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Thrust tectonics and cover-basement relations on the northern margin of the Pelvoux massif, French Alps

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ABSTRACT

In the area around La Grave, Hautes Alpes, France, the thrusts affecting the Jurassic sedimentary succession that constitute the Ultradauphinois zone meet the northern margin of the Pelvoux massif of pre-Triassic crystalline basement. The geometry of both cover and basement structures, and their relation, are examined. It is suggested that two major basement thrusts, emplacing the Combeynot and La Meije parts of the Pelvoux massif from northeast to southwest, undergo lateral climb up through basement until they reach the cover where they turn back into incompetent horizons to form cover thrusts. The two important structural elements forming the northern margin of the massif in this area are thus like the basement scoops of ELLIOTT & JOHNSON (1980). An estimate of 35 km displacement on the La Meije thrust, from the known offset of the unconformity, is broadly consistent with a previous estimate of cover shortening from simple restoration of a cross section. The Pelvoux massif is a tectonic culmination resulting from the stacking of basement thrust scoops during the main phase of Alpine deformation.

RÉSUMÉ

Dans la région de la Grave, Hautes Alpes, France, les chevauchements déformant la série sédimentaire jurassique qui constituent la zone ultradauphinoise, rencontrent le bord septentrional du massif du Pelvoux qui est un socle cristallin pré-triasique. La géométrie des structures du socle et de la couverture et leur relation sont examinées. Il est proposé que deux chevauchements majeurs de socle, qui déplacent les parties «Combeynot» et «La Meije» du massif du Pelvoux du nord-est au sud-ouest, subissent une montée latérale dans le socle jusqu'à la couverture, où ils se coupondent avec des horizons incompétents et forment les chevauchements de la couverture. Les deux éléments structuraux importants qui forment le bord septentrional du massif dans cette région sont semblables aux écopes du socle d'ELLIOTT & JOHNSON (1980). Une évaluation du déplacement de 35 km sur le chevauchement de la Meije, calculée par le désaxé de la discordance triasique est en gros compatible avec une évaluation antérieure du raccourcissement de la couverture par le rétablissement d'un profil. Le massif du Pelvoux est une culmination tectonique résultant de l'entassement des écopes des chevauchements du socle pendant la phase principale de la déformation alpine.

Introduction

In many parts of the external French Alps, sedimentary successions of the Triassic, Jurassic and Cretaceous rest unconformably on older basement rocks of the

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massifs of Mt. Blanc, Aiguilles Rouges, Belledone, Grandes Rousses and Pelvoux (RAMSAY 1963), and form the Dauphinois zone (DEBELMAS & LEMOINE 1970, RAMSAY 1963). The more internal part of this zone is a variably thrust sequence of the same Mesozoic successions, and is termed the Ultradauphinois zone. Such a thrust zone can readily be traced from the southern end of the Mt. Blanc massif to the northern margin of the Pelvoux massif. North of the former the Mesozoic cover rocks form the large Helvetic nappes, whilst south of the latter massif the zone is not recognized. The internal (i. e. upper) boundary of the Ultradauphinois zone is clearly defined by the basal surfaces of the overthrust sheets of the internal nappes (Sub-Briançonnais and Briançonnais zones). The external boundary of the zone is more difficult to define since no clearly recognized thrust front in the cover exists. The main key to a real understanding of the tectonics of the Ultradauphinois zone is an appreciation of the relationships between cover and basement around the various external massifs listed above. The classic Chamonix syncline is gradually being recognized as a major basement overthrust zone (AYRTON 1980), whilst TRÜMPY (1973) has invoked basement overthrusting in the Helvetic zone. The geophysical sections of HSÜ (1979) show the latter more clearly, whilst similar work in the French Alps (MÉNARD 1979) suggests considerable thrusting in the external massifs here also.

The area described is one where a thrust tectonic interpretation leads to a much clearer understanding of basement-cover relations than apparently existed before. The study area is centered on the village of La Grave on the road from Grenoble to Briançon (Fig. 1), just where the thrusts in the cover sequence abut against the northern edge of the Pelvoux massif (locally, La Meije massif). The area is covered by a recent 1:50,000 geological sheet (B.R.G.M., sheet No. 798, 1976) based largely on the work of Barbier and co-workers (see for example BARBIER 1948, 1963) during the period from 1948 onwards. The map is essentially stratigraphic with very little in the way of structural data or interpretation.

The approach used here benefits from and is based upon recent developments in the understanding of thrust geometry following extensive work in the Canadian Rockies (BALLY et al. 1966, DAHLSTROM 1970) and applications elsewhere (ELLIOTT & JOHNSON 1980). The "rules" of thrust geometry established by these authors provide an invaluable way of approaching thrust zones. Thrusts climb stratigraphic section from décollement levels established in more ductile stratigraphic horizons, carrying older rocks onto younger. The direction of climb of a thrust is in the direction of movement of the overthrust block. Thrusts are thus mapped by recognition of stratigraphic duplication and a thrust is terminated on a map where stratigraphic separation is lost across the thrust between rocks in the hanging wall and the footwall (see ELLIOT & JOHNSON 1980). Where a thrust climbs section to form a ramp, imbrication of either the footwall or the hanging wall may lead to isolation of small thrust blocks which are carried along a main thrust and remain as "horses" decorating such a thrust (ELLIOTT & JOHNSON 1980). In addition to climbing section in the direction of movement, a thrust may also climb sideways along its length, forming a scoop from which the overthrust block is removed. These simple geometries may interact in many ways to give quite complex thrust zones.

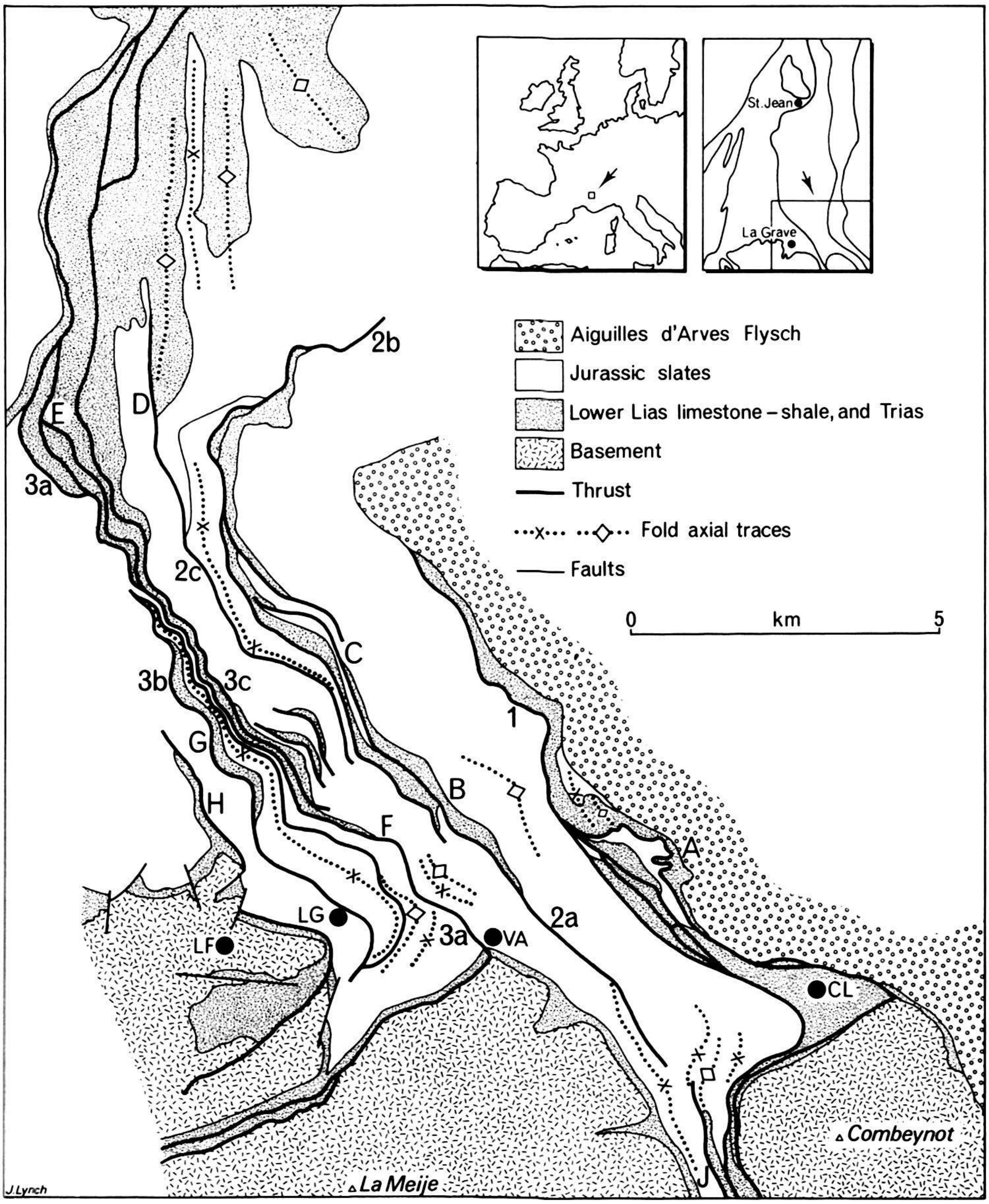

Fig. 1. The area around La Grave, Hautes Alpes, France, showing the main thrusts in relation to the northern margin of the Pelvoux massif. Numbers 1, 2, 3 identify thrusts discussed in the text and letters A-J denote localities referred to in the text. Place names are: LG = La Grave, VA = Villar d'Arêne, CL = Col du Lautaret.

Stratigraphy and cover thrusts

The stratigraphy in the area under discussion is described by BARBIER (1948) and RAMSAY (1963). In summary, a thin, largely dolomitic Triassic sequence rests unconformably on crystalline basement, followed by a thin, calcareous lower Lias facies. The rest of the sequence is of calcareous and argillaceous shales, possibly reaching middle Jurassic. No Cretaceous rocks are present. Tertiary (Eocene) conglomerate and flysch rest unconformably across the Mesozoic and the basement.

In the autochthonous sequence, the principal décollement level is located at the transition from the Trias to the Lias. Thrusts climbing from this level form the principal structures in the Ultradauphinois zone north of La Grave (Fig. 1), and can only be recognized where the distinctive lower Lias calcareous facies is present in the overthrust block. Numerous slices and blocks of Triassic dolomite and cargneule decorate these thrusts and are interpreted to have originated as footwall imbricates. Where the thrusts pass up into Jurassic shales, it is usually not possible to recognize stratigraphic duplication. All the structures dip to the northeast and thrust movement was from northeast to southwest (see BEACH 1980).

Three principal groups of thrusts are recognized in the cover and shown on Figure 1. The uppermost (most easterly, labeled 1 in Fig. 1), termed the Lautaret thrust, passes up into the base of the Eocene succession at its northwestern end. This is another major décollement level and forms the upper bounding surface to the thrusts in the Jurassic rocks, no thrust being seen to climb above this level and duplicate Jurassic on Eocene strata. Thus while the latter were originally deposited unconformably on the former, the unconformity has undergone considerable movement. It is this relation that erroneously led BARBIER (1963) and DEBELMAS (1970) to interpret the thrusts in the Jurassic rocks as being pre-Eocene in age. It is quite clear from an examination of the fabrics and state of strain that both sets of rocks underwent their main deformation together during the phase of thrusting.

The Lautaret thrust has several associated imbricate slices of lower Lias below the Col de Côte Plaine (locality A on Fig. 1). Similarly, the middle group of thrusts (labelled 2 on Fig. 1, and termed the Valfroide thrusts) is not a single surface, but consists of two main thrusts with subsidiary imbricates. The two main thrusts (2a and 2b on Fig. 1) overlap such that as the displacement on one decreases, it is taken over by the other, in the manner described by PRICE (1973). Thrust 2a hat its maximum displacement near Valfroide (locality B on Fig. 1), climbing out of the lower Lias to both the northwest and southeast of here. Further southeast, stratigraphic separation is lost and it is difficult to trace the thrust through this poorly exposed ground. To the northeast it joins with thrust 2b close to the latter's area of maximum displacement in the Martignare valley (locality C on Fig. 1). Thrust 2b is terminated at its northern end on Figure 1 where stratigraphic separation is lost.

Just beneath this is a third thrust (2c on Fig. 1) that is a southerly development out of the steep to overturned limb of an anticlinal fold. Maximum stratigraphic separation is seen at point D on Figure 1, and from here the thrust starts to climb in a southeastern direction until it is lost south of locality C (Fig. 1).

The third group of thrusts is more extensive and complex than the previous two. North of Pic du Mas de la Grave (locality E on Fig. 1) stratigraphic separation is small and the thrusts are marked by fairly continuous strips of Trias thrust on lower Lias. One thrust (marked 3a on Fig. 1, and termed the Les Hières thrust) can be followed southeast from this point to Les Hières (locality F on Fig. 1) where it starts to climb out of the lower Lias. Below this lies the Rivet thrust (3b on Fig. 1) which has maximum displacement at locality G (Fig. 1). In the well exposed Martignare valley (running from locality H to C) this thrust is seen to be overturned in a large synformal fold beneath the Les Hières thrust (3a), this fold closing both to the northwest and the southeast, so that the Rivet thrust maps out as a closed loop (Fig. 1). The Les Hières thrust (3a) in fact is cutting out of the complementary antiform above this synform, and the age relation is that thrust 3a is folding 3b and is thus later. Thrust 3b presumably reappears over the antiform, above 3a, but since the exact geometry of the folds and the displacement on the Les Hières thrust (3a) are not known, it is impossible to be certain of its location. If it reappears as thrust 3c (Fig. 1), the displacement on 3a must be rather small; if, as suggested below, the displacement on 3a is quite large, then folded thrust 3b may correspond to one of the group 2 thrusts.

It is clear that the Les Hières thrust 3a is the most continuous structure in the area depicted on Figure 1, and indeed to the north it becomes the only thrust, forming the base of a large thrust sheet that lacks the complex deformation and imbrication seen in the La Grave area (see Beach, in press). The relationship, discussed above, between thrusts 3a and 3b, leads into a consideration of the basement-cover relations, which has so far been avoided.

Basement-cover relations

Three areas of crystalline basement are shown on Figure 1: Les Fréaux, La Meije and Combeynot. Cover rocks rest unconformably on the former and on the northeast margins only of the latter two. Between the Combeynot and the La Meije massifs lies the upper Romanche valley (locality J on Fig. 1) and running southeast from here for some distance is a thrust emplacing the Combeynot massif over the La Meije massif and its cover (cf. Beach, in press). This thrust dips to the northeast with overturned Triassic cover beneath it. The northwestern corner of the massif (Fig. 1) is formed by this thrust, in plan, turning through 90° and then running in a northeast direction until it meets the Triassic unconformity close to the Col du Lautaret (Fig. 1). Barbier (1963) found this geometry difficult to explain and invoked two phases of faulting and movement, again appealing to a "pre-Nummulitique" timing for part of the deformation. This does not adequately explain the continuity of structures and rock units around the northwestern corner of the massif, nor the point at the northeastern corner where overturned strata beneath basement along the northwestern edge become vertical and meet normal strata resting unconformably along the northeastern edge (Fig. 1).

The interpretation proposed here is that the Combeynot massif is in overthrust relation with the La Meije massif, the thrust trending southeast along the upper Romanche valley. The turn round to a northeast strike represents the lateral climb of this thrust up through basement to form one end of a scoop structure. On reaching the basement-cover contact, the thrust bends sharply back into a stratigraphic décollement horizon. This geometry is most clearly illustrated in a schematic longitudinal (i.e. NW–SE) section (Fig. 2) from the Col du Côte Plaine (A on Fig. 1) southeast to Combeynot.

One feature which complicates the geometry when reconstructing the thrust movements is the nature of the unconformity at the base of the Eocene succession. To the north of the area shown on Figure 1, this rests on upper Jurassic rocks, whilst along the northeast margin of Combeynot, Eocene rocks rest across the basal Trias sandstone and dolomite and the basement itself; indeed, the basal Eocene is largely a breccia-conglomerate of locally recognizable basement fragments. On formation of a basement scoop, the basement thrust block moved towards the southwest and a décollement horizon developed northwards from the point at which the basement scoop thrust met the unconformity (i.e. on reaching incompetent horizons). Décollement occurred within a thickness of shales close to the base of the Eocene succession, and while the basal breccias southeast of Lautaret (Fig. 1) are little deformed, northwest from here they occur as isolated lenses of very deformed material within strongly deformed shales underlying strongly deformed sandstones. It is inferred that considerable displacement occurred at this décollement horizon, though it is not seen to develop into a climbing thrust.

As the basement scoop was thrust towards the southwest, an increasing thickness of Mesozoic (Triassic and Jurassic) is preserved beneath the Eocene unconformity on the northwestern side of the scoop thrust. As and when possible, it is likely that décollement and displacement was transferred to horizons beneath the Eocene in the Mesozoic rocks. First of all, Triassic and lower Liassic rocks would be present beneath the unconformity. Successive imbrication of this sequence beneath the basal Eocene décollement level would give rise to the present distribution of thrust

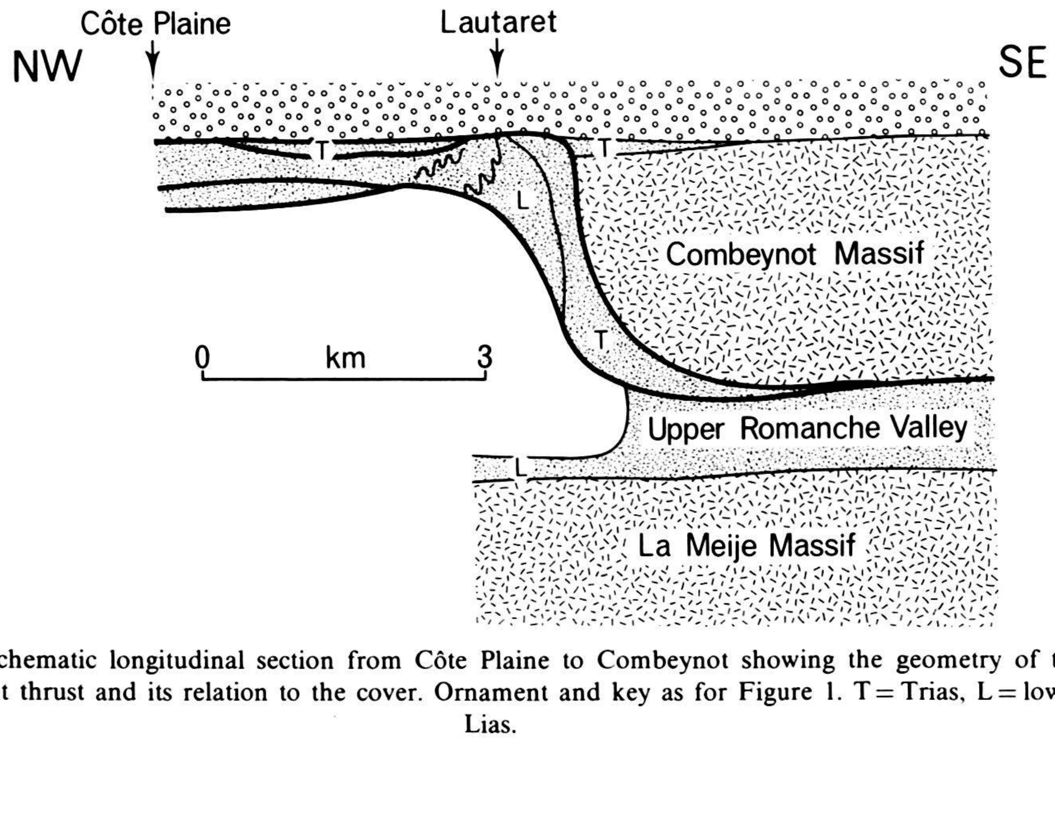

Fig. 2. Schematic longitudinal section from Côte Plaine to Combeynot showing the geometry of the basement thrust and its relation to the cover. Ornament and key as for Figure 1. T = Trias, L = lower Lias.

sheets on this region. Thus first of all isolated lenses of basal breccia were formed, and these are now found decorating the base of the main décollement from Lautaret to Côte Plaine and northwestwards. Immediately below this is a thrust sheet containing part of the upper Triassic sequence of dolomitic rocks, and including a basaltic lava, and below this again, several thrust sheets of predominantly lower Lias facies with sheets and lenses of Trias decorating their bases. This is the group of thrusts marked 1 on Figure 1, the lowermost resting on middle Jurassic rocks for most of its length. Accepting the proposition that thrust develop in "piggy-back" fashion (see ELLIOTT & JOHNSON 1980), it is probable that the cover thrusts of group 2 developed next, effecting a transfer of displacement from the décollement at the base of the Eocene succession (and its associated thrusts) to a main Trias-Lias décollement horizon. This is interpreted to be a consequence of the increasing deformation and displacement in the narrow zone where the Combeynot was overthrusting the La Meije massif, the décollement at the base of the Eocene probably becoming more or less dormant at this stage.

The structure forming the northwestern edge of the La Meije massif will now be examined. Near the southwestern corner of Figure 1 this structure disappears beneath the glaciers of le Rateau and la Girose. However, along the segment shown on Figure 1, overturned Trias and lower Lias dips to the southeast at 45° beneath basement, immediately south of La Grave; to the northeast, this structure gradually steepens until it is vertical, and then it meets the Triassic unconformity nearly at right angles close to the village of Villar d'Arêne (Fig. 1). No structure is seen northeast of here. BARTOLI et al. (1974) connect this fault as part of a thrust running to the west through much of the Pelvoux massif, though they do not include an interpretation of the cover-basement relations at Villar d'Arêne. They do record that the part shown on Figure 1 here had a largely subhorizontal dextral displacement.

It is proposed that the northwestern margin of the La Meije massif, like that of the Combeynot, is formed by the lateral climb of a basement thrust with an approximate NE-SW direction of movement, thus forming the end of another basement scoop. This is seen as the most plausible interpretation of two geometrically similar structures, of the continuity of structures between basement and cover, and of the relation between basement thrust and unconformity. The La Meije thrust block is considerably larger than the Combeynot block. About 16 km southwest from Villar d'Arêne, the scoop part of the thrust turns southeast through the Pelvoux basement. The dip of the unconformity along the northeastern edge of the massif varies from 30 to 40°, and whilst the dip of the basal thrust is not known, a thrust block thickness of 8-10 km of basement is quite probable.

At Villar d'Arêne, the lateral climb of the basement thrust turns abruptly into the cover on meeting an incompetent horizon, in much the same way as the structure at Lautaret, and passes to the northwest as the Les Hières thrust (3a on Fig 1). The sequence of development is similar to that already illustrated in Figure 2, and the description is not repeated. Following an orderly sequence of thrust development and piggy-back stacking, this basement-cover cover thrust is inferred to develop below and subsequently to the Combeynot thrust and its associated cover structures of groups 1 and 2 (Fig. 1). The Les Hières thrust, as discussed earlier is interpreted to fold the Rivet thrust (3b on Fig. 1), which may be tentatively related to a preexisting group 2 thrust in the cover. The Les Hières thrust, also has its own associated imbricate slices. The magnitude of the basement thrust block, and the continuity northwards of the cover thrusts, suggests that this is a structure of considerable displacement.

There is no sound way of calculating the displacement but taking a very simple model of a constant movement direction along the basement scoop thrust, the offset of the unconformity either side of it, that is between southeast of Villar d'Arêne and south of Les Fréaux (Fig. 1), may provide an estimate. The minimum dip of the unconformity southeast of Villar, observed in the upper Romanche valley, and necessary to clear all the peaks leading up to La Meije, where no cover outcrops, is 30°; the trace of this surface on the vertical fault at Villar therefore pitches 30° northeast. The unconformity also dips at about 30° in the area south of Les Fréaux, i.e. on the north side of the fault, and the inferred movement direction in the fault (slickensides) pitches at 40° northeast. A variation in pitch of the latter from 40° to 60° would give rise to a variation in the estimated displacement from 35 km to 10 km respectively, to account for the observed offset of the unconformity. The former is proposed as an order of magnitude estimate for the displacement of this basement fault, a displacement transmitted to the cover on the Les Hières and associated thrusts.

By way of comparison, a simple restoration (see HOSSACK 1979) of a cross section of the cover thrust sequence between point H on Figure 1 and the base of the Eocene succession, provided an estimate of the shortening in the cover of 70 km (BEACH, in press). It is now suggested that this shortening is matched in the basement by movement on two principal thrusts which emplace the Combeynot and the La Meije massifs to form part of the much larger Pelvoux massif. A third, very minor, basement fault of similar geometry is seen near Les Fréaux (Fig. 1) but is insignificant in terms of its displacement (which, in any case, is included in the estimate above).

Conclusion

An interpretation of thrust geometry has been presented that relates basement and cover structures in one main phase of thrusting, following the methods outlined in, for example, ELLIOTT & JOHNSON (1980). The geometry of the structures shown on Figure 1 is reasonably explained by major basement thrusts climbing laterally into the cover rocks during a displacement from northeast to southwest. It is no longer necessary to assign part of the tectonic evolution of these structures to a "pre-Nummulitique" phase of Alpine deformation as was preferred by BARBIER (1963) and suggested by BARTOLI et al. (1974).

The stacking of basement thrust slices of the size shown here has the effect of considerably increasing the thickness of the crust, a point brought out by the geophysical work of MÉNARD (1979). An examination of the 1:80,000 geological sheet of Briançon (B.R.G.M., No. 189), which covers most of the Pelvoux massif, suggests that a number of other major thrust structures run through the massif, and many areas for further study are indicated. The conclusion is that Pelvoux is a massif of considerable thickness ($\sim$40 km) because of the stacking of a series of basement thrust sheets terminated laterally by sideways climb of thrust surfaces into the cover to form basement scoops. The massif is thus a tectonic culmination resulting from the accumulation of basement thrust sheets beneath the main Briançonnais and Pennine nappes which must have covered the area at the time. Though the scale is different, many analogies exist between this area and that of the Moine thrust as described by ELLIOTT & JOHNSON (1980).

Acknowledgments

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