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Structure and evolution of a rocksalt-mudrock-tectonite: The haselgebirge in the Northern Calcareous Alps

Christoph Leitner[a,*], Franz Neubauer[a], János L. Urai[b], Johannes Schoenherr[c]

[a] Fachbereich für Geographie und Geologie, Universität Salzburg, Hellbrunnerstraße 34, 5020 Salzburg, Austria
[b] Geologie-Endogene Dynamik, RWTH Aachen, Lochnerstraße 4-20, 52056 Aachen, Germany
[c] Exxon Mobil Upstream Research Company, Carbonate Reservoir Performance Prediction, 3319 Mercer Street, Houston, TX 77027, USA

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ABSTRACT

The Northern Calcareous Alps are part of the Eastern Alps in Austria and Germany. The Mesozoic units of this fold-and-thrust belt were detached, thrusted and stacked along the evaporitic Haselgebirge Formation. Exposed in salt mines, rocksalt and mudrock form a two component tectonite: The rock type “haselgebirge” consists of 10–70 wt % halite with silt- to gravel- or block-sized components within a halite matrix, and the “kerngebirge” with >70 wt % halite. All rock types studied are fault rocks. By use of a temperature-independent subgrain size piezometer, the paleo-differential stress of halite was calculated at ca. 2.5 MPa in Altaussee and ca. 4.5 MPa in Berchtesgaden. Including data from a grain-size piezometer, temperatures were estimated at ca. 150 ± 20 °C and 110 ± 10 °C. This implies very high strain rates, which are about 10^{-10}–10^{-9} s^{-1}. During the tectonic movement, the halite deformed, recrystallized, and crystallized as veins in mudrock fractures. We interpret high overpressure of the pore fluid to have significantly contributed to fracturing of the mudrock.

1. Introduction

Formations comprising rocksalt or other evaporites at the basis of thrusted cover units exist for instance, in the Appalachians (Davis and Engelder, 1985), Swiss Jura (Sommaruga, 1999), the Salt Range in Pakistan (Jadoon and Frisch, 1997) and in the Zagros Mountains (Alavi, 2007). The taper of salt thrust wedges may be very small ($\approx 1°$), providing shallow overthrusts (Davis and Engelder, 1985). The Northern Calcareous Alps (NCA, Fig. 1a) form a fold-and-thrust belt within the Austroalpine unit of the Austrian Eastern Alps. The rheologically weak evaporitic series at the base acted as one of the major detachment levels of nappes in high structural levels within NCA (e.g. Linzer et al., 1995).

The Haselgebirge Formation (Buch, 1802) is an evaporitic succession, which was formed as a rift sequence close to the lithostratigraphic base of the NCA succession. Operating salt mines provide subsurface exposures, where the salt has been mined in central sectors of the Northern Calcareous Alps (Salzkammergut, Fig. 1a–b) for more than 3000 years (Stöllner, 2003; Klein, 2006; Grabner et al., 2007). Halite, mudrock and subordinate anhydrite and polyhalite form an evaporitic mélange (Schauberger, 1931, 1949, 1986). The foliation visible in underground mines was first interpreted as sedimentary (Schauberger, 1953), but structures pointing to ductile deformation and folds combined with brittle deformation of the mudrock suggested a tectonic origin of the layering (Mayerhofer, 1955; Spötl, 1989a). The average halite content ranges between ca. 30–65 vol % (Schauberger, 1986). This rock type is called “haselgebirge” (nomenclature after Schauberger, 1986).

The central sectors of the Northern Calcareous Alps underwent strong diagenetic modifications to low-grade metamorphic conditions during the Late Jurassic to early Late Cretaceous. Maximum temperatures at around 200–300 °C were estimated (Kralik et al., 1987; Spötl, 1992; Götzinger and Grum, 1992; Gawlick et al., 1994; Wiesheu and Grundmann, 1994; Spötl et al., 1996, 1998a, 1998b; Wiesheu, 1997; Spötl and Hasenhüttl, 1998; Rantitsch and Russegger, 2005). Maximum temperatures increase towards the south, while cooling ages get younger towards the southern margin. Age estimates for this thermal peak range between 150 Ma and 90 Ma (Kirchner, 1980; Kralik et al., 1987; Hejl and Grundmann, 1989; Götzinger and Grum, 1992; Gawlick et al., 1994; Spötl et al., 1996, 1998a, 1998b; Gawlick and Höpfer, 1996; Rantitsch and Russegger, 2005; Frank and Schlager, 2006).

The aim of this study is to constrain the conditions and the mechanisms by which the haselgebirge developed. Underground

* Corresponding author. Tel.: +43 662 8044 5400; fax: +43 662 8044 621.
E-mail address: christoph.leitner@sbg.ac.at (C. Leitner).

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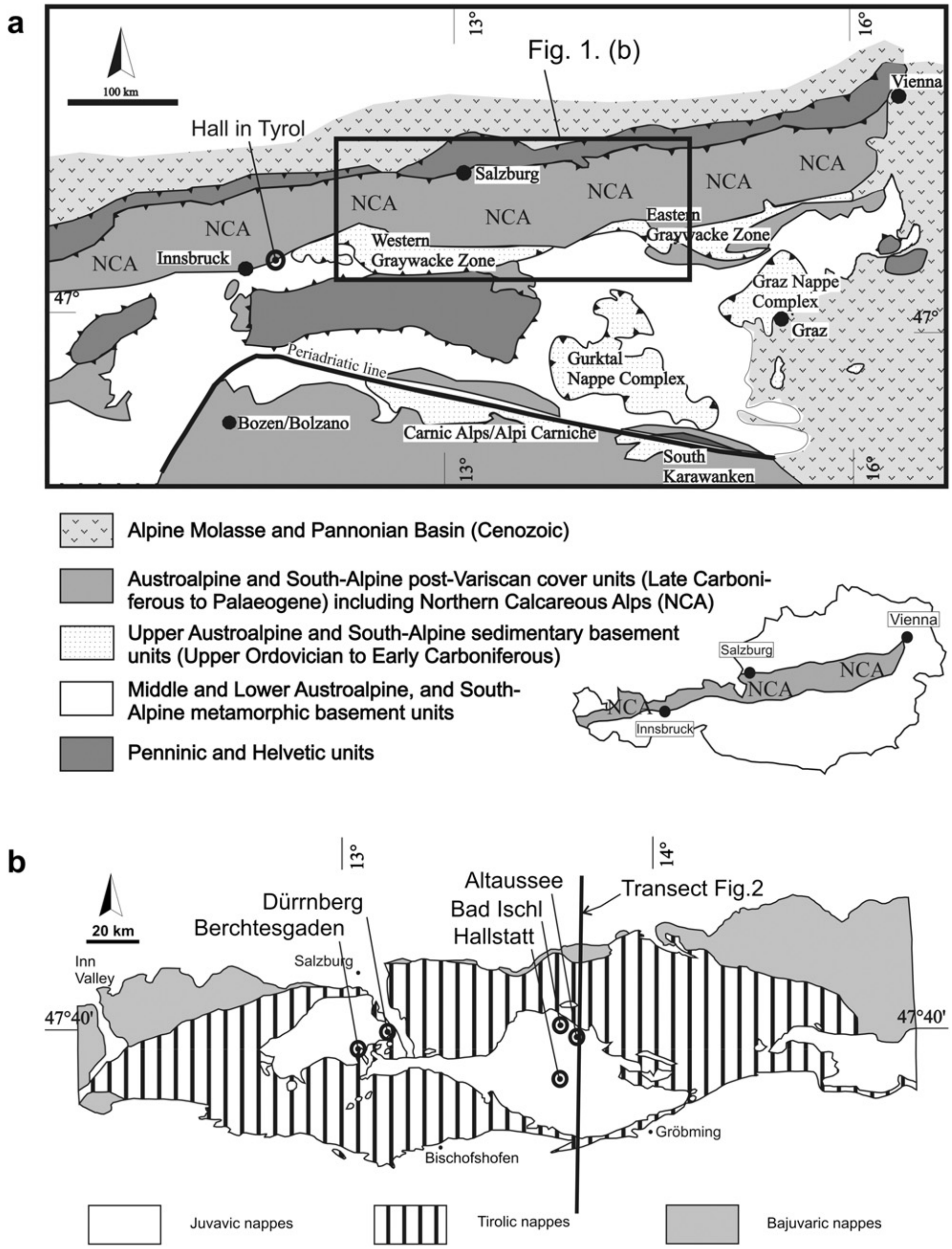

Fig. 1. (a) Overview of the Eastern Alps. Main tectonic units and location of the NCA. Insert at right bottom gives the position within Austria. (b) Fold-and-thrust belt of the central Northern Calcareous Alps, based on Oberhauser (1980). Circles mark rocksalt deposits.

observations were combined with thin section analysis, and paleostress and strain rate were calculated using experimental calibrations.

2. Mechanical behaviour of rocksalt and mudrock

In the following, “halite” is used as the name of the mineral, “rocksalt” refers to the monomineralic rock of halite with only minor xenolithic inclusions, “salt rock” refers to rocks with various halite contents and “salt” is an undifferentiated expression.

Piezometers relate subgrain and grain size and differential stress during deformation. The piezometer for halite (Carter et al., 1993; Schléder and Urai, 2005, 2007) relates differential stress to the steady-state subgrain size in halite:

$$D = 215\sigma^{-1.15} \quad (1)$$

where D is the average diameter of the subgrains and σ is the differential stress. It is almost temperature-independent. The new piezometer of Ter Heege et al. (2005) relates the actual grain size to differential stress and temperature. Armann (2008) observed the evolution of different grain sizes by recovery processes during deformation in simple shear experiments.

A creep law relates differential stress and strain rate. For rocksalt, deformation by dislocation creep the strain rate $\dot{\varepsilon}$ can be related to the flow stress ($\Delta\sigma$) using a power law creep equation:

$$\dot{\varepsilon} = A\exp(-Q/RT)\Delta\sigma^n \quad (2)$$

where the pre-exponential constant A has the dimensions M Pa^{-n} s^{-1}, Q is the apparent activation energy for creep in J mol^{-1}, R is the gas constant in J mol^{-1} K^{-1}, T is the temperature in °K, $\Delta\sigma = \sigma_1 - \sigma_3$ is the differential stress in MPa and n is the dimensionless stress exponent. Extrapolation is only valid, if the deformation