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Source rock investigations and organic geochemistry of a Cretaceous succession of the Outer Dinarides (Mokra Gora, Tara Mountain, SW Serbia)

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A Cretaceous (Albian to Turonian) succession containing organic-rich sediments is exposed in the area of Mokra Gora and Tara Mountain (SW Serbia). Four sections representing different positions of the basin were investigated regarding source rock potential and organic geochemical characteristics. The Cretaceous geodynamic history and the depositional settings of organic-rich sediments in the Alpine-Dinaric realm is still not completely understood and controversially discussed. After an orogenetic process with decreasing tectonic activity during the Late Jurassic to Early Cretaceous a new depositional cycle started around the Early/Late Cretaceous boundary. In the Outer Dinarides of SW Serbia a Cretaceous sedimentary succession on top of the former nappe stack is preserved. The investigated succession is characterized by a basal transgressive part (Albian) followed by a series of alternating layers of siliceous to marly limestones and thin bedded black marls rich in organics (Cenomanian). This series represents a deepening upward. The black marls contain pithonellas, rarely heterohelicides, hedbergellas, ammonites, echinoderms and molluscs. On top of the investigated succession light limestones with rudists, shell fragments and gastropods represent a shallow water development of Upper Cenomanian to Turonian age.

The stratigraphic age of the organic-rich interval is proven as Cenomanian by means of *Aeolisacus inconstans, Ovalveolina maccagnae, Rhapidionina laurinensis* and *Cisalveolina fraasi.*

All samples were investigated by means of Leco- and Rock Eval analyses regarding their source rock characteristics. For selected samples organic-geochemical analyses were performed to determine the origin and composition of the organic matter.

The black marl development in the investigated area can be divided into two parts due to the gained results. The samples of the stratigraphic lower part reach peak values of more than 18 % total organic carbon (TOC) and hydrogen indices (HI) of greater than 700 mg HC/g TOC. Based on a modified van-Krevelen-diagram the kerogen of the samples can be classified as type I and II. Lamalginite is by far the most abundant maceral in these samples and indicates algae to be the primary source of the organic matter. In the stratigraphic higher part values for TOC and HI are below 2.5 % and 400 mg HC/g TOC, respectively. The samples plot in the field of type II and III kerogen. The frequent abundance of vitrinite also indicates a stronger terrestrial influx for these samples. Tmax-values between 400 and 426 °C indicate low maturity of 0.3 to 0.5 % Ro for all investigated samples of the succession. This is confirmed by organic geochemical results (sterane-ratio, MPI). Results of organic geochemistry analyses further argue for open marine to transitional depositional environments with anoxic to partly euxinic conditions poor in oxygen. The organic matter is mainly of marine origin, terrestrial input is more important for the upper units of the succession. This argues for differing water depths. The presence of arylisoprenoids is an indicator for photic zone anoxia. Cadalene, which is typical for terrestrial input, could be detected in the higher parts of the succession displaying the transition to more shallow water environments.

Due to these results the investigated black sediments can be seen as excellent potential source rocks featuring high potential to generate hydrocarbons in the nappe stack of the Dinarides.

In-sequence and out-of-sequence thrusts: nappe structure of the western Northern Calcareous Alps revisited

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In fold-and-thrust belts, syntectonic sediments provide a means to date deformation. The youngest sediments below a thrust sheet give the maximum age of thrusting, and growth strata record growth of individual structures. Applying this concept shows that the Northern Calcareous Alps (NCA) thrust sheets were emplaced from the Barremian onwards. Thrust activity propagated from the SE to the NW and reached the South Penninic units in the Turonian or Coniacian. Shortening did not cease after thrust sheet emplacement, while the NCA were carried piggy-back over Penninic units. Growth strata in the various Cretaceous syntectonic clastics (Branderfleck Fm., Gosau Group) document significant contraction after thrust sheet emplacement well into the Maastrichtian.

As defined by previous authors, the major thrust sheets of the western NCA are from base to top: The Allgäu thrust sheet, the Lechtal thrust sheet and the Inntal thrust sheet. The first two are part of the Bajuvaric nappe complex, whereas the last belongs to the Tirolic nappe complex. This model of the NCA thrust sheets assumes far-travelled nappes that are entirely separated and have a continuous thrust at their base. If the NCA thrust sheets would adhere to such a simple model the thrusts should display ramp-flat geometry and form a hinterland dipping duplex, which they do not.

Using the information from syntectonic sediments following problems with the traditional nappe subdivision emerge:

(1) The Inntal thrust sheet was emplaced out-of-sequence after thrusting of the Lechtal thrust sheet in its footwall. In the Karwendel mountains, it is connected to the Lechtal thrust sheet in a north-facing anticline dissected by out-of-sequence thrusts. These were originally interpreted to be the base of the Inntal thrust sheet.
(2) The Albian Lechtal thrust ends in a tight anticline in the Arlberg area and is replaced by the Coniacian to Santonian Mohnenfluh thrust.
(3) The Tirolic basal thrust has an Eocene age, where it was drilled (well Vordersee1 east of Salzburg); At the surface, the sinistral Inntal shear zone separates the Bajuvaric Lechtal thrust sheet from the Tirolic nappe complex, and not a flat-lying thrust.

In fact the western NCA are one single tectonic unit. All thrusts end laterally. However, individual thrusts do have offsets in the range reported previously, but thrusts loose offset laterally. In many cases, thrusts do display to out-of-sequence geometries: The Inntal out-of-sequence thrust truncates folds in its footwall and hanging wall, as it should. However, also the Lechtal thrust dissects pre-existing anticlines and synclines. We speculate that only a model of thrust propagation involving significant footwall deformation can describe these thrusts correctly.