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Volcanism and reef development in the Devonian: A case study from the Lahn syncline, Rheinisches Schiefergebirge (Germany)

P. Königshof[a,*], H.-D. Nesbor[b], H. Flick[c]

[a] *Senckenberg, Forschungsinstitut und Naturmuseum Frankfurt, Senckenberganlage 25, 60325 Frankfurt, Germany*
[b] *Hessisches Landesamt für Umwelt und Geologie, Abteilung Geologie und Boden, Geologischer Landesdienst, Rheingaustraße 186, 65203 Wiesbaden, Germany*
[c] *Carl-Orff-Ring 5, 87616 Marktoberdorf, Germany*

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ABSTRACT

New data from the Rheinisches Schiefergebirge in Germany offer insights into a complex marine basinal facies setting on the southern shelf area of the Old Red Continent. This interdisciplinary approach has the aim of providing a reconstruction of depositional and palaeoecological conditions of volcanic island induced reef growth during the Middle Devonian time. Devonian volcanic activity culminated in a Givetian–Frasnian phase producing mainly alkali-basaltic to basanitic melts. Some volcanic buildups reached sea level and gave rise to the development of reefs during times of reduced volcanic activity. Reef communities in the Lahn syncline were dominated by corals and stromatoporoids. In terms of conodont stratigraphy they began to flourish during the Middle *varcus*-subzone in the Givetian and lasted until the Late *falsiovalis*-subzone in the Frasnian. A facies model is presented for the entire area that clarifies the association of volcanism and reef development.

1. Introduction

As one of the structural units of the Variscan orogen, the Rheinisches Schiefergebirge in Germany (Fig. 1) is known for its accumulation of Devonian sediments and has been a classical region of Devonian research since the time of its discovery in the 19th century. During Devonian time the Rheinisches Schiefergebirge formed part of the southern shelf area of the Old Red Continent, accumulating siliciclastic debris mainly delivered by deltaic sedimentation (e.g., Langenstrassen 1983; Stets and Schäfer, 2002, 2009). The accumulation of up to several thousand metres of sediment was accommodated by thinning and subsidence of the continental crust. However, whether this resulted from the development of a passive margin along the northern border of the Rheic Ocean (Franke and Oncken, 1995; Oncken, 1998; Nance et al., 2010-this issue; Murphy et al., 2010-this issue) or a back arc situation (Flick and Nesbor, 1988; Ziegler, 1989; Floyd, 1995; Smith, 1996) it is still a matter of debate.

Marine Devonian sediments in the Rheinisches Schiefergebirge are traditionally assigned to two facies settings, the "Rhenish" facies and the "Hercynian" facies (Erben, 1962). The "Rhenish" facies represents the onset and retreat of a deltaic shallow marine environment through Early Devonian time (Stets and Schäfer, 2002, 2009; Wehrmann et al., 2005). Conditions changed to the open marine (pelagic) "Hercynian" facies shortly before the end of the Lower Devonian when the shoreline retreated to the north due to eustatic sea-level rise (Johnson, 1970; House, 1985). Typical sediments of the "Hercynian" facies comprise argillaceous shales and pure limestones, whereas sandstones are rare. These sediments are widely distributed, occurring also in eastern Europe (e.g., Boncheva et al., 2010-this issue).

Where water depth was suitable, barrier-type reefs grew close to the shoreline, which can be traced from the western Rheinisches Schiefergebirge (Eifel area), via the Harz Mountains to Moravia in eastern Central Europe during Middle Devonian time. In the open shelf area further to the south only fringes of islands could sustain reef growth. Here extensional tectonics led to intense submarine volcanism that provided opportunities for the development of reefs in basinal facies. These carbonates occur preferentially in the Lahn-Dill area in the southeastern Rheinisches Schiefergebirge and in the Harz Mountains farther northeast. Reef development flourished during Givetian and Frasnian time and ceased as a result of the Kellwasser event at the end of the Frasnian, which is considered to be one of the major extinction events of the Phanerozoic (Sepkoski, 1995).

Situated at a tropical latitude south of the equator during Middle to Late Devonian time, the Lahn-Dill area resembles the modern South Sea island area. However, the Lahn-Dill area was underlain by continental rather than oceanic crust, such that a modern analogue is

* Corresponding author. Tel.: +49 69970751686.
E-mail addresses: peter.koenigshof@senckenberg.de (P. Königshof), heinz-dieter.nesbor@hlug.hessen.de (H.-D. Nesbor), heiner-flick@t-online.de (H. Flick).

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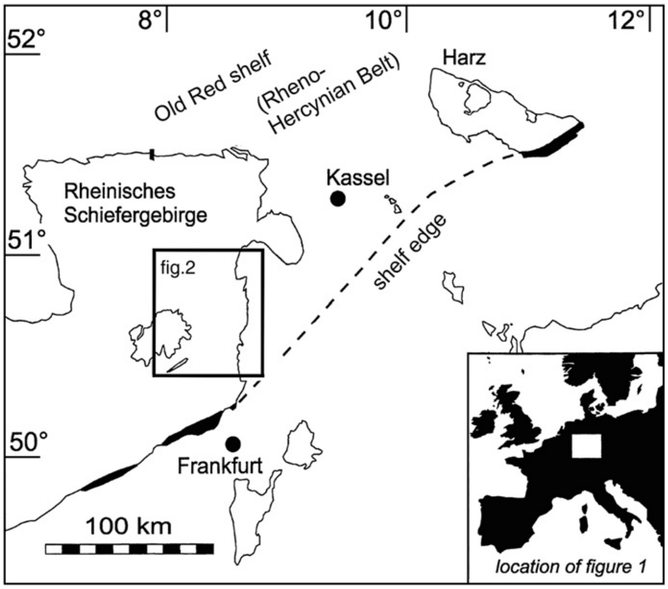

Fig. 1. Outline and location (inset) of the Rheno-Hercynian Zone in Germany also showing location of Fig. 2.

perhaps best found in the island areas of Southeast Asia in the region of the Philippines and Indonesia. Following volcanism, reef growth and further sedimentation, the Lahn-Dill area suffered deformation, uplift and differential denudation from late Palaeozoic times onward. This makes it difficult to reconstruct an entire reef, but it does give insights into the reef interior and the interaction of volcanism and reef growth, which are not accessible in modern analogues, particularly since modern sponges live in different habitats and do not build reefs as they did in Devonian time.

Conditions for modern reef development are dependent on the requirements of the main reef builders, sceleractinian corals and calcareous algae. These conditions include normal marine salinity, fairly strong insolation, dissolved calcium carbonate and abundant nutrients, low terrigenous clastic input and a stable substrate for the attachment of reef builders (e.g., Hallock and Schlager, 1986; Scoffin, 1987, 1992; Tucker and Wright, 1990; Wood, 1999). One of the most limiting resources in shallow marine environments is the availability of sufficient substrates for the attachment of benthos because any sessile benthic organism must secure attachment long enough to reproduce. Substrates can range from dead shells that are small and unstable, to highly stable, laterally extensive areas which persist unchanged for decades or even centuries (Jackson, 1985; Wood, 1999), such as hardgrounds where hemispherical forms occur. More delicate, branching forms occur in lower energy environments. The substrate is thus, in part, dependent on the hydrodynamic regime. Ecological succession in a modern reef is quite variable but can be very rapid. Tomascik et al. (1996) have shown that the emplacement of submarine lava flows on Gunung Api, Banda Islands (Indonesia) took only a few years. The study of ancient reef successions is more difficult because the nature of preservation of fossil communities rarely allows the recognition of ecological succession upon a single substrate (Wood, 1999).

We have combined geochemical and palaeontological datasets from the literature with new data in order to gain a better understanding of the interaction between volcanism and reef growth in deeper water settings within the Rheinisches Schiefergebirge. The aim of the present study in the Lahn syncline is the reconstruction of the depositional and palaeoecological conditions of volcanic island induced reef growth. This is a contribution to the special volume: The Rheic Ocean: Origin, Evolution and Correlatives.

2. Geological setting

The Lahn-Dill area has been defined as a synclinal structure within the southeastern Rheinisches Schiefergebirge with a geological history extending from about Middle Devonian time until the Variscan orogeny. The area is divided into the so-called Lahn syncline and Dill syncline, respectively, separated by the Hörre unit (Fig. 2). The tectonic structure of the latter has been the subject of controversy. Today it is considered to represent a tectonic nappe derived from the south of the Rheinisches Schiefergebirge (Oncken and Weber, 1995; Franke, 1995, 2007; Bender, 2006). This model is supported by local evidence of benthic fauna (Flick, 1999). Thus, the Lahn syncline and the Dill syncline can actually be considered a single unit, the Dill syncline being more influenced by the influx of clastic sediments from the Old Red Continent. The Palaeozoic successions were folded and thrusted with decreasing deformational magnitude towards the northwest during the Variscan orogeny, producing NE–SW trending tectonic structures. The massive reefal limestones of the Lahn syncline follow this tectonic pattern.

Except for volcanic structures in the north of the Rheinisches Schiefergebirge, shelf topography was presumably not very pronounced until about the end of Early Devonian time. Repeated volcanic debris flows from the north could consequently reach far to the south of the Rheinisches Schiefergebirge (Kirnbauer, 1991). Prior to the end of the Lower Devonian pelitic sedimentation prevailed in the Lahn-Dill area (and beyond) in the facies of the Wissenbach slates (Requadt and Weddige, 1978). The presence of local hiatuses until late Middle Devonian time demonstrates the existence of islands in the southwest part of the Lahn-Dill area, indicating pronounced relief change on a relatively small scale. This is confirmed by assemblages of benthic faunas, especially trilobites, beginning in Early to Middle Devonian time that constitute habitats below and above storm wave base (Flick and Struve, 1984; Flick et al., 1998, 2006). Sedimentation in the Lahn-Dill area was generally controlled by basin development and volcanism, both reflecting the thinning of the crust due to extensional tectonics. Volcanic activity can be assigned to two cycles, a Devonian one and a Carboniferous one (Nesbor, 2004), each of which comprised several phases. Altogether volcanism was intermittently active for more than 50 Ma (Fig. 3).

The Devonian volcanic cycle consists of three phases. The initial phase is mostly confined to the southwest of the Lahn syncline where trachytic to alkali-rhyolitic products overlie Lower Devonian clastic sediments of different age. This makes it difficult to constrain the beginning of volcanic activity. However, part of it can be assigned an early Givetian age (W. Dörr, pers. communication). The volcanic edifices are also difficult to reconstruct, although there should have been several. But, the rising felsic melts are known to have built volcanic islands since subaerial stages have been described (Breitkreuz and Flick, 1997).

Volcanic activity of the Devonian cycle culminated in the Givetian–Frasnian phase. Generally, activity begins in the early Givetian (Lippert, 1970; Requadt, 1990; Buggisch and Flügel, 1992; Bender et al., 1997), dominating the geological successions throughout that stage and intermittently reaching into early Frasnian (Adorfian) time. The voluminous alkali-basaltic to basanitic melts generally did not rise directly from their mantle source to the surface but accumulated in magma chambers on their way up. Products from differentiation processes range from low ankaramitic melts enriched in mafic phenocrysts via trachybasaltic and trachyandesitic to trachytic or rhyolitic melts. Felsic volcanics and volcaniclastics built rather short-lived volcanic islands on top of the submarine basaltic volcanic edifices (cf. Flick and Schmidt, 1987) as can be deduced from polymict debris sediment, generally known as Dillenburg formation, on top of the volcanic successions. Basaltic volcanism in the Givetian–Frasnian phase took place at many overlapping eruptive centres (Nesbor et al., 1993). The products of the individual volcanic edifices built up to