Oligocene uplift of the Western Greater Caucasus: an effect of initial Arabia–Eurasia collision

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ABSTRACT

The Greater Caucasus is Europe’s largest mountain belt. Significant uncertainties remain over the evolution of the range, largely due to a lack of primary field data. This work demonstrates that depositional systems within the Oligocene–Early Miocene Maykop Series on either side of the Western Greater Caucasus (WGC) display a similar provenance and divergent palaeocurrents away from the range, constraining a minimum age for the subaerial uplift of the range as early Early Oligocene. An Eocene–Oligocene hiatus, basal Oligocene olistostromes and a marked increase in nanofossil reworking also point to initial deformation in the earliest Oligocene. The initial uplift of the WGC occurred during the final assembly of the Tethysides to its south. Uplift commenced after the Late Eocene final suturing of northern Neotethys and during the initial collision of Arabia with the southern accreted margin of Eurasia. This suggests that compressional deformation was rapidly transferred across the collision zone from the indenting Arabian plate to its northern margin.

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Introduction

The Greater Caucasus is Europe’s largest mountain belt, with peaks in excess of 5.6 km (Figs 1 and 2). Despite this, surprisingly little geological data on the evolution of the range are available in the non-Russian-language literature and primary field observations are extremely sparse. As a result, significant uncertainties remain regarding the timing of key events in the evolution of the range. For example, estimates for the initial uplift of the Western Greater Caucasus (WGC) range between the Late Eocene (Lozar and Polino, 1997; Saintot and Angelier, 2002; Saintot et al., 2006) and the Pliocene (Philip et al., 1989). Most estimates fall in the Miocene (e.g. Nikishin et al., 1998; Ershov et al., 1999, 2003; Meulenkamp and Sissingh, 2003).

This paper presents new, testable, field, micropalaeontological, heavy mineral and fission track evidence from the accessible parts of the WGC in Russia and West Georgia as to the timing and nature of the initial emergence and uplift of the range. The relationship between Caucasus uplift and the closure of Neotethys/evolution of the Arabia–Eurasia collision zone is then discussed and an improved temporal framework proposed.

Background

The WGC is situated at the southern deformed edge of the Seythian Platform (part of the East European Plate), north of the Eastern Black Sea basin and a series of amalgamated arcs, oceanic slivers, continental fragments and sedimentary basins of the Tethyside orogenic collage (Şengör, 1987; Şengör and Natal’ in, 1996). The Greater Caucasus region underwent a protracted and complex history of extensional and compressional events throughout the Mesozoic during the generation and closure of various strands of the Tethys Ocean to the south (Nikishin et al., 1998, 2001; Dercourt et al., 2000; Golonka, 2004; Saintot et al., 2006). Deformation continued into the Cenozoic across a large part of the Tethyside orogenic collage prior to Arabia–Eurasia collision (Şengör and Yilmaz, 1981; Şengör and Natal’ in, 1996; Okay and Tüysüz, 1999; Robertson, 2000). The WGC region, however, was relatively quiescent. Palaeocene–Eocene facies are dominated by fine-grained shelfal carbonates, with deeper-water turbidite facies being developed in the far north-west of the range (Kopp and Shcherba, 1998).

Initial uplift of the Western Greater Caucasus

Observations

The Eocene–Oligocene boundary

This is marked by the development of the mudstone-dominated Maykop Series across much of eastern Paratethys. At its type-section on the Belaya River (Figs 2 and 3F), the base of the series is conformable and is marked by a switch from carbonate to clastic deposition; farther to the west a stratigraphic gap is more typical (Akhmietiev et al., 1995). Olistostromes mark this hiatus at a number of outcrops on either side of the Russian WGC (Figs 2 and 4). Olistoliths are typically dominated by Palaeogene and Late Cretaceous sediments, although on the Pshekha River (Fig. 2E) meta-igneous and metasedimentary basement clasts are also present. Unpublished subsurface data from hydrocarbon exploration in the
adjacent Indolo-Kuban Basin indicate that a number of olistostome units are present in the Oligocene succession and that much of the lower part of the Maykop Series may be missing at outcrop due to pinch out and onlap.

Analysis of samples collected from a measured section along the Chanis River in West Georgia indicates that a marked increase in nannofossil reworking occurs at the Eocene–Oligocene (E–O) boundary (Figs 2 and 3A). Levels of reworking increase from ~1% to up to ~30% 10 m above the boundary and continue in the range of ~10–65% throughout the rest of the Maykop Series. Reworked forms are predominantly Cretaceous in age.

The Oligocene–Early Miocene succession

On the Chanis River, the Oligocene to Early Miocene Maykop Series displays a broad coarsening and shallowing upward trend from hemipelagic organic-rich mudstones at the base of the section, through thin-bedded turbidites into shallow-water, probable deltaic sediments near its top (Fig. 3A). Palaeocurrent directions are typically to the S to SE (Figs 2 and 3A). Farther to the west, Maykopian facies around Sochi are dominated by hemipelagic mudstones and thin- to thick-bedded turbidites that display palaeocurrent indicators to the S to W (Figs 2 and 3B). On the northern side of the Western Caucasus, the Maykop Series is again mudstone dominated, almost exclusively so at its type-section on the Belaya River (Fig. 3F). However, to the east on the Laba River, a series of 30 m plus thick tidally-influenced deltaic to shelfal sand bodies are developed with palaeocurrent indicators to the N to NNE (Figs 2 and 3H). Similar sandstones form hydrocarbon reservoirs in the Indolo-Kuban Basin. Further NNE- to NE-directed palaeocurrent indicators were obtained from rare sandstone outcrops on the northern side of the Caucasus on the Psekups and Fars rivers (Fig. 2C,G). Leaf impressions and coaly fragments are present throughout many of the observed sections (e.g. Fig. 3).

Heavy mineral analysis

Maykop Series sandstones from both sides of the Russian WGC have similar heavy mineral characteristics (Fig. 5), although a limited number of samples from both areas display a strong depletion of garnet relative to...
zircon, a process typical of surface weathering (Morton and Hallsworth, 1999). Maykop Series sandstones from the West Georgian WGC display a tightly clustered, but slightly different composition, reflecting a greater proportion of zircon. Both sample sets fall within the range of mineral compositions of Jurassic to Eocene sandstones exposed within the range (Fig. 5).

Thermochronometric analysis

Apatite fission track analysis was carried out on nine Maykop Series samples. All samples had only experienced modest amounts of post-depositional burial. Central cooling ages range from 176 ± 12 to 57 ± 3 Ma (Table S3). Two samples from the Chanis River section, West Georgia, however, contain two apatite age populations, the younger of which are roughly 10 Myr older than their depositional ages (Fig. 6a; Table S3). U/Th–He age dating of apatites within the older of these samples displays a cooling age that is almost identical to its estimated depositional age (Table S4).

Interpretation and discussion

Field data derived from the coarse clastic components of the Maykop Series across a large part of the WGC show: (1) divergent palaeocurrents away from the axis of the range (Fig. 2), and (2) heavy mineral compositions on either side of the range that are similar to each other and to Jurassic–Eocene sandstones in the WGC itself (Fig. 5). These observations demonstrate for the first time a shared WGC source for these sediments and hence date the minimum age of clastic derivation from parts of the range. In the Sochi region, these sediments are as old as the early Early Oligocene (Fig. 3B), whilst in West Georgia and on the northern side of the range they are probably Late Oligocene in age (Fig. 3A,H). The volume of derived sediment, presence of plant material and evidence for varying degrees of garnet surface weathering all indicate that this sediment source was in part subaerial.

A discussion of the variation in the age of initial sandstone deposition in the Maykop Series is beyond the scope

Fig. 3 Stratigraphic logs of Oligocene to Early Miocene Maykop Series strata at the margins of the Western Greater Caucasus. (A) Simplified field log from the Chanis River section. (B) Schematic log from the Sochi region, based on field observations and Lavrishchev et al. (2000). (F) Simplified log from the Belaya River based on Saint-Germès (1998), with additional data from Zaporozhets (1999) and Akhmetiev et al. (1995). (H) Schematic log from the Laba River section based on field observations and unattributed well data. Log locations are shown in Fig. 2. Numbers refer to the position of analysed heavy mineral/fission track samples (see Figs 5 and 6, and Tables S2 and S3).

Fig. 4 Field photograph of part of an ~80 m thick olistostrome at the base of the Maykop Series on the Pshish River. Olistoliths are up to 6 m long and comprise Late Cretaceous to Early Oligocene lithologies. The olistostrome is difficult to date due to reworking, but is probably Late Chattian–Early Langhian (late Late Oligocene to early Early Miocene) in age. It unconformably overlies Late Bartonian–Early Priabonian (late Late Middle to early Late Eocene) mudstones. Location marked as E in Fig. 2.
of this study. However, even where sandstones are not present in the Early Oligocene part of the series, basal olistostrome deposition and the increase in the degree of microfossil reworking (as originally noted by Lozar and Polino, 1997) constrain initial uplift and sediment derivation from the WGC to the earliest Oligocene.

An earliest Oligocene eustatic sea-level fall of 80–90 m (Lear et al., 2004) may have enhanced some of these sedimentary responses (cf. Sobornov, 1994). However, sediment derivation from the WGC continued during the subsequent Early Oligocene eustatic sea-level rise (and beyond), discounting the possibility of a purely eustatic control on the emergence of the WGC landmass.

Previous work has identified a phase of Late Eocene or latest Eocene–earliest Oligocene deformation in the WGC and North Caucasus basin (e.g. Lozar and Polino, 1997; Nikishin et al., 1998, 2001; Mikhailov et al., 1999; Saintot and Angelier, 2002; Ershov et al., 2003; Saintot et al., 2006). A number of observations in this work support the notion of syn-depositional tectonism around the E–O boundary. These are: (1) the southerly onlap and pinch-out of reservoir units onto a basal unconformity in the subsurface on the northern side of the WGC; (2) the large and variable stratigraphic gap associated with this unconformity and the wide range of olistolith types in the overlying olistostromes (where present); and (3) the ongoing high levels of nannofossil reworking above the boundary, suggesting that these resulted from a continuous process.

Fig. 5 Rutile/Zircon vs. Garnet/Zircon heavy mineral ratio:ratio plot of Jurassic to Eocene sandstones from the Western Greater Caucasus and Oligocene–Early Miocene (Maykop Series) sandstones from either side of the range. Heavy mineral pairing with similar densities and grain sizes are used to minimize compositional differences due to sorting during transport as set out in Morton and Hallsworth (1999). Labelled points are located in Fig. 3.

Fig. 6 (a) Radial plots showing the distribution of single apatite fission track ages, principal age components and their relationship to depositional age of two Maykop Series sandstones from the Chanis River section, West Georgia (Figs 2 and 3A). These samples were derived from the Caucasus and have not subsequently been buried sufficiently to reset track distributions, such that they record the palaeo-exhumation history of their source areas prior to deposition. (b) Time–temperature paths of apatites in the younger of the two source area age populations, with an additional U/Th–He age for sample A2 further constraining its cooling pathway.
Thermochronometric analysis of Maykop Series sandstones derived from the WGC indicates that apatites in the source area to these sediments cooled from partial annealing zone to surface temperatures (~60–10 °C), were exhumed and redeposited in c. 152–25 Myr (Table S3). Assuming a typical geothermal gradient of ~3 °C km⁻¹, this indicates slow average apatite exhumation rates of ~0.01–0.07 mm yr⁻¹. Where sub-populations are present, however, the younger of the apatite age populations indicate an increased average Oligocene exhumation rate within part of the catchment to these sandstones of ~0.17 mm yr⁻¹ (Fig. 6b). Furthermore, U/Th–He dating of apatites within one of these samples is suggestive of a short pulse of rapid (~0.7 mm yr⁻¹) exhumation not resolvable by the fission track analysis (Fig. 6b).

**Causes of Western Greater Caucasus uplift**

The WGC is located at the northern margin of the Arabia–Eurasia collision zone, a region of elevated topography that resulted from the closure of Neotethys (Fig. 1). Constraining the timing of deformation and initial uplift within the WGC enables this to be integrated into the wider tectonic context of the evolving Tethysides and the cause of uplift to be better understood.

Collision between Pontide and Tauride-Anatolide continental fragments along the Izmir-Ankara-Erzincan, Intra-Pontide and Inner Tauride sutures resulted in the final closure of northern Neotethys during the Late Cretaceous to Eocene (Fig. 1; Şengör and Yilmaz, 1981; Göür et al., 1984; Şengör and Natal’in, 1996; Robertson and Tüysüz, 1999; Göür and Tüysüz, 2001; Robertson and Ustaömer, 2004). This culminated in suture tightening, thrusting and regional uplift in the Miocene to Late Eocene (Şengör and Yilmaz, 1981; Göür and Tüysüz, 2001; Clark and Robertson, 2002; Meulenkamp and Sissingh, 2003; Rice et al., 2006). Terrestrial Oligocene sediments, where present, were deposited in post-collisional sedimentary basins above a regional unconformity (Kelling et al., 2005 and references therein).

Closure of southern Neotethys and initial collision between the Arabian promontory and the accreted southern margin of Eurasia occurred along the Bitlis and Zagros sutures in the Late Eocene-Oligocene (Hempton, 1987; Şengör and Natal’in, 1996; Robertson, 2000; Robertson et al., 2006). Data are primarily derived from Hempton (1985), Yilmaz (1993) and Robertson et al. (2006) who proposed mid to Late Eocene, Late Eocene to Oligocene and post-Eocene (probable Oligocene) ages, respectively, based on structural and stratigraphic relationships near the Bitlis suture zone in SE Turkey. Along the Zagros suture zone in Iran, Agard et al. (2005) constrained collision to have occurred shortly after 35 Ma (Late Eocene mafic intrusion) and prior to Late Oligocene (25–23 Ma) sedimentation. Compressional stresses were transferred into the Arabian plate around the same time, with initial folding and uplift in the Zagros (Hessami et al., 2001) and renewed deformation of the Syrian arc (Robertson, 2000; Walley, 2001) commencing in the Late Eocene. Much of the initial post-suturing convergence was accommodated by the thickening of attenuated continental material along numerous submarine thrusts (Hempton, 1987; Yilmaz, 1993). Arabia has moved northwards by ~700 km relative to Eurasia since the beginning of the Oligocene (A. Smith, pers. comm., 2006) and is currently moving northwards by ~15 mm yr⁻¹ (Reilinger et al., 2006; Fig. 1).

Deformation around the E–O boundary, followed by initial uplift and emergence of the WGC in the earliest Oligocene occurred after northern Neotethyan suturing had ended. Instead, events recorded in the WGC suggest that compressional deformation resulting from the closure of southern Neotethys and the initial collision of Arabia with Eurasia in the Late Eocene-Oligocene transferred rapidly across the Tethyan collage to the northern margin of the collision zone. If this is the case, evidence for Late Eocene–earliest Oligocene inversion and compressional deformation should also be present in intervening parts of the Arabia–Eurasia collision zone north of the Arabian indenter. Vincent et al. (2005) noted Late Eocene to Early Oligocene slope instability features in the Talysh belt of Azerbaijan (Fig. 1) and interpreted them to mark the onset of compressional deformation in the eastern Lesser Caucasus. Subsurface thickness variations also led Patton (1993) to postulate Late Eocene syn-deformational compressional deformation in the Upper Kura Basin of eastern Georgia, between the Lesser Caucasus and Eastern Greater Caucasus. This wave of deformation may have also been responsible for the large-scale palaeo-oceanographic changes at the base of the Oligocene evidenced by the birth of the marginal Paratethyan sea (Baldi, 1984; Rögl, 1999; Schulz et al., 2005), the switch from carbonate to clastic deposition and the widespread occurrence of organic-rich sediments – all manifest in the development of the Maykop Series.

Initial Caucasian deformation is likely to have been relatively limited and to have involved the inversion and/or reactivation of pre-existing structures. Fission track data indicate that overall exhumation rates were low, despite localized rapid cooling events. Significant Caucasian mountain building was probably only initiated in the late Early to Late Miocene (Nikishin et al., 1998; Saintot and Angelier, 2002; Ershov et al., 2003; Saintot et al., 2006). This is roughly synchronous with the final closure of southern Neotethys and Arabia–Eurasia suture tightening in the Early to Middle Miocene (Hempton, 1987; Yilmaz, 1993; Robertson et al., 2006), with the seving of the marine connection between Tethys and the Indian Ocean and the development of a landbridge occurring around the Early–Middle Miocene boundary (Woodruff and Savin, 1989; Rögl, 1999).

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Supplementary Material
The following material is available at http://www.blackwellpublishing.com/products/journals/suppmat/TER/TER731/TER731sm.htm:
Appendix S1 Supplementary data tables.
Table S1 Nannofossil reworking data.
Table S2 Heavy mineral data.
Table S3 Apatite fission track data.
Table S4 Helium age data.