[PS]Organic Geochemical and Petrographical Characterization of Continental Triassic Source Rocks, Madygen Basin, Southern Tien Shan, Kyrgyzstan*

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Abstract

Along the northern foothills of the Turkestan-Alai Range (SW Kyrgyzstan) outcrops of a 1000 to 1500 m thick succession of Mesozoic sediments document regional changes of the paleo-landscape from small upland basins during Triassic times to near-shore marine environments of the Cretaceous. Due to the paleo-geographic position of Central Asia during the Early Mesozoic the investigated area has to be considered as a point of intersection of the North American-European, Siberian, and SE Asian faunal and floral provinces. As an all-time tectonically active region, tectonic movements have changed the sedimentary properties through subsidence and uplift and have likely led to thermal alteration of the sedimentary organic matter.

Organic petrographical and organic geochemical methods (the latter including RockEval, biomarker and stable isotope analyses) were applied to a suite of terrestrial sedimentary rocks from the Triassic Madygen Basin with the intention to identify the depositional environment. Special attention was paid to the assessment of the hydrocarbon potential and source rock maturity and to the identification of secondary alteration processes of the sedimentary organic matter.

Microscopic analyses indicate that the sedimentary organic matter is dominated by land plant material (inertodetrinite, detrovitrinite, vitrinite, cutinite, sporinite), but also contains smaller amounts of aquatic material (alginite) which suggests a deposition in swamp-like and/or lacustrine environments. Vitrinite reflectance data show that the sediments have undergone thermal alteration processes, which, however, are limited to a narrow maturation spectrum from immature to the early oil window.

Organic Geochemical and Petrographical Characterization of Continental Triassic Source Rocks (Madygen Basin, Southern Tien Shan, Kyrgyzstan)

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Introduction

Along the northern foothills of the Turkestan-Alai Range (SW Kyrgyzstan, Fig. 1) outcrops of a 1000 to 1500 m thick succession of Mesozoic sediments document regional changes of the paleo-landscape from small upland basins during Triassic times to near-shore marine environments of the Cretaceous. Due to the paleo-geographic position of Central Asia during the Early Mesozoic the investigated area has to be considered as a point of intersection of the North American-European, Siberian, and SE Asian faunal and floral provinces. As an all-time active region, tectonic movements have changed the sedimentary properties through subsidence and uplift and have likely led to a thermal alteration of the sedimentary organic matter.
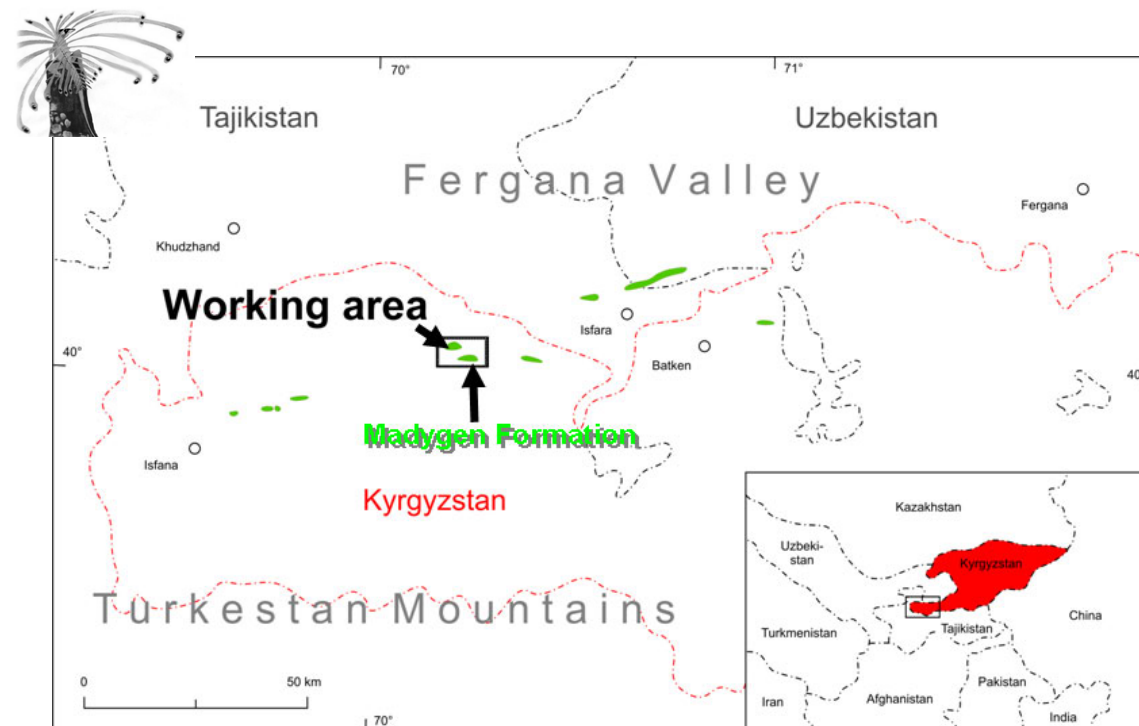

Fig. 1

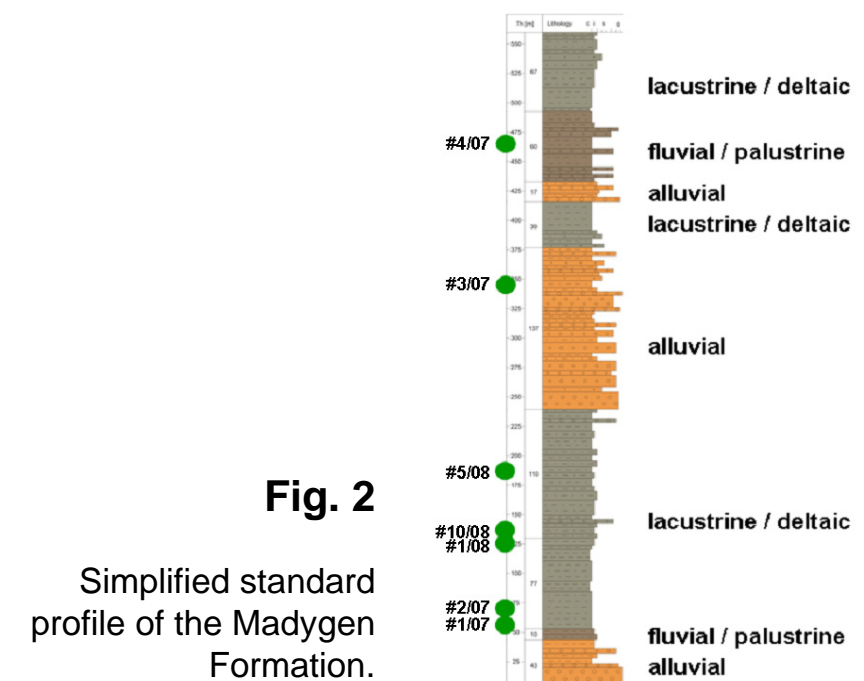**Working area on the southern margin of the Fergana Valley (Kyrgyzstan).**

Fig. 2

Simplified standard profile of the Madygen Formation.

Ongoing geological and palaeontological investigations of the TU Bergakademie Freiberg, which started in 2006, provided for the first time a nearly complete standard profile of the Triassic Madygen Formation of Kyrgyzstan (Fig. 2). Our recent investigations aim at supporting the description of the depositional environment via organic petrographical and organic geochemical methods. We also intended to identify secondary alteration processes, which might have affected the sedimentary organic matter and assess the hydrocarbon potential of the Madygen Formation.

Geological overview

The working area is the stratotype locality of the Madgyen Formation and one of only few known places with continental Triassic deposits in Central Asia. The Madygen Formation is represented by an up to 560 m thick succession of alluvio-fluvial to lacustrine deposits, which are disconformably interbedded between marine Palaeozoic and continental Jurassic strata. The strata focussed herein are most famous for its abundant fossil content including plants, molluscs, annelids, arthropods, fishes, and tetrapods (Voigt et al., 2006). Based on macrofloral remains the sediments have been assigned Middle to Late Triassic ages (Dobruskina 1995).

A recently performed analysis of the depositional palaeoenvironment suggests that the predominantly clastic sediments of the Madygen Formation accumulated in a densely vegetated, intermontane basin under humid to semihumid climatic conditions. Recurrent associations of characteristic sediments allow the differentiation of three major facies belts:

- laminated mudstones are interpreted as deposits of a permanent lake which probably occupied the more central parts of the basin.
- heavily rooted mudstones to siltstones with intercalated coal seams are referred to alluvial plain deposits from the surroundings of the lake.
- coarse-grained sandstones and conglomerates are typical deposits of alluvial fans fringing the basin lowland area.

Abrupt vertical changes of the major facies belts indicate severe synsedimentary tectonic activity. Common shallowing upward sequences and various other features like dense vegetation, wet soils, and the lack of desiccation cracks, typify the depositional environment of the Madygen Formation as an overfilled lake-basin sensu Bohacs et al. (2000).

Analytical methods

A total of 14 samples which are representative of the above described major facies types of the Madygen Formation have been subjected to organic petrographical and organic geochemical analyses. The samples have been crushed and ground for the subsequent investigations.

Organic petrographical preparations and analyses have been conducted according to German DIN 22020. Measurements were carried out on a Leica DMR microscope, which was coupled to a MPV-Compact-2 photometer (for a description of the methods also compare Stach et al., 1982).

We measured total sedimentary sulphur (TS) and total organic carbon (TOC) on a LECO CS-200 with standard methods (Peters et al., 2005). RockEval pyrolyses were carried out according standard procedures described by Behar et al. (2001) on a Delsi RockEval-6, and resulting parameters S1, S2, S3 and Tmax have been used to calculate hydrogen, oxygen and production indices.

The ratios of stable carbon isotopes of the sedimentary bulk organic matter have been analyzed according to the methods given in Brand (1998). We used a system of an elemental analyzer (Carlo Erba CHN1100) coupled to an isotope-ratio mass-spectrometer (Finnigan DeltaPlus). Carbon isotope ratios are reported as delta values with reference to the international standard PDB (Brand, 1998).

Depending on the amount of organic matter we extracted 10 to 30 g of selected samples (see below) with dichlorid methanol using a Dionex ASE-200. We removed elemental sulphur from the hydrocarbon extract by treatment with activated copper granular, and also separated the asphaltenes by a treatment with dichloride methanol and an addition of petroleum benzene. The residual fraction of maltenes and resins has been separated into aliphatic and aromatic fractions as well as into hetero-compounds by mid-pressure liquid chromatography using a BESTA-MPLC with different organic solvents. Gas chromatographic analyzes on the aliphatic fraction provided a typecast of the fraction and an estimation of biomarker concentrations using an Agilent 6890 GC-FID-system equipped with a 50 m UltraII column. Single biomarker compounds have been determined by a gas chromatographic separation of the aliphatic fraction and a subsequent mass spectrometric determination on a coupled system of an Agilent 6890 GC and a Finnigan MAT95S mass spectrometer (compare Wehner et al., 2008).

Organic-petrographical characterization

For the organic-petrographical investigations four organic-rich samples (#1/07 to #4/07) have been selcted which represent the major facies types of coals, pluvial and alluvial sediments. The deltaic facies has been omitted for these kind of analyses as only minor concentrations of organic matter were observed (compare organic geochemical investigations below).
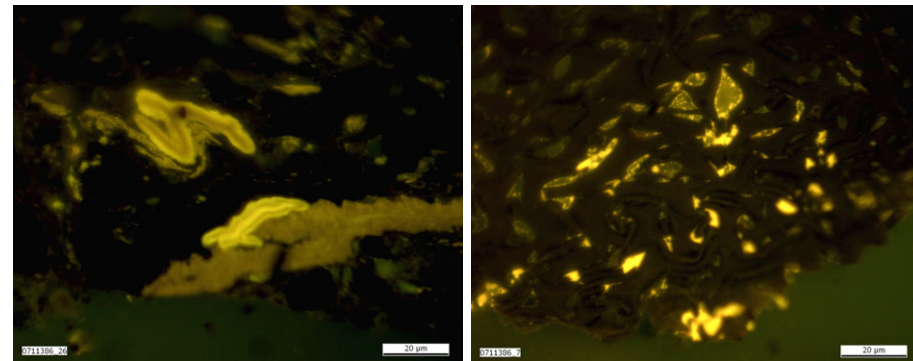

Fig. 3

Sample #1/07; left: yellow fluorescing spores; right : yellow fluorescing bitumen within densinite (fluorescing light).
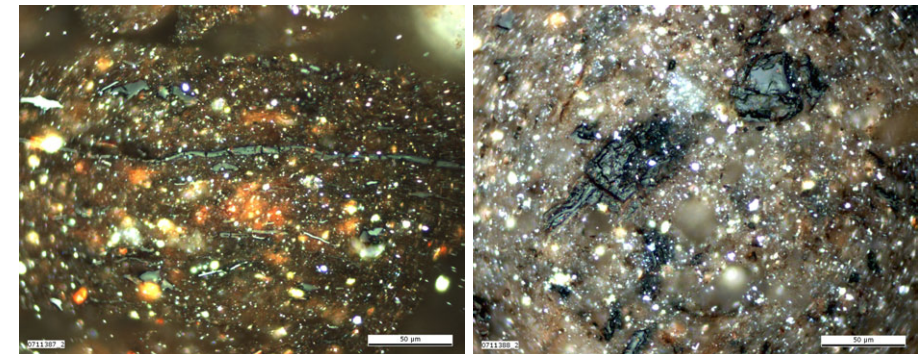
Fig. 4

Left: sample #2/07; huminitic band within mineral matrix and disperse detrohuminitic particles; right: sample #3/07; detrovitrinites in mineral matrix (normal light).

Sample #1/07 is a huminitic subbituminous brown coal (0.45 %-Rr, vitrinite reflectance; Mattbraunkohle) partly rich in mineral matter. The mineral inclusions contain numerous inertodetrinites and oxyinertinites. Within the vitrinitic layers of the coal cell-filling mikrinites as well as numerous well preserved suberinites and resinitic structures are visitble. We also observed tectonically overprinted coal particles with sheer structures and microfractures. Liptinitic macerales are represented through liptodetrinite, macro and micro spores, pollen, cutinite as well as fluorinite(?). The fluorescence of sporinites is dark yellow to dark orange. We also observed at a magnification of 1000x numerous intensively yellow fluorescing solid bitumines within the intraparticulare spaces of densinites. Furthermore, numerous exhudatinites exist within fissures and fractures. Their fluorescence is intensively yellow to drak yellow. We observe at numerous locations within the solid bitumens and exhudatinites an early formation of petroleum.

Sediment samples #2/07 and #3/07 (Fig. 4) are organic-rich clay stones. The organic detritus is dominated by macerals of the huminite group with detrohuminite and lesser amounts of detroinertinite. Vitrinite reflectance is 0.26 %-Rr with #2/07 and 0.66 %-Rr with sample #3/07. We also observe well preserved huminite-rich layers in these sediments. Sample #2/07 contains redeposited clay stone particles with two detrovitrinite populations of 0.44 %-Rr and 0.61 %-Rr, respectively.
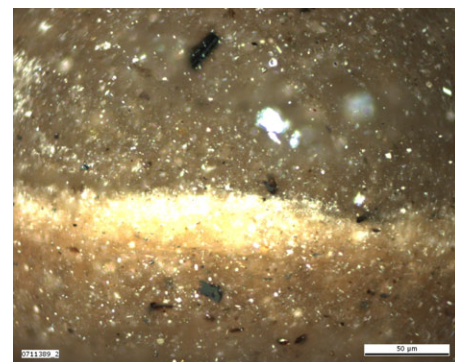

Fig. 5

Sample #4/07; vitrodetrinites in mineral matrix (normal light).

The micro photometric analyses show a coal as well as clay stones with predominately dispersly distributed terrigenous organic matter. The thermal maturities vary from imature (samples #1/07 and #2/07) to the lower maturity range of the so called oil window (#3/07 and #4/07). The samples have not been collected from a continuous profile at one location but come from different members of the Madygen Formation at different sites. Therefore, the measured maturities do not resemble a continuous trend at one location but are related to the tectonic and thermal history of each sampling site.

Organic-geochemical characterization

Organic-geochemical investigations have been performed on all fourteen samples (#1/07 to #10/08) using elemental analyses, RockEval pyrolyses and stable carbon isotope measurements. The amounts of extractable hydrocarbon have only been determined on sediments which contain more 0.3 % total organic carbon. Table 2 summarizes the results of our investigations.

The amounts of total sedimentary sulfur and total organic carbon (Fig. 6) suggest that the sediments have been deposited under pluvial or lacustrine conditions (Berner & Raiswell, 1983), and support the geological interpretation on the sedimentary environment.
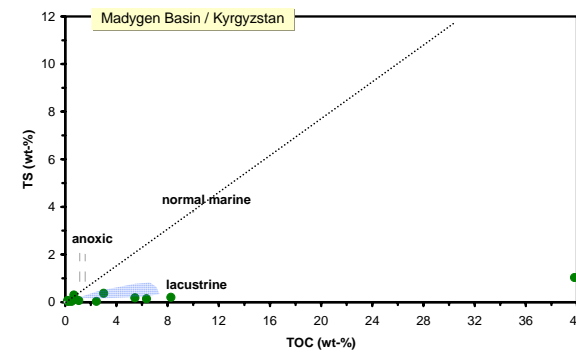
Fig. 6

Total sulfur (TS) and total organic carbon (TOC) in samples of the Madygen Formation (compare Berner & Raiswell, 1983).

Fig. 7

Oxygen and hydrogen indiices of samples of the Madygen Formation (after Espitalié et al., 1977; Lafargue et al., 1998).
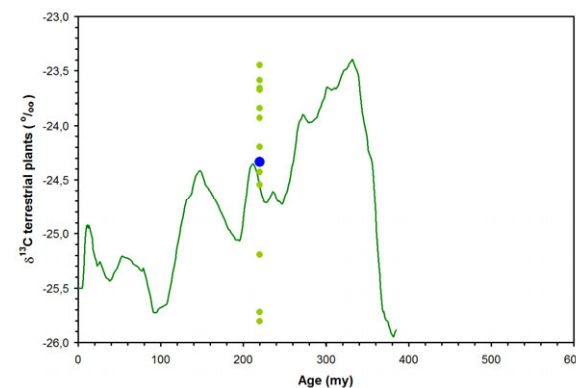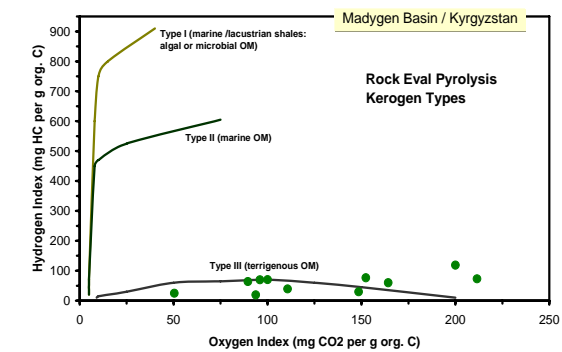

Fig. 8
Stable carbon isotope values of samples of the Madygen Formation (blue dot average of Madygen samples) compared to the Phanerozoic isotope variability of terrestrial plants (BGR database, 2009).

Oxygen and hydrogen indices derived from RockEval pyrolyses (Fig. 7) also indicate a terrestrial origin of the sedimentary organic matter (Espitalié et al., 1977; Lafargue et al., 1998). Although carbon isotope values of the sedimentary organic matter vary over a range of 2.5 ‰ (Fig. 8) the average data value is compatible to the data of average Triassic carbon isotope ratios of terrestrial plants (BGR, database 2009).

The hydrocarbon potential of samples of the Madygen Formation ranges from poor to excellent (Fig. 9). The sediments containing more than 0.5 % TOC may be regarded as sources of gaseous hydrocarbons rather than of oil.

Aliquots of the four samples that have been selected for organic petrographic inspection (see above) have been subjected to stable isotope investigations of aliphatic and aromatic extract fractions and biomarkers analyses. These investigations suggest that the sediments where deposited in swamps, palustrine or lacustrine environments.

The dominance of terrestrial sedimentary organic matter is also supported by the distribution of n-alkanes of the aliphatic hydrocarbon fraction as odd-numbered rather than even-numbered n-alkanes predominate in comparison with carbon isotope ratios of bulk organic matter (Fig. 10).
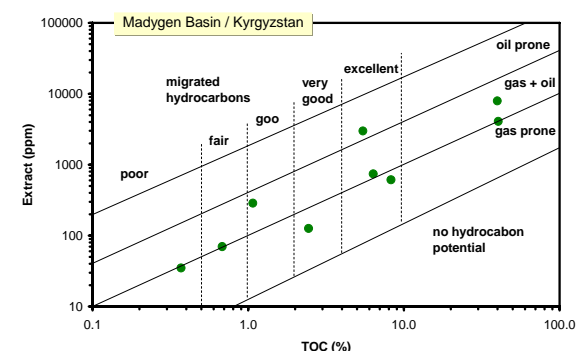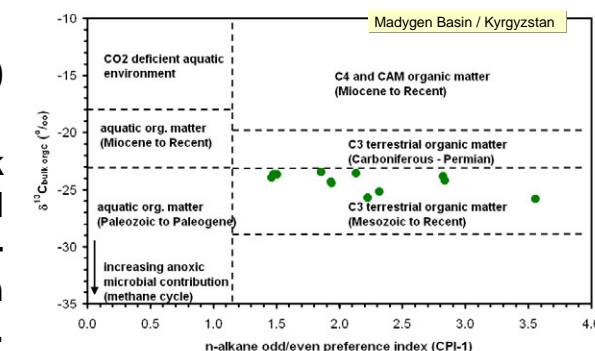

Fig. 9

Total organic carbon (TOC) and amounts of extractable hydrocarbons (ppm related to sediment weight) of samples of the Madygen Formation.

Fig. 10

Carbon isotope ratios of bulk organic matter and calculated odd/even predominance (CPI-1) of samples of the Madygen Formation.

Phytane and pristane in comparison with the n-alkanes n-C17 and n-C18 (Peters et al., 2005) indicate a dominance of terrestrial organic matter for most of the samples (coals and lacustrine-deltaic facies; Fig. 11) and as well as aquatic input for samples of palustrine and alluvial environments.

Concentrations of C27- to C29-steranes also indicate a terrestrial source of the organic matter of the coal sample #1/07 (Fig. 12). According to the sterane based classification samples #2/07 to #4/07 appear to be mixtures between aquatic and terrestrial organic sources (Peters et al., 2005).
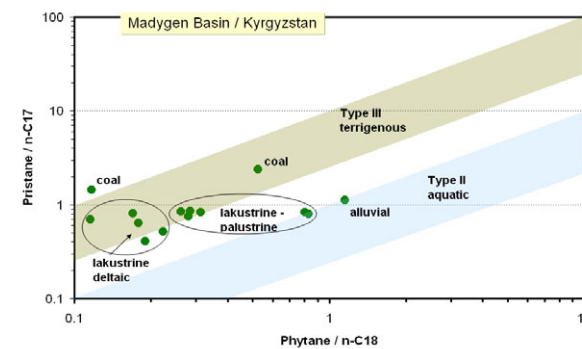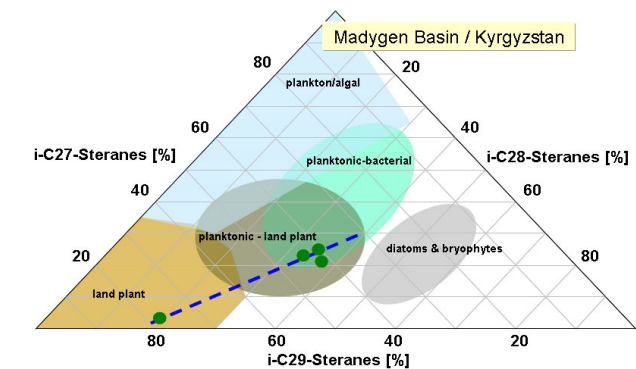

Fig. 11

Ratios of phytane over n-C18 and pristane over n-C17 of samples of the Madygen Formation (classification after Peters et al., 2005).

Fig. 12

Distribution of sterane biomarkers of samples of the Madygen Formation (classification modified after Peters et al. (2005))

Molecular maturity parameters (Fig. 13) such as the ratios of trisnorneohopane over trisnorhopane and C32-hopane ratios of 22S- over 22R-isomers (Peters et al., 2005) indicate that the hydrocarbons have been generated from a narrow maturity range, which corresponds to the initial stages of hydrocarbon generation and compares well with the organic petrographic observations (Fig. 14). Tmax derived from RockEval suggest higher thermal maturities (Fig. 15) for most of the samples and a comparison between HI and vitrinite reflectance values suggest that samples with low HI may contain Type IV organic matter (Fig. 16). Degradation of the sedimentary organic matter under present day arid climate conditions (Fig. 17) cannot be excluded and might have biased Tmax values.
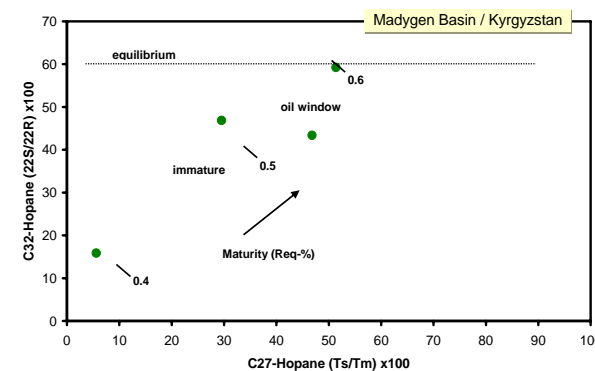
Fig. 13

Ratios of hopane biomarkers of samples of the Madygen Formation indicate varying maturities (compare Peters et al., 2005)

Fig. 14

Average thermal maturities calculated from different biomarker ratios and direct microphotometric data of samples of the Madygen Formation.
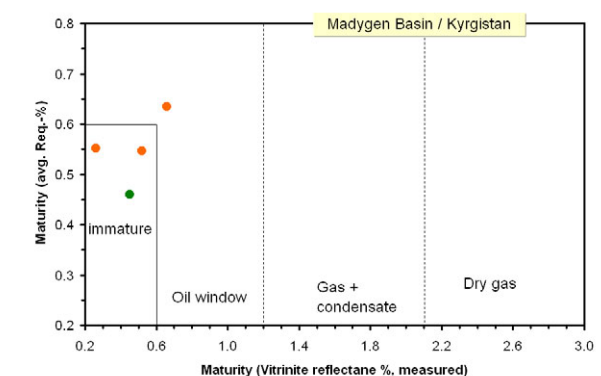
Fig. 15
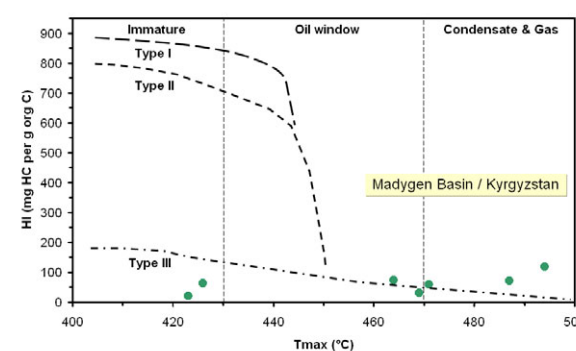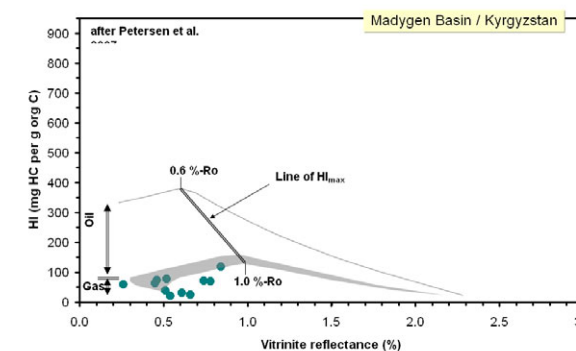
Tmax and HI values of samples from the Madygen Formation.

Fig. 16

Hydrogen indices from RockEval pyrolyses and random vitrinite reflectance values of sediments of the Madygen Formation.

Fig. 17

Present day arid climate conditions affect the Triassic sediments of the Madygen.

Conclusions

Microscopic analyses indicate that the sedimentary organic matter is dominated by land plant material, but also contains aquatic material, which suggests a deposition in swamp-like and/or lacustrine environments. The presence of inertodetrinite and oxyinertinite among the terrestrially derived material indicates a subaquatic deposition within a limno-telematic environment and/or a fluctuating water table and aerobic decay.

Vitrinite reflectance data show that the sediments have undergone thermal alteration processes, which, however, are limited to a narrow maturation spectrum from immature to the early oil window. We observe direct evidence of hydrocarbon generation processes in one sample where solid bitumen (wurtzilite), exhudatinite and oil droplets are present.

The inspection of organic geochemical parameters supports the microscopic analyses and hydrocarbon extracts indicate mixtures related to varying contributions of higher land plants and aquatic organic matter. Biomarker investigations suggest that the sediments where deposited in swamp like and/or lacustrine environments. Molecular maturity parameters indicate that the hydrocarbons have been generated from a narrow maturity range, which corresponds to the initial stages of hydrocarbon generation and compares well with the organic petrographic observations.

Our investigations suggest that the potential source rocks of the terrestrial Madygen Formation (lake shore facies) might generate predominantly gaseous hydrocarbons at higher maturities.

Acknowledgements

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