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Re-examining Argand's view of the Siviez–Mischabel nappe

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Abstract

We present the results of field work in the frontal part of Siviez–Mischabel nappe near Chandolin (Valais, Switzerland). Mapping reveals packages of interleaved cover and crystalline basement strata. We focus on monocyclic units (cover units and the Randa orthogneiss) in order to understand the structural geometry of the Siviez–Mischabel nappe. Sedimentary 'way-up' criteria consistently indicate that cover units are upright, even for strata previously mapped as overturned. In general, primary foliation (S_1) parallels or dips more steeply to the south than bedding throughout the study area. An L_1 lineation lies in the plane of foliation and trends north–south. Kinematic indicators in the Randa orthogneiss consistently yield a top-to-the-north sense of shear, consistent with the orientation of L_1. These relations indicate that the frontal part of the Siviez–Mischabel is a series of thrust imbricates, rather than a large-scale recumbent fold as originally suggested by Argand in 1916. © 1999 Elsevier Science Ltd. All rights reserved.

Résumé

La cartographie détaillée de la zone frontale de la nappe du Siviez–Mischabel, près de Chandolin (Valais, Suisse), a mis en évidence une série d'écailles tectoniques formées de socle cristallin et de sa couverture. L'analyse structurale des séries monocycliques post-hercyniennes contraint la géometrie de la nappe et les sens de polarité relevés dans les roches métasédimentaires indiquent que cette série est essentiellement à l'endroit, même dans les unités cartographiées comme des flancs inverses de plis. En général, la relation schistosité–stratification indique également une séquence à l'endroit. Les critères de cisaillement bien développés dans les gneiss oeillés de Randa indiquent un sens de cisaillement homogène vers le nord. Ces relations suggèrent que le front de la nappe de Siviez–Mischabel correspond à une série de chevauchements imbriqués, et non à un pli couché comme l'ont suggéré Argand en 1916 et d'autres auteurs après lui. © 1999 Elsevier Science Ltd. All rights reserved.

1. Introduction

The pioneering work of Émile Argand elucidated the relationships between the geologic provinces of the western Alps. His splendid 1916 map (Fig. 1a) and cross-section (Fig. 1b) are remarkably similar to modern versions (cf. Ramsay, 1963; Escher and Beaumont, 1997). Fundamental to his understanding of the geometry of the western Alps is the concept of nappes, map-scale recumbent folds involving both basement and cover units. 'Embryonic' nappes developed slowly during Mesozoic and early Tertiary time (Fig. 1c) and were later amplified, stacked, and refolded during the Tertiary Alpine orogeny (Argand, 1916). Like his map and cross-section, Argand's fold-nappes have become a fundamental tenet of Alpine geology. Spectacular examples such as that exposed in the Dent de Morcles confirm that map-scale recumbent folds are common features in the foreland (Helvetic) province of the wes-

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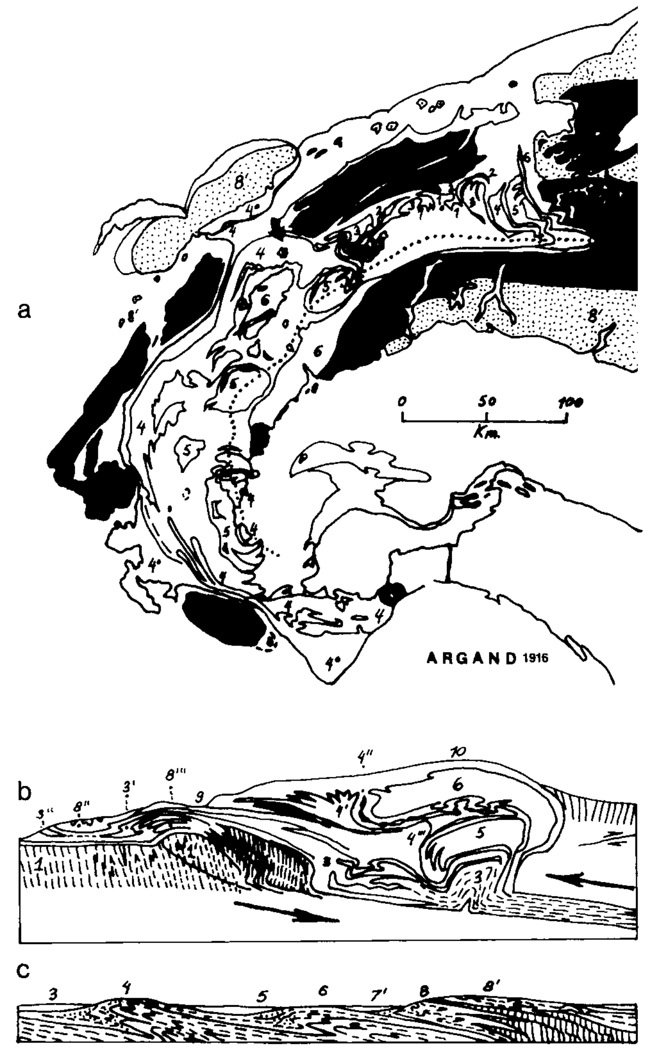

Fig. 1. Directly from Émile Argand's 1916 work *Sur l'arc des Alpes Occidentales*. (a) Geologic map of the Alps. The arrow points to the study area (Fig. 3) in the Siviez–Mischabel nappe of the Penninic Alps. Black units represent Hercynian massifs and the ancient cores of Austroalpine nappes. Dotted units are allochthonous cover units from Austroalpine and other nappes. Penninic nappes are (1) Antigorio–Campolungo–Leventina–Simano, (2) Lebendun–Predoira–Val Soja, (3) Monte Leone–Poncione di Braga–Poncione Massari–Adula, (4) Grand Saint Bernard–Tambo, (5) Dora Maira–Grand Paradis–Mont Rose–Suretta, and (6) Dent Blanche. The dotted line represents the Alpine *faîte structural* (crest). (b) Argand's synthetic cross-section showing: (1) the Hercynian foreland [basement], (3) Valaisan and simplo-tessinois nappes, (3′) lower Prealpes, (3″) external Prealpes, (4) Briançonnais units (including the Siviez–Mischabel and Grand Saint-Bernard Nappe), (4′) *eventail de Bagnes*, (4″) *faisceau vermiculaire* of the Grand Saint-Bernard Nappe now known as the Tsaté Nappe, (4‴) Siviez–Mischabel backfold, (5) Monte Rosa Nappe and Piemontais Zone, (6) Dent-Blanche Nappe and MontDolin units, (8″) allochthonous Mesozoic cover units, (8‴) Morcles Nappe and parautochthonous folds, (9) *sillon* occupied by the Rhône River, and (10) *faîte structural*. (c) Argand's *embryons*. This cross-section shows Argand's image of the Alps during the last stage of embryonic nappe development. Gentle folds that affected both basement and cover units were later amplified, stacked, and back-folded during the early Oligocene *paroxysme orogénique*. Reprinted from Eclogae Geologicae Helvetiae, 14, Argond, Sur l'arc des Alpés Occidentales, pp. 145–204, 1916, with permission from Birkhaeuser Publishers Ltd.

tern Swiss Alps (Escher et al., 1993). Most Alpine geologists also visualize the greenschist- and higher-grade units of the Alpine hinterland (Penninic province) as ductile basement fold nappes. Escher et al. (1993) use the Siviez–Mischabel nappe of the western Alps (nappe 4 in Fig. 1b) as an example of a Penninic basement nappe displaying "the typical geometry and stratigraphy of fold nappes with a normal flank, a frontal part and an overturned limb". This vision of ductile basement fold nappes, based on the Alpine example, is commonly applied to the hinterlands of other collisional orogens (e.g. Steck et al., 1998).

We present the results of field work and mapping in the frontal (northern) part of Siviez–Mischabel nappe near Chandolin (Valais, Switzerland). Here, the Rhône Valley and Val d'Anniviers cut into the frontal tip of the Siviez–Mischabel nappe and provide magnificent structural sections through the nappe. Previously published maps and cross-sections that include this region (Marthaler, 1984; Escher, 1988) follow Argand's example and show the frontal part of the Siviez–Mischabel nappe as a stack of complex recumbent folds in basement and cover units. We argue below, however, that stratigraphic and structural relations exposed near Chandolin indicate that the Siviez–Mischabel nappe is a series of thrust imbricates, rather than a large-scale fold.

2. Field mapping results

2.1. Stratigraphy and basic structure

The Siviez–Mischabel nappe comprises basement orthogneisses unconformably overlain by relatively thin covers of greenschist facies metasedimentary rocks. Basement and cover units share the same Tertiary Alpine thermal and kinematic history. For mapping, we use a simplified version of formations outlined by Escher (1988) and Sartori (1990) that includes two basement and three cover units. Basement units comprise 'polycyclic' gneiss, schist, and amphibolite previously deformed and metamorphosed to amphibolite facies during the Hercynian orogeny. These polycyclic units are intruded by a porphyritic alkaline to subalkaline granite of early Permian age (Thélin, 1987). This granite is now metamorphosed and deformed to become the Randa orthogneiss. At the base of the cover sequence, a graphitic micaschist is a metamorphosed Permo-Carboniferous volcano-sedimentary unit. This unit has extremely variable thickness, and it is generally absent from stratigraphic pile in the map area. A thick sequence of quartzite and related metasedimentary rocks represents metamorphosed continental sandstone, semi-pelite, and conglomerate deposited during Permian and Triassic time.

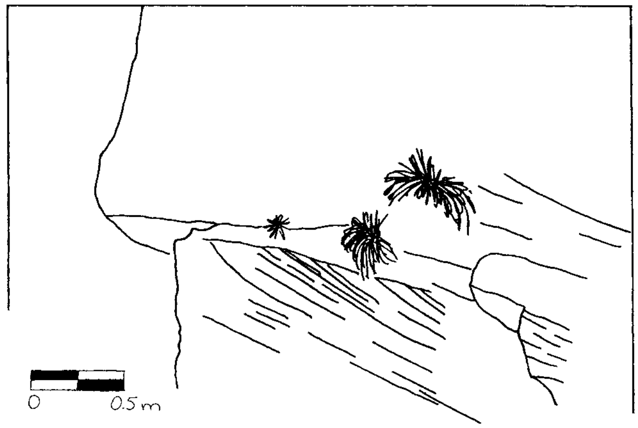

Fig. 2. Sketch of cross-stratification in massive quartzites of the Permo-Triassic cover at a road cut north of Vissoie. Bedding is subhorizontal, and truncated cross-stratification indicates that these units are upright. Such 'way-up' indicators consistently indicate that cover units are upright, even where they have previously been mapped as overturned.

Triassic dolomite and limestone cap the preserved cover sequence in the study area. The bulk of the Mesozoic carbonate cover sequence typical to the western Alps was tectonically displaced to the north (the Préalpes) during emplacement of the Siviez–Mischabel nappe (Escher et al., 1993). All three cover units and the Randa orthogneiss are 'monocyclic' in the sense that they record only Alpine deformation and metamorphic events. We focus on monocyclic units in order to understand the structural geometry of the Siviez–Mischabel nappe.

Mapping reveals packages of interleaved cover and crystalline basement strata. In general, both bedding in cover units (S_0) and contacts between basement and cover dip gently to the south. Deformation in cover units is heterogeneous, but sedimentary structures are locally preserved. Many such structures are useful as 'way-up' indicators, and we report results obtained from a range of way-up criteria: truncations in cross-

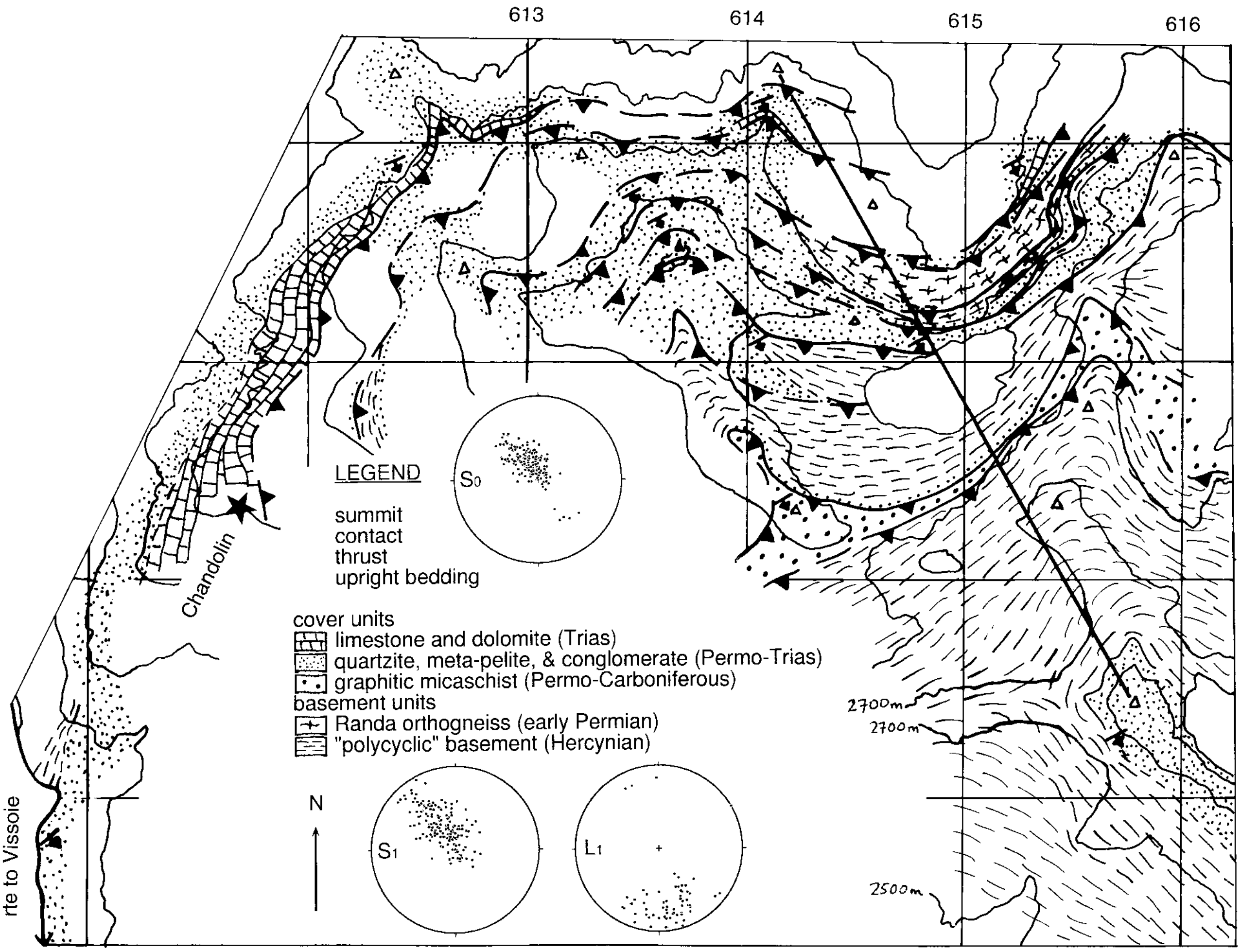

Fig. 3. Geologic map of Chandolin area, Siviez–Mischabel nappe, western Swiss Alps. Longitude and latitude graticules are of the Swiss coordinate system, and grid boxes represent 1 km^2. Thick line marks cross-section of Fig. 4. Insets are stereographic projections (equal area) that show data from cover units only: bedding (S_0) $N = 192$, mean plane 061:20°S; primary foliation (S_1) $N = 164$, mean plane 061:26°S; primary lineation (L_1) $N = 65$, mean line 26:171°.

stratified beds (Fig. 2), concavity of cross-stratification, graded bedding, channels, and apparently undisturbed stratigraphic contacts between units. These criteria, where observed, consistently indicate that cover units are upright, even for strata previously mapped as overturned (Marthaler, 1984; Escher, 1988). This simple observation has important implications for the basic structure of the Siviez–Mischabel nappe. Fig. 3 is a geologic map of the study area that shows the basic geometrical relations between basement and cover units.

2.2. Alpine fabrics and kinematics

All mapped units display tectonic foliation and lineation. Below we discuss in detail the primary Alpine foliation (S_1), lineation (L_1), and associated kinematic indicators in monocyclic units. These fabrics are useful for understanding the Tertiary structural and kinematic history of the Siviez–Mischabel nappe because they formed during nappe development beneath overriding Piemontais and Austroalpine nappes (Steck, 1984; Markley et al., 1998). A crenulation cleavage (S_2) whose axial planes dip gently to the north crosscuts primary fabrics. This crenulation is commonly interpreted as being associated with late backfolding (*retrocharriage*) of the Siviez–Mischabel nappe ca. 25 km to the south of the study area (Steck, 1984). The documentation and significance of this late crenulation in the study area, however, is not the focus of our study.

In cover units, S_1 foliation strikes at 060° and dips gently to the south (Fig. 3). This foliation is defined by a strong preferred orientation of phengitic white micas and pressure shadows around detrital quartz grains. Mesoscale folds, whose axial planes strike east-northeast and dip to the south, show a consistent relation between S_1 and S_0. On upright limbs, S_1 dips more steeply than bedding, and on overturned limbs, bedding dips more steeply than S_1. This observation is consistent with the field geologist's rule of thumb that uses the geometric relation between foliation and bedding on limbs of recumbent folds to distinguish between upright and overturned limbs (Ramsay, 1967). On a larger scale, however, the orientation of S_1 with respect to bedding is remarkably consistent throughout the study area. Except for the overturned limbs of mesoscale folds, S_1 parallels or dips more steeply to the south than bedding throughout the study area. This observation further supports our observation that none of the mapped Siviez–Mischabel cover units appear to be overturned.

An L_1 lineation, defined by stretched quartz pebbles and elongate mineral orientation in cover units, lies in the plane of foliation and trends north–south (Fig. 3). This lineation is consistent with northward transport

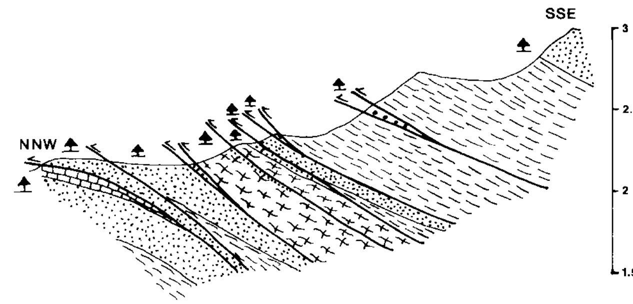

Fig. 4. Schematic cross-section (location on Fig. 3) through the Siviez–Mischabel nappe exposed near Chandolin (Valais, Switzerland). No vertical exaggeration, and vertical scale represents kilometers above sea level. Stratigraphic and structural relations indicate that the frontal part of the Siviez–Mischabel is a series of thrust imbricates, rather than a large-scale fold as originally suggested by Argand (1916). The peak in the SSE is Rothorn (2998 m elevation).

of the Siviez–Mischabel units during nappe development (Steck, 1984). In the monocyclic Randa orthogneiss of the basement, sigma-type feldspar porphyroclasts (Passchier and Simpson, 1986), tiled (piggy-back) porphyroclasts (Ildefonse and Fernandez, 1988), and *C–S* fabric (Berthé et al., 1979) are particularly well developed. These kinematic indicators consistently yield a top-to-the-north sense of shear, consistent with the orientation of L_1.

Fig. 3 depicts the study area as an imbricated sequence of thrust faults that interleave slices of cover and basement units. The observation that cover units appear to be stratigraphically upright geometrically necessitates this interpretation. Inferred thrusts, however, are rarely identifiable in the field as zones of intense deformation. Instead, the distribution of deformation throughout the study area is heterogeneous on all scales. In cover units, micaceous layers generally show stronger fabrics than more massive layers, indicating that Alpine strain partitioned according to lithology. Where cover overlies basement, strain intensity generally increases down-section. Fabrics in the polycyclic basement units, however, are complex and difficult to interpret in terms of Alpine deformation alone. Therefore, we map thrusts where older units overlie younger ones. To continue thrusts along strike, we rely on projection and repetitions in the internal stratigraphy of the Permo-Triassic metasedimentary unit.

3. Discussion and conclusions

Fig. 4 is a schematic cross-section through the study area. We interpret the frontal part of the Siviez–Mischabel nappe as a sequence of upright thrust imbricates because preserved sedimentary structures indicate that cover units are upright. The observation that fault surfaces are implied by stratigraphy and geometry but do not manifest themselves as zones of high strain suggests that the application of Steck's tectonic chronology (Steck, 1984) to this region of the Siviez–Mischabel nappe may be unwarranted. In this classical chronology, the first episode of Alpine deformation records simultaneous metamorphism, nappe development (recumbent folding), translation of nappes to the north and northwest, and development of L_1 and S_1 (Steck, 1984). In this scenario, fault surfaces in the Chandolin area would be identifiable as zones of large displacements and intense ductile strain. A solution to this problem may lie in alternative tectonic chronologies that have been proposed for the Penninic nappes. Both Ayrton and Ramsay (1974) and Platt et al. (1989) have suggested that the Penninic nappes developed by localized, brittle faulting followed by a ductile metamorphic overprint.

Our interpretation contrasts sharply with other interpretations of the basic geometry of the Siviez–Mischabel nappe (Argand, 1916; Escher et al., 1993). Furthermore, the observations above beg a reexamination of the 'overturned limb' of the Siviez–Mischabel, which does not outcrop in the study area but rather to the west of this region near St Niklaus (Escher, 1988). Although deformation is intense in this limb (Escher, personal communication), way-up criteria may be locally preserved in Permo-Triassic metasediments, as is the case near Chandolin.

Our conclusion is consistent with recent studies of Penninic nappe geometry in the eastern Alps (Baudin et al., 1993; Marquer et al., 1996; Schmid et al., 1997). These studies describe Penninic units similar to the Siviez–Mischabel as a succession of imbricate thrusts in normal stratigraphic position rather than as folds. The agreement of results from the Siviez–Mischabel nappe of the western Alps (reported here) with those from the Tambo and Suretta nappes (Baudin et al., 1993; Marquer et al., 1996; Schmid et al., 1997) extends the controversy about Penninic nappe geometry to the Alpine scale. This controversy has implications for all geometric models of collisional orogens because Argand's vision of nappes is paradigmatic in structural geology.

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