Mitt. Österr. Geol. Ges.	ISSN 0251-7493	**94** (2001)	55-61	Wien, August 2003

Keywords
Structural analysis
strike-slip deformation
Neogene
Eastern Alps
Carinthia

Postcollisional stress field changes in Eastern Carinthia (Austria)

J. KUHLEMANN[1], T. SCHOLZ[1] & W. FRISCH[1]

4 Figures and 1 Table

Content

Abstract

Structural analysis revealed up to 7 fault generations of Miocene to recent brittle deformation in the southeastern Eastern Alps, which are attributed to four episodes of deformation. Calculated paleostress orientations record a local modification of strike-slip movements widely observed in the Eastern Alps during the first deformation episode of E-directed lateral extrusion between 21 and 12 Ma. Apparent counterclockwise (CCW) rotation of the stress field is probably caused by CCW rotation of crustal blocks. The second episode exhibits E-W compression at the end the extrusion phase. Late Miocene normal faulting of the third episode is probably related to the evolution of the intramontane Klagenfurt basin, which became overthrust from the S and accordingly down-warped. This caused local extension along a flexural bulge at its northern margin. Pliocene to recent deformation of the fourth episode records neotectonic strike-slip movements compensating for ongoing SE-directed extrusion in the easternmost Southern Alps (Slovenia).

1. Introduction

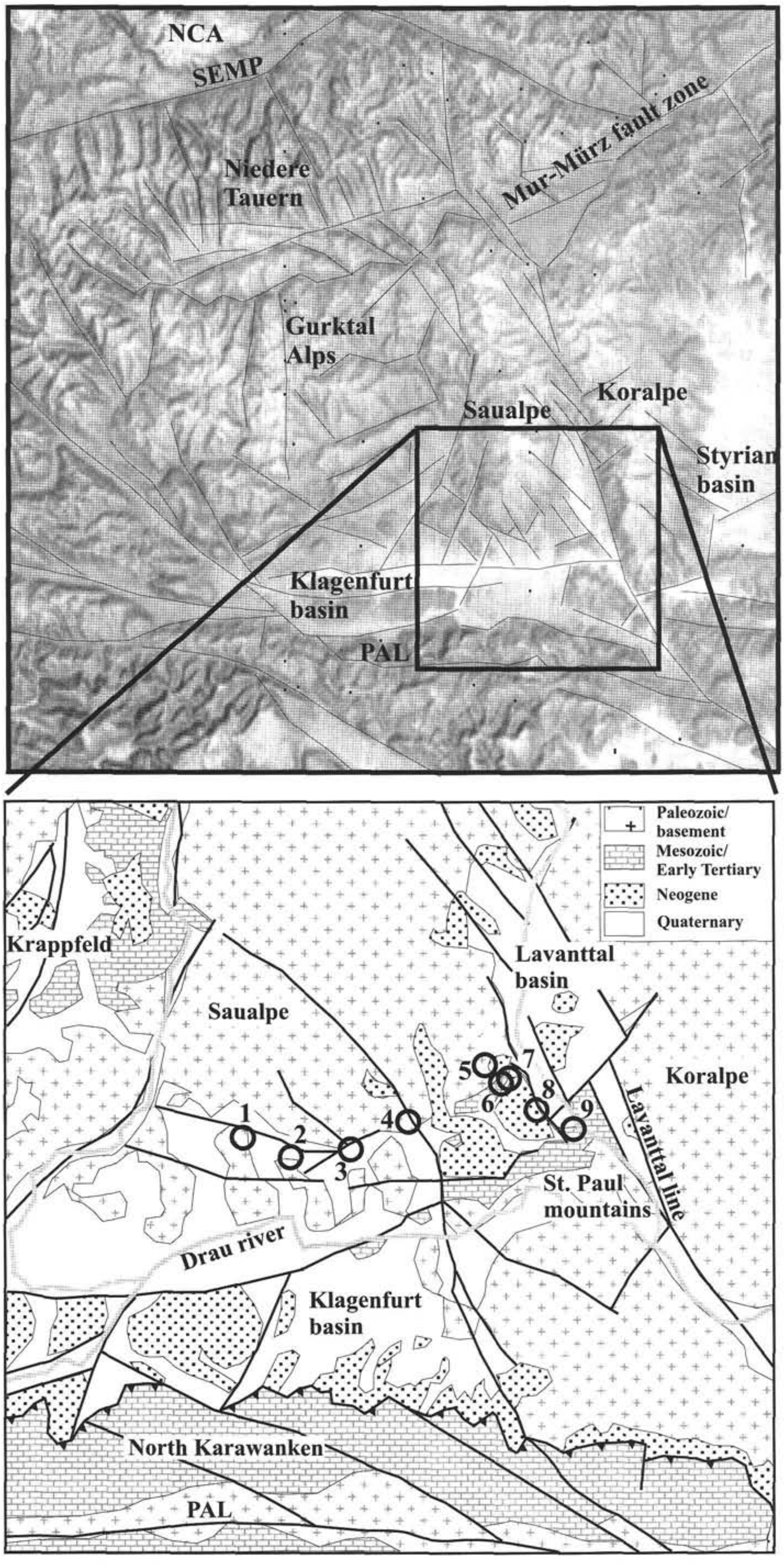
Since the introduction of the concept of Miocene lateral extrusion of the Eastern Alps (RATSCHBACHER et al., 1991a, b), this model has undergone numerous regional refinements. FRISCH et al. (1998, 2000) restored crustal blocks to a pre-extrusion palinspastic setting and found that the main extrusion channel between the Salzach-Ennstal-Mariazell-Puchberg line (SEMP) in the N (LINZER et al., 1995; PERESSON and DECKER, 1997a, b) and the Periadriatic lineament (PAL) in the S is bordered by a wide transitional zone of crustal blocks. This applies especially to the Northern Calcareous Alps (NCA), which also experienced E-W extension in the same magnitude as the central axis of the orogen (FRISCH et al., 1998). MÁRTON et al. (2000) showed that stronger differential eastward movement close to the PAL caused counterclockwise rotations of crustal blocks within the extrusion channel.

The investigated area is characterized by a morphologic break between hilly relief to the S and mountainous relief of the Saualpe to the N (Fig. 1a). This break may indicate the existence of an E-W striking fault zone. In closer detail W-E striking morphological lineaments visible on a DEM image occur especially in a transition zone between the Klagenfurt basin to the S, and the Saualpe-Gurktal Alps to the N. The foothills of the Saualpe and the Gurktal Alps, however, are characterized by roughly NW-SE and NE-SW running alignments.

The timing of possible stress field changes in the eastern Eastern Alps is inferred from sheared Tertiary and Quaternary sediments along the SEMP (NEMES et al., 1995; PERESSON and DECKER, 1996a, b), the Mur-Mürz fault zone (ZEILINGER et al., 1999; REINECKER, 2000), and the PAL (POLINSKI, 1991; POLINSKI and EISBACHER, 1992; SPRENGER and HEINISCH, 1992; FODOR et al., 1998). These studies consistently show pre-extrusional NW-SE compression and thickening, and E-W extension during lateral extrusion in Early to late Middle Miocene times, interrupted by a short-lived local N-S compressive updoming event in late Early Miocene time, a short-lived E-W compressional event at the the termination of lateral extension, and neotectonic N-S compression (see compilation in REINECKER, 2000).

Address of the authors

[1] J. KUHLEMANN, T. SCHOLZ and W. FRISCH, Institut für Geowissenschaften, Universität Tübingen, Sigwartstraße 10, D-72076 Tübingen, Germany



2. Regional structural setting of Eastern Carinthia

The investigated area (Fig. 1b) is located between the Neogene basins of Klagenfurt and Lavanttal at the southern face of an Austroalpine Saualpe crystalline basement block (GOSEN and THIEDIG, 1982). The area is characterized by klippen of Mesozoic strata in the St. Paul mountains, which are underlain by low-grade metamorphic Paleozoic Austroalpine terrains (Gurktal nappe; SCHÖNENBERG, 1970). These units are unconformably overlain by Early Miocene siliciclastic deposits of the so-called Granitztal subbasin (BECK-MANNAGETTA, 1952). The area has been mapped by THIEDIG and WEISSENBACH (1975), SEEGER and THIEDIG (1983) and SCHOLZ (2000).

The structural frame of the Granitztal subbasin is not clear (THIEDIG et al., 1975). The Lavanttal basin to the E started to form as a half graben (BECK-MANNAGETTA, 1952) modified by local pull-apart and flower structures along the dextral Lavanttal fault. This fault is stepping over to the NW into the Pöls line, which displays neotectonic activity (RITSEMA, 1974). The Early to Middle Miocene succession of the Lavanttal basin is intruded by the basalt stock of Kollnitz, which formed in the Middle Miocene according to whole rock K-Ar dating (LIPPOLT et al., 1975).

The E-W extending Klagenfurt basin to the SW is a flexural intramontane basin, downwarped along its southern margin by the North Karawanken unit (POLIN-

Fig. 1
(a) Digital Evelation Model (DEM) image of the Eastern Alps east of the Tauern window, showing lineaments of some larger faults of the Miocene extrusion pattern and the frame of the (b) geologic sketch map of the investigated area (simplified after BECK-MANNAGETTA, 1964) including the location of open pits selected for structural analysis. For abrevations, see text.

SKI, 1991; NEMES et al., 1997). Mesozoic rocks of this unit are thrust to the NW and N in Late Miocene times (VAN HUSEN, 1984).

3. Structural analysis

Nine fresh outcrops mainly in active open pits have been selected for structural analysis of brittle deformation (Fig. 1b; Tab. 1). The mined rocks are low-grade metamorphic Paleozoic carbonates and calcphyllites, Triassic dolomites, and the Middle Miocene basalt of Kollnitz. All outcrops displayed a complex history of brittle deformation. The succession of deformation events has been separated according to crosscutting relationships of shear sense indicators, especially of slickenside striae. Paleostress orientations of deformation phases have been analyzed and separated with the programme INVERS by SPERNER et al. (1993) and the programme NDA by RATSCHBACHER et al. (1994). The methods are described in detail by MESCHEDE (1994) and SPERNER (1996). For a critical appraisal of the assumptions involved in such paleostress analysis, we refer to ANGELIER (1989), ALLMENDINGER (1989), and WILL and POWELL (1991).

Structural analysis (Fig. 2) revealed 7 phases of brittle deformation (D_1-D_7):

D_1 reflects sinistral strike-slip movement along NNE-SSW and conjugate dextral WNW-ESE trending faults. The paleostress orientation reveals subhorizontal NW-SE compression and NE-SW tension. Towards the E the paleostress orientation shows clockwise rotation of c. 40. Faults of this phase are common only in half of the outcrops.They have been reactivated and overprinted during the D_4-event. The D_1 deformation phase is not present in the Middle Miocene basalt of Kollnitz. The preferred orientation of most fold axes in Late Cretaceous to Early Paleogene Gosau sediments in the area matches with post-depositional NW-SE compression (SCHOLZ, 2000). POLINSKI (1991) and POLINSKI and EISBACHER (1992) found such a paleostress orientation together with the latest Oligocene to Early Miocene deformation of the PAL. FODOR et al. (1998) attribute a similar paleostress orientation to an early extrusional phase along the PAL. Subsidence of the Lavanttal basin s.str. at the eastern boundary of the investigated area in latest Early Miocene time may have started at the end of the deformation phase during local NNW-SSE compression. Subsidence occurred within local pull-apart and flower structures formed parallel to the NNW-SSE running dextral Lavanttal master fault.

D_2 reflects dextral strike-slip movement along NNE-SSW striking faults with conjugate sinistral WNW-ESE striking faults. The paleostress orientation reveals subhorizontal NE- SW compression and NW-SE extension. Faults of this phase are found only in sites where they overprint D_1 deformation features. D_2 faults are probably reactivated during the D_5-event. This deformation event may reflect a regional variation of the well-known phase of E-W extension during lateral extrusion between 21 Ma and 12 Ma (RATSCHBACHER et al., 1991a), which fits to the regional paleostress orientation found by FODOR et al. (1998) 20-40 km further to the SE.

D_3 reflects convergent sinistral strike-slip movement along WNW-ESE trending faults with few conjugate dextral NE-SW D_2 striking faults. The paleostress orientation reveals subhorizontal W-E compression and N-S tension. Faults of this phase are the most common and are thus of special importance for the relative dating of deformation phases and regional correlation. They are observed in the Middle Miocene basalt of Kollnitz and thus younger than 15 Ma. This event which inverted fault movements of the extrusion pattern was attributed to the far field-effect of the "soft collision" of the Carpathian arc by PERESSON and DECKER (1997) and REINECKER (2000).

D_4 structures record dextral strike-slip movement along E-W striking faults with conjugate sinistral N-S trending faults. The paleostress orientation reveals subhorizontal NW-SE compression. Faults of this phase are very common and probably overprinted the D_1-structures. The D_1 and D_4 deformational events are clearly separated by crosscutting relationsships with structures formed during the D_2 and D_3 deformational events. NW-directed

Tab. 1
Localities selected for structural analysis along the southern margin of the Saualpe (Eastern Alps).

No Locality	Map	coordinates R/H	type/age of rock	outcrop type	n = No of data
1 Mittertrixen	204 Völkermarkt	546600/173260	dolomite/ L. Triassic	active pit	100
2 Attendorf	204 Völkermarkt	550350/172665	calcite marble/ E. Paleozoic	fresh inactive pit	105
3 Enzelsdorf	204 Völkermarkt	554040/173165	calcite marble/ E. Paleozoic	fresh inactive pit	100
4 Griffener Schloßberg	204 Völkermarkt	556660/174805	calcite marble, age uncertain	rock wall and cave	105
5 Schönweg	204 Völkermarkt	560405/178690	calcite marble and phyllite/ E. Paleozoic	active pit	100
6 Granitztal West	204 Völkermarkt	561450/177155	dolomite/ M. Triassic	active pit	70
7 Granitztal East	204 Völkermarkt	561705/177205	dolomite/ ? L. Triassic	fairly old inactive pit	78
8 Kollnitz	205 St. Paul	636810/175900	basalt 15 Ma	fresh inactive pit	41
9 St. Paul	205 St. Paul	638700/174160	dolomite/ L. Triassic	ancient pit	100

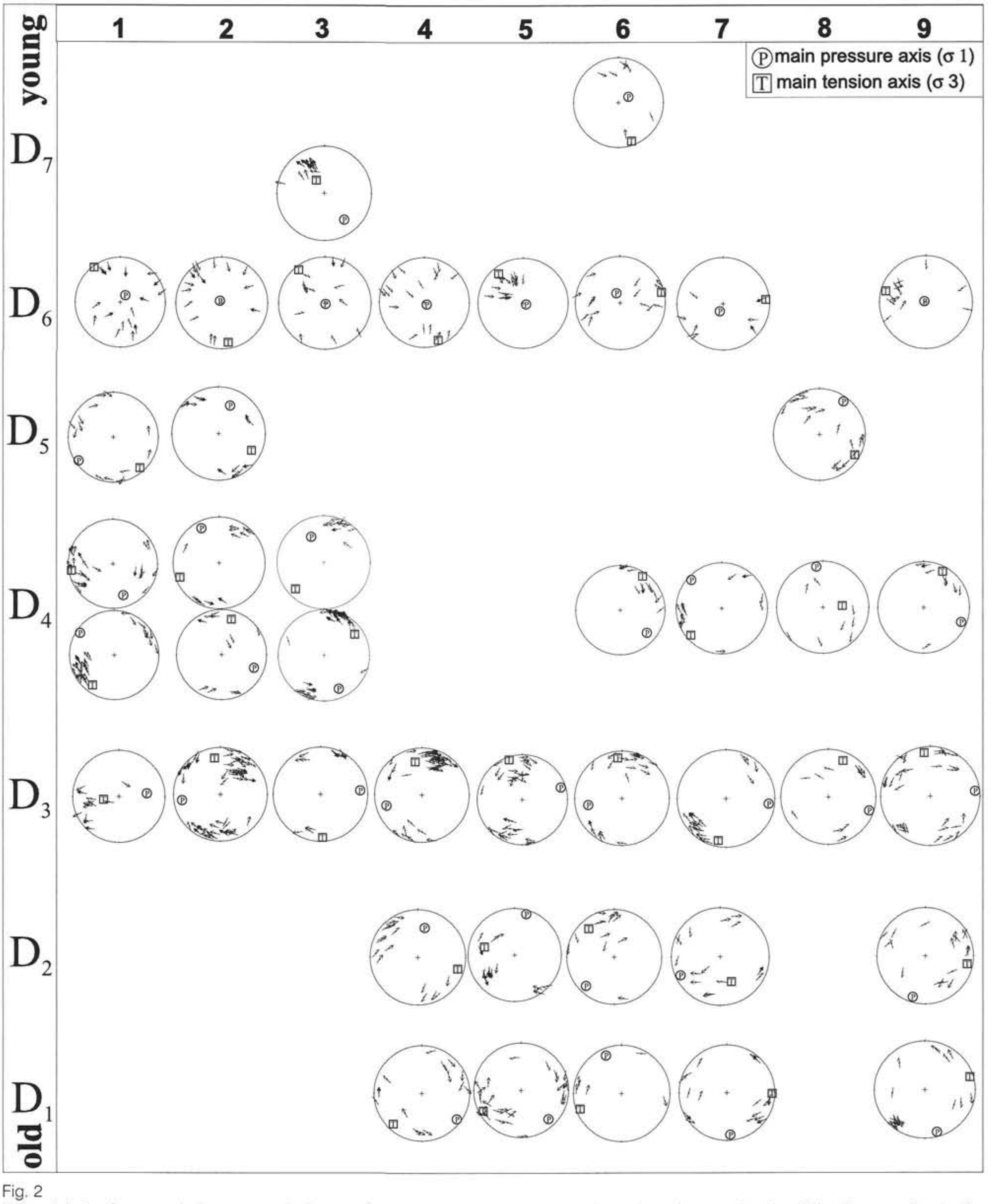


Fig. 2
Plots of fault planes and shear sense indicators (lower hemisphere) of the nine investigated open pits (see Tab. 1), according to the separation of deformation events. For the methods of separation, see text.

thrusting and rapid uplift of the North Karawanken unit started in early Pannonian/Tortonian time (VAN HUSEN, 1984). According to POLINSKI (1991), GOSEN (1989) and FODOR et al. (1998) paleostress orientation in early Late Miocene time would match NW-SE compression revealed from D_4 structures.

D_5 reflects sinistral strike-slip movement along E-W striking faults with conjugate dextral N-S striking faults. Faults of the D_5 phase are documented by rare fibres and probably reactivate D_2-structures. This deformation event indicates subhorizontal NE-SW compression and NW-SE extension.

D_6 reflects widely scattering normal faulting without preferred direction of dip, largely documented by calcite fibres. These structures are freqently observed on relatively small fault planes and represent the last deformational phase in several exposures. They indicate vertical shortening and overall horizontal extension.

D_7 records local minor NW-SE compression, matching the recent stress field and current motion of the Adria plate (WARD, 1994). Local very minor NW-SE extensional movements, probably caused by a variation of the local stress field, are hardly meaningful. Post-Miocene sediments which might enable to unravel neotectonic movements have not been studied.

4. Discussion and conclusions

The brittle deformation history of the St. Paul mountains (locations 5-7, 9) records the period of Miocene lateral extrusion (see RATSCHBACHER et al., 1991a) with N to NE-directed maximum compressional stress due to South Alpine indentation (Fig. 3). The change from NW-SE compression (D_1) to NE-SW compression (D_2) may be interpreted either in terms of a clockwise rotation of the stress field or in terms of a counterclockwise rotation of crustal blocks under more or less constant principal stress directions (Fig. 4). Paleomagnetic data from Miocene sediments of the intramontane basins east and southeast of the Tauern window indicate that counterclockwise (CCW) rotation of crustal blocks of this region in fact accounts for up to 65 degrees of rotation after c. 18 Ma (MÁRTON et al., 2000). The direction of motion of the Adria plate as a whole changed from NE between 25 and 16 Ma (magnetic anomaly 5C) to N until 9 Ma (magnetic anomaly 5) and to NW since then (MAZZOLI and HELMAN, 1994). Thus, the principal stresses rather rotated counterclockwise by 45 degrees in the later part of the lateral extrusion period, i. e., after ~16 Ma. Nevertheless, this superimposed trend may have been partly compensated by indentation and differential clockwise rotation of the Dolomites indenter during the extrusion period (see RATSCHBACHER et al, 1991a), which may have rotated the regional stress axis.

According to PERESSON and DECKER (1997b), the period of lateral extrusion in the Eastern Alps terminated in the course of "soft collision" of the Carpathian arc which caused inversion of the former sense of displacement along major faults of the extrusion channel sensu RATSCHBACHER et al. (1991b). This event occurred after intrusion of the 15 Ma old basalt stock of Kollnitz. The timing of regressive facies changes and local basin inversion in the Lavanttal basin (BECK-MANNAGETTA, 1952), the western Styrian basin (WINKLER-HERMADEN, 1957), and termination of crustal extension in the Rechnitz window after c. 14 Ma (DUNKL and DEMÉNY, 1997) suggests a time around c. 11 Ma (terminal Sarmatian/Serravallian time) for a first regional response to

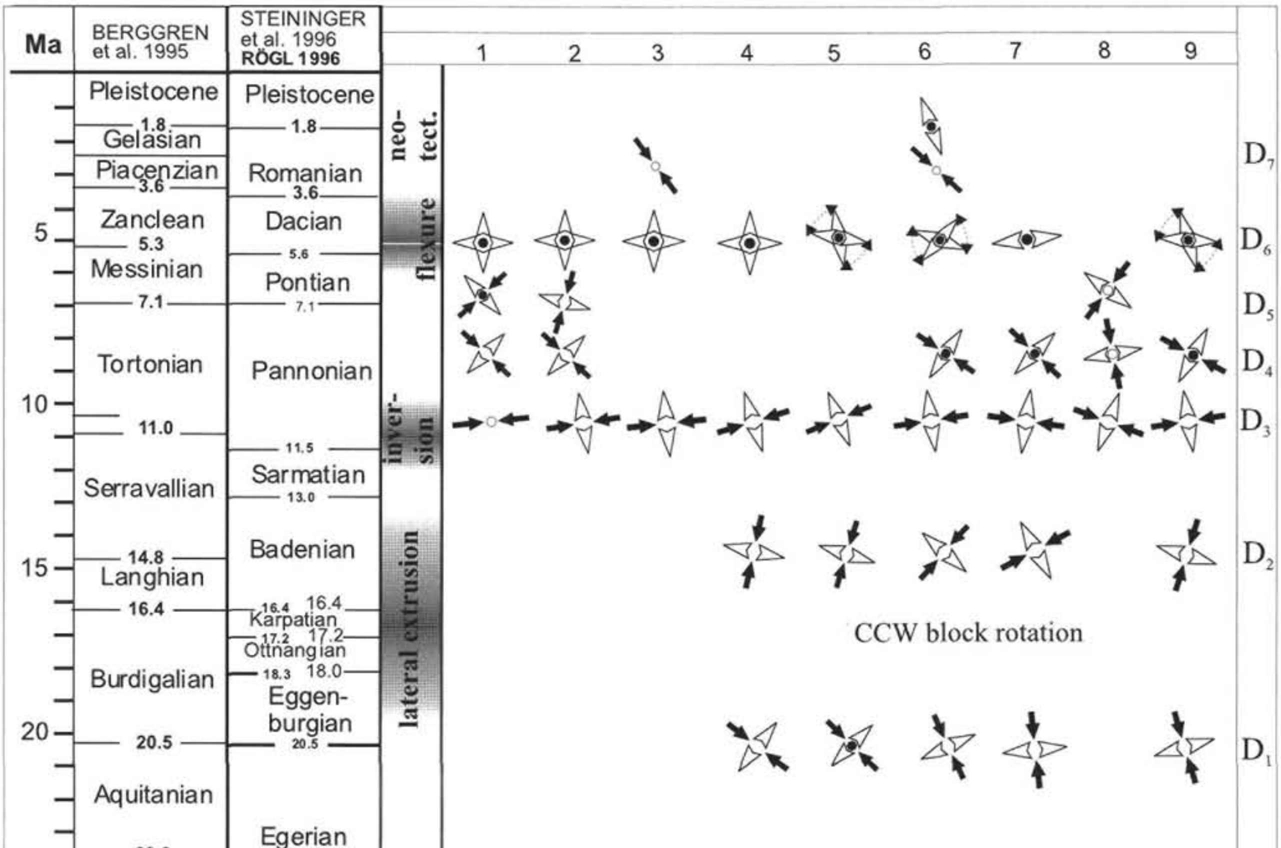


Fig. 3
Calculated paleostress axis orientation of deformation events D_1-D_8 and deformation episodes (left) within the Neogene time frame.

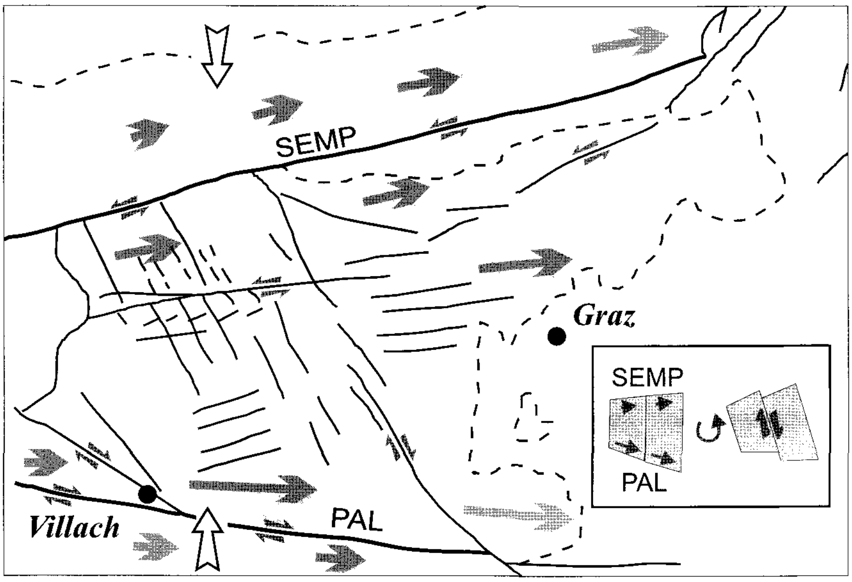


Fig. 4
Tectonic sketch map of the Eastern Alps east of the Tauern window during lateral extrusion after c. 18 Ma, indicating relative vectors of movement (grey arrows) for large displacement (long) and minor displacement (short). The small sketch illustrates the domino model of counterclockwise rotation during lateral extrusion (see MÁRTON et al., 2000).

the "soft collision" (KUHLEMANN, 2000). According to PERESSON and DECKER (1997b), deformed Pannonian strata in the eastern Styrian basin and Vienna basin indicate that this paleostress regime lasted until c. 6 Ma and may have started as late as 9 Ma. It seems that more effort has to be dedicated to a chronostratigraphic refinement of tectonic events with respect to regionally different response to large-scale tectonic events. However, the consequence of the "soft collision" was a short-term inversion of the former stress field and a reactivation of older faults in the opposite sense of shear, related to E-W compression.

After the "soft collision" the former stress field established with NW-SE compression documented in D_4 structures, which is compatible with N and NW-directed movement of the Adriatic plate (MAZZOLI and HELMAN, 1994). N to NW-directed thrusting and rapid uplift of the North Karawanken unit started in early Pannonian/Tortonian time (VAN HUSEN, 1984), accompanied by dextral strike-slip deformation along WNW-ESE trending faults within this unit (POLINSKI, 1991). The deformations D_1 to D_4 are observed and interpreted in a similar way by REINECKER (2000).

The D_5 structures may reflect minor regional extension in the southeastern part of the Eastern Alps as a response to Late Miocene SE-directed migration of wedge-shaped crustal blocks in the eastern Southern Alps (FODOR et al., 1998), resulting in multiple reorientations of the stress field described in eastern Slovenia (PREMRU, 1976). Late Miocene to Pliocene extrusion of crustal wedges and complex deformation patterns along major faults in Slovenia is also corroborated by paleomagnetic data (FODOR et al., 1998).

Within the multiple reorientations of the neotectonic stress field a discrete, well-documented phase of flattening strain occurs in D_6. Locally varying orientation of normal faults might by related to flexural bulging and S-dipping normal faulting along the northern rim of the Klagenfurt basin, triggered by loading of the Karawanken unit on the downwarped intramontane foreland basin in late Neogene times (NEMES et al., 1997), perhaps during deposition of the Sattnitz conglomerate in latest Pannonian/Tortonian to Pontian/Messinian times (see GRIEM et al., 1991). Bulging could have started coeval to the onset of thrusting of the Karawanken unit, but due to low rates of thrusting and a southward steepening of the thrust plane, northward migration of the flexural bulge took about 5 Ma to reach the investigated area.

Our study documented 7 relevant deformation phases, some of which (D_1 and D_4; D_2 and D_5) reveal similar paleostress orientation. Without some key findings of crosscutting slickenside striae and a Middle Miocene basalt stock a separation of these phases would have been unreliable. Moreover, without constraints provided by previous work cited above a timing of tectonic events would have been far less precise. Apart from support of former studies from a so far not investigated region of the Eastern Alps the following new conclusions are drawn:

1. The late evolution of the Klagenfurt basin caused a flexure of its northern margin, which seems to have caused deformation of locally flattening strain (D_6), possibly in latest Miocene time. Separation of this tectonic phase enables to trace locally variable neotectonic movements
2. Early NW-SE compression during D_1, hardly fitting to the movement of the Adriatic microplate in middle Tertiary times (MAZZOLI and HELMAN, 1994), is interpreted in terms of passive rotation of paleostress indicators by CCW rotation of crustal blocks during lateral extrusion in the Eastern Alps (MARTÓN et al., 2000).

5. Acknowledgements

This study has been supported by Collaborative Research Center (SFB) 275 financed by the German Science Foundation (DFG). The study benefited from continuous exchange with John REINECKER. Constructive reviews of Kurt DECKER, Marko VRABEC and Hugo ORTNER are gratefully acknowledged.

References

ALLMENDINGER, R. D, GEPHARD, J. W. & MARRETT, R. A., 1989: Notes on fault slip analysis. – Geol. Soc. Am., Short course on "Quantitative interpretation of joints and faults", Ithaca, New York, 68 p.

ANGELIER, J., 1989: From orientation to magnitude in paleostress determination using fault slip data. – J. Struct. Geol., **11:** 37-50.

BECK-MANNAGETTA, P., 1952: Zur Geologie und Paläontologie des Tertiärs des unteren Lavanttales. – Jahrb. Geol. Bundesanstalt, **95:** 1-102.

BECK-MANNAGETTA, P., 1964: Geologische Übersichtskarte der Republik Österreich, Maßstab 1:1.000.000. Geol. Bundesanstalt Wien.

DECKER, K. & PERESSON, H., 1996: Tertiary kinematics in the Alpine-Carpathian-Pannonian System; links between thrusting, transform faulting and crustal extension. – In: WESSELY, G. & LIEBL, W. (eds.): Oil and Gas in Alpidic Thrust Belts and Basins of Central and Eastern Europe. EAEG Spec. Publ., **5,** London, 69-77.

DUNKL, I. & DEMÉNY, A., 1997: Exhumation of the Rechnitz Window at the border of the Eastern Alps and the Pannonian basin during Neogene extension. – Tectonophysics, **272:** 197-211.

FODOR, L., JELEN, B., MÁRTON, E., SKABERNE, D., CAR, J. & VRABEC, M., 1998: Miocene-Pliocene tectonic evolution of the Slovenian Periadriatic fault – implications for Alpine-Carpathian extrusion models. – Tectonics, **17:** 690-709.

FRISCH, W., KUHLEMANN, J., DUNKL, I. & BRÜGEL, A., 1998: Palinspastic reconstruction and topographic evolution of the Eastern Alps during Late Tertiary tectonic extrusion. – Tectonophysics, **297:** 1-15.

FRISCH, W., DUNKL, I., & KUHLEMANN, J., 2000: Post-collisional large-scale extension in the Eastern Alps. – Tectonophysics, **327:** 239-265.

V. GOSEN, W., 1989: Fabric developments and the evolution of the Periadriatic Lineament in Southeast Austria. – Geological Magazine, **126:** 55-71.

V. GOSEN, W. & THIEDIG, F., 1982: Die Gurktaler Decke (Oberostalpin) und ihr unterlagerndes mittelostalpines Kristallin (Kärnten/ Steiermark-Österreich). – Mitt. Geol.-Paläont. Inst. Univ. Hamburg, **53:** 11-32.

GRIEM, W., WOLF, S., SYLVESTER, H. & THIEDIG, F., 1991: Sedimentologie und Sedimentpetrographie des teriären Sattnitzkonglomerats zwischen Villach und Klagenfurt (Kärnten, Österreich). – Jb. Geol. Bundesanstalt, **134:** 27-36.

KUHLEMANN, J., 2000: Post-collisional sediment budget of circum-Alpine basins (Central Europe). – Mem. Sci. Geol. (Padova), **52/1:** 1-91.

MÁRTON, E., KUHLEMANN, J., FRISCH, W. & DUNKL, I., 2000: Miocene rotations in the Eastern Alps – paleomagnetic results from intramontane basin sediments. – Tectonophysics, **323/3-4:** 163-182.

MAZZOLI, S. & HELMAN, M., 1994: Neogene patterns of relative plate motion for Africa-Europe: some implications for recent central Mediterranean tectonics. – Geol. Rundschau **83,** 464-468.

MESCHEDE, M., 1994: Methoden der Strukturgeologie. Enke-Verlag, Stuttgart, 169 p.

NEMES, F., PAVLIK, W. & MOSER, M., 1995: Geologie und Tektonik im Salzatal (Steiermark) – Kinematik und Paläospannungen entlang des Ennstal-Mariazell-Blattverschiebungssystems in den Nördlichen Kalkalpen. – Jb. Geol. Bundesanstalt, **138/2:** 349-367.

NEMES, F., NEUBAUER, F., CLOETINGH, S. & GENSER, J., 1997: The Klagenfurt basin in the Eastern Alps: an intra-orogenic decoupled flexural basin? – Tectonophysics, **282:** 189-203.

LINZER, H.-G., RATSCHBACHER, L. & FRISCH, W., 1995: Transpressional collision structures in the upper crust: the fold-thrust belt of the Northern Calcareous Alps. – Tectonophysics **242:** 41-61.

LIPPOLT, H. J., BARANYI, I. & TODT, W., 1975: Das Kalium-Argon-Alter des Basalts vom Lavant-Tal in Kärnten. – Der Aufschluß, **26:** 238-242.

PREMRU, U., 1976: Neotectonic evolution of Eastern Slovenia. – Geologija, **19:** 241-249.

PERESSON, H. & DECKER, K., 1997a: The Tertiary dynamics of the northern Eastern Alps (Austria); changing palaeostresses in a collisional plate boundary. In: NEUBAUER, F., CLOETINGH, S., DINU, C. & MOCANU, V., (Eds.), Tectonics of the Alpine-Carpathian-Pannonian region; II.- Tectonophysics, **272:** 125-157.

PERESSON, H. & DECKER, K., 1997b: Far-field effects of late Miocene subduction in the Eastern Carpathians; E-W compression and inversion of structures in the Alpine-Carpathian-Pannonian region. – Tectonics, **16:** 38-56.

POLINSKI, R. K., 1991: Ein Modell der Tektonik der Karawanken, Südkärnten, Österreich. – Ph.D. Univ Karlsruhe, 143 p.

POLINSKI, R. K. & EISBACHER, G. H., 1992: Deformation partitioning during polyphase oblique convergence in the Karawanken Mountains, southeastern Alps. – J. Struct. Geol., **14:** 1203-1213.

RATSCHBACHER L., MERLE, O., DAVY, P. & COBBOLD, P., 1991a: Lateral extrusion in the Eastern Alps, part 1: boundary conditions and experiments scaled for gravity. – Tectonics, **10:** 245-256.

RATSCHBACHER, L., FRISCH, W., LINZER, H.-G. & MERLE, O., 1991b: Lateral extrusion in the Eastern Alps, part 2: Structural analysis. – Tectonics, **10:** 257-271.

RATSCHBACHER, L., SPERNER, B., MESCHEDE, M., FRISCH, W., 1994: Computer techniques and applications: A program library for stress and strain analysis. – Tübinger Geowiss. Arbeiten, A21, 62 p.

REINECKER, J., 2000: Stress and deformation: Miocene to present-day tectonics in the Eastern Alps. – Tübinger Geowiss. Arbeiten, **55,** 128 p.

REINECKER, J. & LENHARDT, W. A., 1999) Present-day stress field and deformation in eastern Austria.- Int. Journ. Earth. Sciences, **88:** 532-550.

RITSEMA, A. R., 1974: The earthquake mechanisms of the Balkan region. – Koninklijk Nederlnds Meterogogisch Instituut, UNESCO, Survey of the seismicity of the Balkan region, UNDP project REM/70/172, 36.

SCHOLZ, T., 2000: Geologische Kartierung und Strukturanalyse in den St. Pauler Bergen, Österreich. – Unpubl. Master thesis Univ. Tübingen, 84 p.

SCHÖNENBERG, R., 1970: das variszische Orogen im Raum der Südostalpen. – Geotektonische Forschungen, **35,** 1-22.

SEEGER, M. & THIEDIG, F., 1983: Alpidischer Überschiebungsbau in den St. Pauler und Griffener Bergen (Ostkärnten, Österreich). – Verh. Geol. Bundesanstalt, 1982/3: 269-284.

SPERNER, B., 1996: Computer programs for the kinematic analysis of brittle deformation structures and the Tertiary tectonic evolution of the Western Carpathians (Slovakia). – Tübinger Geowiss. Arbeiten, A27, 120 p.

SPERNER, B., OTT, R. & RATSCHBACHER, L., 1993: Fault-striae analysis: a Turbo Pascal program package for graphical presentation and reduced stress tensor calculation. – Computers and Geosciences, **19:** 1361-1388.

SPRENGER, W. & HEINISCH, H., 1992: Late Oligocene to Recent brittle transpressive deformation along the Periadriatic Lineament in the Lesach Valley (Eastern Alps): remote sensing and paleo-stress analysis. – Annales Tectonicæ, VI/2 : 134-149.

THIEDIG, F. & WEISSENBACH, N., 1975: Die junge Bruchtektonik im Bereich der Saualpe. – Claustaler Geologische Abhandlungen, Sonderband 1, 155-174.

VAN HUSEN, D., 1984: Synsedimentäre Gleitschollen großen Ausmaßes im terrestrischen Jungtertiär der Karawanken. – Geol. Rdsch., **73:** 433-445.

WARD, S. N., 1994: Constraints on the seismotectonics of the central Mediterranean from Very Long Baseline Interferometry. – Geophys. J. Int., **117:** 441-452.

WILL, T. M. & POWELL, R., 1991: A robust approach to the calculation of paleostress fields from fault plane data. – J. Struct. Geol., **13:** 813-821.

WINKLER-HERMADEN, A., 1957: Geologisches Kräftespiel und Landformung. – 822 p., Springer, Heidelberg.

ZEILINGER, G., KUHLEMANN, J., REINECKER, J., KÁZMÉR, M., & FRISCH, W., 1999: Das Tamsweger Tertiär im Lungau (Österreich): Fazies und Deformation eines intramontanen Beckens und seine regionale geodynamische Bedeutung. – N. Jb. Geol.-Paläont. Abh., **214/3:** 537-568.

Manuscript received: 21. 03. 2002 ●
Revised version received: 20. 10. 2002 ●
Manuscript accepted: 20. 12. 2002 ●