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Autor: Homewood, Peter / Gosso, Guido / Escher, Arthur

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Cretaceous and Tertiary evolution along the Besançon-Biella traverse (Western Alps)

By PETER HOMEWOOD[1]), GUIDO GOSSO[2]), ARTHUR ESCHER[3]) and ALAN MILNES[4])

ABSTRACT

A synoptic table of Alpine events has been drawn up for the Besançon-Biella traverse as a first step to drafting palinspastic profiles. Lack of data and contradictory interpretations impede palinspastic reconstruction of cover formations and their related basement to any great detail.

RÉSUMÉ

Des essais de reconstructions palinspastiques de la traverse Besançon-Biella, partant des arguments géométriques, géochronologiques, sédimentologiques, stratigraphiques, structuraux et métamorphiques, ont abouti à des profils soulevant de nombreux problèmes, notamment en ce qui concerne l'évolution parallèle des différents niveaux structuraux. En effet, bien que des arguments et hypothèses provenant des observations de terrain et de laboratoire soient parfois concordants, certaines contradictions, ainsi que des données incomplètes, empêchent la réalisation de profils palinspastiques satisfaisants.

D'une part, les événements éoalpins sont attestés de façon cohérente par les diverses voies d'argumentation, mais le détail de la paléogéographie demeure obscur (nombre de bassins «océaniques», localisation des sources détritiques, directions d'apport, localisation des plans de subduction). D'autre part, les événements mésoalpins et néoalpins, pour lesquels la paléogéographie est mieux connue, montrent une histoire structurale complexe dont la chronologie absolue, et même relative, prête encore à discussion.

Une liste des données est établie comme premier pas dans le but des reconstructions palinspastiques. Les événements principaux sont ainsi présentés sur un tableau chronologique avec une discussion des divers éléments.

Introduction

The following list of alpine events, established for the Besançon-Biella traverse, is the result of a joint effort instigated by R. Trümpy and J.P. Schaer, in which we have tried to combine data from the fields of sedimentary geology, structural and

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[1]) Institut de Géologie, Pérolles, CH-1700 Fribourg (Switzerland).

[2]) Istituto di Petrografia, and Centro di Studio Orogeno Alpi Occidentali C.N.R., via San Massimo 24, Torino (Italy).

[3]) Laboratoire de Géologie, Palais de Rumine, CH-1005 Lausanne (Switzerland).

[4]) Geologisches Institut, ETH-Zentrum, CH-8092 Zürich (Switzerland).

metamorphic petrology, and tectonics, in order to draw palinspastic profiles for the traverse at several Cretaceous and Tertiary epochs.

We rapidly became aware of many discrepancies between the classical interpretations of data, in particular where sedimentary geology and structural and metamorphic geology (abetted by geochronology) are concerned. The table of events (Table) which was therefore drawn up to provide a reasonably objective basis for these profiles, obviously reflects the state of more general knowledge at the time of publication. It is evident that modifications will be necessary, particularly as a number of teams are now actively working in field areas that had not been studied for some time previously.

The following text is intended as a brief description of the table, together with comments on the significance of possible relationships between superficial and deep-seated events.

Some further explanation is necessary as to the way the table has been set out:

Columns I to XII (right to left) list the major events (*a* to *s*) affecting the *structural units* which are drawn on the schematic cross section of the traverse (Plate). Throughout the text, in a general manner, forward folding indicates north-facing anticlines whereas backfolding (and by analogy thrusting) indicates south-facing anticlines.

The external massifs (X) do not crop out along the traverse, so information is derived both from the Aiguilles Rouges/Mont Blanc group and the Aar/Gotthard group. Reasoning for the Simplon/Ticino nappes (VII), which are classically projected as the basement of the Sion-Courmayeur zone (VIII), is provided from observations to the northeast of the traverse.

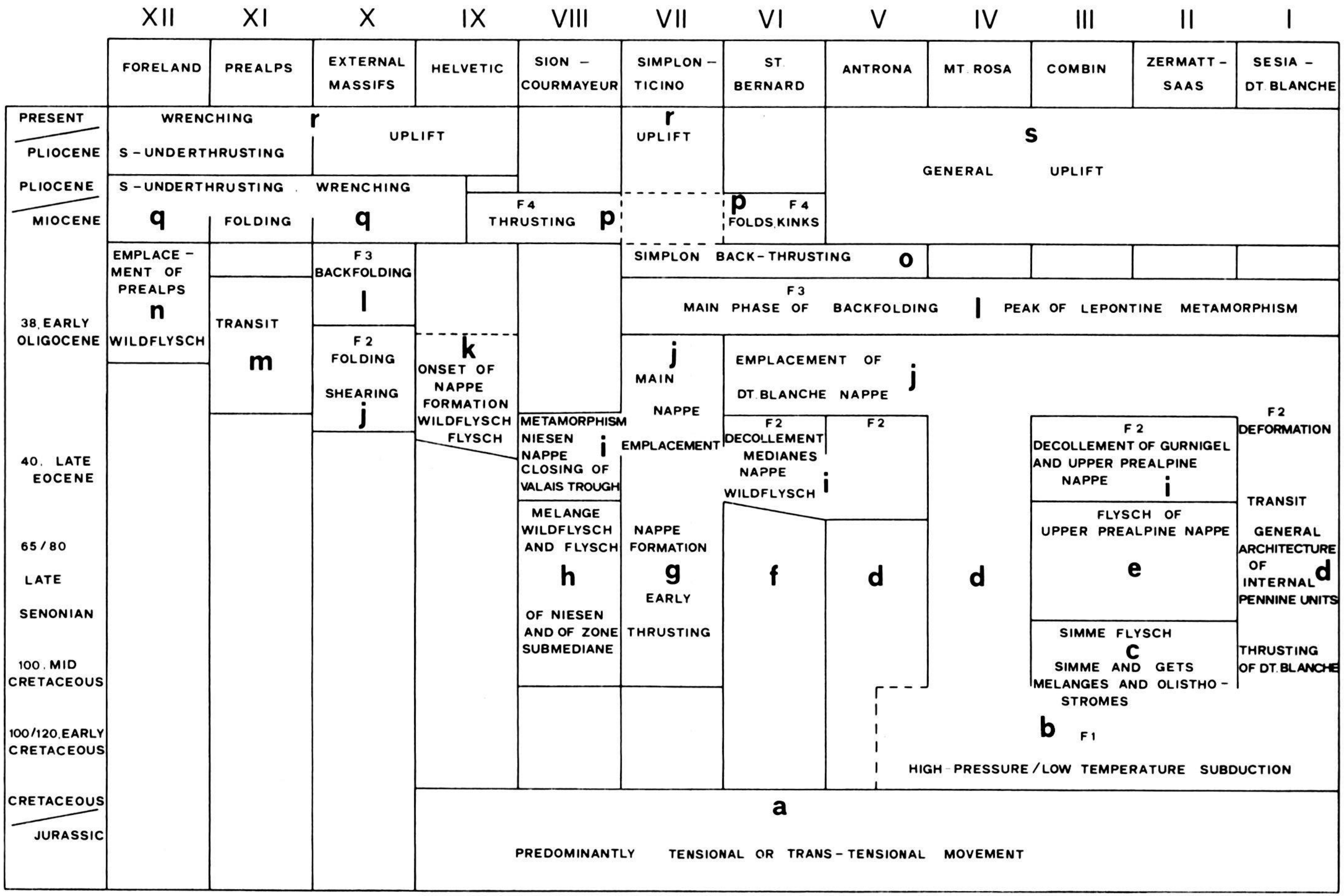
The Prealps (XI) figure as a separate unit after décollement, whereas information from the Prealpine nappes about events preceding that time are referred to appropriate structural units. Solutions chosen for the Niesen nappe (relating to VIII, the Sion-Courmayeur zone) and for the Médianes nappe (relating to VI the St. Bernard nappe, i.e. the Barrhorn sedimentary sequence and the Mischabel-Siviez basement) are generally accepted. The same may be said for relating the Upper Prealpine nappes to II, the Zermatt-Saas and to III, the Combin zone, at least in part. However, possible relationships of the Simme nappe with the Canavese (not on this profile) suggest over-simplification on the Table. As a further complication, the Combin zone (III) appears to comprise several parts or units with different histories.

It has been customary to associate the Brèche nappe with the Monte Rosa basement (IV), but taking into consideration the Cretaceous deformation and metamorphism of the latter, it is more likely that the Brèche sediments were deposited on a margin directly between VI, the St. Bernard craton (with Camughera-Moncucco) and either an "Antrona Ocean", or a "Combin-Zermatt/Saas Ocean". The interpretation of Antrona (V) is at present highly conjectural.

The Dent Blanche nappe and the Sesia zone (I) have been grouped together not only according to fashion but also as their histories are similar.

The dates and time intervals recorded on the Table are not inscribed on a continuous scale for obvious reasons of spacing. Whatever the deformation rates of earlier (Cretaceous) and later (Neogene) phases may have been, this underlines the catastrophic nature of late Eocene to early Oligocene events.

Table: *A chronology of main events from the Besançon–Biella traverse. Numbers I to XII and letters* a *to* s *refer to the text.*



1. Earlier Alpine history

a)[5]) *Predominantly tensional or trans-tensional movement*

During Jurassic and early Cretaceous times, basins and intervening highs of the Alpine realm ("geosyncline") developed under a predominantly tensional or trans-tensional regime (Trümpy 1960, 1973; Lemoine 1975; Bourbon et al. 1977; Homewood 1977), with the formation of new oceanic crust, probably in several areas (Lemoine 1971; Trümpy 1971). Although this phase precedes the events with which we are concerned, the general configuration acquired, together with earlier structural lineaments, obviously controlled the subsequent evolution to some extent.

2. Early subduction (Cretaceous) affecting I to V[5])

b) High-pressure, low-temperature metamorphism, FI deformation

Mineral parageneses recording high-pressure, low-temperature metamorphic conditions occur in the Sesia-Dent Blanche system, both the Furgg zone and the main Monte Rosa unit, the Zermatt-Saas unit, part of the Combin zone and possibly in the Antrona unit (Dal Piaz et al. 1972; Compagnoni & Maffeo 1973; Compagnoni et al. 1975; Bocquet-Desmons 1974; Bearth 1973; Dal Piaz 1971; Wetzel 1972; Martin, pers. comm.).

Some structural events took place before peak metamorphic conditions, but others certainly post-date high-pressure recrystallization, particularly in the Zermatt-Saas and Sesia-Dent Blanche units. Dismembering of the metamorphic zonation and imbrication of units, as well as large-scale isoclinal folding, took place before readjustment under later, mainly Lepontine metamorphic conditions (Gosso 1977). This earlier phase of deformation, which may be generally referred to as *FI*, resulted in a deep-seated nappe pile with complex internal structures in the Sesia-Dent Blanche and Monte Rosa basements, together with implication of Mesozoic sedimentary sequences.

Radiometric ages span a fairly long period of time: 130-110 my (Hunziker 1970) for the frontal part of the Monte Rosa, 80-100 my for glaucophane of the Zermatt-Saas zone (Bocquet-Desmons et al. 1974, Hunziker 1974), 130 my for total rock (Dal Piaz et al. 1978) and 90-60 my for phengites (Hunziker 1974), both of the high-pressure events in the Sesia zone. These figures definitely point to a Cretaceous age for this phase (mid-Cretaceous or early late Cretaceous) but the correlation between the ages and one or several precise events is still rather vague.

c) Simme Flysch, olisthostromes and melanges of Simme and Gets nappes (Prealps)

Both the Simme nappe (s.s. throughout this paper) and the Gets nappe show sequences in which olisthostrome or melange formations of early Late Cretaceous age are overlain by flysch (Caron 1972). In the Simme nappe in particular, olistholiths of South-Alpine or Austroalpine facies not younger than Turonian are overlain

[5]) a), b) ... and I, II, ... refer to the Table.

by a conglomeratic or sandy flysch. Apart from the tectono-sedimentary significance of the olisthostromes ("wildflysch") the subsequent flysch sequence shows an admixture of two petrographic suites. On the one hand, clasts of composition similar to the olistholiths derive from a sunken marginal platform sequence and a continental crystalline and metamorphic basement (ELTER et al. 1966), while on the other hand the heavy mineral spectrum shows up to 75% of chromite (FLÜCK 1973) and analysis of the sand fraction shows frequent spilite and diabase rock fragments and mineral grains, presumably derived from Mesozoic oceanic crust. In the Gets nappe, clastic facies of uncertain olisthostrome or melange character, and of early Late Cretaceous age, contain both oceanic ophiolites with Jurassic and Cretaceous radiometric ages, and variscan granites (BERTRAND 1970).

b + c) Cretaceous subduction

This data from deep-seated and superficial levels is coherent with the hypothesis of a Cretaceous subduction event affecting a segment of Tethyan Mesozoic oceanic crust and a southerly marginal sequence laid down on continental crust. Several points remain obscure however, in particular the precise location and strike of the apparently south-dipping subduction zone, as well as the nature and subsequent evolution of the terrain, tens of kilometers thick, lying between the surface and the deeply buried high-pressure metamorphic domain.

3. Further deformation (Cretaceous to Paleocene) of I to V

d) General architecture of internal Pennine units

Continued deformation of the Antrona, Monte Rosa, Combin (in part), Zermatt-Saas and Sesia-Dent Blanche units is shown by regional tight to isoclinal folding of nappe boundaries. Large infolding structures were formed and high-pressure units were displaced to shallower levels during progressive unloading, which lead to decompressional reequilibration of eclogite assemblages in the Zermatt-Saas zone (ERNST & DAL PIAZ 1978) and in the Sesia zone. These polyphase processes are pre-Lepontine according to micro- and meso-structural observations (GOSSO et al. 1979). Radiometric ages related to these events are difficult to separate from those cited above for the high-pressure metamorphism, but the younger dates obtained (60 my) suggest that this post nappe folding continued throughout the late Cretaceous to the Paleocene.

Mesozoic sediments, at present related to the Dent Blanche nappe are not younger than middle Jurassic (Mont Dolin series, WEIDMANN 1974) and might, therefore, have been implicated by Cretaceous deformation; the same may hold for the Mesozoic sediments of the Monte Rosa nappe (BEARTH 1976). Facies of the Mesozoic metasediments of the Zermatt-Saas and part of the Combin zones are suggested to be Jurassic and Cretaceous in age by analogy with the Apennine-Ligurian sequences (BEARTH 1976). However, some of the latter reach late Cretaceous and even early Tertiary ages (the Val Lavagna slates and their "schistes à blocs", cf. ELTER 1976).

e) Senonian and early Tertiary Flysch of the Upper Prealpine nappes

The late Cretaceous Helminthoid Flysch (Dranses nappe, CARON 1972) is considered to be of a more external origin than the Simme nappe (most internal) and the Gets nappe, for reasons of facies and petrographical composition (C. Caron, pers. comm.). But interstratified conglomerates of the Helminthoid Flysch show a close affinity to the older Mocausa conglomerates of the Simme nappe. The Maastrichtian to middle Eocene Gurnigel Flysch, the youngest of the internally derived flysch units (CARON 1976, VAN STUIJVENBERG 1979), has variscan igneous clasts of South-Alpine affinity.

d + e) Late Cretaceous to Paleocene tectonics and sedimentation of internal Pennine units

The apparent contradiction between Cretaceous metamorphism and deformation of part of the Combin zone and a possible Tertiary age of some of its sediments (which admittedly follows from a sequence of hypothetical assumptions) may find an explanation which also satisfies some of the details of stratigraphy and petrography of the different sequences of the Upper Prealpine nappes. Continued compressive ductile deformation at lower structural levels, resulting in northward encroachment of southern elements and relative narrowing of the basins, may have provided evolving superficial sources for the flysch sequences (Simme, Gets, Helminthoid Flysch, Gurnigel). Sedimentation would then have been continuous in an active structural environment (on a wide scale) with successive accumulation and tectonization of deep-marine clastic and pelagic deposits. The lack of units from recognized intermediate structural levels would thus result from them having been progressively eroded to feed the sedimentary basins.

4. Late Cretaceous and Paleogene events affecting more external units (VI?), VII, VIII

f) Absence of Cretaceous events in the Mischabel-Siviez basement

High-pressure, low-temperature metamorphism, similar to that mentioned above for more internal units (I, II, etc.) affects sequences comparable with those of the St. Bernard in the French Alps. BOCQUET-DESMONS (1974) has discussed the possible Cretaceous or Paleogene (Lepontine) age of this event. However, close analogies between the Barrhorn metasediments and the Médianes décollement nappe of the Prealps suggest an Eocene age at least for the wildflysch which terminates the Barrhorn Meso-Cainozoic cover sequences (ELLENBERGER 1952; MARTHALER 1980). This would preclude the implication of Mischabel basement in Cretaceous and Paleocene structural events, unless the present Barrhorn-Mischabel association results from Paleogene cover substitution.

g) Early thrusting and Nappe formation of the Simplon-Ticino units

The Simplon-Ticino basement units are not exposed at the surface along our traverse, onto which they are traditionally projected at intermediate depths as basement of the Sion–Courmayeur zone. The complicated sequence of structural events which they have recorded has been set out by MILNES (1974*a*). Precise dating of the earlier stages of deformation has not yet been established, but "early thrusting", which individualized the Lebendun unit and with which the "Monte Leone mélange" might be associated, could be late Cretaceous or Paleocene in age. The obliterative nature of the early Oligocene Lepontine metamorphism (HUNZIKER 1970), which gives an indication of the age of the post-nappe Wandfluhhorn fold phase (MILNES 1974*a*), together with the unknown rate of deformation during the development of early ductile nappe-forming phases, only allows vague speculation as to dates and conditions of recognizable pre-Lepontine events (LADURON 1976).

h) Flysch and wildflysch of the Niesen nappe, Zone Submédiane and Sion–Courmayeur zone

Late Cretaceous ages are indicated by fairly poor paleontological evidence for the younger sequences of the Sion–Courmayeur zone (BURRI 1967; ANTOINE 1971). These deposits show flysch facies and megabreccias suggesting an active structural environment during sedimentation (Burri, Jemelin, pers. comm.); this may have been compressive or trans-pressive.

Decollement nappes of the Prealps having a more external origin include the coarse upper Cretaceous Niesen Flysch and coeval flysch and pelagic sediments of the Zone Submédiane. Paleocene olisthostromes of the Zone Submédiane were subsequently incorporated into Paleogene wildflysch and melange formations (WEIDMANN et al. 1976; HOMEWOOD 1977).

f, g, h) Late Cretaceous to Paleocene tectonics and sedimentation of external Pennine units

Too little precise data is available to allow us to tie the varied structural and sedimentary events referred to together. All the same there is a general indication of basement deformation at various levels which may well have controlled deposition of flysch, megabreccias and olisthostromes in more external basins during late Cretaceous and Paleocene times. Recently evoked units such as the "Monte Leone mélange" of the Penninic Alps (MILNES 1974*a*) and the "North-Penninic mélange" of the Prealps (HOMEWOOD 1977) suggest interesting comparisons.

5. Paleogene continental collisions affecting units I to X

i) Wildflysch formation and decollement of Pennine cover units

During the Eocene, flysch deposition (CARON et al. 1979; BERNOULLI et al. 1979; HOMEWOOD 1977) spread to shallower environments overlying continental crust (on a sunken microcraton for the middle Eocene sequence of the Médianes nappe of the Prealps; in a marginal basin for the upper Eocene flysch of the Ultrahelvetics) while flysch sedimentation continued through middle Eocene in the Penninic oceanic or para-oceanic basins (?Niesen, Zone Submédiane, Gurnigel nappe). Wildflysch (tectono-sedimentary melange formations in which olisthostromes are subsequently sheared and imbricated beneath an encroaching allochthon, CARON 1966) terminate the stratigraphic sequences of outer Penninic units. They are more or less well dated as middle to late Eocene, becoming younger towards more external positions. Sedimentation over the more internal domain was cut off at middle to late Eocene (VAN STUIJVENBERG 1979). Decollement must have preceded Lepontine metamorphism, as this did not effect the majority of cover sequences. The Niesen nappe shows anchi to epimetamorphic characteristics (KUBLER et al. 1979, MULLIS 1979, FREY et al. 1980) acquired before emplacement, but these are not dated relative to decollement.

j) F2 deformation

Several events pertain to the period closely preceding the peak of Lepontine metamorphism and may be generally termed *F2*. These include the completion of the overall pre-backfolding architecture of the Pennine alps (see *d* and *e* above); the thrusting of the Barrhorn-Mischabel complex over the Simplon-Ticino nappes (the Mischabel basement, devoid of pre-Lepontine alpine metamorphic associations, suffered an intense folding history which predates the Lepontine greenschist facies metamorphism, SAVARY 1979; R. Müller, pers. comm.); the "main nappe emplacement" of the Simplon-Ticino nappes (MILNES 1974*a*); the closing of the sedimentary basins of both more internal and more external position; the folding and shearing of the External massifs (Aar and Gotthard, STECK et al. 1979), and the emplacement of the Dent Blanche nappe at the highest structural position of the present profile.

k) Flysch, wildflysch and onset of nappe formation in the Helvetics

Flysch of the Helvetics is dated as late Eocene (eventually early Oligocene in part). The overlying wildflysch is early Oligocene, predominantly made up of "diverticules" (regional term employed in the same sense as olistholiths) of ultrahelvetic facies (HOMEWOOD 1976; MASSON 1976). Unless some of these elements derive in fact from the Médianes or other nappes of the Prealps (a possibility not often voiced by protagonists), the lack of such facies types infolded with the Helvetic nappes would suggest that the passage of the Prealpine units occurred after the onset of Helvetic nappe formation. This seems valid for the Diablerets and Wildhorn nappes but may not hold for the Morcles nappe (e.g. possible Médianes origin of the Bovonne series overlying the Morcles nappe, GABUS 1958). Recent observations (STECK 1979) indicate that both the internal Aar massif and the external lower Pennine nappes have been affected by the same main phase of backfolding (*l*, below) during the early Oligocene. This deformation postdates earlier phases of intense folding in the external massifs and their Helvetic cover.

It seems therefore likely that the diverticulation of the Ultrahelvetic sediments, followed by the initial formation of the Helvetic nappes and the passage of the Prealps, took place in the limited time span between the late Eocene (Flysch) and the early Oligocene (backfolding). This view is confirmed by the absence of any relic-backfolding in the Prealps.

The Helvetic nappes, in their final shape, have been generally considered to date from Miocene time (TRÜMPY 1973), but radiometric ages of post-nappe metamorphism (related to the overburden of the nappe pile) point to the Oligocene age of (main) nappe formation (FREY et al. 1973; see also MILNES & PFIFFNER 1977). Clasts of Helvetic facies types (post deformation), occurring in upper Miocene Molasse (TRÜMPY 1973), give a limit to this period of nappe building. As suggested above, the Morcles nappe (BADOUX 1972) may well have formed during a slightly later period (cf. KÜNZI et al. 1979), in any case the present configuration must have been acquired over several events. Details of super-imposed folding during and after the nappe formation have been worked out by GENOUD (1978) and MASSON (MASSON et al. 1980).

i, j, k) Catastrophic collision with wildflysch formation and decollement of cover nappes

This group of events illustrates a very short period of time, from the spreading of flysch sedimentation (45 my) to the peak of Lepontine metamorphism (38 my), during which deformation was extended to zones previously unaffected. This phase is generally considered to represent the final collision at shallow to intermediate depths, with superficial formation of wildflysch, of the various fragments of continental crust which had been rifted apart (?transtension) during the earlier phases of Alpine evolution (I above, MILNES 1978). From this time onwards, the previously individual crustal fragments will remain locked together (MILNES 1978) whereas part of the cover sequences, detached as decollement nappes and remaining at superficial levels, will transit towards the present external position of the Prealps and the Klippen.

6. Post-collision events, Alps and Alpine foreland, I to XII

l) Lepontine metamorphism and backfolding (F3)

Peak conditions of Lepontine metamorphism were reached at early Oligocene (38 my, HUNZIKER 1970) whereas high temperatures lasted until late Miocene (biotite system closing around 10–15 my, JÄGER et al. 1967). The entire Penninic pile, in which preformed nappe structures had already juxtaposed deep and relatively superficial units was subjected to metamorphism ranging from greenschist to amphibolite grade. Isotherms were probably strongly disturbed in places, but subsequent thermal readjustment produced crosscutting isograds of complex significance.

The peak of Lepontine metamorphism gives a general date for the synmetamorphic backfolding (south-closing major antiforms and north-closing synforms) which is typified by the Mischabel fold near Zermatt and referred to here in a general way as *F3*. Intense deformation produced several generations of folds in some units (AYRTON & RAMSAY 1974; MILNES 1974*b;* WILSON 1978; KLEIN 1978; SAVARY 1979), but only one main generation of folds is developed in the outer Monte Rosa section (GOSSO et al. 1979). Although evidence for backfolding has not been recognized from the Sion–Courmayeur zone (BURRI 1968, Burri & Jemelin, pers.

comm.), Steck (Steck et al. 1979) suggests that backfolding in the Aar and Gotthard massifs relates to the same phase as the main backfolding of the Pennine Alps.

m, n) Emplacement of the Prealps

The transit and emplacement of the Prealpine nappes has recently been shown by Plancherel (1979) to be separated in time from subsequent wrenching, folding and imbrication. The timing of the earlier, possibly gravitational phase is indicated by the ?early to mid-Oligocene age of the foreland wildflysch and the late Oligocene age of the red-bed Molasse formations, both fed from the encroaching allochthon. Wrenching and associated deformation may already have been active in the foreland of our traverse at this time (Rigassi 1977; Plancherel 1979). The nature of the original emplacement of the Prealps, as one composite unit or as two (or more) separate groups, has been obscured by subsequent deformation and has yet to be elucidated.

o) Backthrusting in the external Pennine units

The Simplon backthrust (Bearth 1956) is a major post-nappe feature which displaces Lepontine metamorphic isogrades and illustrates differential brittle-ductile response at various depths. It directly post-dates the main phase of backfolding, transecting the Berisal synform and probably the lower part of the Antrona synform (Milnes & Steck, in Steck et al. 1979).

p) F4 deformation

A forward thrusting phase of regional importance ("*F4*") affects units near the present Rhone valley. Folds in the internal Helvetic zone (Masson 1980) and the outer part of the St. Bernard nappe grade southwards to kinks before dying out (Savary 1979). This late phase of forward folding appears to be absent in the lower Pennine nappes (VII).

q) Main deformation of the Prealps

The *F4* thrusting phase might be contemporaneous with the main onset of wrenching and associated deformation ("en échelon" folding, imbricate thrusts) which affect the foreland and the Prealps. There are indications that this deformation was in progress as from Eocene times (Rigassi 1977), but as predominantly Oligocene and Miocene Molasse is affected together with the allochthonous pile of the Prealps, the underthrusting and wrenching are essentially Mio-Pliocene (Plancherel 1979).

r, s) Recent deformation and uplift

Pliocene deformations of the Jura (Laubscher 1973; Trümpy 1973) together with present day geophysical evidence (e.g. Pavoni 1977) suggest that further underthrusting of the foreland (XII) has continued through Pliocene times, accompanied by structural activity along the pre-existing wrench zones (Plancherel

1979). Uplift of the External massifs, together with their overlying Helvetic units may correlate with the major infolding which affects the frontal part of the Helvetic nappes, the internal Prealps and the parautochthon of the Rhone valley (WEIDMANN et al. 1976) as well as with an underthrust beneath the External massifs (PLANCHEREL 1979; TRÜMPY 1975).

Finally both the External massifs and the Penninic Alps have been subjected to uplift and faulting (e.g. Centovalli fault, MILNES in STECK et al. 1979).

l, m + n, o, p, q, r + s) Lepontine metamorphism and backfolding, backthrusting, deformation of the foreland and uplift

This rather incoherent list of events forms two fairly homogeneous groups separated in time by the Simplon backthrust event (*o*). Firstly, main Lepontine metamorphism; "Mischabel backfolding" (*F3*); transit and emplacement of the Prealps. Secondly, underthrusting of the foreland (accompanied by wrenching and folding of the tectonic and sedimentary cover); thrusting in the Helvetic and outer Penninic units (*F4*); infolding of decollement nappes, Helvetic nappes and foreland Mesozoic; uplift of the External massifs and faulting of the main Pennine mass.

Although independent events and sequences of events can be recognized in most places, criteria for absolute timing are unsatisfactory to date, beyond very general distinctions between "Oligocene" and "Mio-Pliocene". The main interest here lies in the kinematic interpretation of this mixture of northward and southward verging movements.

Problems for palinspastic profiles

The list of events outlined above and set out on the Table is intended to provide a reasonably objective basis for a comic-strip presentation of palinspastic reconstructions. This step may only be taken by making a number of arbitrary assumptions.

Recognition of individual paleogeographic domains

Traditionally, each unit occurring on the structural section (the projection of some is quite hypothetical) calls for a separate paleogeographical domain placed along a transect of similar orientation at the epoch considered. Higher units are generally considered to be of more internal origin, in spite of indication of south-facing movement (backfolding, backthrusting) for some phases (e.g. MILNES & SCHMUTZ 1978). Internally derived decollement units are fitted in according to facies and stratigraphic sequences (e.g. TRÜMPY 1960, 1973). Precise positions may be shown by infolding of similar formations into the main Alpine body, but more than one solution is usually possible for the original location of a given decollement sequence. Where the Pennine Alps of our traverse are concerned, the alignment of units along a N-S section presumes an arbitrary unravelling of the highly complex polyphase structures into a simple linear sequence. In fact we have very little (if any) data on absolute displacement directions for any Cretaceous and many Paleogene events.

The general subdivisions thus obtained, the Helvetic, Penninic (outer, middle, inner), Austroalpine and South-Alpine domains are only fairly satisfactory where the cover sequences are concerned. The importance and relative position of such domains as Ligurian and Canavese, compared to Piemont are not entirely clear (e.g. TRÜMPY 1976, DEBELMAS 1976). For instance, suggestion of oceanic and para-oceanic basins comes from the Zone Submédiane (Prealps), the Upper Prealpine nappe, the Sion–Courmayeur zone, the Antrona and Zermatt–Saas units and perhaps the Canavese. They may indicate from two (North- and South-Penninic) to four (North-Penninic, Antrona, Piemont, Ligurian) of these basins. Further investigation is obviously needed, particularly in the case of Antrona. Where the microcratons are concerned, the Briançonnais facies type may delimit a fairly simple north-east trending belt (MEGARD-GALLI & BAUD 1977) or a fragmentary chain of basins and intervening highs not easily represented on a single profile. Similar questions may be asked of the Dent Blanche system. To crown it all we have no indication as to how many elements of the puzzle are at present hidden beneath the Alps and which will not be available for investigation over the next few generations.

Relation of deep-seated to superficial events and timing

In many cases we have glimpses of behaviour at both superficial and deep-seated levels, but we may rarely observe remnants from the terrains between. While correlating deep-seated events (dated by radiometric ages for *closing* systems) with superficial events (dated by bio- or lithostratigraphy) there is no indication of possible time lag or of the inevitable special distribution between the two.

To conclude, it would appear that several arguments would favour modifications in the palinspastic profiles customarily drawn on University blackboards, but the moment is not yet propitious to start a new fashion.

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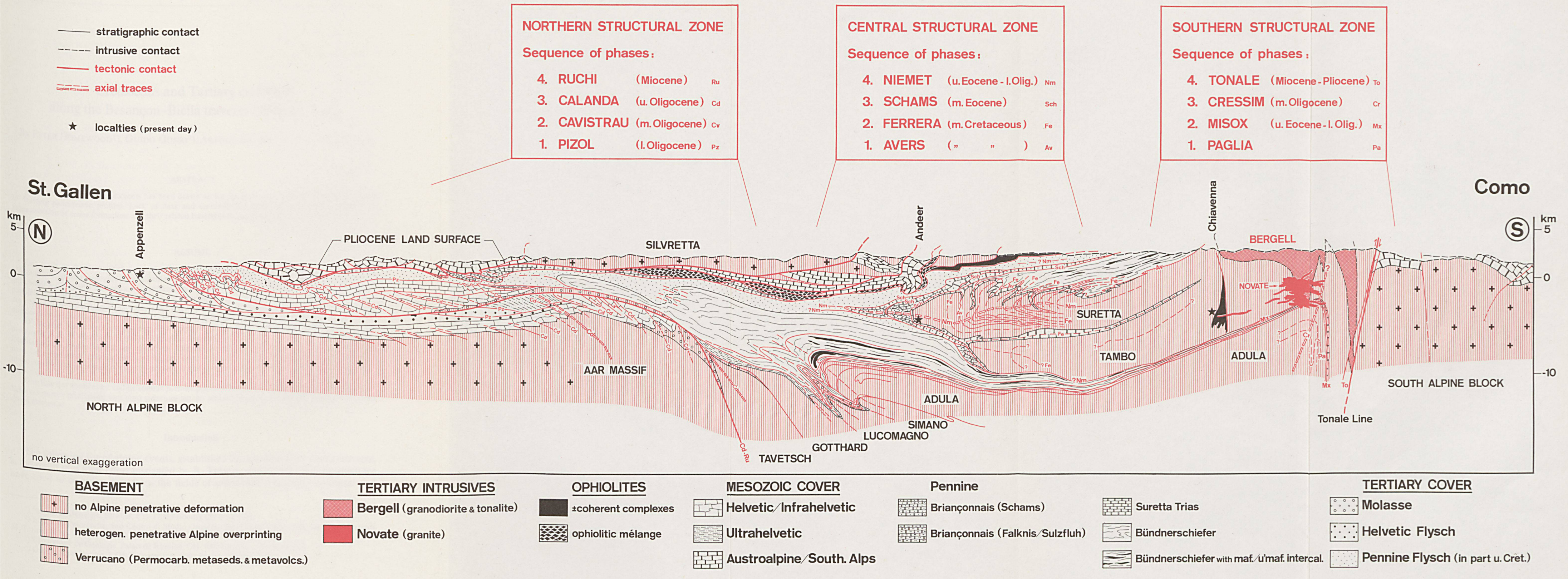
stratigraphic contact
intrusive contact
tectonic contact
axial traces
localties (present day)
NORTHERN STRUCTURAL ZONE
Sequence of phases:
4. RUCHI (Miocene) Ru
3. CALANDA (u. Oligocene) Cd
2. CAVISTRAU (m. Oligocene) Cv
1. PIZOL (l. Oligocene) Pz
CENTRAL STRUCTURAL ZONE
Sequence of phases:
4. NIEMET (u. Eocene - l. Olig.) Nm
3. SCHAMS (m. Eocene) Sch
2. FERRERA (m. Cretaceous) Fe
1. AVERS (" ") Av
SOUTHERN STRUCTURAL ZONE
Sequence of phases:
4. TONALE (Miocene - Pliocene) To
3. CRESSIM (m. Oligocene) Cr
2. MISOX (u. Eocene - l. Olig.) Mx
1. PAGLIA Pa
St. Gallen
Como
km
5
0
-10
N
S
Appenzell
PLIOCENE LAND SURFACE
SILVRETTA
Andeer
Chiavenna
BERGELL
NOVATE
SURETTA
TAMBO
ADULA
AAR MASSIF
NORTH ALPINE BLOCK
SOUTH ALPINE BLOCK
Tonale Line
SIMANO
LUCOMAGNO
GOTTHARD
TAVETSCH
Cd-Ru
no vertical exaggeration
BASEMENT
no Alpine penetrative deformation
heterogen. penetrative Alpine overprinting
Verrucano (Permocarb. metaseds. & metavolcs.)
TERTIARY INTRUSIVES
Bergell (granodiorite & tonalite)
Novate (granite)
OPHIOLITES
±coherent complexes
ophiolitic mélange
MESOZOIC COVER
Helvetic/Infrahelvetic
Ultrahelvetic
Austroalpine/South. Alps
Pennine
Briançonnais (Schams)
Briançonnais (Falknis/Sulzfluh)
Suretta Trias
Bündnerschiefer
Bündnerschiefer with maf./u'maf. intercal.
TERTIARY COVER
Molasse
Helvetic Flysch
Pennine Flysch (in part u. Cret.)