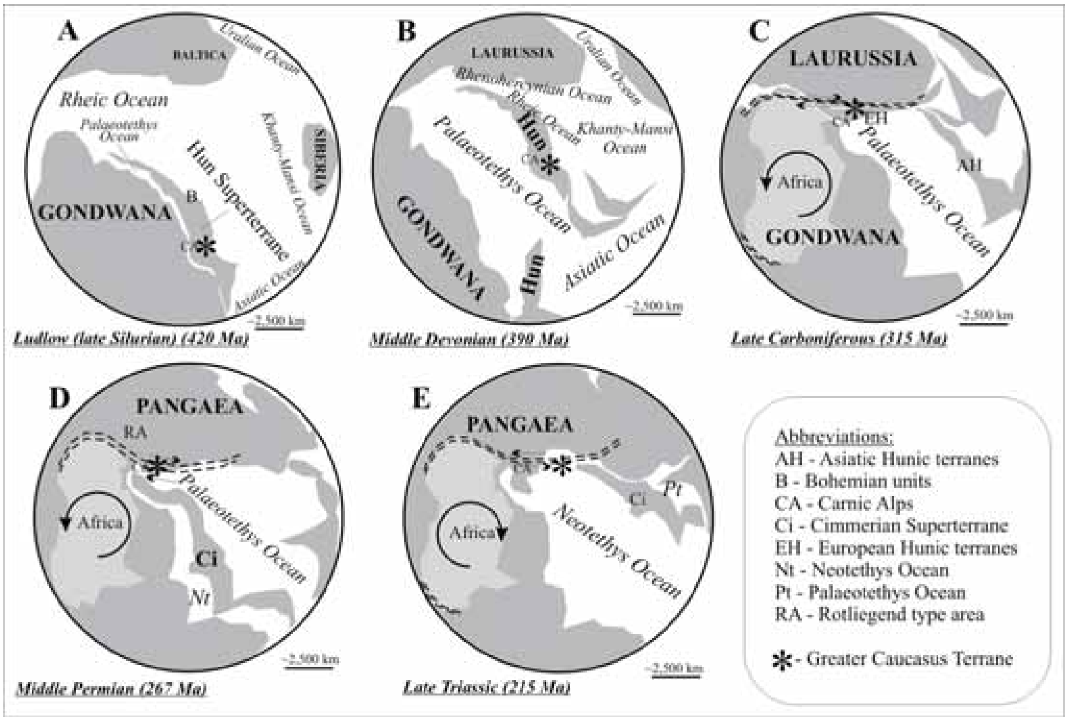

Figure 3. A hypothetic model of the GCT migration from Middle Palaeozoic to Triassic. Global reconstructions after Stampfli & Borel (2002) (partly adapted from Ruban 2007 a, b) and absolute ages after Gradstein et al. (2004). On maps C-E, rotating Africa is highlighted to be separated from other blocks of Pangaea.

Hun Superterrane, which also included the Carnic Alps, and separated from Gondwana in the Silurian (Stampfli and Borel, 2002; Stampfli et al., 2002; von Raumer et al., 2003) (Fig. 3A). In the Late Palaeozoic, the GCT was located on the northern margin of the Palaeotethys Ocean (Fig. 3B), where the European Hunic Terranes were docked after the partial closure of the Rhenohercynian Ocean in the Late Devonian (Stampfli and Borel, 2002; von Raumer et al., 2003; Torsvik and Cocks, 2004).

This speculation raises two significant questions. How and when did the GCT migrate to its present position? To reach its current position, the GCT must have been displaced eastward to reach the southern periphery of the Russian Platform. Such movement may be linked to displacements along a large-scale shear zone between Africa and Europe in the Late Palaeozoic and Early Mesozoic (Arthaud and Matte, 1977; Swanson, 1982; Rapalini and Vizán, 1993; Stampfli and Borel, 2002; Vai, 2003; Garfunkel, 2004; Ruban and Yoshioka, 2005) (Fig. 3C-E). Sinistral movements along this shear zone began in the Late Triassic and lasted to the Early-Middle Jurassic, as caused by the change in the direction of rotation of Africa (Swanson, 1982; Rapalini and Vizán, 1993). As a part of the European Hunic Terranes, the GCT might have been displaced eastward because of movements along the aforementioned shear zone in Late Triassic-Early Jurassic (Fig. 3E). This speculation is supported by a study of the uppermost Permian and Lower Mesozoic deposits (Gaetani et al., 2005), which presented solid evidence for strike-slip movements in the western part of the Greater Caucasus.

Discussion

The new hypothesis on the position of the Greater Caucasus Terrane in the Late Palaeozoic-Early Mesozoic presented above requires further data to be verified. Unfortunately, such data are scarce, doubtful or not available, because of lack of high-quality geological studies in the Greater Caucasus.

Research on several lines is needed to verify our interpretation. 1) New palaeomagnetic studies may document the migration route of the Greater Caucasus Terrane, as indicated by the preliminary study of Shevljagin (1986). 2) It is also important to delineate the present-day boundaries of the Greater Caucasus, nowadays buried underneath deep sedimentary basins, where the Palaeozoic basement was barely penetrated by boreholes. In the Ciscaucasian depressions located north of the Greater Caucasus, some major faults are delineated in recent geophysical studies (Lebed'ko, 2007). 3) The main task, however, is to understand the structure of the Palaeozoic-Triassic complexes of the Greater Caucasus. For a long time, the interpretation of nappe structures was prohibited, in favour of tectonic interpretations according to the geosyncline theory. Nappes are now recognized in some parts of this region (Gamkrelidze and Gamkrelidze, 1977; Shevljagin, 1986), but their role in the structural architecture is still unclear. New plate tectonic interpretations recently proposed (e.g., Ershov et al., 2003), are still related to the geosynclinal concepts. A direct comparison of the structural architecture of the Greater Caucasus region with those of Europe, especially its Hunic counterpart, will shed light on our hypothesis presented above.

Conclusions

This study outlines a number of similarities in the palaeontological and lithological records between the Greater Caucasus Terrane and the European Hunic terranes and adjacent regions. The similarities include the Ludlow (Silurian) and the earliest Devonian faunal assemblages, the Upper Carboniferous floral assemblages, and the most part of the Silurian-Triassic sedimentary record, except for the Middle Devonian. On the basis of these similarities, we speculate that the Palaeozoic evolution of the Greater Caucasus Terrane was linked to that of the European Hunic terranes. The Greater Caucasus Terrane was probably derived from Gondwana in the Silurian and then docked on the northern Palaeotethyan margin in the Late Devonian. In the Late Triassic, the GCT was displaced along a major shear zone to its present position.

Acknowledgements

We gratefully thank an anonymous reviewer for his valuable suggestions, the “Trabajos de Geología” editors for their help, Yu. V. Mosseichik (Russia) for her correction of palaeobotanical data, M. Pondrelli (Italy) and J. von Raumer (Switzerland) for their useful comments on the earlier versions of this paper, and many colleagues, particularly M. Bécaud (France), M. A. Efendiyeva (Azerbaijan), R. Jach (Poland), N. M. M. Janssen (Netherlands), A. Kahn (USA), and M. Schöning (Germany) for their help with literature. V. I. Pugatchev (Russia) is thanked for his field assistance.

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