Source Rock Evaluation of Triassic Black Shales from Austria

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The lower Carnian (Late Triassic) black shale intervals in the Northern Calcareous Alps (NCA) in Austria are organic rich deposits that were deposited in a marine environment on the north-western Tethys shelf. They represent potential petroleum source rocks.

At the time of deposition, the area was characterized by the demise of carbonate platforms and reefs, accompanied by a biotic turnover and environmental changes (Simms and Ruffell, 1990). A lithological change from carbonates to siliciclastics is interpreted to be the result of increased continental runoff. Increased runoff, in turn, was caused by a phase of increased precipitation in the adjacent continental areas and is known as Carnian Pluvial Event (CPE).

Geological setting

The investigated area is located around Lunz am See approximately 100km west of Vienna (Fig.1). The studied sequence is cropping out at several locations in the region. The sections compose a lithostratigraphical succession from the Reifling Formation, the Göstling Member and the Reingraben Formation (Fig.2). Initially, the carbonate platform fed the basin in which the limestones were deposited. With the onset of the CPE the sea-level dropped (Hornung et al., 2007). The platform demise started when periplatform–mud with reefal influence deposited in a deep and low–energy setting (Göstling Member) (Hornung and Brandner, 2005). The increase in fresh water caused a nutrient excess and lead to oxygen depletion due to eutrophication (Hornung et al., 2007). Then decrease in the oxygen supply continued and indicated a dysaerobic setting. Subsequently, a massive river system running from the Fennoscandian Craton across most of Western Europe deposited large volumes of siliciclastic sediments into the shallow shelfs leading to a drowning of the carbonate platforms (Arche and López-Gómez, 2014). The high terrigenous influx and very low carbonate supply resulted in an almost restricted anoxic setting (Hornung and Brandner, 2005). This sedimentological change in the Western Tethys region of the NCA is regionally also known as the Reingraben Turnover (Schlager and Schöllnberger, 1974).

Methods

Palynofacies analysis on microscopic slides and Rock-Eval pyrolysis from crushed rock samples were performed on sedimentary organic matter extracted from these Carnian black shales covering the CPE. In addition, the data were integrated with bulk C-isotope data from organic matter and organic carbon data (TOC). The results are used for the reconstruction of the palaeoenvironmental conditions during the black shale formation and source rock potential.

Palynofacies slide preparation was done according to standard procedures at the University of Oslo, bulk $\delta^{13}C_{org}$ and TOC analysis was performed with an Elemental Analyzer–Isotope Ratio Mass Spectrometer (EA–IRMS), by Iso Analytical Ltd (UK). The Rock-Eval analysis was carried out at Deltares (The Netherlands). For palynofacies analysis approximately 300 particles per slide were counted with Nikon Optiphot (transmitted light) and a Leitz Diaplan (fluorescence light) microscopes with magnifications of ×20, ×40 and ×65 (oil immersion).

The paleoenvironmental interpretation is based on palynofacies kerogen classification and the AOM-phytoclast-palynomorph (APP) ternary diagram (Tyson 1993, 1995). The source rock potential is based on quality, quantity and thermal maturity of the organic matter.

Results and discussion

The interpretation of the results shows that the sediments were deposited in an epeiric neritic shelf of dysoxic-anoxic redox conditions with small intervals of suboxic-oxic and high algae and bacteria productivity (Fig. 3). The high productivity was caused by the humid climate during the CPE. Rivers from the Fennoscandinavian hinterland transported nutrients into the depositional setting and created stagnating conditions in the shelf basin which resulted in eutrophication due to flourishing algae and bacteria. The high content of amorphous organic matter (AOM), up to 15% in the claystones of Göstling Member, is of algal-bacterial origin and is a result of the high concentration of organic matter. Furthermore, a negative bulk carbon isotope excursion coincides with the change in organic matter (Fig. 4). This excursion is thought to be related to the release of isotopically lighter carbon as a result of a volcanic eruption which had a global impact on the carbon cycle (e.g. Dal Corso et al., 2012).

Rock-Eval pyrolysis results are combined with palynofacies data for evaluating the source rock potential of these black shales (Fig. 4). The majority of the studied rocks have TOC values of less than 2% and are interpreted to be barren or contain only gas prone hydrocarbons. Only few source rocks contain sufficient TOC to be economically relevant with TOC values of more than 2%; they are mainly gas prone. In addition, the rocks are immature with T_{max} values lower than 435°C and a production index of less than 0.1. Very few source rocks have reached an early/peak maturity stage. The clay intercalations of the Reifling Formation are considered as kerogen type IV (inert), while the palynofacies suggests kerogen type III (gas-prone). This discrepancy is due the high abundance of wood particles that show a weak fluorescence and indicates oxidized particles; these opaque particles are inertinite. The Göstling Member contains mudstone intervals that are characterized by kerogen type III but the palynofacies show kerogen type II (oil-gas-prone) due to high concentrations of AOM and more marine algae. The TOC values reach up to 15% in the lower part of the Member indicating excellent to good hydrocarbon potential. However, the Hydrogen Index (HI) is low. This misleading is explained by the high degree of weathering of the outcrops where the samples were taken. Additionally, the limited thickness of the source rock intervals prevented generating economic volumes of hydrocarbons. Lastly, the organic rich Reingraben Formation is mainly of kerogen type III whereas palynofacies show kerogen type II. The weathered outcrop samples influence the HI to lower values. Nevertheless, the TOC is lower than 2%, this verifies that these shale intervals could potentially have generated only small gaseous amounts of hydrocarbons. The upward part of the Reingraben Formation is characterized by poor source rock quality and is a type IV kerogen. These samples contain mainly translucent phytoclasts which are weakly fluorescent and indicate that they are oxidized particles (pre-form of opaque phytoclasts).

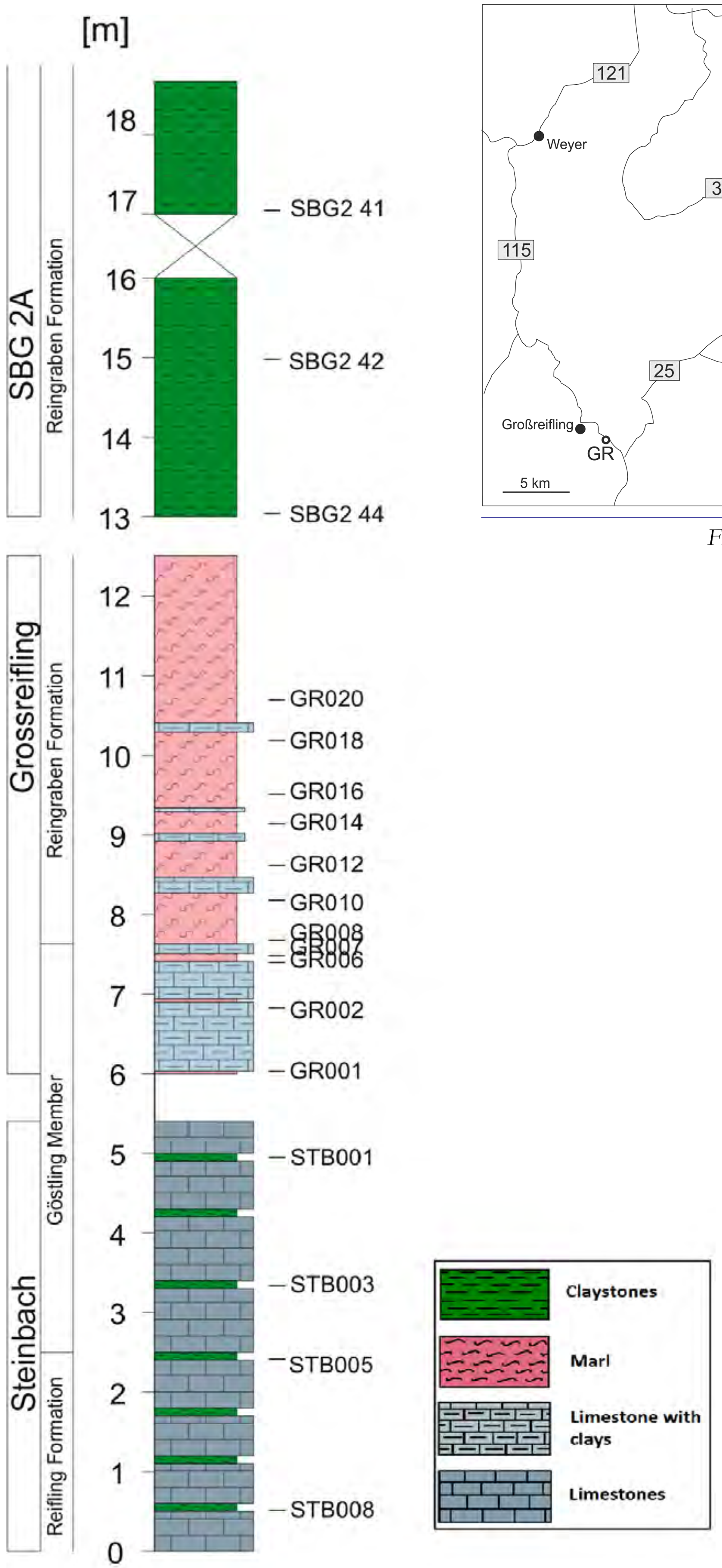

Fig.2: The lithostratigraphy and samples of the studied succession (Panou, 2015)

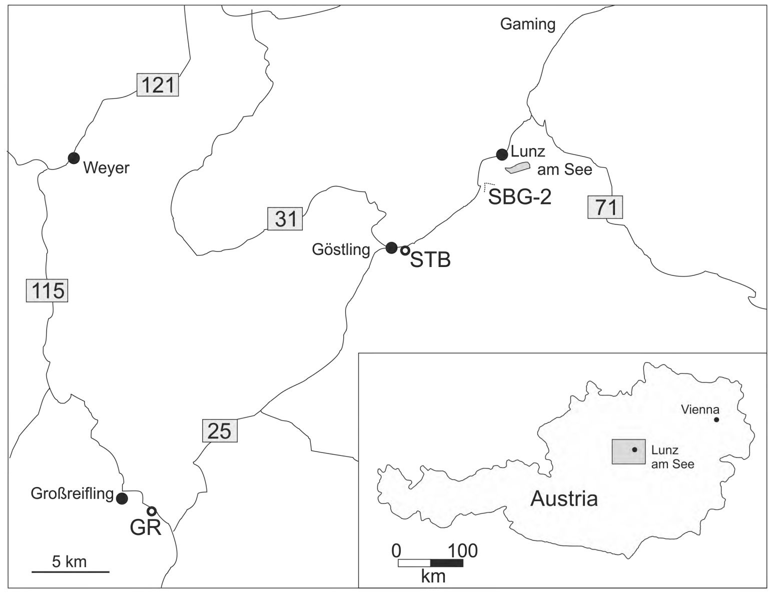

Fig. 1: Map of outcrop localities (from Panou, 2015)

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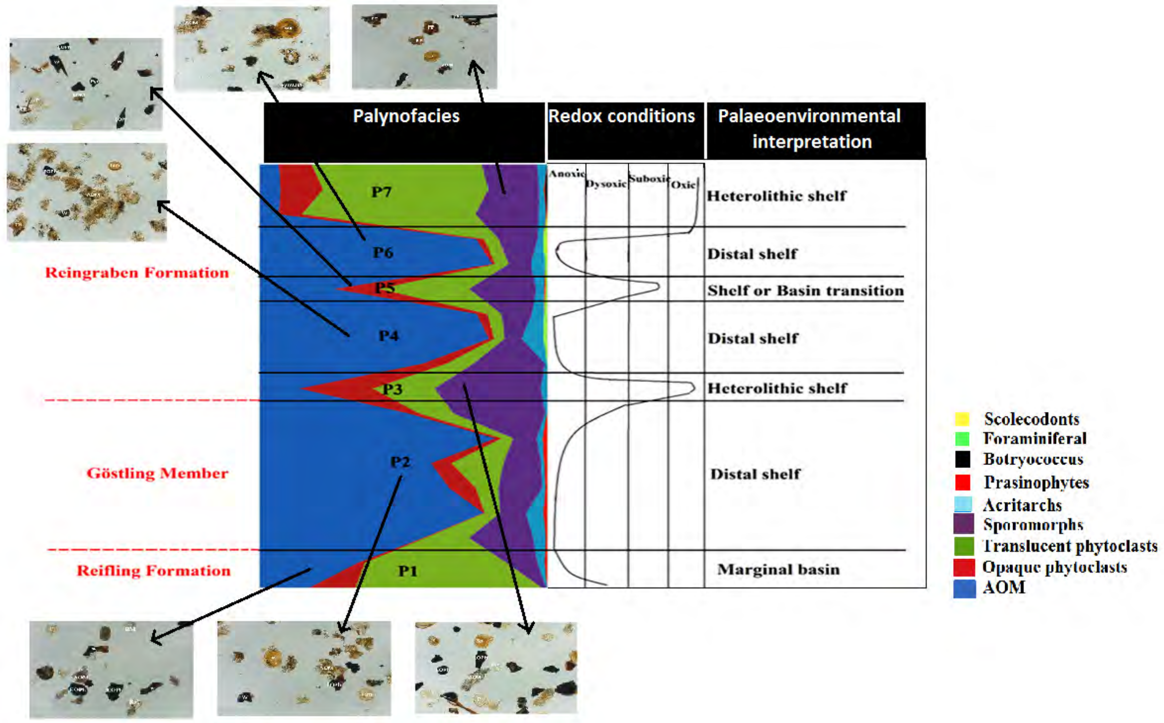

Fig.3: Palynofacies, redox conditions and palaeoenvironmental interpretation throughout the succession. The images are representatives of each palynofacies (Panou, 2015)

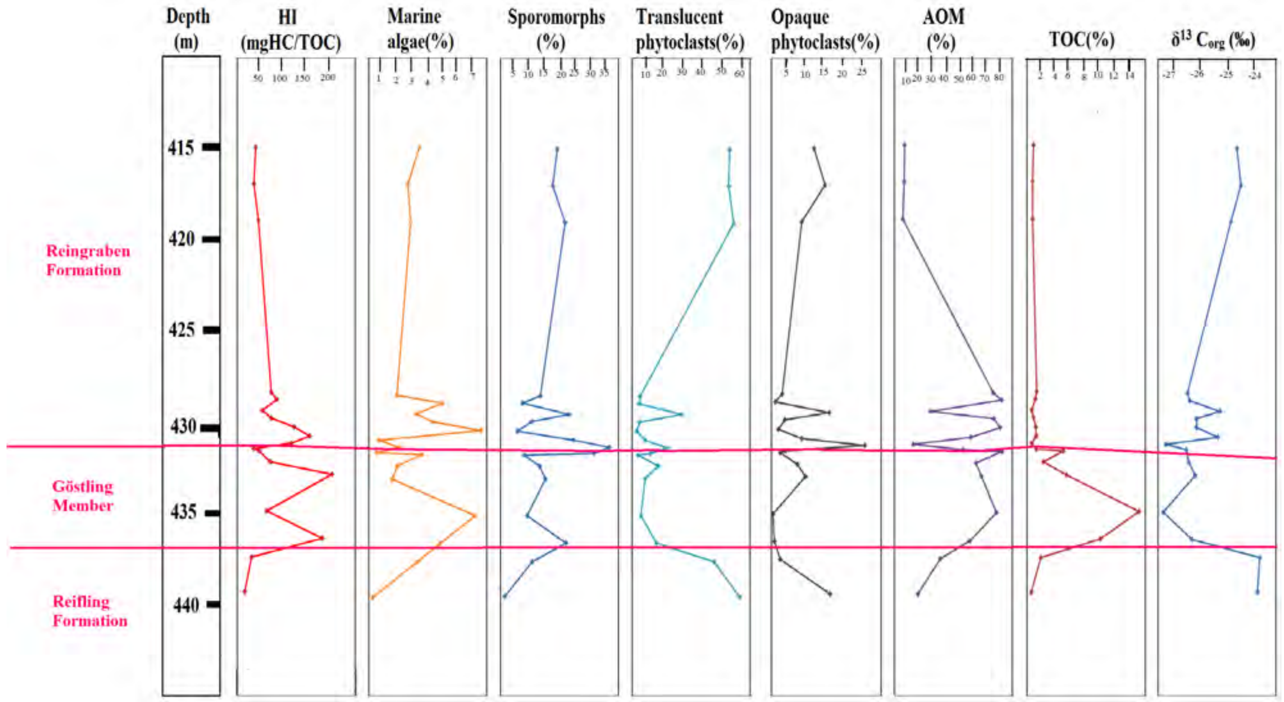

Fig. 4: The main palynofacies categories compared to HI, TOC and $\delta^{13}C_{org}$ (Panou, 2015)

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P-wave AVO in tilted transversely isotropic media

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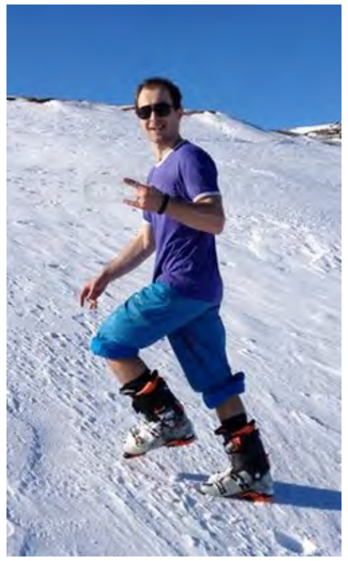

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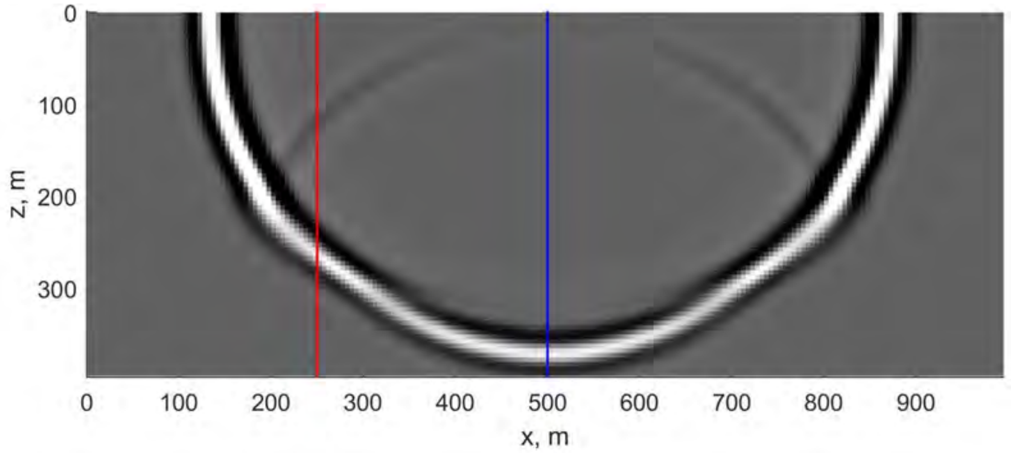
The importance of accounting for seismic anisotropy in seismic exploration and reservoir exploitation has become an accepted fact somewhat two decades ago. Nowadays, modern processing work flow would include seismic anisotropy and very often seismic acquisition is planned in such a way that seismic anisotropy can be estimated.

Anisotropy is the dependence of a physical property (in seismic case, we are talking about seismic wave propagation velocity v) upon the direction of measurement. Mathematically it can be formulated in the following way:

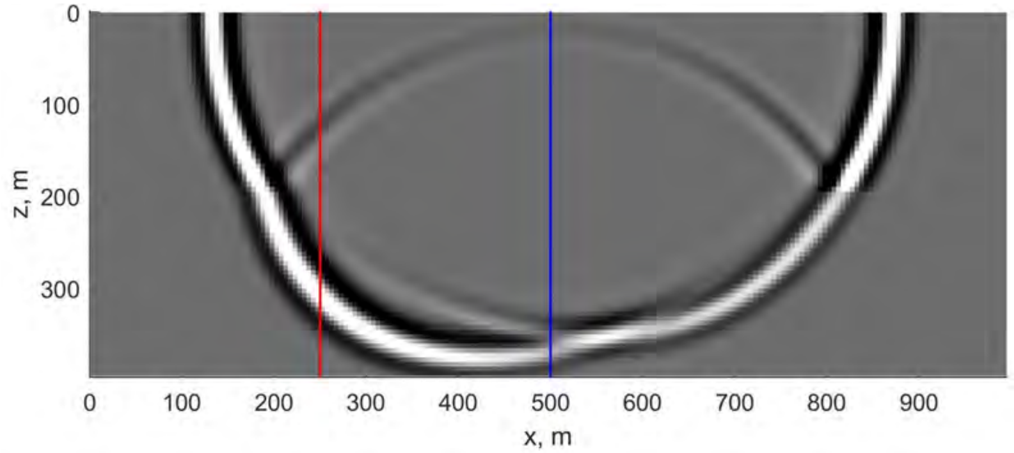
$$v \equiv v(\vec{x}, \vec{n}),$$

velocity v is measured at the point $\vec{x}$ in space along the direction $\vec{n}$. As a result, anisotropy affects both kinematic and dynamic properties of the wavefield, and if we are to obtain a reliable subsurface image, it cannot be ignored. Anisotropy in subsurface is very often associated with intrinsic properties of rocks, fine layering, or sets of fractures (which can occur due to e.g. special stress regime). Understanding of the seismic anisotropy can be useful in exploration and reservoir characterization since it can provide additional important information. For example, shale reservoirs are very often discovered based on the effect of seismic anisotropy. There is number of different mathematical models to describe seismic anisotropy. The simplest and the most commonly used one is vertical transverse isotropy or VTI model. Finely (compared to the wavelength) layered medium will exhibit VTI properties, affecting seismic wave propagation through it.

Amplitude variation with offset techniques are widely used nowadays, because reflection amplitudes are highly resolved in depth/time, unlike traveltime methods, providing a detailed measure of local properties of the subsurface. It has been also noticed that effect of seismic anisotropy on reflected and transmitted amplitudes is strong even when the magnitude of anisotropy is small (Ruger, 1998) and, hence, can be estimated using AVO analysis. Understanding the behavior of P-wave reflection coefficient in presence of anisotropy



(a) VTI layer



(b) TTI layer

Figure 1: Wavefront distortion due to presence of TTI anisotropy