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A northern hinge zone of the arc of the western Alps

By HANS P. LAUBSCHER[1])

ABSTRACT

Probably Tortonian (10 my b.p.) cross-cutting features in the frontal decollement nappes along Lake Thun and the Kander valley may be attributed to a northern hinge zone of the arc of the western Alps. Tentative estimates of kinematic quantities give 8 km dextral displacement along the Lake Thun zone, and 8.5 km sinistral displacement along the Kander valley zone. Where they meet, at Merligen, there must be a triple junction, the third zone of movement compatible with the other two being the Helvetic Border Range, with a late displacement of 14 km. The Lake Thun zone has been carried by CHENEVART (1978) across the Molasse basin; it must somehow connect with the prominent system of dextral-sinistral strike-slip faults which, from Lake Neuchâtel, passes across the central Jura. To the south, the young cross-cutting features surrounding the southwestern end of the Aar massif seem to be coeval and are interpreted as a link to the Simplon-Centovalli zone and thus to the Tortonian southern Alps. This cross-cutting zone then appears to extend all the way from the external front of the Jura to the southern Alps. It is the most prominent part of a much broader and more diffusely deformed hinge zone which includes the Rawil depression between the Aar and Mont Blanc Massifs. These cross-cutting features define probably ephemeral "platy domains" which severely limit cylindrical developments of the compressional features.

ZUSAMMENFASSUNG

Elemente einer Transversaltektonik in den frontalen Abscherdecken des Berner Oberlandes (Thunersee-Kandertal-Zone) können einer wahrscheinlich tortonischen (10 Mio. J.) nördlichen Scharnierzone des Westalpenbogens zugeordnet werden. Versuchsweise quantitative Abschätzungen ergeben 8 km Dextralverschiebung längs der Thunerseezone und 8,5 km Sinistralverschiebung längs der Kandertalzone. Wo die beiden Verschiebungen aufeinandertreffen, bei Merligen, muss ein Tripelpunkt vorliegen; als dritte Bewegungszone kommt die Randkette in Frage, die von diesem Punkt gegen ENE abzweigt, mit einer späten Nordwest-Überschiebung von 14 km. CHENEVART (1978) hat aufgrund von Reflexionsprofilen die Fortsetzung der Thunerseezone durch das Molassebecken bis an den Jura postuliert; irgendwie sollte sie mit der kombinierten dextral-sinistralen Querstörungszone zusammenhängen, die den Jura vom Neuenburgersee bis Salins quert. Im Süden spielen die jungen kombiniert sinistral-dextralen Verschiebungszonen am Südwestende des Aarmassivs die Rolle eines Bindeglieds zur Simplon-Centovalli- und damit zur Insubrischen Störungszone. Dieses System von Querstörungen, das von der Jurafront bis zu den Südalpen reicht, ist nur der am schärfsten definierte Teil einer breiteren und diffuseren nördlichen Scharnierzone des tortonischen Westalpenbogens, zu der z. B. auch die Rawil-Depression gehört. Solche Querzonen scheinen ihre Stelle von Zeit zu Zeit zu wechseln. Als älteres Segment kommt die Tessiner Querzone in Betracht, während das Rawil-Simplon-Gebiet durch heutige Seismizität nebst quartären Bewegungen gekennzeichnet ist.

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Introduction

One of the tectonic problems of the arc of the western Alps is the degree of smoothness of its curvature. LAUBSCHER (1971) has opted for an indenter on its internal side ("Insubric plate") which, as indenters are prone to do, gives rise to more and more distributed shear in the external units. Moreover, he argued for a Neogene age of the arc as it is seen today, and for the Jura being its most external unit. Later, LAUBSCHER & BERNOULLI (1980) reestimated the date of Jura folding to be roughly 10 my (Tortonian). This turns out to be a time of important tectonic events all across the Alps, and particularly along a zone which may be termed the "northern hinge zone of the arc of the western Alps".

The Thun–Kander valley system and the Merligen triple junction

A good starting point for the demonstration of this hinge zone is the Lake Thun area in the external sedimentary decollement nappes (including the Subalpine Molasse).

Inspection of the Geological Map of Switzerland 1:500000 (SPICHER 1980, see also Fig. 1, 2) and of the cross sections of the Helvetic domain (Fig. 1; compare ARBENZ 1934; MASSON et al. 1980) reveals a rather drastic change of geometry across a line that in the north passes through Lake Thun till about Merligen, and then swings to the SSW in the direction of the Kander valley and the Gemmi-Lötschenpass area (Fig. 2).

Apart from the differences in geometry as seen on a cross section, there are large apparent strike-slip displacements.

The apparent displacement is dextral northwest of Merligen, in the Lake Thun direction; correlative points in the Ultrahelvetic–Pennine fronts seem to be B–B′, and in the thrusts of the Subalpine Molasse A–A′. It is apparently sinistral in the Helvetic front south of Merligen, passing into a more diffuse sinistral shear zone farther south. Among the manifestations of this I would count particularly the faults mapped by ADRIAN (1915) between Kandersteg and Kiental in the Gellihorn-Wildhorn-Ultrahelvetic complex; probably the steep fault contact between the Gellihorn and Wildhorn nappes west of Kandersteg mapped by LUGEON (1914); possibly the north-south trending axes of the Doldenhorn nappe west of the Lötschenpass as worked out recently by SCHLÄPPI (in press); and the axial plunge of the lobes of the Aar massif continuing this lineament southward into the Rhone valley.

These shear zones seem to be kinematically linked, they are complementary shears, as they end at their intersection at Merligen. But then Merligen must be a triple junction, from which a third "plate" boundary, a compressive one, takes off to the northeast: this would coincide with the front of the Helvetic Border Range. The kinematics is shown in Figures 2 and 3.

In order to obtain a quantitative estimate of the movements involved, possibly correlative points B–B′ and C–C″ in Figure 2 have been taken at face value for kinematic inversion. These apparent displacements of 8 km dextral and 8.5 km sinistral are compatible with a late thrust of 14 km emerging at the front of the

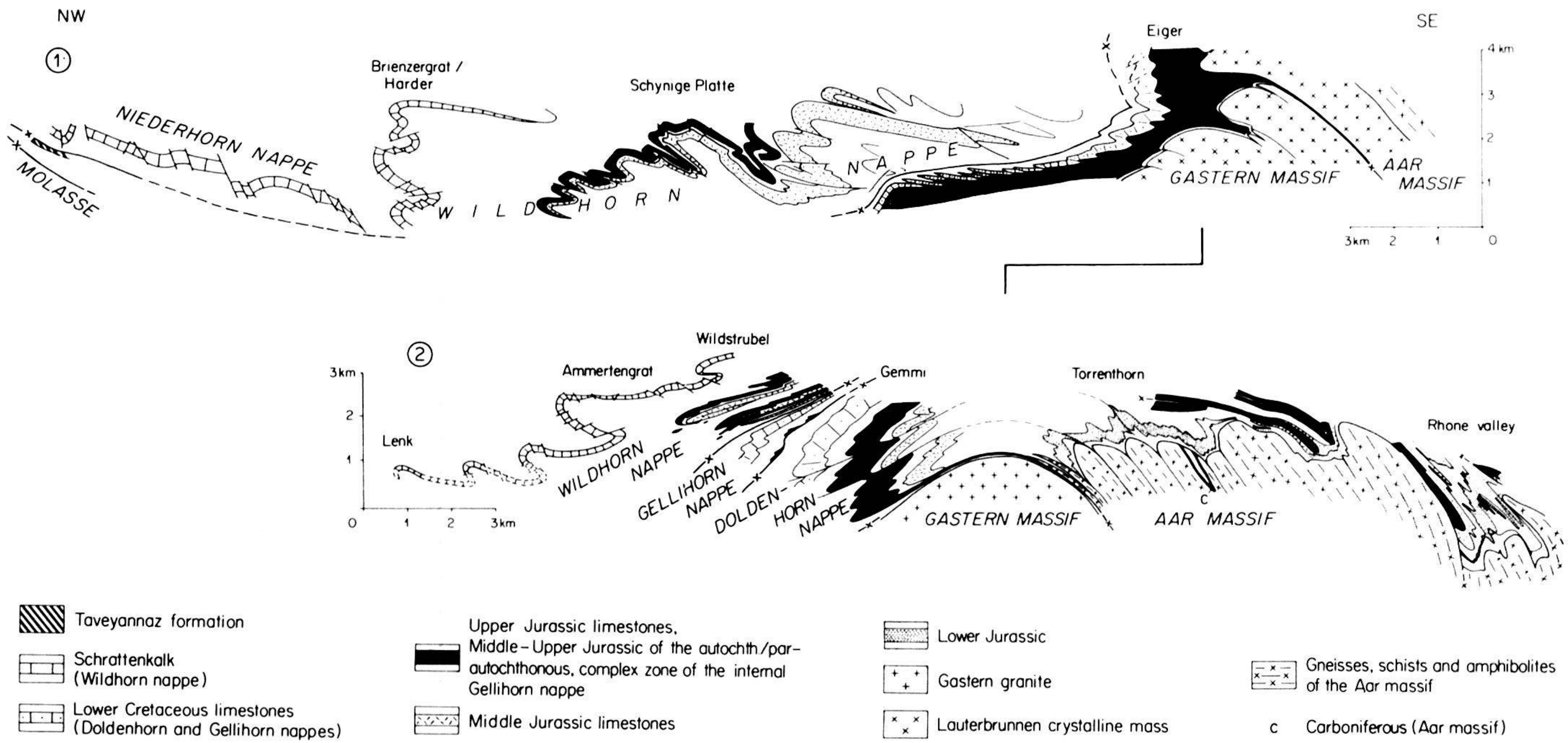

Fig. 1. Cross-sections through the Helvetic nappes from opposite sides of the Kander valley zone (from Herb in Masson et al. 1980). The obvious difference is due to a variety of factors not all of which are directly linked with Tortonian movements along the Kander valley zone. However, the evident sinistral displacement of the front of the Wildhorn nappe, particularly with respect to the Gastern massif, with the appearance of the Niederhorn nappe (="Border Range" in this article) on the east side, requires sinistral motions that probably began before the Tortonian but had important late Tortonian components.

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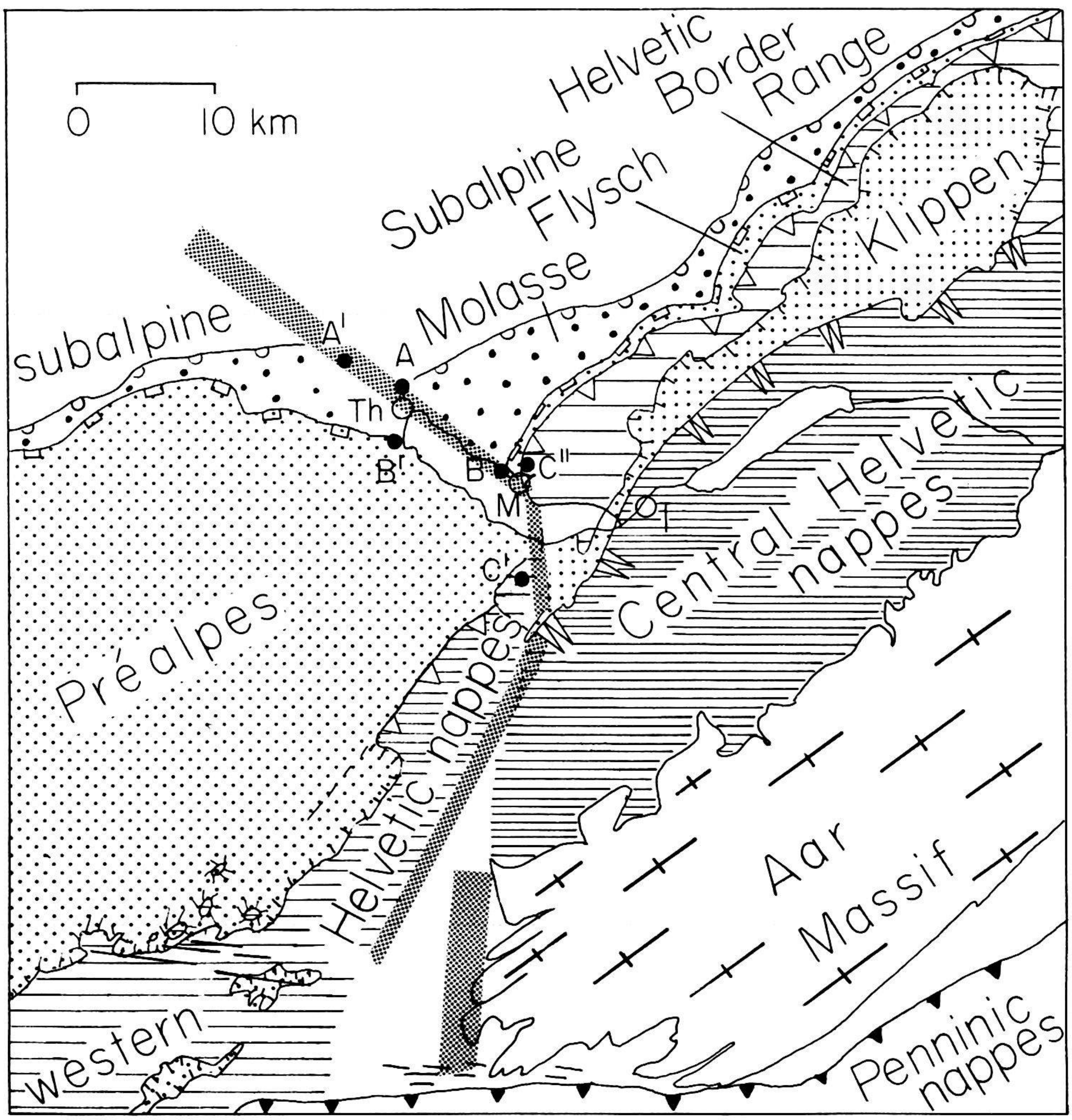


front of Subalpine Molasse

front of Subalpine Flysch and or Prealpes composite nappe

front of Border Range

Paleogene nappe contact

front of Wildhorn nappe s. str., central Helvetic nappes

Tortonian strike-slip zones

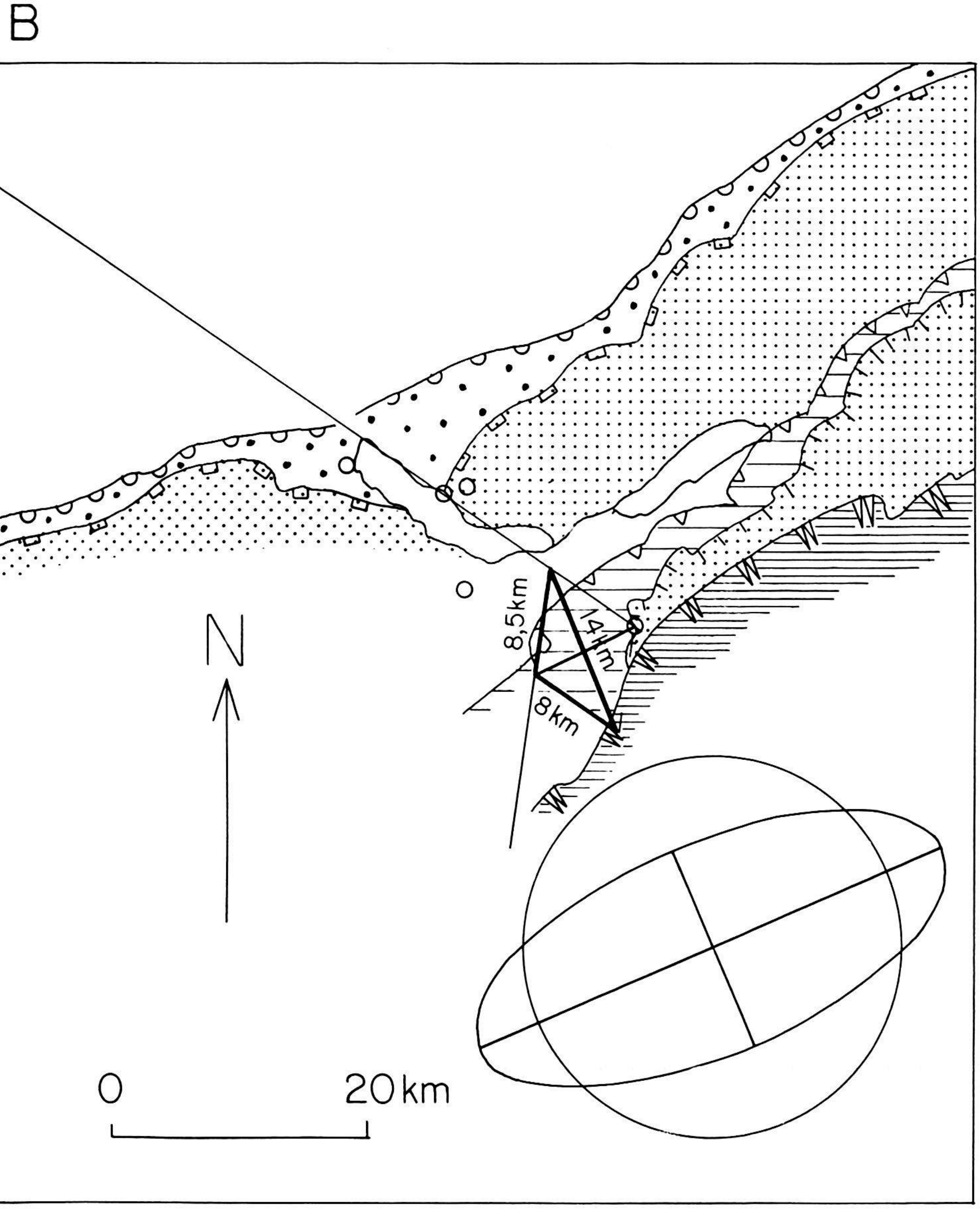
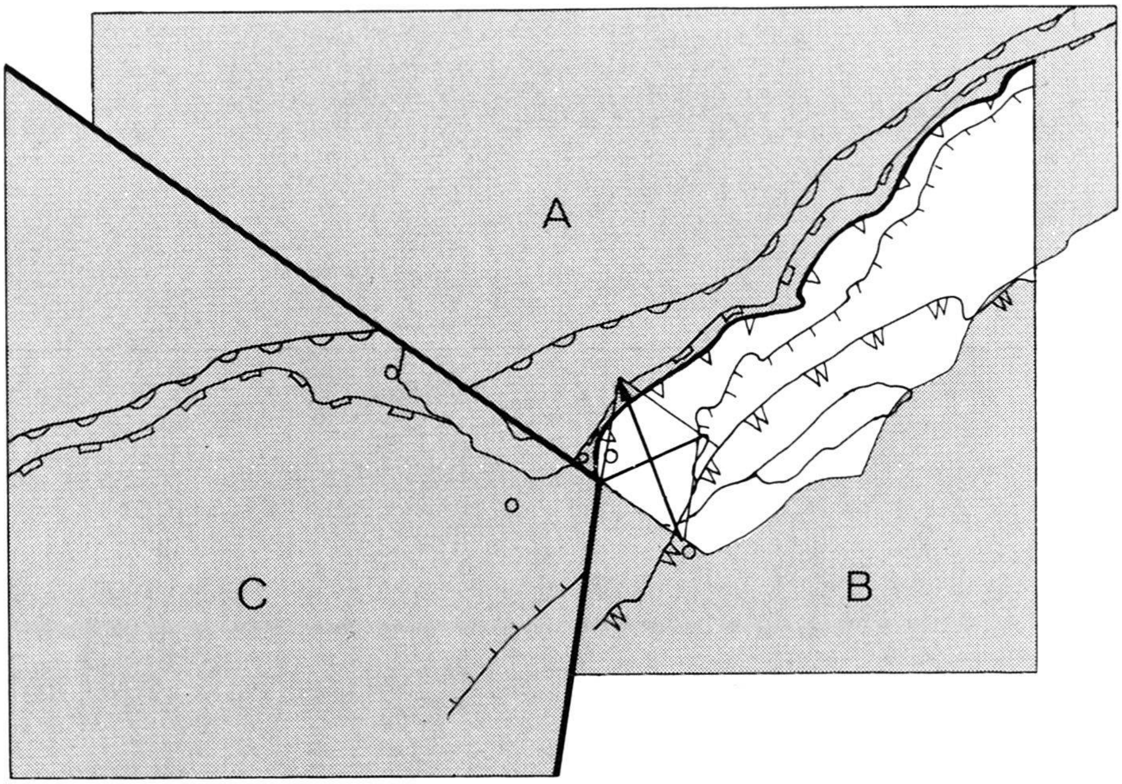


Fig. 2. The Lake Thun and Kander valley zones. A: Present situation. B: Earlier situation (Middle Tortonian?) arrived at by kinematic inversion of apparent strike-slip displacements. Th = Thun, M = Merligen, I = Interlaken. Apparent correlative points are A-A′ B-B′ across the Lake Thun zone, and C′-C″ across the northern part of the Kander valley zone. The double prime for C″ is due to the fact that whereas A and B are in the foreland block of the 3-block mosaic, C″ is in that of the Central Helvetic nappes. For the kinematic reconstruction the complexities of these zones have been simplified to straight lines joining at the Merligen triple junction. Further explanations in the text and in the legend for Figure 3.

A'



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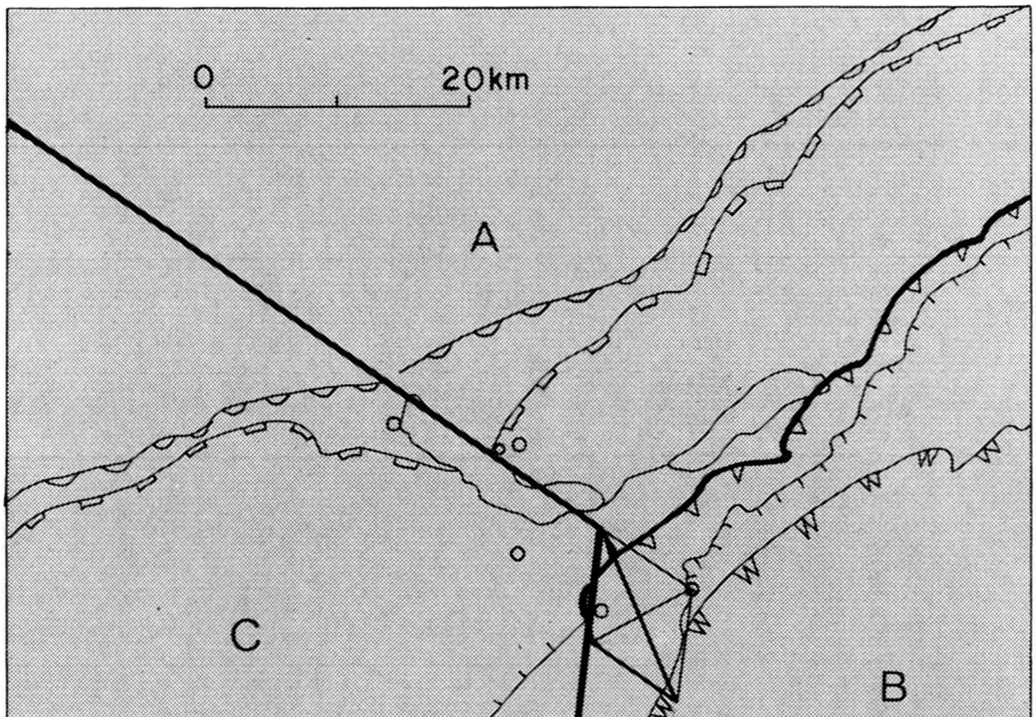

border range, as shown in the vector diagram, assuming pure strike-slip displacement along the shears. Under the same assumptions an extension of 9 km in a southwesterly direction results. If these discrete block displacements are dispersed within a circular area of 30 km diameter (represented by the circle in Figure 2B), a deformation ellipse as shown is obtained. Compare the very similar deformation ellipses arrived at by STECK (1980) in the Rhone valley, in the ductile domain (Fig. 4) of the southeastern projection of the Kander valley zone.

Figure 2 B shows the result of kinematic inversion. The fronts of the Subalpine Molasse and of the Ultrahelvetic to Penninic Préalpes Romandes-Subalpine Flysch line up reasonably well, as do the Helvetic Border Range and the front of the western Helvetic nappes.

In order to further clarify the Merligen triple junction kinematics Figure 2B has been traced on transparent tracing paper, and then a Xerox copy of this was made against a black background (Fig. 3A). Then the transparent paper was cut along the "plate boundaries" of the Merligen triple point and the displacements used for kinematic inversion (Fig. 2B) were carried out in the forward sense; after this, the plates were pasted together again so as to keep them from further drifting apart, and again a Xerox copy was made against a black background (Fig. 3A). The various aspects of the system are now clearly visible. The strike-slips displace the margin of the transparent paper, and the compression across the Border Range branch is the white band resulting from the double thickness there of the tracing paper. Keeping plate A fixed, it is seen that plate B converged in a northwesterly direction by 14 km, whereas plate C diverged in a southwesterly direction by 9 km. It is also obvious that the deformation of the original rectangle is the equivalent in the discrete displacement field of a deformation ellipse in the diffuse, or ductile field.

This kinematic model represents a late stage only of the total kinematics of the Merligen triple point; there is still the residue of the differences of nappe geometry to be explained, which apparently are due to differential developments in the different "plates" at a very early date of nappe forming. The Helvetic Border Range (except for the Standfluh-Wetterlatte, see MASSON et al. 1980, Fig. 4, Profile 2) is found only from Lake Thun eastward. The Ultrahelvetic, Central and South Penninic outliers here sit on top of this Helvetic nappe. From Lake Thun to the southwest, the Central Penninic decollement nappes rest on the Molasse, separated only by irregular slivers of Ultrahelvetic to South Penninic. There are no Helvetic nappes underneath, these remain south of the large Préalpes composite klippe. Starting from the present picture, one would like to conclude that in the eastern part decollement of the Helvetic sediments, overlain at that time by several kilometers of Ultrahelvetic and Penninic decollement nappes, in an early phase spread farther to

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Fig. 3. A cut-paper 3-block kinematic model of the Lake Thun-Kander valley-Border Range system. A corresponds to Figure 2B and represents the situation before activation of the block boundaries. In A′ the sheet of tracing paper has been cut along the block boundaries and the components of motion derived from Figure 2A have been applied. The resulting deformation is obvious from the change of shape of the original rectangular outline of Figure 3A. Also obvious is the necessity of a thrust emanating from the Merligen triple junction to the east (amount of thrusting corresponds to white belt inside Figure 3A′). The parallelogram shows strike-slip, compressional, and extensional components. Further explanations in the text.

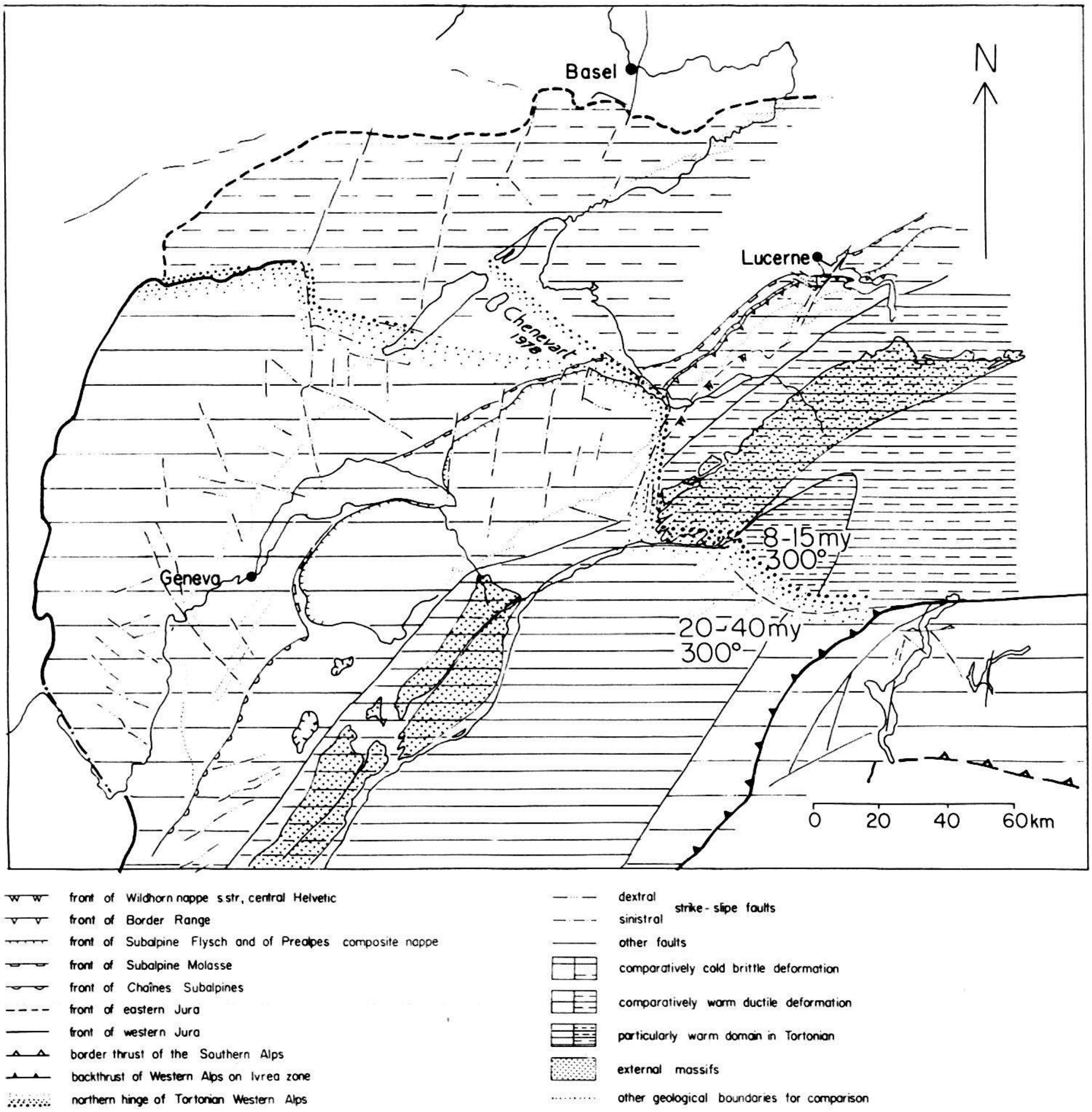

Fig. 4. The northern hinge zone of the Tortonian western Alps. The divergence of motion between the east-west directed compressive movements in the western Alps and the north-south to northwest-southeast directed compression of the central Alps requires axial stretching all across the Alps. Evidence for this is particularly good in the northwest where southwest of the stippled boundary zone ("northern hinge" of the Tortonian western Alps) an abundance of complementary dextral and sinistral strike-slip faults have been mapped. As subsequent deformation affected particularly the metamorphic core of the Alps which among other things was subject to uplift and erosion, deeper levels of Tortonian tectonics are exposed there with a more ductile rheology but a similar pattern of stretching. Figures indicate ages of closing temperature of biotite. Further explanations in the text.

the north (creating the Border Range nappe) than in the western part: here decollement ramped up to the base of the Eocene Préalpes composite nappe. Or, phrased differently one might conclude that in the east depositionally equivalent zones might be tectonically older.

However, this early disharmony across the Kander valley zone may not have been as drastic as it now appears: the Kander valley zone as seen today acquired its main features during the second phase, the Tortonian Doldenhorn-Jura development, and the kinematic inversion illustrated in Figures 2 and 3 lines up the front of the Wildhorn nappe and that of the Border Range quite well. A full analysis of this problem requires additional field work, and this is planned by our colleagues in Bern (Schweiz. Nationalfonds-Projekt Nr. 2.048-0.81; R. Herb, H. Laubscher).

Probable continuations through the Jura and into the Helvetic root zone

If we now try to embed the Merligen triple point kinematics in the late history of their Alpine surroundings, a remarkable picture emerges (Fig. 4). Going first from Lake Thun to the northwest, CHENEVART (1978) has presented reflection seismograph information which he interpreted as showing a continuation of the dextral Lake Thun zone across the Molasse basin into the Jura. The fuzzy segments in the reflection seismograph profiles seem indeed good candidates for strike-slip fault zones as no vertical displacements to speak of seem involved. However, as for instance noted by PLANCHEREL (1979), they may be combined in various ways, and indeed may correspond to boundaries of a block mosaic such as that crossing the Molasse basin northwest of Lake Geneva (SPICHER 1980 and Fig. 4). If we take the cue from the Jura, we find no major dextral strike-slip faulting in that part of the Jura from Neuchâtel to the northeast: it begins at the southwestern end of Lake Neuchâtel with the Mont Aubert, the Chamblon and the Vraconne faults and is kinematically linked through the Faisceau Salinois (which is dextrally-convergent, compare LAUBSCHER 1973) with the marginal overthrust over the Bresse Graben. This zone is outlined on Figure 4 and connected with the Lake Thun zone although the exact nature and location of this postulated connection are unknown. Certainly movements in both the Jura and Lake Thun are roughly coeval: they affect the Miocene molasse, of which the "Pontian" of the Bresse Graben is a part. In absolute ages, an upward revision of the Pontian as characterized by the Hipparion fauna has been made in recent years. While formerly the Pontian was widely believed to straddle the Mio-Pliocene boundary at 5 my b.p., it has now been found to begin about 11.5 my b.p. (BERGGREN & VAN COUVERING 1978), and Jura deformation may now be placed at roughly 10 my b.p. as striated pebbles make their appearance in the probably still Pontain strata of the Bresse (BOISTEL 1894) and because of a possible overlap of Pontian gravels on marginal folds of the Jura in the Ajoie (TSCHOPP 1960), though by and large the Pontian is folded along with the rest of the Miocene (LAUBSCHER 1948, 1962).

This dating is relevant if we now pass from Lake Thun to the south and southeast. Important movements (possibly *the* important movements) in the general domain of the Doldenhorn nappe and the cover of the southwestern Aar massif according to FRANK & STETTLER (1979) took place approximately 10 my ago (plateau age, $^{39}Ar/^{40}Ar$ method): this would probably be coeval with movements along the sinistral Lötschenpass zone of SCHLÄPPI (in press), and the remarkable dextral Rhone valley zone of DOLIVO (in press) and STECK (1980). This dextral zone is manifest on different scales. Microscopic to small-scale stretching occurs in a southwestern direction, with an x-z strain ellipse that is a replica of that shown for the Merligen triple point in the discrete field of block motions: we have entered here the zone of greenschist metamorphism characterized by a predominance of distributed deformation. On a larger scale DOLIVO shows that the northern boundary of this stretching lineation is aligned in an approximately east-west direction, bearing a striking resemblance to an east-west dextral en-échelon zone. On an even larger scale, the southwest plunging lobes of the southwestern Aar massif line up along the Rhone valley again in a pattern evoking dextral en-échelon arrays - until they intersect the sinistral Lötschenpass zone. Farther west, traces of the dextral zone reappear in the field of discrete deformation as the Rawilpass dextral fault zone, of which the Iffigen fault is the most prominent member (LUGEON 1910, SCHAUB 1936). Indeed, the Rawil nappe depression between the Aar and the Mont Blanc massifs may be a rather large-scale expression of the southwest stretching so prominent all across the Alps in this section. It has been further noticed for some time (LAUBSCHER 1971a), that the Aar and the Mont Blanc massifs are displaced dextrally, by as much as 60 km if the outcrop pattern is interpreted (naively, I think) as an originally continuous belt; I prefer the interpretation that the two massifs are arranged in a dextral en-échelon zone with a smaller amount of displacement.

The Lake Thun–Kander valley system as part of a wider hinge zone

Taking this broader view we notice that the Lake Thun–Kander valley system is but the northeastern border of a wide zone of stretching (or divergence, or pull-apart) to the southwest which passes between the Aar and Mont Blanc massifs, through the Rawil depression, and enters the Jura in the frontal decollement part of the orogenic lid (LAUBSCHER, in press) through that broad belt of prominent dextral wrench faults between Mont Aubert in the northeast and Morez–Les Rousses in the southwest. Branches of this zone may correlate with distributed dextral shear farther northeast, e.g. the Tavannes–Les Genevez zone (LAUBSCHER 1981).

Sedimentary decollement and basement tectonics

There is thus a genetic relation between late Middle Miocene developments in the Helvetic domain and in the Jura. This relation has several aspects. One concerns the map view kinematics of the arc of the western Alps and the Jura, the second concerns the cross-sectional kinematics and particularly where, when, and how basement participated in the Helvetic nappes–Jura decollement tectonics.

In the map view, the simultaneous activity of the Kander valley sinistral and the Lake Thun dextral fault zone, as made plausible by the demonstration of the Merligen triple point, is typical of a divergent transport field (compare LAUBSCHER 1980, Fig. 4, 5). Such divergence is expected in an arcuate mountain belt such as the western Alps, and it is striking for the Jura arc. Furthermore, if the Jura is a decollement nappe issuing from the Alps, its strike-slip faults or some kinematical substitution of them, must cross the Molasse basin at least to the very roots of the decollement, where this ramps down into the basement (LAUBSCHER, in press). It then depends on the kinematic relation of Jura basement roots to more internal elements whether the strike-slip zones extend to the latter. I think that in reality they do, as briefly sketched on the following page. The map view further demonstrates that part of this late Jura-Doldenhorn movement to the north is stopped east of the Merligen triple point, as it passes into the Border Range. Or, viewing the situation from the Jura perspective, as one goes east, part of the Jura shortening is transferred to the Helvetic nappes, and Jura compression decreases as Helvetic nappe compression increases.

The cross-sectional aspect of the participation or not in these late movements of basement thrusts external of the external massifs cannot be answered definitely, at least with the information I have at hand. On this information such basement thrusts may exist but are not necessary for a plausible story of late Alpine events; indeed, they would complicate matters. I would argue that the Doldenhorn nappe ist the latest of the Helvetic nappes; that it substitutes the original cover, sedimentary and tectonic, with a total thickness exceeding 10 km, of the Gastern massif and its southern flank; that the decollement zone at the base of the substituted series must somewhere emerge to the surface; that it does so in the Jura and in those Helvetic structures that, like the Border Range, are kinematically linked with it. The basement deformation associated with this decollement system is found in the lobes of the Aar massif which are the basement part of the Doldenhorn nappe (LAUBSCHER, in press). This system is complete, there is not much room for external basement thrusts.

Of course, this story hinges on the assumption that Jura thrusting and Doldenhorn nappe development had been synchronous, which, on the evidence presented above, they may well have been. For the Morcles nappe, which farther west plays the role of the Doldenhorn nappe, an older age than the overlying Diablerets nappe has been claimed as that nappe contact is not folded by the folds of the Morcles nappe (LUGEON & GAGNEBIN 1941). This argument, I believe, is mistaken. The Helvetic nappes are shear-induced folds formed at the base of the overriding masses consisting of largely inactivated earlier nappes (LAUBSCHER, in press). The late Morcles nappe was folded under a shear zone that does not portray these folds.

Thrusts in the crystalline basement have become fashionable with the revolutionary results of the COCORP Project in the Wind River uplift (SMITHSON et al. 1978) and the Southern Appalachians (COOK et al. 1979). There is some question, however, whether these results may be applicable everywhere. Basement deformation in the Aar massif is ductile though diffuse cataclastic processes play an important role (VOLL 1980). There are lobes, not thrusts. This basement behaved entirely differently from that of, say, the Silvretta nappe which moved as a rigid block, thus resembling the Blue Mountains thrust (LAUBSCHER, in press).

A complete kinematic history of the entire Helvetic-Jura domain from the western to the eastern Alps would be an ambitious project in its own right and is not attempted at this time.

A continuation to the Insubric fault zone

The Lake Thun-Kander valley zone seems to connect to the southeast, beyond Brig, with another young fault zone, the Simplon-Centovalli fault zone (BEARTH 1972), see Figure 4. MILNES (in STECK et al. 1979) has expressed the opinion that in spite of the map picture the Simplon and Centovalli faults are separate features, as the first is characterized by mylonites, the second by cataclastic deformation.

This objection is probably not valid: there has been a particularly young, post-10 my uplift in the Simplon area (WAGNER et al. 1977) which helped expose here deformations that had taken place at a deeper level, and there is also quite a bit of cataclastic deformation along the Simplon highway. Taking the cue from the stretching lineations of STECK (1980), the northwest trending Simplon segment should be an extensional feature, a sort of normal fault, with the southwest flank down. This again would fit into the picture of the Rawil depression as the result of northeast-southwest stretching. It would also fit in between a dextral east-west Brig zone and a dextral east-west Insubric-Centovalli zone as a pull-apart feature. I suspect, however, that there is some dextral displacement along the Simplon-Centovalli fault zone as well, having observed a number of small-scale northwest-trending faults in the area to the south which show dextral displacement. The occurrence together of the distributed deformation registered by STECK (1980) and the concentrated deformation along the Simplon fault zone remains to be explained: at this time it would appear that ductile northeast-southwest stretching had migrated in time from the Sesia zone in the south to the Rhone in the north, and that the Simplon fault is connected with the young dextral zone of DOLIVO (in press).

The Centovalli fault is a branch of the Insubric fault zone which borders the domain of the southern Alps. It is interesting to notice the kinematic - or historical - link between events at the marginal thrust of the Jura and the southern Alps, all across the Alps. West of Locarno, where the "northern hinge zone of the western Alps" (Fig. 4) joins both the Insubric fault zone and the northwestern end of the Canavese fault zone (which on the surface bounds the Ivrea body), we again have a triple junction of sorts where the blocks of the central Alps in the north, the southern Alps in the south and the western Alps in the west join.

This triple junction presumably plays an important role in the Tortonian kinematics of the Alps, and particularly for the emplacement of the Ivrea body (LAUBSCHER 1971; LAUBSCHER & BERNOULLI, in press). A more detailed investigation is underway (Schweiz. Nationalfonds-Projekt 2.851.080).

Concluding remarks

There is evidence of a cross-cutting feature in what may be termed the "northern hinge zone" of the Tortonian arc of the western Alps that extends all the way from the front of the Jura in the northwest to the Insubric fault zone in the southeast. It demonstrates the superposition of "block" or "plate" movements on thrusting or folding although the blocks are not rigid and their boundaries are zones rather than sharp faults: a more appropriate term might be "platy domain". As their expression varies with tectonic level and time, a rather complex kinematic picture emerges, in which the tendency of compressional features to develop cylindrically is modified.

These 'platy domain" boundaries seem to be somewhat ephemeral; an older boundary of this kind may have been the Ticino "transverse root", left behind dextrally and inactivated by Tortonian movements of the Insubric indenter; at present, seismicity and young deformations in the Rawil and Simplon regions imply some movements along limited segments of the Tortonian boundary.

Acknowledgment

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REFERENCES

ADRIAN, H. (1915): *Geologische Untersuchung der beiden Seiten des Kandertals im Berner Oberland.* - Eclogae geol. Helv. *13*, 238-351.

ARBENZ, P. (1934): *Die helvetische Region.* In: *Geologischer Führer der Schweiz* (p. 96-120). - Wepf, Basel.

BEARTH, P. (1972): *Atlas géologique de la Suisse, 1:25000, feuille Simplon.* - Comm. géol. Suisse.

BERGGREN, W.A., & VAN COUVERING, J. (1978): *Biochronology.* In: COHEE C.V., GLAESSNER, M.F. & HEDBERG, H.D. (Ed.): *Contributions to the Geologic Time Scale.* - Stud. geol. amer. Assoc. Petroleum Geol. *6*, 39-55.

BOISTEL, M. (1894): *Sur le Miocène de la bordure du Jura aux environs d'Ambérieu.* - Bull. Soc. géol. France (3), *22*, 628-659.

CHENEVART, C.J. (1978): *Seismic profiles as related to wrench-faulting in the Swiss Molasse basin.* - Eclogae geol. Helv. *71*, 53-60.

COOK, F.A., ALBAUGH, D., BROWN, L., KAUFMAN, S., OLIVER, J., & HATCHER, R. (1979): *Thin-skinned tectonics in the crystalline southern Appalachians.* - Geology *7*, 563-567.

DOLIVO, E. (in press): *Nouvelles observations structurales au sud-ouest du Massif de l'Aar entre Visp et Gampel.* - Matér. Carte géol. Suisse.

FRANK, M., & STETTLER, A. (1979): *K-Ar and ^{39}Ar-^{40}Ar systematics of white K-mica from an Alpine metamorphic profile in the Swiss Alps.* - Schweiz. mineral. petrogr. Mitt. *59*, 375-394.

LAUBSCHER, H. (1948): *Geologie des Gebietes von Siegfriedblatt St. Ursanne (Berner Jura).* - Beitr. geol. Karte Schweiz [N.F.] *92*.

— (1962): *Die Zweiphasenhypothese der Jurafaltung.* - Eclogae geol. Helv. *55*, 1-22.

— (1971a): *Das Alpen-Dinariden-Problem und die Palinspastik der südlichen Tethys.* - Geol. Rdsch. *60*, 819-833.

— (1971b): *The large-scale kinematics of the western Alps and the northern Apennines and its palinspastic implications.* - Amer. J. Sci. *271*, 193-226.

— (1973): *Jura Mountains.* In: DE JONG, K.A. & SCHOLTEN, R. (Ed.): *Gravity and Tectonics* (p. 217-227). Wiley, London.

— (1980): *Die Entwicklung des Faltenjuras - Daten und Vorstellungen.* - N. Jb. Geol. Paläont. Abh. *160*, 289-320.

— (1981): *The 3D propagation of décollement in the Jura.* In: *Thrust and Nappe Tectonics* (p. 311-318). - The Geological Society of London.

— (in press): *Detachment, shear and compression in the central Alps.* In: HATCHER, R. (Ed.): *Tectonics and geophysics of Mountain Chains.* - Mem. geol. Soc. Amer.

LAUBSCHER, H., & BERNOULLI, D. (1977): *Mediterranean and Tethys.* In: NAIRN, A.E.M., KANES, W.H., & STEHLI, F.G. (Ed.): *The Ocean Basins and margins. 4A: The Eastern Mediterranean* (p. 1-28). - Plenum, New York.

— (1980): *Cross-section from the Rhine Graben to the Po Plain* (Excursion No. III). - Excursion No. 031A of the 26th Int. Geol. Congr.

— (in press): *Deformation and history of the Alps.* In: *Mountain Building.* - Academic Press, London.

LUGEON, M. (1914): *Les Hautes Alpes Calcaires entre la Lizerne et la Kander (Wildhorn, Wildstrubel, Balmhorn et Torrenthorn).* - Matér. Carte géol. Suisse [N.S.] *30*.

LUGEON, M. & GAGNEBIN, E. (1941): *Observations et vues nouvelles sur la géologie des Préalpes romandes.* - Mém. Soc. vaud. Sci. nat. *7*, 1-90.

MASSON, H., HERB, R., & STECK, A. (1980): *Helvetic Alps of Western Switzerland* (Excursion No. I). In: *Geology of Switzerland, a guide-book* (p. 109-153). - Wepf & Co., Basel, New York.

PLANCHEREL, R. (1979): *Aspects de la déformation en grand dans les Préalpes médianes plastiques entre Rhône et Aar. Implications cinématiques et dynamiques.* - Eclogae geol. Helv. *72*, 145-214.

SCHAUB, H. P. (1936): *Geologie des Rawilgebietes.* - Eclogae geol. Helv. *29*, 337-407.

SCHLÄPPI, E. (in press): *Geologische und tektonische Entwicklung der Doldenhorn-Decke und zugehöriger Elemente.* Beitr. geol. Karte Schweiz.

SMITHSON, S. B., BREWER, J., KAUFMAN, S., & OLIVER, J. (1978): *Nature of the Wind River thrust, Wyoming, from COCORP deep-reflection data and from gravity data.* - Geology *6*, 648-652.

SPICHER, A. (1980): *Carte géologique de la Suisse, 1:500000 (2e éd.).* - Comm. géol. Suisse.

STECK, A. (1980): *Deux directions principales de flux synmétamorphiques dans les Alpes centrales.* - Bull. Soc. vaud. Sci. nat. *75*, 141-149.

STECK, A., RAMSAY, J. G., MILNES, A. G., & BURRI, M. (1979): *Compte rendu de l'excursion de la Société Géologique Suisse et la Société de Minéralogie et Pétrographie en Valais et en Italie nord du 2 au 5 octobre 1978.* - Eclogae geol. Helv. *72*, 287-311.

TSCHOPP, R. (1960): *Geologie des Gebietes von Siegfriedblatt Miécourt.* - Beitr. geol. Karte Schweiz [N. F.] *110*.

VOLL, G. (1980): *Ein Querprofil durch die Schweizer Alpen vom Vierwaldstättersee zur Wurzelzone - Strukturen und ihre Entwicklung durch Deformationsmechanismen wichtiger Minerale.* - N. Jb. Geol. Paläont. [Abh.] *160*/3, 321-335.

WAGNER, G. A., REIMER, G. M., & JÄGER, E. (1977): *Cooling ages derived by apatite fission-track, mica Rb-Sr and K-Ar dating: the uplift and cooling history of the Central Alps.* - Mem. Ist. Geol. Mineral. Univ. Padova *30*.