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A new evaluation of fluid inclusion data based on thermal basin modeling for the Drau Range, Eastern Alps

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3 Figures and 1 Table

Content

Abstract

Published microthermometrical data of fluid inclusions, which were trapped near or subsequent to the time of maximum subsidence of the Drau Range (Eastern Alps) have been used to evaluate the relationship between fluid flow and heat transfer. The evaluation is based on a numerical 1-D heat flow model, calibrated with vitrinite reflectance values. Aqueous fluid inclusions in quartz fissures crosscutting Permo-Scythian sediments and in fluorites hosted by Carnian carbonates give evidence for conductive heat transfer during fluid flow in the Late Cretaceous/Neogene. This implies that trapping temperatures of these fluids (125 °C to 220 °C in quartz, 115 °C to 180 °C in fluorite) can be used to approximate the burial temperatures (190 °C in the Permo-Scythian, 130 °C to 150 °C in the Carnian). In contrast, trapping temperatures of hydrocarbon-bearing fluid inclusions hosted in authigenic quartzes of the Norian Hauptdolomit Formation (120 °C to 130 °C) and aqueous fluid inclusions in deep burial cements (150 °C to 310 °C) exceed the basinal isotherms (100 °C to 120 °C in the Norian and 130 °C to 160 °C in the Carnian) in the peripheral segments of the Drau Range (eastern part of the Gailtal Alps and Dobratsch block, Northern Karawanken Range, parts of the Lienz Dolomiten Range). This is explained by convective heat transfer during a retrograde hyperthermal event.

Eine Neubewertung von Flüssigkeitseinschlussdaten aufgrund einer thermischen Beckenmodellierung des Drauzuges (Ostalpen)

Zusammenfassung

Die Beziehung zwischen Fluidtransport und Wärmegeschichte des Drauzuges (Ostalpen) wurde anhand publizierter mikrothermometrischer Daten von Flüssigkeitseinschlüssen, die während oder nach der Zeit der maximalen Versenkung eingeschlossen wurden, untersucht. Die Untersuchung basiert auf einem numerischen 1-D Wärmeflussmodell, welches mit Vitrinitreflexionswerten kalibriert wurde. Wasserreiche Flüssigkeitseinschlüsse die in Quarzklüften innerhalb permo-skythischen Sedimente sowie in spätdiagenetischen Fluoriten der karnischen Wetterstein Formation eingeschlossen sind, geben Hinweise auf konduktiven Wärmetransport während der Migration fluider Phasen im Zeitraum Oberkreide bis Neogen. Daher können mit deren Bildungstemperaturen (125 °C bis 220 °C im Quarz, 115 °C bis 180 °C im Fluorit) die Versenkungstemperaturen (190 °C im Permo-Skyth, 130 °C bis 150 °C im Karn) abgeschätzt werden. Im Gegensatz dazu, sind die Bildungstemperaturen von kohlenwasserstoffhältigen Flüssigkeitseinschlüssen in authigenen Quarzen der norischen Hauptdolomit Formation (120 °C bis 130 °C) und die Bildungstemperaturen von wasserreichen Flüssigkeitseinschlüssen in spätdiagenetischen Karbonatzementen innerhalb der karnischen Wetterstein Formation (150 °C bis 310 °C) höher als die Formationstemperaturen (100 °C bis 120 °C im Nor und 130 °C bis 160 °C im Karn) in den peripheren Anteilen des Drauzuges (Ostteil der Gailtaler Alpen, Dobratsch Block, Nord-Karawanken, Anteile der Lienzer Dolomiten). Dies wird durch konvektiven Wärmetransport während retrograder hyperthermischer Ereignisse erklärt.

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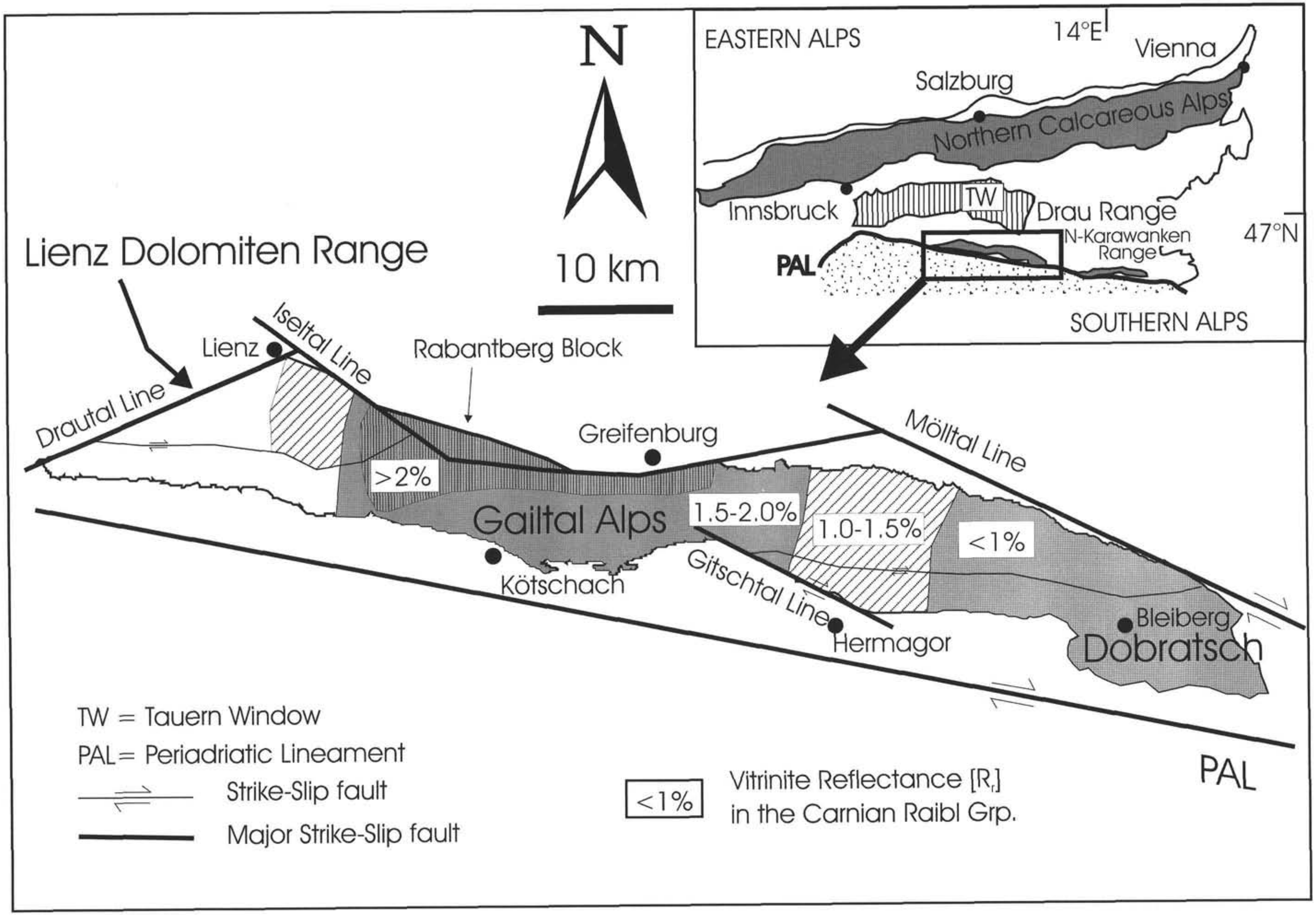
EASTERN ALPS
14°E
Vienna
Salzburg
Northern Calcareous Alps
Innsbruck
TW
Drau Range
47°N
N-Karawanken Range
PAL
SOUTHERN ALPS
N
10 km
Lienz Dolomiten Range
Lienz
Iseltal Line
Rabantberg Block
Drautal Line
Greifenburg
Möltal Line
>2%
Gailtal Alps
1.5-2.0%
1.0-1.5%
<1%
Kötschach
Gitschtal Line
Hermagor
Bleiberg
Dobratsch
PAL
TW = Tauern Window
PAL= Periadriatic Lineament
Strike-Slip fault
Major Strike-Slip fault
<1%
Vitrinite Reflectance [Rr]
in the Carnian Raibl Grp.

1. Introduction

Fluids, which are entrapped as inclusions in natural minerals, provide information about geological processes. Microthermometry has been used extensively to determine the fluid composition, the fluid density, the P-T-conditions of entrapment and the temporal evolution of the inclusion fillings. However, the interpretation of these analytical data is strongly dependent on the knowledge of the physical and chemical properties of the involved phases and additional (e. g. geological) information is needed to be conclusive.

To reconstruct the thermal history of sedimentary basins, fluid inclusions (as relicts of fluids that moved through the basins) have been used widely as a calibrating parameter for numerical models. However, the relationship between fluid circulation, heat flow and fluid inclusion properties may be very complex. Possible sources are expelled fluids during compaction of the pore space and products of diagenetic/metamorphic processes. Circulation may attribute to the presence of allochthone fluids from several sources. Depending on the prevailing process heat flow transfer can be described as a (1) conduction process where heat is transferred by contact according to temperature gradients; or (2) as a convection process where thermal energy is transported by the actual movement of a fluid. In the latter case heat is supposed to be transported by fluid flow in an aquifer (high permeable sediments or fault zones) and may not be in equilibrium with the internal heat flow pattern of the sedimentary basin (e. g. TILLEY et al., 1989; BURLEY et al., 1989; JESSOP and MAJOROWICZ, 1994).

The Drau Range represents a fragmented tectonostratigraphic unit within the Eastern Alps (Fig. 1), composed of 4 to 5 km thick Permo-Mesozoic sediments. Its thermal history has been investigated by means of illite crystallinity (NIEDERMAYR et al., 1984; RANTITSCH, 2003), Conodont Alteration Index investigations (LEIN et al., 1997), coalification studies (RANTITSCH, 2001, RANTITSCH and RAINER, 2003), organic geochemical (BECHTEL et al., 2001), and microthermometrical (NIEDERMAYR et al., 1984; ZEEH, 1995; ZEEH et al., 1995; RANTITSCH et al., 1999) investigations. The internal spatial pattern of vitrinite reflectance (Fig. 1) is explained by RANTITSCH (2001) by thermal alteration during Cretaceous to Paleogene basinal subsidence and by two retrograde thermal events in the Paleogene and Neogene. Within the Drau Range fluid inclusions have been studied in quartz fissures crosscutting Permo-Scythian red beds (NIEDERMAYR et al., 1984), in carbonate cements within Carnian carbonates (ZEEH et al., 1995), in ore minerals of the Bleiberg-type Pb-Zn mineralizations (ZEEH and BECHSTÄDT, 1994; RANTITSCH et al., 1999), and in authigenic quartzes hosted by Norian dolomites (RANTITSCH et al., 1999).

The aim of this paper is a compilation and comparison of microthermometric data from NIEDERMAYR et al. (1984), ZEEH et al. (1995) and RANTITSCH et al. (1999) for the western part of the Drau Range (Dobratsch, Gailtaler Alps, Lienzer Dolomiten Range), using improved thermodynamic models (BAKKER, 1999) and the evaluation of the relationship between fluid flow and the thermal history of the Drau Range, which is represented by a numerical heat flow model (RANTITSCH, 2001).

← Fig. 1
Map of the study area showing the main structures within the Drau Range. In addition the spatial pattern of vitrinite reflectance in the Carnian Raibl Group is indicated. Vitrinite reflectance in the Northern-Karawanken Range corresponds to the values observed in the eastern part of the Gailtal Alps and in the Dobratsch block.

2. Geological setting

The Drau Range belongs to the southernmost part of the tectonically highest unit of the Eastern Alps (Upper Austroalpine sensu TOLLMANN, 1959) and is composed of 4 to 5 km thick Permo-Mesozoic sediments (see TOLLMANN, 1977 for full references), resting transgressively and unconformably on metamorphic rocks of the Austroalpine crystalline basement. Due to Paleogene to Neogene strike-slip tectonics, the Drau Range is now separated into the Northern Karawanken Range, the Dobratsch block, the Gailtal Alps, the Rabantberg block and the Lienz Dolomiten Range (Fig. 1).

Subsequent to the deposition of the Scythian red beds and the Anisian shallow water carbonates, Ladinian to Carnian strata of an intraplatform basin interfinger with the platform carbonates of the Wetterstein Formation. Stratigraphically higher, carbonatoclastic sequences of the Raibl Group (Carnian) are overlain by lagoonal dolomites of the Hauptdolomit Formation (Norian) and basinal shales of the Kössen Formation (Late Norian to Rhaetian). Younger sediments are only exposed in structural synclines of the Lienz Dolomiten Range (SCHMIDT et al., 1991) and at the northern margin of the Northern Karawanken Range. They include Liassic (Hettnangian) to Lower Cretaceous (Valanginian) hemipelagic basin sediments, overlain by Aptian to Albian flysch sediments (BLAU and SCHMIDT, 1988; BLAU and GRÜN, 1995).

The thermal history of the Drau Range is summarized by RANTITSCH (2001) into three stages: (1) relatively low heat flows of approx. 60 mW/m^2 during basinal subsidence, (2) a retrograde thermal event, attributed to Oligocene magmatic activity along the Periadriatic Lineament, (3) strong heating during or after tectonic activity along strike-slip faults bordering the internal structural units of the Drau Range. This heat flow maximum is responsible for the vitrinite reflectance anomaly in the central Gailtal Alps (see Fig. 1) and can be best explained by convective heat transport during the rise of the metamorphic Tauern dome in the Early/Middle Miocene.

3. Fluid inclusion data

NIEDERMAYR et al. (1984) described microthermometrical data of aqueous fluid inclusions hosted in quartz fissures crosscutting the Permo-Scythian red beds (see Tab. 1 a). They are all trapped along healed fractures (secondary inclusions). Because no CO_2, CH_4 or higher hydrocarbons were detected, these fluids are attributed by NIEDERMAYR et al. (1984) to the water-zone in the fluid zonation of MULLIS (1979). By analogy to the Swiss Alps minimum trapping temperatures of 270 °C are assumed. Applying the P-V-T-X data of POTTER and BROWN (1977) and POTTER (1977) 150 to 200 MPa are inferred as trapping pressure (NIEDERMAYR et al., 1984).

Table 1
(a) Microthermometrical data used for isochore calculations (Nr. = sample number in NIEDERMAYR et al., 1984 and ZEEH et al., 1995 [F1 and F2 are own descriptors], HM = Host mineral, Qz= quartz, Cc= calcite, fluo= fluorite, dol= dolomite, N = Number of studied fluid inclusions, Type = fluid inclusion type, sec = secondary fluid inclusion, prim= primary fluid inclusion, Volume = inclusion filling, Tm_ice = mean melting temperature of ice (°C), Th = homogenization temperature of the volatile part to the liquid phase (°C).

(b) Calculated fluid salinity in NaCl equivalents (eq%NaCl), bulk composition (mole %) and bulk fluid density (g/cm³) from microthermometrical data of NIEDERMAYR et al. (1984) and ZEEH et al. (1995). To calculate the fluid properties of the inclusions from ZEEH et al. (1995), mean homogenization temperatures (Th) and mean ice melting temperatures (Tm_ice) of Tab. 1a were used.

Stratigraphical unit	Nr.	HM	N	Type	Volume	Tm_ice	Th	Reference
Permo-Scythian sediments	1	Qz	6	sec	H_2O	-5.7	127	Niedermayr et al, 1984
	2	Qz	10			-5.2	142	
	3	Qz	3			-5.2	128	
	9	Qz	9			-11.7	115	
	7	Qz	10			-7.8	128	
	5	Qz	8			-5.1	102	
	6	Qz	11			-12.3	115	
	8	Qz	7			-3.9	126	
	10	Qz	10			-6.3	132	
Wetterstein Fm	B69	Cc	?	prim	H_2O	-15 to -13	155-184	Zeeh et al. 1995
	F1	fluo				-24 to -20.4	120-142	
	F2	fluo				-6.3 to -3.8	84-120	
	T2	dol				-5 to -3	143-162	
	15/4	dol				-5 to -3	128-140	
	18/8	Cc				-5 to -3	210-245	
	B124b	Cc				-25 to -21	200-250	

Stratigraphical unit	Nr.	Tm_ice	Th	eq%NaCl	mol% H_2O	mol% NaCl	Density	Reference
Permo-Scythian sediments	1	-5.7	127	8.81	94.4	5.6	0.876	Niedermayr et al, 1984
	2	-5.2	142	8.14	94.8	5.2	0.874	
	3	-5.2	128	8.14	94.8	5.2	0.882	
	9	-11.7	115	15.67	89.7	10.3	0.836	
	7	-7.8	128	11.46	92.6	7.4	0.858	
	5	-5.1	102	8.00	94.9	5.1	0.897	
	6	-12.3	115	16.24	89.3	10.7	0.832	
	8	-3.9	126	6.30	96.0	4.0	0.897	
	10	-6.3	132	9.60	93.9	6.1	0.869	
Wetterstein Fm	B69	-14.0	170	17.79	88.2	11.8	0.789	Zeeh et al. 1995
	F1	-20.8	131	22.91	84.5	15.5	0.786	
	F2	-5.1	102	8.00	94.9	5.1	0.897	
	T2	-4.0	153	6.45	95.9	4.1	0.879	
	15/4	-4.0	134	6.45	95.9	4.1	0.891	
	18/8	-4.0	227	6.45	95.9	4.1	0.815	
	B124b	-23.0	225	22.91	84.5	15.5	0.717	

ZEEH et al. (1995) presented microthermometrical data of primary aqueous fluid inclusions entrapped simultaneously with the precipitation of carbonate cements (calcite and dolomite) and fluorites within Carnian carbonates (Wetterstein Formation). Fluid inclusion data of deep burial cements and fluorites which were precipitated after the formation of the clear saddle dolomite are used in this study (Tab. 1 a). Accepting the cement stratigraphy of ZEEH et al. (1995) and KAPPLER and ZEEH (2000 and references cited therein), cement precipitated during the Cenozoic period, thus indi-

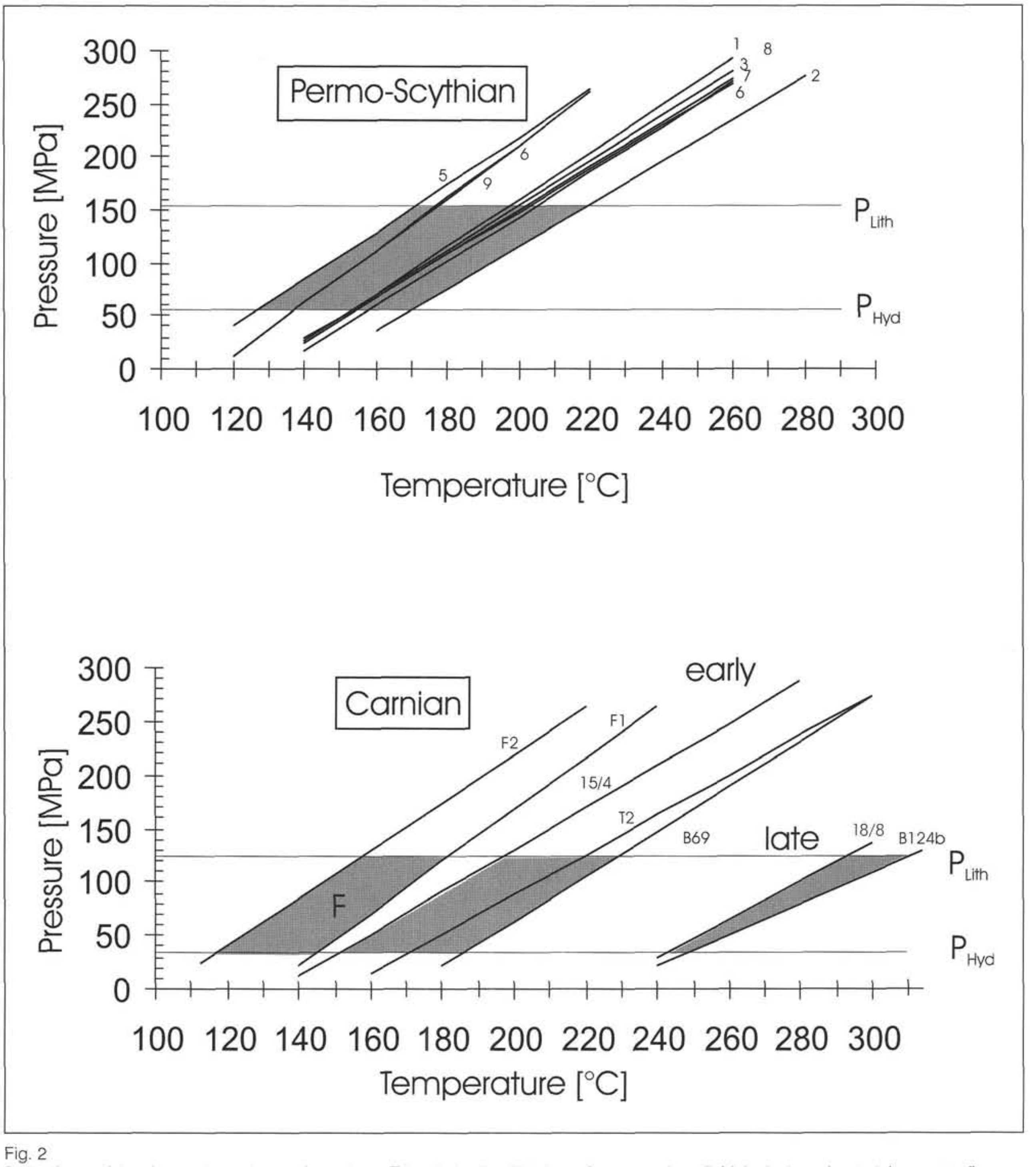

Fig. 2
Projections of isochores (sample numbers from Tab. 1) in the P-T-plane for secondary fluid inclusions hosted in quartz fissures crosscutting Permo-Scythian red beds (NIEDERMAYR et al., 1984) and for primary fluid inclusions hosted in fluorite (F) and Carnian carbonate cement (ZEEH et al., 1995). Minimum and maximum trapping temperatures are estimated with the lithostatic (P_{lith}) and hydrostatic pressure (P_{Hyd}) at the time of maximum subsidence. Fluid inclusion data from deep burial Carnian cements and fluorites can be grouped into two fluid generations. Possible trapping ranges are shaded.

cating fluid entrapment after the time of the maximum subsidence. Applying a pressure correction of 30 MPa (ZEEH et al., 1995), trapping temperatures of 125 °C to 278 °C are estimated by ZEEH et al. (1995) for the inclusions of Table 1a.

Hydrocarbons in ore minerals of Bleiberg-type Pb-Zn minerals and in authigenic quartz of the Lienz Dolomiten Range have been analyzed by microthermometrical methods, bulk-sample gas chromatography and fluorescence microscopy (RANTITSCH et al., 1999). Microthermometrical data of hydrocarbon and aqueous fluid inclusions and the molecular composition of the hydrocarbons indicate trapping at 120 °C to 130 °C and 20 to 25 MPa, inferring a pulse of migrating condensate-like hydrocarbons within Late Triassic sediments during Late Cretaceous to Neogene times.

4. Isochore calculation

Microthermometrical data of NIEDERMAYR et al. (1984) and ZEEH et al. (1995; see Tab. 1 a) are used to recalculate the P-T properties of the fluids by applying the algorithm of BAKKER (1999). In the program „HOMOGEN" density and salinity of the fluids is calculated using the homogenization temperature and the melting point depression as input parameters (BAKKER, 1999). The data of BODNAR (1993) are used to calculate fluid salinity in NaCl-equivalents and the equation of state of ZHANG and FRANTZ (1987) is used to calculate fluid density. Isochores are calculated by means of the program "ISOCHOR" (BAKKER, 1999) using the homogenization temperature and salinity as input parameters and the equation of state of BODNAR and VITYK (1994).

The calculated fluid properties are presented in Tab. 1 b. Although there are no major differences if the fluid densities of NIEDERMAYR et al. (1984) are compared with the densities of this paper, the recalculated isochores (Fig. 2) are significantly steeper than the isochores in NIEDERMAYR et al. (1984).

Fluid temperatures are estimated from the calculated isochores and the burial history of the Drau Range which was used for basin modeling (Tab. 3: RANTITSCH, 2001). A variation of the assumed stratigraphy results in an inappropriate thermal 1-D model. Therefore, no attempt was undertaken to vary the thickness assumptions. Fluid pressures are estimated by assuming a mean density of 2.7 g/cm^3 for the predominantly calcareous overburden. This assumption is based on the physical properties of the lithotypes used for thermal basin modeling (Tab 2: RANTITSCH, 2001).

5. Discussion

Based on thermal basin modeling a pile of 1400 m Late Cretaceous to Eocene sediments, which was eroded during regional uplift in the Cenozoic, has to be added on top of the exposed stratigraphic sequence (RANTITSCH, 2001). This results in a bulk thickness of 5840 m of the basin filling, indicating a maximum overburden load of 155 MPa at the base of the Permo-Scythian sequence (P [Pa] = 2700 kgm^{-3}×9.81 ms^{-2}×5840 m). Consequently, 125 MPa prevail at the base of the Wetterstein Formation (P [Pa] = 2700 kgm^{-3}×9.81 ms^{-2}×4740 m).

MULLIS (1994) demonstrated that fluid pressure in higher crustal levels significantly varies between hydrostatic and lithostatic pressure. Therefore, pressures between these limits are assumed to represent the trapping pressure range.

155 MPa defines the upper (lithostatic) pressure limit for trapping of the aqueous fluids hosted in quartz fissures at the base of the Drau Range. The limit of 57 MPa is given if hydrostatic pressure conditions are assumed (P [Pa] = 1000 kgm^{-3}×9.81 ms^{-2}×5840 m). Isochores of these fluids indicate therefore trapping temperatures of 125 °C to 220 °C (Fig. 2).

In the stratigraphic level of the Wetterstein Formation aqueous fluids display two fluid generations. According to ZEEH et al. (1995), the high temperature generation is younger than the low temperature generation. If the fluid pressure during precipitation of deep burial minerals was nearly constant, the isochores of the fluid inclusions in fluorite point to a trapping at lower temperatures than the trapping of the fluid inclusions in early carbonate cements. Assuming 126 MPa (P [Pa] = 2700 kgm^{-3}×9.81 ms^{-2}×4740 m) as maximum (lithostatic) trapping pressure and 35 MPa (P [Pa] = 1000 kgm^{-3}×9.81 ms^{-2}×3540 m) as hydrostatic trapping pressure, trapping temperatures of 115 °C to 230 °C and 240 °C to 310 °C are indicated by the isochores (Fig. 2). Because the sample localities are not specified in ZEEH et al. (1995), the estimated trapping conditions of the Carnian fluid inclusions give an approximation of the possible range of trapping in the entire stratigraphic thickness of the Wetterstein Formation and only general conclusions about the relationship between fluid flow and heat flow history can be drawn.

To evaluate the relationship between heat transfer and fluid flow it is necessary to investigate the heat flow history of the Drau Range. This has been done numerically by using vitrinite reflectance values as calibrating parameters for a 1-D thermal basin model (RANTITSCH, 2001; Fig. 3). To model the heat flow during Late Cretaceous to Paleogene subsidence, only reflectance values of areas, which are not overprinted by retrograde thermal events (eastern part of the Gailtal Alps and Dobratsch block [i. e. areas outside the 1% R_r isoline in Fig. 1], Northern Karawanken Range, parts of the Lienz Dolomiten Range) are considered. In Figure 3 this model is overlain with the trapping range of the fluids described above, completed with the data of RANTITSCH et al. (1999).

It is obvious that fluid temperatures of fluid inclusions trapped in Permo-Scythian quartz and Carnian fluorite are in accordance with the calculated isotherms. Therefore, there is some evidence for conductive heat transfer during fluid trapping in quartz and fluorite. Thus, the corresponding trapping temperatures are in equilibrium with the paleo-heat flow gradient during basinal subsidence and can be used as an estimate of the burial temperatures.

If any effect of post-entrapment changes in inclusion volume and composition (e. g. stretching, necking-down, diffusion) of the inclusions trapped in deep burial carbonate cements of the Wetterstein Formation are neglected, the corresponding isochores indicate trapping temperatures exceeding the basinal isotherms with up to 70 °C in the early fluid generation and with 110 °C to 180 °C in the late fluid generation. Hydrocarbon-bearing fluid inclusions in Late Triassic dolomites of the Hauptdolomit Formation give evidence of a fluid flow characterized by temperatures exceeding the basinal isotherms by 30 °C at a maximum in the Norian. Therefore, if the fluid inclusions described above, are representative for fluid flow in the peripheral segments of the Drau Range (eastern part of the Gailtal Alps and Dobratsch block [i.e. areas outside the 1%R_r isoline in Fig. 1], Northern Karawanken Range, parts of the Lienz Dolomiten Range), there is evidence for the presence of a local thermal anomaly of limited vertical thickness and an injection of hot fluids into Late Triassic carbonates without significantly affecting the surrounding strata during the time of precipitation of carbonate cements and authigenic quartz. The lack of heat flow into less permeable rocks suggests that the heat transfer was dominated by convection in the permeable zones of high porosity.

All fluid inclusions are supposed to be formed near or subsequent to the time of maximum subsidence (NIEDERMAYR et al., 1984; ZEEH et al., 1995; RANTITSCH et al., 1999).

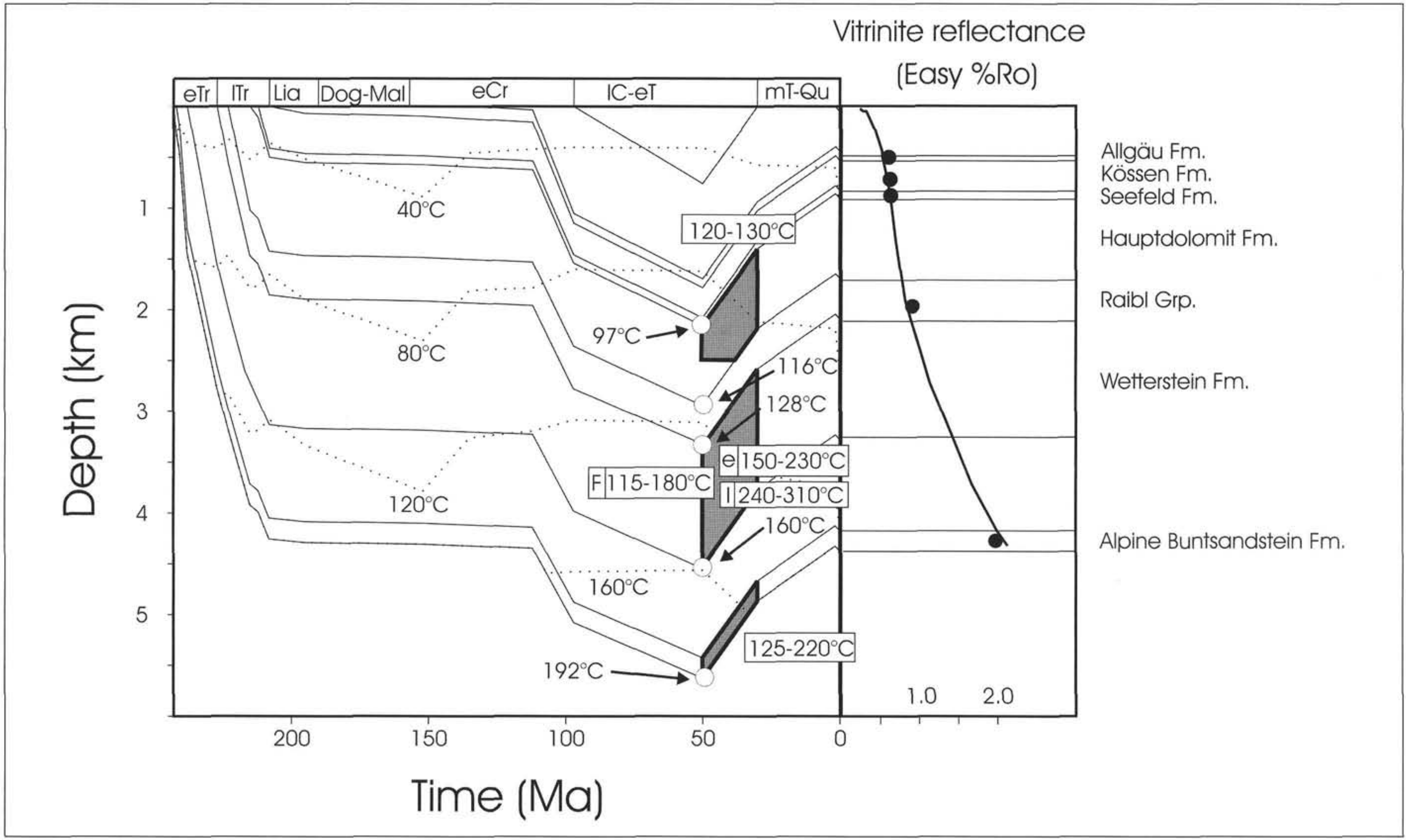

Fig. 3
Burial history, temperature history and heat flow model of the peripheral parts of the Drau Range (Northern Karawanken Range, eastern area of the Gailtal Alps and Dobratsch block, westernmost area of the Lienz Dolomiten Range) based on an assumed heat flow of 60 mW/m². Dashed curves are iso-temperature lines. In the right part of the figure measured (dots) and calculated vitrinite reflectances (line) calculated on the basis of burial and temperature history using the EASY%Ro method are plotted versus depth. Possible trapping fields of fluid inclusions (e = early deep burial cements, l = late deep burial cements, F = deep burial fluorites) are shaded and labeled by their trapping temperatures. Trapping temperatures of aqueous fluid inclusions hosted in quartz fissures crosscutting the Permo-Scythian sediments and in fluorites of the Wetterstein Formation (F) are in accordance with the basinal isotherms. Trapping temperatures of deep burial carbonate cements of the Wetterstein Formation and hydrocarbon-bearing fluid inclusions in the Hauptdolomit Formation exceed the basinal isotherms.

It is not possible to give an exact chronology of trapping events. Furthermore, the relationship between the fluid systems remains unclear. Nevertheless, fluid properties of hydrocarbon-bearing inclusions, which are enclosed in authigenic quartzes of Norian strata argue for convective heat transfer in a fluid system with a complete different fluid source. To produce condensate-like hydrocarbons, the organic matter of a potential source rock must have a vitrinite reflectance of about 2%R_r (TISSOT and WELTE, 1984). This high rank of coalification is only attained in regions near to strike-slip faults, bordering the study area (RANTITSCH et al., 1999, RANTITSCH 2001, see Fig. 1). The cross-cut relationship between this coalification pattern and Miocene (strike-slip) faults proves retrograde thermal events, overprinting the syn-depositional thermal alteration which was achieved during subsidence of the basin filling (RANTITSCH, 2001). Therefore, migration and trapping of hydrocarbon-bearing fluid inclusions is attributed to retrograde thermal events in the Paleogene to Neogene period (see also RANTITSCH et al., 1999). RANTITSCH et al. (1999) supposed a pulse of hot fluids which generated condensate-like hydrocarbons in areas effected by strongly enhanced heat flows. Maybe there is a relationship between this process and the occurrence of high temperature fluids in Carnian cements.

In the Drau Range there is no correlation between the occurrence of water-rich fluid inclusions and the presence of the water zone (MULLIS, 1979) as assumed in NIEDERMAYR et al. (1984). This zone has been described in the external parts of the Swiss Alps and is characterized by trapping temperatures above 270 °C, vitrinite reflectances above 4%R_r and anchi- to epizonal illite crystallinities (MULLIS, 1979, 1987, 1994). In the Drau Range water-rich fluid inclusions in Permo-Scythian to Carnian strata correspond with vitrinite reflectances below 2%R_r (RANTITSCH, 2001) and anchizonal illite crystallinities (NIEDERMAYR et al., 1984). Consequently, the methane zone has to be expected if the metamorphic rank of the host rock is used as an indicator of the fluid chemistry. This discrepancy can be explained by the absence of organic matter rich lithologies in the source rocks of the aqueous fluid inclusions. If such lithologies are missing, no organic matter can provide methane during the process of thermal maturation.

6. Conclusions

Fluid inclusion data of NIEDERMAYR et al. (1984), ZEEH et al (1995) and RANTITSCH et al. (1999) give evidence for fluid flow during basinal subsidence and uplift in the Late Cretaceous to Neogene and for retrograde hyperthermal fluid activity within the Drau Range (Eastern Alps). Based on a thermal basin model of the peripheral segments of the Drau Range (eastern part of the Gailtal Alps and Dobratsch block [i. e. areas outside the 1% R_r isoline in Fig. 1], Northern Karawanken Range, parts of the Lienz Dolomiten Range) established by RANTITSCH (2001), heat transfer at the time of maximum subsidence is supposed to be conductive, whereas convective heat flow characterizes the circulation of retrograde fluid. Trapping temperatures of aqueous fluid inclusions in quartz fissures crosscutting Permo-Scythian sediments and in fluorites of the Carnian Wetterstein Formation (125 °C to 220 °C in quartz, 115 °C to 180 °C in fluorite) can be used as estimates of the burial temperatures (190 °C in the Permo-Scythian, 130 °C to 160 °C in the Carnian). In contrast, trapping temperatures of hydrocarbon-bearing fluid inclusions hosted in authigenic quartzes of the Norian Hauptdolomit Formation (120 °C to 130 °C) and aqueous fluid inclusions in deep burial carbonate cements (150 °C to 310 °C) exceed the basinal isotherms (100 °C to 120 °C in the Norian, 130 °C to 160 °C in the Carnian). If the water zone of MULLIS (1979) is assumed to be present at the base of the Drau Range, the inferred trapping temperature of related fluid inclusions will be erroneous.

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