Computer-constructed cross-sections of the Morcles nappe

Autor(en): **Langenberg, William / Charlesworth, Henry / La Riviere, Allan**

Objekttyp: **Article**

Zeitschrift: **Eclogae Geologicae Helvetiae**

Band (Jahr): **80 (1987)**

Heft 3

PDF erstellt am: **07.05.2024**

Persistenter Link: https://doi.org/10.5169/seals-166019

Eclogae geol. Helv.	Vol. 80	Nr. 3	Pages 655–667	Basel, December 1987

Computer-constructed cross-sections of the Morcles nappe

By WILLEM LANGENBERG[1]), HENRY CHARLESWORTH[2]) and ALLAN LA RIVIERE[2])

ABSTRACT

The Morcles nappe is a large recumbent fold with many minor folds and faults. Computer-based procedures associated with a digitizing tablet enabled positional, stratigraphic and orientation data for the Morcles nappe to be transferred quickly and accurately from the "Dent de Morcles" and "Diablerets" 1:25000 maps of the Geological Atlas of Switzerland to a data base. A computerized data-base management and processing system was then used to divide the nappe into cyclindrical domains and to construct cross-sections.

Eight cylindrically folded domains were established and fold axes calculated using published and unpublished orientation data. Construction of two vertical cross-sections and a profile of the entire nappe involved the following procedure. For each cross-section, data from each adjoining domain were projected independently, parallel to its fold axis, onto the plane of section. Each remote domain was rotated before projection until its fold axis became parallel to that at the section line.

The profile, which has a width to "thickness' ratio of 2.25:1, and the cross-sections probably give a more accurate picture of the structure of the Morcles nappe than do previously published sections.

RÉSUMÉ

La nappe de Morcles est un pli couché avec plusieurs plis et failles secondaires. A l'aide de procédés informatiques associés à une table à digitaliser, les données de position, de niveau stratigraphique et d'orientation des structures ont pu être transférées rapidement et avec précision depuis les cartes géologiques au 25,000e «Dent de Morcles» et «Diablerets» de l'Atlas géologique de la Suisse, jusqu'à un fichier informatique. Un programme permettant de sélectionner et de traiter les données de ce fichier a été utilisé pour compartimenter la nappe en domaines cylindriquement plissés et pour construire des coupes.

Huit domaines cylindriques ont été établis et leurs axes de pli calculés en utilisant des données d'orientation publiées et non-publiées. Deux coupes verticales et un profil de la nappe entière ont été produits de la façon suivante: pour chaque coupe, les données de domaine contigus ont été projetées séparément et parallèlement à leurs axes de pli, sur le plan de coupe. Avant la projection, pour chaque domaine excentré, une rotation a été effectuée jusqu'à ce que l'axe de pli soit parallèle à celui immédiatement adjacent au plan de coupe.

Le profil, d'un rapport longueur – «épaisseur» de 2.25 à 1, et les coupes donnent probablement une idée de la structure de la nappe de Morcles plus précise que les coupes publiées jusqu'ici.

Introduction

Traces of folded surfaces on geologic maps represent cross-sections distorted by irregularities in the topographic surface and in the orientations of fold axes. Elimination

[1]) Alberta Geological Survey, Alberta Research Council, Box 8330, Postal Station F, Edmonton, Alberta, Canada T6H 5X2.

[2]) Department of Geology, University of Alberta, Edmonton, Alberta, Canada T6G 2E3.

of both types of distortion leads to cross-sections displaying the true shapes of folds. Because the graphical procedures (see e.g. WEGMANN 1929; MCINTYRE 1951; DAHLSTROM 1952; TURNER & WEISS 1963) applied by most geologists to eliminate distortion are

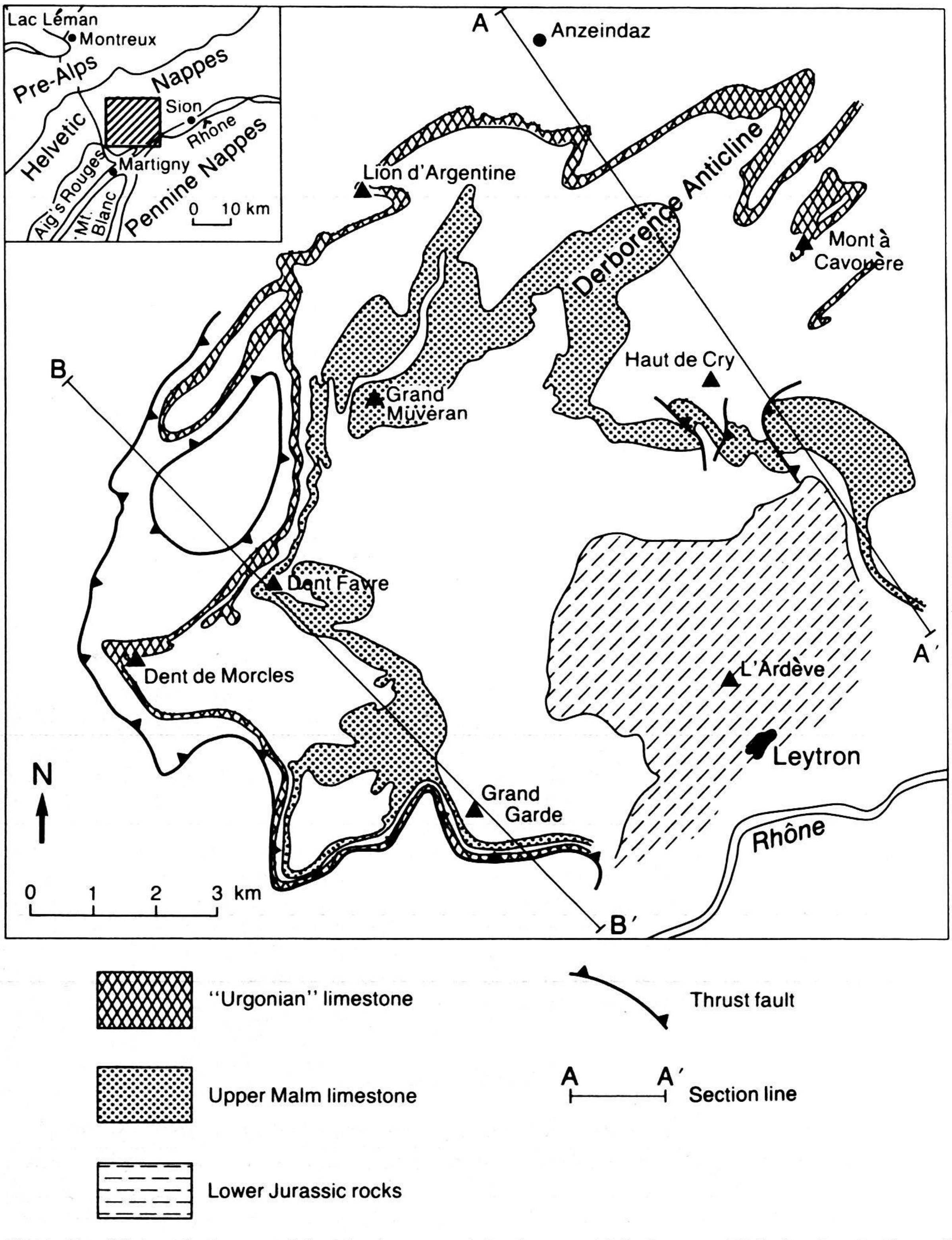

Fig. 1. Simplified geologic map of the Morcles nappe (after LUGEON 1940, BADOUX 1971) showing the lines of section for Figures 5 and 6.

tedious and time consuming, only some of the data on most geologic maps are used to generate cross-sections and analyse structure. Computer-based procedures, as well as generating fewer errors, are quick and can incorporate all the structural, stratigraphic and positional data on a map.

The aim of the project described in this paper was to demonstrate the effectiveness of computer-based procedures, first by building a computer data base for the Morcles nappe (Fig. 1) from the "Dent de Morcles" (BADOUX 1971) and "Diablerets" (LUGEON 1940) map-areas and, secondly, using the data base to produce a profile and two cross-sections of the nappe. We selected the Morcles nappe because (1) it is well known, (2) it has been mapped on a large scale, and (3) its plunge remains essentially constant over large areas. Also the Morcles nappe is appropriate because the equivalent graphical procedures were first applied in this part of the Alps (LUGEON 1901).

Geologic setting

The tectonic setting of the Morcles nappe is summarized in the inset of Figure 1 (see also RAMSAY 1981). The outcrop pattern in the Helvetic chain is affected by the Aiguilles Rouges–Mont Blanc culmination and the adjacent Wildstrubel depression which contains the Morcles, Diablerets and Wildhorn nappes. The highest nappe, the Wildhorn, was formed first, and the lowest, the Morcles, last. The Morcles nappe is a recumbent fold that is essentially a thrust sheet whose basal thrust is superposed on a shear zone (RAMSAY et al. 1983). The "Dent de Morcles" and "Diablerets" map areas are on the SW limb of the Wildstrubel depression, and within these map areas the nappe plunges to the northeast at angles ranging from 5° to 30°.

Within the two map areas the nappe exposes mainly calcareous shelf sediments of Jurassic and Cretaceous age (Tab. 1). Dominating this succession and influencing its structural behaviour are the upper Malm, upper Valanginian, Hauterivian and "Urgonian" limestones. These units, of which two are shown in Figure 1, outline spectacular folds.

Building a data base for the Morcles nappe

The data base for the Morcles nappe was derived from (1) intersections of the traces of geologic surfaces with topographic contours and (2) outcrop symbols on the "Dent de Morcles" and "Diablerets" maps. The data are positional, stratigraphic and, in the case of outcrop symbols, orientational. Positions were recorded as eastings and northings, referred to the kilometric map grid, and as elevations above sea level. The elevations of outcrops were estimated by interpolating between adjacent contours (10 and 20 m for the "Diablerets" and "Dent de Morcles" map sheets, respectively). Stratigraphic position was recorded by designating single letters to refer to certain key stratigraphic horizons. These letters and horizons are identified in Table 1. Orientations were recorded as numerical dip-directions and dips for bedding planes and trends and plunges for mesoscopic fold axes.

A Tektronix 4954 digitizing tablet in the Department of Geology at the University of Alberta and associated software written by Desmond Wynne and Henry Charlesworth were used to transfer the map data quickly and accurately to the data base. This tablet records the (x, y) coordinates of any point on its surface identified by means of a cursor.

Table 1: *Simplified stratigraphic succession in the Morcles nappe. The stratigraphic codes refer to those stratigraphic boundaries that appear on the plots of Figures 3–7. ls = limestone, sh = shale, ss = sandstone, congl = conglomerate.*

Stratigraphic code	Stratigraphic unit	Major Lithologies
	Priabonian - Lower Oligocene	ls, sh, ss
Y		
	Vivipara & Cerithium beds	marl, ls, ss
X		
	"Auversian"	congl
V		
	Upper Aptian - Upper Cretaceous	sandy sh, ls
U		
	"Urgonian"	ls
T		
	Lower Barremian	marl, ls
S		
	Hauterivian	siliceous ls
R		
	Upper Valanginian	ls
Q		
	Portlandian - Lower Valanginian	marl
P		
	Upper Malm	ls
O		
	Argovian	ls
N		
	Bathonian-Oxfordian	marl, sh
L		
	Upper Bajocian	marl, sh
K		
	Lower Bajocian	sh, siliceous ls
J		
	Aalenian	sh
I		
	Upper Toarcian	sh
H		
	Lower Toarcian	sh, ls
G		
	Middle Lias	ls, marl
F		
	Lotharingian	ss
E		
	Hettangian - Sinemurian (undivided)	sh, ls

There are two types of point, namely those lying within (1) a map attached to its surface, and (2) a rectangular template off to one side, known as a "menu", labelled with words, letters and numbers. Placing the cursor over a point on the map causes its map coordinates to be recorded; placing it over a point within the menu records a word, number or letter.

A 2 × 2 transformation matrix converted the (x, y) tablet coordinates of a point on the map to eastings and northings. This matrix was calculated at the beginning of each digitizing session by placing the cursor over four points on the map whose eastings and northings were then entered at the terminal. An elevation and horizon code (Tab. 1) of say 742 and T were entered by placing the cursor successively over the menu squares labelled "elevation", "7", "4", "2", "horizon" and "T". In the case of outcrop symbols, the amount of dip or plunge were recorded using the menu, the dip-direction or trend being recorded by digitizing not one but two points per outcrop, one at either end of the strike-and-dip or trend-and-plunge symbol.

Most of the 2703 points entered into the data base are situated on the traces of stratigraphic horizons or major faults. For each point, only the coordinates and stratigraphic code were recorded. Faults were given numeric codes. For the 114 outcrop symbols (95 strike and dip symbols for bedding and 19 trend and plunge symbols for minor fold axes) on the Dent de Morcles map, the coordinates, structural type (bedding or mesoscopic fold axes) and orientation were recorded. The errors in recording coordinates were small and probably insignificant compared with errors displayed on the maps in the positions of (1) the commonly gradational contracts between stratigraphic units and (2) the contours on the generally steep slopes.

All data were processed using the Morcles data base as input to the TRIPOD computer program written by members of the structural geology research group at the University of Alberta.

Fold axis orientation in the Morcles nappe

To prepare a computer-based cross-section requires (1) dividing the area into domains within which folding can be considered cylindrical, estimating the fold axis for each domain and preparing a machine-constructed plot for each domain that showed the positions of all data points within it projected parallel to the fold axis onto the plane of section, and (2) combining downplunge plots into a single composite cross-section.

Although the fold axis of the Morcles nappe is known to be fairly constant (Badoux 1972), variations in orientation occur (see e.g. Badoux 1971). Another complication is the existence of two phase of folding (Badoux 1972). The F_1 folds include all major folds related to the overall structure of the nappe. The F_2 folds are related to a change in the overthrust direction (Dietrich & Durney 1986) and have different fold axis orientations.

Because of uncertainty in F_1 fold axis orientation, one of us (W. L.) visited the Morcles nappe and took sufficient measurements to estimate fairly precisely the macroscopic fold axes in six areas. The most extensively studied fold is the Derborence anticline in the upper limb of the nappe (Fig. 1). The fold is well outlined by the upper Malm, Valanginian, Hauterivian and "Urgonian" limestones. Five measurements of bedding were measured at each of 86 stations. The mean orientations at these stations indicate that the orientation of the fold axis in upper Malm limestones forming the core of the fold, namely 52° 24°, differs from the value of 63° 33°, obtained in overlying strata exposed to the north-east. An F-test (see Charlesworth et al. 1976) shows that these orientations are statistically different and that the Derborence anticline lies in two cylindrical domains. Other tests (Kelker & Langenberg 1982) show that the fold is cylindrical and not conical. Other prominent F_1 folds near Lion D'Argentine, Mont à Cavouère, Grand

Muveran and Dent Favre (Fig. 1) were also studied and the orientations of their fold axes are found to be 51° 27°, 60° 31°, 63° 19°, and 57° 19°, respectively. Some F_2 folds measured north of Grande Garde have a fold axis of 44° 25°. Bedding orientations given by BADOUX (1971) for the area around Grande Garde give a fold axis orientation of 40° 20°. It follows that this more northerly trending fold axis can be attributed to second phase folding. On the basis of these orientations, supplemented by data recorded on the two published maps, the Morcles Nappe was divided into eight domains. The boundaries of these domains and their fold axis orientations were subsequently modified slightly using interactive graphics: an area was considered cylindrical when most of the data points, when projected in a certain direction lined up in a coherent manner. Using interactive

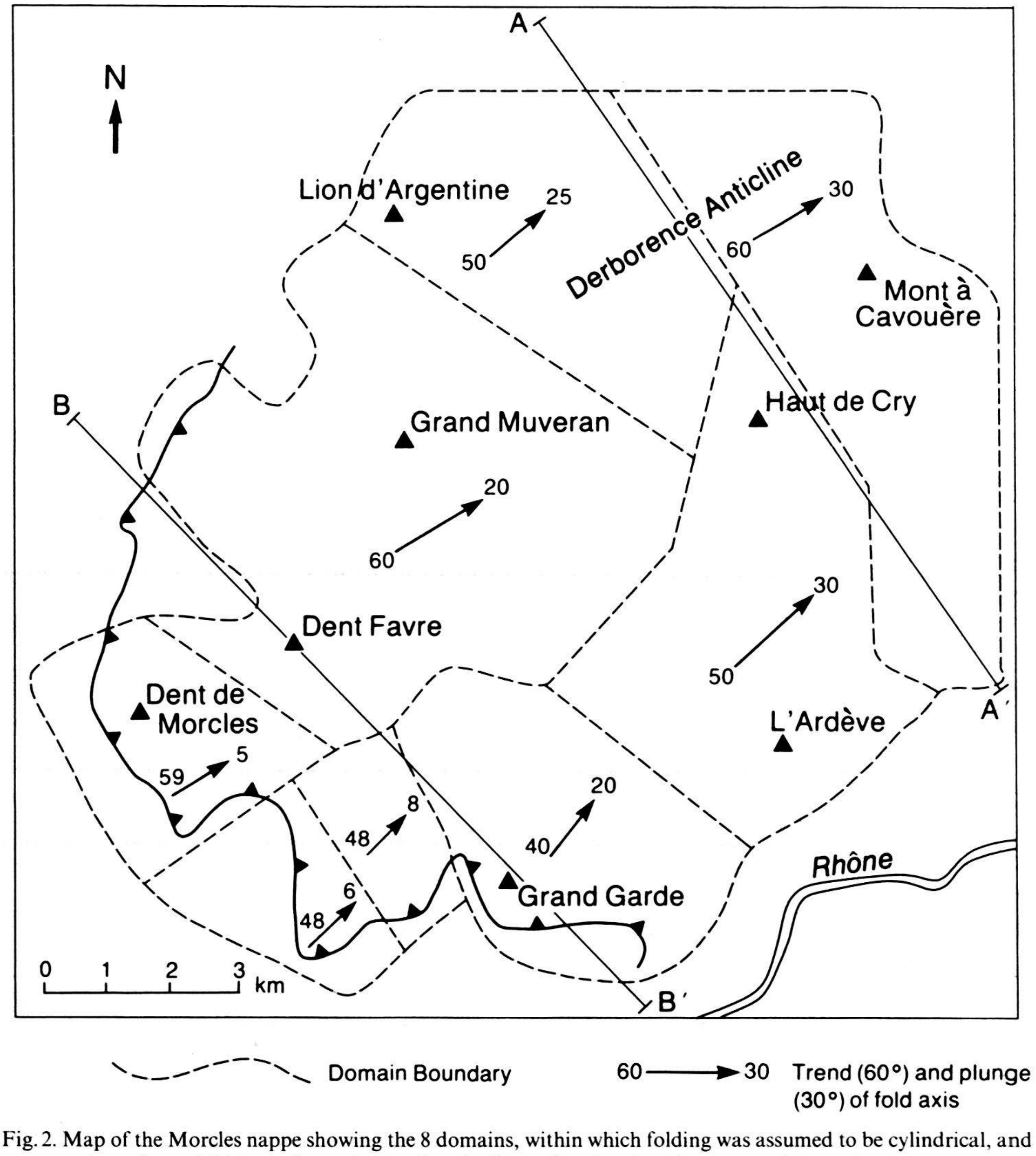

Fig. 2. Map of the Morcles nappe showing the 8 domains, within which folding was assumed to be cylindrical, and the estimated fold axis for each domain. The lines of section for Figures 5 and 6 are also shown.

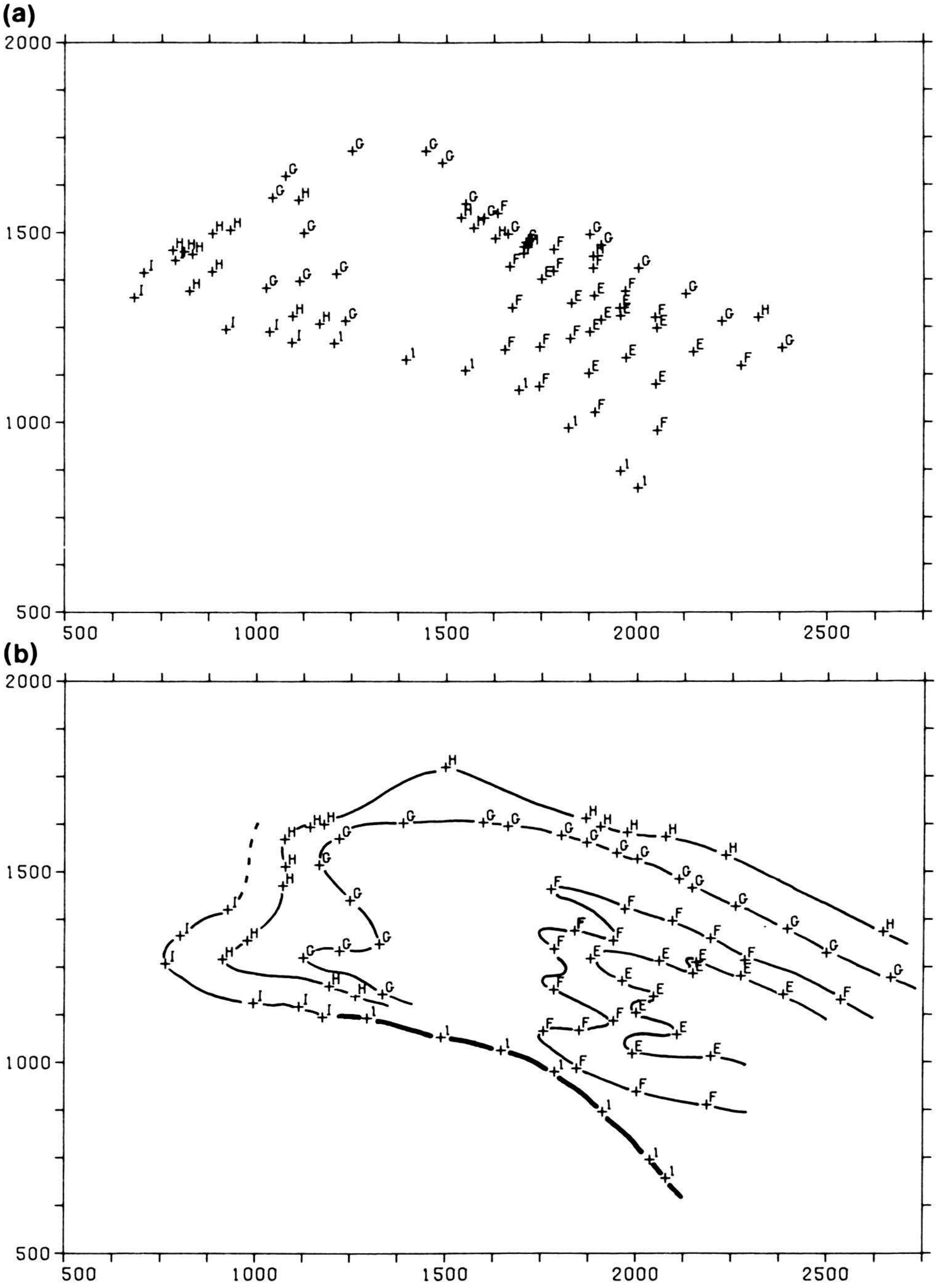

Fig. 3. Machine-contructed plots for part of the Ardève domain. The units are in metres. Crosses denote the positions of projected points on the topographic traces of stratigraphic horizons. Letters identify the stratigraphic horizons of these traces (Tab. 1); numbers denote major faults. (a) Projection direction oblique to the fold axis. (b) Projection parallel to the fold axis.

graphics meant that plots associated with different areas and projection directions could be produced at the rate of one a minute. Where possible, the boundaries between domains were drawn through poorly exposed or structurally simple areas. The locations of the domains and the orientations of the fold axes are shown in Figure 2. Plots for parts of one domain with data points projected obliquely and parallel to the "best" fold axis are shown in Figure 3. The procedure described above also served to detect errors of commission and omission in the data base.

The cross-sections

The composite cross-sections (Fig. 4, 5, 6 and 7) were produced using the original data base as obtained from digitizing the published geologic maps. Data collected by W. L. were used only to help establish domains and calculate fold axes.

To produce a composite plot, the plots from individual domains have to be combined. One method is to allow adjacent domains to overlap slightly, and then to use the points common to adjacent domains to piece together the individual plots. We adopted a different procedure, however, which is as follows. Where all domains end against or enclose part of the line of section, a composite plot showing the data points in each domain projected parallel to its fold axis is obtained. Where a domain is separated from the line of section by a second domain, the procedure for projecting it is slightly more complex (see LANGENBERG et al. 1977). First, the coordinates and orientations in the first domain are rotated about an origin along the boundary of the two domains so that its fold axis becomes parallel to that in the second domain. The rotated data points in the first domain are then projected parallel to the fold axis in the second domain onto the plane of section. Where a domain is separated from the line of section by more than one domain, it has to be rotated more than once before it may be projected. However, in the present study no domain had to be rotated more than once.

While transforming a machine-constructed plot into a cross-section one should remember that the plot is just a framework on which to hang the cross-section, i.e. a trace does not have to pass through each of its data points, particularly if the point is remote from the line of section. Also, as much use as possible should be made of all available photographs and detailed cross-sections such as those in BADOUX (1972) while putting in the fine detail.

The two vertical cross-sections AA′ and BB′ (Fig. 1) were drawn close to section lines AA′ and GG′ presented in the explanatory notes accompanying the "Dent de Morcles" map (BADOUX 1971). Figure 4 shows the computer plot on which cross-section AA′ (Fig. 5) is based. Data points which plotted close to others were omitted from this plot and the traces of the horizons were obtained by connecting points with the same stratigrahic code (Tab. 1). The cross-section AA′ (Fig. 5) and BB′ (Fig. 6) can be compared to those of BADOUX (1971). Because they take into account more information, we believe that our computer-based sections are better models of the true geometry of the nappe than the manually constructed ones. The composite profile of the nappe (Fig. 7) was constructed on a plane through the Ardève and perpendicular to the mean fold axis (51° 20°). Most points in the data base were used to construct the plot on which the profile was based. Points from the gently plunging south-western domains were omitted, however, because they overlapped points from adjacent domains to the north-east.

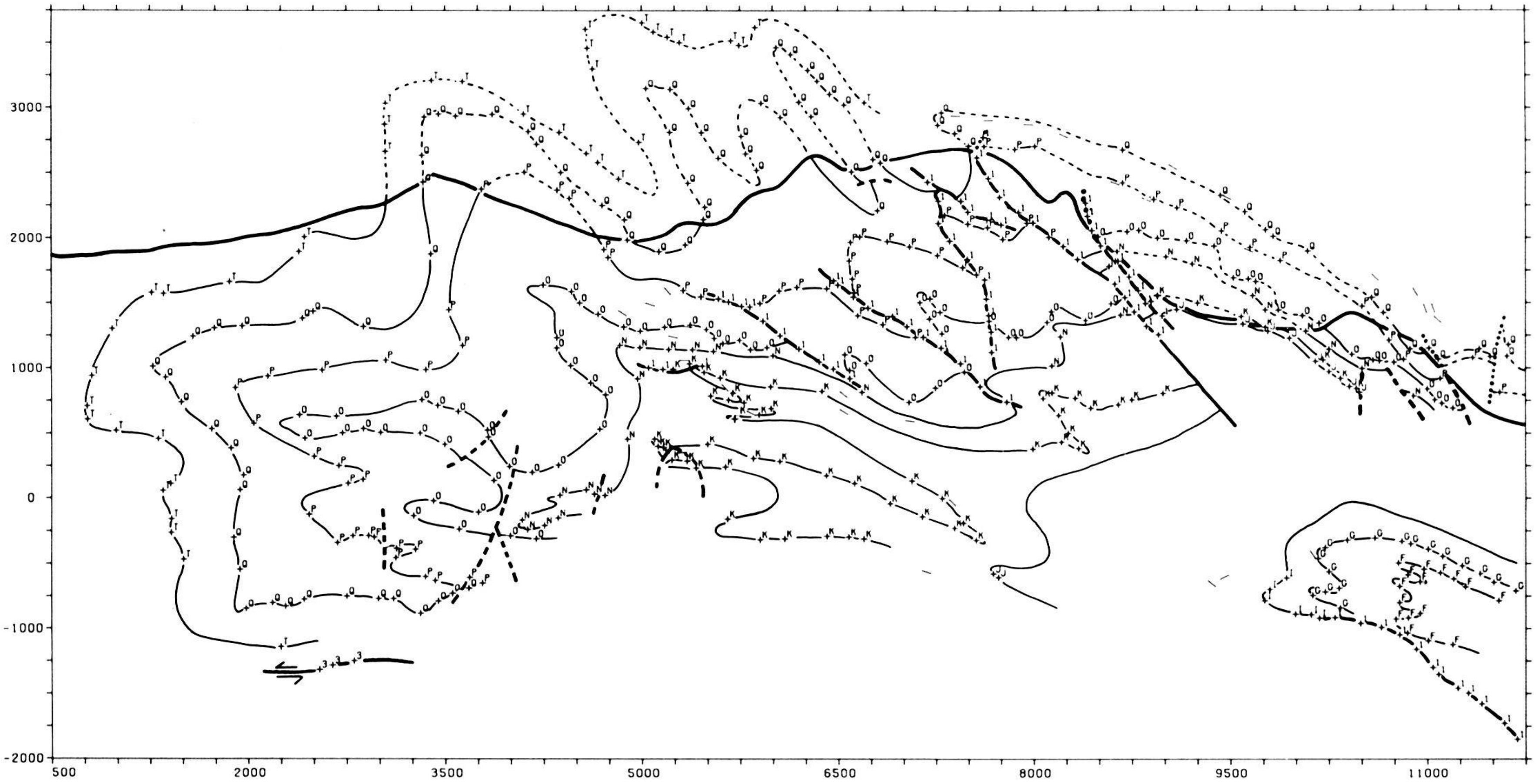

Fig. 4. Computer-plot on which section AA′ (Fig. 5) is based. Letters denote stratigraphic horizons shown in Table 1 (horizons E, H, L, M, R, S, U, V, X and Y have been omitted for reasons of clarity). Numbers denote major faults (1 – thrust faults, 3 – basal thrust of the Morcles nappe).

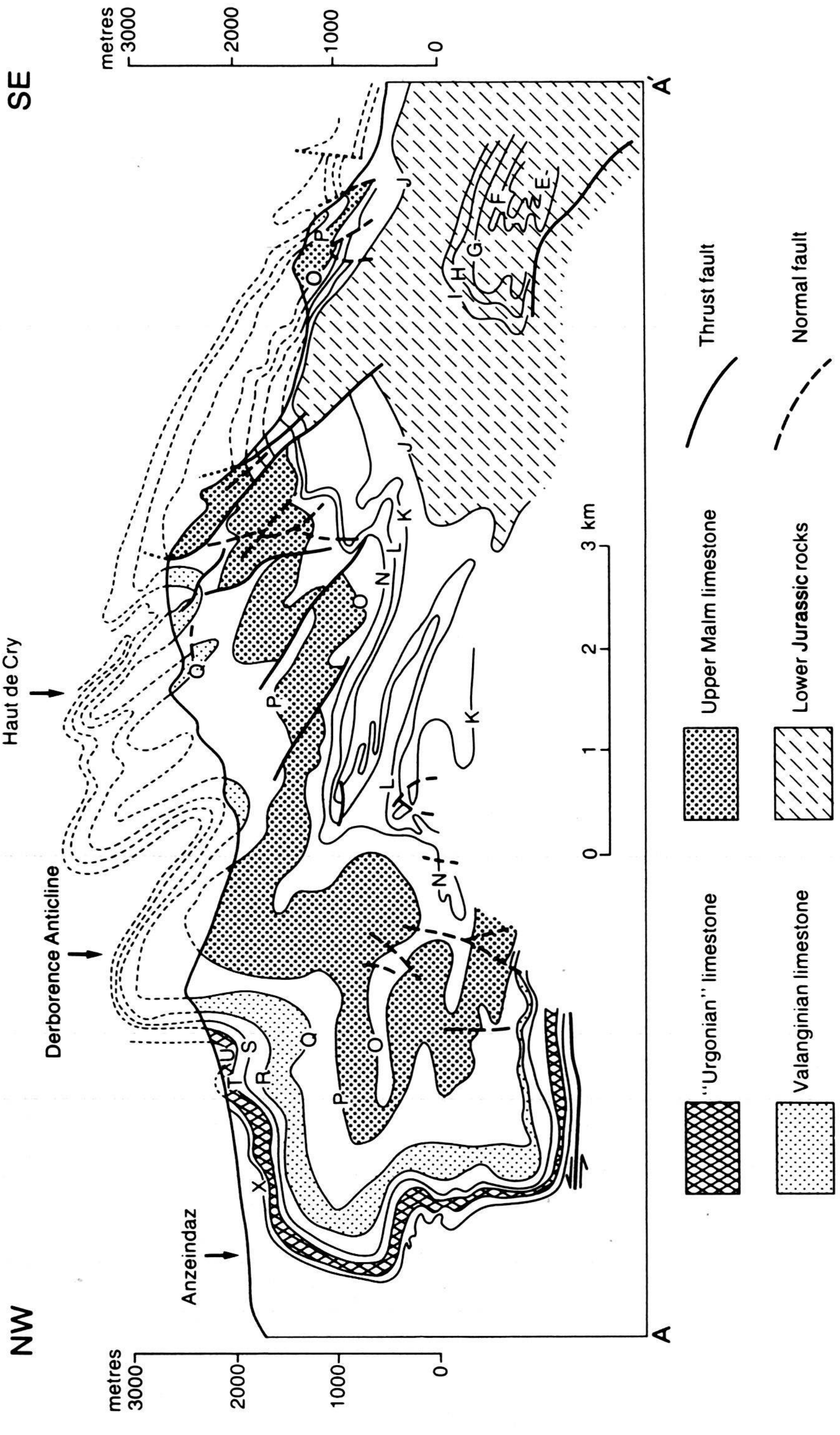

Fig. 5. Vertical geologic cross-section along the line AA′ (see Fig. 1 and 2).

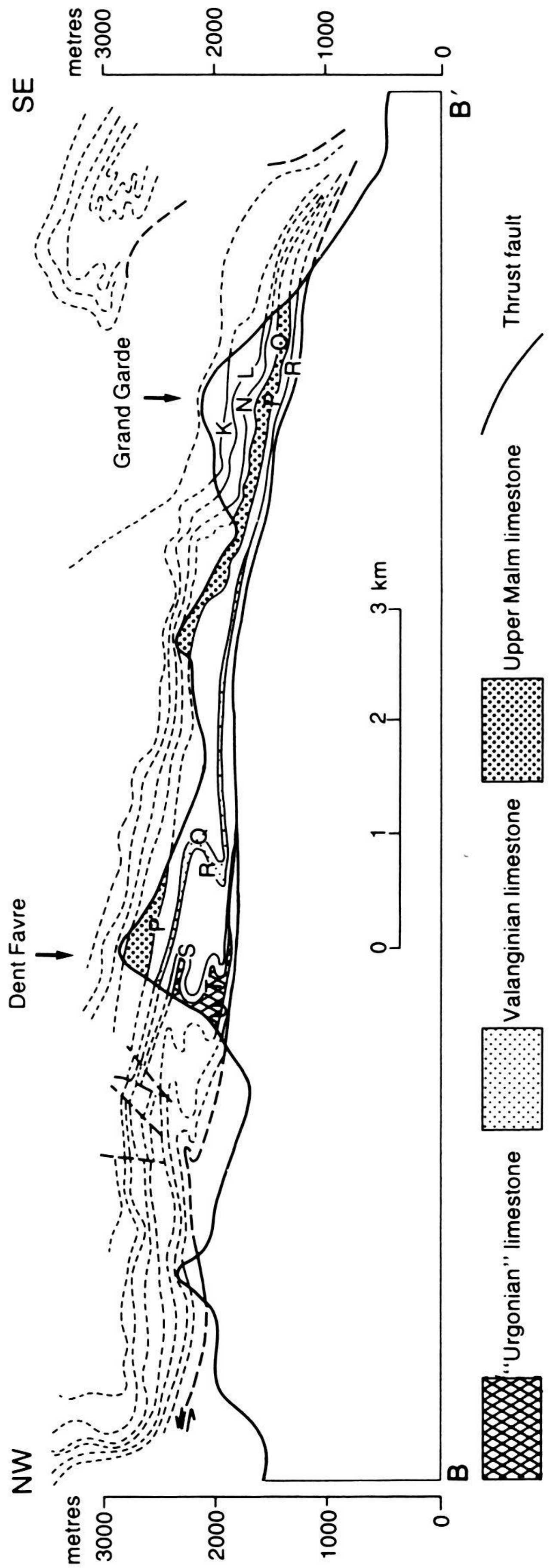

Fig. 6. Vertical geologic cross-section along the line BB′ (see Fig. 1 and 2).

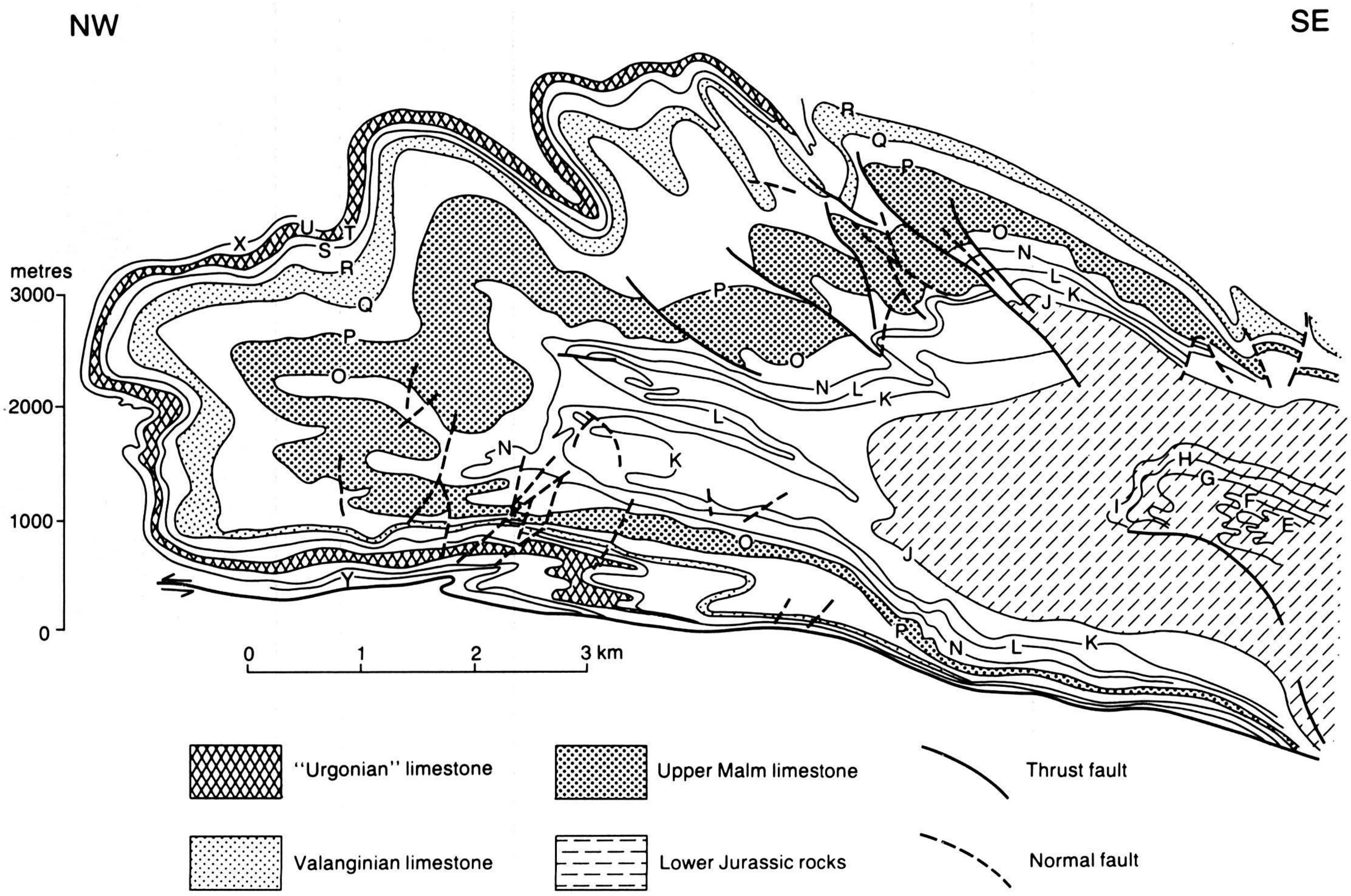

Fig. 7. Profile of the Morcles nappe. The plane of section (231° 70°) is drawn through L'Ardève.

Our profile of the Morcles nappe has a width to "thickness" ratio of 2.25 :1. This differs considerably from the ratios of 3 :1 and 2 :1 displayed by the manually constructed profiles in Ramsay (1981) and Ramsay et al. (1982), respectively. Our profile has a slightly larger ratio than that in Ramsay et al. (1982) because we found that the fold axes in the Lion d'Argentine and Grand Muveran areas plunge at 20° to 25° rather than at the generally accepted value of 30° (Fig. 2). This had implications for the calculation of shortening by bed length measurements within the Morcles nappe. Our profile implies about 4% less shortening than the profile in Ramsay et al. (1982), but about 10% more shortening than the one in Ramsay (1981).

In conclusion we believe that our cross-sections give a more accurate picture of the structure of the Morcles nappe than do previously published sections.

Acknowledgments

Much of the work leading to this article was carried out while W. L. was on research leave from the Alberta Research Council J. G. Ramsay, M. Casey, D. Dietrich and P. Huggenberger are thanked for their kind hospitality at the Geologisches Institut in Zürich and for useful discussions. Some of the work was funded by grants to H. C. by the Natural Sciences and Engineering Research Council of Canada and the Geological Survey of Canada.

REFERENCES

Badoux, H. (1971): Feuille 1305 Dt de Morcles et notice explicative Atlas géol. Suisse 1:25000. – Comm. géol. Suisse.

— (1972): Tectonique de la nappe de Morcles entre Rhone et Lizerne. – Matér. Carte géol. Suisse (n. s.) *143*.

Charlesworth, H. A. K., Langenberg, C. W., & Ramsden, J. (1976): Determining axes, axial planes and sections of macroscopic folds using computer-based methods. – Canad. J. Earth Sci. *13*, 54–65.

Dahlstrom, C. D. A. (1954): Statistical analysis of cylindrical folds. Bull. Canad. Mining Metall. *47*/504, 234–239.

Dietrich, D., & Durney, D. W. (1986): Change of direction of overthrust shear in the Helvetic nappes of western Switzerland. – J. Struct. Geol. *8*, 389–398.

Kelker, D. & Langenberg, C. W. (1982): A mathematical model for orientation data from macroscopic conical folds. – Math. Geol. *14*, 289–307.

Langenberg, C. W., Rondeel, H. E. & Charlesworth, H. A. K. (1977): A structural study in the Belgian Ardennes with sections constructed using computer-based methods. – Geol. Mijnbouw. *56*, 145–154.

Lugeon, M. (1901): Les grandes nappes de recouvrement des Alpes du Chablais et de la Suisse. – Bull. Soc. géol. France 4e Sér. 1, 723–825.

— (1940): Feuille Diablerets et notice explicative Atlas géol. Suisse 1:25000. – Comm. géol. Suisse.

McIntyre, D. B. (1951): The tectonics of the area between Grantown and Tomintoul (mid-Strathspey). – Geol. Soc. London Quart. J. *107*, 1–22.

Ramsay, J. G. (1981): Tectonics of the Helvetic nappes. In: McClay, K. R. & Price, N. J. (Ed.): Thrust and nappe tectonics (p. 293–309). Geol. Soc. London. Spec. Publ. 9.

Ramsay, J. G., Dietrich, D., & Casey, M. (1982): Excursions A & B – western Helvetic nappes. – Excursion guide of internat. conf. planar and linear fabrics of deformed rocks, Zürich.

Ramsay, J. G., Casey, M., & Kligfield, R. (1983): Role of shear in development of the Helvetic fold-thrust belt of Switzerland. – Geology *11*, 439–442.

Turner, F. J., & Weiss, L. E. (1963): Structural analysis of metamorphic tectonites. – McGraw-Hill, New York.

Wegmann, C. E. (1929): Beispiele tektonischer Analysen des Grundgebirges in Finnland. – Bull. Comm. geol. Finlande *87*, 98–127.

Manuscript received 21 July 1986
Revision accepted 30 April 1987