Axial depressions and culminations in the evolution of the Helvetic chain

SCHWEIZ. MINERAL. PETROGR. MITT. 69, 183–189, 1989

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by *Dorothee Dietrich*[1]

Abstract

The Helvetic nappes have been formed by overthrust shear between the already overthrust Penninic nappes and the underthrusting European basement. A change in the direction of overthrust shear from northwards towards westwards occurred during the formation of the nappes. This rotation caused regional extension parallel to the chain in the already formed Helvetic nappes of western Switzerland. A westwards shortening direction is also seen in the later deformation of the basement. The changing direction of overthrust shear is the expression of an overall anticlockwise rotation of the Alpine nappe pile, relative to the European plate. This rotation is related to the formation of the arc of the western Alps.

Keywords: Helvetic nappes, tectonics, overthrust shear, pressure shadow, Western Alps.

Indroduction

Axial depressions and culminations are a characteristic feature of the Helvetic chain. These megastructures comprise both European basement (the external massifs) and the overlying Helvetic carbonate nappes (Figs. 1 and 2). The axial plunge of the Aar and Aiguilles Rouges massifs towards the Wildstrubel depression has been already shown by ARGAND (1902-1911) and is evident from recent deep seismic reflection profiling (line NFP-20 west, SCHWEIZERISCHE ARBEITSGRUPPE FÜR REFLEXIONSSEISMIK, 1988). The axial plunges of the nappes in Fig. 2 have been constructed from regional measurements of bedding/cleavage intersection lineations and from measurements of small and large scale fold axes.

Most authors agree that the uplift of the massifs postdates the formation of the Helvetic nappes. The Aar "massif" has been interpreted from seismic refraction measurements as a crustal flake structure containing internal thrusts (MUELLER, 1982). These basement structures deform the pre-existing folds and thrusts of the overlying nappes. Notwithstanding, the individual folds and thrusts in the nappes show great lateral continuity (RAMSAY, this volume). Such a continuity would not be expected above pre-existing basement culminations and depressions. The questions therefore are: how did the formation of the basement culminations and depressions affect the overlying nappes? How are the basement structures to be integrated in a tectonic model of the Helvetic chain? The Helvetic chain of western Switzerland and its westward continuation, the French Chaînes subalpines, form the external part of the arc of the western Alps. The discussion, based on observations from the Helvetic region of western Switzerland, should therefore be of general interest in relation to curved foreland fold- and thrust belts.

The Helvetic chain is superbly exposed and stratigraphically well studied; the region represents therefore an ideal ground for the application of established and the evolution of new structural geology techniques. New techniques which have been evolved in the Helvetic carbonate multilayer sequence comprise the measurement of deformation using tectonic fibres in pressure shadows and extension veins (DURNEY and RAMSAY, 1973; RAMSAY and HUBER, 1983, 1987). The pressure shadows consist predominantly of quartz fibres around diagenetic pyrite and the individual fibre has a diameter of about a micron (Fig. 3). The fibres developed from a fluid film on the pyrite/matrix interface. The source of the fibres were probably quartz clasts

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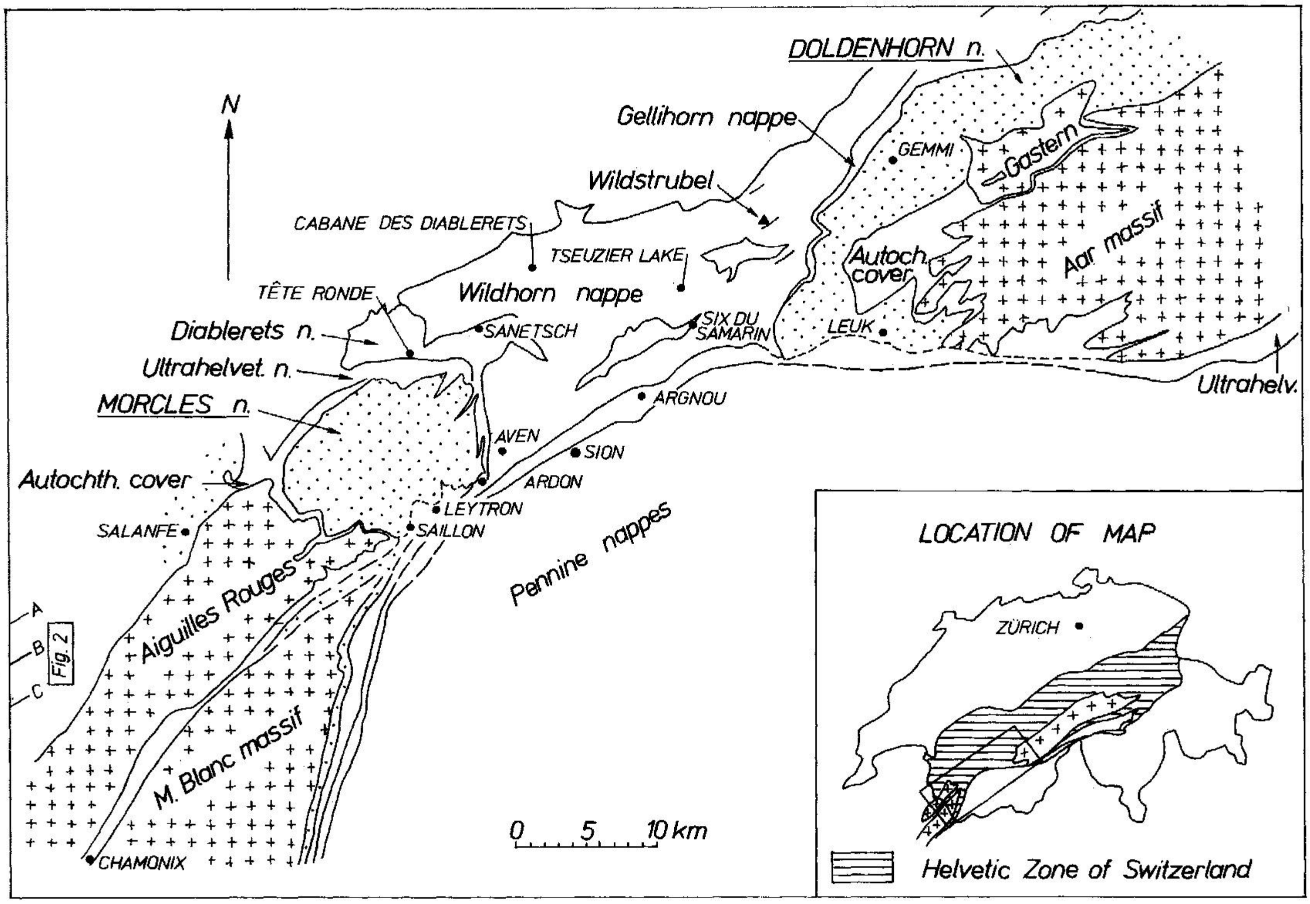


Fig. 1 A tectonic map of the Helvetic nappes of western Switzerland. The traces of the three sections of Fig. 2 are shown.

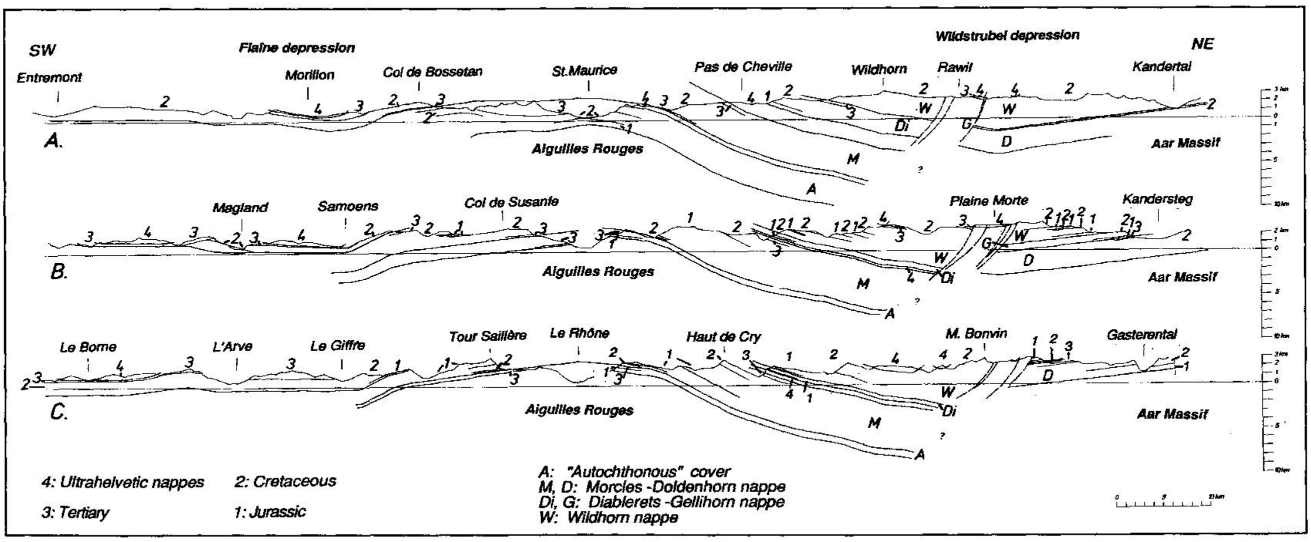


Fig. 2 Three fold-axis parallel sections along the Helvetic chain. A is the most external, C the most internal section. The projection in depth is based on plunge values of cleavage/bedding intersection lineations and of fold axes. A branch line (Hossack, 1983) connecting the Cretaceous in the "synclinal de raccord" of the Diablerets nappe with the most internal Cretaceous outcrops in the Gellihorn nappe is parallel to the fold axis trend and gives an independent check for the choice of the section lines. The thickness of the individual nappes does not correspond to the stratigraphical thickness of the Helvetic sequence, but comprises thickening by folding and faulting. The sections are based on a 1:100.000 compilation of the 1:25.000 geological field maps of the region by J. G. Ramsay.

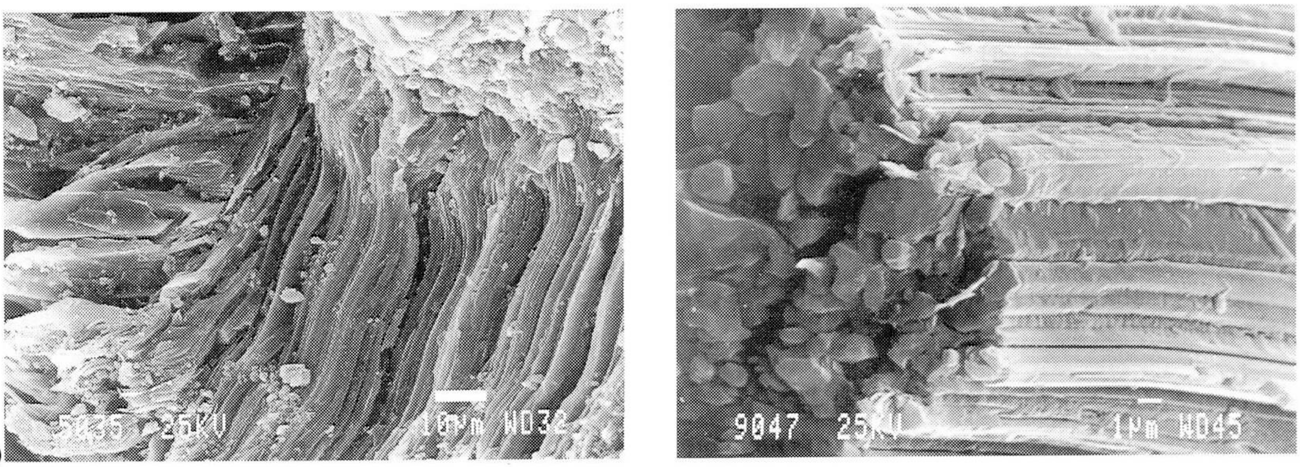
(a)  (b)

Fig. 3 SEM-images of Helvetic pressure shadows. (a) Curving quartz fibres around a framboidal pyrite. (b) Quartz fibres in 3-D. (a) Specimen D 657, Tête Ronde, Diablerets nappe; (b) specimen D 712, Ardon, Morcles nappe (localities indicated on Fig. 1). Both specimens are in Valanginian limestone.

which are common in many Helvetic sediments. Pressure solution was the dominant deformation mechanism in the region (Durney, 1972), and silica had to be present in the fluid phase. The length and direction of these fibres are directly related to the amount of extension in the adjacent rock. Fibre data reveal the progressive evolution of deformation in time at each individual specimen locality. The data should therefore bear important information regarding the tectonic history of the nappes.

Tectonic fibres: data and conclusions

Fig. 4 contains the pressure shadow data obtained from the region. A detailed discussion of

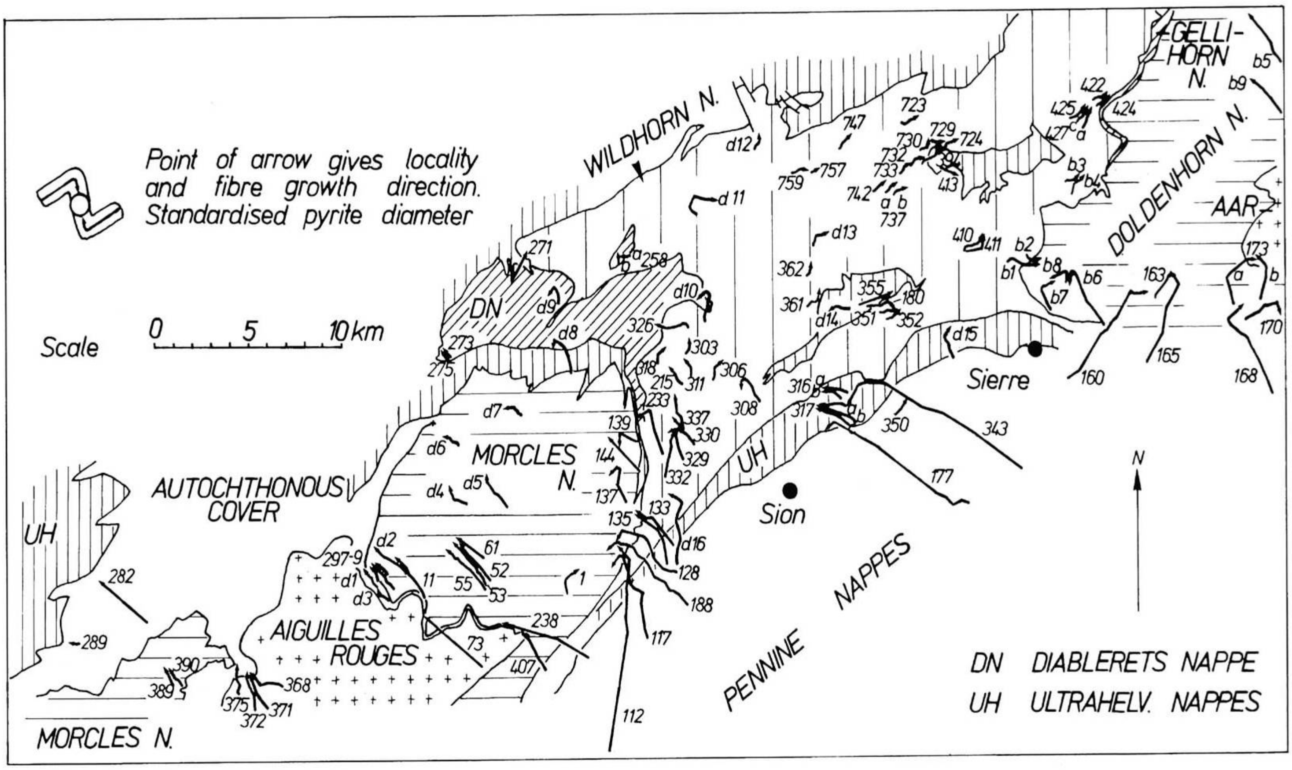


Fig. 4 The pressure shadows – predominantly quartz fibres around pyrite – of the Helvetic nappes of western Switzerland. The length of the fibre increments are normalized relative to the standard pyrite size shown top left. The fibres are represented as seen in thin sections parallel to the cleavage plane. More details can be found in Dietrich (in press). The numbers refer to the individual specimens. d: data from Durney and Ramsay (1973), b: data from Burkhard (1986).

the fibre geometry and strain calculation is contained in DIETRICH (in press). The fibre pattern on this map can be used, together with stretching lineation data (DIETRICH and DURNEY, 1986) and data on the geometric shape of the nappes (DIETRICH and CASEY, 1989) to infer a tectonic model for the region (Fig.5).

The Helvetic nappes have been formed by overthrust shear acting between a rigid, cold orogenic lid (the already overthrust Penninic nappes) and the warm, but highly viscous basement (LAUBSCHER, 1983). In Fig. 5 the nappe formation is assumed to have been sequentially downwards from the uppermost Ultrahelvetic nappes down to the Wildhorn, Diablerets and Morcles nappes, or from the internal to the external part of the Helvetic shelf. Out of sequence deformation has up to now not been documented in the Helvetic nappes of western Switzerland. The data contained in the fibre map, Fig. 4, allow quantification of the overthrust shear events that affected the individual nappes. The principal streching direction expressed by the fibres, i. e. the principal fibre direction, is at a high angle to the chain, and can be related to stretching during overthrust shear. The mean directions of overthrust shear are shown in Fig. 6, and are labelled 1 to 5 ; 1 refers to the oldest, the Ultrahelvetic nappes, 5 to the youngest, the Morcles nappe. A smaller, and later, stretching increment, labelled 6 in Fig. 6, is subparallel to the Helvetic chain. The fibres studied from the Wildstrubel depres-

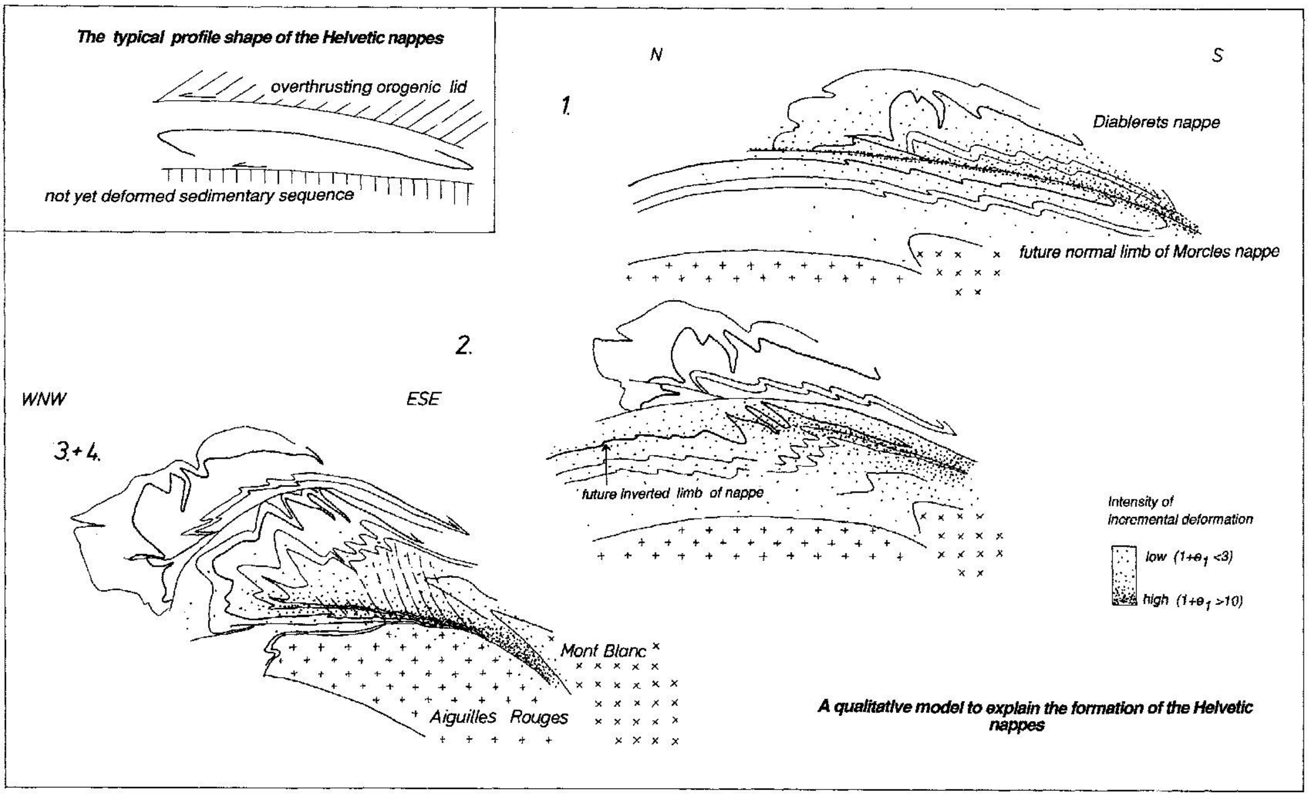


Fig. 5 A qualitative model of the evolution of the Helvetic nappes of western Switzerland. A quantiatative model of the nappe evolution is being presented by DIETRICH and CASEY (1989), and fold formation by overthrust shear has been discussed by CASEY and HUGGENBERGER (1985). The inset shows the basic shape of the nappes, consisting of a "synclinal de raccord" in the rear part and an anticlinal fold hinge in the front. The orogenic lid (sensu LAUBSCHER, 1983) consists of the already overthrust Pennine nappes and progressively activates the underlying sedimentary sequence of the Helvetic shelf, the lowest nappe being the last to be incorporated in the lid. The overall wedge shape of the nappes results from a component of pure shear deformation in the rear part of the nappes, acting contemporaneously with the simple shear deformation. Stages 1 to 4 show, as an example, the evolution of the Diablerets and Morcles nappes. Stage 1: The Diablerets nappe is already deformed; the zone of overthrust shear narrows down and leads to the formation of a thrust contact. Heterogeneous shear deformes the underlying sediments. Stage 2: The zone of active deformation amplifies the gentle folds, to form the folds of the normal limb of the Morcles nappe. Stage 3: The zone of overthrust shear narrows down again and deforms a syncline into the inverted limb of the Morcles nappe. Note the change of direction of overthrust shear (DIETRICH and DURNEY 1986). Stage 4: Formation of the crenulation cleavage in the Morcles nappe, and deformation of the basement.

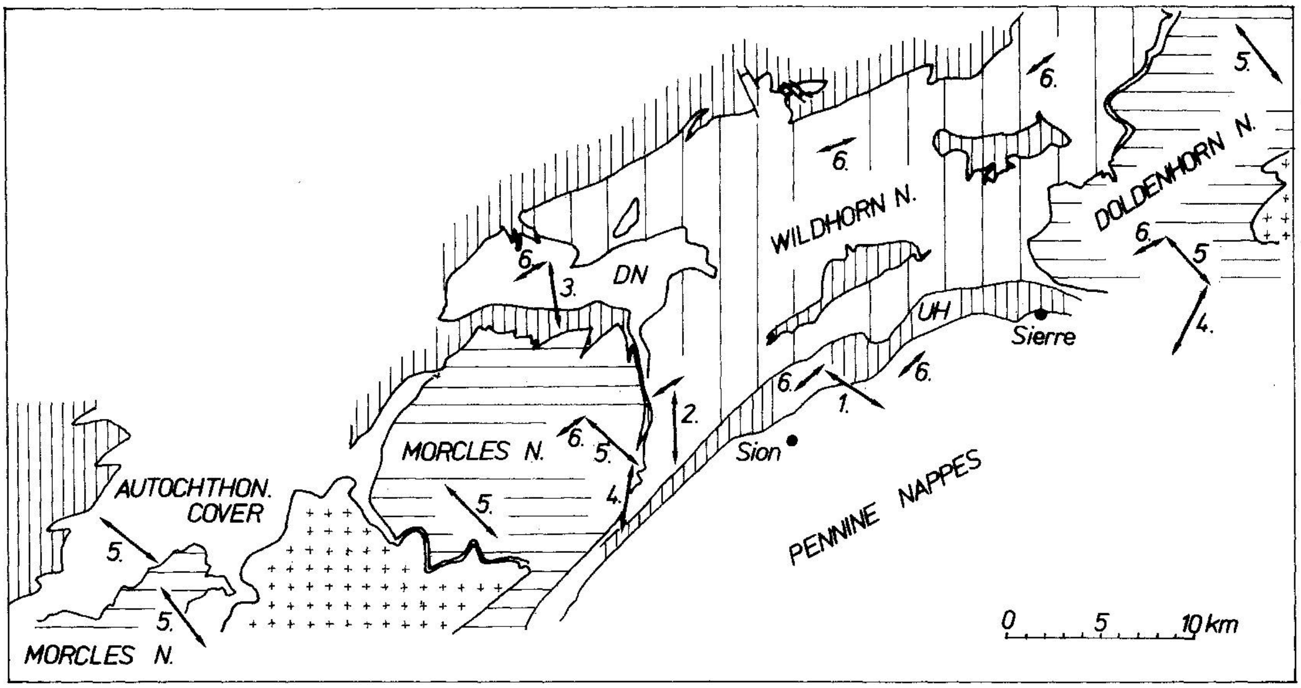


Fig. 6 The extension history deduced from the fibre map, Fig. 4., and represented as a sequence of stretching events. 1 indicates the direction of the oldest and 6 of the youngest event of overthrust shear.

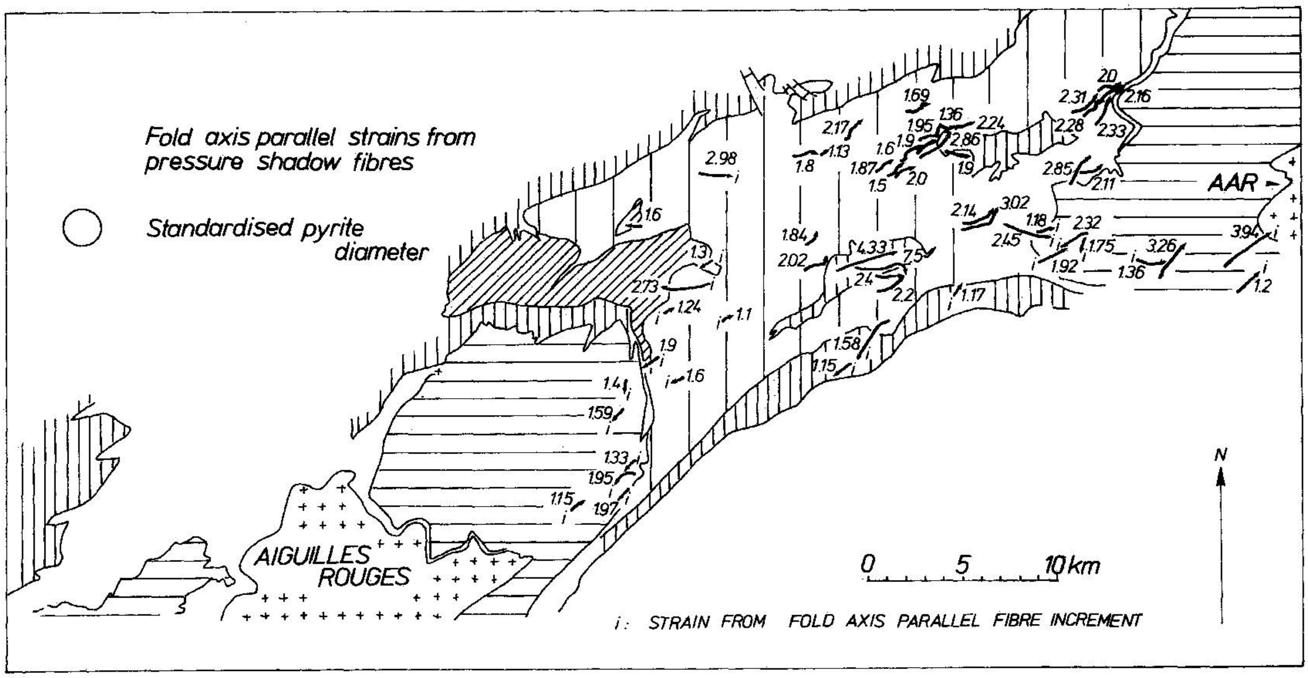


Fig. 7 The fold-axis parallel strain of the Helvetic nappes, as deduced from pressure shadow fibres. This figure contains only the fold-axis parallel fibres of Fig. 4, and the numbers refer to the calculated strain values for the fold-axis parallel extension. In the SE part of the nappes only the very last fibre growth is parallel to the fold-axes (labelled "i" in the figure); in the Wildstrubel depression the overall fibre growth is fold-axis parallel. A discussion of method and results is contained in DIETRICH (in press).

sion show only stretching subparallel to the chain. The arrows 1 to 4 are rotated in a clockwise sense. The shear zone, situated below the advancing orogenic lid and/or above the subducing Helvetic shelf, had probably a relatively stable orientation. If the shear- or overthrust direction was constant, then the orogenic lid, which progressively incorporated the individual nappes after their formation, had to rotate anticlockwise relative to the basement, according to the stretching directions 1 to 4. This rotational movement is in accordance with the view, that the E-W sector of the Alps, in the Miocene, represented a dextrally transpressive belt (LAUBSCHER, 1971). A definite change in the direction of overthrust shear occurred during event 5, which refers to the formation of the inverted limb of the Morcles-Doldenhorn nappe (Fig. 5). The same westwards direction can be inferred from the geometry of the crenulation cleavage in the Morcles nappe. Such westwards movements have not been observed in the corresponding tectonic units in central and eastern Switzerland. The change in the overthrust direction has been interpreted by DIETRICH & CASEY (1989) as being linked to the movements of the Simplon normal fault (MANCKTELOW, 1985).

The data concerning extension subparallel to the Helvetic chain, contained in Fig. 4, are presented seperately in Fig. 7. Previous authors (SANDERSON, 1982 and BURKHARD, 1988, for the western Helvetic nappes; PFIFFNER, 1981, for the eastern Helvetic nappes) have suggested, that this fold-axis parallel extension is related to the formation of the basement culminations and depressions. However, Fig. 7 shows, that the fold-axis parallel strains are not localized parallel to the slopes of the Wildstrubel depression, but affect the overall Helvetic chain of western Switzerland. DIETRICH (in press) discusses this point in detail, based on two strain models. It is therefore suggested, that it is the change in the thrusting direction which led to a stretching of the already formed Helvetic nappe pile. Westwards directed compression by overthrust shear might be also responsible for the later thrusting that led to the formation of the basement culminations. The shapes of the Wildstrubel and Flaîne axial depressions are very asymmetrical, the basement below the eastern slope being much higher than below the western slope. This "Sockelsprung" amounts to several kilometres between the higher Aar basement and the lower Aiguilles Rouges basement (Fig. 2). Westwards directed displacements of the basement thrusts might therefore be responsible for the formation of the asymmetrical depressions. RAMSAY (1989, this volume) reaches the same conclusion from different reasoning. The rotation of the direction of overthrust shear is viewed also as an expression of the migration of the deformation from east towards west, the westwards directed thrusting being younger than the northwards directed thrusting. The Miocene rotation of the direction of overthrust shear, observed not only in the external, but also in the internal part of the central-western Alps (STECK, 1987, MERLE et al., 1989), is therefore an important fact when considering the formation of the arc of the western Alps.

The stretching history of the Helvetic chain - first stretching at a high angle to the chain related to the "mise en place" and main folding history of the nappes, then stretching parallel to the chain related to a change in direction of overthrust shear - is documented as well in the pattern of the extension veins and in the fault and joint pattern of the region (DIETRICH, in press).

Acknowledgements

Martin Casey contributed to the model presented in Fig. 5 by discussion and criticism. John Ramsay is thanked for critical reading of the manuscript. The financial contribution from Schweizerischer Nationalfonds (project nr. 2.2140.86) is gratefully acknowledged.

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Manuscript received and accepted June 16, 1989