A contribution to middle Oligocene paleogeography of central Europe from fission track ages of the southern Rhine graben

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Abstract

Zircon and apatite fission-track (FT) ages of marine well-sorted sandstone layers of late Rupelian age in the southern Rhine graben (Meletta beds) prove an Alpine origin. The FT ages and the heavy mineral spectra suggest that Austroalpine basement rock was the main source. Transport of medium-sized sand contradicts the existence of a marine trough in front of the Swiss sector of the Alpine arc during this time. It rather indicates a shallow marine environment in the central section of the Swiss Molasse basin.

Kurzfassung

Zirkon- und Apatitspaltspurenalter von marinen, gut sortierten Sandsteinlagen des höheren Rupel im südlichen Rheingraben (Septarienton) beweisen eine alpine Herkunft. Die Spaltspurenalter und das Schwermineralspektrum weisen auf austroalpines Kristallin als Hauptliefergebiet hin. Der Transport des mittelkörnigen Sandes widerlegt für diese Zeit die Existenz einer tieferen marinen Rinne vor dem Schweizer Sektor des alpinen Gebirgsbogens. Er deutet vielmehr auf ein flachmarines Milieu im westlichen Sektor der Schweizer Vorlandmolasse hin.

Introduction

Narrow marine gateways are generally a problem of paleogeographic and biogeographic reconstructions (e.g. STEININGER et al. 1985). In dominantly continental settings like central Europe in Tertiary times, marine faunas restricted to euhaline conditions may have crossed narrow land bridges between marine domains, e.g. during episodic storm-driven flooding events. Due to frequent non-sedimentation or erosion in shallow marine gateways, lack of sedimentological evidence for short-term marine connections is the rule rather than the exception.

A marine connection was established along the European Cenozoic rift system between the North Sea, the Saxonian graben system, the Wetterau or Hessian depression, the Upper Rhine graben, the Rhone-Bresse graben, and the western Mediterranean during Early Oligocene (Rupelian) times (WEILER 1953). An exchange of marine fish fauna, and marine planktic and benthic microfauna is well documented (REICHENBACHER 1998, MARTINI 1960, 1982, PROSS 1998; Fig. 1). The rift system, which provided a natural depression for the Rupelian marine gateway between the Oslo graben and the western Mediterranean, formed in late Eocene times as a result of rifting between the North Sea, the Rhine graben and the western Mediterranean (e.g. GORINI et al. 1994, SCHREIBER & ROTSCH 1998). The rift system, however, was segmented by transform faults. The rifted segments, in particular the Upper Rhine valley as the largest segment, remained as isolated depressions with very heterotropic facies until terminal Eocene times (e.g. ILLIES 1962, DURINGER 1988, SISSINGH 1998). Lithospheric cooling after the climax of late Eocene rifting (SISSINGH 1998) and a global transgression in early Oligocene times enabled a short-lived marine gateway to establish for a few million years. A marine connection from the Rhine graben to the Lower Rhine Embayment, forming a bay in the southwestern extremity of the North Sea, is less well documented, but supported by isolated occurrences of marine fauna in basin relics along the Middle Rhine (SCHÄFER 1986).

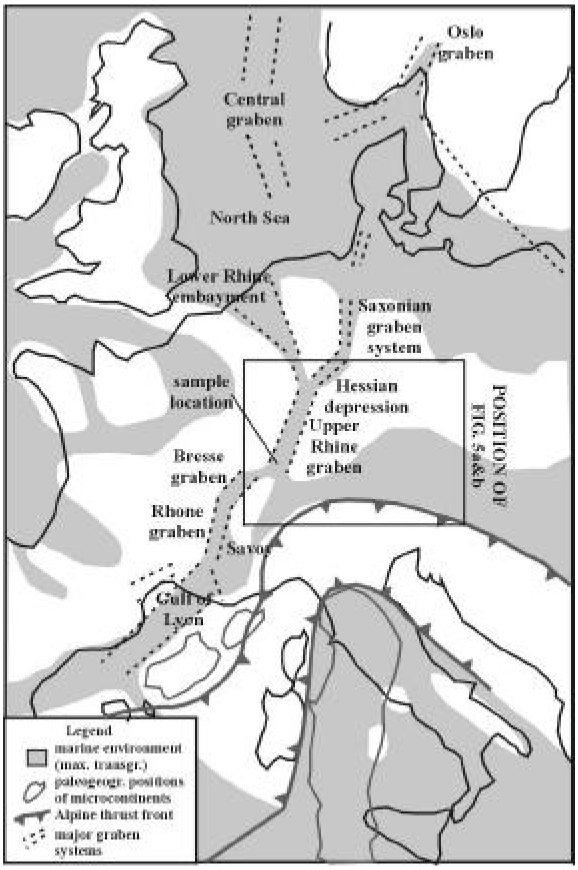

Fig. 1: Marine gateways in Central Europe during late Rupelian times in a recent geographic frame, according to literature.

The character of the connection between the Alpine Molasse foreland basin and the Rhine graben is controversial (see BÜCHI 1983). According to recent paleogeographic reconstructions for Early Oligocene times (DERCOURT et al. 1987, SINCLAIR 1997), the Molasse basin is supposed to have formed an orogen-parallel, deep marine, underfilled trough with predominant sediment transport towards eastern directions. This scenario would prevent any material coarser than silt to travel from the Molasse basin towards the north into the Rhine graben during Rupelian times. Apparently in conflict with this conception, a reworked Cretaceous foraminifera fauna is found in Rupelian sediments in central German basin relics, containing well preserved tests without sediment infill (HUCKRIEDE 1954, FISCHER 1965). According to FISCHER (1965) this fauna is derived from the Helvetic nappes of the Alps, therefore indicating an at least temporal transport of detrital material from the Swiss Alps into the Rhine graben through the gateway of the “Raurachic depression”. The eqivalent hydraulic grain size of empty foraminifera tests, however, is mainly within the silt fraction of quartz, sinking between 100 m and 2 km per day (TAKAHASHI & ALLAN 1984, SCHIEBEL & HEMLEBEN, in press). Transport of resuspended foraminifera tests on the shelf during storms is frequently observed in recent settings (BRUNNER & BISCAYE 1997). Thus, an export of this Alpine-derived fauna to the Rhine graben can hardly be used as a argument against an orogen-parallel trough in front of the Swiss Alpine thrust front.

In the case of fine-grained sand, transported into the submarine depression of the southern Rhine graben from southern directions, suspended transport in surface waters across a marine trough is impossible. The aim of this study is to check whether that sand-sized siliciclastic material of Alpine origin has been transported across the Molasse basin into the Rhine graben already in Early Oligocene (Rupelian) times. Fission-track age spectra allow to specify the cooling history of the source region of the sands and thus yield information about a possible Alpine derivation. The cooling history of Alpine tectonic units are in considerable contrast to those of extra-Alpine, Stable European terrains. Alpine derivation of sand in the Rhine graben would necessitate a modification of paleogeographic reconstructions for the Molasse foreland basin and the adjacent central European marine gateways during Rupelian times.

Methods

The sandstones were sampled in the basal part of a clay pit near Burnhaupt, situated 10 km southwest of Mulhouse in the southern Rhine graben (Fig. 1). The exposed succession belongs to the marine part of the Meletta beds (Upper Rupel clay; SITTLER & SCHULER 1988, with further ref.). The heavy minerals have been extracted by standard magnetic and heavy liquid separation. To decide whether the siliciclastic material forming the sandstones is derived from the Alps or extra-Alpine terrains, detrital zircons and apatites have been dated by the fission track (FT) method, applying the zeta calibration and external detector method. FT dating yields cooling ages with closure temperatures around 250° C for zircon and around 120° C for apatite. Therefore, the resulting age spectra reflect the low-temperature cooling history of the source regions of the clastic sediments. For the Rupelian sandstones of the southern Rhine graben two possible source terrains exist:

(i) the extra-Alpine, Stable European basement, i.e. the Black Forest and the Vosges of the graben shoulders, and their Mesozoic cover,
(ii) or the Alps.
Both regions show distinctly different cooling patterns.

(i) The exposed basement rocks of the Black Forest and the Vosges were metamorphosed during the Late Carboniferous Variscan orogeny and exhumed to the surface before Mesozoic times (e.g., HENK 1993). During Triassic and Jurassic times they were covered by a sediment pile with a thickness hardly exceeding 1 km (ROLL 1979, ROBERT 1985, GEYER & GWINNER 1991). Since Early Cretaceous times the sediment pile experienced stepwise uplifted and erosion. Zircons deriving from the Black Forest and the Vosges have not been buried deep enough during Mesozoic times to reset the

FT ages. Therefore, they must still show late-Variscan (Late Carboniferous and Permian) cooling ages of about 300 to 250 Ma. The apatite FT ages from the topmost Stable European basement should be older than 60 to 70 Ma, which are the oldest cooling ages exposed today (MICHALSKI 1987, WAGNER 1990). Mesozoic clastic sediments generally display early Mesozoic apatite FT ages (HURFORD et al. 1994).

(ii) During middle Oligocene times in most parts of the Swiss Alps Austroalpine basement units and Penninic flysch nappes were exposed (SCHLUNEGGER et al. 1993; HOMEWOOD et al. 1986). In the Swiss Alps, the Austroalpine units are almost completely eroded today. Correlating Austroalpine basement units presently exposed in the Eastern Alps are characterized by zircon FT ages between 170 Ma and 45 Ma (HUNZIKER et al. 1992, FLISCH 1986), with a peak between 80 and 60 Ma due to Late Cretaceous metamorphism and subsequent cooling of the Austroalpine domain. The FT age spectrum of detrital zircons from the Penninic flysch nappes of the Eastern Alps display similar age peaks, but include also syndepositional ages from zircons of probably volcanic origin (Trautwein, pers. comm.).

Therefore, a dominance of Late Cretaceous zircon FT ages would prove an Alpine origin, whereas the presence of exclusively late Variscan zircon FT ages would prove a supply from Stable European sources, from the graben shoulders.

Results

The exposed section is composed of about 20 m of clay with a few intercalated cm-thick siltstone layers. The clay is well stratified, although cm-thick layers are frequently bioturbated. Sandstone layers up to 20 cm thick are restricted to the basal part of the section. The sandstones contain small detrital mica flakes. On the very base of the sandstone layers occasionally larger grains up to 1 mm are observed, indicating graded bedding. Occasionally weak laminar bedding and cross bedding are found in the topmost section of sandstone layers, representing Bouma horizons B and C of turbidite deposits. The sandstone layers are well sorted, as indicated by the grain size distribution of the sand fraction (Fig. 2). Textures of the sandstones display mainly linguid ripples, dm-spaced sinuous current ripples, mm-spaced symmetric "micro-ripples" and, subordinately, groove casts, flute casts, and asymmetric load casts. The current ripples typically form the top of the sand layer and are followed topward by clay without any

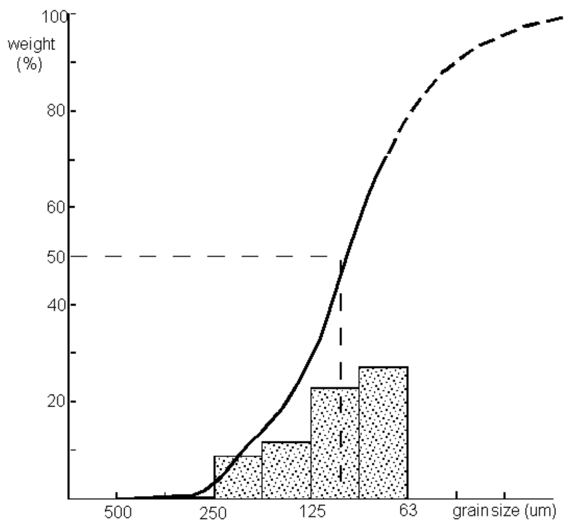

Fig. 2: Grain size distribution of the middle Rupelian sandstone from the southern Rhine graben.

transitional grain size. All current indicators exclusively show a sediment transport from the south. Flute casts show that the submarine topography was inclined to the north. Groove casts indicate that the gradient of the topography exceeded an angle of several degrees. Load casts are relatively rare. The asymmetry of the latter features also indicate northward creeping of the sand downslope a subaquatic relief.

The heavy mineral composition of the sandstone from the southern Rhine graben is dominated by garnet, apatite, zircon, staurolite, epidote, tourmaline, and kyanite, in the order of decreasing importance (Fig. 3a,b).

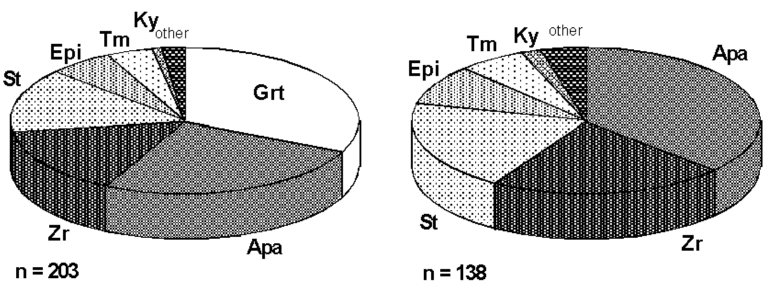

Fig. 3: Semi-quantitative heavy mineral distribution of the sandstone sample. **Fig. 3a** shows the total distribution including garnet, **Fig. 3b** without garnet.

Around 60 single grains of each zircon and apatite have been dated. The zircon age spectrum shows two age clusters: a more distinct one around 80 Ma and a broader one around 150 Ma (Fig. 4a). This age distribution matches with one expected for an Austroalpine source. For an extra-Alpine, Stable European provenance the zircon FT ages are clearly too young (see above). The apatite age spectrum also displays two age clusters: a narrow peak around 35 Ma and a broad one around 65 Ma (Fig. 4b). The 35 Ma age cluster indicates rapid cooling of the source, either due to fast exhumation or volcanic origin. The sandstone contains clear, euhedral and unrounded apatite grains, which are typical for airborne volcanic origin. The 65 Ma-age cluster is in line with the Austroalpine age signature, but we will discuss below whether a contribution from Stable European basement can be excluded or not.

Discussion

FT age spectra The zircon age spectrum definitely proves an Austroalpine source. A similar zircon FT age spectrum has been observed in Swiss Molasse sandstones of the Napf fan deposited in Rupelian to Tortonian times (SPIEGEL et al. 1999). Only 6 grains out of 57 display early Mesozoic or late Paleozoic ages and may thus derive from the graben shoulders. On the other hand, the Penninic flysch nappes also contain zircons of late Variscan FT ages derived from basement highs in the orogen or along the European margin, which were subjected to erosion in Late Cretaceous times (OBERHAUSER 1980). Therefore, isolated grains of late Variscan age cannot prove an input from the graben shoulders to the sampled sandstone. We assume that the sandy material almost exclusively derived from the Alps.

The apatite age spectrum is more difficult to interpret. The 35 Ma age cluster is definitely too young to reflect an Austroalpine cooling pattern. We consider these grains as a product of early Periadriatic volcanism. Volcanic rock fragments, dated at 32 to 31 Ma, are a frequent component in Early Oligocene Taveyannaz sandstone (RUFFINI et al., 1997), deposited in the northern part of the Western Alpine Molasse basin (SINCLAIR 1992). Somewhat later, during Chattian times, volcanic zircons with FT ages around 30 Ma have been supplied to the Austroalpine intramontane Molasse of the Inn valley (BRÜGEL 1998).

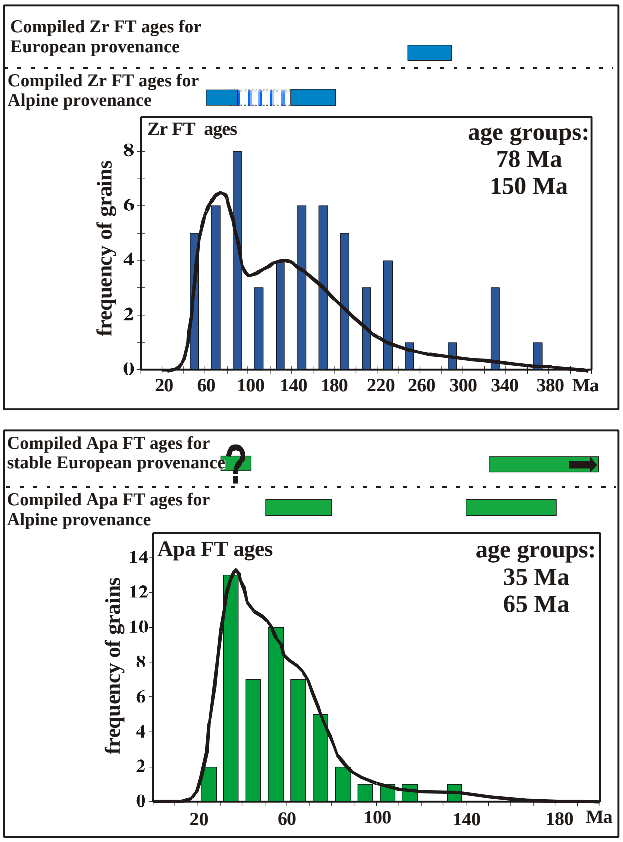

Fig. 4: Zircon **(a)** and apatite **(b)** fission track age spectra of the sandstone.

Apatites of the presently exposed basement rocks of the Black Forest and the Vosges show predominantly late Mesozoic to early Tertiary FT ages (MICHALSKI 1987, WAGNER, 1990). The young apatite FT ages are caused by a enhanced heat flow during Eocene rifting (see ROBERT 1985). However, Late Eocene erosion during uplift of the rift shoulders did not cut deeper than the base of the sediment pile (Bunter sandstone; DURINGER 1988). Erosion of the crystalline basement locally started in Rupelian times despite of decreasing intensity of erosion (ILLIES 1962, DURINGER 1988). An incision in excess of a few hundred meters is unlikely. This conclusion is based on the recent situation in the Black Forest, where the post-Variscan discordance can be shown not to have been higher than several hundred meters above the top of the highest mountains. The elevation of the cliff formed around 18 Ma at the north coast of the Molasse Sea on the Swabian Alb exceed 800 m a.s.l. and provides a minimum estimate of uplift since 18 Ma for the Black Forest on the eastern shoulder of the Rhine graben. The main amount of uplift of the Black Forest started in early Pliocene times (ILLIES 1962).

The 65 Ma apatite FT age cluster is too young for nearby Stable European sources. We assume that erosion in the Stable European basement did not cut into the partial annealing zone of apatite.

Heavy mineral spectrum: An Alpine provenance of the sandy material is also indicated by the heavy mineral spectrum, dominated by garnet, apatite, staurolite, and epidote, which matches the recent Austroalpine heavy mineral spectrum observed in sands of the rivers. The heavy mineral spectrum is quite similar to that found by BRIANZA et al. (1983) in the drill core "Leymen I", south of Basel (Fig. 1), except for the enrichment of zircon. In this core a significant increase in epidote and a decrease in apatite is observed within the late Rupelian section. A trend of increasing epidote content is also a typical feature in the Molasse foreland, but there are no substantial amounts of epidote before Chattian times in the Molasse basin (FÜCHTBAUER 1964, SCHLANKE et al. 1978, MAURER 1983). Zircon-rich Austroalpine spectra (garnet-apatite-zircon-tourmaline) are observed in Swiss Molasse sediments especially of Chattian age (FÜCHTBAUER 1964, 1967, MAURER 1983), derived from Austroalpine basement and from Penninic Cretaceous flysch. Paleogene flysch sections are dominated by stable heavy minerals (FÜCHTBAUER 1964), which may have contributed to the surprisingly high amounts of zircon in the studied sandstone.

The source of the epidote in Rupelian sediments of the Rhine graben remains an open question. This mineral is not observed in simultaneously deposited sediments of the Molasse basin. FÜCHTBAUER (1964) emphasized that even a strongly limited exposure of greenstones would supply large amounts of epidote. Interestingly, a few alkali-amphiboles and -pyroxenes are frequent, especially in Rupelian sediments south of Basel at the southern margin of the Rhine graben (BRIANZA et al. 1983). Rare alkali-amphibole has been found in the studied sandstone. The high-pressure minerals as well as the epidote may derive from Penninic nappes, containing greenstones and high-pressure assemblages. Since Chattian times these tectonic units contributed to the so-called "Genfersee-Schüttung", which represents the westernmost axial supply to the Molasse basin (MAURER 1993). However, alkali-amphibole and epidote is found in basal Oligocene sediments of the Alpine foreland of the Savoy region (VATAN et al. 1957). These minerals may have been transported along the Bresse graben towards the north.

To compare, Mesozoic siliciclastic sediments of southwestern Germany supply mainly the stable heavy minerals rutile, tourmaline and zircon (BLUM & MAUS 1967). These minerals dominate Miocene local fans at the margin of the Black Forest (BLUM & MAUS 1967), probably as a result of long exposure and dissolution of the unstable heavy minerals (see WEYL 1957). The Black Forest, and probably also the Vosges, recently supply zircon, garnet, titanite, amphibole, tourmaline, sillimanite, and rutile. Locally, the southern Black Forest supplies amphibole and garnet (WEYL 1957). The Tertiary "Jura-Schüttung" potentially supplied stable heavy minerals and additionally staurolite, kyanite and andalusite from western directions, which is mixing with the Alpine spectrum in Rupelian marine sediments of the Delémont basin within the Jura mountain chain (BRIANZA et al. 1983). The heavy mineral spectrum of the "Jura-Schüttung" may partly be recycled from Cretaceous sediments of the Jura mountains, which dominantly contain stable minerals (zircon, tourmaline, rutile; MAURER 1983), or be temporally directly derived from the French Massif Central. A direct contribution from the latter source, however, rises the problem of material transport across the Bresse graben, despite of the quiet environment and fine-grained sediments in late Rupelian axial deposits of the graben (SISSINGH 1998).

Paleogeographic and environmental implications: The late Rupelian Meletta beds are characterized by the rapid decrease of sandstone layers upsection, where marine clay prevails. This is best explained by a transgressive trend, which points to a formation age of the sampled sandstone before the late Rupelian sea-level highstand. After HAQ et al. (1988) the Rupelian period is characterized by two global transgressive cycles (TA 4.4 and 4.5), but a minor regional regression in the Rhine graben during formation of the fish shale (SITTLER & SCHULER 1988) within the second cycle TA 4.5 is not recorded in global scale. The section probably belongs to the middle part of the second cycle. According to the timescales of RÖGL (1996) and BERGGREN et al. (1995) this indicates an age of about 30 Ma.

The Meletta beds (NP 24) are by far the thickest member of the late Rupelian succession (see SISSINGH 1998). We interpret the increase of sediment accumulation rates as a result of incoming Alpine debris, whereas the previously deposited foraminifera marl (NP 22) and fish shale (NP 23) reflect starvation of the Rhine graben (see SISSINGH 1998).

The sedimentary features indicate a mixture of proximal turbidite sedimentation and bottom current activity. We explain lack of well developed turbidite bedding features by the relatively narrow grain size spectrum and the interference with bottom currents. The linguid ripples are pointing to relatively high current velocities (COLLINSON & THOMPSON 1989). Transport by rather constant currents and near-shore wave activity prior to final deposition are suitable processes to explain the observed degree of sorting. Events of episodic strong currents from the south, depositing isolated sand layers within an otherwise quiet environment, may be explained by occasional storms. These may resuspend offshore sands and unload them when surface current velocities decrease, e.g. due to widening and deepening of the marine gateway.

A marine trench forming a continuous depression along the northern front of the Alpine arc would prevent transport of sandy material from the Alps into the Rhine graben. While for the East Alpine foreland a deep trough is clearly evident from turbidite sedimentation or quiet clayey sedimentation (FISCHER 1978) shallow marine conditions should have prevailed in the southwestern section of the Swiss Molasse basin and the northern Savoy section (Fig. 5a). This is supported by HOMEWOOD

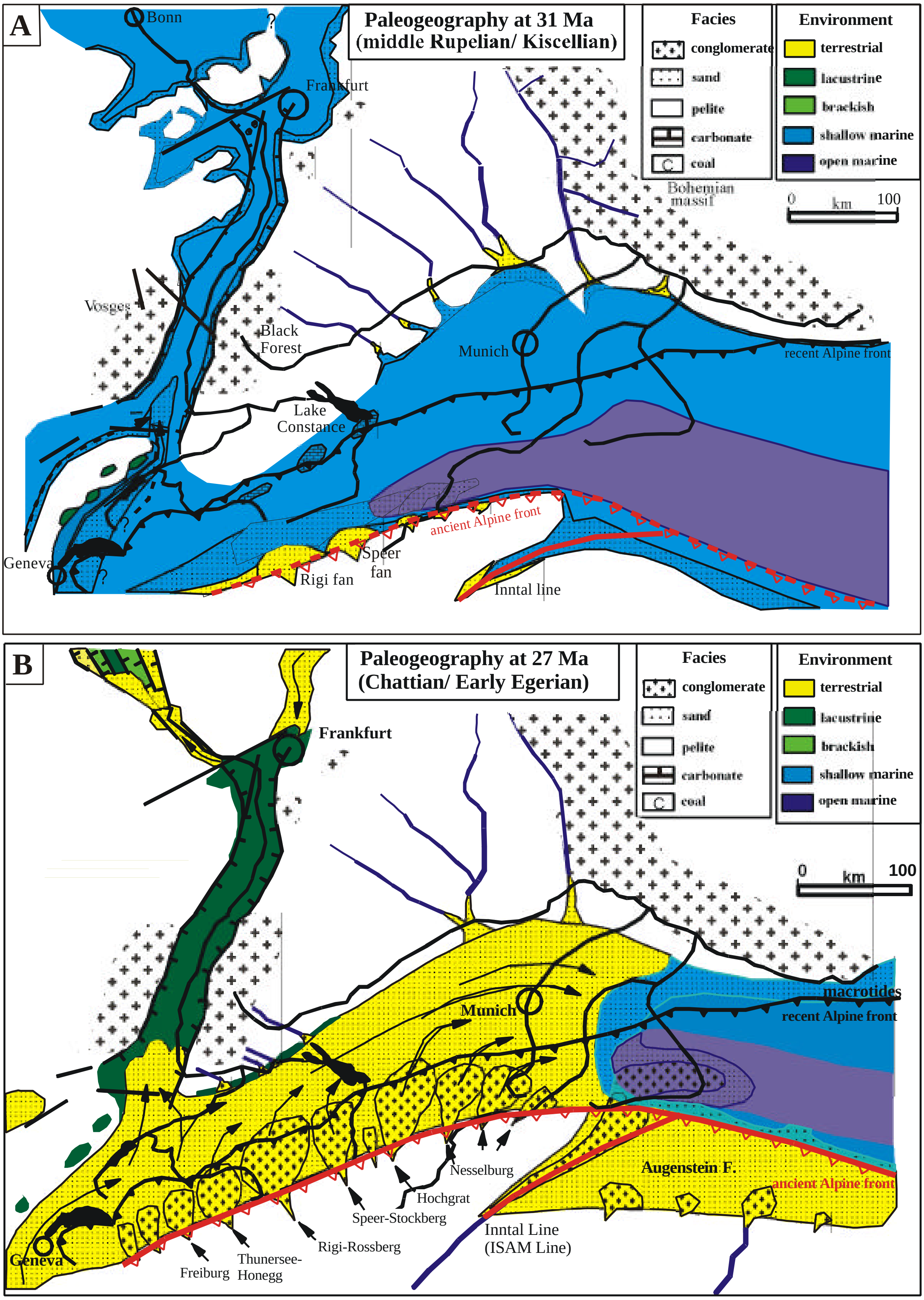

Fig. 5: Sketch map of the Central European paleogeography during (a) the late Rupelian regional maximum transgression and (b) during the Chattian regional lowstand.

(1986), describing flysch-like storm deposits within the Grisigen marls of probably similar age. The shallow water environment, in our opinion, allowed transport of Alpine sand to the north mainly along the western margin of the Molasse basin. The late Rupelian extension of terrestrial environment in the southernmost part of the Molasse basin is poorly constrained. The early Chattian paleogeographic situation is less controversial (see BERGER 1996) and the export of Alpine material to the Rhine graben is evident from the general setting (Fig. 5b).

A shallow marine connection between the Swiss Molasse basin and the Rhine graben during Rupelian times is only possible towards the southeastern corner of the Rhine graben, because further to the west, in the Delémont basin within the Swiss Jura mountains, marine environment in the east interfingers with a lacustrine/terrestrial facies in the west (BERGER 1996, CLEMENT & BERGER, 1999). This funnel-like marine gateway had the potential to build up relatively high current velocities. The most likely transport mechanism for the siliciclastic material as well as for the reworked Helvetic foraminifera fauna, transported over hundreds of kilometers without mechanical destruction (FISCHER 1965), appears to be episodic storm waves.

Storm deposits occur in Late Eocene sediments of the southern Rhine graben (DURINGER 1995), in late Rupelian (HOMEWOOD 1986) and early Chattian sediments of the Molasse basin, and in Rupelian sediments of the northern Rhine graben (HARTKOPF & STAPF 1984). In the last case, additionally constant and strong wave activity, with respect to the limited fetch in the Rhine graben, is indicated by gravel shore facies, thick oyster shells and terraces of up to 1 m high notches. However, a shore-parallel transport by constant wave activity is a problematic mechanism for a large-scale transport of a reworked foraminifera fauna, because mechanical destruction of the thin shells has to be expected in the breaker zone. On the other hand, episodic storm waves may resuspending and transport more fine-grained, offshore sediments together with a reworked fauna, without destroying the shells (see BRUNNER & BISKAYE 1997).

Conclusions

Transport of sand-sized Alpine detritus into the southern Rhine graben in middle Rupelian times has been proven by FT ages of detrital zircon. These FT ages indicate that Austroalpine basement rock, subordinately North Penninic flysch, and Periadriatic volcanic material were the main sources. Our data support former observations of exported Alpine detrital material into the Rhine graben, despite of the intervening marine environment and a well-defined marine trough east of the meridian of Lake Constance (Fig. 5b). The marine gateway between the Molasse basin and the Rhine graben was open for important net export of Alpine material in late Rupelian times by means of wind-driven currents, especially during episodic storms.

Acknowledgements

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