MINISTERE DES AFFAIRES ECONOMIQUES

ADMINISTRATION DE LA QUALITE ET DE LA SECURITE

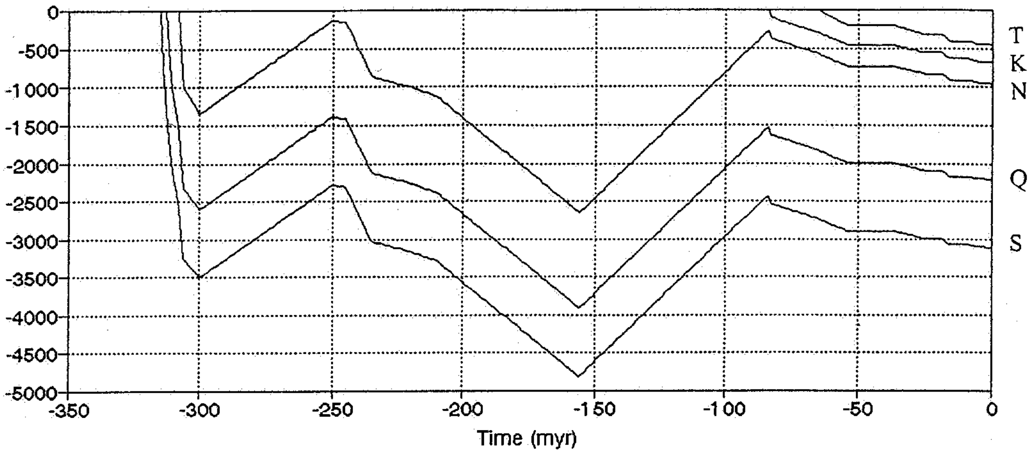
MINISTERIE VAN ECONOMISCHE ZAKEN

BESTUUR KWALITEIT EN VEILIGHEID

GEOLOGICAL SURVEY OF BELGIUM
PROFESSIONAL PAPER
1999/1 - N.289

BURIAL HISTORY AND COALIFICATION MODELLING OF WESTPHALIAN STRATA IN THE EASTERN CAMPINE BASIN (NORTHERN BELGIUM)

by S. Helsen and V. Langenaeker



SERVICE GEOLOGIQUE DE BELGIQUE
BELGISCHE GEOLOGISCHE DIENST

ue Jenner 13 - 1000 Bruxelles
ennerstraat 13 - 1000 Brussel

ISSN 0378-0902

MINISTERE DES
AFFAIRES ECONOMIQUES

ADMINISTRATION DE LA
QUALITE ET DE LA SECURITE
SERVICE GEOLOGIQUE DE BELGIQUE

MINISTERIE VAN
ECONOMISCHE ZAKEN

BESTUUR
KWALITEIT EN VEILIGHEID
BELGISCHE GEOLOGISCHE DIENST

GEOLOGICAL SURVEY OF BELGIUM*
PROFESSIONAL PAPER 1999/1, N. 289

BURIAL HISTORY AND COALIFICATION MODELLING OF WESTPHALIAN STRATA IN THE EASTERN CAMPINE BASIN (NORTHERN BELGIUM)

by

S. Helsen[1] and V. Langenaeker[2]

1999

[1] Historische Geologie, Instituut voor Aardwetenschappen, Redingenstr. 16, B-3000 Leuven
present address: ECOREM, Wayenborgstraat 21, B-2800 Mechelen
[2] Geologica n.v., Tervuursesteenweg 200, B-3060 Bertem
present address: D.H.V., B-3600 Genk

Comité éditorial : L. Dejonghe, P. Laga, R. Paepe
Service Géologique de Belgique
Rue Jenner, 13 - 1000 Bruxelles

Redactieraad: L. Dejonghe, P. Laga, R. Paepe
Belgische Geologische Dienst
Jennerstraat 13, 1000 Brussel

---

* « The Geological Survey of Belgium cannot be held responsible for the accuracy of the contents, the opinions given and the statements made in the articles published in this series, the responsability resting with the authors ».

Toute l'information économique en claire et net sur
http : //mineco.fgov.be

Alle economische informatie rechtstreeks op
http : //mineco.fgov.be

Editeur responsable: Roland PAEPE
rue Jenner 13
1000 Bruxelles
Dépôt légal: D 1999/0880/3

Verantwoordelijke uitgever: Roland PAEPE
Jennerstraat 13
1000 Brussel
Wettelijk depot: D 1999/0880/3

Table of contents

ABSTRACT

One dimensional basin modelling techniques are applied in the eastern Campine Basin in Belgium to reconstruct the burial history and thermal maturation of coal-bearing strata. Separated by two phases of regional uplift and subsequent erosion, subsidence occurred during the Carboniferous, the Late Permian through Jurassic and the Late Cretaceous to Cenozoic. A model with a first phase of important burial during the Westphalian/Stephanian and a second during the Triassic through Middle Jurassic is proposed. For the western and southern wells it appears that maximum coalification was attained immediately after the first stage of burial. For the other wells, especially for those in the northeastern part of the coalfield, maximum thermal maturation may have evolved from the second phase of heating in the Late Jurassic and Early Cretaceous. A best fit between calculated and measured coalification data is obtained by a combination of high heat flows and important packages of Late Carboniferous and Early to Middle Jurassic strata. Heat flows of 102-111 mW/m^2, assumed for Westphalian and Stephanian times, were succeeded by moderate values of 80-60 mW/m^2 in the eastern and 70-60 mW/m^2 in the western part of the Campine coalfield. Estimated thicknesses for now eroded Westphalian D/Stephanian strata are in the range of 1250-1600 m, while thicknesses of Rhaetian through Dogger rocks are varying between 1250-1980 m. Pre-Zechstein erosion of Carboniferous rocks was more important in the south than in the north with maximum values of 2480 m. As a result of Late Jurassic to Early Cretaceous erosion related to the Cimmerian uplift, 2320-2740 m of Carboniferous through Jurassic sediments were removed in the central and southeastern part of the study area. Coalification data indicate thermal potential for gas, which was mainly generated during Carboniferous burial in the south, and during both Carboniferous and Mesozoic burial in the central and northern parts.

KEY WORDS: Burial and thermal history, coalification, Carboniferous, Westphalian, Campine Basin (Belgium)

1. AIM OF THE STUDY

A modelling study was carried out for the Belgian Geological Survey to examine the burial history and the evolution of the coalification of post-Namurian coal-bearing strata in the Campine coalbasin. The aim of this study is to reveal the timing of maximum coalification and the related hydrocarbon generation. In the same area a model study for subsurface methane production in a coalbed methane test well was already evaluated by Fermont et al. (1994). For this study 13 well locations were selected in the Limburg coalfield in the eastern Campine Basin, where sufficient stratigraphic and coalification data are available from exploration wells (Fig. 1). For better geographic coverage a 14th, pseudo-well was chosen in an area where data are scarce. Labeled KBLommel, this well is situated 0.5 km west of the centre of the namesake town. The stratigraphic succession is based, with sufficient confidence, on extrapolation from nearby wells.

Software used in this modelling was developped by one of us (V.L.), based on the models of Sweeney & Burnham (1990) and Sclater & Christie (1980).

2. GEOGRAPHIC AND GEOLOGIC SETTING

The Campine Basin covers a considerable area of the Belgian provinces of Antwerp and Limburg, as well as adjacent areas in the southern Netherlands. The stratigraphy of the gently northward dipping Devonian and Carboniferous rocks is only known from deep exploration wells and collieries in the mining district. Upper Namurian and Westphalian strata consist of a cyclic deposition of shales, siltstones and sandstone with coal. To date, Stephanian rocks have not been recognised in the area. However, this does not exclude their presence in earlier times. In the Campine Basin deformation of the Palaeozoic strata during the Asturian phase of the Variscan orogenic cycle or during the Early Permian Saalian phase resulted in a series of tilted blocks (Bouckaert & Dusar, 1987). A considerable pile of sediment is assumed to have been eroded before the deposition of Late Permian (Zechstein) and Triassic fluviatile and near-shore sediments (Tys, 1980). Early to Middle Jurassic (Lias-Dogger) rocks were deposited in marine environments, created by a rapid subsidence of the Central Netherlands Basin and the Rur Valley Graben (Geluk et al. 1994; Zijerveld et al. 1992). The northwest-southeast striking Jurassic shoreline probably crossed northeastern Belgium (Ziegler, 1990). A second period of regional erosion occurred as a result of the Late Jurassic (Malm) to Early Cretaceous Cimmerian uplift, during which important packages of Mesozoic and Late Palaeozoic strata were removed. Renewed sedimentation started during a Late Cretaceous highstand. However, inversion movements along major faults (Rossa, 1987) resulted in a temporarily period of non-deposition and erosion in the Rur Valley Graben. At present, Quaternary fluvial and aeolian deposits and Tertiary to uppermost Cretaceous marine deposits cover the older substratum.

3. MODELLING

3.1. SOFTWARE

The modelling software was developed by V.L. while at the Institute of Earth Sciences of the K.U.Leuven. Programs are written in TurboPascal, and integrate equations for several procedures during the modelling of burial and coalification.

Decompaction, formed during burial, is based on the exponential relationship between porosity and depth. The equations of Sclater & Christie (1980) are used for detrital sedimentary rocks. The decompaction algorithm is described by Sclater & Christie (1980).

The relationship between porosity and thermal conductivity of rocks is described by Lewis & Rose (1970). For sand and sandstone a constant thermal conductivity of 8 mcal/cm s EC was assumed. For other lithologies a combination of matrix thermal conductivity and porosity was assumed as follows: 5.5 mcal/cm s EC for shale, 7.75 mcal/cm s EC for silt, 6 mcal/cm s EC for chalk and 1.5 mcal/cm s EC for peat-coal series.

Based on the thermal conductivity and the heat flow, burial tempertures are calculated. Coalification, expressed as VRm%, is related to the temperature by a model described in Sweeney & Burnham (1990). This model is based on a number of parallel first order kinetical reactions which describe the thermal alteration of kerogen in source rocks.

The software has been calibrated on published examples of input data and subsequently calculated maturity values. The present model is less elaborated than other existing commercial software used by oil companies and some geological surveys (e.g., GENEX, BasinMod), but has sufficient possibilities regarding the present study. As the model takes into account decompaction, porosity, variations in thermal conductivity, surface temperature and heat flow the thermal model is based on the state-of-the-art thermal maturation theories by Sweeney & Burnham (1990).

3.2. INPUT DATA

3.2.1. Stratigraphic data

Tables 3-16 show for each of the studied sites the lithology, thickness and stratigraphy of the observed post-Namurian succession, as well as the inferred depositional and erosional phases. For this purpose, rocks have been grouped in a number of litho-types, i.e., clay-shale (1), sand-sandstone (2), chalk (3), and silt-siltstone (4). Thicknesses preceded by >-= and >zero= codes for the lithology refer to eroded packages. Geochronologic data are from Harland et al. (1990) or Lippolt et al. (1984) for the Westphalian. Stratigraphic terms are explained in Table 2. Thicknesses of Westphalian A-C, Permian and Triassic strata are from the various well descriptions, summarised in Langenaeker (in prep.), or have been obtained through extrapolation from nearby boreholes (Table 1). Thicknesses of eroded sequences are obtained through modelling processes.

Thicknesses for the Westphalian A series range between 900 m in the eastern mining district and 1050 m in the western mining district. Westphalian B strata show an increasing trend in thickness from the west to the east, i.e., from 520 m in KB186 to 685 m in KB115. Westphalian C rocks are approximately 700 m thick in the central part but measure up to 1000 m in the southeastern corner (KB81). A number of deep wells and seismic data indicate the presence of Westphalian D rocks in central Limburg. Seismic sections show that a thickness of at least 500 m is locally present without all being traversed by boreholes.

Permian strata attain 40 m maximum, and are considered to have been deposited in the northeastern part of the study area only. Buntsandstein sediments are assumed to have covered the entire eastern Campine-Brabant areas but were probably thicking towards the northeast. Cumulative thicknesses indicate values up to 580 m. In KB198 a thickness of 700 m is assumed. Muschelkalk and Keuper deposits are each known to be up to 86 m thick at KB99, 5 km northeast of KB168. In our simulation, these strata vary between 50 m in the southern part and 100 m in KB198. Although their extension throughout the Rur Valley Graben is evident from seismic investigations, Rhaetian and Liassic (Hettangian to Pliensbachian) strata are drilled at KB99 and at KB198 only, where they are at least 480 m thick (Demyttenaere & Laga, 1988). The total preserved thickness from seismic evidence may approach 800 m in the graben.

Stratigraphic information on the Cretaceous and Tertiary cover is from the isopach maps of Legrand (1968), Demyttenaere (1988) and Demyttenaere & Laga (1988). Maximum thicknesses of the Cretaceous succession (Santonian through Maastrichtian) are recorded in the southeast, i.e., 224 m in KB168. Due to inversion tectonics in the Rur Valley Graben, Cretaceous deposits in KB198 are reduced to 27 m of Maastrichtian rocks. Cenozoic strata thicken from the south to the north, ranging between 292 m in KB86 and 1257 m in KB198.

3.2.2. Decompaction data

The decompaction of rocks is based on the litho-type chosen, and on the exponential relationships between porosity and depth (Sclater & Christie, 1980). Compaction or decompaction is only excecuted for the first burial phase after sedimentation. During uplift and renewed burial variations in porosity are dominated by diagenetic reactions, rather than by mechanical reduction of porosity. To a lesser extend, this is also the case during the first burial phase. As a result, the calculation of porosity, and thus of decompaction, is in all cases only approximative. By applying decompaction corrections the burial history of strata can be calculated more precisely.

3.2.3. Porosity and thermal conductivity data

Porosity data, as calculated during the decompaction process, are translated into thermal conductivity data using the equations of Lewis & Rose (1970) and values for matrix thermal conductivity (section 3.1.).

3.2.4. Heat flow models

Actual heat flow in Northeast-Belgium approximates 60 mW/m^2 (Hurtig et al. 1992). However, during extension of the Campine Basin in Carboniferous times, stretching of the crust may have been accompanied by higher heat flows (Leeder, 1987). In this study an average heat flow of 102 mW/m^2 is considered between 315-300 myr, with exception of the southerly locations of KB69, KB81 and KB86, where higher values of 103-111 mW/m^2 have been taken into account. All these figures fall well within the range of heat flow values in actual active (syn-rift) back-arc basins (Allen & Allen, 1990). After a period of basin extension heat flow probably decreased during the Permian. At that time, heat flow is supposed to have been higher within and nearby the Rur Valley Graben than in the western part of the study area. This may be due to the initiation of the rifting in the graben. As a result, heat flow may have dropped to 80 mW/m^2 at 270 myr and 74 mW/m^2 at 260 myr in the eastern part of the study area, and to a value of 70 mW/m^2 at 270 myr in the western part. In the early Tertiary, at 50 myr, heat flow values of respectively 70 and 65 mW/m^2 are considered in the eastern, respectively western part, before reaching the present value (Figs 4-17).

Heat flow simulations in the Campine Basin by Van Keer et al. (in prep.) are different from the above values. Beside an average figure of 63 mW/m^2, high values of 84 mW/m^2 for Westphalian D and Stephanian (KB172 and KB174), 74 mW/m^2 during Dogger (KB172) and 96 mW/m^2 for Oligocene to Pliocene (KB172 and KB174) were considered. In the German Ruhr basin a Carboniferous heat flow of 83 mW/m^2 is supposed to be succeeded by a value of 61 mW/m^2 by Littke et al. (1994).

3.2.5. Surface temperature model

Using palaeogeographic maps of western Europe, according to Dercourt et al. (1993) and Ziegler (1989) and to corresponding actual temperatures for these latitudes, palaeo-surface temperatures for the Campine Basin were estimated for the geological record between 315-0 myr. As a result, values of 25EC, refering to tropical climate conditions, are maintained until 300 myr. Due to the progressive shifting of Gondwana towards higher latitudes, the surface temperature is assumed to have reached its maximum at 27EC between 280-270 myr, after which it dropped gradually into the lower twenties. Until Middle Cretaceous times (100 myr) the surface temperature is supposed to have been 20EC or more. In Early Tertiary times it has been assumed to drop from 19EC (at 60 myr) to 16EC (at 35 myr). An average of 10EC is considered from 9 to 7 myr, after which the surface temperature drops to a minimum of 1EC during the Pleistocene at 1 myr, before reaching the actual 9EC (Fig. 2).

4. RESULTS

4.1. BURIAL HISTORY

Assumed thicknesses of now mostly eroded Westphalian D/Stephanian deposits used in this modelling are in the range of 1250-1570 m (Figs 3-17). These figures are much larger than the 600 m suggested by Bless et al. (1977) for the eastern part of the basin. However, Van Keer et al. (in prep.) suggested cumulative thicknesses for the Westphalian D and Stephanian strata of 1900 m, respectively 2000 m for the KB172 and KB174 wells.

Estimates for the eroded Westphalian series as a result from pre-Zechstein unloading show considerable differences within the Campine Basin. From our modelling, it appears that the greatest thicknesses were stripped off in the south, i.e., near the sites of KB185, KB79, KB86 and KB81, where more than 2300 m were removed by erosion. This confirms earlier theses, e.g. Grosjean (1936). Towards the north, eroded packages are considered to be smaller, averaging around 1200-1300 m in the central part of the study area. This trend can be explained by the more important Late Palaeozoic uplift in the southern area, as compared to the north. Considerable stratigraphic differences in Pre-Zechstein erosion levels between relatively close areas may be explained by block faulting and tilting during the Carboniferous (Tys, 1980). This is further corroborated by up to 1000 m of differential removal of Westphalian strata on both flanks of the Donderslag Fault, deviding the Campine coalbasin in an eastern and western block (Dusar & Langenaeker, 1992). In the Rur Valley Graben (KB198) an eroded thickness of 800 m is assumed. Some of these figures are in good agreement with the results of basin modelling in the German Ruhr Basin. According to Littke et al. (1994), 2200-3500 m of Carboniferous overburden in this basin was eroded during the Stephanian and Rotliegend.

According to Ziegler (1990), sedimentation in the southern part of the study area occurred until the Early Dogger (Aalenian), but continued until the Late Dogger (Bathonian) in the central part (KB174, KB172), and until the Early Malm (Oxfordian) in the very north of the study area (KB198). This resulted in huge packages of Late Triassic and Jurassic sediments, varying between 1250 m (KB86) and 1980 m thickness (KB198) as calculated during the modelling (see also Fig. 3). These figures are in the same range as the 1800 m of Jurassic rocks considered for the KB172 well by Van Keer et al. (in prep.), but they do not agree with their assumption of 400 m of Jurassic strata (Lias only) at the KB174 site. Van Keer et al. (in prep.) assigned the important variation in stratigraphical thickness to differences in geological history of the various tectonic bocks.

Alternatively, Dusar et al. (1987) suggested that the high coalification data in the KB 201-KB172 area may be related to a basic intrusion, dated post-Carboniferous to pre-Tertiary, and associated with a gravimetric anomaly (Petrofina, 1963). Similar anomalies and coalification highs nearby Krefeld and Erkelenz, Germany, are probably produced by Permo-Carboniferous, respectively Permian intrusions (Buntebarth et al. 1982; Drozdzewski & Wrede, 1994, among others). Possibly, the Erkelenz anomaly may be an east-bound continuation of the anomaly in Limburg, actually separated by the Rur Valley Graben. In our model, however, high heat flow up to 120 mW/m^2 and more, related to a possible intrusion, could not produce the actual high thermal maturation and coalification gradient observed in KB172. Numerous simulation runs, with a timing for the thermal event shifting between the latest Carboniferous and the Late Cretaceous, combined with varying sediment loading, did not result in any satisfying match between calculated and measured coalification data.

Post-Cimmerian erosion reaches maximum values of 2320-2740 m in the central and southeastern parts of the studied area. Towards the south and southwest, where the Triassic and Jurassic cover was more reduced, eroded thicknesses are in the range of 2000-2100 m. In the subsiding Rur Valley Graben thick Triassic and Jurassic sequences were less affected by erosion. This can be documented with data from KB198, where the lower part of the Liassic and probably the complete Triassic record are preserved, and probably >only= some 1340 m of Jurassic rocks have been eroded. The great pile of Westphalian through Jurassic sediments considered to be eroded in the Campine Basin is in agreement with the overburden of at least 3000 m on the Ordovician basement of the southern Brabant Massif, estimated to be removed no earlier than the Middle Jurassic (Van den haute & Vercoutere, 1989; Vercoutere & Van den haute, 1993).

The oldest preserved Cretaceous rocks are of Santonian age. Together with Campanian and Maastrichtian strata they account for 250 m maximum. Although deposition in the Tertiary was far from continuous (major hiatuses occur in the Eocene and Neogene), erosion during this period was likely less important. The thickest sequences occur in the Rur Valley Graben. Quarternary strata account only for some tens of m maximum.

The burial history for some Westphalian stratigraphic markers, as well as for the base of the Cretaceous and Tertiary of the studied boreholes, are depicted in Figs 4a-17a. By using these geohistory plots, the selected heat flow models (Figs 4b-17b) and the surface temperature model (Fig. 2) the evolution of the burial temperature is calculated (Figs. 4c-17c). The latter is needed to calculate the thermal maturation of organic matter.

4.2. COALIFICATION

4.2.1. Carboniferous

Figs 18-31 show the evolution in thermal maturation of Westphalian strata in all of the 14 studied wells. Coalification data are from the basal strata of the lower Westphalian A (Sarnsbank Marine Band), upper Westphalian A (Wasserfall Marine Band), lower Westphalian B (Quaregnon Marine Band), upper Westphalian B (Eisden Marine Band), Westphalian C (Maurage Marine Band) and Westphalian D units (Neeroeteren Sandstone). For each of the studied wells, actual (maximum) measured and calculated coalification values for the preserved geological record, including Westphalian rocks, are shown in Tables 2-15, based on Langenaeker (1992). Minor differences between measured and calculated Carboniferous VRm% values may be explained by variations in porosity and thermal conductivity of rocks. In general, however, these differences fall well within the standard deviation of the measured values (Langenaeker, in prep.).

4.2.1.1. Wells KB69, KB 79, KB81, KB86 and KB185

In the southern part of the study area significant thermal maturation was the result of Late Carboniferous burial. VRm% values probably increased after maximum burial at 300 myr, until a maximum in coalification was reached some 290 myr ago. With values of more than 2.4 VRm% for lower Westphalian A strata, thermal maturation was likely most important in KB69 and KB81. Apparently, renewed sedimentary burial resulted in only little, if any, additional thermal maturation for the lower Westphalian. The latter is less than 0.003 VRm% for any of the Westphalian strata in KB86, KB79, KB69 and KB81, but approximates 0.008 VRm% for the base of the Westphalian B (Quaregnon M.B.) in KB185 (Figs 18-22; Tables 3-7).

4.2.1.2. Wells KB115 and KB163

Like in the southernmost wells, thermal maturation of Westphalian rocks in the KB115 and KB163 wells is mainly due to some 15 myr of Late Carboniferous burial. Apparently, the resulting coalification rapidly increased until 295 myr. However, maximum coalification was only attained after a second period of heating by sedimentary burial during the Permian through Middle Jurassic. Situated at approximately 150 myr, this is actually some 20 myr after the time of maximum burial. This additional thermal maturation can be documented by figures for basal Westphalian A rocks (Sarnsbank M.B.), which are in the range of 0.18 VRm% in KB163, and 0.22 VRm% in KB115, resulting in a final coalification for the base of the lower Westphalian A of 1.902 VRm% (KB163) and of 2.088 VRm% (KB115). For the Quaregnon Marine Band the additional coalification is even higher, i.e., 0.290 VRm% in KB163 and 0.320 VRm% in KB115 (Figs 23-24; Tables 8-9).

4.2.1.3. Wells KB174, KB186 and KBLommel (coalification minimum north of Zolder)

In the western part of the study area Late Carboniferous sedimentary burial resulted in important coalification before 295 myr. Additional thermal maturation of Westphalian rocks, produced by heating during Permian and Mesozoic overburden, attained its maximum during Late Jurassic (Malm) times, and is relatively small. Probably, maximum coalification took place at 140 myr for the KB174 site, shifting to younger ages of 135 myr and 130 myr for the more northerly KB186 and KBLommel wells. The overall modest additional coalification is small in KB174, with values of less than 0.050 VRm% for the Sarnsbank and Quaregnon Marine Bands, but it gradually increases to the north with values of 0.220 VRm% for Quaregnon in KB186 and 0.670 VRm% for the same stratigraphic level at KBLommel. This trend can be illustrated with the actual VRm values for the Sarnsbank and Quaregnon Marine Bands, which vary from 1.653% and 0.872% in KB174, to 1.852% and 1.088% in KB186 and 2.255% and 1.447% in KBLommel (Figs 25-27; Tables 10-12).

4.2.1.4. Wells KB168, KB172, K201 and KB198

In the northeastern part of the study area, the evolution of thermal maturation in time is markedly different from that of the other sites. Being the result of Carboniferous overburden, the coalification attained at 295 myr is of the same range as in the south (KB115 and KB163) and the west (KB174, KB186 and KBLommel). In wells KB172, KB169 and KB201 Permian and Mesozoic, mainly Jurassic sedimentation evolved in an important increase of coalification, culminating between 145-135 myr. The additional coalification can be documented by the increase in VRm of approximately 1.5 % for lower Westphalian A strata (Sarnsbank M.B.). In KB198 maximum coalification occurred in the Early Cretaceous at 115 myr, some 29 myr after the time of maximum burial. Here, differences in coalification are as large as 1.7 VRm% for the base of the lower Westphalian A, although smaller differences of 0.9 VRm% are noticed for the basal strata of the Westphalian D Neeroeteren Sandstone. Resulting VRm values are high: for the Sarnsbank Marine Band they are 2.516% (KB168), 2.648% (KB172), 2.889% (KB201) and up to 3.567% (KB198).
Apparently, in none of the 14 studied wells heating from Cretaceous and Cenozoic burial has affected the already attained coalification level, even not in KB198, where these strata are more than 1280 m thick (Figs 28-31; Tables 13-16).

4.2.2. Post-Carboniferous

Permian VRm% values are scarce in the Campine Basin. Among the studied wells, only KB172 and KB201 yielded vitrinite reflectance values in Zechstein sediments. In both wells three populations of vitrinite reflectance data are determined. The lowest reflectance values, assigned to an indigenous population, are of 0.44% in KB172 and 0.47%

in KB201. The other, possibly reworked populations have values of 0.84% and 1.39% in KB172 and of 0.76% and 0.85% in KB201 (Langenaeker, in prep.; Somers, unpubl. documents, Liège). Being substantially lower, the reflectance data of the indigenous populations do not agree with the values of 0.872% and 0.961%, calculated for the KB172, respectively KB201 well. However, the small number of measured particles (6 in KB172 and 9 in KB201) indicates that these measured data are less reliable. A better correspondence is observed between calculated VRm data and reflectance values of vitrinites from the reworked populations. Furthermore, the oxidised nature of the Permian and Triassic rocks possibly hampers the exact identification of the type of maceral, which may be an additional explanation for the discrepancy between measured and modelled values. It is clear that additional measurements on more numerous vitrinite populations may contribute to a better knowledge of the thermal maturation of Permian deposits in the Campine Basin (Petrofina, 1993).

In addition, due to the relatively small number of analysed grains and their low degree of thermal metamorphism (0.46-0.30%), coalification measurements from Liassic, Upper Cretaceous and Paleocene strata in KB172, KB201 and KB198 (Langenaeker, in prep.; Petrofina, 1993) are less reliable than those from Upper Carboniferous deposits (Tables 14-16).

4.3. HYDROCARBON POTENTIAL

Regarding the hydrocarbon potential, the Campine coal basin needs to be differentiated in zones with only one important phase of hydrocarbon generation at the end of the Carboniferous and zones with an important secondary hydrocarbon generation.

In the former areas possible hydrocarbon plays were destroyed by subsequent uplift and erosion. Coalbed methane recovery testing in well KB206, approximately 6 km southeast of KB174, showed that coals in this area are undersaturated (Fermont et al. 1994; Wenselaers et al. 1996).

In the latter areas possible hydrocarbon plays may exist within Buntsandstein reservoirs.

5. CONCLUSIONS

Based on the above explained calculations the following conclusions may be drawn for the burial history of post-Namurian strata in the eastern Campine Basin.

1. Important sedimentary burial and thermal maturation took place during the latest Westphalian (WfD) or Stephanian. Presumed cumulative thicknesses for these strata range between 1570 and 1250 m. The maximum cumulative thickness of the Westphalian preserved in the Campine coalbasin approximates 3 km. For the well sites in the southern part of the study area maximum coalification was attained shortly after this phase of burial.

2. Asturian and/or Saalian deformation and subsequent erosion resulted in important unloading. In the northeastern part of the coalfield at least 800 m were eroded. In the south, where uplift was more important, some 2300-2400 m were removed.
3. A second period of important subsidence and sedimentation which ended in Middle Jurassic (Dogger) times resulted in a maximum burial and additional coalification for most of the sites in the central and northern parts of the area. Permian through Upper Triassic (Keuper) deposits are 250 m thick in the southwestern part and 900 m thick in the northeast. Thicknesses for Rhaetian through Jurassic rocks vary between 1250 m in the southern part and 1980 m in the Rur graben.
4. The study area shows thermal potential for gas generation from Westphalian rocks. Possibly in the central, but certainly in the northeastern areas hydrocarbon gasses were probably generated from the Carboniferous source rocks during both periods of burial.
5. Post-Cimmeric erosion was most important in the central and southeastern part of the area with values up to 2740 m. Likely, the smallest erosion, probably some 1340 m, occurred in the Rur Valley Graben.
6. Late Cretaceous through Cenozoic burial has not affected the coalification resulting from earlier periods of heating.

6. ACKNOWLEDGEMENTS

Dr. M. Dusar (Geological Survey of Belgium, Brussels) is thanked for his suggestions and constructive comments. Financial support by the Geological Survey of Belgium is greatly acknowledged (project NAT/95-2.2.a). Dr. W. Fermont (NITG, Heerlen) made clear that discussion on heat flow models is far from closed. However, our pragmatic approach may provide an impetus for a more thorough international investigation of the crucial problem of explaining the actual coalification values in the Northwestern European Carboniferous.

7. REFERENCES

Allen, P.A. & Allen, J.R. 1990. Basin Analysis. Principles and applications. Blackwell, Oxford, London, 451 pp.

Bless, M.J.M., Bouckaert, J., Calver, M.A., Graulich, J.M. & Paproth E. 1977. Paleogeography of Upper Westphalian deposits in NW Europe with reference to the Westphalian C north of the mobile Variscan belt. Meded. Rijks Geol. Dienst, N.S. 28 (5), 101-127.

Bouckaert, J. & Dusar, M. 1987. Arguments géophysiques pour une tectonique cassante en Campine (Belgique), active au Paléozoique supérieur et réactivée depuis le Jurassique supérieur. Ann. Soc. Géol. Nord 151, 201-208.

Buntebarth, G., Michel, W. & Teichmüller, R. 1982. Das permokarbonische Intrusiv von Krefeld und seine Einwirkung auf die Karbon-Kohlen am linken Niederrhein. Fortschr. Geol. Rheinld. u. Westf. 30, 31-45.

Demyttenaere, R. 1988. De post-Paleozoïsche geologische geschiedenis van Noord-België. Unpub. Ph.D. thesis K.U.Leuven, 175 pp.

Demyttenaere, R. & Laga, P. 1988. Breuken- en isohypsenkaarten van het Belgische gedeelte van de Roerdal Slenk. Belg. Geol. Surv. Prof. Paper 234, 20 pp.

Dercourt, J. Ricou, L.E. & Vrielynck, B. (eds) 1993. Atlas Tethys Palaeoenvironmental Maps. Gauthier-Villars, Paris, 307 pp., 14 maps, 1 pl.

Drozdzewski, G. & Wrede, V. 1994. Faltung und Bruchtektonik. Analyse der Tektonik im Subvariscikum. Fortschr. Geol. Rhld. u. Westf. 38, 159.

Dusar, M., Bless, M.J.M., Borremans, G., Burger, K., De Loose, J., Fairon-Demaret, M., Felder, P.J., Gullentops, F., Lie Sun Fan, Muchez, Ph., Paproth, E., Pierart, P., Rossa, H.G., Smolderen, A., Somers, Y., Steurbaut, E., Streel, M., Viaene, W., Witte, H. & Wouters, L. 1987. De steenkoolverkenningsboring Gruitrode-Ophovenderheide (Boring 172 van het Kempens Bekken), kaartblad Opoeteren, 63E224. Belg. Geol. Surv. Prof. Paper 230, 235 pp.

Dusar, M. & Langenaeker, V. 1992. De oostrand van het Massief van Brabant, met beschrijving van de geologische verkenningsboring te Martenslinde. Belg. Geol. Surv. Prof. Paper 255, 22 pp.

Fermont, W., Jegers, L. & Dusar, M. 1994. A model study of coalbed methane generation in well Peer (KB206) Belgium. Rijks Geol. Dienst Intern. Paper.

Geluk, M.C., Duin, E.J.T., Dusar, M., Rijkers, R.H.B., Van den Berg, M.W. & van Rooijen, P. 1994. Stratigraphy and tectonics of the Roer Valley Graben. Geol. Mijnbouw 73, 129-141.

Grosjean, A. 1936. Les traits essentiels du terrain houiller de la Campine. Ann. Mines de Belgique 37, 263-273.

Hurtig, E., Cermak, V., Haenel, R. & Zui, V. (eds) 1992. Geothermal Atlas of Europe. Intern. Assoc. Seismology and Physics of the Earth=s Interior, Intern. Heat Flow Comm., Central Inst. for Physics of the Earth. GeoForschungsZentrum Potsdam, publ. 1, 156 pp.

Harland, W.B., Armstrong, R.L., Cox, A.V., Craig, L.E., Smith, A.G. & Smith, D.G. 1990. A Geologic Time Scale, 1989. Cambridge Univ. Press, Cambridge, 263 pp.

Langenaeker, V. 1992. Coalification maps for the Westphalian of the Campine Coal Basin. Belg. Geol. Surv. Prof. Paper 256, 34 pp.

Langenaeker, V. 1998. The Campine basin. Stratigraphy, structural geology, coalification and hydrocarbon potential for the Devonian to Jurassic. Ph.D. thesis K.U.Leuven, 213 pp.

Leeder, M.R. 1987. Tectonic and paleographic models for Lower Carboniferous Europe. In: J. Miller, A.E. Adams & V.P. Wright (eds) European Dinantian environments. Wiley, New York 1-20.

Legrand, R. 1968. Le Massif du Brabant. Mém. explic. cartes géol. et min. Belgique 9, 148 pp., 5 pl.

Lewis, C.R. & Rose, S.C. 1970. A theory relating high temperatures and overpressures. J. Petr. Technol. 22, 11-16.

Lippolt, H.J., Hess, J.C. & Burger, K. 1984. Isotopische Alter von pyroklastischen Sanidinen aus Kaolin-Kohlentonsteinen als Korrelationsmarken für das mitteleuropäische Oberkarbon. Fortschr. Geol. Rheinld. u. Westf. 32, 119-150.

Littke, R., Büker, C., Lückge, A., Sachsenhofer, R.F.& Welte, D.H. 1994. A new evaluation of palaeo-heat flows and eroded thicknesses for the Carboniferous Ruhr basin, western Germany. J. Coal Geol. 26, 155-183.

Petrofina, 1963. Reinterprétation de la campagne sismique 1953 à 1956 et compléments 1963 (Heibaart-Bree-Kessenich) pour la compte de la S.C.R.E.M. Unpubl. document.

Petrofina, 1993. Campine basin: thermal maturity assessment of Permian through Tertiary sediments. Spot horizon data compendium. Fina Research, Exploration and Production, Geolab Report EGG/EB134.

Pillement, Ph. 1982. La houillification des formations Carbonifères en Belgique. Sa place dans l=histoire sédimentaire et structurale varisque. Unpubl. Ph.D. thesis Université de Droit, d=Economie et des Sciences d=Aix-Marseille, 220 pp.

Rossa, H.G. 1987. Upper Carboniferous and Tertiary inversion tectonics of the Western part of the Rhenish-Westphalian coal district (FRG) and in the Campine area (N-Belgium). Ann. Soc. Géol. Belg. 109, 367-410.

Sclater, J.G. & Christie, P.A.F. 1980. Continental stretching: an explanation of the post Mid-Cretaceous subsidence of the central North Sea basin. J. Geophys. Res. 85, 3711-3739.

Sweeney, J.J. & Burnham, A.K. 1990. Evaluation of a simple model of vitrinite reflectance based on chemical kinetics. Am. Assoc. Petr. Geol. Bull. 74, 1559-1570.

Tys, E. 1980. De geologische structuur van het steenkoolterrein ten noorden van het ontginningsgebied der Kempense mijnen. Belg. Geol. Surv. Prof. Paper 179, 44 pp.

Van den haute, P. & Vercoutere, C. 1989. Apatite fission-track evidence for a Mesozoic uplift of the Brabant Massif: preliminary results. Ann. Soc. Géol. Belg. 112, 443-452.

Vercoutere, C. & Van den haute, P. 1993. Post-Palaeozoic cooling and uplift of the Brabant Massif as revealed by apatite fission track analysis. Geol. Mag. 130, 639-646.

Van Keer, I., Ondrak, R., Muchez, Ph., Bayer, U., Dusar, M. & Viaene, W. in prep. Contrasting burial history and thermal evolution of Westphalian coal-bearing strata in the Campine Basin (NE-Belgium): the importance of post-Paleozoic tectonism and heat flow. Geol. Mijnbouw.

Wenselaers, P., Dusar, M. & Van Tongeren, P.C.H. 1996. Steenkoollaag methaangaswinning in het Kempisch Kolenbekken. AHet proefproject te Peer@. Min. Vl. Gem., Afd. Nat. Rijkdom. Energie, Brussel, 67 pp.

Ziegler, P.A. 1989. Evolution of Laurussia. A study in Late Palaeozoic Plate Tectonics. Kluwer, Dordrecht, 102 pp.

Ziegler, P.A. 1990. Geological atlas of Western and Central Europe. Shell Int. Petr. Mij. and Geol. Soc., London, 2nd ed., 239 pp.

Zijerveld, L., Stephenson, R., Cloetingh, S., Duin, E. & Vandenberg, M.W. 1992. Subsidence analysis and modelling of the Roer Valley Graben (SE Netherlands). Tectonophysics 208, 159-171.

TABLES

Table 1. Overview of the studied wells.

Nr	BGS Archives	X-Lambert	Y-Lambert	Year	T.D. (m)
KB69	78W203	229013	187040	1908	1050
KB79	62W205	217403	192704	1906	1133
KB81	64W176	243766	188775	1910	1026
KB86	77W174	217105	187372	1920	1912
KB185	46E278	209390	202578	1986	1480
KB115	63E200	235060	191412	1943	1730
KB163	63E220	235956	191512	1983	1253
KB174	47E196	220085	199406	1985	1500
KB186	47W264	213939	206366	1986	1504
KB168	63E223	240545	194697	1983	1247
KB172	63E224	234022	196268	1984	1599
KB198	49W226	247659	207752	1987	1773
KB201	48W191	232836	203184	1989	1340
KBLOMMEL	-	214500	214000		

Table 2. Key stratigraphic units used in Tables 3-16.

WfA	Wesphalian A	**Bathon**	Bathonian
WfB	Westphalian B	**Oxford**	Oxfordian
WfC	Westphalian C	**Sant**	Santonian
WfD	Westphalian D	**Camp**	Campanian
St	Stephanian	**Maastr**	Maastrichtian
Zech	Zechstein	**Paleoc**	Paleocene
Bunt	Buntsandstein	**Eoc**	Eocene
Musch	Muschelkalk	**Olig**	Oligocene
Keup	Keuper	**Mioc**	Miocene
Rhaet	Rhaetian	**Plioc**	Pliocene
Hett	Hettangian	**Quart**	Quarternary
Aalen	Aalenian	**l**	lower
Bajoc	Bajocian	**m**	middle
		u	upper

Table 3. Burial history of well KB69 showing lithologies, thicknesses, ages and thermal maturation data of the different stratigraphic units. Key to lithologies: 0: erosion, 1: shale, 2: sand(stone), 3: chalk, 4: silt(stone). Begin (*b*)and end (*e*) ages are according to Harland et al. (1990) and Lippolt et al. (1984). Measured (*m*) VRm(%) values are from Langenaeker (in prep.). Calculated (*c*) VRm(%) values correspond to the base of the corresponding stratigraphical units.

Lith.	Thickness	Age-b	Age-e	Stratigraphy	Vrm%-m	VRm%-c
4	450.0	315.0	314.0	l WfA	2.357	
4	500.0	314.0	313.0	u WfA	1.68	1.744
4	300.0	313.0	312.0	l WfB	1.26	1.198
4	300.0	312.0	311.0	u WfB		
4	260.0	311.0	310.0	l WfC		
4	260.0	310.0	309.0	m WfC		
4	260.0	309.0	308.0	u WfC		
2	550.0	308.0	307.0	l WfD		
2	540.0	307.0	306.0	m WfD		
2	300.0	306.0	305.0	u WfD		
2	100.0	305.0	303.0	l St		
2	80.0	303.0	300.0	u St		
0	-2114.0	300.0	240.0			
2	440.0	240.0	235.0	Bunt		
1	70.0	235.0	220.0	Musch		
1	70.0	220.0	210.0	Keup		
1	50.0	210.0	208.0	Rhaet		
1	1400.0	208.0	176.0	Hett/Aalen		
0	-2740.0	176.0	84.0			
4	60.0	84.0	83.0	Sant/l Camp		0.313
3	80.0	83.0	74.0	u Camp/l Maastr		0.305
3	60.0	74.0	65.0	u Maastr		0.298
4	112.0	65.0	54.0	Paleoc/l Eoc		0.293
4	112.0	37.0	25.0	u Eoc/Olig		0.269
2	75.0	19.0	0.0	l Mioc/Quart		0.000

Table 4. Burial history of well KB79 showing lithologies, thicknesses, ages and thermal maturation data of the different stratigraphic units. Key to lithologies: 0: erosion, 1: shale, 2: sand(stone), 3: chalk, 4: silt(stone). Begin (b) and end (e) ages are according to Harland et al. (1990) and Lippolt et al. (1984). Measured (m) and extrapolated (e) VRm(%) values are from Langenaeker (in prep.). Calculated (c) VRm(%) values correspond to the base of the corresponding stratigraphical units.

Lith.	Thickness	Age-b	Age-e	Stratigraphy	Vrm%-m	VRm%-c
4	500.0	315.0	314.0	l WfA	1.739	
4	500.0	314.0	313.0	u WfA	1.19	1.237
4	270.0	313.0	312.0	l WfB	0.83(e)	
4	270.0	312.0	311.0	u WfB		
4	220.0	311.0	310.0	l WfC		
4	230.0	310.0	309.0	m WfC		
4	250.0	309.0	308.0	u WfC		
2	550.0	308.0	307.0	l WfD		
2	500.0	307.0	306.0	m WfD		
2	300.0	306.0	305.0	u WfD		
2	100.0	305.0	300.0	St		
0	-2300.0	300.0	240.0			
2	150.0	240.0	235.0	Bunt		
1	50.0	235.0	220.0	Musch		
1	50.0	220.0	210.0	Keup		
1	1350.0	210.0	176.0	Rhaet/Aalen		
0	-2000.0	176.0	84.0			
4	60.0	84.0	83.0	Sant/l Camp	0.322	
3	100.0	83.0	74.0	u Camp/l Maastr	0.312	
3	50.0	74.0	65.0	u Maastr	0.302	
4	157.0	65.0	54.0	Paleoc/l Eoc	0.298	
4	150.0	37.0	25.0	u Eoc/Olig	0.270	
2	25.0	19.0	16.0	l Mioc	0.243	
2	50.0	9.0	6.0	u Mioc	0.233	
	2	10.0	2.0	0.0	Quart	0.000

Table 5. Burial history of well KB81 showing lithologies, thicknesses, ages and thermal maturation data of the different stratigraphic units. Key to lithologies: 0: erosion, 1: shale, 2: sand(stone), 3: chalk, 4: silt(stone). Begin (b) and end (e) ages are according to Harland et al. (1990) and Lippolt et al. (1984). Measured (m) and extrapolated (e) VRm(%) values are from Langenaeker (in prep.). Calculated (c) VRm(%) values correspond to the base of the corresponding stratigraphical units.

Lith.	Thickness	Age-b	Age-e	Stratigraphy	Vrm%-m	VRm%-c
4	450.0	315.0	314.0	l WfA		2.468
4	450.0	314.0	313.0	u WfA		1.829
4	260.0	313.0	312.0	l WfB	1.32	1.315
4	250.0	312.0	311.0	u WfB	1.03(e)	
4	335.0	311.0	310.0	l WfC		
4	335.0	310.0	309.0	m WfC		
4	335.0	309.0	308.0	u WfC		
2	550.0	308.0	307.0	l WfD		
2	550.0	307.0	306.0	m WfD		
2	250.0	306.0	305.0	u WfD		
2	100.0	305.0	303.0	l St		
2	100.0	303.0	300.0	u St		
0	-2482.0	300.0	240.0			
2	480.0	240.0	235.0	Bunt		
1	75.0	235.0	220.0	Musch		
1	75.0	220.0	210.0	Keup		
1	1650.0	210.0	156.0	Rhaet/Bathon		
0	-2580.0	156.0	84.0			
4	75.0	84.0	83.0	Sant/l Camp		0.311
3	50.0	83.0	74.0	u Camp/l Maastr		0.302
3	95.0	74.0	65.0	u Maastr		0.298
4	85.0	65.0	54.0	Paleoc		0.285
4	112.0	37.0	25.0	u Eoc/Olig		0.264
2	40.0	19.0	16.0	l Mioc		0.242
2	10.0	2.0	0.0	Quart		0.000

Table 6. Burial history of well KB86 showing lithologies, thicknesses, ages and thermal maturation data of the different stratigraphic units. Key to lithologies: 0: erosion, 1: shale, 2: sand(stone), 3: chalk, 4: silt(stone). Begin (b) and end (e) ages are according to Harland et al. (1990) and Lippolt et al. (1984). Measured (m)VRm(%) values are from Langenaeker (in prep.). Calculated (c) VRm(%) values correspond to the base of the corresponding stratigraphical units.

Lith.	Thickness	Age-b	Age-e	Stratigraphy	Vrm%-m	VRm%-c
4	480.0	315.0	314.0	l WfA	1.82	1.835
4	500.0	314.0	313.0	u WfA	1.326	
4	270.0	313.0	312.0	l WfB		
4	270.0	312.0	311.0	u WfB		
4	220.0	311.0	310.0	l WfC		
4	230.0	310.0	309.0	m WfC		
4	250.0	309.0	308.0	u WfC		
2	500.0	308.0	307.0	l WfD		
2	500.0	307.0	306.0	m WfD		
2	300.0	306.0	305.0	u WfD		
2	100.0	305.0	303.0	l St		
2	100.0	303.0	300.0	u St		
0	-2340.0	300.0	240.0			
2	150.0	240.0	235.0	Bunt		
1	50.0	235.0	220.0	Musch		
1	50.0	220.0	210.0	Keup		
1	50.0	210.0	208.0	Rhaet		
1	1200.0	208.0	176.0	Hett/Aalen		
0	-2150.0	176.0	84.0			
4	60.0	84.0	83.0	Sant/l Camp		0.315
3	110.0	83.0	74.0	u Camp/l Maastr		0.306
3	30.0	74.0	65.0	u Maastr		0.297
4	120.0	65.0	54.0	Paleoc/l Eoc		0.293
4	152.0	37.0	25.0	u Eoc/Olig		0.270
2	20.0	19.0	0.0	l Mioc/Quart		0.000

Table 7. Burial history of well KB185 showing lithologies, thicknesses, ages and thermal maturation data of the different stratigraphic units. Key to lithologies: 0: erosion, 1: shale, 2: sand(stone), 3: chalk, 4: silt(stone). Begin (b)and end (e) ages are according to Harland et al. (1990) and Lippolt et al. (1984). Measured (m) VRm(%) values are from Langenaeker (in prep.). (Values) are measured above the base of a stratigraphic unit. Calculated (c) VRm(%) values correspond to the base of the corresponding stratigraphical units.

Lith.	Thickness	Age-b	Age-e	Stratigraphy	Vrm%-m	VRm%-c
4	500.0	315.0	314.0	l WfA		1.822
4	500.0	314.0	313.0	u WfA	(1.08)	1.302
4	286.0	313.0	312.0	l WfB	0.94	0.901
4	250.0	312.0	311.0	u WfB	0.74	0.764
4	220.0	311.0	310.0	l WfC		
4	230.0	310.0	309.0	m WfC		
4	250.0	309.0	308.0	u WfC		
2	550.0	308.0	307.0	l WfD		
2	500.0	307.0	306.0	m WfD		
2	300.0	306.0	305.0	u WfD		
2	150.0	305.0	300.0	St		
0	-2396.0	300.0	240.0			
2	370.0	240.0	235.0	Bunt		
1	60.0	235.0	220.0	Musch		
1	60.0	220.0	210.0	Keup		
1	1550.0	210.0	156.0	Rhaet/Bathon		
0	-2090.0	156.0	84.0			
4	65.0	84.0	83.0	Sant/l Camp		0.334
3	133.0	83.0	74.0	u Camp/l Maastr		0.322
3	50.0	74.0	65.0	u Maastr		0.305
4	174.0	65.0	53.0	Paleoc/l Eoc		0.301
4	165.0	37.0	25.0	u Eoc/Olig		0.273
2	35.0	19.0	16.0	l Mioc		0.244
2	125.0	9.0	5.0	u Mioc/l Plioc		0.234
2	10.0	3.0	0.0	u Plioc/Quart		0.000

Table 8. Burial history of well KB115 showing lithologies, thicknesses, ages and thermal maturation data of the different stratigraphic units. Key to lithologies: 0: erosion, 1: shale, 2: sand(stone), 3: chalk, 4: silt(stone). Begin (b) and end (e) ages are according to Harland et al. (1990) and Lippolt et al. (1984). Measured (m) and extrapolated (e) VRm(%) values are from Langenaeker (in prep.). (Values) are measured above the base of a stratigraphic unit. Calculated (c) VRm(%) values correspond to the base of the corresponding stratigraphical units.

Lith.	Thickness	Age-b	Age-e	Stratigraphy	Vrm%-m	VRm%-c
4	450.0	315.0	314.0	l WfA		2.088
4	450.0	314.0	313.0	u WfA	(1.54)	1.653
4	395.0	313.0	312.0	l WfB	1.36	1.311
4	290.0	312.0	311.0	u WfB	1.10	1.070
4	250.0	311.0	310.0	l WfC	0.855	0.898
4	250.0	310.0	309.0	m WfC	0.67(e)	
4	250.0	309.0	308.0	u WfC		
2	500.0	308.0	307.0	l WfD		
2	500.0	307.0	306.0	m WfD		
2	350.0	306.0	300.0	u WfD/St		
0	-1852.0	300.0	250.0			
4	25.0	250.0	245.0	u Zech		
2	490.0	245.0	235.0	Bunt		
1	70.0	235.0	220.0	Musch		
1	70.0	220.0	210.0	Keup		
1	1680.0	210.0	170.0	Rhaet/Bajoc		
0	-2335.0	170.0	84.0			
4	65.0	84.0	83.0	Sant/l Camp		0.319
3	60.0	83.0	72.0	u Camp/l Maastr		0.308
3	75.0	72.0	65.0	u Maastr		0.302
4	132.0	65.0	54.0	Paleoc/l Eoc		0.296
4	133.0	37.0	25.0	u Eoc/Olig		0.269
2	65.0	19.0	16.0	l Mioc		0.246
2	10.0	9.0	6.0	u Mioc		0.232
2	27.0	2.0	0.0	Quart		0.000

Table 9. Burial history of well KB163 showing lithologies, thicknesses, ages and thermal maturation data of the different stratigraphic units. Key to lithologies: 0: erosion, 1: shale, 2: sand(stone), 3: chalk, 4: silt(stone). Begin (b) and end (e) ages are according to Harland et al. (1990) and Lippolt et al. (1984). Measured (m) and extrapolated (e) VRm(%) values are from Langenaeker (in prep.). (Values) are measured above the base of a stratigraphic unit. Calculated (c) VRm(%) values correspond to the base of the corresponding stratigraphical units.

Lith.	Thickness	Age-b	Age-e	Stratigraphy	Vrm%-m	VRm%-c
4	450.0	315.0	314.0	l WfA		1.902
4	450.0	314.0	313.0	u WfA		1.495
4	300.0	313.0	312.0	l WfB	(1.13)	1.185
4	275.0	312.0	311.0	u WfB	1.02	1.006
4	250.0	311.0	310.0	l WfC	0.85	0.866
4	250.0	310.0	309.0	m WfC	0.69(e)	
4	250.0	309.0	308.0	u WfC		
2	500.0	308.0	307.0	l WfD		
2	500.0	307.0	306.0	m WfD		
2	300.0	306.0	300.0	u WfD/St		
0	-1801.0	300.0	250.0			
4	20.0	250.0	245.0	u Zech		
2	460.0	245.0	235.0	Bunt		
1	60.0	235.0	220.0	Musch		
1	60.0	220.0	210.0	Keup		
1	1650.0	210.0	170.0	Rhaet/Bajoc		
0	-2250.0	170.0	84.0			
4	66.0	84.0	83.0	Sant/l Camp		0.319
3	58.0	83.0	72.0	u Camp/l Maastr		0.308
3	80.0	72.0	65.0	u Maastr		0.302
4	124.0	65.0	53.0	Paleoc/l Eoc		0.295
4	133.0	37.0	25.0	u Eoc/Olig		0.269
2	63.0	19.0	16.0	l Mioc		0.244
2	22.0	9.0	5.0	u Mioc/l Plioc		0.232
2	14.0	3.0	0.0	u Plioc/Quart		0.000

Table 10. Burial history of well KB174 showing lithologies, thicknesses, ages and thermal maturation data of the different stratigraphic units. Key to lithologies: 0: erosion, 1: shale, 2: sand(stone), 3: chalk, 4: silt(stone). Begin (b) and end (e) ages are according to Harland et al. (1990) and Lippolt et al. (1984). Measured (m) VRm(%) values are from Langenaeker (in prep.). (Values) are measured above the base of a stratigraphic unit. Calculated (c) VRm(%) values correspond to the base of the corresponding stratigraphical units.

Lith.	Thickness	Age-b	Age-e	Stratigraphy	Vrm%-m	VRm%-c
4	500.0	315.0	314.0	l WfA		1.653
4	450.0	314.0	313.0	u WfA	(0.98)	1.179
4	287.0	313.0	312.0	l WfB	0.88	0.872
4	250.0	312.0	311.0	u WfB	0.74	0.758
4	220.0	311.0	310.0	l WfC		
4	220.0	310.0	309.0	m WfC		
4	220.0	309.0	308.0	u WfC		
2	500.0	308.0	307.0	l WfD		
2	500.0	307.0	306.0	m WfD		
2	350.0	306.0	300.0	u WfD/St		
0	-2111.0	300.0	250.0			
4	27.0	250.0	245.0	u Zech		0.709
2	430.0	245.0	235.0	Bunt		0.702
1	80.0	235.0	220.0	Musch		
1	80.0	220.0	210.0	Keup		
1	1550.0	210.0	156.0	Rhaet/Bathon		
0	-2049.0	156.0	84.0			
2	71.0	84.0	78.0	Sant/l Camp		0.324
3	89.0	78.0	70.0	u Camp/l Maastr		0.319
3	47.0	70.0	65.0	u Maastr		0.308
4	188.0	65.0	50.0	Paleoc/l Eoc		0.303
4	193.0	37.0	25.0	u Eoc/Olig		0.277
2	58.0	19.0	16.0	l Mioc		0.246
2	19.0	9.0	6.0	u Mioc		0.233
2	64.0	5.0	0.0	Plioc/Quart		0.000

Table 11. Burial history of well KB186 showing lithologies, thicknesses, ages and thermal maturation data of the different stratigraphic units. Key to lithologies: 0: erosion, 1: shale, 2: sand(stone), 3: chalk, 4: silt(stone). Begin (b) and end (e) ages are according to Harland et al. (1990) and Lippolt et al. (1984). Measured (m) VRm(%) values are from Langenaeker (in prep.). (Values) are measured above the base of a stratigraphic unit. Calculated (c) VRm(%) values correspond to the base of the corresponding stratigraphical units.

Lith.	Thickness	Age-b	Age-e	Stratigraphy	Vrm%-m	VRm%-c
4	500.0	315.0	314.0	l WfA		1.852
4	500.0	314.0	313.0	u WfA		1.408
4	260.0	313.0	312.0	l WfB		1.088
4	260.0	312.0	311.0	u WfB	0.96	0.933
4	200.0	311.0	310.0	l WfC	0.82	0.832
4	250.0	310.0	309.0	m WfC	(0.73)	0.766
4	250.0	309.0	308.0	u WfC		0.708
2	550.0	308.0	307.0	l WfD		
2	500.0	307.0	306.0	m WfD		
2	400.0	306.0	300.0	u WfD/St		
0	-1695.0	300.0	250.0			
4	20.0	250.0	245.0	u Zech		0.706
2	400.0	245.0	235.0	Bunt		
1	70.0	235.0	220.0	Musch		
1	70.0	220.0	210.0	Keup		
1	1580.0	210.0	156.0	Rhaet/Bathon		
0	-2120.0	156.0	84.0			
4	67.0	84.0	83.0	Sant/l Camp		0.340
3	102.0	83.0	74.0	u Camp/l Maastr		0.329
3	47.0	74.0	65.0	u Maastr		0.314
4	240.0	65.0	54.0	Paleoc		0.308
4	163.0	37.0	25.0	u Eoc/Olig		0.273
2	45.0	19.0	16.0	l Mioc		0.246
2	159.0	9.0	5.0	u Mioc/l Plioc		0.235
2	10.0	3.0	0.0	u Plioc/Quart		0.000

Table 12. Burial history of well KBLommel showing lithologies, thicknesses, ages and thermal maturation data of the different stratigraphic units. Key to lithologies: 0: erosion, 1: shale, 2: sand(stone), 3: chalk, 4: silt(stone). Begin (b) and end (e) ages are according to Harland et al. (1990) and Lippolt et al. (1984). Measured (m) VRm(%) values are from Langenaeker (in prep.). Calculated (c) VRm(%) values correspond to the base of the corresponding stratigraphical units.

Lith.	Thickness	Age-b	Age-e	Stratigraphy	VRm%-c
4	500.0	315.0	314.0	l WfA	2.255
4	500.0	314.0	313.0	u WfA	1.820
4	260.0	313.0	312.0	l WfB	1.447
4	260.0	312.0	311.0	u WfB	1.282
4	200.0	311.0	310.0	l WfC	1.135
4	250.0	310.0	309.0	m WfC	1.019
4	250.0	309.0	308.0	u WfC	0.888
2	550.0	308.0	307.0	l WfD	0.795
2	500.0	307.0	306.0	m WfD	
2	400.0	306.0	300.0	u WfD/St	
0	-1350.0	300.0	250.0		
4	20.0	250.0	245.0	u Zech	0.776
2	400.0	245.0	235.0	Bunt	0.771
1	90.0	235.0	220.0	Musch	
1	90.0	220.0	210.0	Keup	
1	1800.0	210.0	144.0	Rhaet/Oxford	
0	-2280.0	144.0	84.0		
2	80.0	84.0	78.0	Sant/l Camp	0.337
3	40.0	78.0	70.0	u Camp/l Maastr	0.331
3	55.0	70.0	65.0	u Maastr	0.325
4	300.0	65.0	50.0	Paleoc/l Eoc	0.317
4	140.0	37.0	25.0	u Eoc/Olig	0.272
2	80.0	19.0	16.0	l Mioc	0.249
2	180.0	9.0	6.0	u Mioc	0.237
2	50.0	5.0	0.0	Plioc/Quart	0.000

Table 13. Burial history of well KB168 showing lithologies, thicknesses, ages and thermal maturation data of the different stratigraphic units. Key to lithologies: 0: erosion, 1: shale, 2: sand(stone), 3: chalk, 4: silt(stone). Begin (b) and end (e) ages are according to Harland et al. (1990) and Lippolt et al. (1984). Measured (m) VRm(%) values are from Langenaeker (in prep.). Calculated (c) VRm(%) values correspond to the base of the corresponding stratigraphical units.

Lith.	Thickness	Age-b	Age-e	Stratigraphy	Vrm%-m	VRm%-c
4	450.0	315.0	314.0	l WfA		2.516
4	450.0	314.0	313.0	u WfA		2.086
4	300.0	313.0	312.0	l WfB		1.683
4	300.0	312.0	311.0	u WfB		1.443
4	250.0	311.0	310.0	l WfC		1.231
4	250.0	310.0	309.0	m WfC	0.925	1.085
4	250.0	309.0	308.0	u WfC		0.924
2	500.0	308.0	307.0	l WfD	0.77	0.814
2	500.0	307.0	306.0	m WfD		
2	250.0	306.0	300.0	u WfD/St		
0	-1168.0	300.0	250.0			
4	20.0	250.0	245.0	u Zech		
2	460.0	245.0	235.0	Bunt		
1	70.0	235.0	220.0	Musch		
1	70.0	220.0	210.0	Keup		
1	1700.0	210.0	170.0	Rhaet/Bajoc		
0	-2320.0	170.0	84.0			
4	85.0	83.0	78.0	Sant/l Camp		0.327
3	80.0	78.0	70.0	u Camp/l Maastr		0.311
3	59.0	70.0	67.0	u Maastr		0.302
4	134.0	67.0	54.0	Paleoc		0.297
4	151.0	37.0	25.0	u Eoc/Olig		0.272
2	85.0	19.0	16.0	l Mioc		0.246
2	41.0	9.0	5.0	u Mioc/l Plioc		0.233
2	18.0	3.0	0.0	u Plioc/Quart		0.000

Table 14. Burial history of well KB172 showing lithologies, thicknesses, ages and thermal maturation data of the different stratigraphic units. Key to lithologies: 0: erosion, 1: shale, 2: sand(stone), 3: chalk, 4: silt(stone). Begin (b) and end (e) ages are according to Harland et al. (1990) and Lippolt et al. (1984). Measured (m) VRm(%) values are from Langenaeker (in prep.). Calculated (c) VRm(%) values correspond to the base of the corresponding stratigraphical units.

Lith.	Thickness	Age-b	Age-e	Stratigraphy	Vrm%-m	VRm%-c
4	450.0	315.0	314.0	l WfA		2.648
4	450.0	314.0	313.0	u WfA		2.207
4	270.0	313.0	312.0	l WfB		1.790
4	260.0	312.0	311.0	u WfB		1.532
4	250.0	311.0	310.0	l WfC	1.32	1.323
4	240.0	310.0	309.0	m WfC		1.172
4	240.0	309.0	308.0	u WfC		1.039
2	500.0	308.0	307.0	l WfD	0.93	0.903
2	450.0	307.0	306.0	m WfD		
2	400.0	306.0	300.0	u WfD/St		
0	-1225.0	300.0	250.0			
4	22.0	250.0	245.0	u Zech	0.44	0.872
2	540.0	245.0	235.0	Bunt		0.864
1	85.0	235.0	220.0	Musch		
1	85.0	220.0	210.0	Keup		
1	1800.0	210.0	156.0	Rhaet/Bathon		
0	-2381.0	156.0	84.0			
4	78.0	84.0	83.0	Sant/l Camp	0.39	0.329
3	67.0	83.0	74.0	u Camp/l Maastr		0.314
3	77.0	74.0	65.0	u Maastr		0.305
3	155.0	65.0	54.0	Paleoc		0.298
4	142.0	37.0	25.0	u Eoc/Olig		0.271
2	106.0	19.0	16.0	l Mioc		0.249
2	46.0	9.0	5.0	u Mioc/l Plioc		0.233
2	10.0	3.0	0.0	u Plioc/Quart	0.000	

Table 15. Burial history of well KB201 showing lithologies, thicknesses, ages and thermal maturation data of the different stratigraphic units. Key to lithologies: 0: erosion, 1: shale, 2: sand(stone), 3: chalk, 4: silt(stone). Begin (b)and end (e) ages are according to Harland et al. (1990) and Lippolt et al. (1984). Measured (m) and extrapolated (e) VRm(%) values are from Langenaeker (in prep.). Calculated VRm(%) (c) values correspond to the base of the corresponding stratigraphical units.

Lith.	Thickness	Age-b	Age-e	Stratigraphy	Vrm%-m	VRm%-c
4	450.0	315.0	314.0	l WfA		2.889
4	450.0	314.0	313.0	u WfA		2.421
4	300.0	313.0	312.0	l WfB		1.993
4	300.0	312.0	311.0	u WfB		1.732
4	260.0	311.0	310.0	l WfC		1.477
4	260.0	310.0	309.0	m WfC		1.294
4	260.0	309.0	308.0	u WfC		1.128
2	550.0	308.0	307.0	l WfD		1.05(e)
2	400.0	307.0	306.0	m WfD		
2	400.0	306.0	300.0	u WfD/St		
0	-1360.0	300.0	250.0			
4	39.0	250.0	245.0	u Zech	0.47	0.961
2	600.0	245.0	235.0	Bunt		0.939
1	85.0	235.0	220.0	Musch		
1	85.0	220.0	210.0	Keup		
1	1900.0	210.0	156.0	Rhaet/Bathon		
0	-2216.0	156.0	84.0			
4	90.0	84.0	83.0	Sant/l Camp		0.337
3	75.0	83.0	74.0	u Camp/l Maastr		0.319
3	70.0	74.0	65.0	u Maastr		0.308
4	150.0	65.0	54.0	Paleoc/l Eoc		0.301
4	177.0	37.0	25.0	u Eoc/Olig		0.278
2	120.0	19.0	16.0	l Mioc		0.250
2	75.0	9.0	5.0	u Mioc/l Plioc		0.234
2	49.0	3.0	0.0	u Plioc/Quart		0.000

Table 16. Burial history of well KB198 showing lithologies, thicknesses, ages and thermal maturation data of the different stratigraphic units. Key to lithologies: 0: erosion, 1: shale, 2: sand(stone), 3: chalk, 4: silt(stone). Begin (b) and end (e) ages are according to Harland et al. (1990) and Lippolt et al. (1984). Measured (m) VRm(%) values are from Langenaeker (in prep.). (Values) are measured above the base of a stratigraphic unit. Calculated (c) VRm(%) values correspond to the base of the corresponding stratigraphical units.

Lith.	Thickness	Age-b	Age-e	Stratigraphy	Vrm%-m	VRm%-c
4	450.0	315.0	314.0	l WfA		3.567
4	450.0	314.0	313.0	u WfA		3.120
4	330.0	313.0	312.0	l WfB		2.628
4	330.0	312.0	311.0	u WfB		2.285
4	250.0	311.0	310.0	l WfC		1.958
4	250.0	310.0	309.0	m WfC		1.736
4	250.0	309.0	308.0	u WfC		1.508
2	550.0	308.0	307.0	l WfD		1.324
2	500.0	307.0	306.0	m WfD		
2	200.0	306.0	305.0	u WfD		
2	50.0	305.0	303.0	l St		
2	50.0	303.0	300.0	u St		
0	-800.0	300.0	250.0			
4	40.0	250.0	245.0	u Zech		1.117
2	700.0	245.0	235.0	Bunt		1.095
1	100.0	235.0	220.0	Musch		0.862
1	100.0	220.0	210.0	Keup		0.821
1	1980.0	210.0	144.0	Rhaet/Oxford	(0.46)	0.782
0	-1280.0	144.0	74.0			
3	27.0	74.0	65.0	Maastr.	0.30	0.333
4	150.0	65.0	54.0	Paleoc/l Eoc		0.325
4	333.0	37.0	25.0	u Eoc/Olig		0.305
2	369.0	19.0	16.0	l Mioc		0.259
2	169.0	9.0	5.0	u Mioc/l Plioc		0.237
2	236.0	3.0	0.0	u Plioc/Quart		0.000

FIGURES

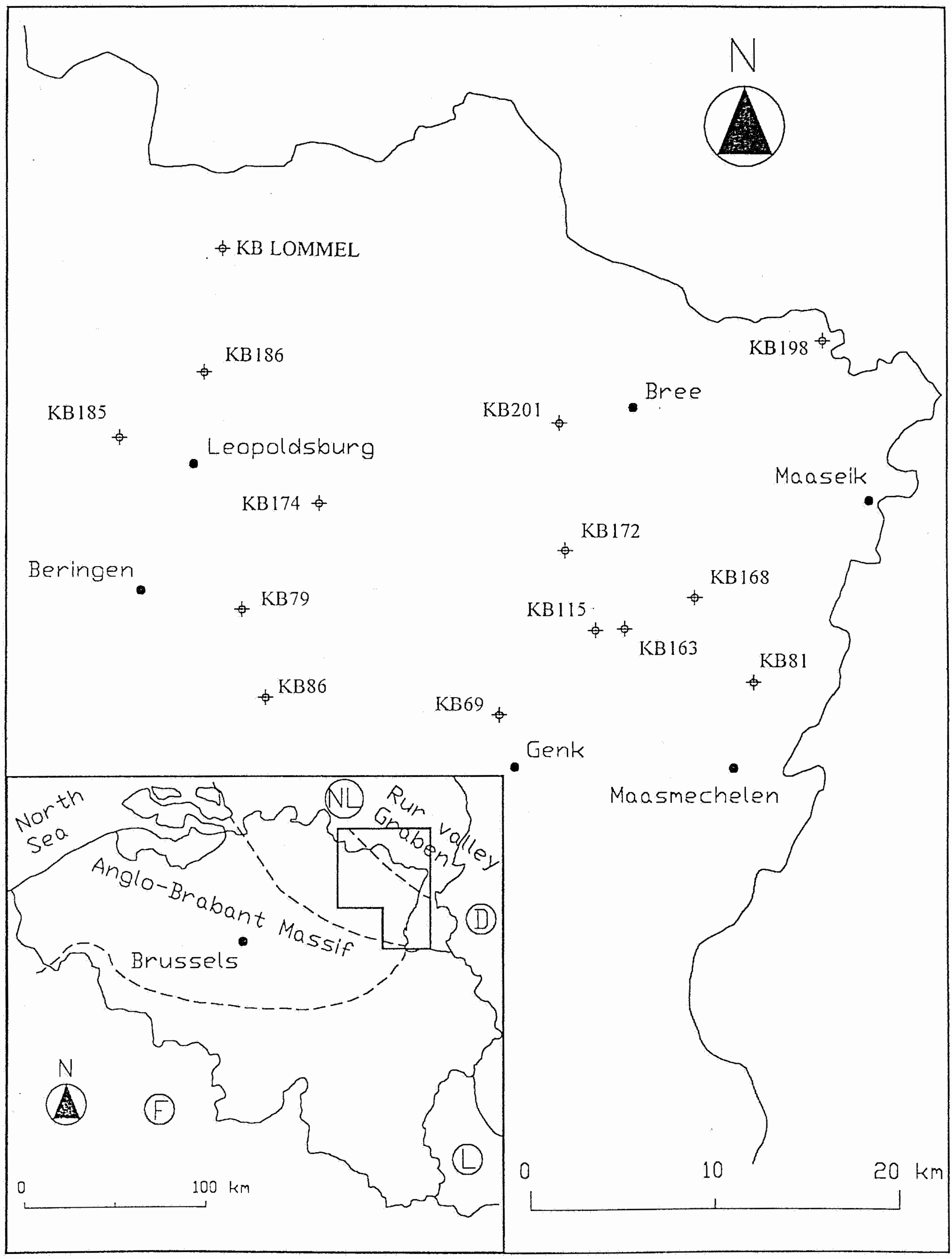


Fig. 1. Location of the studied wells. Corresponding localities for the wells are Winterslag-Genk (KB69), Zolder (KB79, KB86), Eisden (KB81), Opglabbeek (KB115), Opoeteren (KB163, KB168), Gruitrode (KB172), Hechtel (KB174), Oostham (KB185), Lommel (KB186, KBLom.), Molenbeersel (KB198) and Bree (KB201).

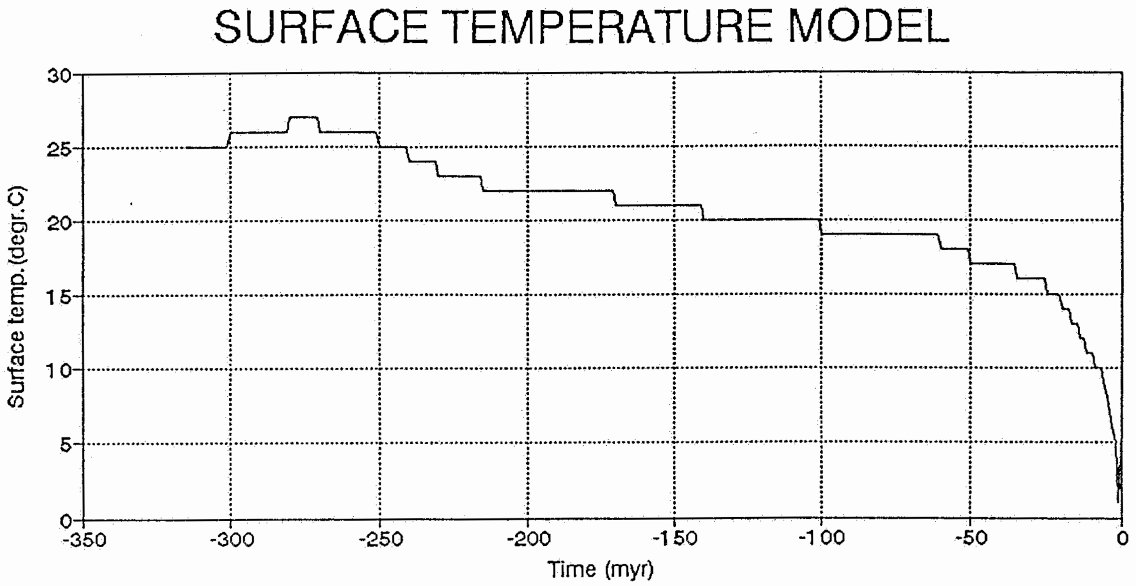


Fig. 2. Surface temperature model for the Campine Basin, showing the evolution of temperature in time.

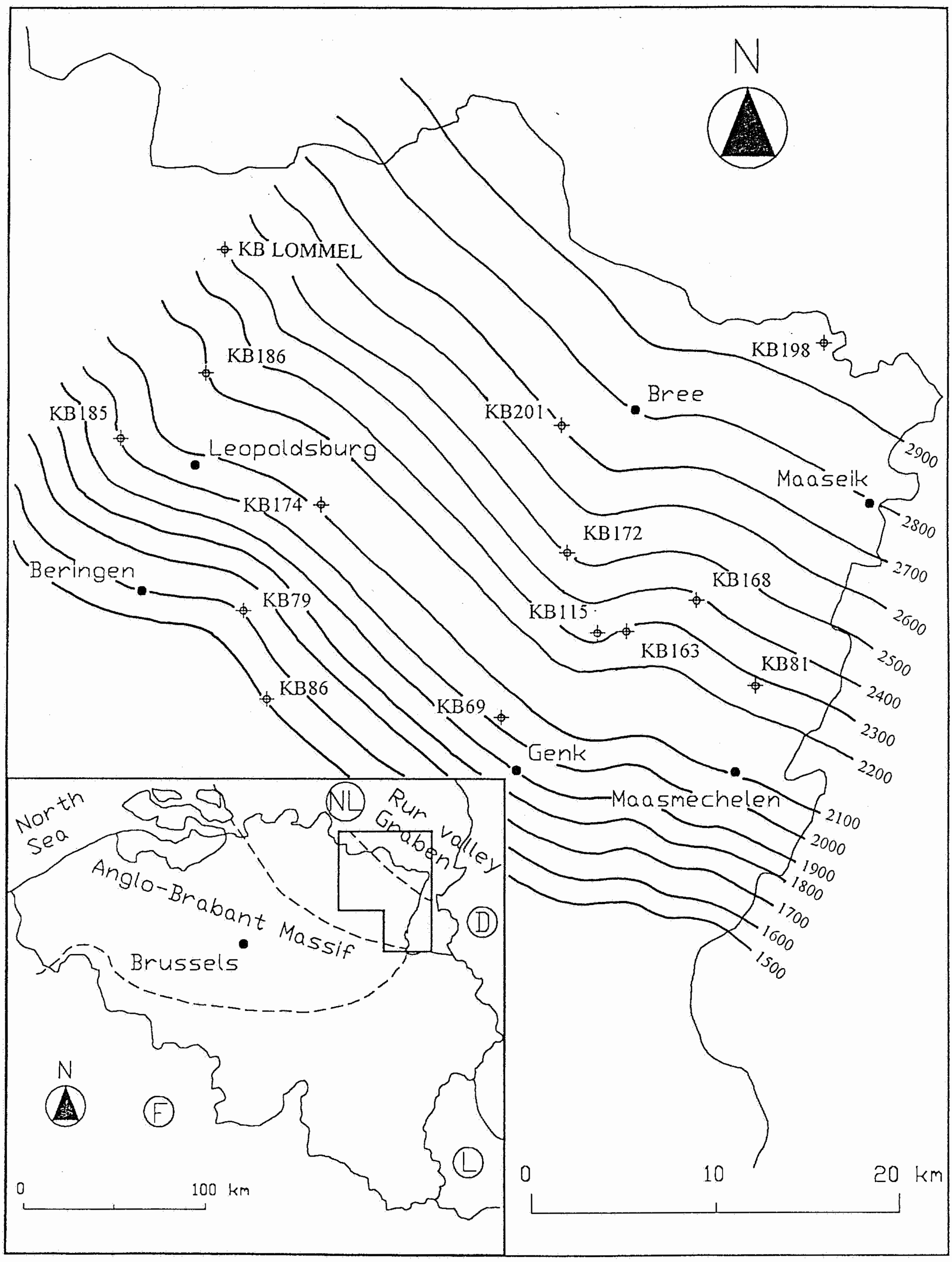


Fig. 3. Isopach map for Permian through Jurassic strata in the eastern Campine Basin.

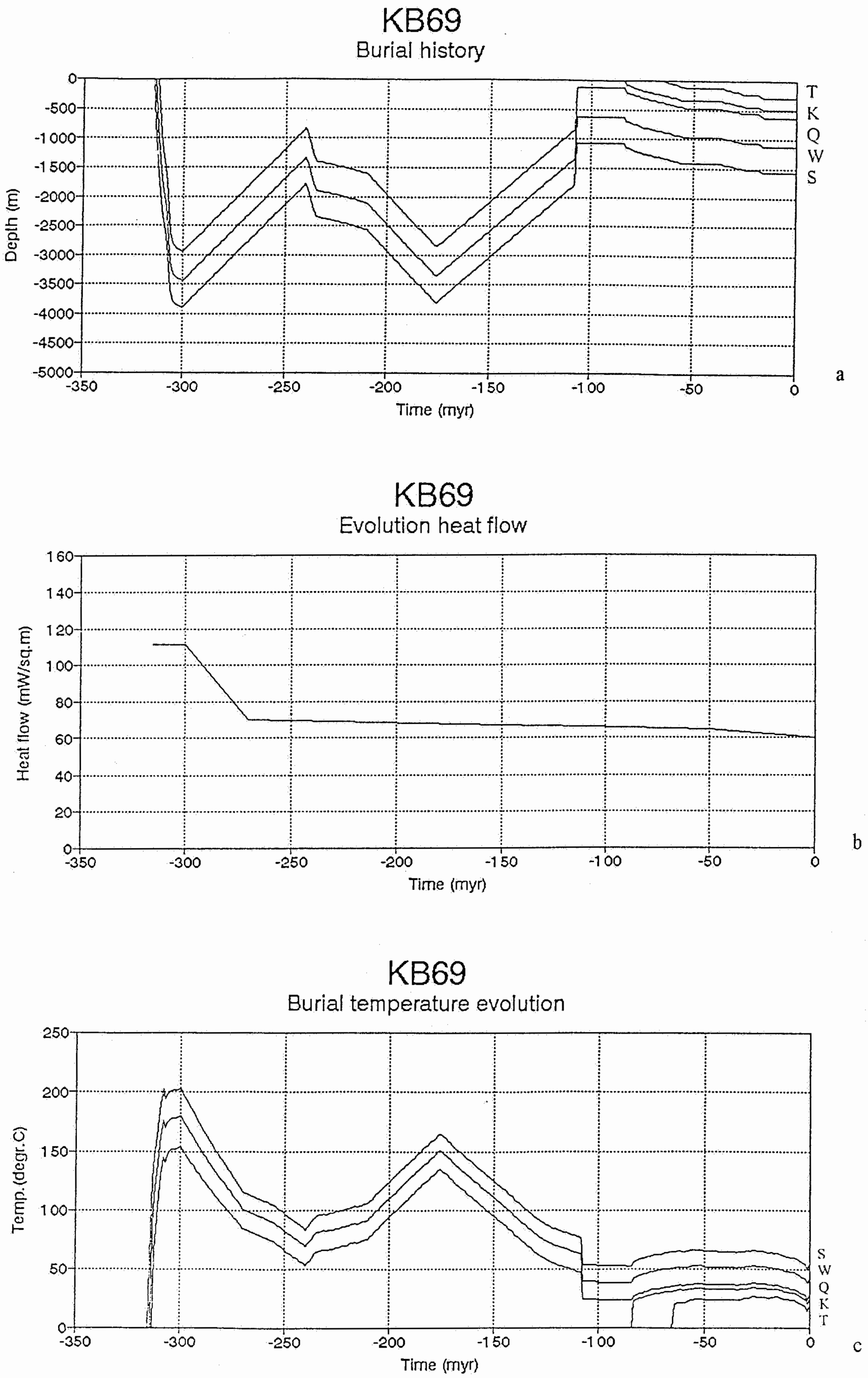


Fig. 4. Burial history (a), evolution heat flow (b) and burial temperature (c) in the deep well KB69. Key to stratigraphic markers: *S*: Sarnsbank M.B., *W*: Wasserfall M.B., *Q*: Quaregnon M.B., *K*: Base Cretaceous, *T*: Base Tertiary.

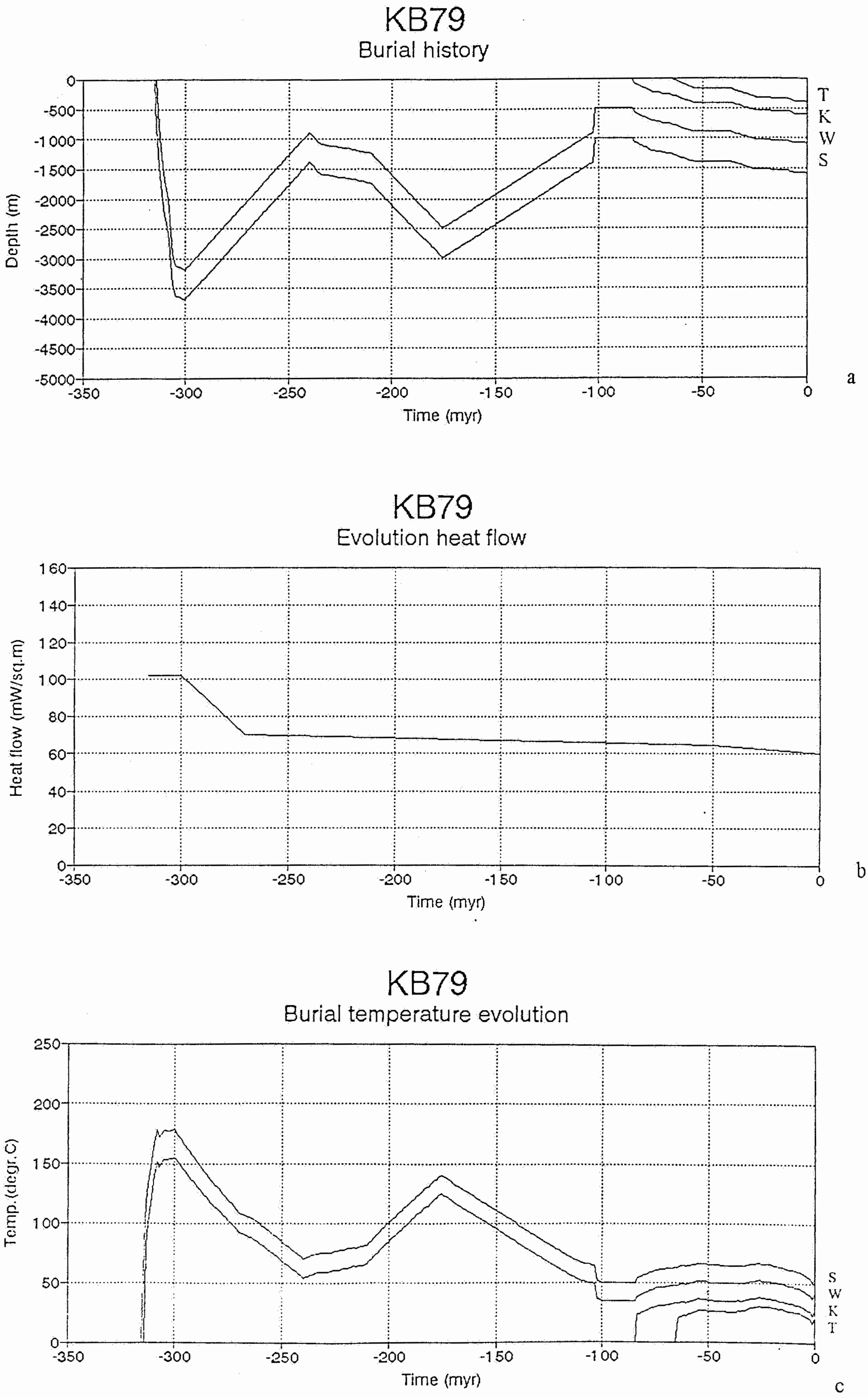


Fig. 5. Burial history (a), evolution heat flow (b) and burial temperature (c) in the deep well KB79. Key to stratigraphic markers: *S*: Sarnsbank M.B., *W*: Wasserfall M.B., *K*: Base Cretaceous, *T*: Base Tertiary.

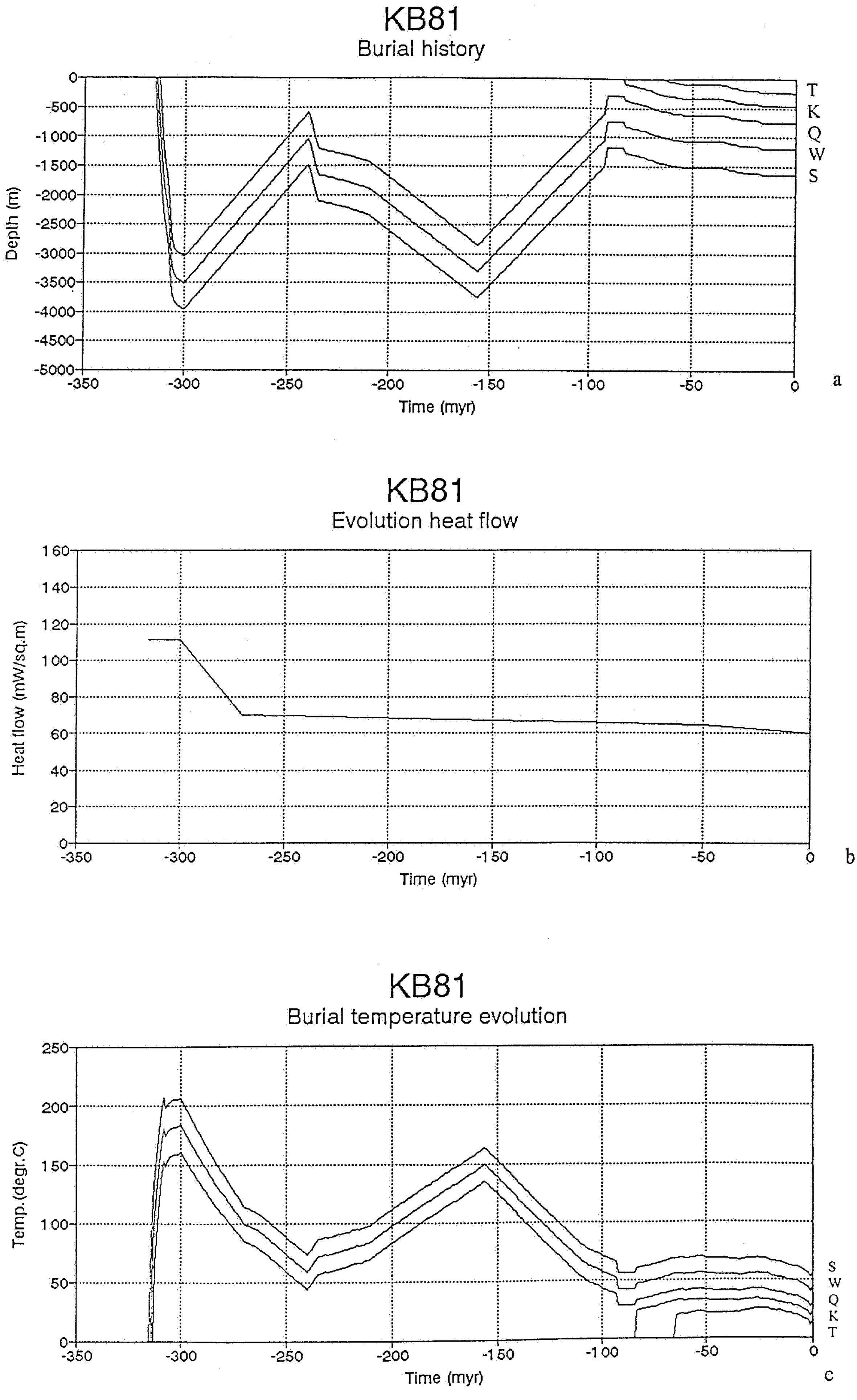


Fig. 6. Burial history (a), evolution heat flow (b) and burial temperature (c) in the deep well KB81. Key to stratigraphic markers: *S*: Sarnsbank M.B., *W*: Wasserfall M.B., *Q*: Quaregnon M.B., *K*: Base Cretaceous, *T*: Base Tertiary.

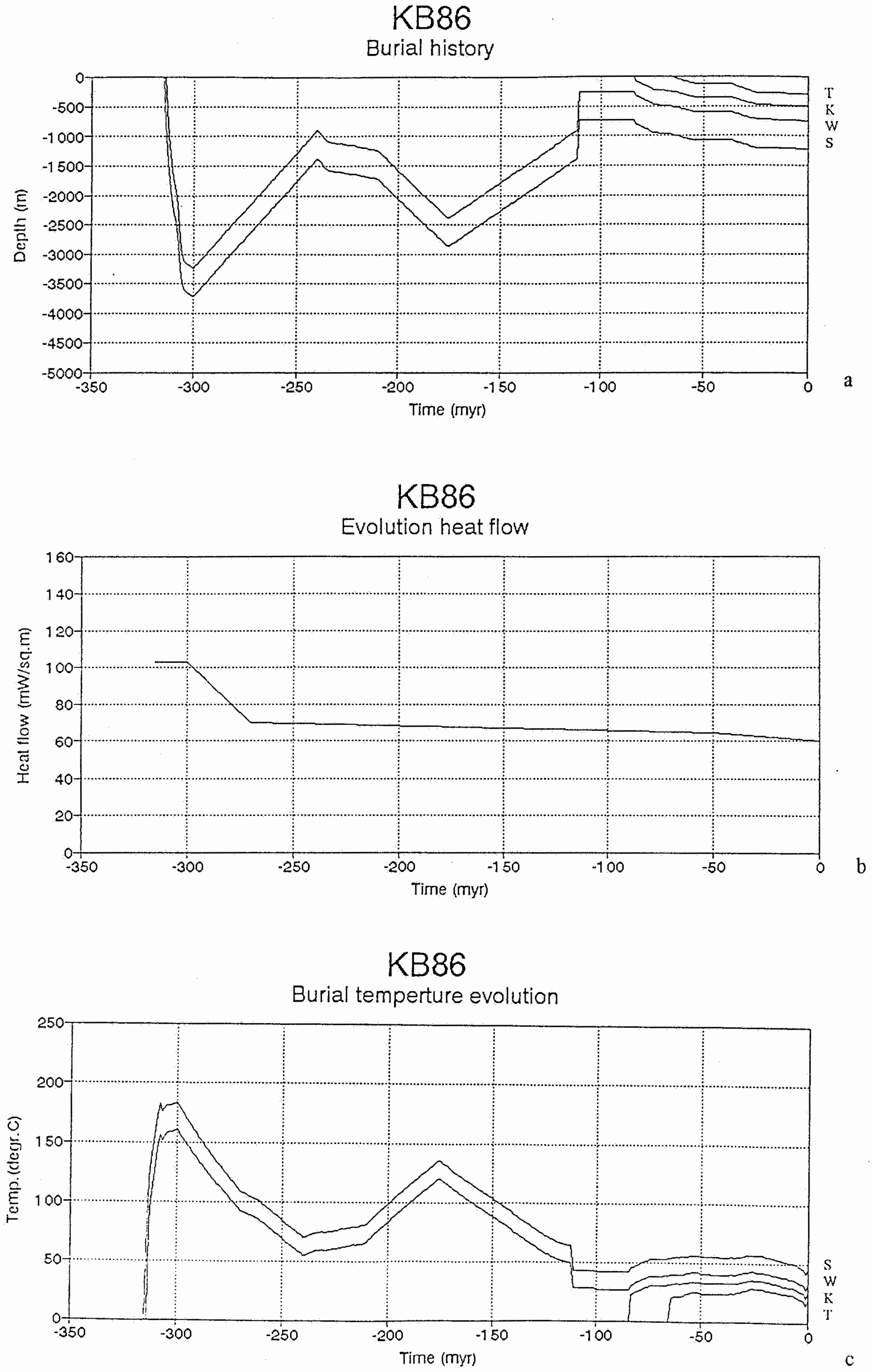


Fig. 7. Burial history (a), evolution heat flow (b) and burial temperature (c) in the deep well KB86. Key to stratigraphic markers: *S*: Samsbank M.B., *W*: Wasserfall M.B., *K*: Base Cretaceous, *T*: Base Tertiary.

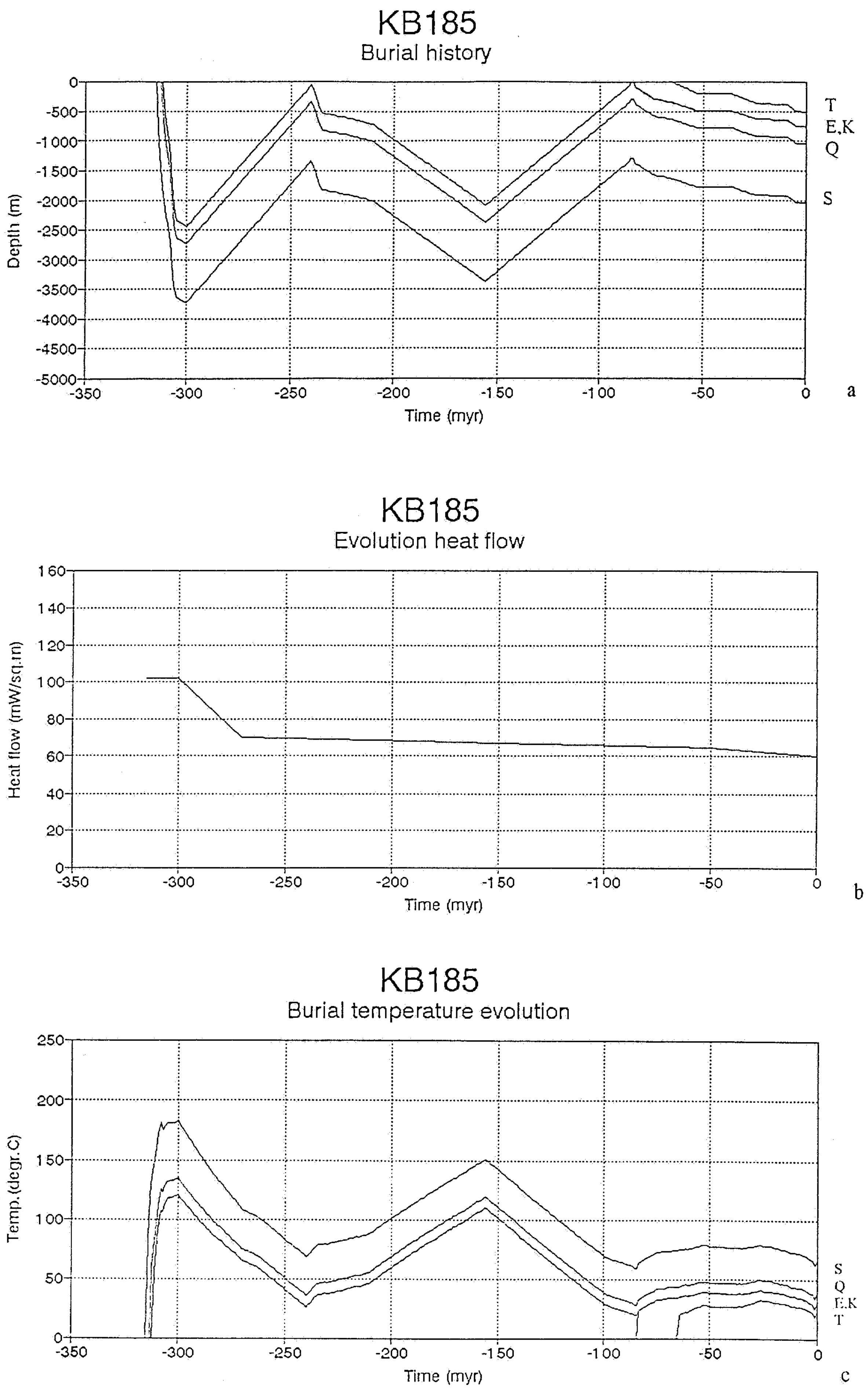


Fig. 8. Burial history (a), evolution heat flow (b) and burial temperature (c) in the deep well KB185. Key to stratigraphic markers: *S*: Sarnsbank M.B., *Q*: Quaregnon M.B., *E*: Eisden M.B., *K*: Base Cretaceous. *T*: Base Tertiary.

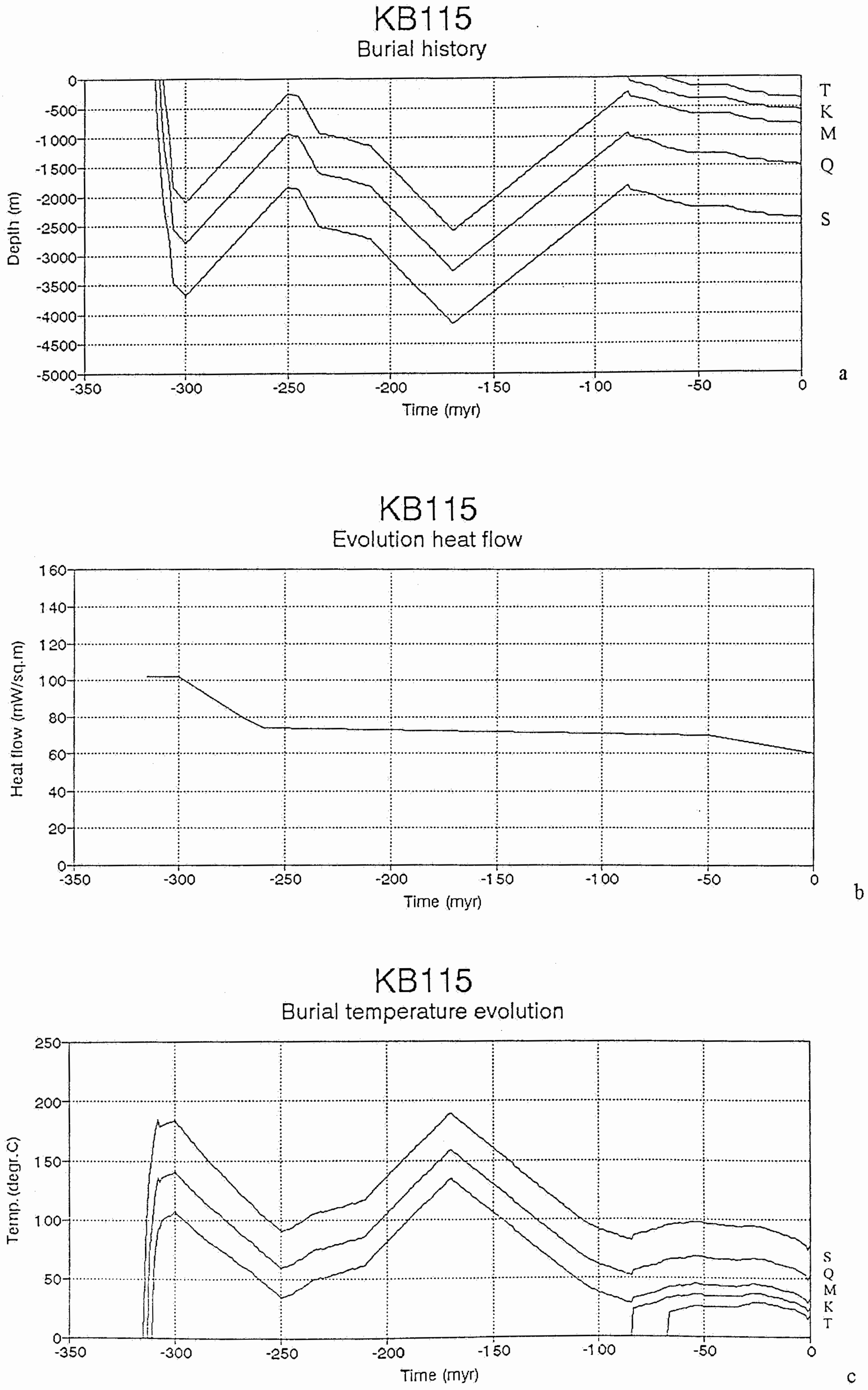


Fig. 9. Burial history (a), evolution heat flow (b) and burial temperature (c) in the deep well KB115. Key to stratigraphic markers: *S*: Samsbank M.B., *Q*: Quaregnon M.B., *M*: Maurage M.B., *K*: Base Cretaceous, *T*: Base Tertiary.

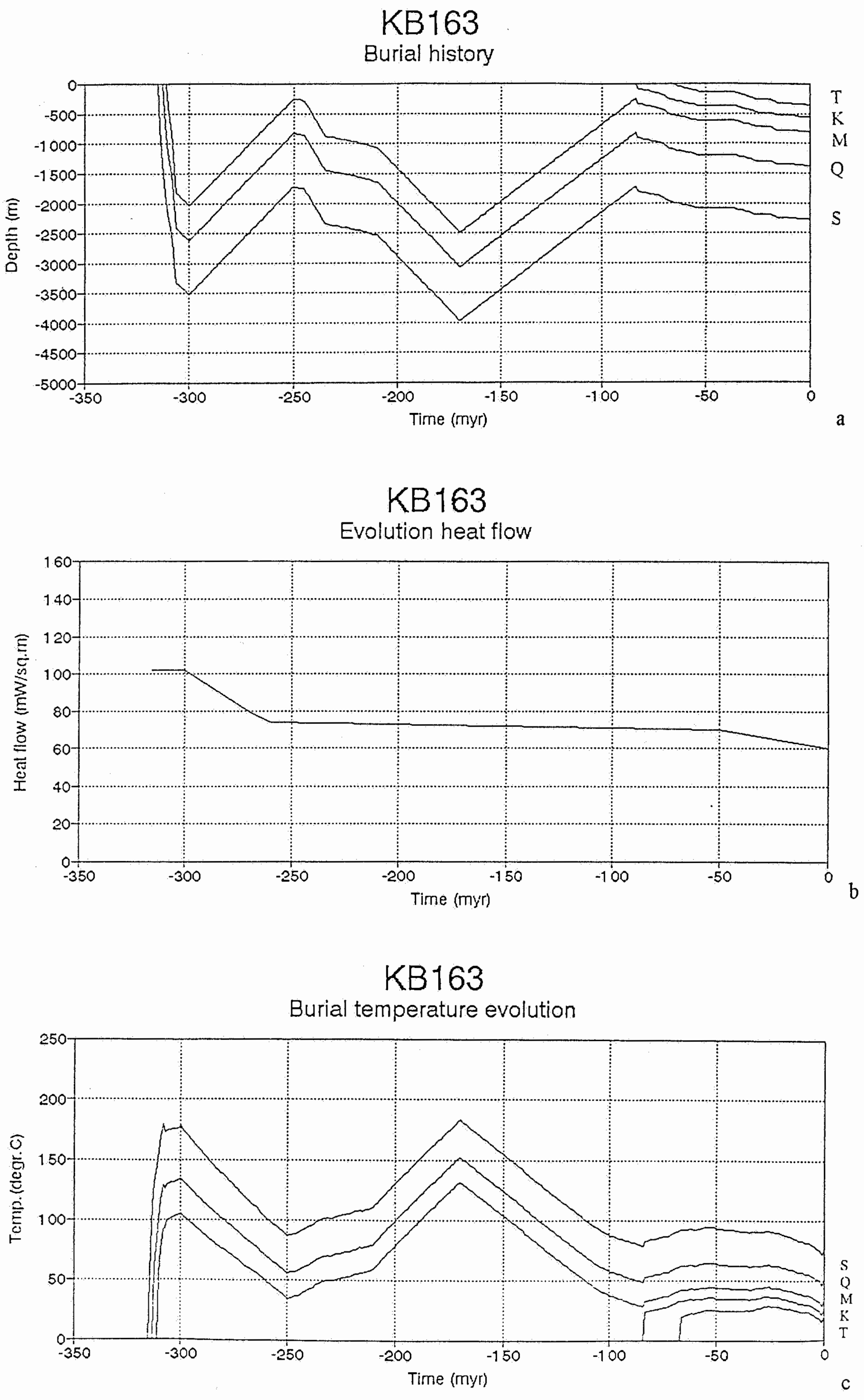


Fig. 10. Burial history (a), evolution heat flow (b) and burial temperature (c) in the deep well KB163. Key to stratigraphic markers: *S*: Sarusbank M.B., *Q*: Quaregnon M.B., *M*: Maurage M.B., *K*: Base Cretaceous, *T*: Base Tertiary.

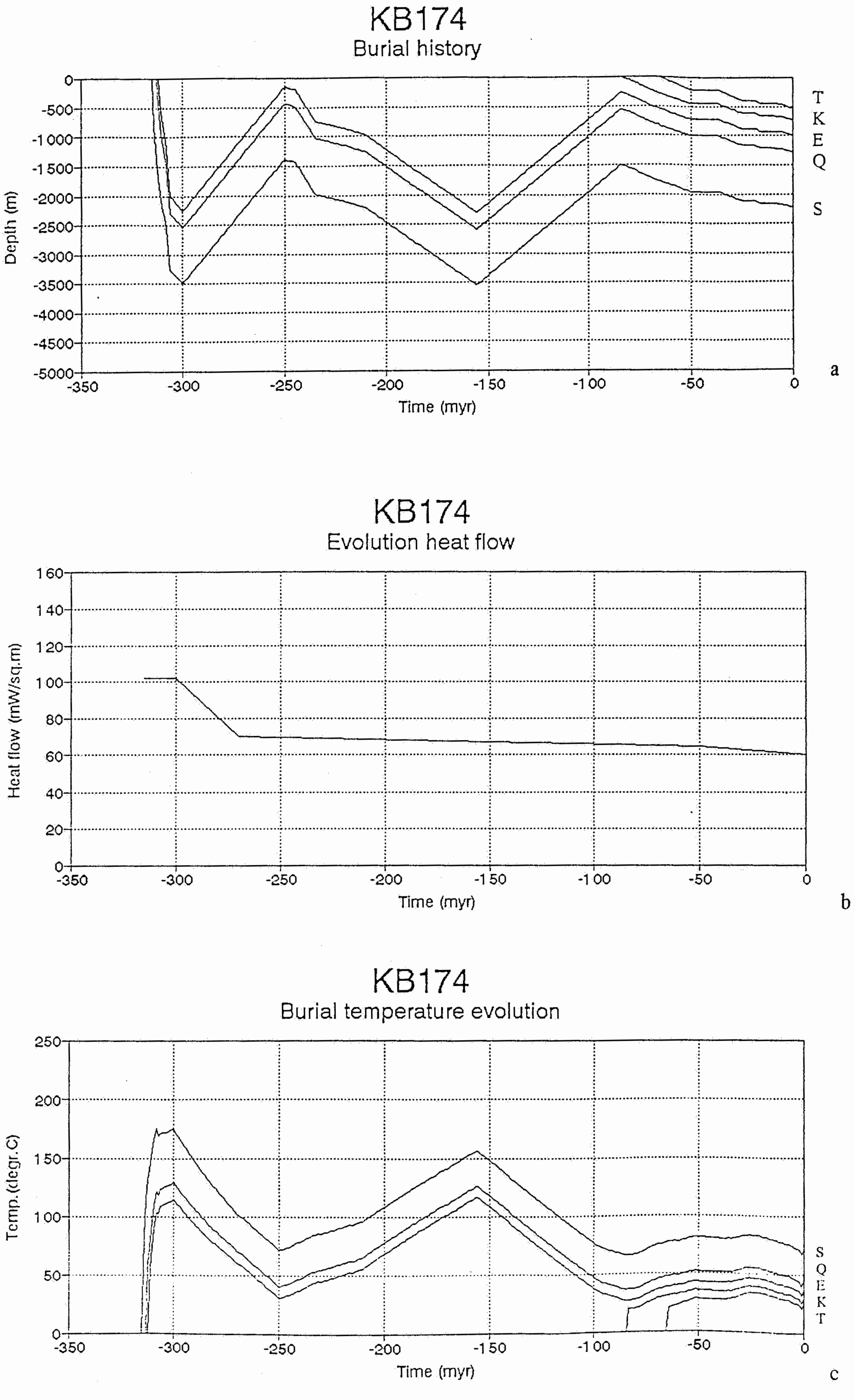


Fig. 11. Burial history (a), evolution heat flow (b) and burial temperature (c) in the deep well KB174. Key to stratigraphic markers: *S*: Sarnsbank M.B., *Q*: Quaregnon M.B., *E*: Eisden M.B. *K*: Base Cretaceous, *T*: Base Tertiary.

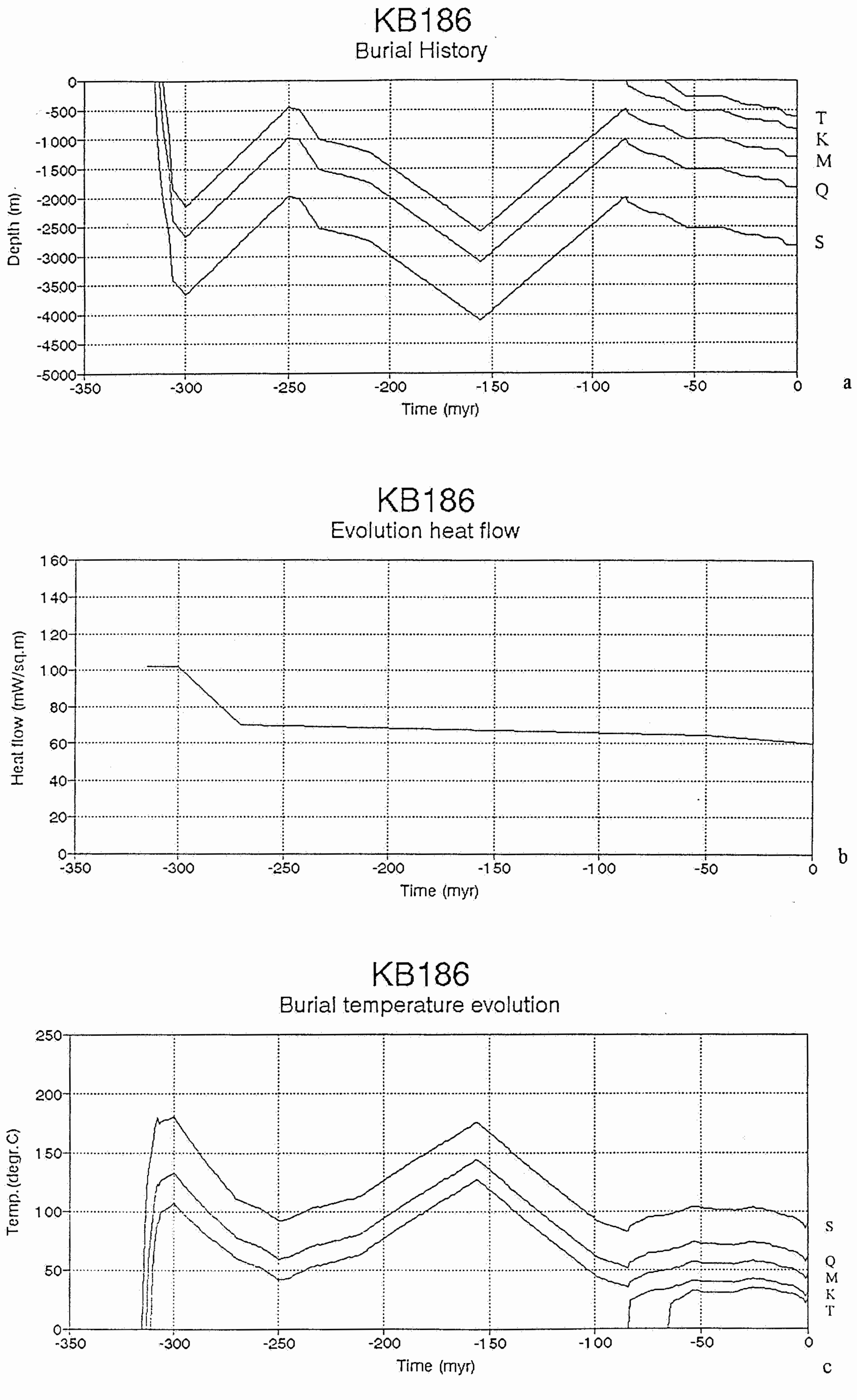


Fig. 12. Burial history (a), evolution heat flow (b) and burial temperature (c) in the deep well KB186. Key to stratigraphic markers: *S*: Samsbank M.B., *Q*: Quaregnon M.B., *M*: Maurage M.B., *K*: Base Cretaceous, *T*: Base Tertiary.

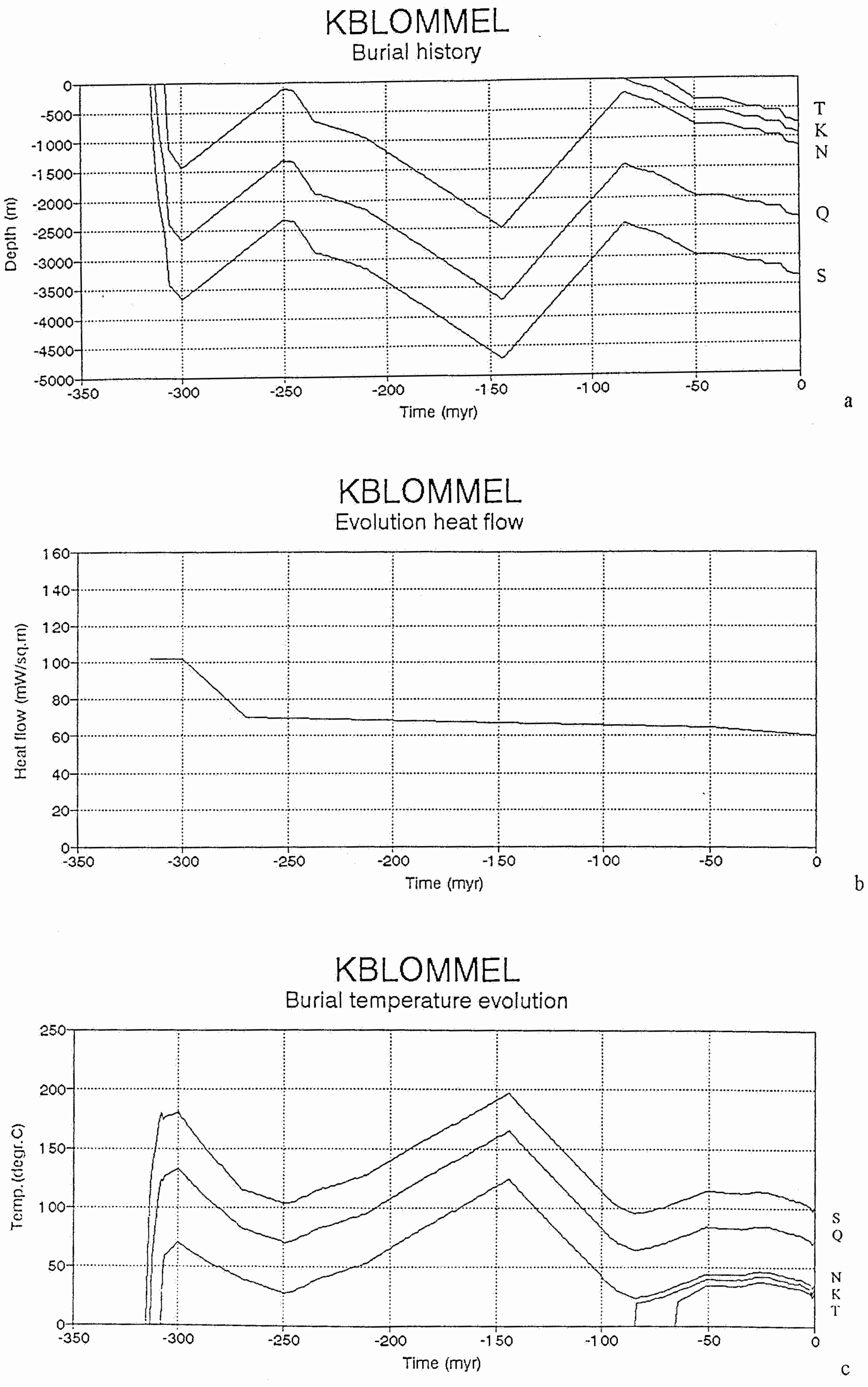


Fig. 13. Burial history (a), evolution heat flow (b) and burial temperature (c) in the deep well KBLommel. Key to stratigraphic markers: *S*: Samsbank M.B., *Q*: Quaregnon M.B., *N*: Base Neeroeteren Sst., *K*: Base Cretaceous, *T*: Base Tertiary.

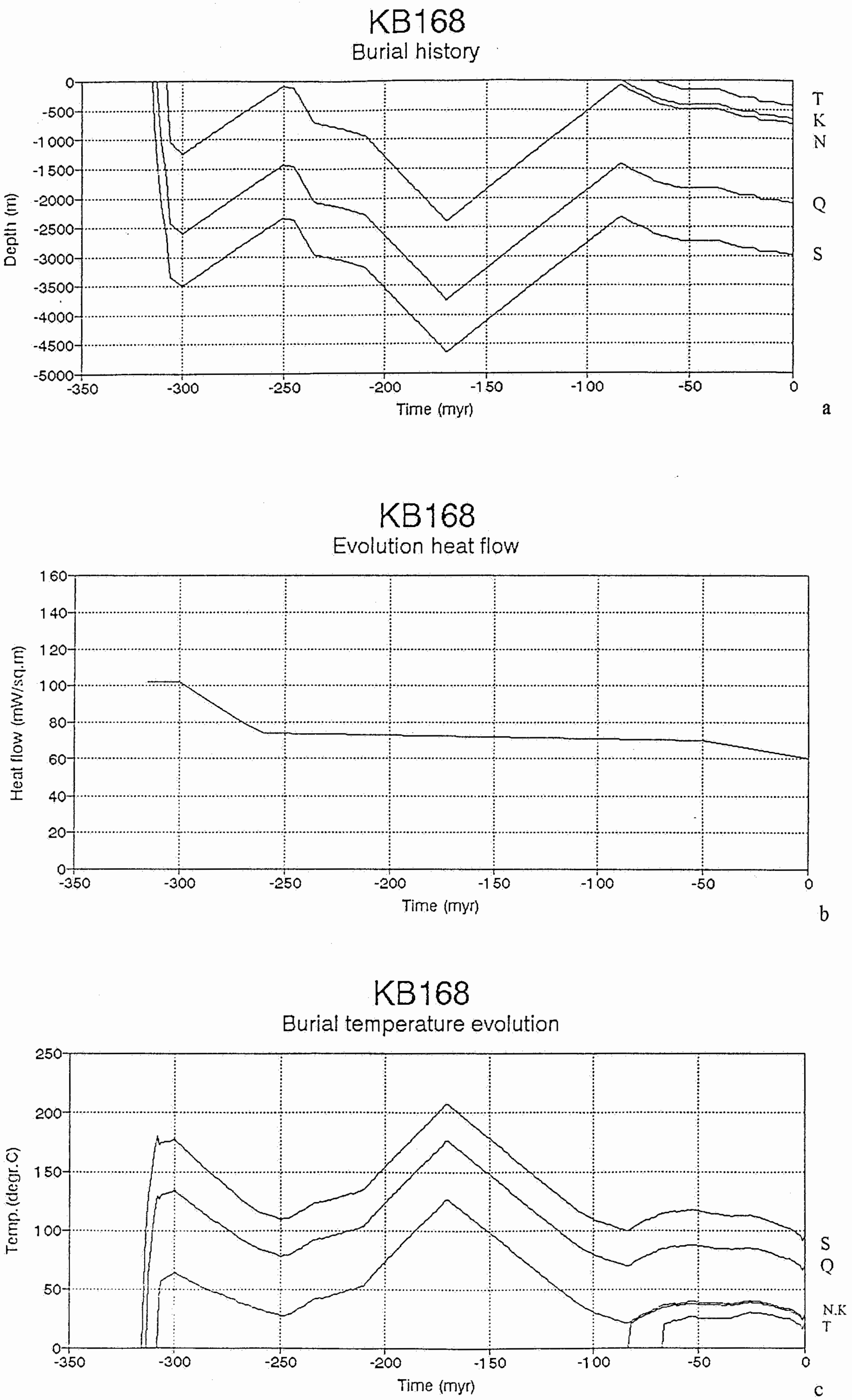


Fig. 14. Burial history (a), evolution heat flow (b) and burial temperature (c) in the deep well KB168. Key to stratigraphic markers: *S*: Sarnsbank M.B., *Q*: Quaregnon M.B., *N*: Base Neeroeteren Sst., *K*: Base Cretaceous, *T*: Base Tertiary.

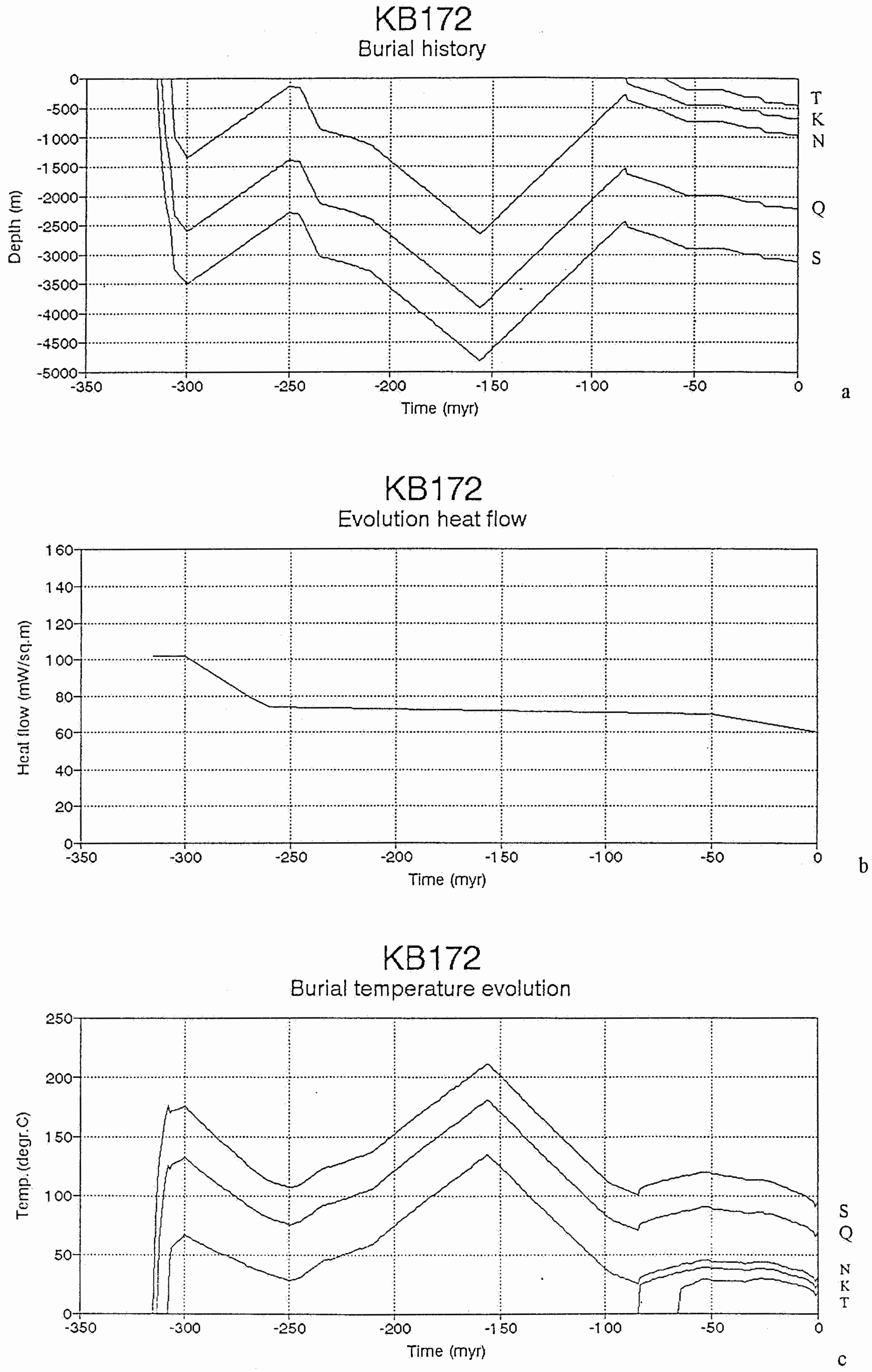


Fig. 15. Burial history (a), evolution heat flow (b) and burial temperature (c) in the deep well KB172. Key to stratigraphic markers: *S*: Samsbank M.B., *Q*: Quaregnon M.B., *N*: Base Neeroeteren Sst., *K*: Base Cretaceous, *T*: Base Tertiary.

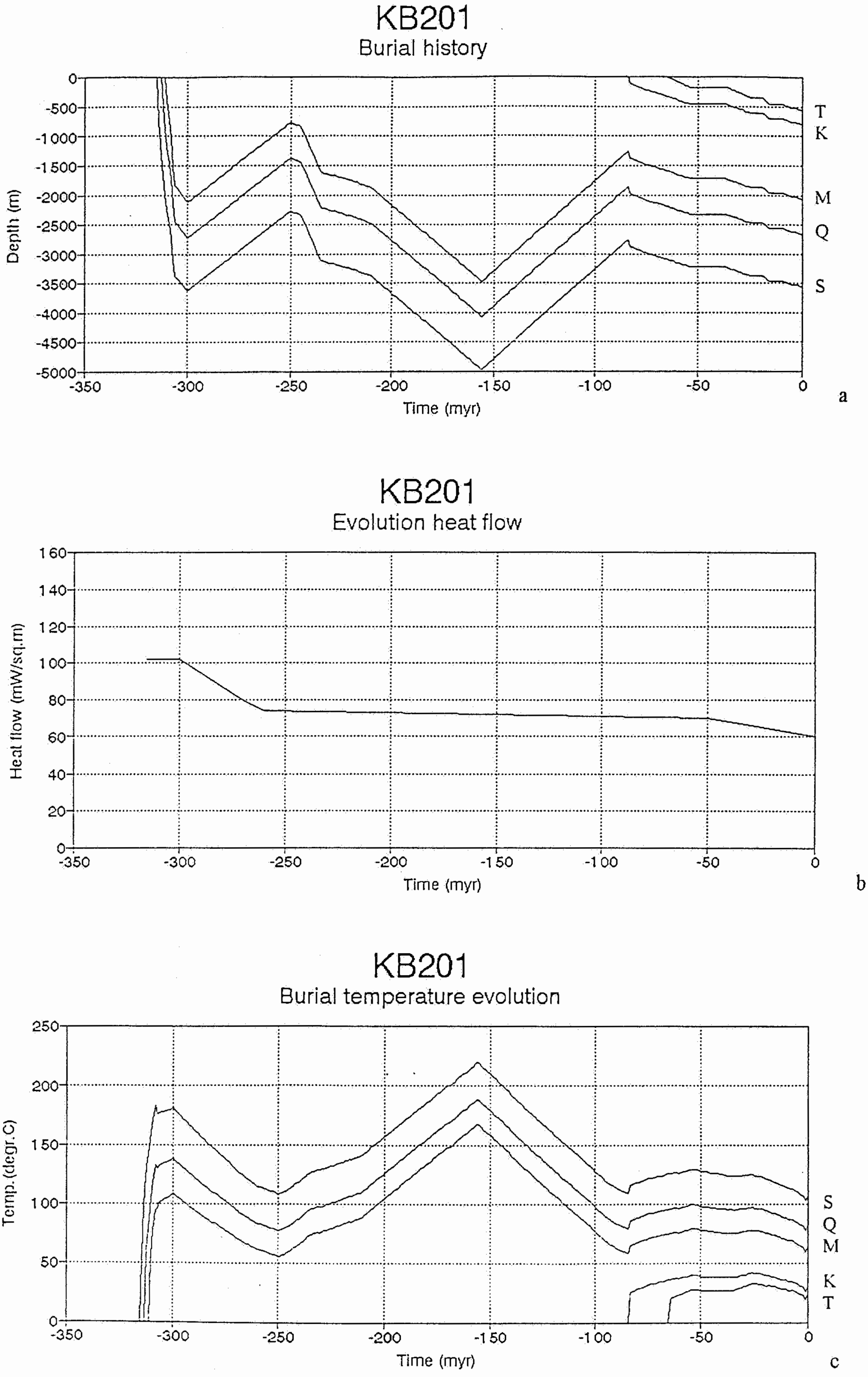


Fig. 16. Burial history (a), evolution heat flow (b) and burial temperature (c) in the deep well KB201. Key to stratigraphic markers: *S*: Samsbank M.B., *Q*: Quaregnon M.B., *M*: Maurage M.B., *K*: Base Cretaceous, *T*: Base Tertiary.

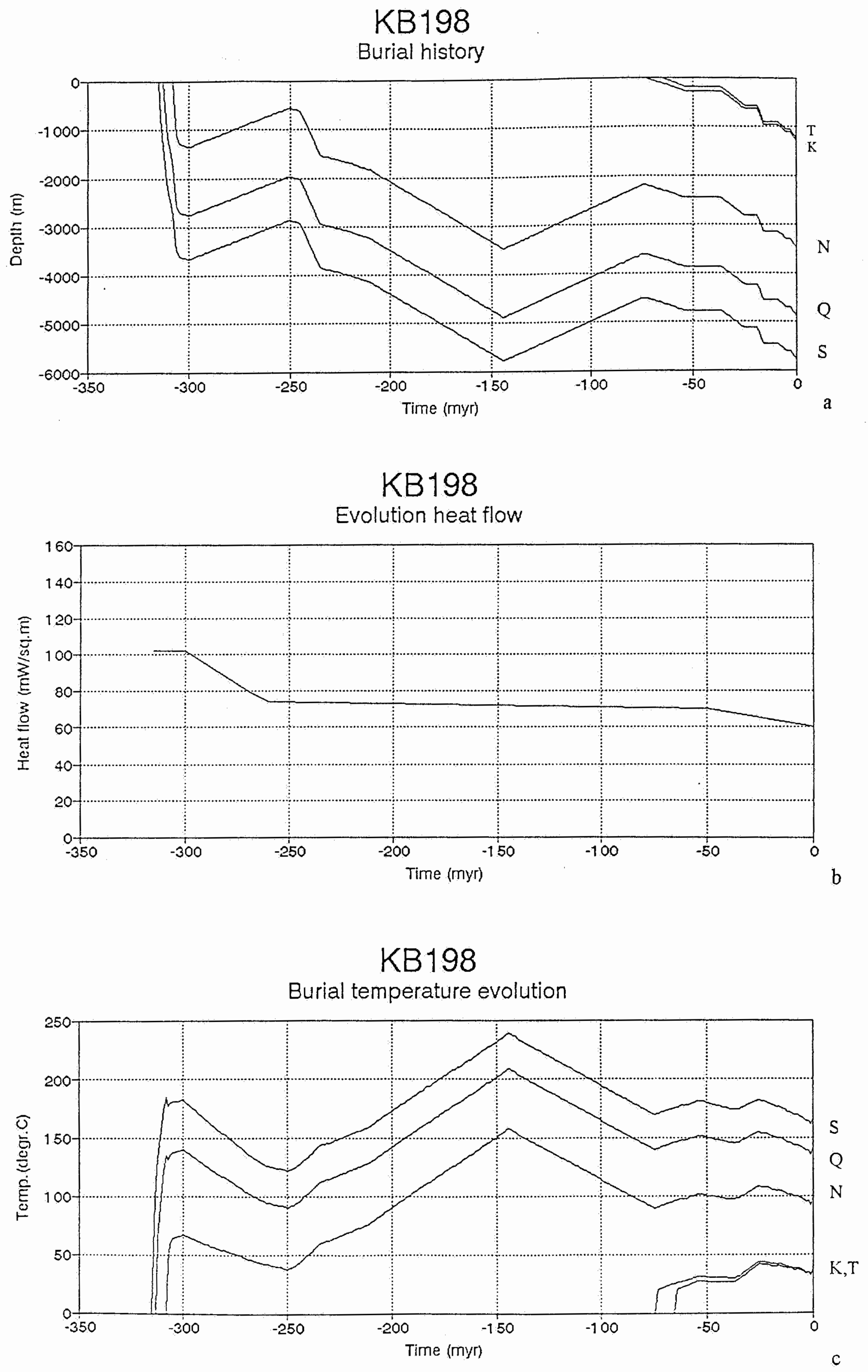


Fig. 17. Burial history (a), evolution heat flow (b) and burial temperature (c) in the deep well KB198. Key to stratigraphic markers: *S*: Samsbank M.B., *Q*: Quaregnon M.B., *N*: Base Neeroeteren Sst., *K*: Base Cretaceous, *T*: Base Tertiary.

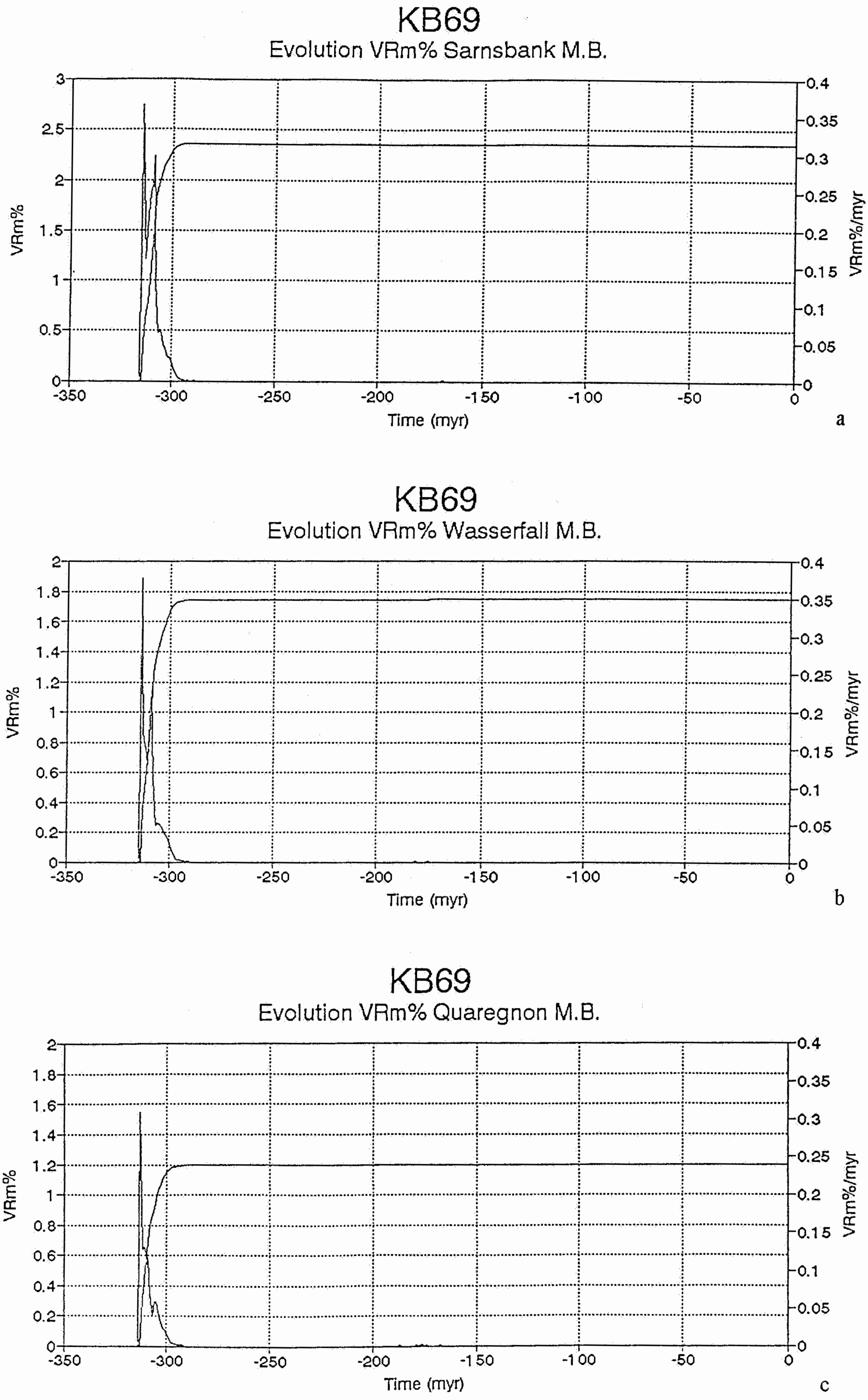


Fig. 18. Evolution of VRm(%) (continuous line) and VRm(%)/myr (dashed line) in the deep well KB69 (a: Sarnsbank M.B., b: Wasserfall M.B., c: Quaregnon M.B.)

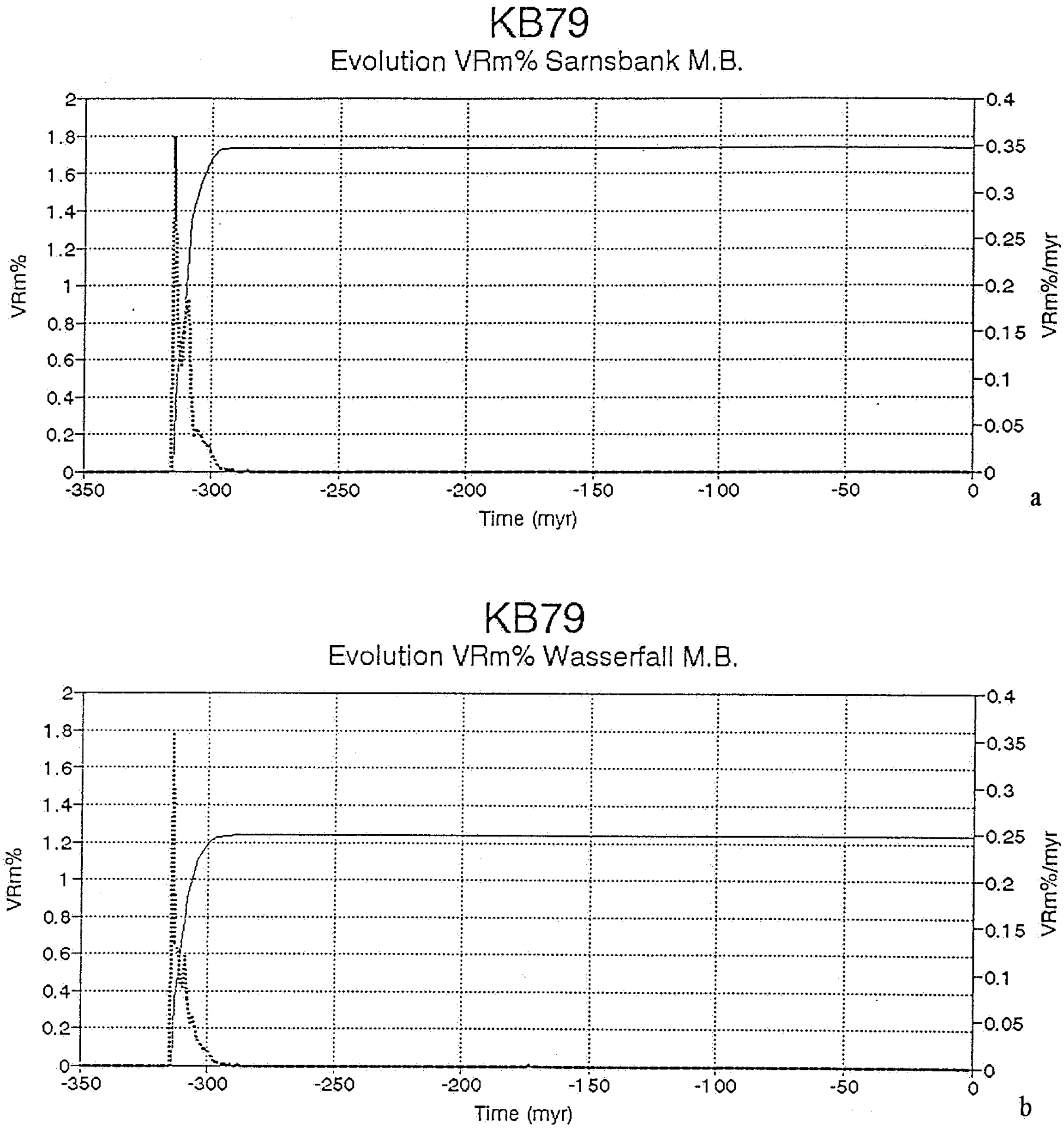


Fig. 19. Evolution of VRm(%) (continuous line) and VRm(%)/myr (dashed line) in the deep well KB79 (a: Sarnsbank M.B., b: Wasserfall M.B.)

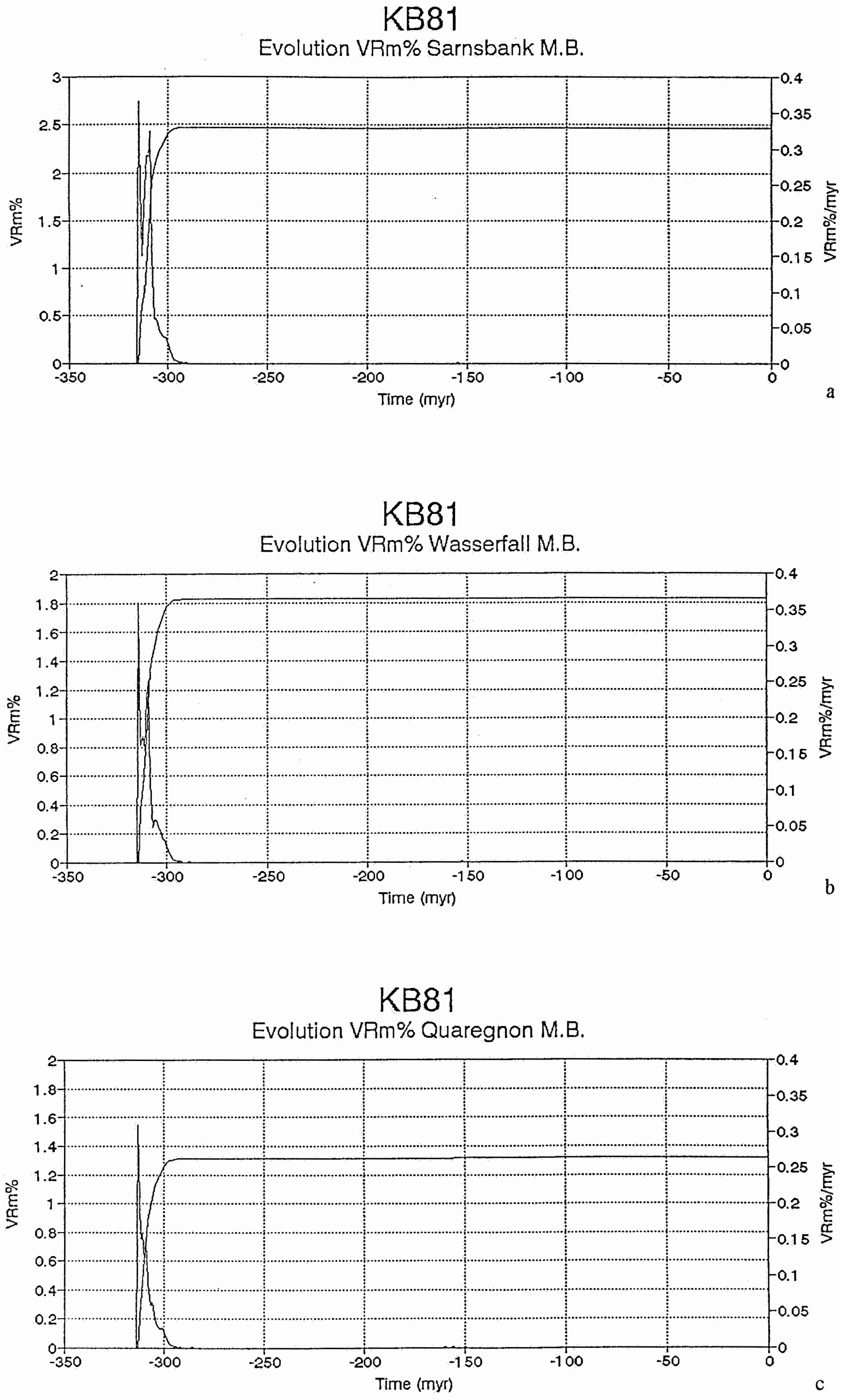
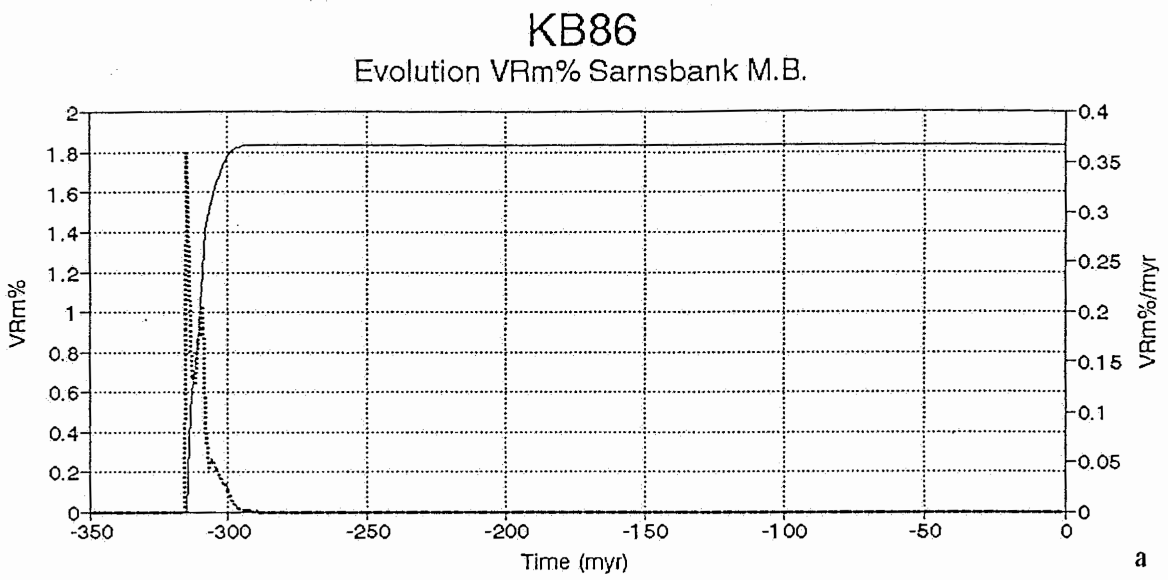


Fig. 20. Evolution of VRm(%) (continuous line) and VRm(%)/myr (dashed line) in the deep well KB81 (a: Sarnsbank M.B., b: Wasserfall M.B., c: Quaregnon M.B.)



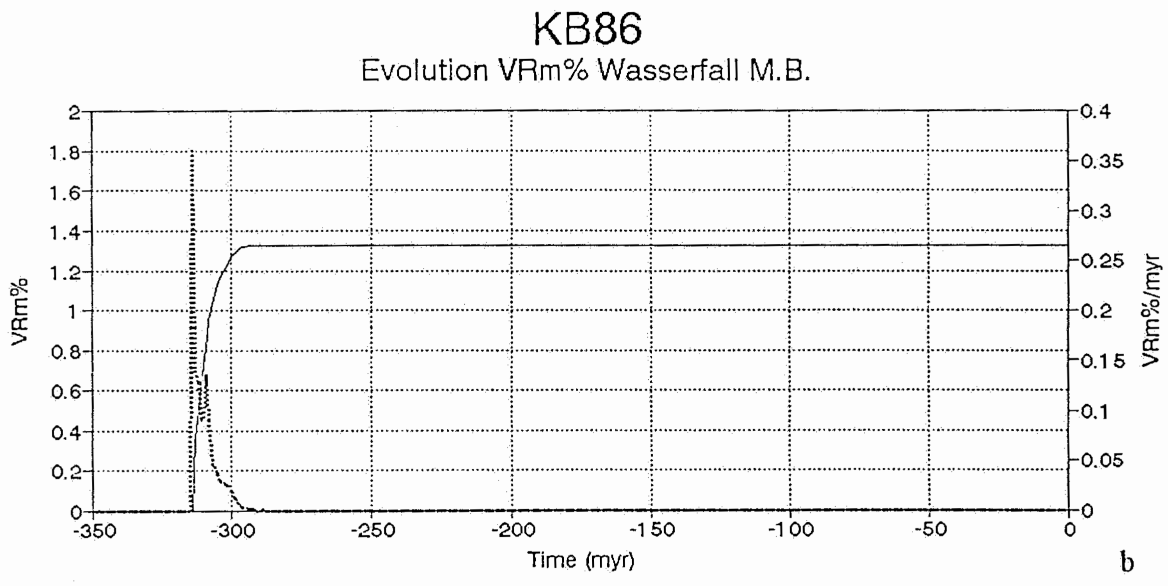


Fig. 21. Evolution of VRm(%) (continuous line) and VRm(%)/myr (dashed line) in the deep well KB86 (a: Sarnsbank M.B., b: Wasserfall M.B.)

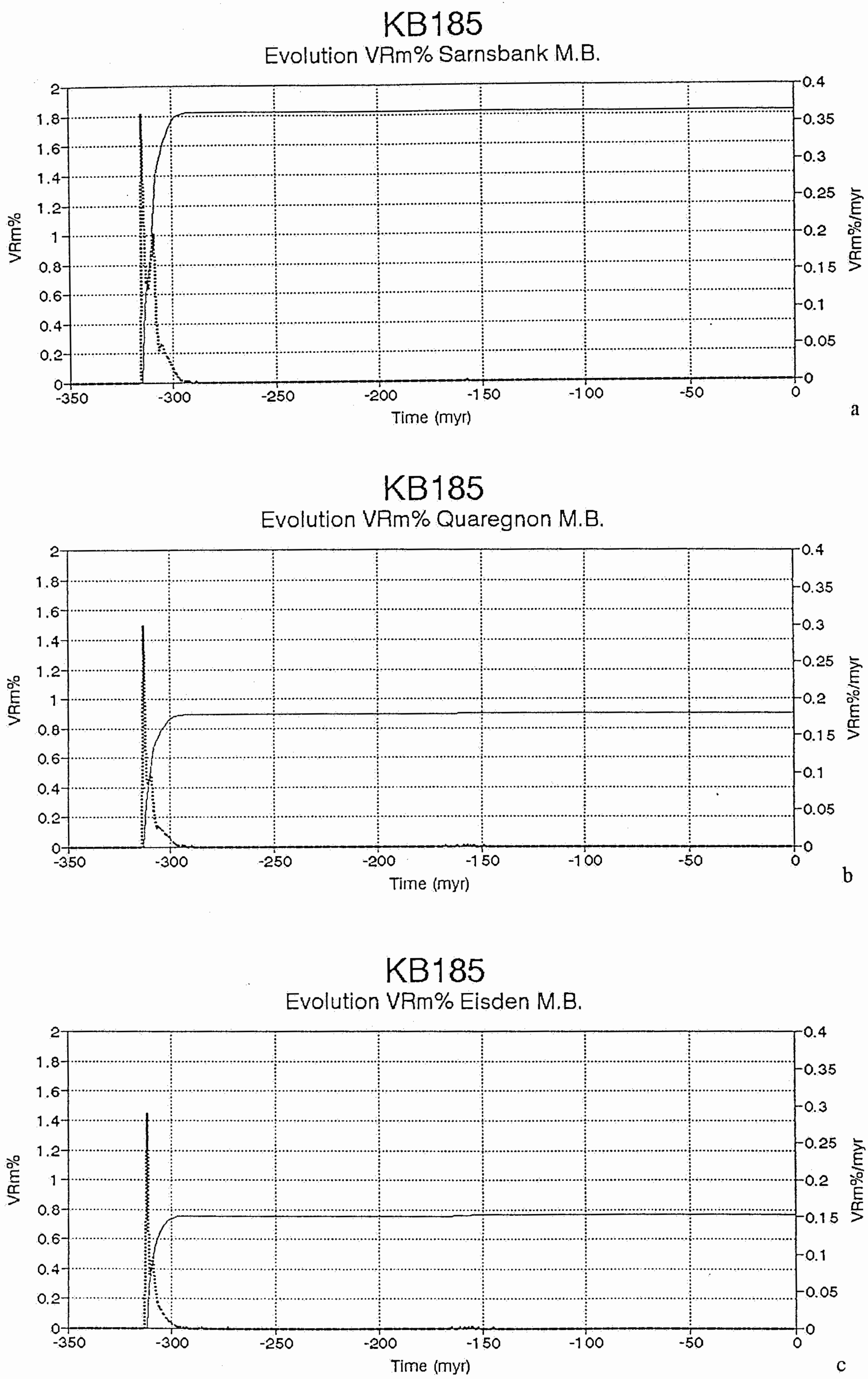


Fig. 22. Evolution of VRm(%) (continuous line) and VRm(%)/myr (dashed line) in the deep well KB185
(a: Sarnsbank M.B., b: Quaregnon M.B., c: Eisden M.B.)

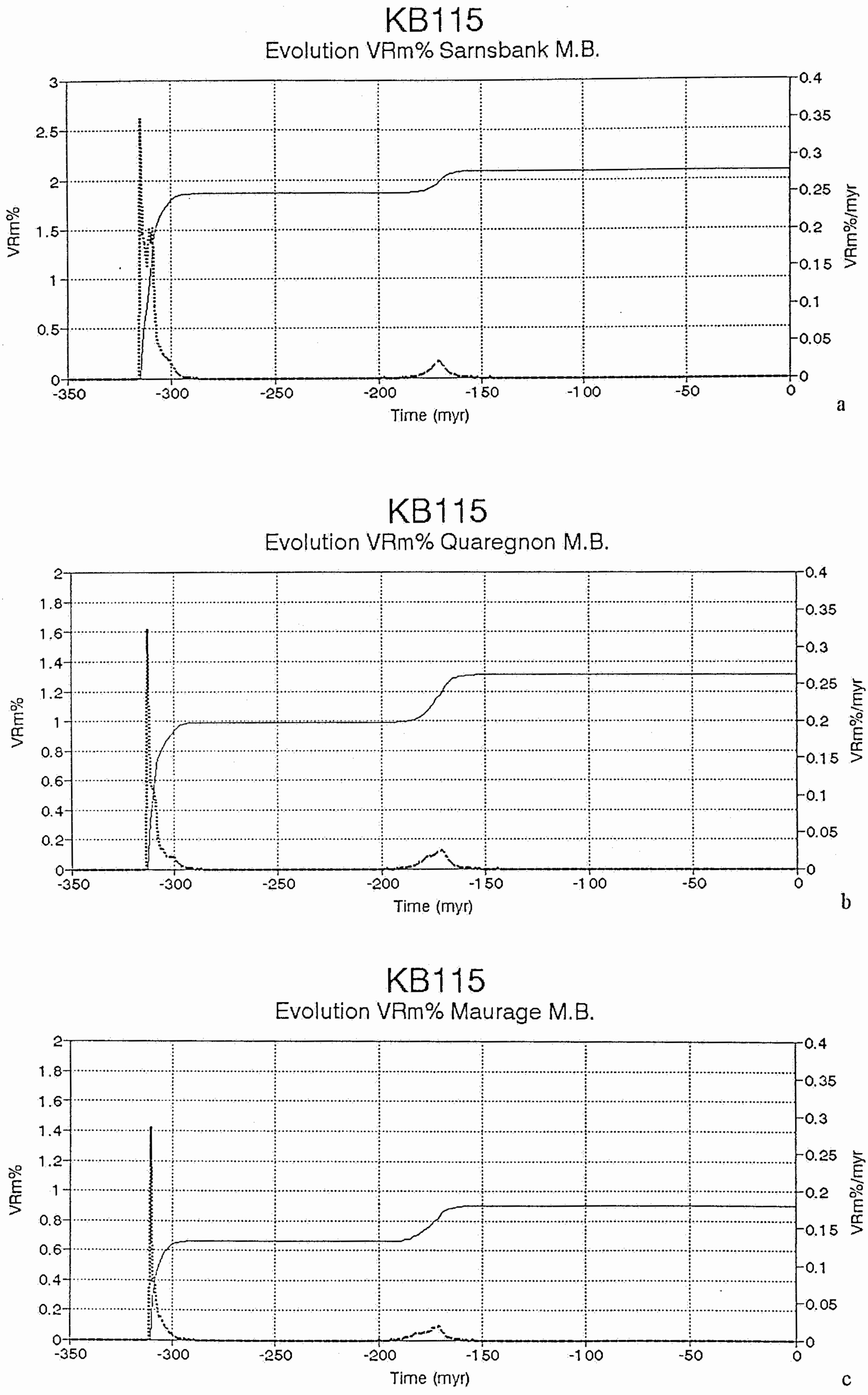


Fig. 23. Evolution of VRm(%) (continuous line) and VRm(%)/myr (dashed line) in the deep well KB115 (a: Sarnsbank M.B., b: Quaregnon M.B., c: Maurage M.B.)

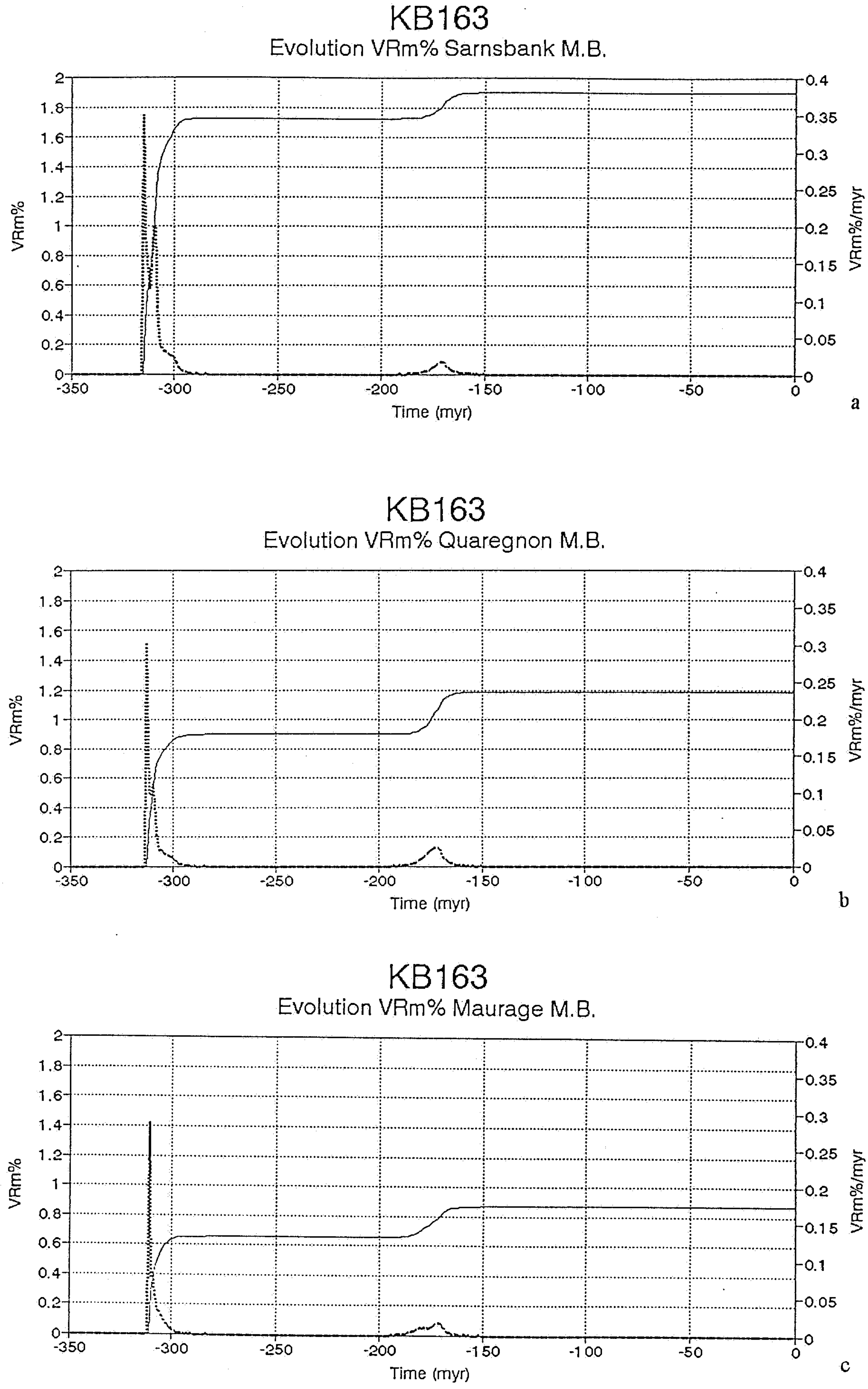


Fig. 24. Evolution of VRm(%) (continuous line) and VRm(%)/myr (dashed line) in the deep well KB163 (a: Sarnsbank M.B., b: Quaregnon M.B., c: Maurage M.B.)

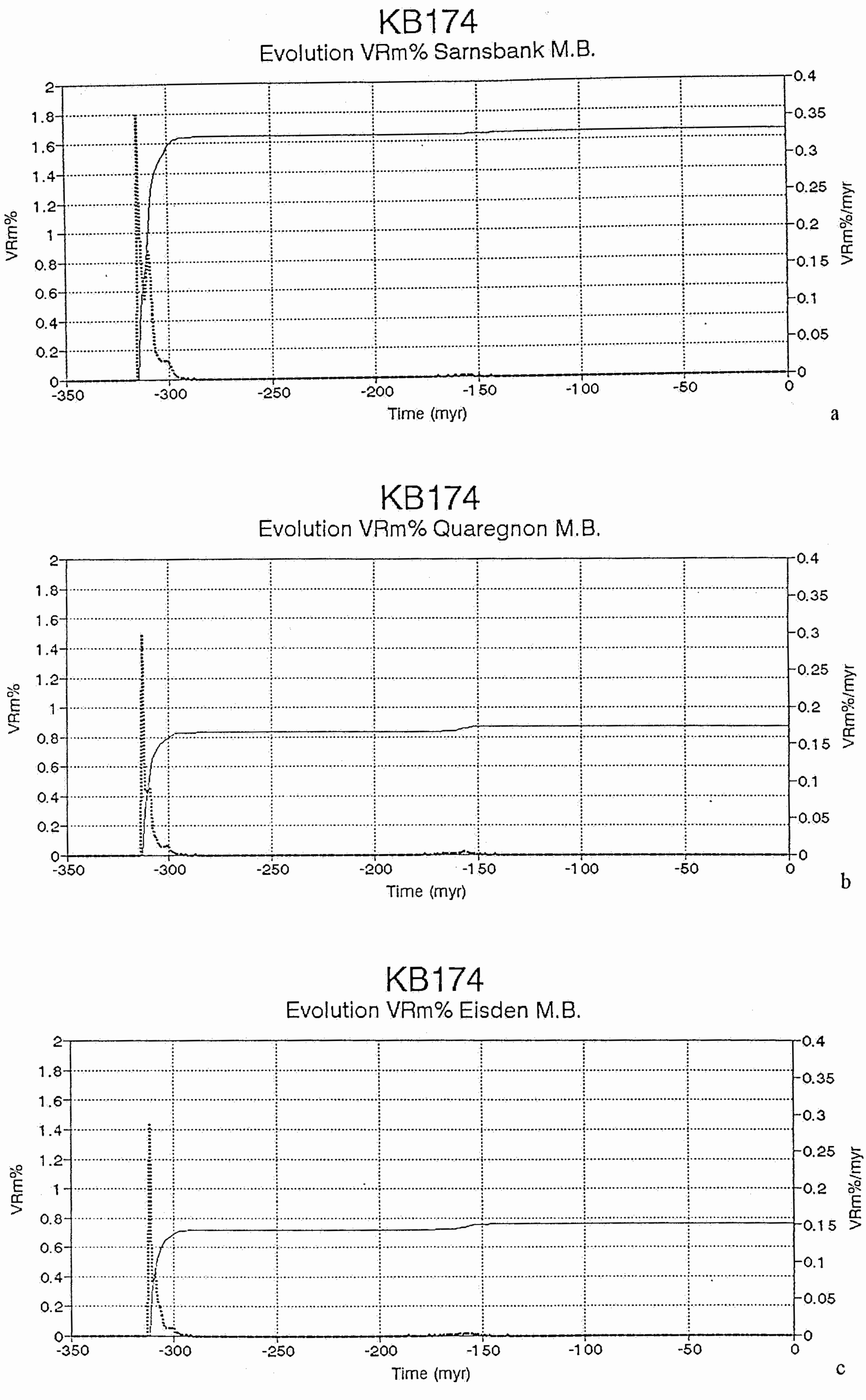


Fig. 25. Evolution of VRm(%) (continuous line) and VRm(%)/myr (dashed line) in the deep well KB174 (a: Sarnsbank M.B., b: Quaregnon M.B., c: Eisden M.B.)

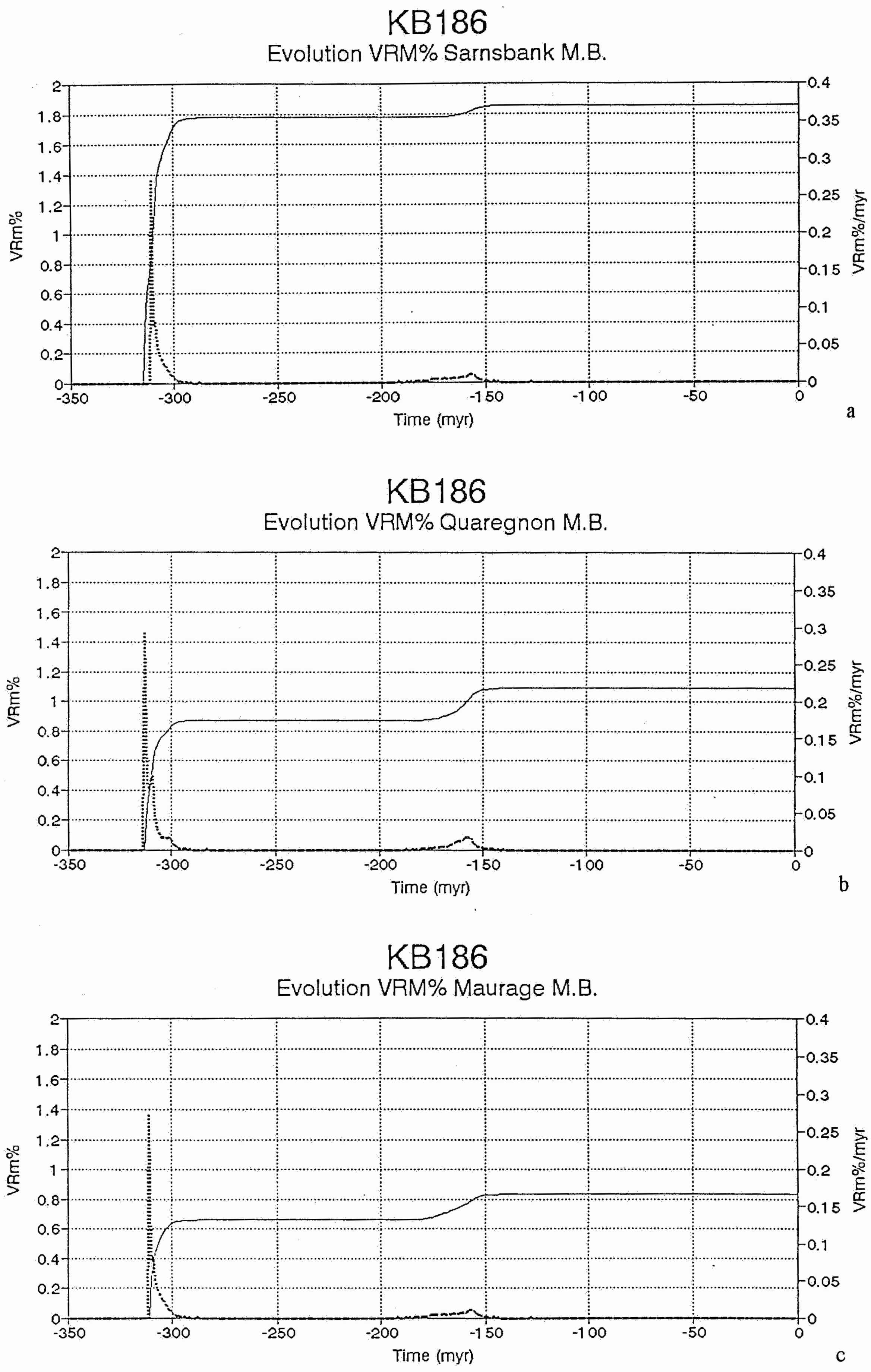


Fig. 26. Evolution of VRm(%) (continuous line) and VRm(%)/myr (dashed line) in the deep well KB18((a: Sarnsbank M.B., b: Quaregnon M.B., c: Maurage M.B.)

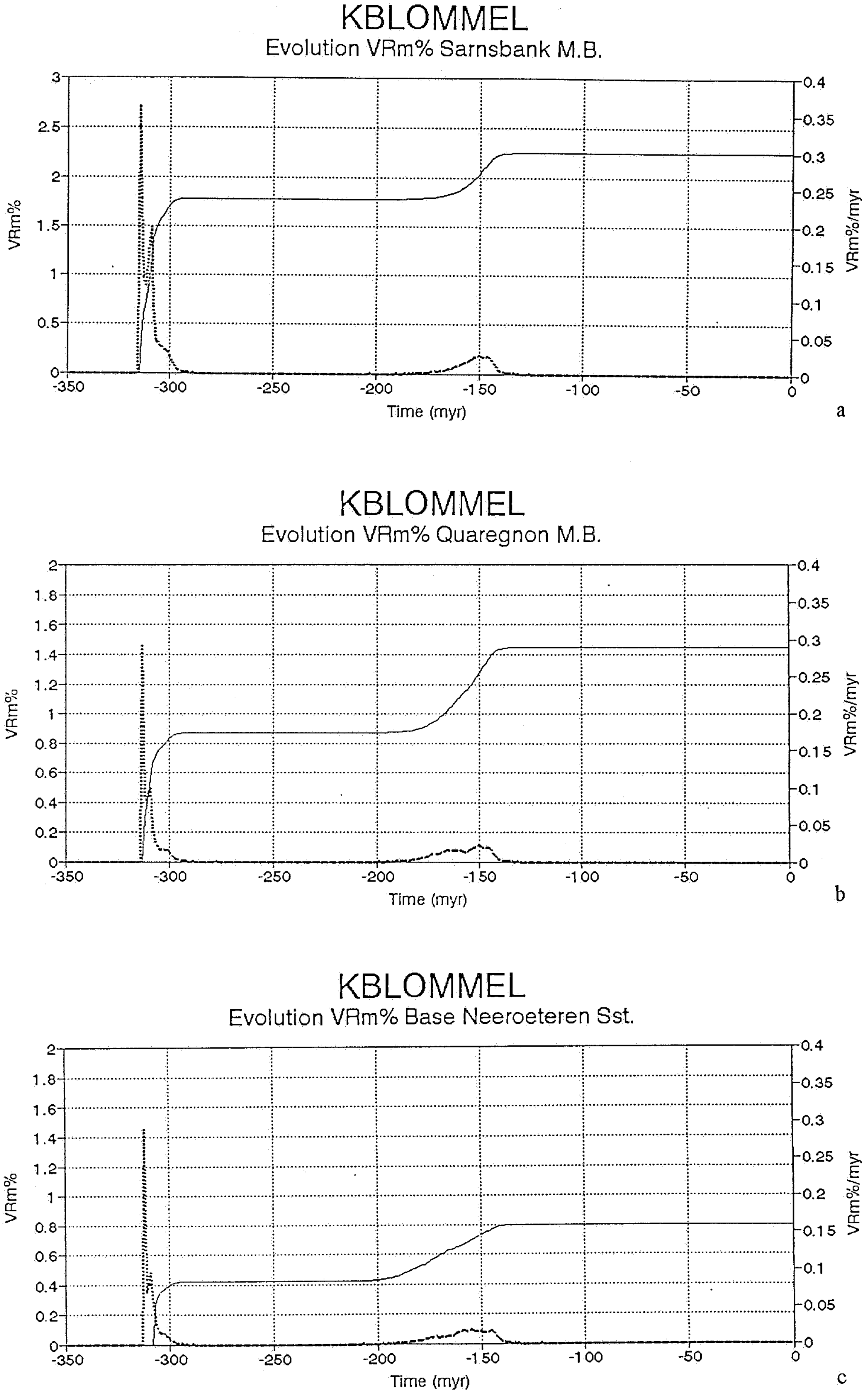


Fig. 27. Evolution of VRm(%) (continuous line) and VRm(%)/myr (dashed line) in the deep well KBLommel (a: Sarnsbank M.B., b: Quaregnon M.B., c: Base Neeroeteren Sst.)

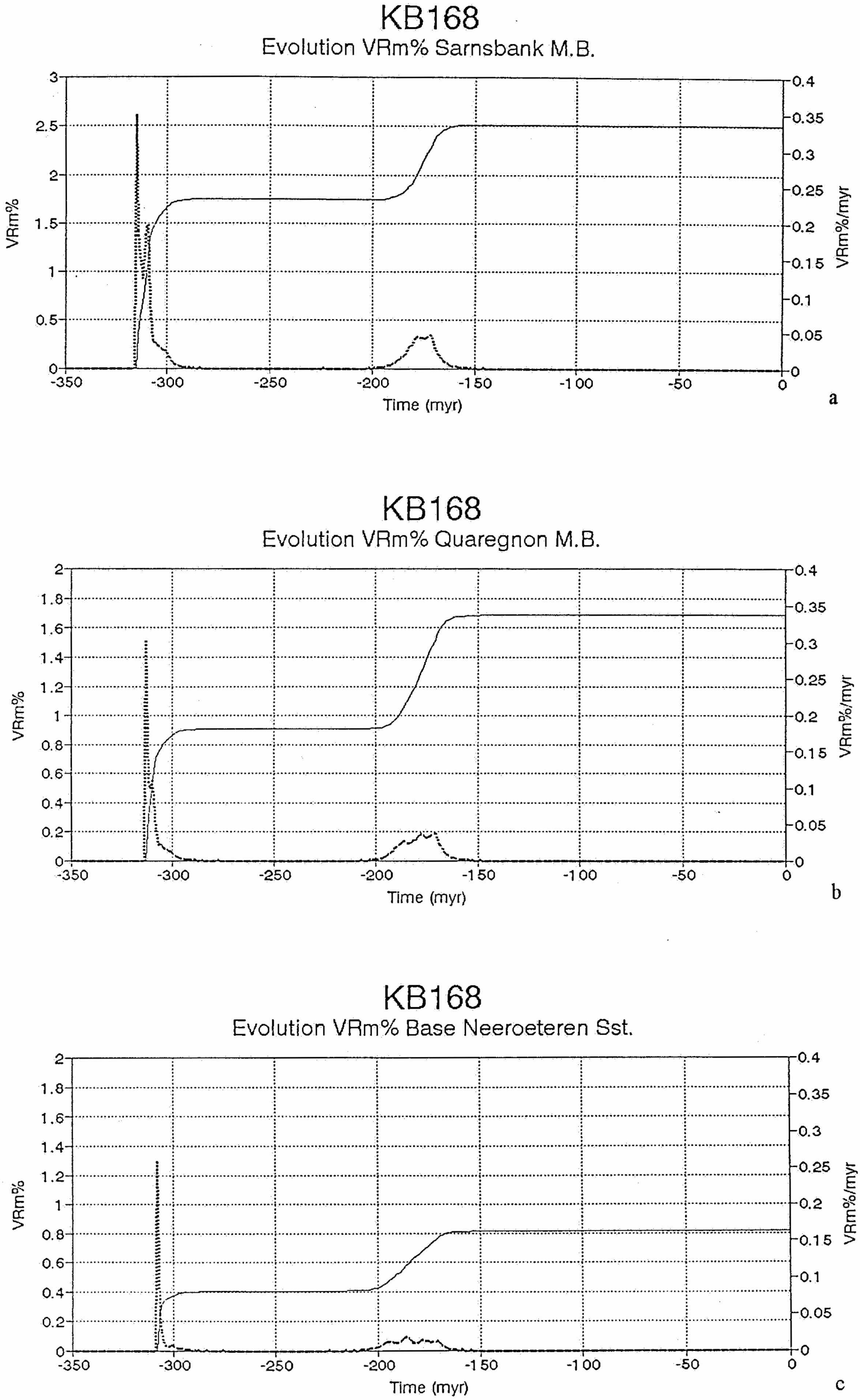
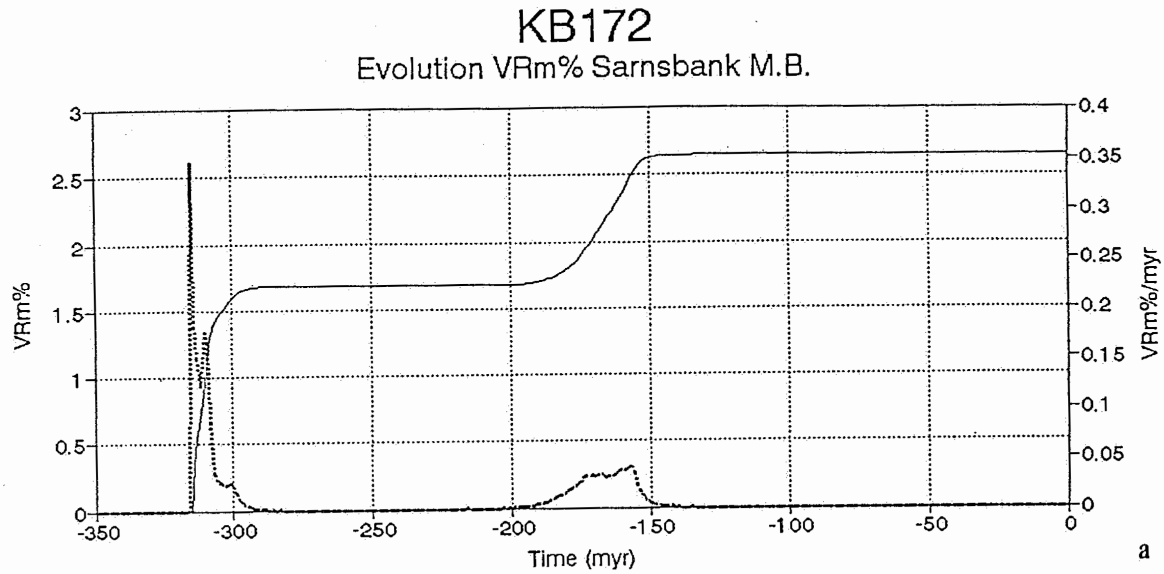
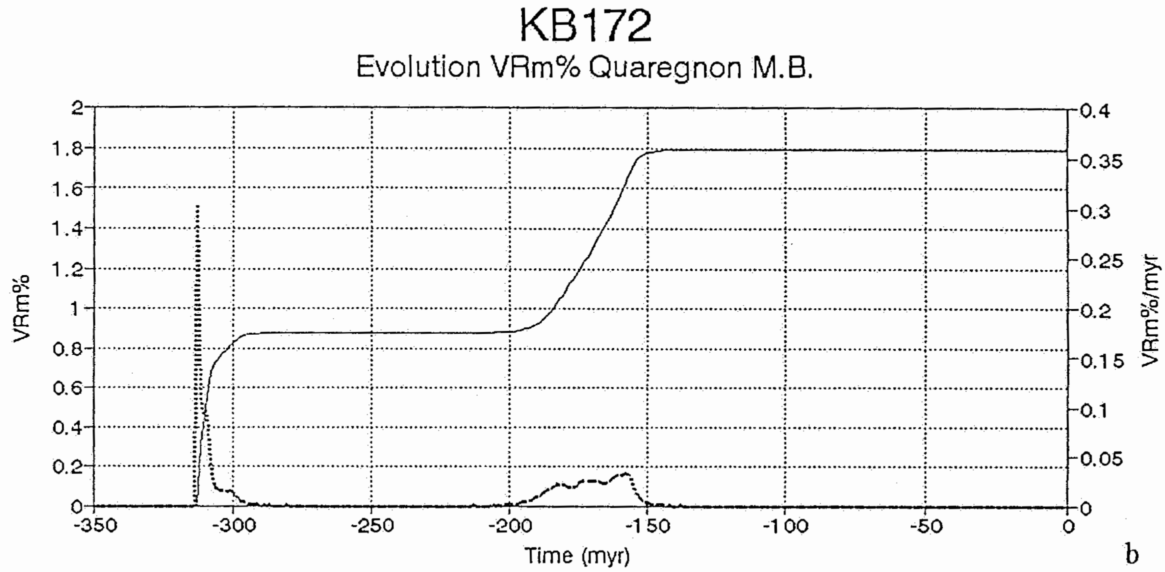


Fig. 28. Evolution of VRm(%) (continuous line) and VRm(%)/myr (dashed line) in the deep well KB16
(a: Sarnsbank M.B., b: Quaregnon M.B., c: Base Neeroeteren Sst.)


KB172
Evolution VRm% Sarnsbank M.B.


KB172
Evolution VRm% Quaregnon M.B.

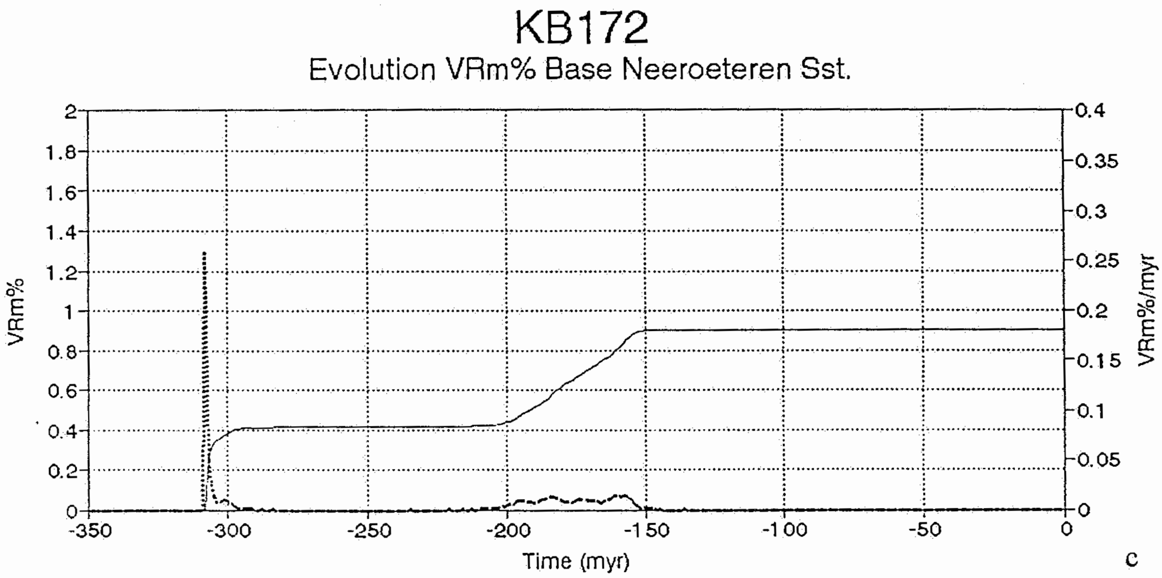

KB172
Evolution VRm% Base Neeroeteren Sst.

Fig. 29. Evolution of VRm(%) (continuous line) and VRm(%)/myr (dashed line) in the deep well KB172 (a: Sarnsbank M.B., b: Quaregnon M.B., c: Base Neeroeteren Sst.)

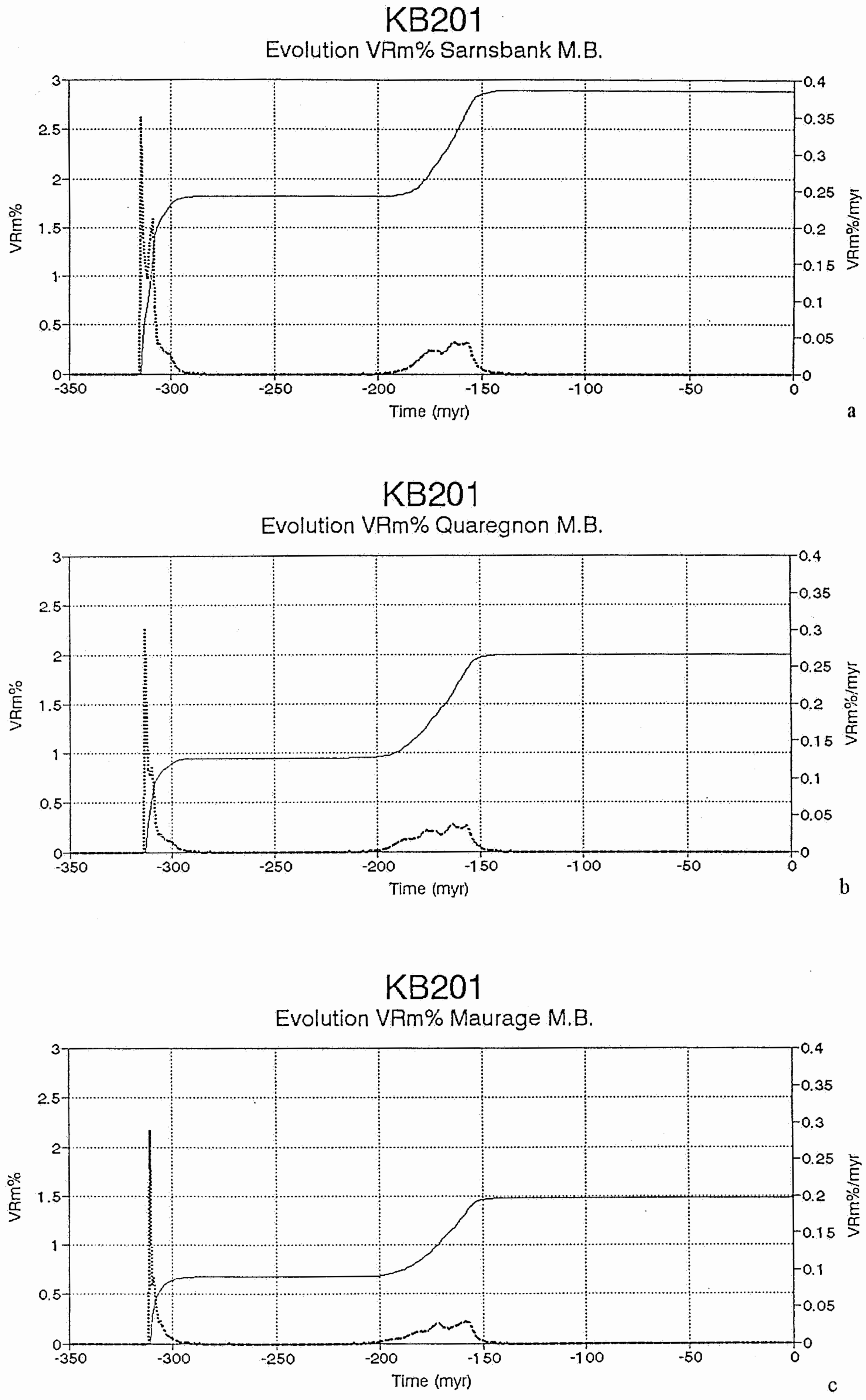
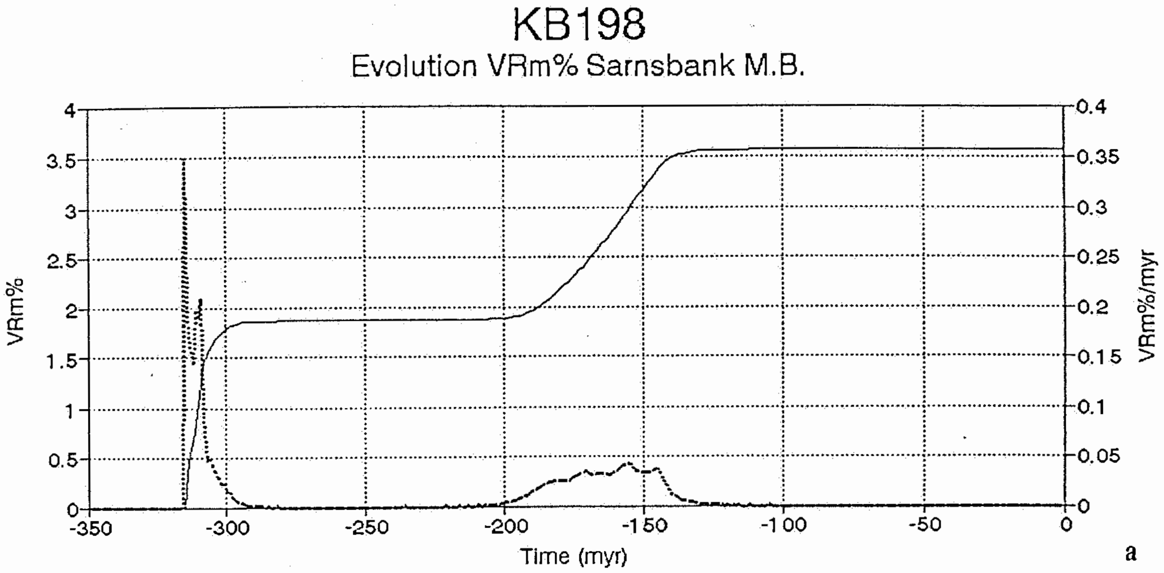
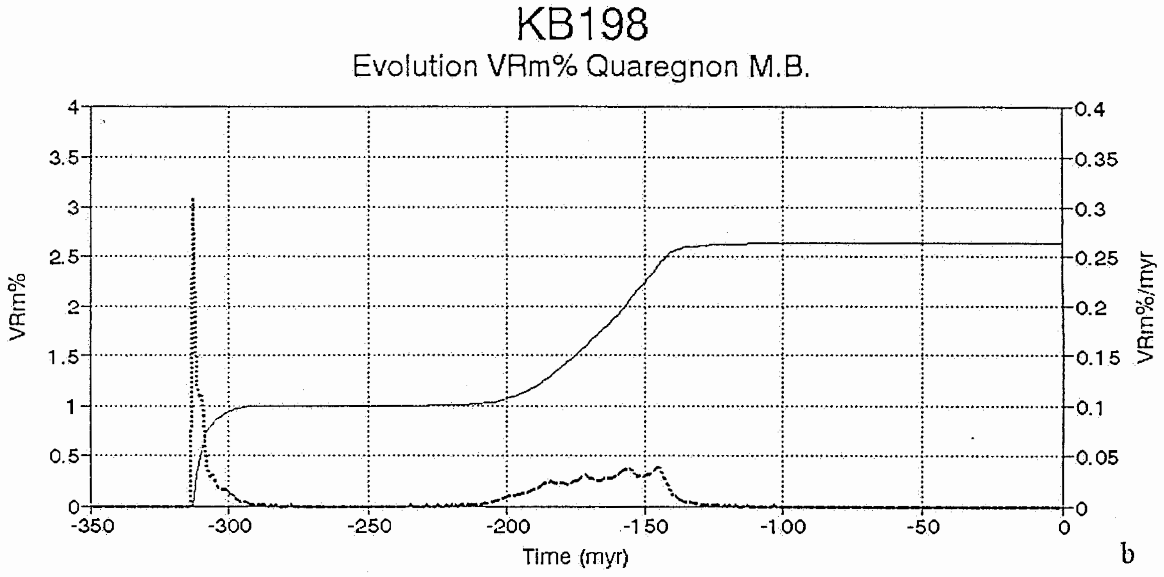


Fig. 30. Evolution of VRm(%) (continuous line) and VRm(%)/myr (dashed line) in the deep well KB201 (a: Sarnsbank M.B., b: Quaregnon M.B., c: Maurage M.B.)





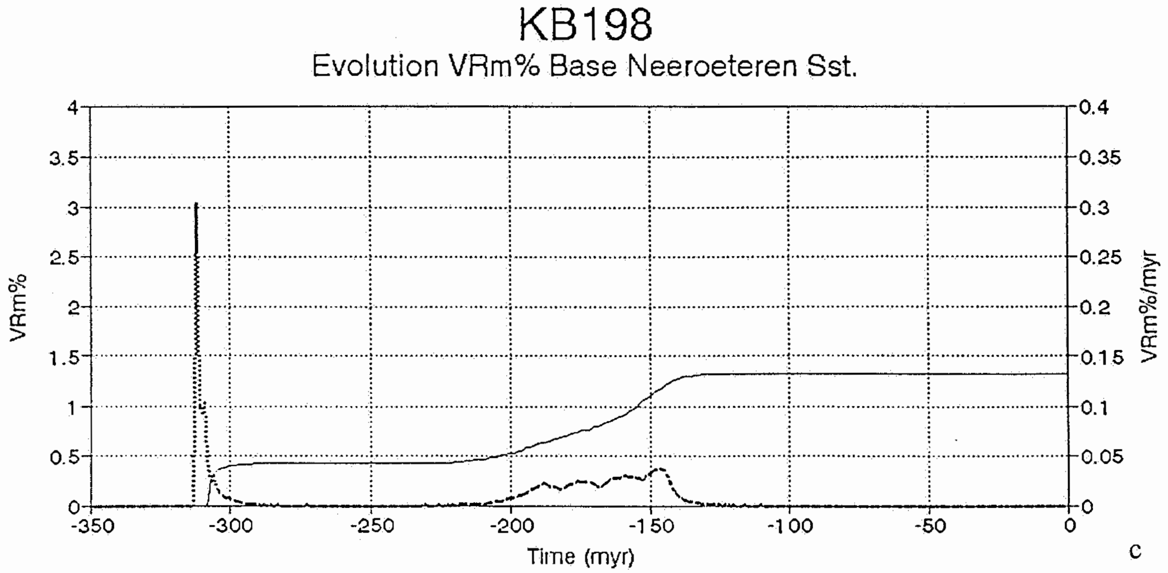


Fig. 31. Evolution of VRm(%) (continuous line) and VRm(%)/myr (dashed line) in the deep well KB198 (a: Sarnsbank M.B., b: Quaregnon M.B., c: Base Neeroeteren Sst.)