

The Late Ordovician (Hirnantian) Lederschiefer Formation in Thuringia – evidences for a glaciomarine origin from the Berga Antiform (Saxo-Thuringian Zone)

Die oberordovizische (Hirnantium) Lederschiefer-Formation in Thüringen – Beweise für eine glaziomarine Entstehung aus dem Berga-Antiklinorium (Saxothuringikum)

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Abstract

This article gives the first evidences for a glaciomarine setting of the Late Ordovician (Hirnantian) Lederschiefer Formation found at the Berga Antiform. Former interpretations of the diamictite were always based on studies done in the Schwarzbburg Antiform (e.g. Deubel 1929, Katzung 1961, Ellenberg 1992, Linnemann et al. 2008a) and were than assumed for other outcrops. Both antiforms are separated by the Ziegenrück-Teuschnitz Syncline (Linnemann 2008b).

We present a faceted and striated pebble from the Lederschiefer diamictite that now confirms the interpretation as glaciomarine sediment also for the Berga Antiform. In addition, the whole section described in this study shows glacial influences. These glacial deposits belong to the Hirnantian (Late Ordovician) "Sahara glaciation" (Linnemann et al. 2008a), where glaciers covered most parts of Gondwana. The increasing load of ice resulted in local subsidence of crust in the northern part of the West African Craton. This effect locally counteracted the global sea-level development: While there was a general global glaciation-triggered fall of sea-level, the simultaneous subsidence caused transgression and ongoing sedimentation in areas of peri-Gondwana (especially in the Saxo-Thuringian Zone). Due to general movement direction of the glaciers, the West African Craton can be seen as the main source area for the Hirnantian glacial sediments of Cadomia (including the Saxo-Thuringian Zone). The discussed section is interpreted as being a proximal equivalent of the more distal Late Ordovician sediments of the Schwarzbburg Antiform (e.g. Linnemann et al. 2008a).

Kurzfassung

Mit dieser Studie werden erstmals Beweise für glaciomarine Bedingungen während der Ablagerung der Lederschiefer-Formation im Ober-ordovizium (Hirnantium) durch Funde aus dem Berga Antiklinorium erbracht. Frühere Interpretationen des Diamiktits stützten sich auf Untersuchungen im Schwarzburger Sattel (z. B. Deubel 1929, Katzung 1961, Ellenberg 1992, Linnemann et al. 2008a), die dann für alle Lederschieferaufschlüsse generalisiert wurden. Das Berga-Antiklinorium ist durch das Ziegenrück-Teuschnitz-Syklinorium vom Schwarzburger Sattel getrennt (Linnemann 2008b).

Der Fund eines facettierten und gekritzten Geschiebes aus dem Lederschieferdiamikt bestätigt nun auch für das Berga-Antiklinorium die Interpretation der Lederschiefer-Formation als glaciomarines Sediment. Zusätzlich zeigt das gesamte aufgenommene Profil eine starke glaziale Beeinflussung. Die Ablagerungen gehören zur „Sahara-Vereisung“ (Oberordovizium, Hirnantium, Linnemann et al. 2008a), während der Gletscher den Großteil Gondwanas bedeckten. Die zunehmende Eisauflast führte zur Subsidenz kontinentaler Kruste im nördlichen Teil des Westafrikanischen Kratons. Dieser Effekt wirkte der Entwicklung des globalen Meeresspiegels lokal entgegen: Während des generellen eiszeitbedingten Abfalls des Meeresspiegels, bedingte die Subsidenz eine Transgression sowie weiterführende

Sedimentation in Gebieten Peri-Gondwanas (speziell im Saxo-Thuringikum). Durch die allgemeine Bewegungsrichtung der Gletscher nach Norden kann der Westafrikanische Kraton als Liefergebiet für die oberordovizischen Eiszeitsedimente Cadomias (inkl. Saxo-Thuringikum) angesehen werden. Das vorgestellte Profil wird als proximales Äquivalent der eher distalen oberordovizischen Sedimente des Schwarzburger Sattels angesehen (z. B. Linnemann et al. 2008a).

1. Introduction and geological setting

In Thuringia Ordovician deposits occur in the Ruhla Formation and in the Schwarzburg and Berga antiforms (Fig. 1). As fossils are rare in Ordovician sediments, the stratigraphic subdivisions are mainly based on lithological properties and correlations (Falk & Wiefel 2003). Outcrops with nationwide importance can be found in the southeastern part of the Schwarzburg Antiform, due to the good exposing conditions and the content of relatively well preserved fossils. Therefore, the Schwarzburg Antiform is the type area for the German Ordovician. In general, Ordovician deposits in Thuringia comprise Tremadocian to Hirnantian, thus representing the complete Ordovician. The Late Ordovician (Hirnantian) is characterized by glacial deposits of the “Sahara glaciation” (Linnemann et al. 2008a) (Fig. 2). The Gräfenthal Group comprises the whole Upper, Middle and the upper stages of the Lower Ordovician (Floian to Hirnantian) and is build up of three different lithological units: the slate unit (Griffelschiefer, Floian) at the base, followed by a lithologically highly variable interval and the glaciomarine unit (Lederschiefer, Hirnantian) at the top (Falk & Wiefel 2003). The interval in-between the Griffelschiefer and the Lederschiefer units mainly consists of an ore rich, thin layered intercalation of fine-grained, dark grey mudstones and quartzites (gebänderter Lederschiefer) in the southeastern part of the Schwarzburg Antiform, whereas in the Berga Antiform (study area), it is represented by a quartzite (Hauptquarzit, see Fig. 3).

The Late Ordovician Lederschiefer Formation has a diamictitic texture with a fine-grained matrix of slate, containing rock boulders of different types and sizes. In general, it is unsorted and shows a lot of mica in the fine grained matrix (Katzung 1961). A fresh (unweathered) sample has a dark grey colour. Weathering causes a change in colour of the surface to brownish, similar to leather naming this formation (German “Leder” = English “leather”). The total thickness of the Lederschiefer diamictite is about 110 to 250 m but decreases fast towards the NE (Falk & Wiefel 2003).

The Lederschiefer in Saxo-Thuringia is considered as glaciomarine deposit (diamictite) since Deubel (1929) and Katzung (1961). But both were working in the Schwarzburg Antiform, and evidence for glaciomarine origin of the Lederschiefer in other structural units of Thuringia has been missing. In general, the assumptions

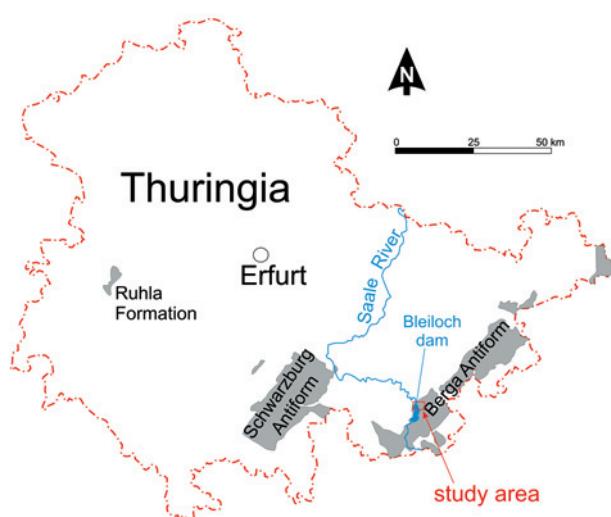


Fig. 1. Ordovician deposits in Thuringia (based on Falk & Wiefel 2003) are restricted to the Ruhla Formation and the Schwarzburg and Berga antiforms. The study area lies within the Berga Antiform, at the northeastern part of the Bleiloch dam in the Wettera bay. A detailed map of the study area is given in Fig. 3.

Abb. 1. Ordovizische Ablagerung sind in Thüringen (basierend auf Falk & Wiefel 2003) begrenzt auf die Ruhla-Formation, den Schwarzburger Sattel und das Berga-Antiklinorium. Das Untersuchungsgebiet liegt innerhalb des Berga-Antiklinoriums, am nordöstlichen Ende der Bleilochtalsperre in der Wetterabucht. Eine detaillierte Karte des Untersuchungsgebiets ist in Abb. 3 dargestellt.

made in the Schwarzburg Antiform were also used for interpretation of the Lederschiefer Diamictite in e.g. the Berga Antiform.

To finally confirm this interpretation, we present the discovery of a faceted and striated quartzite pebble from the Lederschiefer Formation, found in the Berga Antiform in the northeastern part of the Bleiloch dam (Wettera bay). In addition, we measured a section from the quartzite (Hauptquarzit) at the base to the Lederschiefer unit at the top, showing glacial influence.

1.1. The Late Ordovician glaciation

The glacial event in the Hirnantian (uppermost Ashgill in British stages) did comprise biggest parts of Gondwana (e.g. Linnemann et al. 2008a). Fig. 2 shows a possible expansion and configuration of this Late Ordovician ice shield that influenced the peri-Gondwana terranes as well

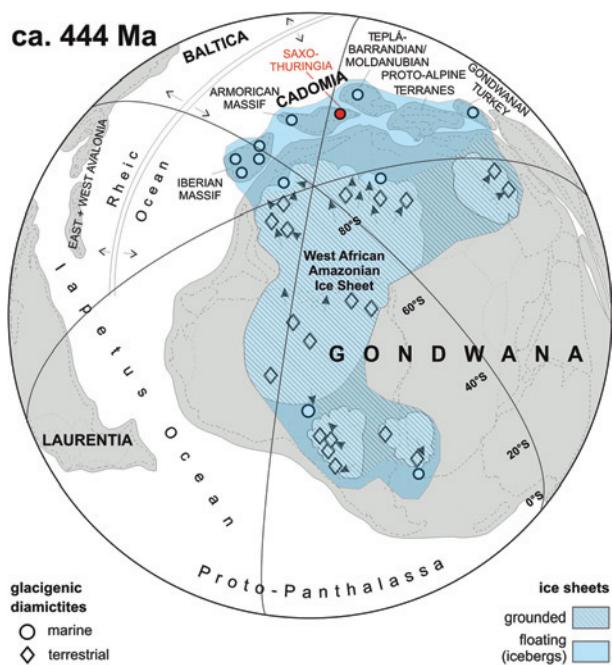


Fig. 2. The “Sahara glaciation”: The expansion of the Late Ordovician (Hirnantian or Ashgill, respectively) ice shield that covered big parts of Gondwana is estimated by known glaciomarine deposits (map slightly modified after Linnemann et al. 2011). The position of Saxo-Thuringia as a part of Cadomia in peri-Gondwana is marked (red circle). Except for the glaciomarine Lederschiefer diamictite, there are also other coeval glacial deposits known from peri-Gondwana (e.g. from the Iberian and American massifs, the Teplá-Barandian/Moldanubian and from Turkey) that can be correlated with the Lederschiefer Formation. As the Avalonian terranes drifted away from peri-Gondwana at ca. 480 Ma towards Baltica and Laurentia in the NW, they were not influenced by this glaciation (Linnemann et al. 2008a).

Abb. 2. Die „Sahara-Vereisung“: Die Ausbreitung des spätordovizischen (Hirnantium bzw. Ashgill) Eisschildes, welches den Großteil Gondwanas bedeckte, ist anhand bekannter glaziomariner Sedimente abgeschätzt (leicht verändert nach Linnemann et al. 2011). Die Position von Saxo-Thuringia in Cadomia als ein Teil peri-Gondwanas ist dargestellt (roter Kreis). Neben dem Lederschiefer Diamiktit gibt es weitere gleichaltrige Eiszeitsedimente im peri-Gondwanaraum (z. B. in Iberia, Amerika, dem Teplá-Barandium/Moldanubikum und in der Türkei) welche mit der Lederschiefer-Formation korreliert werden können. Da Avalonia bereits um 480 Ma von peri-Gondwana in Richtung Baltika und Laurentia im NW driftete, ist es – wie auch Letztere – nicht von der Vereisung betroffen (Linnemann et al. 2008a).

as the cratonic hinterlands (Linnemann et al. 2011). The main transport directions of the ice shield propose the West African Craton as the sediment source area for the Upper Ordovician deposits in Cadomia. Gondwana was located at the South Pole at that time. Cadomia, Iberia, Armorica, the Teplá-Barrandian/Moldanubian, the Proto-Alpes as well as the Gondwanan Turkey were situated as terranes on the northern rim of the West African Craton, forming peri-Gondwana (Linnemann 2008c; Fig. 2). East and West Avalonia started to drift away from peri-Gond-

wana at ca. 480 Ma, opening the Rheic Ocean (Linne-
mann et al. 2008d). As the Late Ordovician “Sahara
glaciation” (e.g. Linnemann 2008b) only affected Gond-
wana, coeval glacial sediments are absent in Avalonia,
Baltica and Laurentia. This fact can be used as “Gond-
wana fingerprint”, indicating a possible connection of a
terrane with Gondwana. All terranes along the northern
margin of the West African Craton (see Fig. 2) show this
typical “fingerprint” (Iberia, Armorica, Saxo-Thuringia,
Teplá-Barandian/Moldanubian, Turkey).

2. The section

The section (Fig. 3) was examined at the Wetterabey in the NE of the Bleiloch dam. It represents the Ashgill (in international stages: Hirnantian and Upper Katian) and starts with the deposits of the Hauptquarzit, a massive quartzite of 250 m thickness maximum (Wiefel 1998). It is characterized by fan delta deposits (Ellenberg et al. 1992, Falk & Wiefel 2003) on the shelf of the northern West African Craton that was connected to the peri-
Gondwanan terranes, e.g. Cadomia (see Fig. 2). The northern shelf area was exposed to the approaching glaciation, because the growing glaciers accumulated big amounts of water that lead to a global sea-level drop (Linnemann et al. 2008c, Cooper et al. 2012; see Fig. 3). The Hauptquarzit is only present in the Berga Antiform and in the Vogtland (Falk & Wiefel 2003). In the Schwarzbburg Antiform it equates to the condensed layer of the so-called gebänderter Lederschiefer directly at the base of the glaciomarine Lederschiefer diamictite. Thus, the gebänderter Lederschiefer represents the distal variety of the Hauptquarzit (Ellenberg et al. 1992). Therefore, the studied section (Fig. 3) implies a more proximal depositional environment (closer to the West African Craton) than the sediments found in the Schwarzbburg Antiform (Linnemann et al. 2008a).

The Hauptquarzit shows turbiditic activity at its top, followed by the deposition of black shales. This points to increasing water depths and is in contrast to the global trend of sea-level drop (Fig. 3). The glaciation reached its maximum in the Hirnantian (uppermost Ordovi-
cian). As the glaciers finally arrived at the northern shelf areas, they started to float on sea water. The developing icebergs melted and dropped their carried sediments on the ocean floor, where they formed massive layers of fine-grained mud containing unsorted rock components of different types and sizes: the Lederschiefer diamictite. The latter one varies in thickness between 110 to 250 m in Thuringia. Its glacial character was first noticed in outcrops of the Schwarzbburg Antiform (e.g. Deubel 1929, Katzung 1961, Linnemann et al. 2008a) and then assumed for all coeval diamictite layers in Saxony and Thuringia.

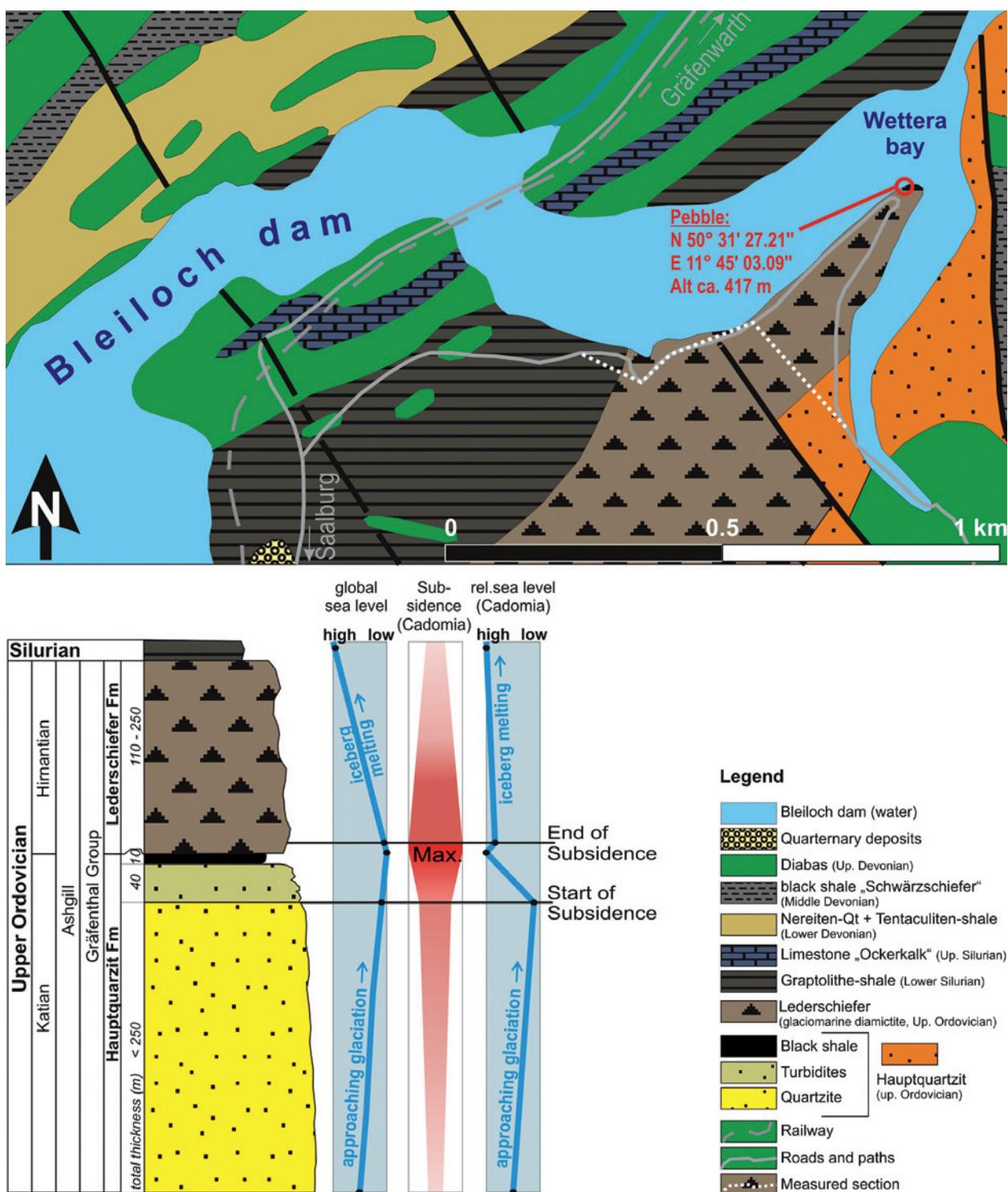


Fig. 3. Geological map of the study area, additionally showing the analysed section and related sea-level changes. The location of the faceted and striated pebble and the measured transect are indicated in the map (modified after Gräbe et al. 1996). The illustration of global sea-level changes is based on Linnemann (2008c) and Cooper et al. (2012).

Abb. 3. Geologische Karte des Untersuchungsgebiets mit dem bearbeiteten Profil und dazugehörige Meeresspiegelschwankungen. Der Fundpunkt des facettierten und gekritzten Gerölles sowie der Profilschnitt sind in der Karte markiert (verändert nach Gräbe et al. 1996). Die Darstellung der globalen Meeresspiegelschwankungen basiert auf Linnemann (2008c) und Cooper et al. (2012).

The deposition of the glaciomarine Lederschiefer sediment (Lederschiefer Formation) marks the end of the Hirnantian glacial event. The melting glaciers and icebergs caused global sealevel rise (Linnemann et al.

2008a, Cooper et al. 2012) resulting in the sedimentation of the Lower Silurian (Llandovery) black shale (Graptolite shale). It covers the Lederschiefer diamictite and terminates the section (Fig. 3).

3. The sample

In general, the boulder content of the Lederschiefer diamictite increases towards. According to Katzung (1961), boulders are mainly quartzites (46.5%), cherts (39.4%), slates (7.8%), and ooid-containing rocks (5.3%). Discoveries of mafic magmatites exist but are very rare. The boulder sizes vary from pebbles and sand (dominating) up to ca. 30 cm in diameter (Katzung 1961).

The quartzite pebble presented in this study (Fig. 4) was found in the Wettera bay NE of the Bleiloch dam in the Berga Antiform (Figs. 1, 3). The sample was weathered out of the matrix. Its exact location and the coordinates are given in Fig. 3. The pebble itself is only about 4.5 cm long and shows features typical for glacial transport, like a faceted form and striations on the surface (see Fig. 4). It is coated with patina and has remnants of the fine-grained slate matrix of the Lederschiefer diamictite. It experienced only weak deformation that did not overprint the striations.

4. Interpretation and discussion

The finding of a striated and faceted clast confirms the glaciomarine origin of the Lederschiefer diamictite. The presentation of a boulder from the Berga Antiform is new, as such clasts were known from the Schwarzburg Antiform only (e.g. Katzung 1961). Both structural units are separated by the Ziegenrück-Teuschnitz Syncline (Linnemann 2008b).

The sequence stratigraphy of the herein presented sedimentary section (Fig. 3) is influenced by two big mechanisms:

-
- 1 changes of the global sea-level mainly linked to the glaciation process and
-
- 2 subsidence rates of the shelf regions and peri-Gondwana terranes at the northern West African Craton.
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The subsidence is predominantly triggered by the northward movement of the glaciers (Fig. 2). The increasing load pushed the shelf areas down. The interplay of both mechanisms (sea-level fall vs. subsidence) as well as the resulting relative sea-level changes in the study area (Cadomia) are shown in Fig. 3. It turns out that the local sequence stratigraphic patterns and the connected sea-level high- or low-stands do not correlate with the global sea-level changes. The influence of crustal subsidence of the shelf regions due to the enormous weight of the covering glaciers partly reversed the influence of the global sea-level drop (Fig. 3).



Fig. 4. Quartzite pebble from the Lederschiefer Formation found at the Wettera bay (Bleiloch dam). For exact sample location, see Fig. 3. The pebble shows a typical faceted form and striations at its surface. It is coated with patina and shows remnants of the fine-grained slate matrix of the Lederschiefer. It confirms the glaciomarine origin of the Lederschiefer diamictite. Scale: 1 cm.

Abb. 4. Quarzgeschiebe aus der Lederschiefer-Formation von der Wetterabucht (Bleilochtalsperre). Zur Angabe des genauen Fundpunkts siehe Abb. 3. Das Geröll zeigt eine typische facettierte Form und Kritzungen auf der Oberfläche. Es ist mit Patina überzogen und weist Reste der feinkörnigen Lederschiefermatrix auf. Dieses Geröll bestätigt die glaciomarine Entstehung der Lederschierereinheit. Maßstab: 1 cm.

The turbidite overlying the quartzite in the section (see Fig. 3) is the first hint for a crustal subsidence in the shelf areas and the peri-Gondwana terranes. It marks the start of subsidence in the area. As the subsidence counteracted the global sea-level fall it lead again to flooding of these areas. The maximum of subsidence is represented by the sedimentation of the black shales at the very top of the Hauptquarzit Formation, directly underlying the glaciomarine Lederschiefer sediment (see section in Fig. 3). At this time, there was a relative local sea-level highstand what is in contrast to the general global lowstand.

The West African Craton is interpreted as being the main source area for Paleozoic sediments of Saxo-Thuringia (as a part of Cadomia, Linnemann 2008c). This sedimentary setting did not change during the Late Ordovician glacial event (“Sahara glaciation”, Linnemann et al. 2008a). The movement direction of glaciers was towards the N (Fig. 2), coming from the West African Craton. As the glaciers reached areas of today’s Saxo-Thuringian region, they floated on water and break to pieces of single icebergs that melted and left behind the material they had eroded on the West African Craton.

According to Katzung (1961) the total thickness of the Lederschiefer Formation decreases towards the N. The quartzite unit below the Lederschiefer at the Berga Antiform (Hauptquarzit) is absent in the Schwarzburg Antiform but corresponds there to a fine grained intercalation of silt- and sandstones (gebänderter Lederschiefer). These two facts support the interpretation of the sediments of the Berga Antiform as representing a more proximal facies than the deposits of the Schwarzburg An-

tiform. On the base of Cadomia (including Saxo-Thuringia) being a terrane at the peri-Gondwanan margin of the northern West African Craton (Fig. 2, Linnemann 2008c), we interpret the section (Fig. 3) presented in this study as a proximal equivalent to the more distal Upper Ordovician sediments of the Schwarzbburg Antiform.

5. Summary

The main results of this study can be summarized in seven points:

- **1** The quartzite pebble represents the first striated and faceted boulder found in the glaciomarine Lederschiefer diamictite of the Berga Antiform. Influences of glacial transport are obvious (Fig. 4).
- **2** This discovery confirms the interpretation of the Lederschiefer unit as being of glaciomarine origin (as already proposed by other authors, e.g. Deubel 1929, Katzung 1961, Ellenberg 1992, Linnemann et al. 2008a). These former assumptions were based on studies done in Ordovician sections of the Schwarzbburg Antiform and were inferred hypotheses for the Berga Antiform.
- **3** The glacial deposits belong to the Hirnantian “Sahara glaciation” (Linnemann et al. 2008a), where glaciers covered most parts of Gondwana (Fig. 2).
- **4** The section shows local changes of sea-level (for Cadomia) that are in contrast with the global sea-level developments. We demonstrated the influence of local subsidence of crust caused by the weight of glaciers leading to transgression for distinct areas of peri-Gondwana (especially Saxo-Thuringia as part of Cadomia), although there was a glaciation-triggered global sea-level drop (Fig. 3).
- **5** Subsidence started with the sedimentation of the turbiditic part of the Hauptquarzit Formation and reached its maximum during the deposition of the black shales at the top of the formation (see section Fig. 3).
- **6** Due to general direction of movement of the glaciers (Fig. 2), the West African Craton can be seen as the main source area for the Hirnantian glacial sediments of Cadomia (including the Saxo-Thuringian Zone).
- **7** The discussed section (Fig. 3) is interpreted as being a proximal equivalent to the Upper Ordovician sediments of the Schwarzbburg Antiform (according to Linnemann et al. 2008a).

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