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REPORT

Volcaniclastic events in coral reef and seagrass environments: evidence for disturbance and recovery (Middle Miocene, Styrian Basin, Austria)

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Abstract Volcanic disturbances and ecosystem recovery at sites of neritic carbonate production are rarely documented, neither in the recent nor past geological record. Herein, we present a Middle Miocene (ca 14.5 Ma) shallow-marine carbonate record from the Styrian Basin (Austria) that shows recurrent breakdowns of the carbonate producers (i.e., coralline red algae and zooxanthellate corals) in response to ashfalls from nearby volcanic island sources. These volcanic events are preserved as distinct marl layers with idiomorphic biotite crystals and volcaniclasts that mantle the former seafloor topography. The pyroclastic sediments suffocated the carbonate producers in coral reef and seagrass environments. A subsequent turbid, eutrophic phase caused by the redistribution, suspension, and dissolution of volcaniclastics is characterized by the spreading of suspension-feeding biota, coralline algae, and the larger benthic foraminifer *Planostegina*. During this stage, rapidly consolidated pyroclastic deposits acted as hard grounds for attached-living bivalves. The fact that the facies below and above the studied ashbeds are almost identical suggests that volcaniclastic events had no long-lasting effects on the structure of the carbonate-producing benthic communities. Although Miocene shallow-water carbonate systems of the circum-Mediterranean region are well known and situated in one of the geodynamically most active regions worldwide, this study is the first that exams the impact of volcanic sedimentation events on shallow marine ecosystems.

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Introduction

Volcanism is an important geological process that affects shallow-marine carbonate producers and their surrounding environments by its influence on differential subsidence/uplift, substrate morphology, hydrothermal venting, and the nature and distribution of pyroclastic sediment (Pichler and Dix 1996; Pandolfi et al. 2006; Doborek 2008; Lokier et al. 2009; Engel 2010). Volcaniclastic input into a site of carbonate production has a number of detrimental effects on benthic calcifiers. Even if organisms are not completely buried by volcanic ash, their partial covering or being surrounded by volcaniclastics will result in physiological stress and tissue necrosis (Fortes 1991; Heikoop et al. 1996a, b). Fine-grained volcanic ash when suspended in water results in decreased light penetration (Short and Wyllie-Echeverria 1996) and reduction in photosynthesis with concomitant changes in water depth thresholds for photoautotrophic biota (Wilson and Lokier 2002). In contact with water, ash also influences alkalinity and increases the concentration of ions released from ash particles. Hence, high volcaniclastic discharge can cause temporary changes in water chemistry and fertilization of the marine environment with potentially negative effects on shallow-marine carbonate producers (Frogner et al. 2001; Ralph et al. 2006; Duggen et al. 2010). As a result, shallow-marine carbonate successions have the potential to record even relative minor volcanic events (Heikoop et al. 1996b; Pandolfi et al. 2006). However, there are problems when interpreting the volcanogenic origin of sedimentary rocks due to the similarity of volcanogenic lithologies (including claystones, clayey siltstones, clayey sandstones, or clayey limestones) to those of non-volcanogenic origin because explicit structures such as vitroclastic ash textures are rarely preserved (Jeans et al. 2000).

Herein, we present a sedimentary model for a Middle Miocene mixed siliciclastic-carbonate platform in the Styrian Basin (Austria). A special feature of the studied sedimentary succession is the repeated collapse of the shallow-marine carbonate factory due to ashfalls from a close-by volcanic island complex. Although Miocene neritic carbonates from the circum-Mediterranean region are among the best-known fossil shallow-water carbonate systems in a volcanically active area (e.g., Esteban et al. 1996; Pedley and Carannante 2006; Mutti et al. 2010), this study is the first record of volcaniclastic sedimentation as an environmental constraint for shallow-marine carbonate production.

Geological background and setting

The Styrian Neogene Basin (Fig. 1) is 100-km-long, 50-km-wide, and 4-km-deep and is part of the Pannonian Basin System located at the southeastern margin of the Eastern Alps (Ebner and Sachsenhofer 1995). It is framed by the Alps in the west and north and separated from the adjacent Western Pannonian Basin by the NE–SW-striking South Burgenland High (Kröll et al. 1988). The N–S orientated Middle Styrian High subdivides the Styrian Basin into a N–S trending Western Styrian Basin and a SW–NE-trending Eastern Styrian Basin. Other basement highs and spurs cause further differentiation into smaller subbasins and embayments (Kröll et al. 1988).

After an initial terrestrial phase, sedimentation started in limnic-fluvial and marginal marine settings during the Ottnangian/early Burdigalian (Kollmann 1965). Subsequently, strong subsidence led to rapid drowning and a marine ingression into the Styrian Basin during the Karpatian/Late Burdigalian (Ebner and Sachsenhofer 1995). At this time, eruptive volcanism occurred in the Styrian Basin in response to extensional tectonics (Balogh et al. 1994; Slapansky et al. 1999), producing a volcanic island complex that remained active until the early Badenian/Langhian. Its major eruptive center was a 500 km^2 by 1,000-m-thick-shield volcano in the area of Bad Gleichenberg (Eastern Styrian Basin). Another important shield volcano, extending $\sim$125 km^2 and 200–300 m thick (Slapansky et al. 1999), was located at Weitendorf (Western Styrian Basin; Fig. 2). During the Badenian (Langhian–Serravallian), three marine transgressions promoted the wide-spread development of coralline algal limestones, known locally as the Leitha Limestone. In areas of low terrigenous sedimentation, such as the Middle Styrian High, coral growth was prolific (Friebe 1990, 1993). The studied Leitha Limestone succession is exposed in the Retznei Lafarge-Perlmooser cement quarries (Rosenberg quarry) that are located 40 km south of Graz (Fig. 1; N 15°33′48″, E 46°44′32″).

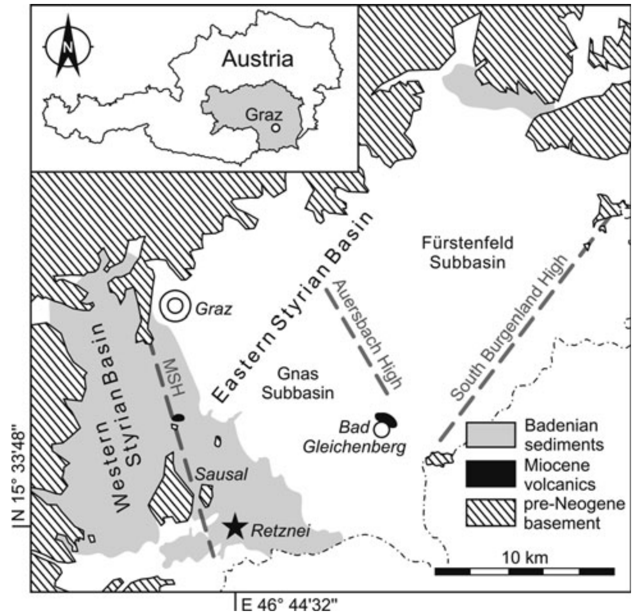


Fig. 1 Geological map of the Styrian Basin showing the main structural elements as well as the distribution of Badenian sediments and Miocene volcanic rocks at the surface; *black asterisk* study site at Retznei, *MSH* Middle Styrian High

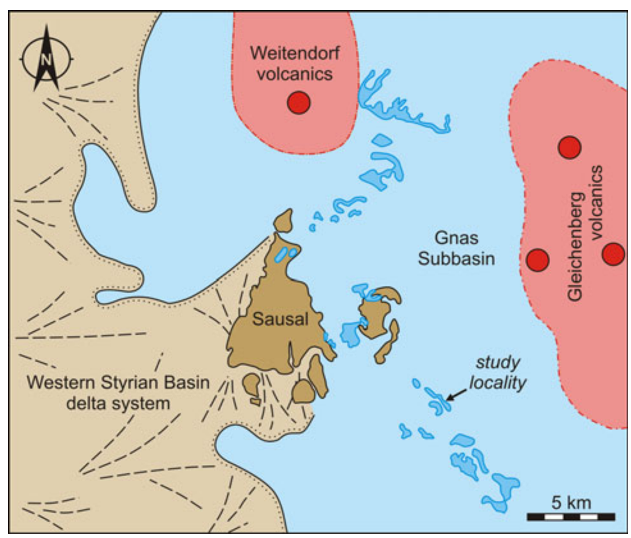


Fig. 2 Badenian palaeogeography of the Middle Styrian High. The Sausal represents the exposed part of the Middle Styrian High and acted as source for local alluvial fans during deposition of the Leitha Limestone. Distribution of Miocene volcanics from Slapansky et al. (1999); delta and alluvial fans boundaries after Flügel and Heritsch (1968); *red* volcanics, *red circles* volcanic conduits (after Ebner 1981), *light blue* marine siliciclastics, *dark blue* Leitha Limestone, *light brown* terrestrial fluvial deposits, *dark brown* islands

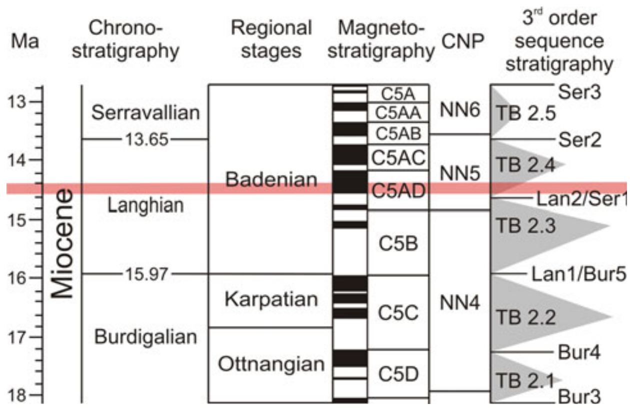


Fig. 3 Stratigraphic chart of the Retznei carbonate complex. Correlation of chronostratigraphy of Gradstein et al. (2004) with the regional stages follows Piller et al. 2007 (with further references therein)

Stratigraphy

Friebe (1993) correlates the Retznei carbonate complex with the sea level rise of the second Badenian transgression into the Central Paratethys (=TB 2.4 of Haq et al. 1988; Strauss et al. 2006). *Helicosphaera ampliaperta* and *Sphenolithus heteromorphus* suggest calcareous nannoplankton zone NN5 for the carbonates and overlying siliciclastics in Retznei (Hohenegger et al. 2009). The top of the carbonates was constrained by radiometric dating of a volcanic ash layer to 14.39 ± 0.12 Ma and correlated with polarity chron C5ADn (Handler et al. 2006; Hohenegger et al. 2009). A compilation of these stratigraphic constraints is given in Fig. 3.

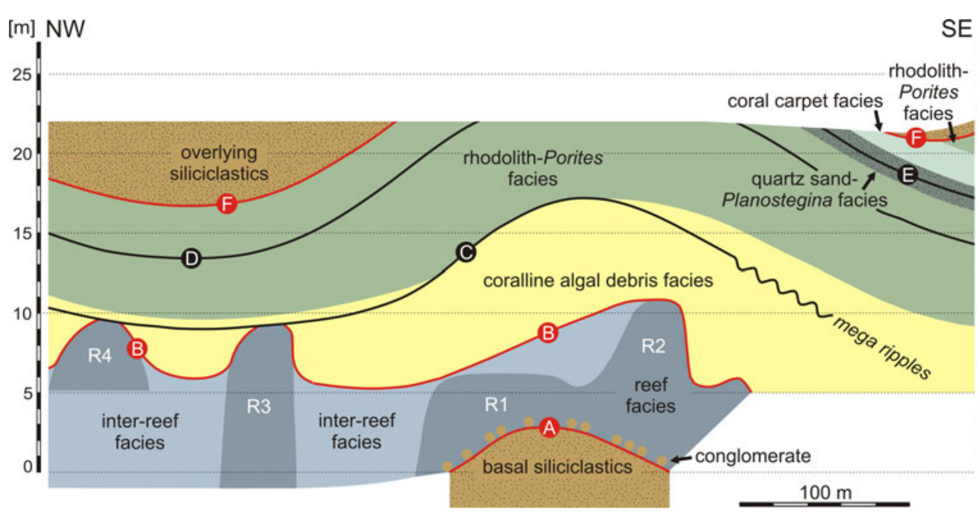
Results

Rosenberg quarry exposes a 25-m-thick carbonate succession composed of clay-rich coralline algal- and coral-dominated limestones by over 600 m in NW–SE and 200 m in NE–SW direction (Fig. 4).

The carbonates rest on a 50-cm-thick clast-supported conglomerate that acted as substrate for 3 coral patch reefs ranging from 30 to 100 m in length and up to 9 m in thickness (R1–3; Fig. 4; Riegl and Piller 2000). They are composed of up to 1-m-wide massive coral colonies predominantly of *Tarbellastraea reussiana* and yet unidentified *Porites* with a smaller contribution by *Montastraea*, *Mussismilia,* and branching *Porites*. The surfaces of many coral colonies are stained black, heavily bored by bivalves and clionid sponges, and encrusted by coralline algae and balanids (Fig. 5a, b). Marl layers, sloping towards the buildups′ margins and tracing the outer shape of the buildups, outline the patch reefs but are typically discontinuous in the centers of the reefs. Rarely, reddish-brown weathered pyroclasts, up to 3-cm long, were also found within the coral frameworks of R1–3. A fourth 4-m-high coral patch reef (R4) occurs further to the NW in stratigraphically higher position than R1–3 (Fig. 4). In contrast to R1–3, the corals in R4 are not encrusted by coralline red algae and balanids, and show minor amounts of bivalve and sponge borings. Marl layers and volcaniclasts are not observed within R4. The patch reefs are surrounded by coarse-grained coralline algal-dominated skeletal limestones with large (1–3 cm) individuals of the benthic foraminifer *Planostegina giganteoformis* (Fig. 5c), which occur locally in rock-forming quantities. Also here, many of the skeletal components (except of *Planostegina* tests) are stained black.

An erosive surface (level B) terminates the coral buildups (Fig. 4) and is onlapped by well-sorted and well-winnowed cross-bedded coralline algal debris grainstones with large foresets (coralline algal debris facies). Another distinct surface is intercalated with the coralline algal debris facies (level C; Fig. 4), following the topographic high formed by patch reefs R1 and R2, and correlating with

Fig. 4 Facies architecture of the studied carbonate body; *red lines* erosive surfaces, *black lines* pyroclastic beds, *R1–R4* patch reefs



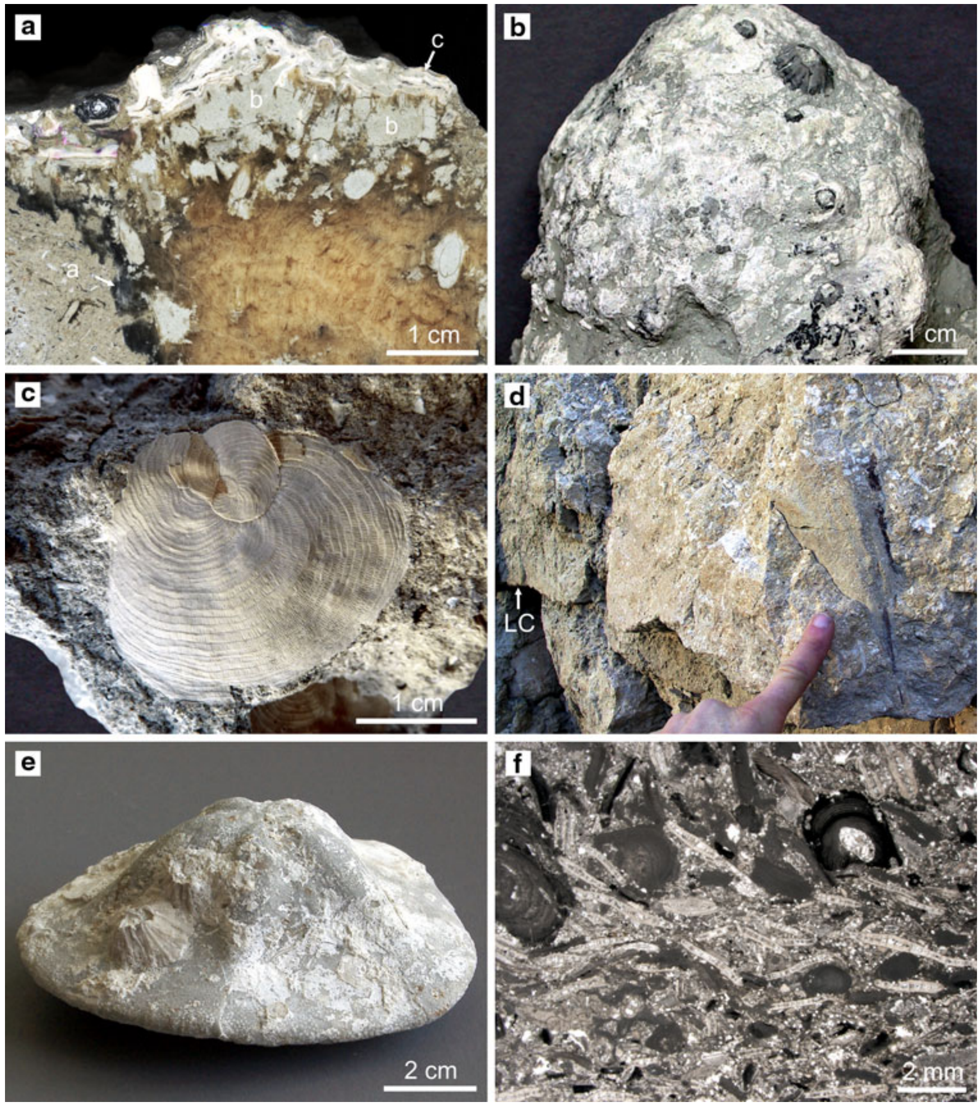


Fig. 5 Biofacies. **a** Massive *Tarbellstraea* colony from patch reef R2. The coral surface exhibits a *black ash* band (*a*), intense bioerosion (*b*) and coralline red algae encrustation (*c*); **b** Coralline red algae–balanid crust on a massive *Porites* colony; patch reef R1; **c** Large *Planostegina giganteoformis* in the inter-reef facies point to a poorly illuminated environment; **d** *Pinna* in life position indicating a seagrass environment; *Pinna* horizon above level C (*LC*); **e** *Clypeaster campanulatus* from the surface of the tuffite above level D. The corona was colonized by balanids and coralline red algae. This documents exposure of the dead semi-infaunal echinoid at the sediment surface during an episode of intensified balanid and coralline algae recruitment subsequent to the deposition of volcanic ash; **f** *Planostegina* concentration in the quartz sand-*Planostegina* facies above level E. The black staining of coralline algal fragments indicates burying beneath pyroclastics. *Planostegina* tests are not stained black, because they occurred only temporary after a volcaniclastic sedimentation event when the reworking of volcanic ash increases the water turbidity

a megaripple field in the eastern part of the outcrop (Fig. 4). This surface is covered with a few centimeters of soft, dark gray to gray-greenish laminated marl with idiomorphic biotite crystals as well as few coralline algae and oyster fragments. Immediately above the marl of level C clusters of oysters and *Isognomon* occur, as well as abundant *Clypeaster campanulatus* coronas and in situ *Pinna* (Fig. 5d). At the topographic high formed by R1 and R2 (Fig. 4), level C is not covered by marl.

The coralline algal debris facies is topped by an 8.5-m-thick unit of thick-bedded marly limestones characterized by variable amounts of rhodoliths and non-framework forming platy *Porites* colonies (rhodolith-*Porites* facies; Fig. 4). Bedding is caused by increasing clay content towards the top of each bed. A 5–40-cm-thick, distinct layer of soft, dark gray to gray-greenish marl with a sharp irregular lower surface is intercalated with the rhodolith-*Porites* facies (level D; Fig. 4). This fine-grained deposit contains isolated idiomorphic biotites as well as up to 15-cm long dark gray to greenish-gray friable volcaniclasts with idiomorphic biotite crystals and oxidized pyroclasts of reddish-brown color. Locally, the pyroclasts make up ~30 % of the sediment. Fragmented coralline algae, echinoids, and oysters contribute only a small portion to the sediment. Similar to level C, patches of in situ oysters and frequent *Clypeaster campanulatus* coronas (Fig. 5e) are found on the upper surface of level D.

The rhodolith-*Porites* facies grades upsection gradually into well-sorted, bioclastic coralline algal-*Planostegina* limestones with quartz sand (quartz sand-*Planostegina* facies; Fig. 4). Many bioclasts (except of *Planostegina* tests) are stained black (Fig. 5f). A distinct 15-cm-thick smeary marl horizon with sharp irregular bottom surface (level E) occurs 40 cm above the base of this depositional unit (Fig. 4). Similar to the marl deposits of levels C and D, it also contains idiomorphic biotite platelets and large

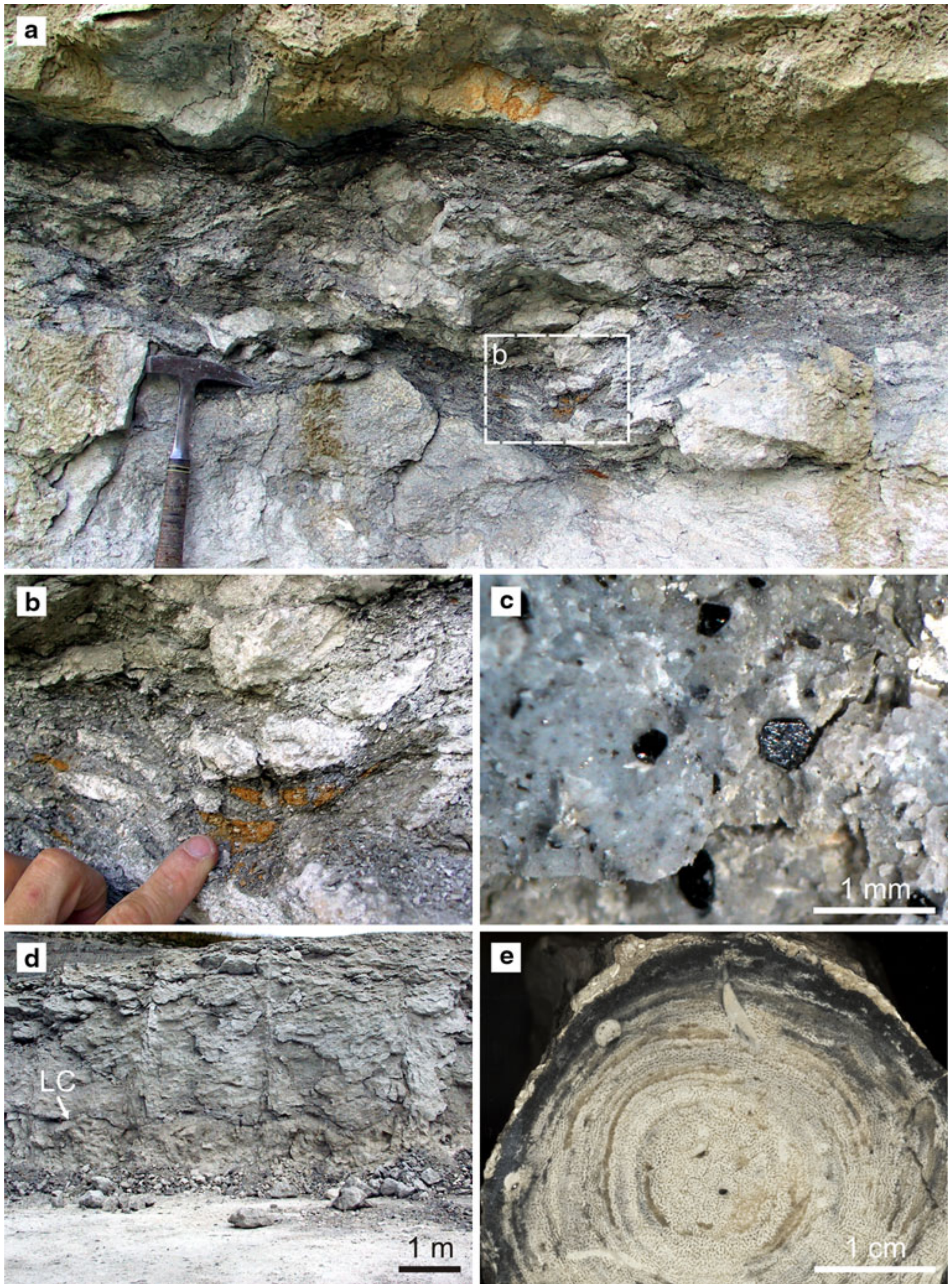


Fig. 6 Volcanic ash deposits. **a** Argillaceous tuffite intercalated within the rhodolith-*Porites* facies (level D; the *white box* locates Fig. 5b). Evidence for a pyroclastic origin are friable, red oxidized pyroclasts (**b**) and idiomorphic biotite crystals (**c**); **d** Megaripple field buried beneath the tuffite of level C (*LC*). The detailed preserved topography points to event sedimentation; **e** Columnar *Porites* branch from the margin of patch reef R1. This coral branch was preserved in-life position and exhibits a circumferential black-stained rim due to infiltration of fine volcanic ash at the surface

(>10 cm) dark gray to greenish-gray biotite-rich pyroclasts as well as small amounts of coralline algal debris. Directly above level E, the amount of *Planostegina* debris increases (Fig. 5f) and a concentration of *Clypeaster campanulatus* coronas is found.

Towards the outcrop's top, a 2-m-thick succession of two coral carpets composed of phaceloid corals (lower carpert) and *Leptoseris* (upper carpet) passes upsection into a ca 5-m-thick unit of argillaceous rhodolith limestone with scattered platy *Porites* (rhodolith-*Porites* facies; Fig. 4).

An erosive surface (level F) truncates the carbonate succession and is overlain by a 35-m-thick unit of sandstones and siltstones (Fig. 4). Two pyroclastic layers containing idiomorphic biotites and zircons, unaltered feldspar phenocrysts, and bentonites are interbedded within the siliciclastics (Hauser 1951; Bojar et al. 2004; Handler et al. 2006; Hohenegger et al. 2009).

Discussion

Depositional environment

The impure limestones of the Retznei carbonate complex reflect a highly turbid environment (Riegl and Piller 2000). In general, the carbonate-accreting benthic communities of the Leitha Limestone are considered as strongly influenced by siliciclastic input from a delta system as well as by local alluvial fans (Fig. 2; Friebe 1990). The amount of siliciclastic discharge is interpreted to be controlled by shifting locations of terrigenous influx in response to allo- and autocyclic processes (sea level changes, delta dynamics; Friebe 1993). The Leitha Limestone carbonate body at Retznei is considered to have caught up with the sea level rise of the second Badenian transgression (=TB 2.4 of Haq et al. 1988; Strauss et al. 2006; Fig. 3), which was superimposed by low-amplitude eustatic sea level fluctuations and/or regional tectonic uplift (Friebe 1993). Carbonate sedimentation was initiated on a transgressive lag deposit, the substrate for coral patch reefs R1–3 (Fig. 4; Friebe 1993). Based on the foraminiferal fauna and sirenian bones, Friebe (1993) assumed seagrass in the inter-reef areas. The patch-reef unit kept up with relative sea level rise (Friebe 1993) and was terminated by an erosive surface indicating emergence (level B). The onlap of coralline algal sands (coralline algal debris facies) against level B documents renewed marine flooding. Foreset structures and megaripples suggest a mobile submarine dune environment. Seagrass vegetation is indicated by an in situ occurrence of *Pinna* (Fig. 5e; Hofrichter 2002; Mikkelsen and Bieler 2008). For the above following rhodolith-*Porites* facies, the non-framework forming level-bottom coral community of platy *Porites* as well as the increased content of clay points to a sediment-impacted low-light environment (Wilson and Lokier 2002; Sanders and Baron-Szabo 2005). The predominantly open laminar and boxwork rhodolith growth forms are interpreted to represent a rather low-hydrodynamic energy environment in deeper water (Rasser 2000). In contrast, the clast-supported bioclastic texture and high quartz sand content in the overlying quartz sand-*Planostegina* facies provides evidence of a higher energy setting during a relative sea-level lowstand. The next relative sea-level rise is displayed by the transition from the coral carpets to the rhodolith-*Porites* facies. A deeply incised erosive surface (level F) truncates the carbonates during long-term emergence. After that a generally increasing water depth can be reconstructed based on the dinocyst and benthic foraminiferal assemblages in the overlying siliciclastic succession (Friebe 1993; Gross et al. 2007; Hohenegger et al. 2009). Synsedimentary volcanic activity is documented by tuff layers (Bojar et al. 2004; Handler et al. 2006). This shift from carbonate to siliciclastic sedimentation is interpreted as being caused by accelerated basin subsidence and hinterland uplift as a result of intensified tectonic activity (Friebe 1993).

Volcanic disturbance to shallow-marine carbonate environments

The carbonate-producing fauna and flora at Retznei collapsed episodically in response to increased fine-grained siliciclastic sedimentation. Three distinct marl layers are laterally continuous throughout the entire outcrop and preserved the topography of the carbonate body (Fig. 4). Their deposition interrupted carbonate sedimentation in the coralline algal debris facies (level C), the rhodolith-*Porites* facies (level D), and in the quartz sand-*Planostegina* facies (level E). Because these marl layers are recognized in different facies, but are not associated with facies changes, the increased fine-grained siliciclastic sedimentation cannot be related to sea-level changes. The fact that the facies below and above levels C, D, and E are virtually identical suggests that these sedimentation episodes had no significant long-lasting effects on the structure of the affected coralline algal- and coral-dominated benthic communities.

The marls characteristically are associated with idiomorphic biotite platelets and volcaniclasts (Fig. 6a, b, c)—both indicating altered volcanic ash beds (Ebner 1981; Friebe 1993; Ebner et al. 1998; Jeans et al. 2000; Bojar et al. 2004; Handler et al. 2006). Volcanic tuffs (bentonites, glasstuffs) appear in terrestrial, marginal marine, and open marine facies throughout the Karpatian–lower Badenian Styrian Basin and suggest the deposition of extensive ash blankets (Ebner and Gräf 1982). Typical for these beds is a well-defined base (Ebner and Gräf 1982), a feature also observed at levels C–E, that points to an abrupt sedimentation event (Reading 1996). In the coralline algal debris facies the detailed preserved relief of an entombed megaripple field (level C; Fig. 6d) also provides evidence of a rapid burial event (Fig. 7a). *Clypeaster campanulatus* (Fig. 5e) is concentrated in distinct horizons directly above the fine-grained deposits on levels C, D, and E. In today's ocean, large clypeasterids with a raised petalodium and a large, flat base, similar to *C. campanulatus,* usually live semi-infaunally, the petalodium not covered by sediment. An epifaunal mode of life, which is developed by some modern clypeasterids (e.g., *C. rosaceus*) seems unlikely for *C. campanulatus,* because these specialists are characterized by a swollen corona and large infundibulum (Kier and Grant 1965; Rose and Poddubiuk 1987). Probably, the

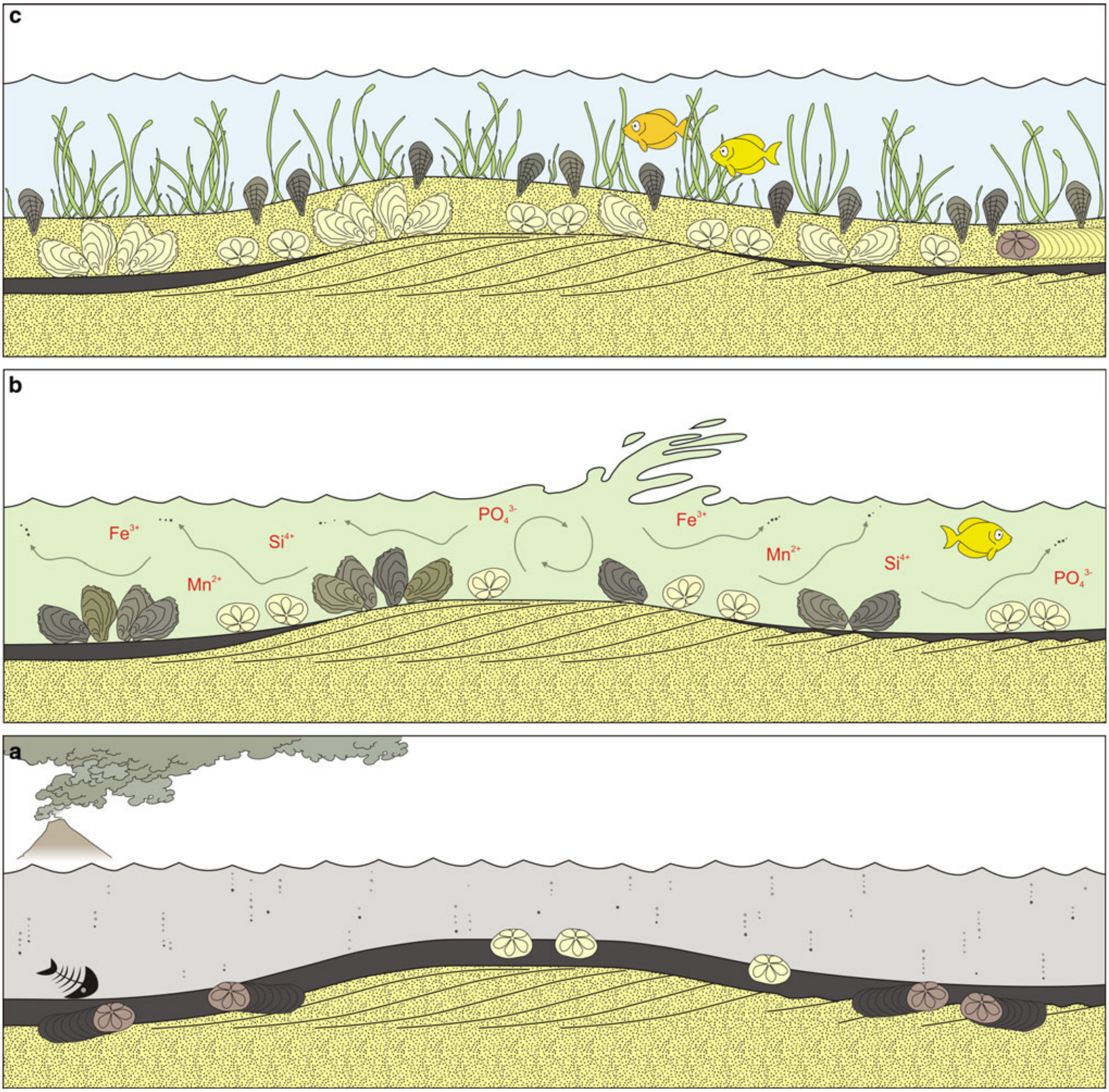


Fig. 7 Disturbance recovery model for volcanic ashfall into a seagrass environment (level C). **a** The pyroclastic sediment eliminates seagrasses. Vagile *Clypeaster* echinoids tried to escape by burrowing but died in the ash or at the devastated seafloor; **b** Water currents remove unconsolidated ash from exposed areas (*arrows*) and concentrate *Clypeaster* coronas at the surface. The basal consolidated part of the volcaniclastics forms a hard substrate for the colonization of oysters and *Isognomon*. These suspension-feeding bivalves benefit from eutrophication owing to the dissolution of suspended ashes; **c** Recovery is documented by a *Pinna* bed. It indicates that seagrasses vegetation was able to recruit after nutrient levels decreased

irregular echinoids were able to escape volcaniclastic burial but finally died of starvation at the contaminated sea floor (Heikoop et al. 1996a; Fig. 7a).

The interruption of the pyroclastic deposit above level C in the area of the topographic high formed by patch reefs R1 and R2 (Fig. 4) shows evidence of removal of fine-grained sediments from wave-exposed areas (Fig. 7b). Accordingly, lateral thickness changes and the mixture of volcaniclastic material and bioclasts indicate lateral sediment transport. In contrast, clusters of attached-living *Isognomon* and oysters on the upper surfaces of levels C and D support early consolidation and sediment stabilization (Zuschin et al. 2001; Printrakoon and Tëmkin 2008; Fig. 7b). Decaying organic matter likely accelerated the

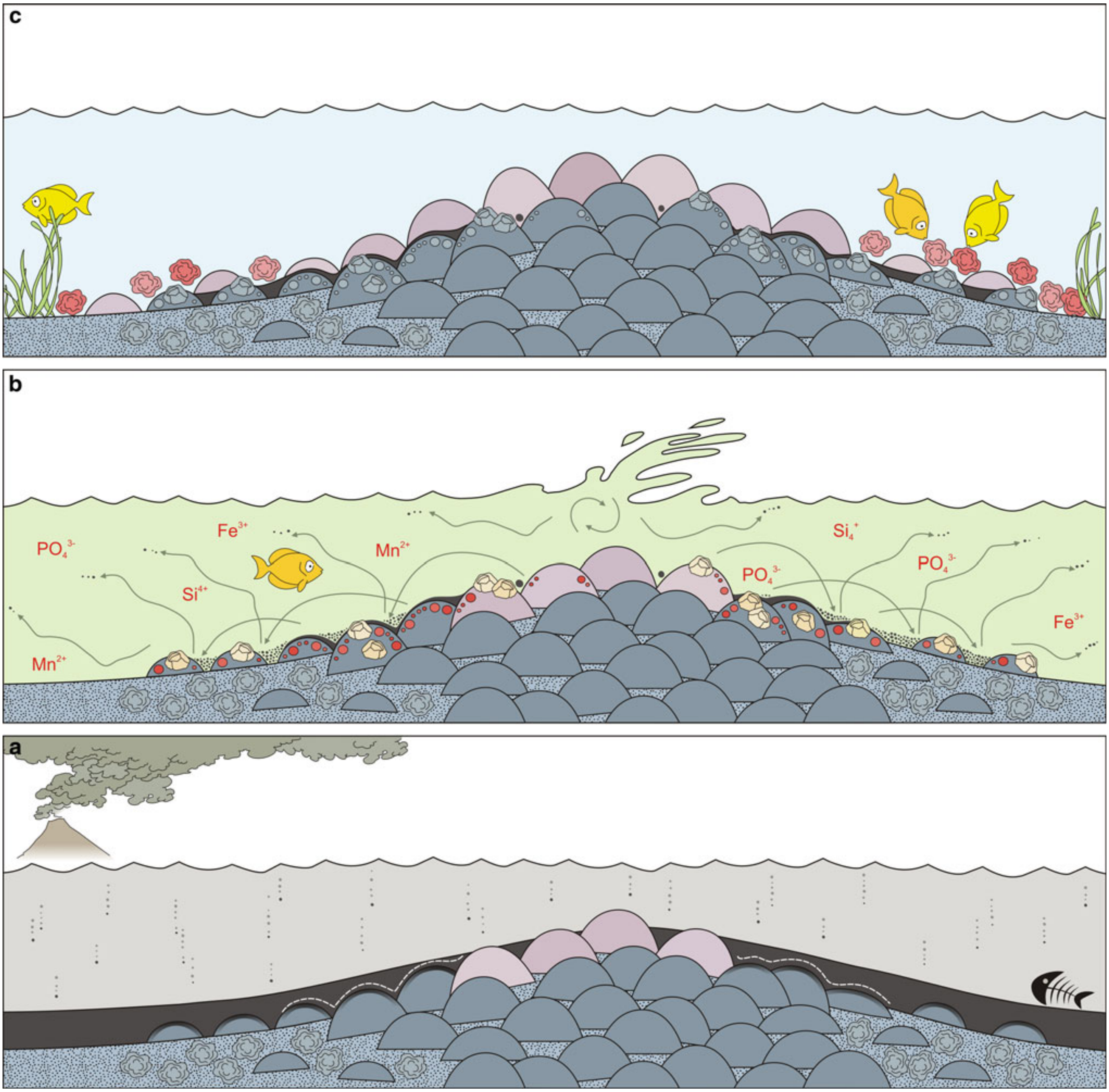


Fig. 8 Disturbance recovery model for volcanic ashfall into a coral reef site. **a** The volcanic ash kills most of the corals. Ash particles infiltrate dead colony surfaces and produce black bands. Soon after deposition of an ash blanket, the initial layer is lithified due to decaying organic matter on the reef surface (*dashed line*); **b** Agitated water removes unconsolidated ash from exposed parts of the patch reef (*arrows*), while at the more protected reef flanks, ash particles are baffled. Dissolution of the suspended ash fertilizes the shallow-marine environment by the release of ions such as phosphate, silica, iron, and manganese (Frogner 2001). This, and the increased availability of dead coral skeletons, favor the spreading of coral boring sponges and bivalves as well as encrusting coralline red algae and balanids; **c** Recovery of coral patch reefs and surrounding seagrass areas

cementation of subaqueous volcanic ashes (Heikoop et al. 1996a). Abundant organic matter on coral surfaces (coral tissue, microbial films, etc.) caused the lowermost portion of ash layers in coral reefs to be preferential sites of early diagenetic lithification. They likely consolidated soon after deposition before the entire deposit could be removed by erosion (Heikoop et al. 1996a). In a comparable situation, Eldredge and Kropp (1985) noticed that only 2 months after the eruption of Mt. Pagan (Mariana Islands) in 1980, reef spurs in the heaviest area of ashfall were covered by a hard tuff layer. This diagenetic pathway may also apply to the thin marl layers, which display the inner structure of patch reefs R1–3, for which synsedimentary volcanism is supported by the presence of scattered volcaniclasts between the corals (Fig. 8). Coral growth was most favorable on top of the patch reefs as higher water movement enhanced sediment removal (Fig. 8b). In contrast, fine-grained sediment accumulated at the reef flanks. Volcanic ash layers are not continuous in inter-reef facies due to a slower consolidation process and bioturbation (Heikoop et al. 1996a, 1996b). Original deposits may not have been sufficiently thick to allow cementation of their basal parts prior to being completely reworked (Fig. 8b; Heikoop et al. 1996a). Over time, the volcanic ash beds became transformed to marl layers when subaqueous alteration produced significant quantities of clay minerals, and most of the cement was leached (Heikoop et al. 1996a). Such argillized ash is susceptible to suspension and must have increased turbidity at Retznei. Since recent *Planostegina* species generally inhabit poorly illuminated deeper water environments (50–100 m; Hohenegger et al. 2000; Renema 2006), the mass-occurrence of *Planostegina giganteoformis* in shallow-water facies (inter-reef facies, quartz sand-*Planostegina* facies; Fig. 5c, f) most likely represents turbid conditions. The *Planostegina* accumulation above the volcaniclastic deposit on level E suggests that this deeper water foraminifer flourished in shallow water when turbidity decreased light levels after pyroclastic sedimentation.

Volcanic ashfall caused coral mass mortality (Fig. 8a) and impaired coral recruit survival as is indicated by thick coralline algal-balanid encrustations and densely bored corals in patch reefs R1–3 (Fig. 5a, b; Heikoop et al. 1996b; Pandolfi et al. 2006; Chui and Ang 2010). This assumption is supported by patch reef R4, which lacks interbedded marl layers and volcaniclasts, and is less affected by biotic encrustations and borings. Dead coral surfaces are also preferential sites for the incorporation of ash particles into the underlying skeletal pores resulting in the formation of dark bands (Fig. 8a; Heikoop et al. 1996b). This may be the reason why intensively bored and encrusted corals typically exhibit black-stained surfaces (Figs. 5a, 6e). Outside the reefs, infiltration of ash particles and fluids into the pores of underlying skeletal components produced black-stained calcitic grains. Remarkably, associated *Planostegina giganteoformis* tests are not stained (Fig. 5f). This indicates that *Planostegina* was not buried beneath pyroclastic deposits and therefore must have thrived only for a short time after the ashfall events. Consistant with this interpretation, Pandolfi et al. (2006) considered that a fully functional reef became established within decades (<100 years) after a volcanic disturbance.

Volcaniclastic sedimentation can fertilize ocean surface waters, which is detrimental for reef corals but stimulates the proliferation of coralline algae, balanids, and bioeroding organisms (Fig. 8b; Hallock 1988; Frogner et al. 2001; Fabricius 2005; Halfar and Mutti 2005; Aguirre et al. 2008). This is indicated by the succession of bivalve communities above the tuffite on level C (Fig. 7b). After consolidation, the tuffite layer was first colonized by pioneer assemblages of oysters and *Isognomon* that are tolerant to increased nutrients (Hendry et al. 2001; Minchinton and McKenzie 2008). Subsequently, a *Pinna* bed (Fig. 5d) developed, which implies a seagrass environment (Fig. 7c; Hofrichter 2002; Mikkelsen and Bieler 2008). Seagrass is notoriously slow to recolonize following a decline. It takes many years to recover from eutrophication, because there is a significant nutrient load stored in the sediment that is released for years after the source of nutrients vanished (Ralph et al. 2006).

In summary, short-term (decadal-scale) breakdowns of the shallow-marine carbonate factory in the Middle Miocene Leitha Limestone were caused by volcaniclastic sedimentation events. These events produced extensive ash blankets that trace the ancient seafloor relief. They are characterized by a mixture of volcaniclasts, idiomorphic biotite crystals, and bioclasts in a clay matrix (tuffite). In coral reefs, these events are represented by indistinctive marl layers and dark bands on coral surfaces. Biotic successions reveal a 2-phase sequence of disturbance in coral reef and seagrass environments. The initial phase is characterized by rapid burial and mass mortality of the carbonate producers. During the second phase, volcaniclastic sediments were redistributed and the dissolution of suspended ash particles released nutrients. The turbid nutrient-rich environment impaired coral and seagrass recruitment but favored the development of *Planostegina*, coralline red algae, and suspension feeders. Early consolidated tuffite layers acted as substrate for attached-living bivalves. Our results suggest that volcanism was a hitherto unnoticed controlling factor for short-term environmental perturbations to benthic carbonate communities in the Miocene peri-Mediterranean region.

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