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Finite strain patterns in some Alpine nappes

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Abstract—The patterns of finite strain in some Alpine nappes and thrust sheets are reviewed, together with their tectonic evolution.

Glarus Nappe. The finite strain pattern, approximately that of heterogeneous simple shear, was acquired during Upper Oligocene times when the Helvetic thrust block was deformed together with its infrastructure and basement. The Glarus Thrust was formed during Miocene times and modified by Pliocene to Recent differential uplift.

Morcles Nappe. This large recumbent fold nappe overrode the Aiguilles Rouges Massif and its cover towards the northwest. The finite-strain pattern resulted from successive diagenetic compaction, multilayer buckling and heterogeneous simple shear. High strains occur along the inverted limb of the nappe and fold hinges are oriented subperpendicular to the NW stretching lineation. Final emplacement of the nappe, during the Miocene, was perhaps a later event.

Chartreuse Massif. 33% E–W shortening was developed across this fold and thrust belt during post-Helvetian times by décollement along the Oxfordian shales, in response to thrusting and uplift in the Belledonne basement. The Oxfordian shales had earlier accommodated a pre-Helvetian (probably Oligocene) deformation in the basement and its Trias–Bajocian cover, when N030° trending, subhorizontal folds, cleavage and a stretching lineation (18% N030° stretching) were developed.

Digne Nappe. Detached along the Keuper evaporites, the cover was displaced westwards in two stages: (1) late Oligocene, with folding, cleavage development, formation of the frontal slices and an overall E–W shortening of 20% and (2) late Miocene–Pliocene, after emplacement of the Embrunais Nappes in the east, producing the Digne Thrust.

It is concluded that for these Alpine nappes geological criteria must be used to establish their evolution. If the internal deformation can then be assigned to part of this evolution, the pattern of finite strain can be used to quantify and elucidate that part. A maximum of information is gained if the incremental deformation history can also be obtained from study of syntectonic fibres.

INTRODUCTION

FINITE strain states have been determined in terrains involving thrust tectonics in external parts of the West and Central Alps (Helvetic Nappes of Glarus and Valais, Switzerland and in the Sub-Alpine Chains of France). These terrains have recently been subject to detailed geological study, including structural analysis. It, thus, seemed worthwhile to compare the tectonic evolution of these several nappes and thrust sheets, as deduced from geological evidence, with their patterns of finite strain.

The geographical and geological situations of the various areas, in the context of the Alpine Chain and its evolution, can be found in the recent reviews by Trümpy (1980) and by Debelmas & Kerckhove (1980). Ramsay (1981) provided a more comprehensive review of the Helvetic Zone of Switzerland.

THE GLARUS NAPPE

The continuing debate about Alpine thrust tectonics started here, in east Switzerland, almost a century ago, when Bertrand (1884, fig. 2) reinterpreted the beautiful cross-sections of Heim (1878, plate VII, section 13) in terms of a thrust plane, rather than a double-fold. An excellent geological map of the Glarus Alps was produced by Oberholzer (1942) and during the 1960s a number of Zürich theses described the region in great detail (references in Siddans 1979a, Pfiffner 1981; see also the review by Trümpy 1969). Modern structural studies of the Helvetic thrust block in east Switzerland, of which the Glarus Nappe is the lowest unit, the infrastructure and their tectonic evolution, are described by Schmid (1975), Milnes & Pfiffner (1977,1980), Milnes (1978) and Pfiffner (1981). Following these authors the tectonic history of the Glarus Nappe is broadly divisible into three phases.

(1) *The Calanda Phase (Upper Oligocene)*. The future Tavetsch and Gotthard Massifs, together with their Permian–Lower Oligocene cover, were located in a southerly dipping ductile shear zone below northwards-overriding (probably gravity spreading) Pennine and Austro-Alpine Nappes. Later during the Calanda Phase this ductile shear zone steepened and extended northwards to include the internal margin of the Aar Massif. The bulk of the internal deformation of the Glarus Nappe was achieved during this time.

(2) *The Ruchi Phase (Miocene)*. The Helvetic nappe complex was transported northwards a minimum of 35 km along the Glarus Thrust, with shearing concentrated into the narrow zone between the Aar and Tavetsch Massifs. At this time the northern part of the Glarus Thrust dipped gently south, the dip increasing towards the south.

(3) *Pliocene and Recent.* Post-tectonic differential uplift, more rapid in the south than the north, resulted in the present day geometry, with the thrust plane dipping gently north in northern parts.

This tectonic evolution is illustrated by Milnes & Pfiffner (1977, fig. 3).

Siddans (1979a, table 1) presented the results of finite strain analyses from measurement of green-spot shapes in the red Permian mudstones of the Glarus Nappe. These were total strain estimates and include any diagenetic compaction that the rocks may have suffered prior to tectonic deformation. A strain map, combining this data with observations previously recorded in the Zürich theses, a deformation plot and an analysis of the bulk extension parallel with the thrust plane using the method of Hossack (1978), were presented (Siddans 1979a, figs. 1, 5, & 6; see also the similar strain map by Pfiffner 1981, fig. 1c). It was found that in the lower (Permian) and northern parts of the nappe, finite flattening planes dip gently south and contain the finite stretching direction, N–S. Finite strain states plot in a band containing the line $k = 1$ on the Flinn diagram and a bulk N–S extension of 14% is recorded parallel to the thrust plane. This extension is heterogeneously distributed with finite shortening seen in the extreme northern parts. The bulk reciprocal quadratic elongation down-dip in the cleavage (=0.26) is identical with that recorded by Milnes & Pfiffner (1977) in the underlying Infrahelvetic complex. Upwards in the Glarus Nappe, deformation decreases and the cleavage steepens.

The pattern of finite strain within the Glarus Nappe is thus broadly consistent with that of a ductile shear zone, corresponding with the Calanda-Phase events, but tells us little about the later Ruchi-Phase events and the formation of the Glarus Thrust, except that there was apparently little associated internal deformation within the bulk of the Glarus Nappe.

THE MORCLES NAPPE

The Morcles Nappe in west Switzerland is analogous in its structural position to the Glarus Nappe in east Switzerland; that is, it is the lowest of the Helvetic Nappes. It is a large recumbent fold nappe with the Mont Blanc Massif occupying its core which overrides the most external of the crystalline massifs, its 'autochthonous' cover and various parautochthonous slices. It is very beautiful and magnificently exposed on either side of the Rhône Valley, north of Martigny. Following the descriptions by Lugeon, in a series of articles (1901–1914), detailed memoires on the terrains west and east of the Rhône Valley were presented by de Loys (1928) and by Badoux (1972b). The youngest rocks involved in the nappe are of Priabonian age. A minimum of some 20 km NW displacement are indicated, and the final emplacement was during Miocene times.

Following the pioneer work in estimating the deformation history of the Western Helvetic Nappes from syntectonic fibre development (Durney 1972, Durney & Ramsay 1973), the Western Helvetic Nappes have recently been the subject of an intensive research campaign by the Zürich group (abstracts to date Ramsay *et al.* 1981, Dietrich 1982, Casey & Huggenberger 1982). A model seems to be emerging for the Morcles Nappe of multilayer buckling, followed by heterogeneous simple shear which displaced the nappe towards the NW along a ductile shear zone. Late displacements in the SE are oriented SW–NE, but these are far more important in the higher nappes.

As a complement to this work and to supplement earlier studies by Badoux (1963, 1972a) and Durney (1972), a programme of finite strain measurement was carried out in the Morcles Nappe, the parautochthonous slices and the 'autochthon'. Using mainly oolitic rocks and conglomerates, at various stratigraphic levels (Callovian, Valanginian, Urgonian, Aptian and Tertiary, for details see Table 1), finite strains were estimated from Rf/ϕ analysis of measurements on three perpendicular surfaces (Dunnet 1969, Dunnet & Siddans 1971, Siddans 1980). Where possible, field-oriented samples were cut in the laboratory, though many of the conglomerates had to be measured in the field. Results of the 47 new finite strain analyses and their geographic locations are given in Table 1. The axial ratios were calculated assuming that an original sphere of equivalent volume had a radius of 1 unit; they are total deformation ellipsoids (i.e. they include the effects of any diagenetic compaction). It was found impossible to separate the effects of any diagenetic compaction or primary sedimentary fabric, which certainly means that the conglomerate results overestimate the tectonic deformation. The results are plotted on a logarithmic deformation plot in Fig. 1, coded according to structural level and rock type. Results are incomplete from the southern parts of the lower limb, where the tectonic strains are so great that in combination with the original shape fabrics, the deformed objects are not measurable. (Conglomerates are so stretched that it is impossible to find both ends of single pebbles in samples that can be carried off the mountain).

A strain map is shown in Fig. 2 and two NW–SE strain cross-sections, east and west of the Rhône valley, are shown in Fig. 3. These confirm quantitatively the patterns given by Ramsay (1981, fig. 5), though the strains recorded here in the parautochthon and in the inverted limb of the nappe, are respectively rather higher and rather lower than the corresponding values suggested by Ramsay (1981). In general, the following pattern is observed: strains increase upwards, from zero near the crystalline basement, through the 'autochthon' and parautochthonous slices, attain high values in the inverted limb of the nappe, then decrease upwards through the hinge zone to locally zero in the normal limb. With the exception of the classic stretched belemnite locality, HB1 at Leytron, in the extreme south (Badoux 1963), the finite extension directions within the nappe are uniformly NW–SE. The dip of the flattening planes (XY), is towards the SE in the 'autochthon' and parautochthonous slices (see localities 10C, HB2, 6; the

Table 1. Finite strain analyses in the Morcles Nappe region. Rock types are coded: LB Lias belemnites, CO Callovian oolites, BC Bajocian conglomerates, MC Malm conglomerates, VO Valanginian oolites, UO Urgonian oolites, AC Aptian conglomerates, N Nummulitic, CF conglomeratic flysch. Grid references refer to the Swiss National Grid, altitudes are in metres. For details of sites HB1 and HB2 see Badoux (1963, 1972a).

Loc	Rock	Grid Ref	Alt	X:Y:Z	Pl X	Pl Z
1	CO	57970/11937	1720	1,19 1,01 0,83	26/153	38/267
1A	CO	57970/11937	1720	1,32 1,22 0,62	26/153	38/267
2	VO	58524/11724	680	2,00 1,05 0,48	23/140	58/277
3	VO	56945/11862	1495	1,36 1,01 0,73	62/323	28/143
3A	VO	56945/11862	1495	1,21 1,20 0,69	62/340	25/132
4G	AC	56320/11180	2360	3,03 1,04 0,32	5/308	75/064
4B	CF	56320/11180	2350	2,20 1,04 0,44	10/309	65/061
4F	CF	56320/11180	2340	3,14 0,81 0,39	10/309	65/061
4C	CF	56320/11180	2330	2,34 1,22 0,35	10/309	65/061
5	VO	56122/10990	2200	1,74 1,11 0,52	4/130	86/323
5F	CF	56155/10990	2010	2,85 1,10 0,32	8/310	80/131
5A	CF	56170/10985	1980	2,45 1,28 0,32	9/299	82/131
5X	CF	56115/11140	2485	3,05 1,36 0,24	0/300	90/000
6B	CO	56480/11120	2180	1,67 1,63 0,37	17/163	72/316
6A	BC	56480/11120	2190	2,46 0,96 0,42	17/163	72/316
6D	CO	56480/11120	2180	1,23 1,23 0,66	17/163	72/316
7	UO	55705/11550	990	1,00 1,00 1,00		
7A	UO	55735/11550	940	1,00 1,00 1,00		
7B	CF	55750/11390	1270	1,00 1,00 1,00		
9	VO	55455/11162	1230	1,00 1,00 1,00		
8A	VO	57465/11675	2220	2,08 0,96 0,50	21/131	69/311
8B	VO	57465/11675	2220	2,11 1,13 0,42	21/131	69/311
8C	VO	57465/11675	2220	1,49 1,15 0,58	21/131	69/311
8P	MC	57643/11625	2050	3,25 1,22 0,25	5/299	61/199
8D	BC	57640/11660	2080	1,49 1,45 0,46	0/303	90/000
10B	CF	57099/11660	2400	2,15 1,41 0,33	11/126	70/248
10A	CF	57099/11660	2390	2,37 1,11 0,38	11/126	70/248
10	CF	57099/11660	2370	2,16 1,50 0,31	11/126	70/248
10M	CF	57099/11660	2350	2,74 0,87 0,42	11/126	70/248
10C	CF	57099/11660	2280	1,50 1,24 0,54	1/089	80/350
11	N	58185/12365	1740	1,00 1,00 1,00		
11A	N	58185/12365	1740	1,00 1,00 1,00		
11B	VO	58237/12385	1790	1,28 1,19 0,65	64/132	27/312
11C	VO	58270/12380	1810	1,00 1,00 1,00		
11F	CF	58250/12500	1560	1,38 1,38 0,53	13/125	77/305
11D	VO	58525/12350	1200	1,30 1,00 0,77	50/118	40/299
12	N	58160/12580	1750	1,00 1,00 1,00		
12A	N	58160/12580	1750	1,00 1,00 1,00		
12C	N	58100/12550	2000	1,00 1,00 1,00		
12D	UO	58260/12575	1640	1,00 1,00 1,00		
12B	UO	58120/12560	2010	1,33 0,91 0,83	40/113	50/293
13	VO	57622/12350	1600	1,36 0,96 0,76	4/108	40/015
13D	UO	57590/12420	2000	1,00 1,00 1,00		
13E	UO	57590/12420	2000	1,00 1,00 1,00		
13B	UO	57618/12395	1820	1,30 1,00 0,77	34/089	63/215
13C	CF	57640/12380	1720	1,42 1,41 0,50	49/125	41/305
13F	CF	57640/12380	1720	1,30 1,30 0,59	49/125	41/305
HB1	LB	58210/11580	720	2,71 1,20 0,31	30/045	43/283
HB2	CO	57230/11440	2350	1,89 1,39 0,38	25/146	65/329

oolites at localities 3, 3A show initial compactional strains) and decreases upwards. In the inverted limb of the nappe the flattening planes are subhorizontal, though locally reoriented by later, coaxial folds, then steepen with SE dips upwards into the hinge zone and lower parts of the normal limb. Conglomerates in the normal limb and hinge zone (localities 11F, 13C, 13F) locally show only compaction and/or intial shape fabrics. Axial ratios group around 1.35:1.35:0.55 and it may well be that the finite strain ellipsoid axial ratios, estimated from the deformed conglomerates, overestimate the tectonic deformation by about this amount. These finite strains plot near the line $k = 1$ or in the flattening field of the deformation plot. In accordance with the model proposed by Casey & Huggenberger (1982), this pattern of finite strain can be interpreted in terms of diagenetic compaction and initial shape fabrics, followed by multi-layer buckling controlled by the competent limestones, and then heterogeneous simple shear, with a shear direction towards the NW, very high values being attained in the inverted limb of the nappe and associated with the marked NW–SE stretching lineation. A feature of the finite strain pattern not explained by this model is the increase in strain towards the SE at any structural level.

Whether this heterogeneous simple shear was alone responsible for the emplacement of the Morcles Nappe, or whether it represents a relatively early stage in the tectonic evolution (cf. the Glarus Nappe), remains uncertain. The presence of Ultrahelvetic units in front of, and structurally lower than, the Morcles Nappe (see Badoux 1972b, fig. 13), suggests similarities with the Eastern Helvetic and Infrahelvetic evolution.

A feature of the finite strain pattern on the normal limb of the nappe is that the steep (locally inverted) parts of folds are more highly deformed than their adjacent normal parts (see Figs. 2 & 3, localities 11B, 12B). Throughout the nappe, major fold hinges remain remarkably constant in their NE–SW orientation over many km in this finite strain regime, even at very high

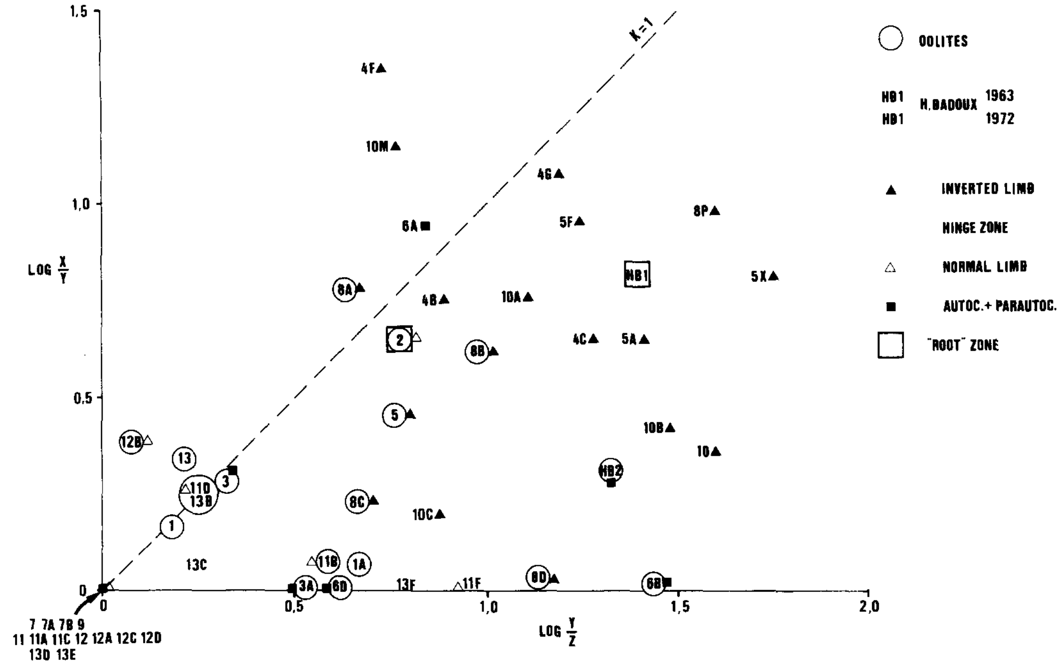

Fig. 1. Logarithmic deformation plot of finite strain analyses in the Morcles Nappe region.

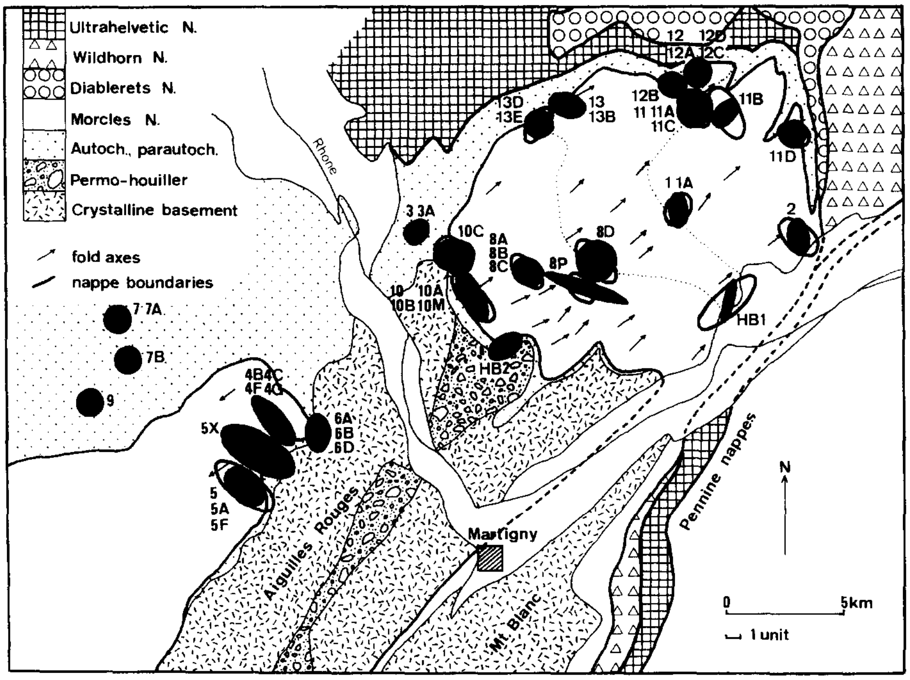

Fig. 2. Outline structural map of the Morcles Nappe region showing the sites of finite strain analyses. Dotted lines traversing the Morcles Nappe delimit the map extent of, from SW to NE: the inverted limb, the hinge zone, the normal limb (after the Atlas Géologique de la Suisse, 1 : 25000, sheet 1305 Dt. de Morcles). Solid ellipses represent horizontal sections through the finite strain ellipsoids, open ellipses correspond to XY plane sections, with X correctly oriented. The scale bar represents the radius of an original sphere of equivalent volume.

strains. This orientation is subperpendicular to the regional stretching direction.

THE CHARTREUSE MASSIF

The fold and thrust tectonics of the Chartreuse Massif are well documented in the map and serial cross-sections by Gidon (1968). The sedimentary cover of the external margin of the Belledonne Massif (Trias–Bajocian) was described by Barféty *et al.* (1972) and studied from a structural viewpoint by Gratier *et al.* (1973). An Electricité de France tunnel, completely traversing the Belledonne Massif provided valuable new data on the Alpine deformation of the massif (Gasquet 1979). The internal border of the Belledonne Massif and its

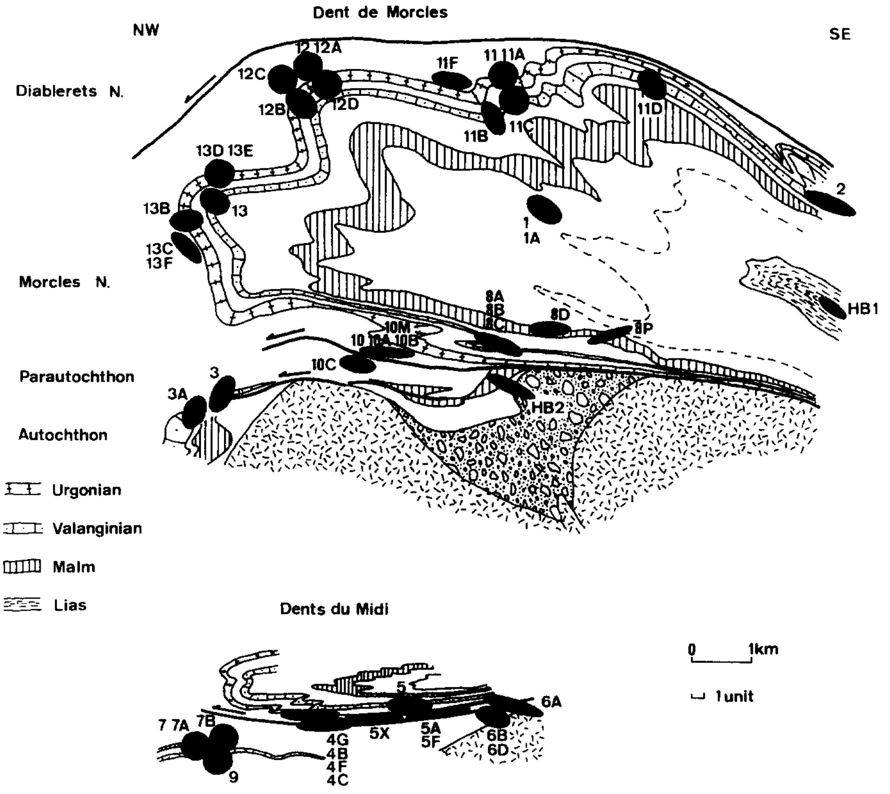

Fig. 3. NW–SE cross sections through the Morcles Nappe region showing sites of finite strain analyses. Solid ellipses represent vertical sections through the finite strain ellipsoids. The one-unit scale bar represents the radius of an original sphere of equivalent volume.

sedimentary cover have been studied by Gratier *et al.* (1973) and by Verjat (1980). A collation of seismic and borehole data enabled Ménard (1979, 1980) to map the depth of the pre-Triassic crystalline basement. This information is brought together in an outline map (Fig. 4) and an approximately E–W cross-section (Fig. 5).

Rocks ranging from Oxfordian to Miocene (Helvetian) in age are involved in the fold and thrust tectonics of the Chartreuse Massif. It is the competent limestones of Kimmeridgian–Tithonian age and the Urgonian facies of the Barremian that appear to have controlled the tectonics. The NNE–trending folds have amplitudes and wavelengths measured in kilometres; they are cut by a series of NE-trending, dextral, strike-slip faults whose frequency increases northwards across the massif (Goguel 1948, Kerckhove & Antoine 1964), and by two major thrusts: the 'faille de Voreppe' (3 km WNW displacement) and the 'chevauchement de Chartreuse orientale' (1.5 km WNW displacement). The faille de Voreppe is here effectively the frontal Alpine thrust, separating the sub-Alpine Chains from the Jura and the peri-Alpine molasse zone. Geometric relations suggest that the folding, strike-slip faults and thrusts were broadly contemporaneous (cf. the model experiments of Dubey & Cobbold, 1977). Both the thrusts pass downwards into a décollement level in the Oxfordian shales. These structures are post-Helvetian in age and the folds are labelled F3 in Fig. 4. There is apparently no measurable internal deformation associated with this phase in the Chartreuse Massif. Unfolding the limestones and restoring the thrust displacements indicates an overall E–W shortening across the massif of 36% for the Urgonian and 33% for the Tithonian (see lines CC′ and BB′ in Fig. 5).

Stratigraphically and structurally lower, the Trias–Bajocian cover of the external margin of the Belledonne Massif has here, in the absence of Keuper evaporites, remained stuck to the basement. These rocks show evidence of an earlier (pre-Helvetian and probably Oligocene) deformation (see Gratier *et al.* 1973, p. 73 *et seq.*), which produced N030°-trending folds with axial planes dipping SE and subhorizontal hinges. A penetrative cleavage is axial planar with the folds and a study of deformed belemnites, ammonites and pyrite nodules shows that the maximum finite extension direction (about 18% stretching) is parallel with the N030° fold hinges (see Gratier *et al.* 1973, pp. 75–76). At the latitude of Grenoble, the penetrative cleavage is sporadically deformed by subhorizontal crenulations. These are more strongly developed along strike to the NE, where they produce a crenulation cleavage. These pre-Helvetian structures are labelled F2 and S2 in Fig. 4. They are spectacularly developed in the Trias–Lias cover of the internal margin of the Belledonne Massif (e.g. in the Bourg d'Oisans syncline, see Gratier *et al.* 1973, Gratier & Vialon 1980). Here, as in the Eastern Dauphinois Zone, the pre-Helvetian structures are superposed on ESE-trending upright folds of pre-Nummulitic age, with no associated cleavage development (Barbier & Barféty 1972, Gratier *et al.* 1973, p. 27 *et*

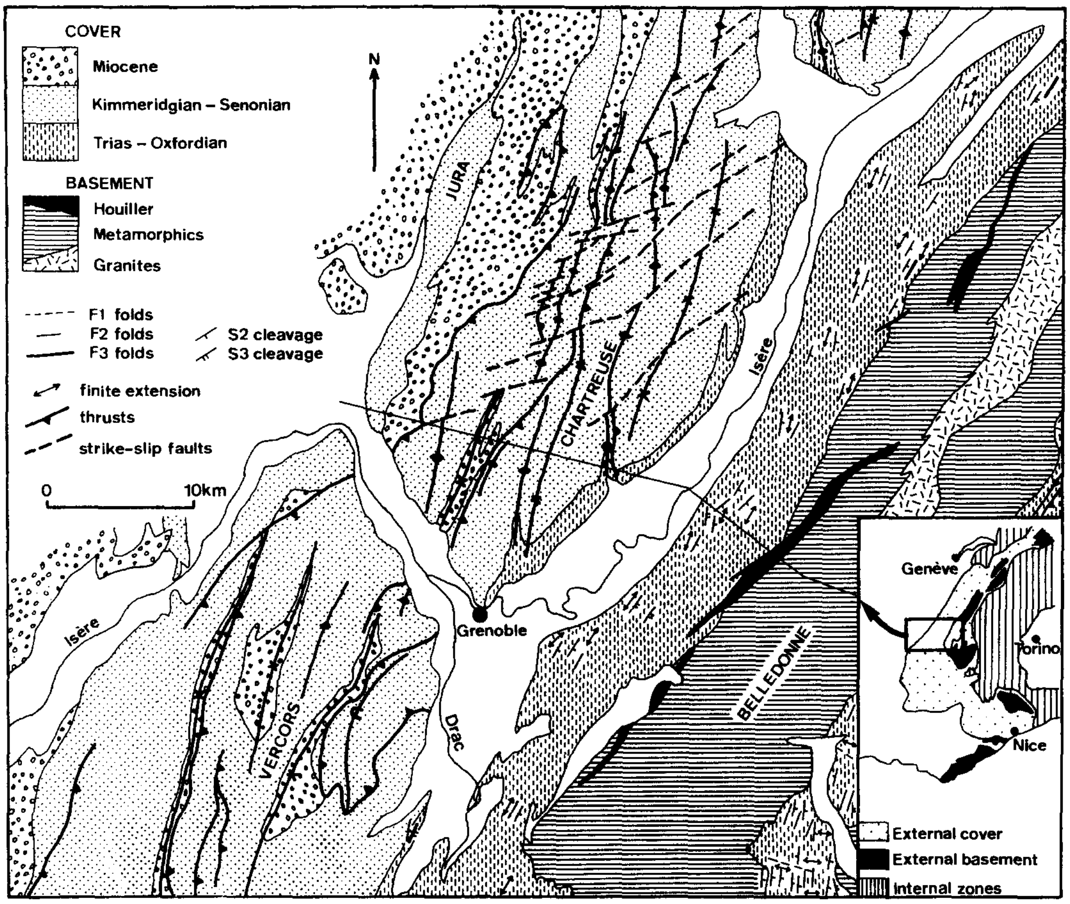

Fig. 4. Outline structural map of the Grenoble region (see text for references and details).

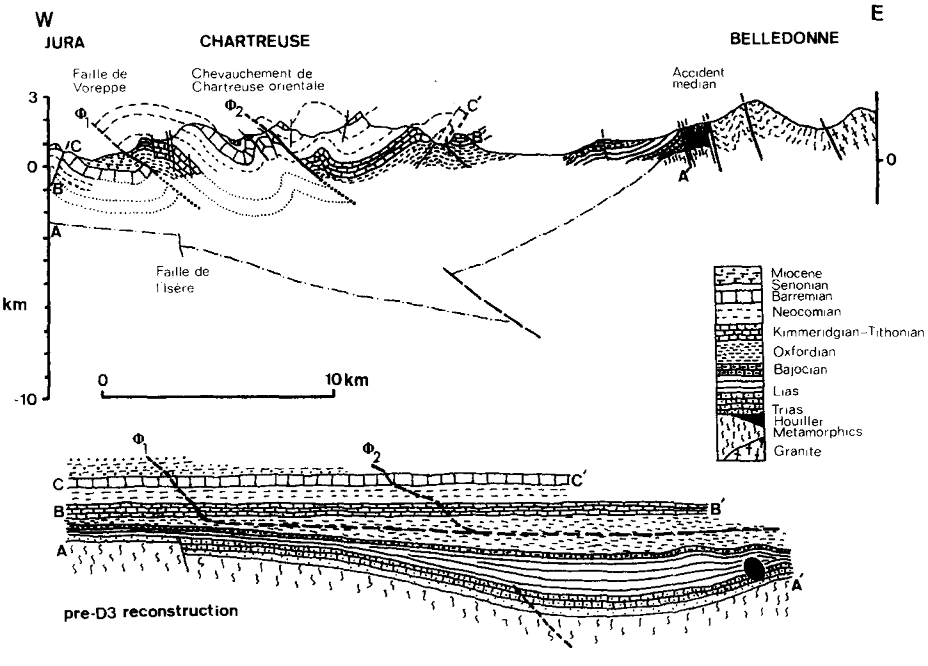

Fig. 5. E–W cross section through the Grenoble region (see text for references and Fig. 4 for the line of section). The broken line at depth represents the top of the crystalline basement. Lower diagram: the same cross section restored to its pre D3 state.

seq.). These pre-Nummulitic folds are labelled F1 in Fig. 4.

Following Ménard (1979, pp. 53–61, 1980) the depth of the pre-Triassic crystalline basement is shown in the cross-section of Fig. 5 (see also Perrier & Vialon 1980, Thouvenot & Perrier 1980). The apparent continuity of the chevauchement de Chartreuse orientale with the basement thrust in the cross-section of Fig. 5 is only apparent, and is unique to a section drawn at this latitude; in map view the two structures diverge. In unfolding the Tithonian and Urgonian limestones of Chartreuse and restoring the displacements along the two major thrusts, the altitude of the limestones west of the faille de Voreppe were taken as datum levels. It was found necessary to restore the 4–5 km displacement along the basement thrust at this stage, in order to keep the Tithonian limestones in their correct stratigraphic position relative to the Bajocian (see the pre-D3 reconstruction in Fig. 5). This suggests that the post-Helvetian fold and thrust belt of Chartreuse formed in response to basement thrusting and uplift; the upper part of the stratigraphy with its competent limestones simply slid off the rising basement at the level of the Oxfordian shales.

Studies by Gasquet (1979) in the Belledonne Massif show that there was significant Alpine deformation in the massif. The 'accident médian' for example, was an Alpine thrust, involving rocks of Trias–Lias age, though as Barféty *et al.* (1970) have shown, it was a normal fault and controlled sedimentation during Upper Trias–Lias times. Other thrusts and mylonite zones in the massif have a systematic sense of displacement towards the NW. The strain ellipse, illustrated at the eastern end of the pre-D3 reconstruction (Fig. 5), thus relates to the pre-Helvetian phase of deformation, which continues down into the basement. Upwards, this deformation with its 18% N030° horizontal stretching must have been accommodated by décollement along the Oxfordian shales, allowing the upper part of the cover to escape this deformation.

THE DIGNE NAPPE

The Digne Nappe, its frontal slices (écaille de Barcillonnette, écaille de Valavoire and the complex terrain of Faucon–Turriers) and autochthon, have been extensively studied by the Grenoble group. Perhaps the most useful summaries and data relevant to this discussion are to be found in Afchar & Gidon (1974) and in Arnaud *et al.* (1977, 1978 see in particular the structural map). With much simplification the evolution of this region can be summarized as follows:

(1) pre-Upper Senonian folds trending N040–N090°, which affected the autochthon and terrains later destined to become the frontal slices;
(2) pre-Nummulitic folds trending N030°, with NNW thrusting in the Faucon–Turriers region;
(3) late Oligocene folds trending E–W to NW–SE, with thrusting towards the SW forming the frontal slices (écaille de Barcillonnette, écaille de Valavoire) and strike-slip displacements in the Faucon–Turriers region and
(4) late Miocene–Pliocene folds trending NW–SE, with thrusting towards the SW forming the Digne Thrust.

At each stage there was rejuvenation of pre-existing structures.

Siddans (1977) described the succession of structures and finite strain states encountered on a WSW to ENE traverse from the autochthon, through the frontal slices and across the Digne Nappe. A map showing the sample sites, a logarithmic deformation plot and tabulated strain data were presented (Siddans, 1977, figs. 1 & 16, table 1). It was argued on geological grounds that the bulk of the internal deformation, which increases from zero to 75% flattening across the Digne Nappe, was produced during the late Oligocene phase. Siddans (1979b) discussed the two-phase development of the nappe and attributed the late Oligocene phase to an externally applied compression at the back end of the nappe (cf. the model of Chapple 1978), with décollement along the Keuper evaporites, though perhaps ultimately involving the crystalline basement in the east (see Gidon 1975). A finite strain cross-section was presented (Siddans, 1979b, fig. 5) and it was estimated that there was some 20% E–W shortening overall across the nappe.

The finite strain patterns in the Digne Nappe tell us something about the late Oligocene development of the frontal slices, but nothing directly about the Digne Thrust and the proven 7 km displacement along a Pliocene erosion surface (see Gigot *et al.* 1974).

DISCUSSION

The distribution of finite strain in the Glarus Nappe is related to Upper Oligocene (Calanda Phase) deformation, whereas the Glarus Thrust was formed during Miocene times (Ruchi Phase). The Morcles Nappe may yet turn out to have had a similar history. Deformation in the Trias–Bajocian cover of the Belledonne Massif relates to a pre-Helvetian (Oligocene) phase; the fold and thrust tectonics of the Chartreuse Massif were post-Helvetian events. Finite strains in the intervening Oxfordian shales, if they are measurable, would record a composite history of décollement. The important internal deformation within the Digne Nappe was associated with late Oligocene events, including formation of the frontal slices and cleavage development; the Digne Thrust was formed during late Miocene–Pliocene times.

It seems that great caution should be exercised in interpreting Alpine thrust tectonics from patterns of finite strain. It is imperative first to establish the tectonic history using geological criteria. If the overall finite strain can then be assigned to a part of that history, the pattern of finite strains can be used to quantify and clarify that part of the history (e.g. overall stretching, overall shortening, finite strain distribution consistent with heterogeneous simple shear, etc.). A maximum of information is gained in the case where study of syntectonic fibres can be used to provide information on the incremental deformation history as well.

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