

PS Influence of Sill Intrusions on the Organic Geochemistry of Upper Triassic Lacustrine and Fluvial Sediments at Timber Peak, Antarctica*

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Abstract

The Timber Peak of North Victoria Land, Antarctica, exposes, embedded between two 150 m thick Early Jurassic mafic sills, 80 m of Late Triassic sediments of the Beacon Supergroup. The sediments comprise fluvial channel sandstones interbedded with lacustrine and palustrine deposits containing Dicrodium-dominated floras. The sandstones show a thin fused margin at the contact to the sills.

During the German Antarctic North Victoria Land Expedition IX (2005/2006) an approximately 3.5 m thick section of carbonaceous mudstones and coals, 12 m above the lower sill, was sampled for organic geochemical and petrographical analyses in order to better describe the depositional environment and to investigate whether the sill intrusions are responsible for thermal alteration processes of the sedimentary organic matter.

Hydrogen and oxygen indices of RockEval pyrolyses suggest that the sediments contain degraded terrestrial organic matter (Type IV). Carbon isotope ratios of aliphatic and aromatic fractions show typical values related to land plant dominated material. Varying abundances of C27- to C29-steranes reveal mixtures between land plant and aquatic organic matter, which in turn suggests that the sediments were likely deposited in swamp-like and/or lacustrine environments.

Sterane isomerisation parameters indicate that the sediments have reached maturities of the oil window, which is supported by vitrinite reflectance data. We observe a general increase of vitrinite reflectance (VR) values from the top to the lower parts of the analyzed section. The increase of approximately 0.4 %-VR over a depth interval of 3.5 m is unusual and cannot be explained through subsidence processes, but must be related to an abnormal heat flow related to the sill intrusions. The maturity data suggests that the underlying sill had a greater thermal influence on the sediments than the overlying one. This assumption seems plausible as the vertical distance between the sample positions and the lower sill is 12 m compared to 65 m towards the upper sill. The increase of reflectance values, however, is not uniform and the observed scattering of the data might be attributed to the influence of the variability of the thermal conductivity of different sediment types.

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Influence of Sill Intrusions on the Organic Geochemistry of Upper Triassic Lacustrine and Fluvial Sediments at Timber Peak (Antarctica)

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Introduction

The Beacon Supergroup of North Victoria Land (Antarctica) comprises a Late Triassic to Lower Jurassic succession of siliciclastic and volcanoclastic deposits, which are intruded by mafic sills of Early Jurassic age (Ferrar Group). The sediments contain fluvial channel sandstones as well as lacustrine and palustrine deposits containing *Dicroidium*-dominated floras. These sediments have been sampled during the German Antarctic North Victoria Land Expedition IX (2005/2006) for organic geochemical and petrographical analyses in order to better describe the depositional environment and to investigate whether the sill intrusions are responsible for thermal alteration processes of the sedimentary organic matter.

At Timber Peak (Fig. 1) 80 m of sediments are embedded between two 150m thick sills (Fig. 2), and an approximately 3.5 m thick section of carbonaceous mudstones and coals, 12 m above the lower sill has been investigated. The sandstones show a thin fused margin at the contact to the sills.

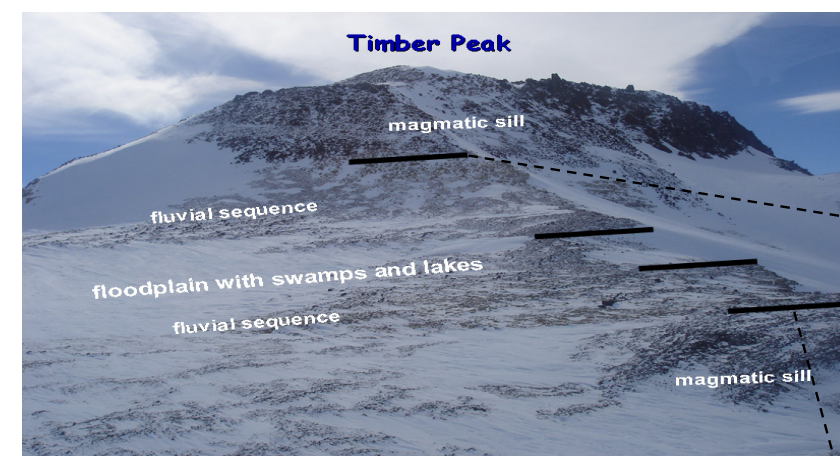
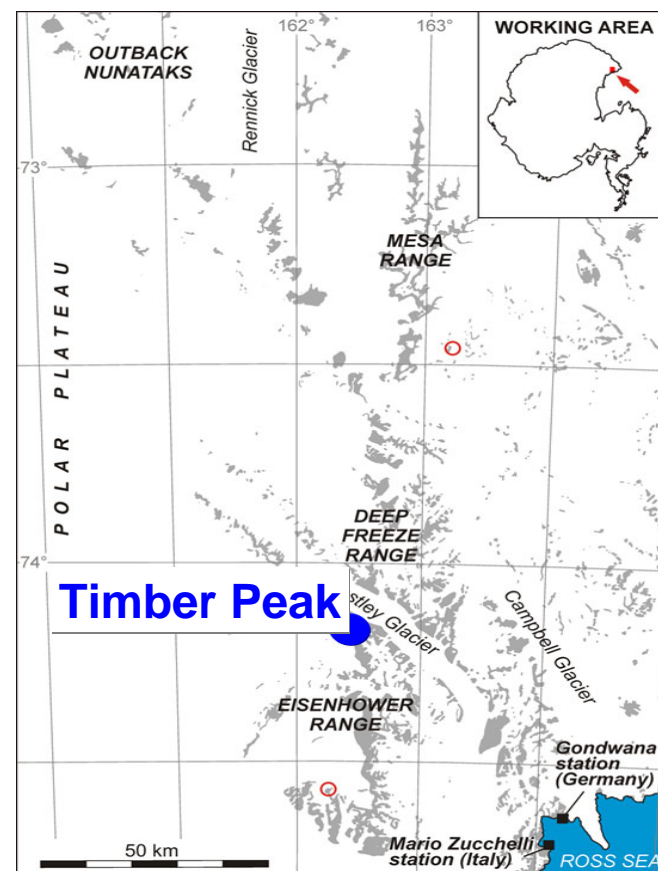
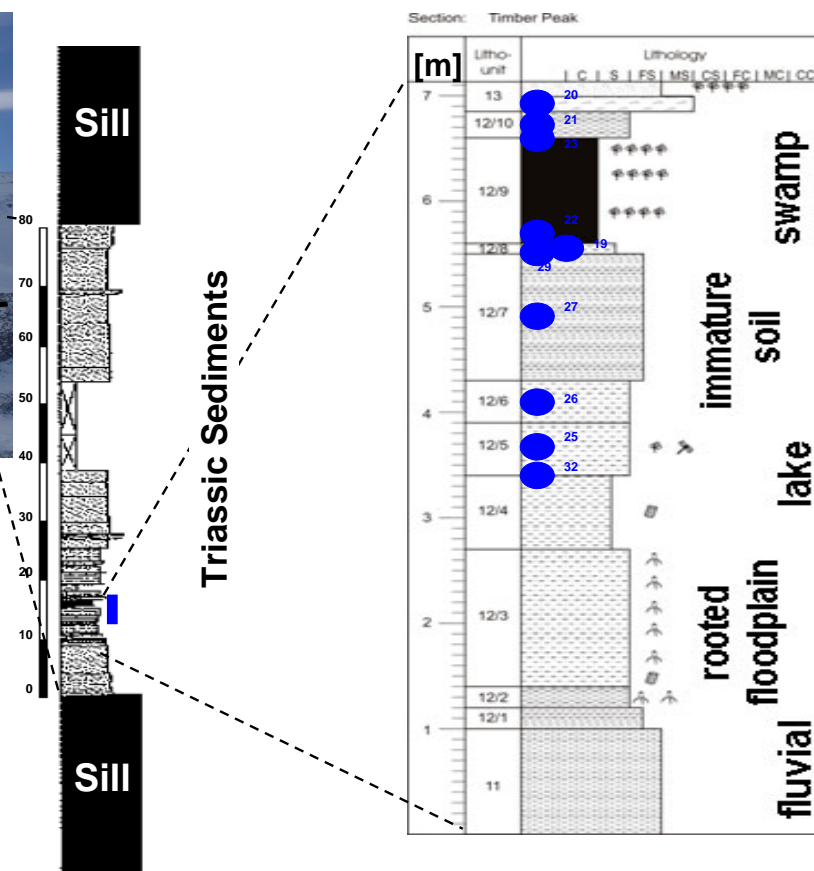


Fig. 2

Landscape (above) and geological profile (right) at Timber Peak (Antarctica)

Fig. 1

Location of investigated area.



Timber Peak Sediments

Sediments at Timber Peak (Fig. 3 to 10) belong to the Triassic Section Peak Formation, which consists of braided river sandstones, lake and swamp deposits.

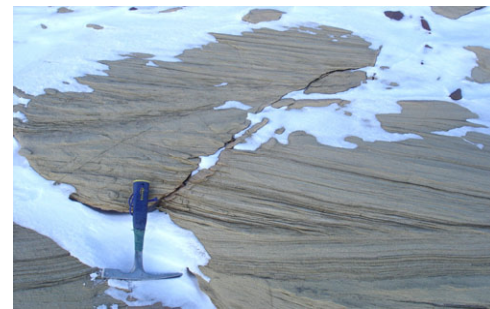


Fig. 3

Cross-bedded sandstones of a braided river system.



Fig. 4

Sandstones with synsedimentary deformation (slumping) structures..



Fig. 5

Silicified trunk/ roots? within river sandstones.



Fig. 6

River transported trunks (silicified).



Fig. 7

Silicified trunk deformed by compaction.



Fig. 8

Coal seam at Timber Peak (& Jörg successfully digging for fossils).



Fig. 9

Dicroidium sp. from Timber Peak (photo Benjamin Bomfleur, University Münster).

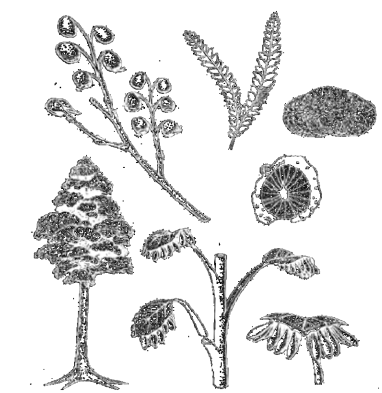


Fig. 10

Dicroidium sp. (Taylor, 1996)

Analytical methods

Ten samples of Timber Peak sediments have been analyzed by organic petrographical and organic geochemical methods. 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 Ultrall 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 Geochemistry

Organic geochemical methods (elemental analyses, RockEval pyrolyses, biomarker investigations) indicate that all sediments contain mixtures between land plant and aquatic organic matter, which in turn suggests that the sediments were likely deposited in swamp-like and/or lacustrine environments (Fig. 11 to 17).

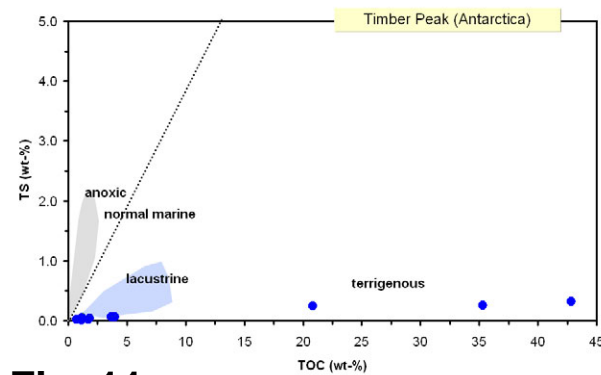


Fig. 11

Total sulfur (TS) and total organic carbon (TOC) in samples of Timber peak (classification after Berner & Raiswell, 1983).

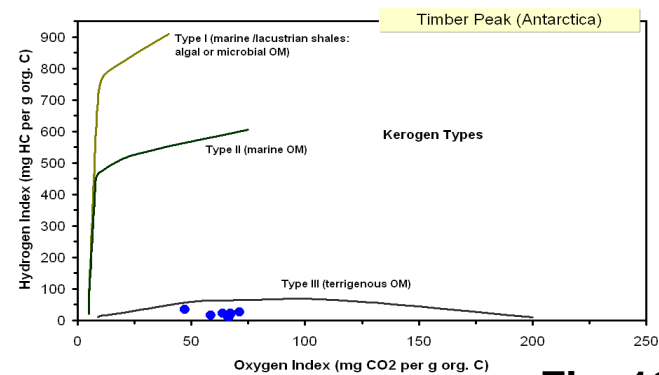


Fig. 12

Oxygen and hydrogen indices of samples of Timber Peak (after Espitalié et al., 1977; Lafargue et al., 1998)

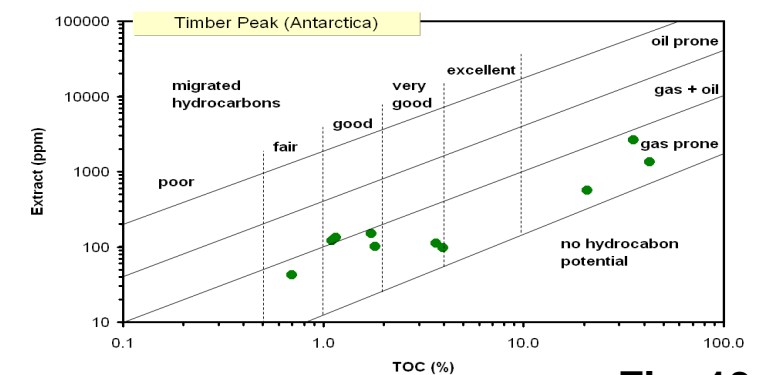


Fig. 13

Total organic carbon (TOC) and amounts of extractable hydrocarbons (ppm related to sediment weight) of samples of Timber Peak.

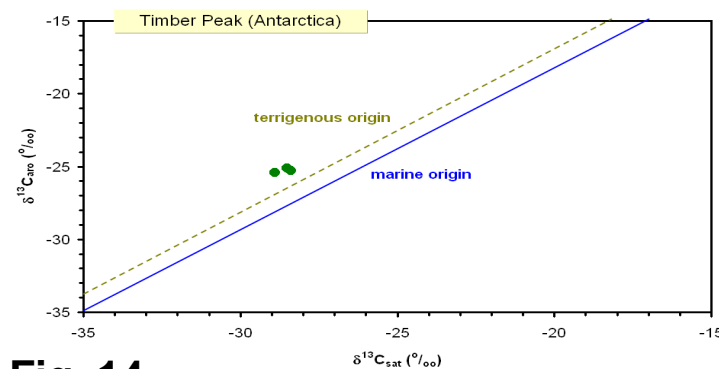


Fig. 14

Stable carbon isotope values of the aliphatic and aromatic extract fractions of two samples of Timber peak (classification after Sofer, 1984).

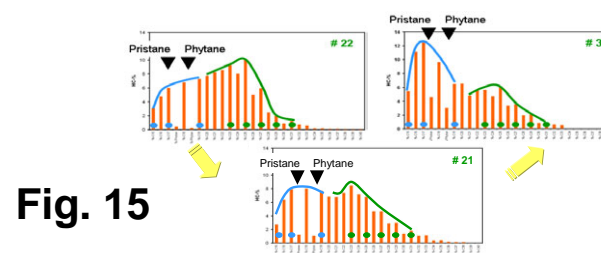


Fig. 15

Variability of n-alkane spectra of samples of Timber Peak.

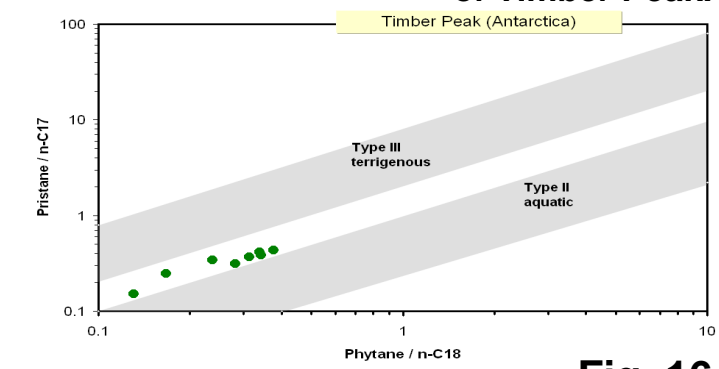
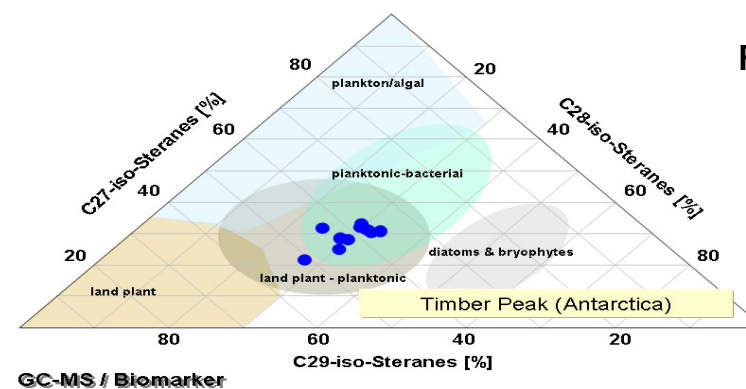


Fig. 16

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

Distribution of sterane isomers of samples of Timber Peak (classification modified after Peters et al., 2005)

Fig. 17



GC-MS / Biomarker

Thermal Maturity

Biomarker investigations suggest that the sediments at Timber Peak have reached thermal maturities of the oil-window (Fig. 18) which is compatible to organic petrographic analyses with the exception of two samples where vitrinite reflectance data suggest slightly higher maturities (Fig. 19).

We observe a general increase of vitrinite reflectance (VR) values from the top to the lower parts of the analyzed section (Fig. 20 & 21). The increase of approximately 0.5 %-VR over a depth interval of 3.5 m is unusual and cannot be explained by subsidence processes, but must be related to an abnormal heat flow related to the sill intrusions. The maturity data suggests that the underlying sill had a greater thermal influence on the sediments than the overlying one. This assumption seems plausible as the vertical distance between the sample positions and the lower sill is 12 m compared to 65 m towards the upper sill. The increase of reflectance values, however, is not uniform and the observed scattering of the data might be attributed to variable thermal conductivities of different sediment types.

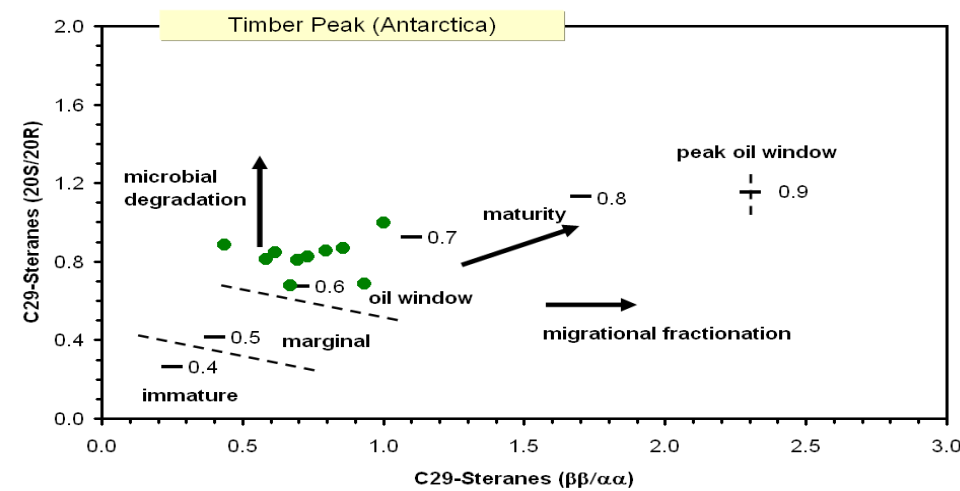


Fig. 18

Ratios of sterane biomarkers of samples of Timber Peak indicate varying maturities (compare Peters et al., 2005).

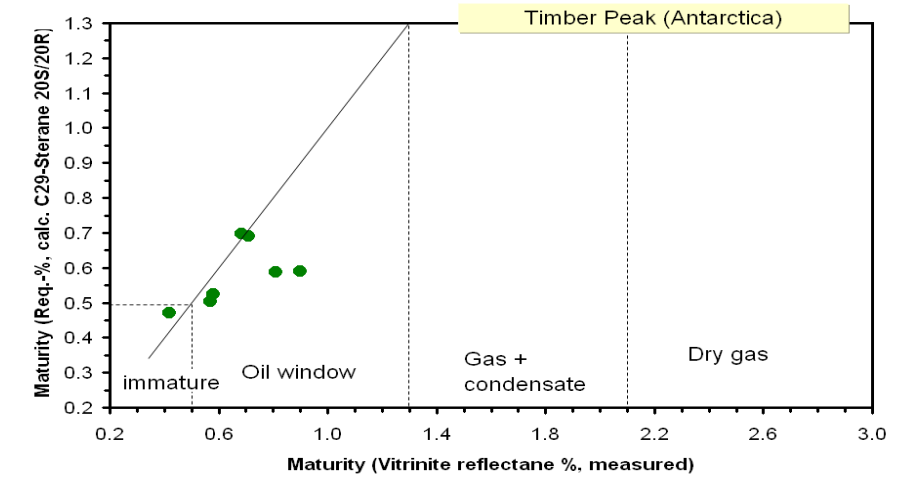


Fig. 19

Ratios of sterane biomarkers of samples of Timber Peak indicate varying maturities (compare Peters et al., 2005).

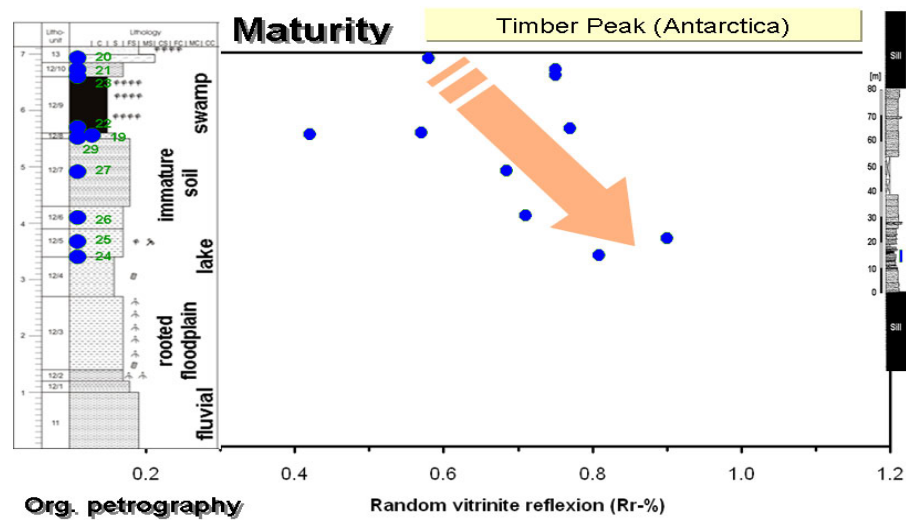


Fig. 20

Random vitrinite reflectance values of samples of the sedimentary profile of Timber Peak.

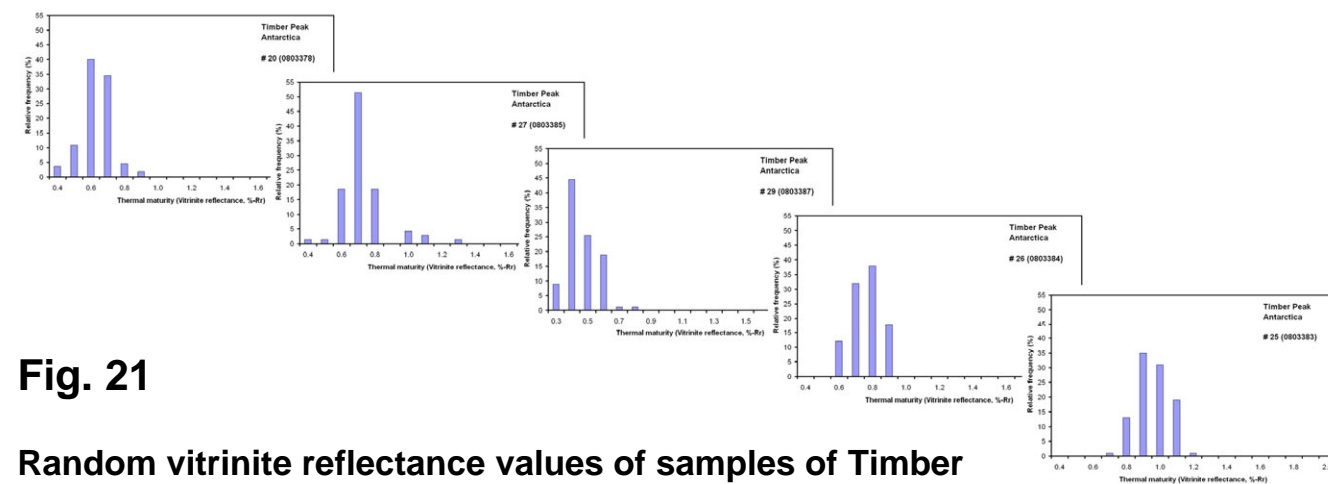


Fig. 21

Random vitrinite reflectance values of samples of Timber Peak.

Modeling the Thermal Field

We combine our investigations with kinetic modeling of vitrinite alteration (Fig. 22 to 24; compare Berner et al. 1997) and estimate the maximum temperatures, which have affected the sediments at Timber Peak (Fig. . Estimates on the relevant residence time of sediments at maximum temperatures were calibrated by heat flow modeling (Fig. 25 to 27). The resulting relationship between maximum temperatures and maturities of organic matter has been approximated by curve fitting methods (Fig. 28) and applied to the maturity data of Timber Peak (Fig. 29).

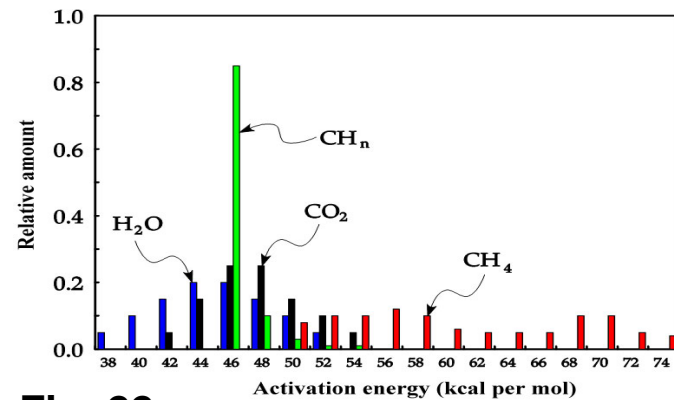


Fig. 22

Activation energies of thermal vitrinite alteration (compare Berner et al. 1997).

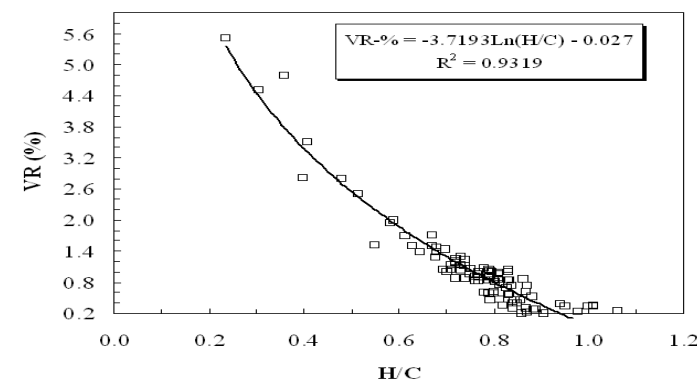


Fig. 23

Estimation of vitrinite reflectance values from H/C ratios (compare Berner et al., 1997)

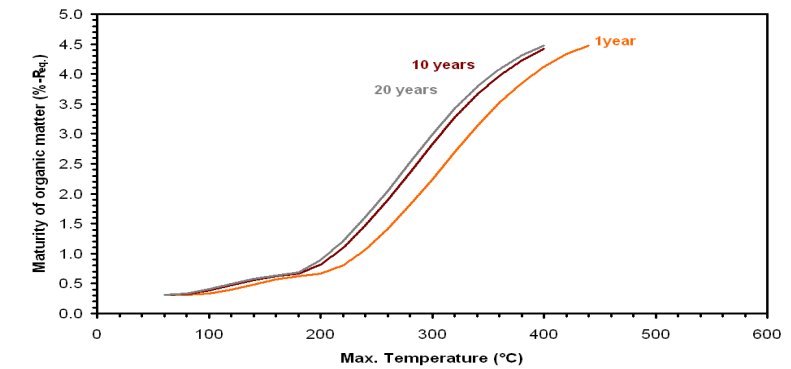


Fig. 24

Theoretical temperature and maturity relationships for different prevalence times

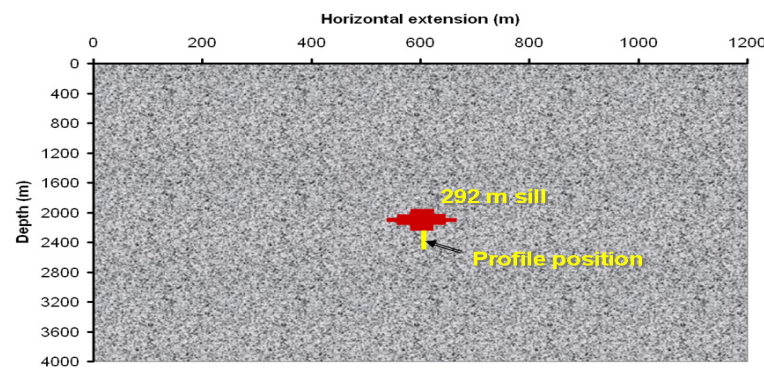


Fig. 25

Example of model set up for temperature and heat flow modeling.

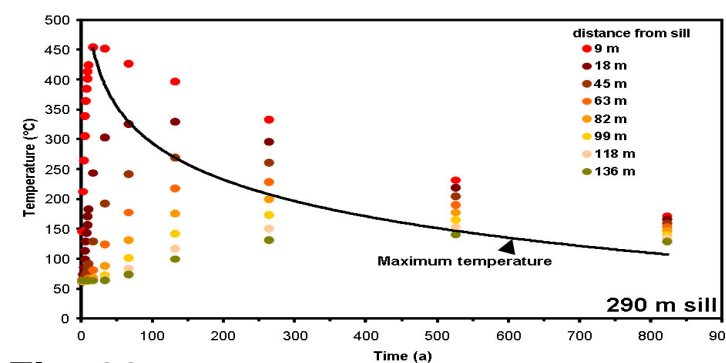


Fig. 26

Example of estimation of prevalence times for maximum temperatures from modeling.

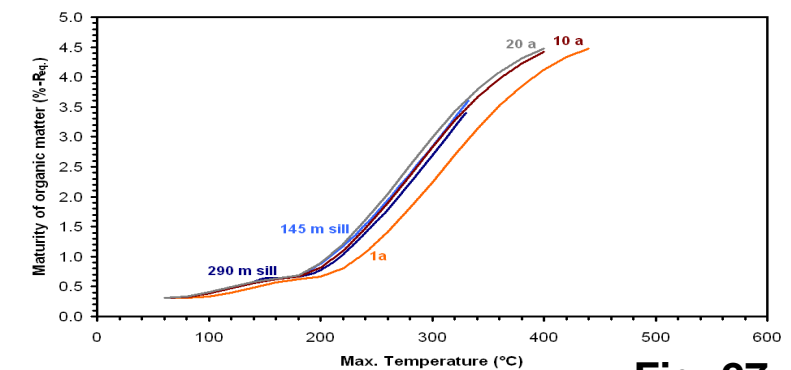


Fig. 27

Theoretical temperature and maturity relationships for different sill thicknesses.

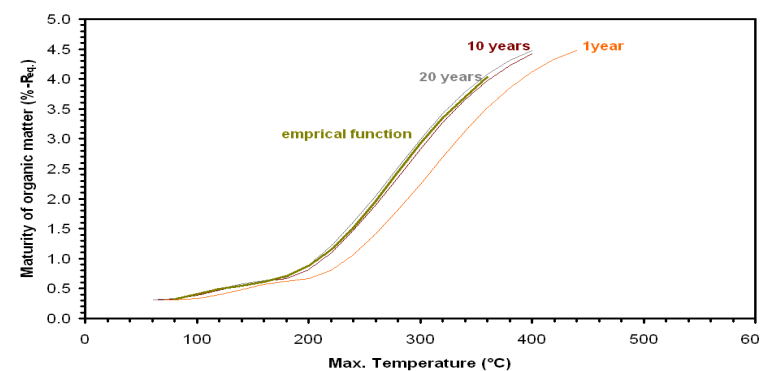


Fig. 28

Estimation of vitrinite/temperature date from curve fitting.

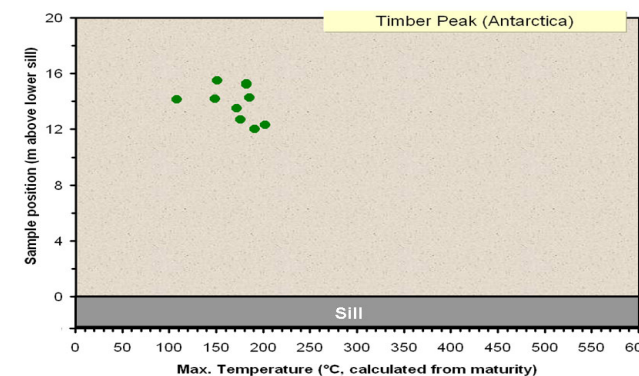


Fig. 29

Estimation of sediment temperatures at Timber Peak.

Conclusions

Sediments at Timber Peak belong to the Triassic Section Peak Formation, which consists of braided river sandstones, lake and swamp deposits and contains a variety of plant fossils.

Elemental analyses classify the sediments as terrestrial/lacustrine environment and support the geological interpretation. Hydrogen and oxygen indices derived from RockEval pyrolyses indicate that the organic matter of the sediments consist mostly of Type III or Type IV kerogens.

The amounts of extractable hydrocarbons in relation to organic carbon contents indicate that the sediment samples are dominated by terrestrial material. The data also suggests that the hydrocarbon potential of the organic matter is related to gas generation. Carbon isotope ratios of aliphatic and aromatic fractions also propose a predominance of terrestrial material whereas the n-alkanes distribution suggest mixtures between aquatic and terrestrial organic matter. This interpretation is supported by isoprenoide and biomarker data.

Maturity sensitive biomarkers are present and C29-sterane ratios (20S/20R as well as $\beta\beta/\alpha\alpha$) suggest that the extracted hydrocarbons come from a coalification range, which covers the early oil window.

A general increase of vitrinite reflectance values from the top to the lower parts of the analyzed section is observed. The increase of approximately 0.5 %-VR over a depth interval of 3.5 m is unusual and cannot be explained by subsidence processes, but must be related to an abnormal heat flow related to the lower sill intrusions.

Kinetic modeling suggests that the effective maximum temperatures of the investigated portion of the sedimentary profile reached 100 to 200 °C.

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