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Geochemical interpretation of the Precambrian basement and overlying Cambrian sandstone on Bornholm, Denmark: Implications for the weathering history

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ABSTRACT

A geochemical study of the Precambrian basement granites from the Borggård borehole on Bornholm, Denmark, suggests that the granites were moderately weathered (Chemical Index of Alteration-CIA = 66–71) during subaerial exposure in a humid climate. The microcline is well preserved, whereas plagioclase was thoroughly altered to clay minerals (Plagioclase Index of Alteration-PIA = 93–99) which is likely due to its original Ca-rich composition. The primary Fe–Ti accessory minerals were oxidized to hematite and anatase. Evidence from REE distribution patterns and immobile element ratios, e.g. Zr/Hf and Nb/Ta, between the weathered basement granite from the Borggård borehole and regional granitoids on Bornholm, constrains the Svaneke Granite as the original basement lithology. A tau (τ) mass transport model (assuming immobile Ti) was applied to quantify the mass transfer during weathering of the basement granite. The results show a depletion of major elements in the following order: Na > Ca > Mg > Si; Al and Ti are immobile and stay constant; K shows sample dependent enrichment or depletion; Fe is slightly enriched. The Cambrian sandstone overlying the basement in the Borggård borehole, assigned to the Gadeby Member of the Nexø Formation, is feldspathic litharenite–litharenite in composition. Provenance indicators including $(Gd/Yb)_N$, Zr/Hf and Nb/Ta ratios and petrological features indicate that source material was derived from both weathered and fresh basement granite of intermediate composition. The Gadeby Member equivalents in Germany, the basal lower Cambrian Adlergrund Konglomerat Member (AKM) in the offshore G-14 well north of Rügen, and the approximately coeval Lubmin Sandstein Formation (LSF) from the Loissin-1 borehole, mainland Germany, must have been sourced from a basement with compositions comparable to the intermediate group of the regional granitoids on Bornholm. The source materials for the AKM (CIA = 71–72, PIA = 94–96), the Gadeby Member in the Borggård borehole (CIA = 52–69, PIA = 56–99) and an outcrop in Nexø, eastern Bornholm (CIA = 52–66, PIA = 61–96), have endured similar degrees of weak to moderate weathering but lost most of the plagioclase. The LSF has a comparable weathering history (CIA = 63–73), but the plagioclase is better preserved (PIA = 65–78). The significant variation of weathering rates of plagioclase and K-feldspar in the basement granite and the provenance of sandstone from the Borggård borehole are likely due to the different permeability developed within the internal crystal structures, a Ca- rich plagioclase original composition of the plagioclase, and the occurrence of weathering in a very humid climate. K metasomatism occurred in the basement granite and sandstone in both the Borggård and the G14–1 boreholes, mainly through the conversion of aluminous clay minerals (e.g. kaolinite) to illite, with transformation of plagioclase to K-feldspar occurring locally. This my have taken place during deep burial in the Caledonian foreland basin.

1. Introduction

Weathering by physical and chemical alteration of rocks and minerals at or near the Earth's surface forms detrital sediment and is also an important process for the development of soil profiles (Birkeland, 1984). Weathering processes in the past were closely constrained by hydrosphere and atmosphere conditions as recorded by mineral transformations (Nesbitt and Young, 1982). Constituents are released as dissolved ions stoichiometrically during mineral transformations, therefore making it possible to determine the complex mineralogical changes by comparing bulk compositions in weathering profiles to those of fresh unaltered rocks. This information can be used to assess

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the paleoclimate during the Earth's early evolution (Feakes and Retallack, 1988; Gay and Grandstaff, 1980; Holland, 1984; Schau and Henderson, 1983). In addition to the redox significance, erosion of weathering profiles and hydraulic sorting in fluvial systems can produce sands and muds, the compositions of which reflect the geochemistry and mineralogy of the source rocks (Nesbitt et al., 1996). The proportion of felsic or mafic contributions to siliciclastic sediments can be discriminated using provenance sensitive indicators, such as ratios of immobile elements, e.g. La or Th to Co, Sc, or Cr, size of Eu anomaly, combined with the distribution patterns of Rare Earth Elements (REE). Geochemical evidence thus has been broadly demonstrated to be useful for interpreting the provenance of siliciclastic sediments, and to unravel the mineralogical transformations that occurred during the weathering of the source rocks (Bhatia, 1983, 1984; Condie, 1993; Cullers, 1994, 2000; Dickinson et al., 1983; McLennan et al., 1993; Nesbitt et al., 1996; Roser and Korsch, 1988).

The Island of Bornholm in the Baltic Sea hosts the only basement exposures in Denmark. It links the exposed crustal provinces in southern Sweden and the Precambrian rocks buried beneath the sedimentary cover in the southern Baltic Sea, Lithuania, northeast Poland and northernmost Germany (Fig. 1A, B, Bogdanova et al., 2006, 2008). The granitoids on Bornholm were formed during a short time interval between 1.47 and 1.44 Ga (Waight et al., 2012; Zariņš and Johansson, 2009). Prior to deposition of the overlying Cambrian sandstone the basement rocks were extensively subaerially weathered (Gravesen et al., 2011). However, the paleo-weathering processes, especially for ancient weathering conditions during the Precambrian, are still poorly understood. The basement is overlain by a reddish fluviatile-aeolian

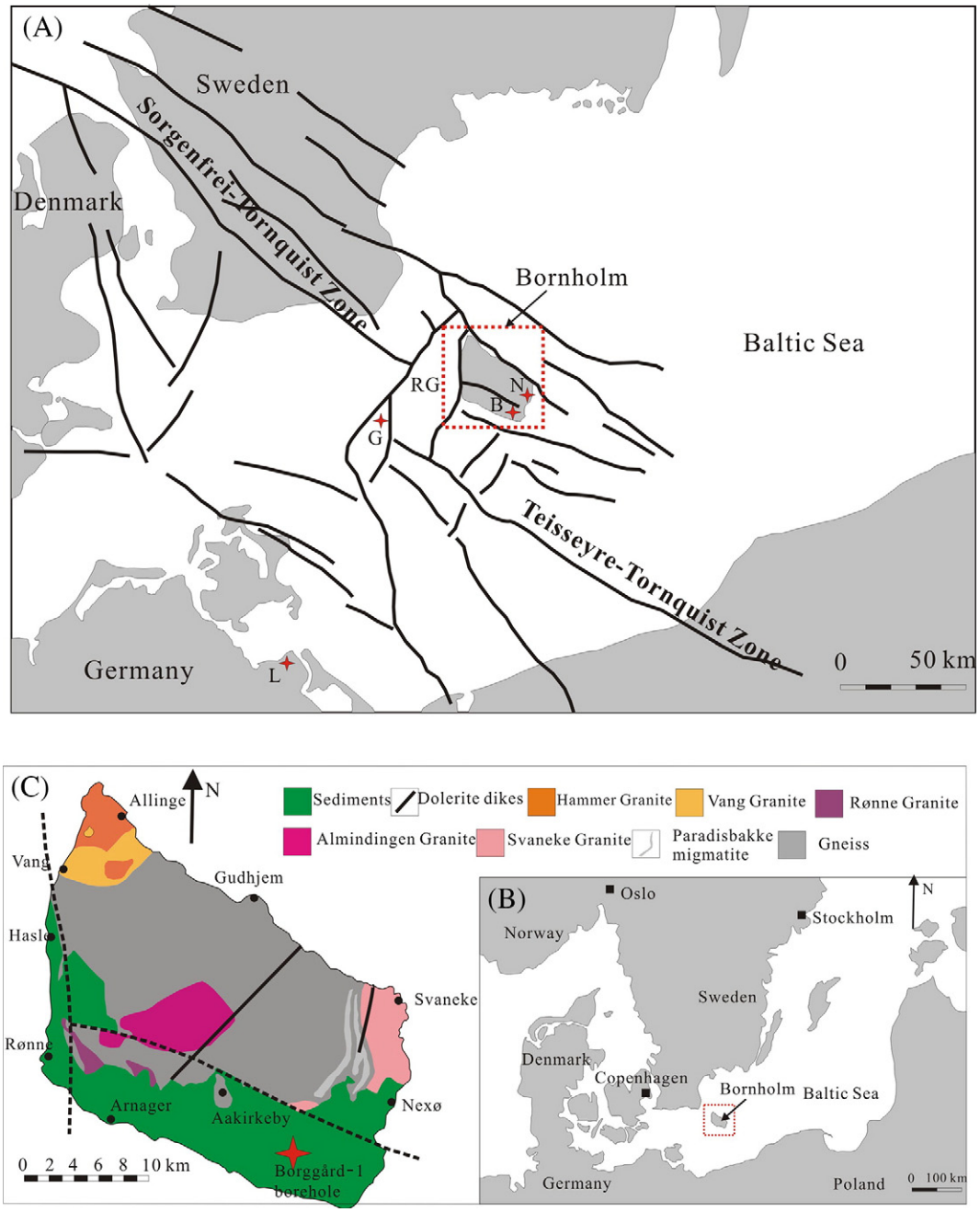

Fig. 1. Regional geology of Bornholm. (A) Location of Bornholm in the transition between the Sorgenfrei-Tornquist Zone and the Teisseyre-Tornquist Zone (Vejbæk et al., 1994). Abbreviations: RG-Rønne Graben; B-Borggård borehole; G-G14-1 borehole; L-Loissin1 borehole; N-Nye Frederiks quarry; (B) Location of Bornholm on East European Craton; (C) Local geology of Bornholm (Callisen, 1934; Waight et al., 2012).