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Ultrahelvetic and North-Penninic Flysch of the Prealps: A general account[1])

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ABSTRACT

Ultrahelvetic and North-Penninic flysch formations of the Prealps (Western Alps) are reviewed in the light of recent studies. Whereas the Gurnigel Flysch is no longer considered Ultrahelvetic but of probably Upper-Penninic origin, the Niesen Flysch, diverse flysch of the North-Penninic Mélange (here defined) and the truly Ultrahelvetic Flysch of the "Zone des Cols" are briefly described. A tentative story of the Mesozoic to Early Cenozoic evolution of the domain considered is proposed to provide a framework for control of the sedimentation of these different classical sequences.

RÉSUMÉ

Sur la base de travaux récents, la nature des flyschs préalpins d'origine ultrahelvétique et nord-pennique est d'abord décrite de façon sommaire. Parmi les flyschs attribués classiquement à l'Ultrahelvétique, le Flysch du Gurnigel (Maastrichtien à Eocène moyen), à caractère nettement distinct, s'est révélé être d'une origine toute autre, éventuellement pennique supérieure. Les divers flyschs affleurant dans la Zone Submédiane (ex-Grande Fenêtre Mitoyenne) se différencient aussi très nettement de ceux, certainement ultrahelvétiques, de la Zone des Cols. Toutefois, l'état de tectonisation et de dissociation de ces séquences à faciès flysch (? Aptien-Albien, Sénonien, Paléocène, Eocène) du «Mélange nord-pennique» de la Zone Submédiane, rend illusoire une reconstitution précise de leurs bassins d'accumulation. Le Flysch du Niesen (Maastrichtien à ?Eocène) est une puissante série où les phénomènes de «mass-flow» et les turbidites très grossières montrent le caractère proximal du dépôt accumulé dans un bassin marin relativement profond. Les Flyschs ultrahelvétiques de la Zone des Cols (Eocène moyen à supérieur) témoignent de cônes de déjection sous-marins de dimensions relativement faibles, localisés le long de la bordure sud d'un bassin marin de profondeur moyenne, prolongement méridional du bassin helvétique.

Un essai de reconstitution de l'histoire mésozoïque et cénozoïque du domaine ultrahelvétique et nord-pennique permet ensuite de placer ces séquences classiques à faciès flysch dans un contexte d'évolution structurale. Les bassins sédimentaires s'individualisent au cours d'une période de distension, du Trias au Jurassique, avec indices de «rifting» précoce mais avorté dans le domaine ultrahelvétique au Trias supérieur et au Lias. Cette phase a pu s'accompagner d'un certain amincissement de la croûte dans le domaine nord-pennique, et de l'apparition d'un horst marginal («marginal basement high») séparant le bassin ultrahelvétique de la «Fosse» valaisanne. Au cours du Jurassique, un régime de cisaillement horizontal («strike-slip») a pris la relève du régime de distension dans le domaine nord-pennique, dirigeant ainsi le contrôle structural des bassins jusqu'au Crétacé supérieur. A partir de ce moment, la tectonique, surtout compressive, se manifeste dans le domaine nord-pennique où se déposent des sédiments détritiques à faciès flysch. Là, le «Mélange nord-pennique» commence à se former lors de la fermeture des bassins. Au cours du Paléocène, les forces tangentielles augmentent dans la croûte plus

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épaisse sise au nord du domaine valaisan, alors que la formation du «Mélange nord-pennique» continue. C'est à l'Eocène moyen et supérieur que le dépôt du Flysch ultrahelvétique précède immédiatement la déformation de son propre bassin sédimentaire.

ZUSAMMENFASSUNG

Aufgrund neuerer Erkenntnisse werden zuerst die präalpinen Flysche ultrahelvetischer und nordpenninischer Herkunft kurz beschrieben. Von den traditionsgemäss dem Ultrahelvetikum zugeschriebenen Flyschen hat sich der in seinem Charakter sehr typische Gurnigel-Flysch (Maastrichtien bis Mitteleozän) von ganz anderer, eventuell oberpenninischer, Herkunft erwiesen. Auch die verschiedenen Flysche der «Zone Submédiane» (ehemals «Grande Fenêtre Mitoyenne») unterscheiden sich deutlich von den sicher ultrahelvetischen Flyschen der «Zone des Cols». Jedoch machen die Tektonisierung und die Zertrennung dieser verschiedenen Flyschsequenzen (? Aptien-Albien, Senon, Paleozän, Eozän) des «Mélange nord-pennique» der «Zone Submédiane» eine genaue Erfassung ihres Sedimentationsbeckens illusorisch. In der mächtigen Folge des Niesen-Flysches beweisen «mass-flow» und sehr grobe Turbidite den proximalen Charakter einer verhältnismässig tiefmeerischen Ablagerung. Die ultrahelvetischen Flysche (Mittel- bis Obereozän) der «Zone des Cols» deuten auf relativ kleine untermeerische Schuttfächer längs dem Südrand eines mitteltiefen Beckens in der südlichen Verlängerung des helvetischen Sedimentationsraumes hin.

Weiter wird versucht, durch eine Erfassung der mesozoisch-caenozoischen Entwicklung des ultrahelvetischen und nordpenninischen Raumes diese altbekannten Flyschsequenzen in das Licht der strukturellen Evolution zu stellen. Die Sedimentationsbecken bilden sich während einer triasischen bis jurassischen Dehnungsphase aus, mit Anzeichen von frühzeitigem, jedoch abgebrochenem «rifting» im ultrahelvetischen Raum während der oberen Trias und dem Lias. Diese Phase dürfte im nordpenninischen Bereich von einer gewissen Krustenverdünnung begleitet worden sein sowie vom Auftauchen eines randlichen Horstes («marginal basement high») zwischen dem ultrahelvetischen Becken und dem Walliser Trog («Fosse» valaisanne). Im Laufe des Jura wird im nordpenninischen Raum die Dehnung von horizontaler Scherung («strike-slip») abgelöst, welche die strukturelle Entwicklung der Becken bis in die obere Kreide bestimmten. Von dieser Zeit an äussert sich hauptsächlich kompressive Tektonik im nordpenninischen Bereich, wo detritische Sedimente in Flyschfazies zur Ablagerung kommen. Mit dem Schliessen der Becken beginnt hier die Bildung der «nordpenninischen Mélange». Im Laufe des Paleozän wächst der tangentielle Druck in der dickeren, im Norden des Walliser Raumes gelegenen Kruste, während sich die «nordpenninische Mélange» weiterbildet. Im Mittel- und Obereozän endlich geht die Ablagerung des ultrahelvetischen Flysches unmittelbar der Deformation seines eigenen Sedimentationsbeckens voran.

Introduction

Recent work on Prealpine flysch (Western Alps), has led to reappraisal of the customary attribution of particular sequences to specific paleogeographic realms, especially where the Ultrahelvetic and North-Penninic are concerned.

It is the aim of this paper, therefore, to integrate the information from varying sources, and to attempt to synthesize available data in order to give a coherent picture of the Mesozoic-Early Cenozoic evolution of the North-Alpine domain, particularly with respect to flysch sedimentation.

Prealpine flysch sequences currently attributed to Ultrahelvetic or North-Penninic origin are shown on the map Figure 1.

Gurnigel Flysch: odd man out!

In spite of its representing the type sequence of Ultrahelvetic Flysch for many (see for example CROWELL 1955; TRÜMPY 1960, 1973; HSÜ & SCHLANGER 1971,

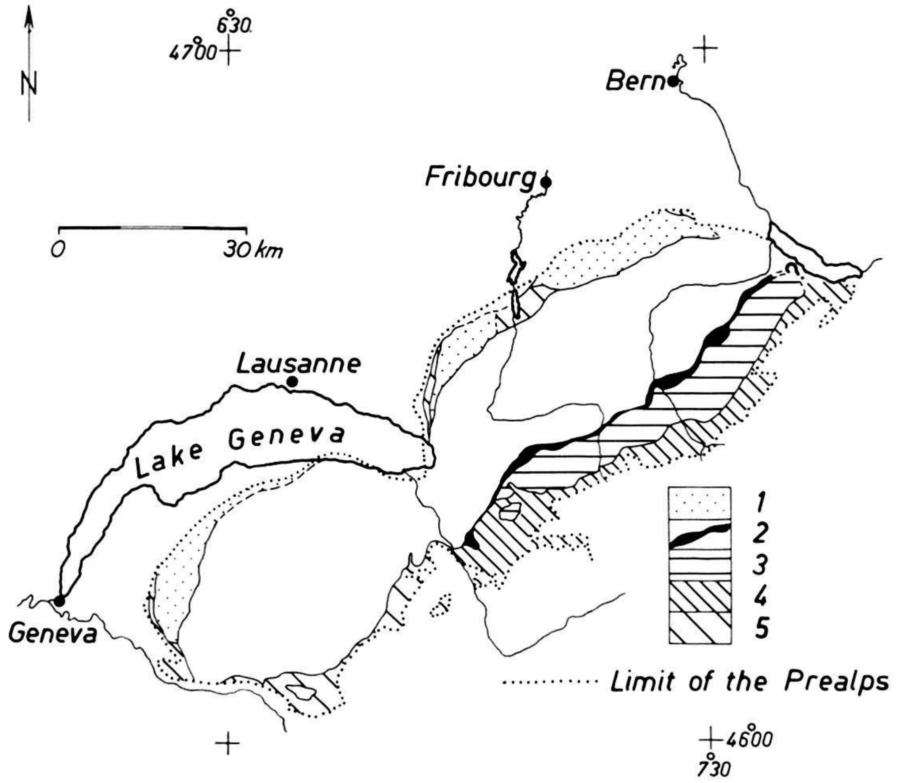

Fig. 1. Localisation of units commented by the text.
1 = Gurnigel Flysch; *2* = Zone Submédiane; *3* = Niesen nappe; *4* = nappes of the Zone des Cols; *5* = nappes of the Zone des Cols, North-Penninic Mélange and Mesozoic of the External Prealps, undifferentiated.
The other units of the Prealps (Subalpine Flysch, Préalpes Médianes nappe, Breccia nappe and Nappe Supérieure or Simme nappe s.l.) are not distinguished (blank space).

amongst others), the Gurnigel Flysch has been singled out by recent studies as a misfit among the various North-Penninic and Ultrahelvetic flysch units of the Prealps. TERCIER's (1925) premonition is thus confirmed, fifty years later.

Whether one considers composition of clastic material, time-span of sedimentation in relation to sedimentology, structural history, or general character, and particularly when one considers the sum of these criteria, the Gurnigel Flysch shows notable differences and several major incompatibilities with all other Prealpine flysch units of supposedly similar origin (see VAN STUIJVENBERG et al. 1976). This reasoning also applies to the Schlieren Flysch, which lies to the north-east of Lake Thun, and is generally admitted to be closely related to the Gurnigel Flysch.

A general review of the case has been made by CARON (1976) who, in addition to listing the sum of arguments against an Ultrahelvetic origin for this flysch nappe, concludes that in the light of present knowledge, an Ultra-Briançonnais origin is the most likely. As CARON has suggested, the greatest affinities shown by the Gurnigel Flysch are with the Sarine nappe (CARON 1972), the lowest of the units of the "Nappe Supérieure des Préalpes" (previously Simme nappe s.l.). Remarkable similarity of all sections of equal age of the Sarine nappe and the Gurnigel Flysch has so far been observed (VAN STUIJVENBERG & MOREL, pers. comm.).

The Gurnigel Flysch is not therefore taken into further consideration in this paper. A detailed account will shortly be provided by regional studies under way (MOREL, VAN STUIJVENBERG, Ph.D. theses in preparation; WEIDMANN et al., in press).

The "Zone Submédiane": a North-Penninic Mélange

The Niesen and Préalpes Médianes nappes are separated by a narrow, highly complex zone which was first recognized and described, as the Zone Submédiane, by DE RAAF (MCCONNELL & DE RAAF 1929). Subsequently interpreted as a structural window of Ultrahelvetics (their "Grande Fenêtre Mitoyenne") by LUGEON & GAGNEBIN (1941), this zone has recently been shown to consist of a mélange, partly sedimentary partly structural in fabric, of a wide variety of elements (WEIDMANN et al. 1976). It should perhaps be emphasized at once that this mélange is relatively "colourless" - "ophiolites" only occur as very rare slices or as debris in Tertiary flysch.

The term "Zone Submédiane" defines the present structural and geographic situation of the mélange, but becomes somewhat ambiguous when used with reference to the origin of its contents. The whole unit is here called the North-Penninic Mélange (i.e. of the Zone Submédiane). It includes both the slices of Niesen and Préalpes Médianes nappes, and the numerous other elements which have been observed. The latter derive from several different sedimentary environments, all of which were probably located in the North-Penninic domain (Valais and at least part of the Subbriançonnais, see WEIDMANN et al. 1976).

The stratigraphic and sedimentological data gleaned from the study of the many varied elements of the mélange is most informative:

Triassic gypsum, dolomite and sandstones; neritic and basinal Liassic facies; marine breccias and resedimented deposits with cristalline clasts from the Middle and Upper Jurassic; radiolarian cherty limestones and pelagic calpionellid limestones interbedded with resedimented deposits, red nodular pelagic limestones, and a possible primary contact between ophiolites and calpionellid limestones: Upper Jurassic-Tithonian; flysch facies dated from middle Cretaceous times; Upper Cretaceous pelagic limestones and marls of several facies, together with both limestone and clastic flysch of similar age; pelagic limestones, various types of flysch, wildflysch and olistostrome deposits apparently of Paleocene age: the latter two contain ubiquitous but rare ophiolite debris; flysch and wildflysch of various types dating from the Eocene. All these facies occur as slices, blocks etc. in a matrix of wildflysch and/or gypsum.

This chaotic zone has been interpreted as a mélange, or the superposition of several mélanges, formed during the compression of the North-Penninic realm, between Late Cretaceous and Late Eocene (WEIDMANN et al. 1976). The mechanism of mélange formation is here suggested to be analogous to the imbricate thrust model proposed by SEELY et al. 1974 (Fig. 2 of this paper), but is not necessarily ascribed to a trench located at a lithospheric subduction zone; the respective roles of purely compressive and strike-slip crustal movements are not under consideration here either (see conclusions). Subsequent to the synsedimentary mélange formation

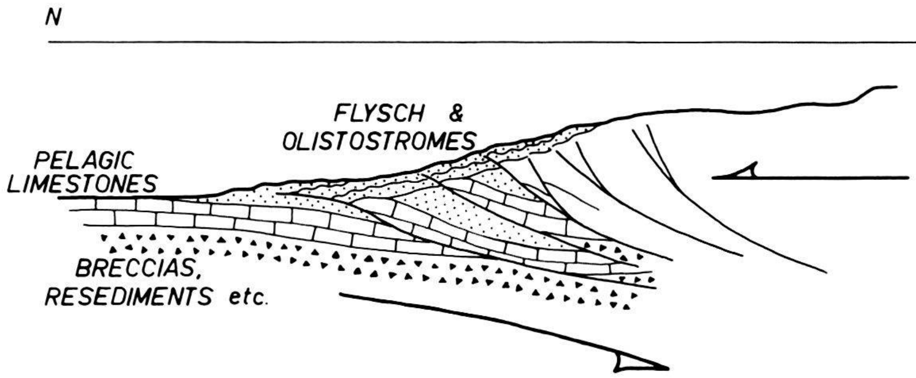

Fig. 2. Formation of the North-Penninic Mélange by imbricate thrusting (during Late Cretaceous to Late Eocene), adapted from SEELY et al. (1974). Location on Figure 6 given by arrow *1*.

large slices of the Niesen and Préalpes Médianes nappes may have been incorporated through purely structural movements.

The North-Penninic Mélange thus provides stratigraphic and structural information on an important tract of the North-Penninic realm, a tract which has disappeared as an inevitable corollary to mélange formation, leaving no other trace on the same traverse.

Little else may be said to date about the various flysch sequences, either of limestone (redeposited pelagic lime muds) or of clastic composition, as the original turbidite accumulations have been too extensively dislocated and dissociated to allow reconstruction of initial facies associations and their geometry.

Niesen Flysch: a mainly Cretaceous proximal turbidite sequence from the northern part of the Valais realm

This morphologically well-defined unit was regionally mapped and subdivided into lithostratigraphic units long before the turbidity current hypothesis came to help the unravelling of ancient turbidite basin deposits (ANDRAU 1929; BORNHAUSER 1929; DE RAAF 1934; MCCONNELL 1951). LOMBARD has since applied various sedimentological methods ("analyse stratonomique", LOMBARD 1971, and previous publications) and has also made a certain revision of the original maps, lithostratigraphic units and structural subdivisions. Nevertheless a clear picture of the sedimentation of this series will result only from a general study of depositional processes, facies associations and geometry, and a more precise bio- and lithostratigraphy than that which is available to date. (This long-term programme has been broached only in the past few years.)

Preliminary studies of this kind so far confirm the general picture of a north-west to south-east sediment influx given by LOMBARD (1971) and previous authors. The present south-western outcrops of the Chaussy-Sépey area are more proximal (extremely coarse boulder-conglomerates and coarse sandstones - probably channelized; sheet-flow boulder-conglomerates and thick coarse-grained clastic turbidites interbedded with intrabasinal lime-mud turbidites, Fig. 3), than the north-eastern outcrops, such as the more regular turbidites along the railway leading to

Niesen, south of Lake Thun. Facies associations and their geometry imply that sedimentation is at least partly of a deep-sea fan type (taken in a general sense). However the characteristics and number of individual fans involved are not yet clear. Hemipelagic intervals suggest relatively deep-water conditions, but this must yet be ascertained from more detailed analysis.

Most authors have suggested that the Niesen nappe was derived from the northern part of the Valais trough (e.g. TRÜMPY 1960; LOMBARD 1971) and this solution is supported by the comparative study of clast composition from the Niesen Flysch and those of the Ultrahelvetics (HOMEWOOD 1974).

The main part of the flysch, probably only Campanian-Maastrichtian, is overlaid by a Tertiary sequence (Middle to Upper Eocene) in at least one locality. This is on the western flank of the Simme valley, above St. Stephan (ARBENZ 1947; LOMBARD 1971). Whether or not sedimentation was continuous from Cretaceous to Middle Eocene times is so far unknown, but both continuous successions and discordant Tertiary on Upper Cretaceous sequences ascribed to similar origin (Northern Penninic or Southern Ultrahelvetic) are known elsewhere; for example the Sardona Flysch of the Glarus Alps (see WEGMANN 1961) which has an internal Ultrahelvetic origin according to RÜEFLI (1959), and the transgressive North-Penninic Prättigau Flysch of the Rhine valley section (THUM & NABHOLZ 1972).

The immaturity and variety of the clastic sediments of the Niesen Flysch, together with other sedimentological features, indicate rapid accumulation of material from a freshly eroded subaerial to shallow marine source area, suggesting simultaneous structural activity. Although sedimentation may have taken place over

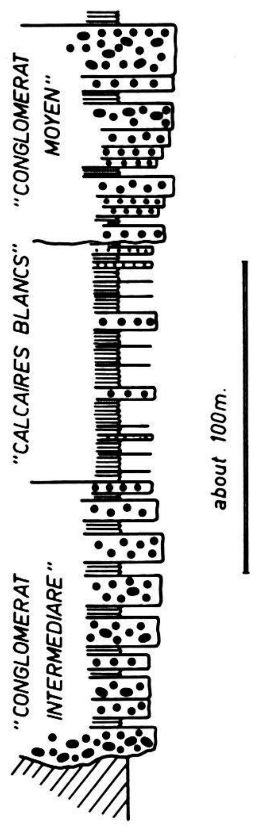

Fig. 3. Vertical profile of the more proximal part of the Niesen Flysch, Aigle-Diablerets railway, near Sépey. Boulder conglomerates and coarse sandstones are distinguished from thinner, finer grained basinal turbidites.

a longer time-span, peaks of sediment input, and therefore structural activity in the source area, apparently occurred during Maastrichtian and Middle to Late Eocene times.

Ultrahelvetic Flysch: a clastic turbidite wedge on the margin of the Helvetic miogeosyncline

The flysch units of the Zone des Cols have recently (HOMEWOOD 1976) been studied along the lines proposed by MUTTI & RICCI LUCCHI (1972) and MUTTI et al. (1975). Apart from frequent chaotic facies (wildflysch, CARON 1966), many of which date from a gravity sliding phase posterior to the Ultrahelvetic flysch sedimentation ("diverticulation", see BADOUX 1963), stratified facies and their facies associations

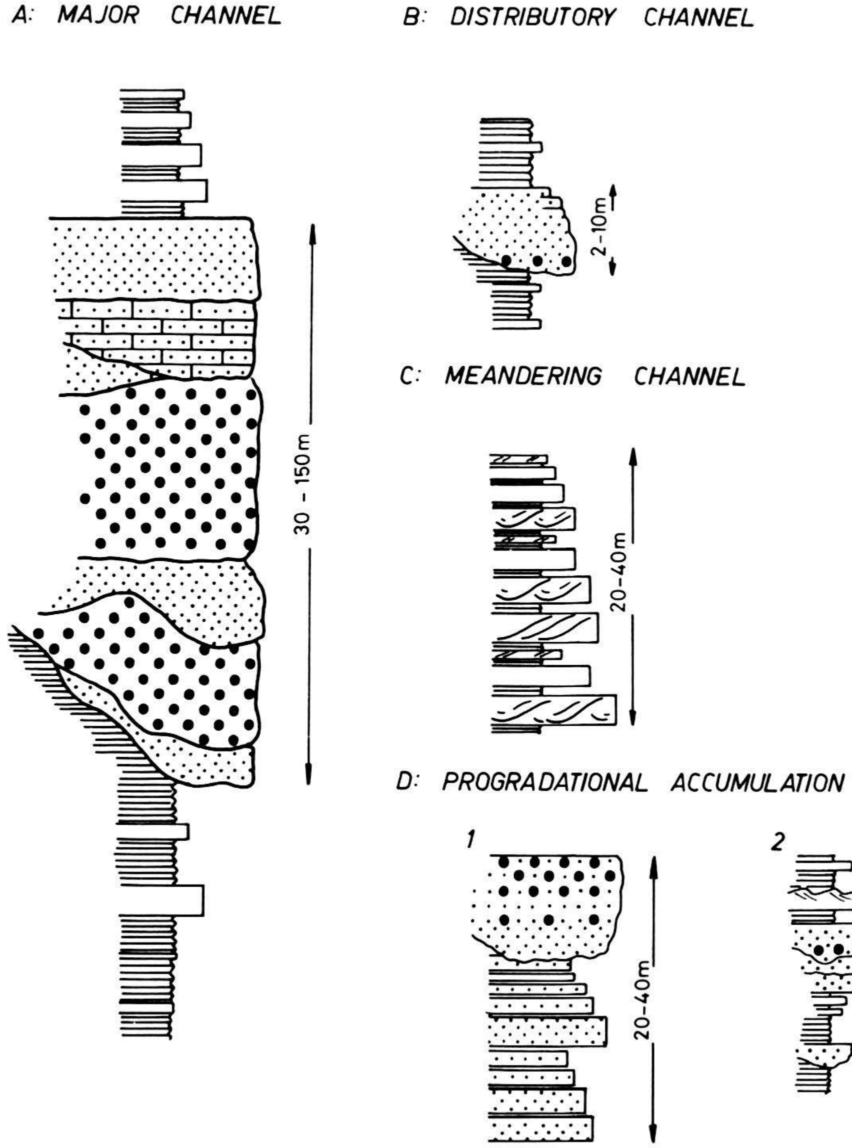

Fig. 4. Facies associations of Ultrahelvetic flysch sequences near the Rhône Valley section. A = Meilleret, near Diablerets; B = Chaux Ronde, near Barboleusaz; C = Valère, above Monthey; D_1 = Valerette, above Monthey; D_2 = Orsay, near Villars.

allow a coherent picture of flysch accumulation. Regional data permit a reasonably soundly based model of the relationship between flysch sedimentation and structural control of the basin and source area (HOMEWOOD 1976).

A number of small fans (several kilometres or tens of kilometres lateral scale and a few hundred metres maximum thickness) fed by major channels from a source area located to the south, accumulated at five- to twenty-kilometre-intervals along the basin. These fans of highly immature terrigenous clastic and shallow carbonate-shelf material, were built up over a period of some five million years during Middle to Late Eocene times. Clasts of pre-Triassic basement showing a wide variety of cristalline and metamorphic rock types (entirely similar to those of the Niesen Flysch) as well as of Mesozoic sediments of Ultrahelvetic and North-Penninic type and penecontemporaneous shallow carbonate-shelf material, form boulder-conglomerates and coarse lithic arenites which were emplaced by a wide variety of tractional, turbidity current and "mass-flow" processes (HOMEWOOD 1976).

Facies associations (Fig. 4) are indicative of major and minor distributory channels, meandering channels and of progradational "lobe" deposits of a ten- to fifty-metre-thick scale. Turbidite basin plain associations are notably absent, and most facies types are interbedded or interfingered with more or less silty Globigerina marls entirely similar to those of the Helvetic basin.

The clastic fans may therefore be assumed to have built out directly into Globigerina marls which accumulated as rapidly as the turbidite sequences, and formed the basinal deposit of the flysch. The same grey to brown Globigerina marls form the hemipelagic intervals between many of the resedimented deposits, and basin depth can therefore be estimated to have been well above Calcite Compensation Depth (Fig. 5).

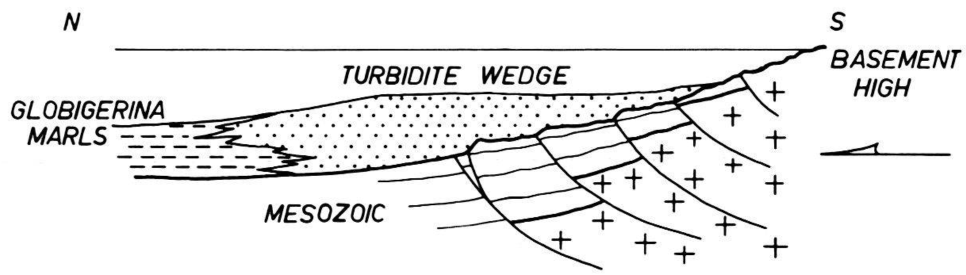

Fig. 5. Schematic section of Ultrahelvetic Flysch (Middle to Upper Eocene), showing the relationship with the Globigerina Marls and the marginal basement high. Location on Figure 6 given by arrow *2*.

Sedimentation seems to have been rapidly followed by and may well have been terminated by large scale gravity sliding, at least in the southern, proximal part of the basin (HOMEWOOD 1974); this indicates a northward progression or increase, as from Late Eocene times, of the compressive regime which controlled the flysch source area and basin during sedimentation.

The paleogeographical boundary between the Helvetic and Valais realms: a marginal basement high?

Study of the structural units from the northern part of the Valais realm, or simultaneous study of those from the Valais together with the Ultrahelvetic slices, both in the Swiss and the French Alps, has almost invariably led to the suggestion of the presence of a basement high separating the two domains (see for example LEUPOLD 1933; NÄNNY 1948; ALLEMANN 1957; RÜEFLI 1959; ANTOINE 1971; HOMEWOOD 1974). LOMBARD (1971, p. 153) refutes this as he considers the Gurnigel Flysch representative of the Ultrahelvetics.

This important morphological and structural feature exerted a strong control on flysch sediments of Late Cretaceous and Tertiary age. It appears to have been in existence during the Middle Jurassic to Lower Cretaceous period because the pre-flysch facies of the Niesen nappe and of the more southerly of the Ultrahelvetic slices show a strong terrigenous influence. Abundant clasts of cristalline composition are frequent and features indicating fairly shallow marine conditions occur (HUBER 1933; LUGEON 1938; BADOUX 1945; HOMEWOOD 1974; BADOUX 1975; BADOUX & HOMEWOOD, in prep.).

Mesozoic facies of the Ultrahelvetic basin, mainly ammonite-bearing marls and limestones are indicative of open marine conditions and moderately deep water, above Aragonite Compensation Depth; ante-flysch Upper Jurassic and Upper Cretaceous flysch facies from the Valais trough (at least in the North-Penninic Mélange and the Niesen nappe) do however suggest relatively greater depths, occasionally attaining Calcite Compensation Depth.

One is thus led to imagine a horst-like feature, with pre-Triassic basement rocks reaching the surface at places, separating the Helvetic shelf and moderately deep Ultrahelvetic basin to the north, from a much deeper realm, the Valais trough, to the south.

This feature is to a certain extent comparable with the marginal basement highs revealed by recent oceanographic studies (e.g. BURK 1968; RABINOWITZ 1974), both in dimensions, and in structural context, limiting a marginal shelf and basin from a deeper, more oceanic realm.

One should obviously beware of taking the analogy too far. The ophiolites of the Valais trough are not, according to most authors, remnants of an oceanic crust at least in so far as the more westerly occurrences are concerned (for instance: LOUBAT 1968; ANTOINE 1971; ANTOINE et al. 1973). In fact these rocks would not qualify as fully developed ophiolites according to the Penrose field conference definition ("Conférence Participants" 1972), as in the Valais several types are missing from the "ideal" sequence. However, when taken into consideration together with other evidence for Mesozoic evolution of this domain, they do suggest intrusion of mafic rocks, presumably derived from the upper mantle, into and through a considerably thinned continental crust (TRÜMPY 1971; ANTOINE et al. 1973), or possibly a crust of some intermediate type (TRÜMPY 1971).

Where the flysch sediments of the Prealps are concerned, the marginal basement high was the source area for the Niesen Flysch in the Valais realm, as well as for the Ultrahelvetic Flysch of the Zone des Cols. This is witnessed by the high degree of similarity of clast composition in the two sequences, equally for cristalline, metamorphic, and sedimentary clasts (HOMEWOOD 1974).

Conclusion: a general review of Mesozoic - Early Cenozoic evolution of the Ultrahelvetic - North-Penninic domain

There is fairly general agreement on Mesozoic evolution of the Western Alps (e.g. TRÜMPY 1973, 1975; LEMOINE 1975) at least as far as the sedimentary basins are concerned, but wide disagreement on the interpretation of field evidence as regards microplate - plate - global scale tectonics (e.g. DEWEY et al. 1973 versus LAUBSCHER & BERNOULLI 1976). It may therefore be of interest to try to fit the various North-Penninic and Ultrahelvetic flysch sequences treated above into a regional framework of Mesozoic and Early Cenozoic evolution (Fig. 6).

Early Mesozoic rifting might well be testified by the Middle to Upper Triassic breccias of the Moûtiers unit of the North-Penninic Tarentaise zone, French Alps (see FUDRAL 1973; ANTOINE et al. 1973) and by the Upper Triassic to Lower Liassic spilitic volcanism of the Dauphiné (BARBIER & DEBELMAS 1966; ANTOINE et al. 1973; VATIN-PÉRIGNON et al. 1974). In connection with this it may be of interest to note the Ultrahelvetic location of the Upper Triassic rock-salt deposits of the Prealpine traverse[3]).

The Jurassic period was characterized by a certain amount of stretching and crustal thinning, which may be deduced from the deeper basinal facies occurring in many places (TRÜMPY 1971). In the case of the North-Penninic units of the Prealps this tendency is particularly well illustrated by the deep-marine resedimented deposits of the North-Penninic Mélange. Compressional movements are however also suggested in the Valais trough during the Middle Jurassic, both in the French Alps (ANTOINE et al. 1972) and in the Prealps by the Jurassic "flysch" of the Niesen nappe (LUGEON 1938; BADOUX & HOMEWOOD, in prep.). Ophiolites may have appeared in the North-Penninic realm during Upper Jurassic times (WEIDMANN et al. 1976), more certainly so during the Early Cretaceous (ANTOINE 1971).

Whereas the Helvetic-Ultrahelvetic shelf and marginal basin continued to accumulate mainly marine carbonates and marls throughout the Cretaceous, the Valais trough, now separated from the former by a marginal basement high, received both flysch and pelagic limestones. The flysch facies, occurring as from late Early Cretaceous times, may be interpreted as indicative of a compressional regime, if but of a local extent.

As already stated, ophiolites, or at least basic to ultrabasic intrusives and extrusives, occur in the Valais trough during the Lower Cretaceous, but lack associated radiolarites or other typical "oceanic" facies (LEMOINE 1971); sediments interstratified with the mafic rocks are of flysch type (ANTOINE 1971; LOUBAT 1968).

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[3]) After the final draughting of this paper, A. Baud kindly showed me the unpublished palinspastic sections for the Trias of the Western Alps drawn by J. Mégard-Galli and himself. The Upper Triassic section proposed here, developed simultaneously to theirs but along different lines, is in general agreement with their interpretation.

Thus there is evidence for both extension and compression, which may have been simultaneous, together with ophiolite intrusion, during the Upper Jurassic and Lower Cretaceous. This may well give a clue as to the general structural control of the North-Penninic domain during this time. Pull apart basins together with tipped fault wedges and zones of simultaneous compressive deformation are typical of anastomosed strike-slip fault zones (see CROWELL 1974*a*, 1974*b*). In the case of the North-Penninic domain, if dimensions may be accepted as analogous to actual structural features, a similar model may suggest a transform fault zone.

Lateral movements of considerable importance may be deduced for Alpine basins from consideration of the history of the North Atlantic Ocean (see for instance DEWEY et al. 1973; DEBELMAS 1975; TRÜMPY 1976; LAUBSCHER & BERNOULLI 1976; BOURBON et al. 1976) and as far as timing is concerned, a North-Penninic location of some of these lateral movements is not incompatible with available evidence (cf. LAUBSCHER 1975).

Normal marine facies continued to accumulate on the marginal shelf and basin during Latest Cretaceous times, while pelagic limestones, flysch and mélange formed in the North-Penninic. The variety of facies and number of sedimentary and structural events shown by the North-Penninic Mélange suggest a fairly continuous compressive regime in this domain from Late Cretaceous to Eocene times. Apparently, therefore, the preceding dominantly lateral movements gave way to a convergent type of structural control, effectively closing a part of the North-Penninic realm (this would fit in with the views of THUM & NABHOLZ 1972, after STAUB 1937). This phase might correspond to a crustal subduction (TRÜMPY 1975; for instance his uncommented "S_1 ?", p. 124).

Sedimentation of the Niesen Flysch mainly occurs during this phase, while the marginal basement high, emerged, protected most of the marginal shelf and basin from the compressive regime reigning further south.

TRÜMPY'S "Paleocene restoration" (1973) is well marked in the flysch sequences fed from the marginal basement high, but apparently not so well in the mélange, which exhibits olistostrome deposits and flysch which are fairly well dated from Paleocene times. This might well indicate build-up of tangential stress in the marginal basement high once much of the thinner North-Penninic crust had been subducted during the various stages of mélange formation.

The Middle to Upper Eocene Ultrahelvetic Flysch pinpoints the moment when the compressive regime attained the marginal basin, and clastic flysch built out northwards into the Helvetic Globigerina marls as a turbidite wedge from the marginal basement high. This phase culminated in the northward diverticulation of the Ultrahelvetic series as gravity slides and olistostromes. The accumulation of the latter forms an important part of the wildflysch of the Helvetic domain (HOMEWOOD 1976).

Subsequent history of the North-Penninic and Ultrahelvetic basins and their contents relies on other records than their own flysch sediments and is beyond the scope of this review.

To sum up this tentative overall picture, Middle Triassic to Lower Jurassic rifting was followed by widening of the North-Penninic to Helvetic domain, accompanied

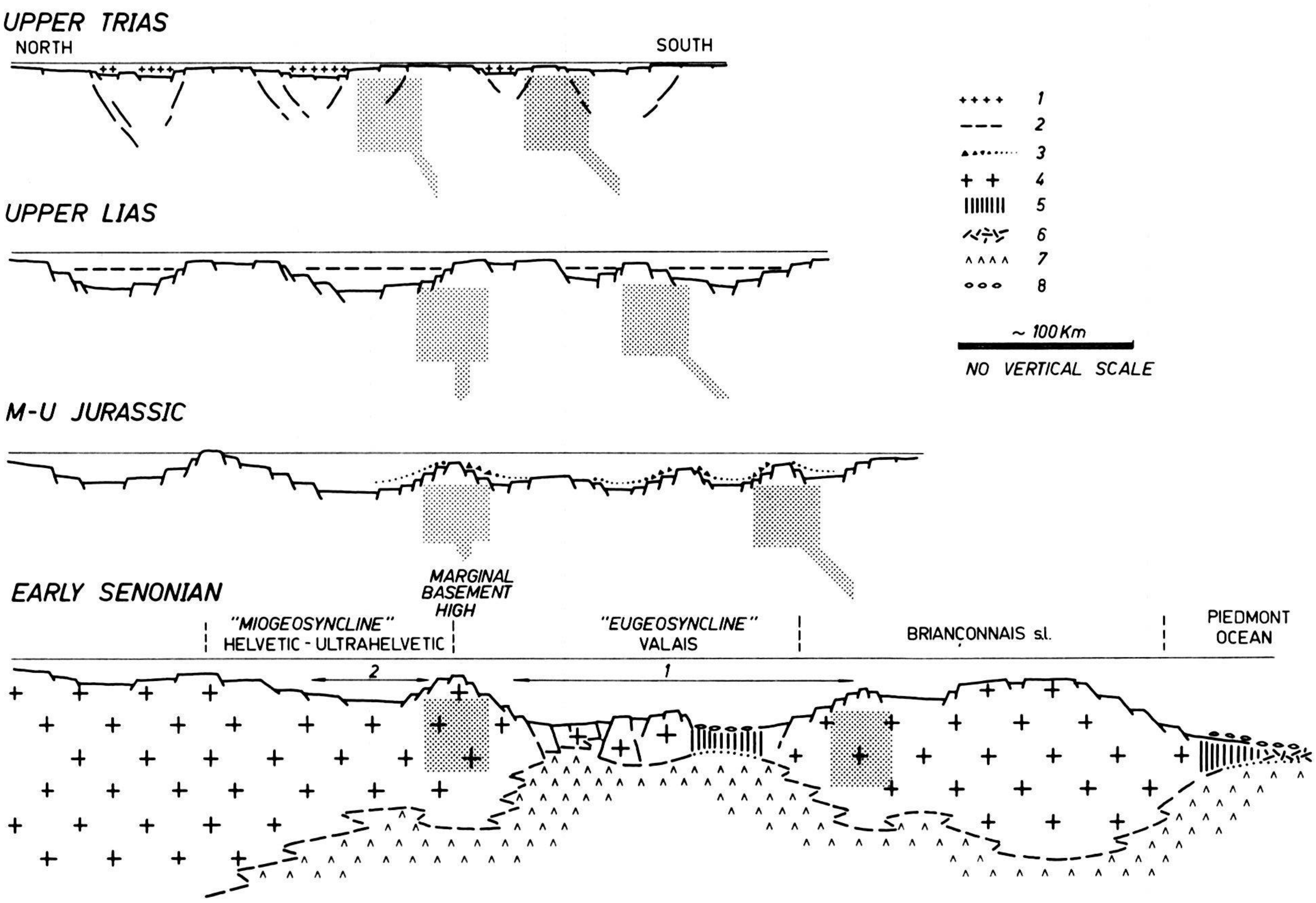

Fig. 6. Schematic representation of successive stages of the Mesozoic evolution of the North-Penninic and Ultrahelvetic domains. Early rifting (stippled zones) followed by strike slip movement more or less perpendicular to the sections, led to widening of the initial area (mainly between the early rifting zones) and individualization of the later flysch basins (Fig. 2 and 5).

Sequence of insignia: *1* = evaporites with rock-salt; *2* = basinal facies; *3* = marine breccias and resedimented deposits; *4* = continental crust; *5* = intermediate crust; *6* = oceanic crust; *7* = upper mantel; *8* = ophiolites.

by a certain amount of crustal thinning (genuine oceanic environments on this traverse only appeared much further south in the Piedmont-Ligurian realm, see for instance LEMOINE 1971). By Late Jurassic times extension had resulted in individualization of a marginal shelf and basin (Helvetic-Ultrahelvetic) separated from a more southerly deep-marine realm, the Valais trough, by a marginal basement high. Strike-slip structural control began during Jurassic times and then governed the North-Penninic basins, probably intermittently, until a generally compressive phase set in during the Uppermost Cretaceous. Compression controlled the North-Penninic domain from that time, but only affected the Ultrahelvetic marginal basin during Middle to Upper Eocene.

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