# TERTIARY AND QUATERNARY SEDIMENTATION IN THE CONFLENT

## AN INTRAMONTANE RIFT-VALLEY IN THE EASTERN PYRENEES

BY

E. OELE, W. J. SLUITER AND A. J. PANNEKOEK.

### INTRODUCTION

The eastern Pyrenees are crossed obliquely by a long depression which in various places has the character of a rift-valley (fig. 1). In this rift-valley there are a number of deeper depressions filled with Upper-Tertiary deposits. Although much of the subsidence occurred along faults, these depressions are usually called basins, partly because they were later deformed into basin-like shapes. They have long interested geologists and geomorphologists because the deposits which they contain reflect the epeirogenic and morphologic evolution of this mountain chain.

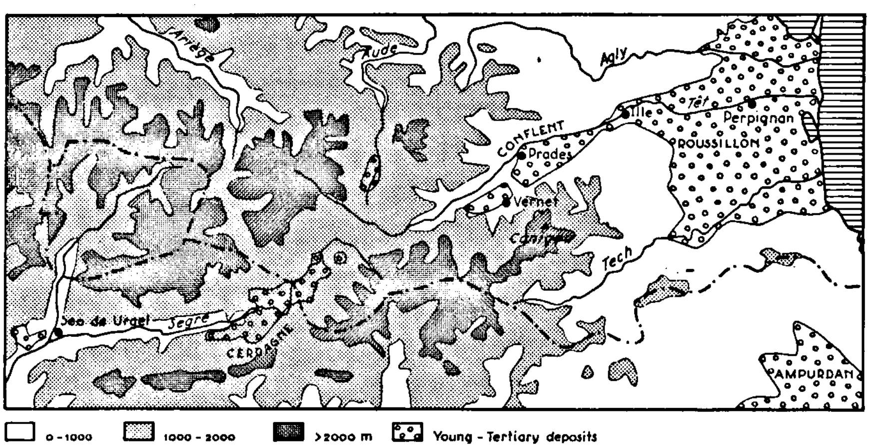


Fig. 1. Situation of the Neogene basins in the Eastern Pyrenees. Scale 1 : 1 250 000.
*Situation des bassins néogènes dans la partie orientale des Pyrénées.*

The southwestern section is formed by the Cerdagne Basin, drained by the river Segre, which runs towards the WSW and then turns S towards the Ebro. The oldest sediments it contains are lacustrine clays and lignites of Sarmatian

[1]) The authors' thanks are due to Dr. P. Hartman (Leyden) and Mr. Th. W. Levelt (Amsterdam, Institute of Physical Geography) who analysed the clays, to Mrs. I. Seeger—Wolf, who corrected the English text, and to Mr. J. Bult, who executed the drawings.

to Pontian age (Depéret & Rérolle 1885, Astre 1927, Boissevain 1934, Menéndez Amor 1955). These deposits are thought to be contemporaneous with, or somewhat younger than, the extensive denudation surfaces at altitudes of 2000—2400 m found in the central zone of the Pyrenees (cf. Boissevain 1934, Birot 1937, Sermet 1950).

The northeastern half of the rift zone contains the Conflent Basin, the subject of the present paper. It is drained by the river Têt flowing to the ENE, i. e. towards the Mediterranean, and is bounded on its southern side by the huge Canigou Massif (2785 m), the last high culmination of the Pyrenean chain before it reaches the Mediterranean; the mountains to the north of the Conflent Basin are lower and rise more gradually towards the west.

The deposits of the Conflent are coarser than those of the Cerdagne, and have generally been considered to date from the Pliocene. They have been studied by investigators from various countries, among whom we may mention Depérèt, Mengel, Birot, and Bourcart (France), A. Penck (Germany), Nussbaum (Switzerland), and Pannekoek (The Netherlands). Various opinions concerning the origin of these sediments have been given, and they have been variously interpreted as talus debris; soils; deposits of fluvial, torrential, or glacial origin; or as deposits by mud flows.

New field work, supplemented by sedimentological analyses in the laboratory, was carried out in 1957 and 1958 by the junior authors (E. O. and W. J. S.) under the supervision of the senior author, in order to supplement the latter's and Bourcart's earlier work and to obtain more information about the mode of deposition of these remarkable sediments, the climate during their deposition, and tectonic movements. There remain, however, many unsolved questions which may perhaps be brought nearer to solution by further field and laboratory work.

In the east the depression opens into the Rousillon, a coastal plain alongside the Mediterranean. It is a true subsiding sedimentary basin, in the centre of which 784 m of Miocene has been encountered in one boring and 775 m of Pliocene in another (Gottis 1958). Only the Pliocene deposits, many of which are fossiliferous, are outcropping in the low hills and along the upwarped border of the Roussillon. These deposits are the subject of the classic monograph of Depérèt (1885) and of the later work by Bourcart (1945). The Pliocene sequence of the Roussillon, according to the latter author, is as follows:

| | |
|---|---|
| Villafranchian | red sands with quartz gravels |
| Upper Astian (lacustrine Pliocene) | loams, freshwater limestone, and arkosic sands |
| Piacenzan (Plaisancien) | blue clays, marine sands, and gravelly sands |
| Rhodanian [2]) | arkosic sands. |
| | red clays and clayey breccias. |

## THE CONFLENT BASIN

The Conflent Basin, which derives its name from the confluence of a considerable number of rivers, is, geologically speaking, not a single basin, but consists of two distinct areas filled up with younger Tertiary deposits, incompletely separated by a ridge of Palaeozoic rocks (fig. 2). Their topography is

[2]) See footnote 4.

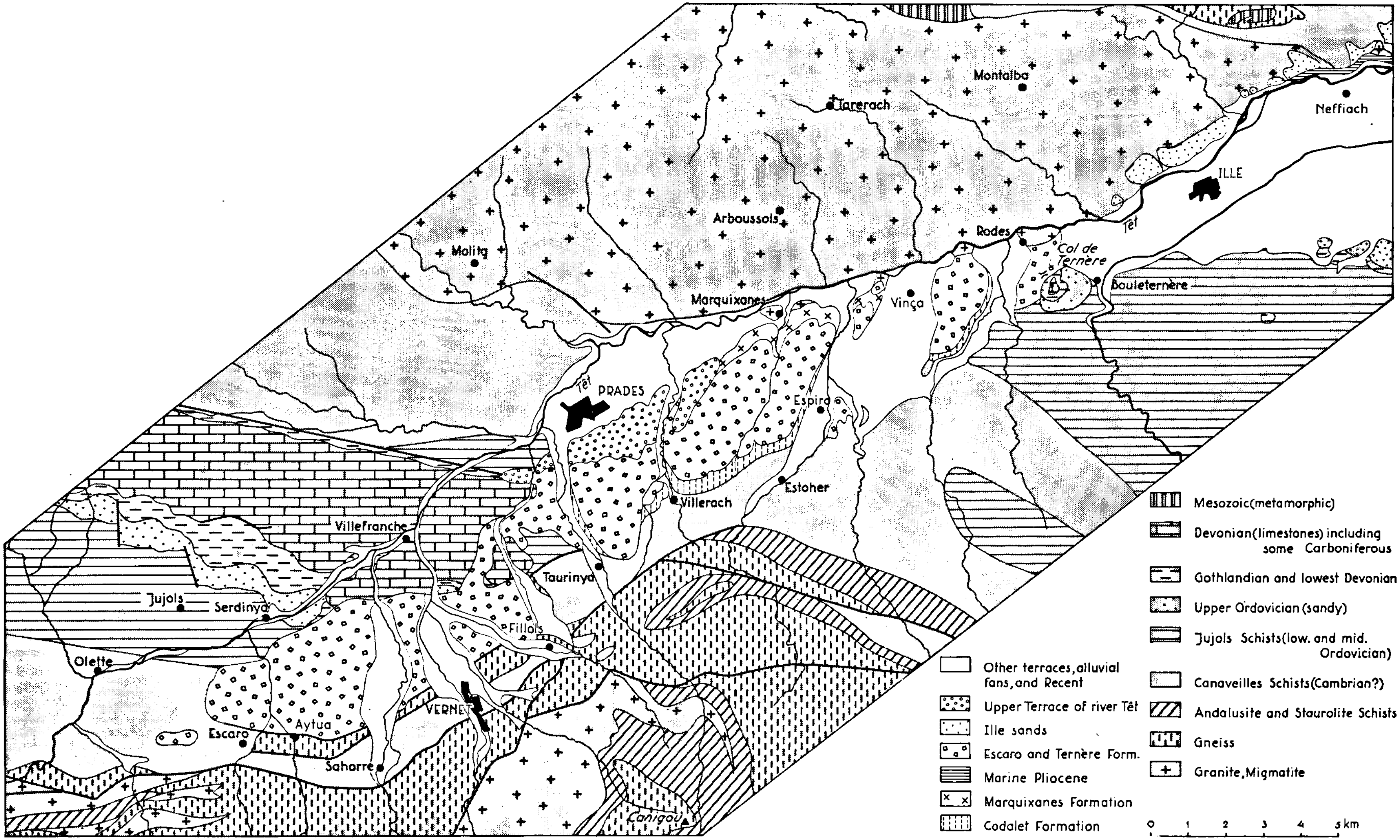


Fig. 2. Geological Map of the Conflent. Scale 1 : 160 000.
Older formations mainly after Cavet (1959) and Guitard (1958), simplified.

*Carte géologique du Conflent. Echelle 1 : 160 000.*
*Dépôts anciens en grande partie d'après Cavet (1959) et Guitard (1958), simplifié.*

rather different. The western basin, or Basin of Vernet, is a hilly area, cut into parallel ridges by several river valleys running from south to north across the basin. They originate on the metamorphic and Palaeozoic Canigou massif in the south, cross the basin and enter again into the Palaeozoic at the north side of the basin. There only do they flow into the longitudinal Têt river, which runs not through the basin but at some distance north of it through a narrow epigenetic valley cut into the Palaeozoic rocks.

The eastern basin, that of Prades, is traversed in its full length by the river Têt, which runs near its northern margin. Because the Têt could easily erode the Pliocene sediments, the Prades Basin is lower than that of Vernet and exhibits broad Quaternary terraces and wide alluvial valleys which are now the sites of abundant peach and apricot orchards.

At four places along the northern border, however, the granite massif which lies to the north of the Prades Basin has small extensions south of the river. At these places the Têt River has a narrow valley in the granite instead of following the easier path south of these granitic spurs. The fourth of these spurs, the Col de Ternère, is the downstream end of the basin, which is narrowest here. It then widens again, but this funnel-shaped part is already within the Roussillon. It is here, on top of the marine Pliocene, that the so-called Ille Sands are found, which are included in the following description.

Among the Upper Tertiary deposits of the Conflent Basin the senior author (1935) distinguished various types, the names of which have been retained in the present paper, because it is not yet possible to correlate them all with the stratigraphy of the Roussillon as established by Depérèt and Bourcart. These are:

a. the Codalet Formation, a red-bed deposit, corresponding with Bourcart's "argiles rutilantes" (red clayey breccia);
b. the Marquixanes Formation, an arkosic deposit corresponding with Bourcart's lower "sables arkosiques"; they were formerly thought to laterally replace the red beds, but because Bourcart found them on top of the red beds at other localities, they may indeed be younger;
c. the Escaro Formation, containing coarse boulders, and overlying the two deposits just mentioned;
d. the Ternère Formation, also overlying the Codalet and Marquixanes Formations, and of a more fluvial character;
e. the fluviatile Ille Sands in the Roussillon near the lower end of the Conflent Basin.

## THE RED BEDS: CODALET FORMATION

This is essentially a red-bed formation, the layers of which are full of angular fragments of Lower-Palaeozoic micaschists. The bedding is often obscure but, whenever visible, it appears to be strictly parallel, as was also observed by Bourcart. The thickness is at least 50 m. The outcrops occur in a zone along the southern border of the Prades basin (fig. 2, 4), at the base of the Pliocene sequence, but in deeper valleys the formation can be seen to extend rather far to the north. Along the border of the basin the formation is always in contact with the Cambrian (?) Canaveilles Schists or with the Ordovician Jujols Schists, fragments of which occur in the red beds. Bourcart, too, found similar deposits (his "argiles rutilantes") at the base of the Pliocene, at various localities around the Roussillon basin, up to 300 m thick, always in contact with Lower-Palaeozoic schists or phyllites.

In the south-eastern part of the Vernet Basin lenses of similar composition occur, intercalated within the Escaro Formation, which means that there they must have formed together with the latter.

*Grain-size.*

The non-pebble fraction (the term matrix is less appropriate because this fraction comprises the greater part of the sediment) is very badly sorted, and the cumulative curve accordingly gives a nearly straight, though irregular, line (fig. 5). Only rarely is there a differentiation into a more clayey and a more sandy layer.

*Pebble-composition.*

The pebbles, as already stated, consist almost entirely of rather flat fragments of the same mica- to sericite-schists which at these places adjoin the basin. The pebbles are mostly angular, but layers with more rounded pebbles occur in the SE. Exceptionally, a few gneiss and quartz fragments have been found in the SW.

The pebbles are usually floating in the matrix and evenly distributed in the layer, without a trace of grading. Although the majority lie more or less parallel to the bedding, others are steeply inclined or even perpendicular to it.

*Heavy minerals.*

The heavy mineral composition is by no means so homogeneous as that of the pebbles. There are samples in which an andalusite-epidote-alterite association predominates, others show zircon with epidote and alterite, or tourmaline and zircon with rutile of garnet. This is in accordance with the heavy mineral composition of the schists, in which zircon, garnet, andalusite, or rutile variously attain high values.

*Clay minerals.*

Illite is the main component, montmorillonite coming second. The material is more decomposed than in recent weathering soils on the adjoining micaschists, which soils contain much chlorite besides illite. The number of samples is, however, too small to draw definite conclusions.

*Mode of deposition.*

The first fact to account for is that all grain sizes, from pebbles to clay, are evenly mixed and were apparently deposited together. The most probable medium fulfilling this condition is a mud flow [3]) which spread out on the basin floor, whereby the velocity decreased until it came to a stop. This explanation, which is in agreement with Bourcart's opinion, also accounts for the parallel bedding, indicating successive mud-flows, and for the angularity of the pebbles.

The deposit was not a talus, as was supposed by Depérèt, because then the finer particles would have been partially washed out; moreover, the original slope angle is much too low. There are practically no indications for normal fluvial transport either, such as channelling, cross-bedding, or sorting into more gravellly, sandy, and silty layers or lenses, except for a few beds in which the coarse sand fractions or the silt fractions predominate, or in which the pebbles are more rounded.

[3]) In the sense of a "lave torrentielle" as described by Tricart (1957) and Dollfus (1960), or a "debris flow" (Varnes 1958), which is much more fluid than a mud-slide (Sharpe 1938, Cailleux & Tricart 1950).

*Conditions in the source area.*

The deposits of the Codalet Formation must have had a very local origin, if only on account of the fact that the zone of Canaveilles Schists bordering the basin in the SW is less than 1½ km wide (fig. 2). South of it occur gneisses, and nevertheless, near these places the Codalet pebbles consist mainly of schists and phyllites, with only very few gneisses. Because the grain size distribution is not very different from that of a soil, and also on account of the deep red colour (7.5 YR 5/6 to 10 YR of the Munsell scale), we presume that the deposits derive from red soils formed on the schists neighbouring the basin. These may have been residual soils formed in a warm and intermittently humid climate on the low relief assumed for at least the later part of the Miocene. These soils became soaked after occasional heavy rains, giving rise to mud-flows, perhaps initiated by land-slides.

A newly-created slope was necessary for starting these mud flows and their initial land-slides. At that time a differentiation must have occurred between an area of relative subsidence, where the deposits could accumulate and be covered by later deposits, and a rising source area from which the material was removed. This source area must still have been rather flat and cannot yet have had deep erosion valleys, because then fresh gneiss material would have been transported into the basin. There was only an initial slope with shallow gullies bordering the basin, and from this slope the thick soil cover came down.

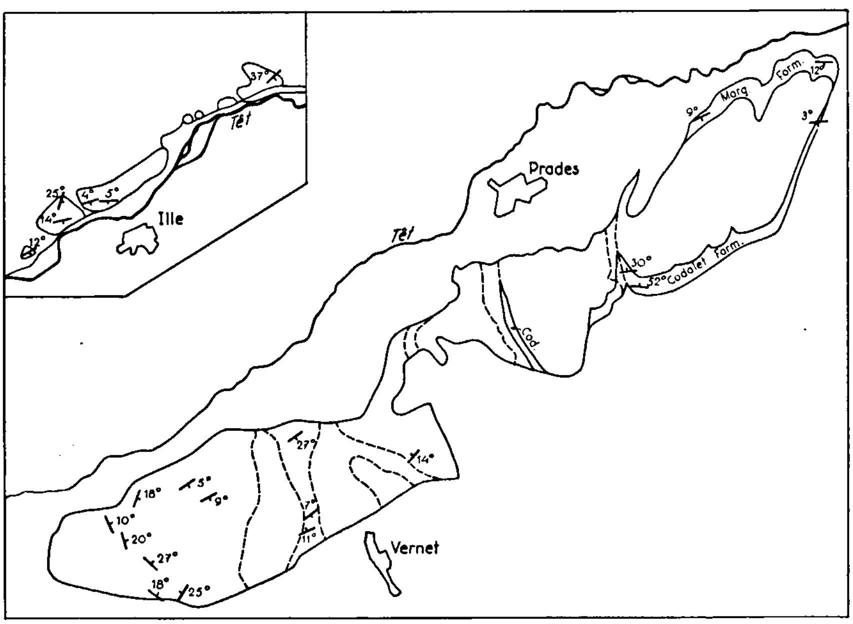


Fig. 3. Dips in the Plio-Pleistocene formations of the Conflent. Scale 1 : 160 000.
*Pendages des couches plio-pléistocènes du Conflent.*

*Age.*

The deposit being unfossiliferous, there is no direct evidence as to its age. Bourcart states that wherever it occurs together with marine Plaisancian, it always underlies the latter, while in the Cerdagne similar sediments occur on top of Sarmatian-Pontian deposits (Depéret & Rérolle 1885). Accordingly, there is much to be said for Bourcart's opinion that the red beds date from the end of the Pontian or the earliest Pliocene [4]. There is no certainty, however, that the conditions which led to the formation of the red beds acted strictly contemporaneously in neighbouring areas. This is, for instance, indicated by the occurrence of red lenses of the same composition within the younger Escaro Formation.

*Deformation.*

After its deposition, the Codalet Formation was affected by tectonic deformation. Near the southern border of the basin, dips of 40° and even 50° occur (fig. 3). These are much too steep for primary dips, even for talus slopes in this clayey material. More to the north the dip rapidly decreases and even a slight southerly dip has been observed. The primary dip will rather have amounted to a few degrees only, and the high dip values represent for the most part a later tilting of the beds, other arguments for which will brought forward later.

## THE ARKOSIC BEDS: MARQUIXANES FORMATION

The Marquixanes Formation occurs in the Prades Basin only in a narrow strip along the northern border, at the base of the Pliocene sequence. It was once supposed to replace laterally the Codalet Formation towards the north, but Bourcart found equivalents of the Marquixanes Formation, his lower arkosic sands, to lie in the Roussillon Basin exclusively on top of the red beds which are equivalent to the Codalet Formation, so that it is probably younger than the latter.

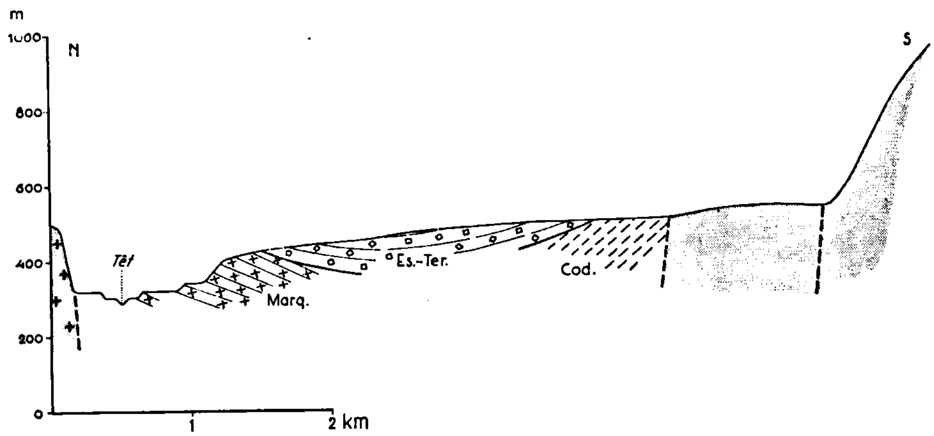


Fig. 4. Schematical section through the Prades Basin west of Marquixanes.
*Coupe schématique à travers le bassin de Prades à l'ouest de Marquixanes.*

At first sight the Marquixanes Formation is very different from the Codalet Formation: it consists mainly of light-coloured sands with, in some layers, granitic pebbles. There are, however, some points of resemblance. Both deposits consist

[4]) Bourcart proposes the time-stratigraphic term Rhodanian for them, because he thinks them approximately contemporaneous with Stille's Rhodanian orogenic phase. We are not, however, in favour of calling stratigraphic units after orogenic phases, instead of the reverse. Others have used the term Messinian for this time-interval.

of material derived from the area directly adjacent to the basin, which in the case of the Marquixanes Formation is the eastern extension of the granite massif of Quérigut, and both formations have parallel bedding planes and angular pebbles floating in the finer-grained material. Indications of normal fluvial action (such as channelling, lenses, cross-bedding) are absent in both formations.

The total thickness can be estimated at 100 m, the thickness of the individual beds is in the mean 30 cm.

*Grain-size.*

Although the deposit has the aspect of a coarse sand, the cumulative curve is less steep and the sediment less well sorted, than would be expected. There is a minimum in the silt-size fraction fraction but the clay-content is always more than 10 %, in some samples up to 25 %. Because the feldspars are strongly weathered and crumble into powder when taken out, the clay content is likely to be largely due to weathering after deposition and, accordingly, the deposit will have been coarser and somewhat better sorted at the time of deposition.

The pebbles are angular, with sizes often reaching 20 cm, occasionally ½ m.

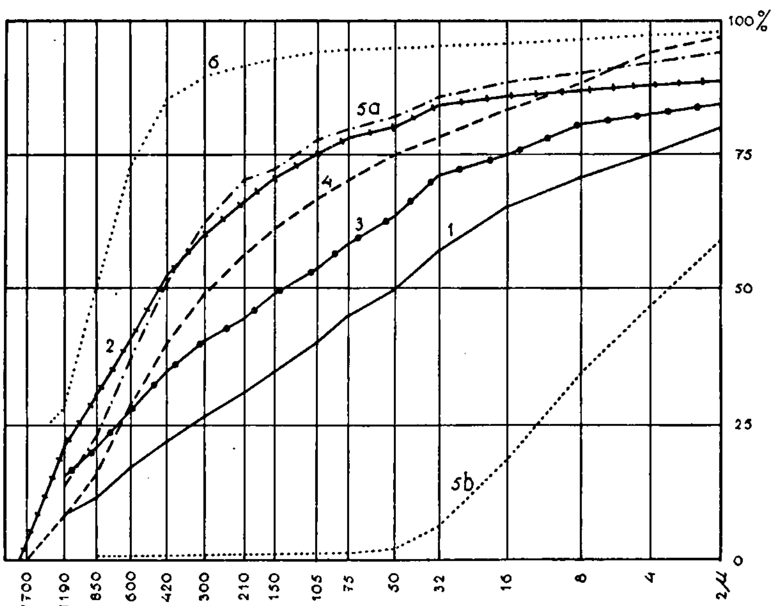


Fig. 5. Typical grain-size distributions of Pliocene and Quaternary sediments of the Conflent basin.
1: Codalet Formation. 2: Marquixanes Formation. 3: Escaro Formation. 4: Ternère Formation. 5a: Ille Sands. 5b: Clay layer in Ille Sands. 6: Recent fluvial deposit.
*Courbes granulométriques typiques des sédiments pliocènes et quaternaires du Conflent.*

*Pebble and sand composition.*

The greater part of the pebbles, as has already been mentioned, consists of granite, with a small admixture of pebbles of crystalline schist which may have derived from xenoliths and schistose border-zones of the granite. The pebbles, too, are strongly weathered, and crumble to small fragments as soon as an attempt is made to take them out.

The sands consist of quartz, feldspar, biotite and muscovite, with a small admixture of schist fragments. They are typical arkoses and subarkoses.

*Heavy minerals.*

The heavy mineral composition is different from what would be expected from the light mineral and pebble composition. In most samples epidote (including zoisite) predominates heavily, sometimes reaching values of more than 60 %, with alterite coming second. In exceptional cases the zircon and rutile contents rise to about 10 % and that of garnet to 18 %.

*Clay minerals.*

The clay is mainly illitic, with indications of some kaolinite. On the other hand, on the adjoining granites locally occur deep weathering zones which, because of their thickness (2½—3 m), may be old. These weathering zones have a considerable kaolinite content (20—40 %). This also points to a post-depositional origin of the clay in the Marquixanes formation.

*Conditions in the source area.*

The mineralogy of the Marquixanes deposit gives an initial clue to the conditions in the source area, especially regarding the type of weathering. Because feldspars and biotite are at least partly preserved and chemical weathering must thus have been incomplete, the climate must have been rather arid. Moreover, there are no traces of a red soil. Another indication for aridity are lime crusts (caliche) occurring at various levels in the upper part of the Marquixanes-formation.

The clay mineral composition, which is largely illitic, cannot serve as an indication for conditions in the source area because, as we have said, at least a large part of the clay content will have been formed after deposition, and the clays in the source area are of unknown age.

It is remarkable that a heavy mineral association with such large amounts of epidote has derived from a granite. There are, to be sure, many schistose zones and lenses in the granite, but it remains difficult to explain why meso- to epimetamorphic minerals should dominate in the heavy fraction, and granitic minerals in the light fraction. In weathering soils on the adjoining granite massif the same heavy mineral association occasionally occurs, but more often associations with a predominance of hornblende, or sometimes zircon, though in some cases with an admixture of epidote.

*Mode of deposition.*

Regarding the mode of deposition, there are some differences from, but also some points of resemblance to the Codalet Formation. The thick parallel beds with floating pebbles suggest deposition from a highly turbulent medium, strongly loaded with coarse material. We presume that the waters from sudden cloud-bursts spread over the granite surface as sheet-floods and then collected to form alluvial fans at the foot of the granite hills. Part of the finer-grained sands may have been transported further into the Roussillon Basin by intermittent rivers and deposited as arkosic sands, either at the same time or somewhat later, whereby the alluvial fans served as sources of the material.

The deposition of the alluvial fans and their preservation under younger deposits must also in this case have been initiated by a fault movement. We are inclined to suppose that, in the same way as with the Codalet Formation, a rise of the northern block and a relative subsidence of the basin caused the sediments to accumulate at the foot of the granite massif.

If we follow Bourcart in assuming that the Marquixanes Formation is younger than the Codalet Formation, the conclusion would be that these differential movements occurred later along the northern border than on the southern border of the basin. It is not clear, then, what the conditions were at the northern border at the time when the Codalet Formation, in which no granitic material has ever been found, was deposited. Was the granite still covered by a soil formed in a humid climate, as was the southern block, and where was this soil material transported to? Was the clay mixed with the red Codalet deposits, or carried away into the Rousillon Basin, or to the north? Bourcart supposed that the granite was still covered by schistose rocks but this is not very likely because the contact planes of the granite are very steep so that a large volume of granite must have lain above the present surface.

## THE BOULDER BEDS: ESCARO FORMATION

This formation fills the whole of the Vernet Basin and part of the Prades Basin, where it overlies the Codalet and Marquixanes Formations. It shows various points of resemblance with the Codalet Formation, although there are also important differences. The material is again very poorly sorted, some beds containing particles ranging from boulders to clay size fraction (fig. 6), but on

Fig. 6. Escaro Formation north of Vernet. The bedding in visible in the upper left corner.
*Assise d'Escaro au nord de Vernet. La stratification est visible à gauche vers le sommet.*

the whole there is more differentiation between the layers, so that some layers may be termed sands, others gravels and conglomerates, but with a large amount of matrix. The boulders and pebbles, moreover, are often floating in the matrix and do not show a preferential orientation. The deposit is thickly bedded, the thicknesses of the beds ranging up to about 3 m, and the bedding planes are again parallel. Only occasionally can channelling be observed.

The main differences from the Codalet Formation are the more varied pebble composition, the maximum size of the particles — among which there are boulders of up to 3 m in length — and the colour, which ranges from lighter red to yellow.

*Grain size.*

The non-conglomeratic layers and the matrices of the conglomerates are more sandy than in the Codalet Formation. The sand fraction (particles of more than 50 microns) comprises 60—80 %, the clay 10—15 % (though some of the clay may have originated by weathering in situ). The histograms show a maximum in the coarse sand sizes, a minimum in the fine sands, and a second maximum in the clay or, in some cases, in the fine silt fraction. The same was observed by Bourcart; he attributes the coarse sands to the decomposition of granites (to which coarse gneisses may be added), the fine-grained silts and clay to decomposed micaschists and phyllites.

Occasionally some more clayey layers occur between the coarser beds, with a clay content of about 30 %.

*Pebble roundness.*

The roundness values vary considerably within one outcrop. The lowest values (with median values below 100 according to the Cailleux-Tricart scale) occur in the Vernet Basin along the southern border, i. e. in the lower part of the sequence, whereas in the upper part of the deposit, which, because of the synclinal position of the beds, occurs near the axis of the basin, the median values

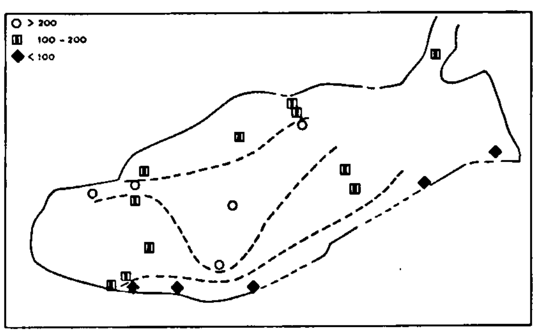


Fig. 7. Distribution of roundness values in the Vernet Basin.
*Répartition d'indices d'émoussé dans le bassin de Vernet.*

tend to rise above 200 and to attain fluvial values, especially in the channel fillings (fig. 7).

*Pebble composition.*

This is much more varied than in either the Codalet or the Marquixanes Formation.

Gneiss distinctly predominates, comprising up to 80 %. Various gneiss types outcropping in the Canigou Massif are found as boulders or pebbles in the basin. They show that the main supply must have come from the south, because gneisses do not occur near the northern border of the basin.

Micaschists and phyllites take the second place, but their sizes are smaller because of their greater friability. Quartz comes next, likewise as small pebbles (up to 6 cm) owing to the small width of the quartz veins.

Granites comprise only a few percents. This is a remarkable fact which needs some comment, because granites are now extensively exposed in the Canigou Massif (fig. 2), and in the rivers presently draining the Canigou Massif granite and pegmatite pebbles are in the majority. The difference may in part be explained by assuming that the granites weathered more rapidly at that time, when the climate was different and the Canigou Massif was less high than it is at present, so that fewer unweathered pebbles reached the basin. But in all probability the granite was also less exposed at that time, when the valleys were much less deeply eroded than at present.

There is no indication of a supply from the north, where there are no gneiss massifs in the surroundings of the basin. On that side, the Vernet basin is partly bounded by Devonian limestones (fig. 8). These limestones do not provide many

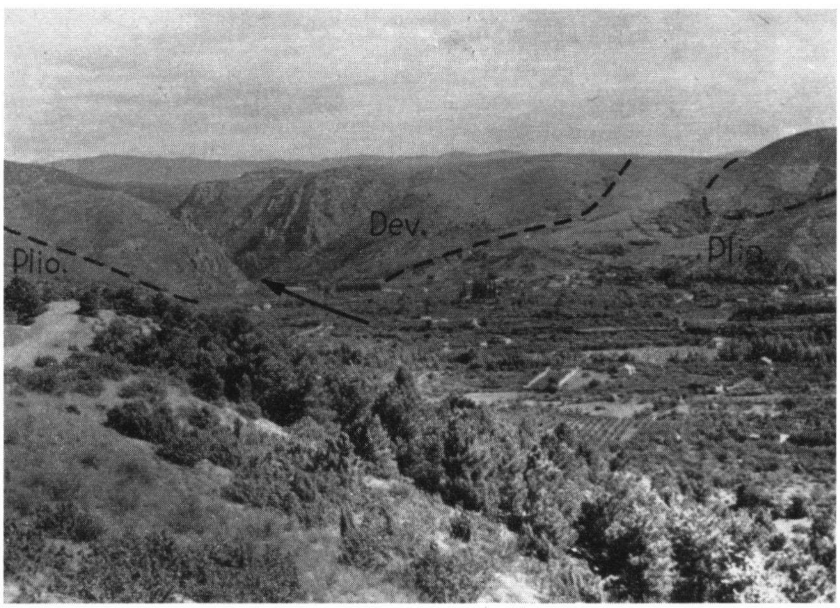


Fig. 8. Vernet Basin and its northern border, north of Vernet, with epigenetic valley in Devonian limestones.

*Bassin de Vernet et sa bordure septentrionale, au nord de Vernet. Vallée épigénétique dans les calcaires dévoniens.*

pebbles even at present: the rivers crossing this limestone barrier now carry only 7 % of limestone pebbles. But only once has a limestone pebble been found in the Tertiary basin deposits, again proving that a supply from the north was negligible. Nor is there any indication of a river having run longitudinally through the basin (as had formerly been presumed by the senior author). If a forerunner of the river Têt existed at that time, it must have been situated north of what is now the Vernet Basin, as at present.

*Heavy minerals.*

Like the pebbles the heavy minerals of the Escaro Formation show great diversity. In the basin of Vernet, zircon generally takes first place, with epidote and zoisite, or alterite, coming next. There are, however, individual samples containing some 10—20 % of either garnet, hornblende, or, more often, tourmaline. The samples with hornblende and those with the highest tourmaline contents originate from the western end of the basin, which may be an indication that the heavy mineral association varied with the river that supplied the sediment. This tendency is much more pronounced with the recent rivers crossing the basin, and also with their Pleistocene terraces: the river passing Vernet carries predominantly andalusite (29—55 %), with much less tourmaline and saussurite, whereas in the river passing Sahorre, running parallel to it a few kilometers to the west, epidote ranks first (28—45 %), followed by hornblende and saussurite (7—18 %).

*Mode of deposition.*

Because the Escaro Formation presents some similarity to the Codalet Formation, viz. thick parallel beds, extremely unsorted material, floating pebbles (in this case also boulders) which are at least partly angular, a similar transport medium and way of sedimentation may be assumed: sudden deposition from turbid, muddy flows which were initiated by cloud-bursts in the adjoining mountains and spread out in fans on the basin floor. Here the dense suspension was unmixed: the sediment stopped moving as soon as the particles touched, and the water, with perhaps some clay, flowed out.

A somewhat similar mechanism, though with more sandy material, can frequently be observed today on a very small scale in this region, as in other areas of bad-land topography. After heavy rains the basin sediments are easily eroded where bad-land gullies have destroyed the vegetation. The eroded material, mixed with water, runs down as a sludge which gradually unmixes, until it comes to a sudden stop. It covers the slope as a continuous sheet of sediment after the water has flowed out.

At the time of the Escaro Formation, the relief in the source area must have become stronger and the valleys, which had then cut into the gneiss, must have had steeper gradients, on which the muddy flows could transport huge boulders. This, too, can occur even today in normal rivers, though under particular circumstances, as evidenced by the flood of 16—19 October 1940 (cf. Pardé 1941). During this period the rainfall on the Canigou Massif reached the exceptional value of some 1500 or 2000 mm, with maxima of perhaps 500 mm lasting for a few hours. The rivers running down from the Canigou caused a disastrous flood, destroying part of the town of Vernet and all the bridges downstream from it. Boulders measuring a cubic metre can still be seen in the riverbed near Vernet, and boulders of ½ cubic metre reached a distance of 40 km downstream.

*Conditions in the source area.*

We have already mentioned that at the time of the deposition of the Escaro Formation, the Canigou Massif must have been deeply incized by steep valleys or ravines, so that various gneisses and micaschists became exposed and could supply boulders into the basin. However, the proportions of the various rock types among the boulders was quite different from at present (more gneisses and much less granites than now), and the same applies to the heavy minerals. It may be that chemical weathering was stronger at that time than it is now, which could explain, at least partially, the scarcity of granites. But probably, too, the rock types were exposed in the Canigou Massif in different proportions than at present, as is demonstrated by the completely different heavy mineral associations.

It follows that the level in which the rivers of that time were flowing must lie considerably above the present topography, which would give a possible explanation of the different assemblage of rocks outcropping in the Canigou Massif as compared with the present distribution. This would mean that the mountain block must have risen considerably since then; we will find later that there are other arguments in favour of this assumption. If this is true, the whole mountain must have been much lower than at present.

This agrees with the stronger chemical weathering at that time, as indicated by the Escaro sediments. The soils were more often yellow than red, if we may take as evidence the present colour of the Escaro Formation, in which red beds occur only occasionally. Other evidence is found in the fair rounding of the sand grains (with values ranging from 164 to 237) and the considerable clay and fine silt content of the Escaro Formation. In this respect the latter strongly differs from the deposits of the present rivers draining the Canigou Massif and from their Pleistocene terraces, of which more than 90 %, or even 95 %, consists of particles larger than 0.2 mm.

*Deformation.*

After deposition, the beds of this formation in both the Vernet and the Prades basins were bent into one wide syncline. This is most spectacular in the Vernet basin where dips of up to 27° occur on both flanks (fig. 3). That they are not primary dips is shown conclusively by the southerly dips of deposits which have been supplied from the south.

On both flanks the beds strike out into the air or are bordered by faults, which means that their former extension was greater and that the marginal parts of both flanks were removed by erosion. Actually, the present Vernet basin is separated from the high mountains by a rim of lower hills consisting of Palaeozoic and metamorphic rocks (fig. 4). The same applies to the southern border of the Prades basin. We are inclined to presume that the sedimentary basin formerly extended over parts of these hills and reached to near the higher escarpments of the mountain masses.

Especially on the south side, this escarpment is extremely steep, high, and rectilinear, and in all respects has the character of a fault scarp (fig. 9) with facets, although not very fresh ones. Its formation may locally have been favoured by rock differences, but it is also present in places where the rock on both sides is the same. This escarpment is another argument for assuming a considerable rise of the Canigou block in respect to the basin zone. The rise may have started at the time when the sedimentary basin was first formed, and at that time it initiated the erosion of the rising mass and the deposition of the material in the relatively downwarped zone. It is likely to have been strongly active during the deformation of the basin, and may have continued moving even afterwards. Some of the faults follow old fault lines of the Hercynian basement along which movement was re-activated.

*Age.*

Since there is reason to believe that the Ternère Formation laterally replaces the Escaro Formation, its probable age will be discussed together with that of the Ternère Formation in the next chapter.

## THE TORRENTIAL BEDS: TERNERE FORMATION

This formation occurs in the eastern part of the Prades Basin where it disconformably overlies the Codalet and Marquixanes Formations, but its relation to the Escaro Formation is less clear. At some places near Vinça it seems to overlie the Escaro Formation, but in general there may be a gradual transition, and the Ternère Formation may replace the Escaro Formation towards the east.

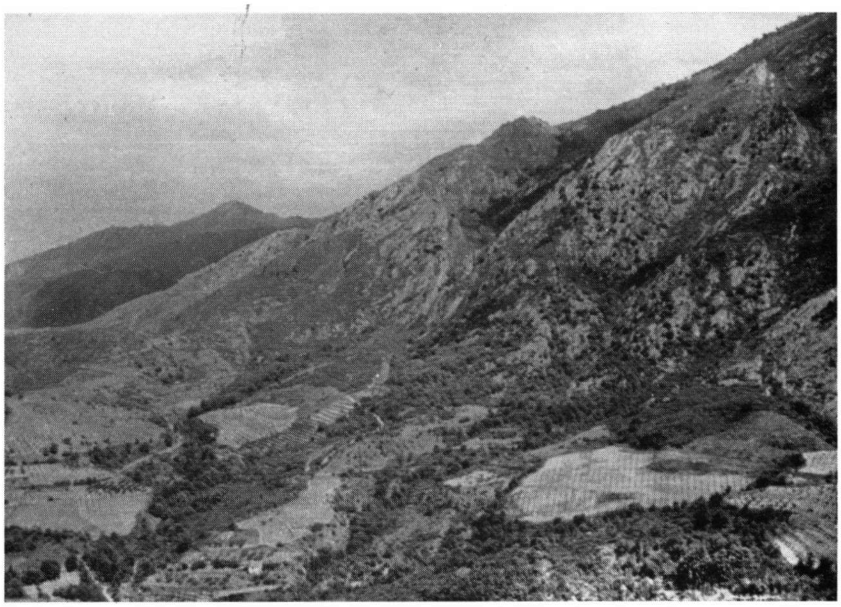

Fig. 9. Fault scarp south of Prades Basin, between Taurinya and Estoher, seen towards the east.
*Escarpement de faille au sud du bassin de Prades entre Taurinya et Estoher, vue vers l'E.*

The Ternère Formation is distinguished by a much more pronounced fluvial character. Current-bedding is frequent, the layers are more differentiated as to grain size than in the Escaro Formation, and the pebbles are better rounded. Most of the layers, with thicknesses up to 150 cm, are conglomerates with a sandy matrix, alternating with coarse sand layers with a thickness of 20—50 cm. Their colour is predominantly yellow. The total thickness may amount to at least 150 m.

### *Grain size*

Most of the sands have a maximum in the coarse sand sizes, but there is always a weaker maximum in the fine silt sizes as well; the clay content amounts to 5—10 %. The sands are poorly sorted. Some layers occur which are much finer, with median values of 15—50 microns, and clay percentages of 10—20 %. The clay is again mainly illitic, with a small admixture of kaolinite.

*Roundness.*

The values for the pebble roundness are in general higher than in most of the Escaro Formation, and range from 218 to 300. These are truly fluvial values, according to Tricart & Schaeffer (1950). The spread is, however, great. Well-rounded pebbles were probably mixed with badly-rounded ones, which latter may partly have been taken up from the near-by Escaro Formation.

*Pebble composition.*

This is not unlike that of the Escaro Formation. The gneisses are dominant (28—58 %), although less so than in the Escaro Formation. Micaschists comprise 5—40 %, quartz ranges from 5 to 30 %, but granites are less scarce than in the Escaro Formation, ranging from 8 to 20 %. The composition is thus on the whole more mixed.

The gneisses are evidence that the main supply came from the south, which means that, if there was a longitudinal river at that time, it will have flowed along the north side of the basin, as at present.

*Heavy minerals.*

The heavy mineral association is dominated in most cases by andalusite, with epidote, zoisite, or alterite coming second, followed by fair amounts of tourmaline, garnet and saussurite. There is, however, considerable variation, even between the beds of a single outctrop. Epidote or alterite may also dominate, and the percentages of saussurite may very between 0 and 20, those of garnet from 0 to 11, of tourmaline from 1 to 9, while zircon and staurolite do not rise above 7 %. This picture agrees with the structure of the source area, which, more to the east, contains more micaschists and andalusite schists and less gneisses and granites than south of the Vernet Basin.

*Mode of deposition.*

Whereas the Escaro Formation in the Vernet Basin shows few indications of fluvial activity (channelling, greater pebble roundness), in the Ternère Formation this activity is dominant. The formation was aparently formed by torrents which came out of steep valleys of the Canigou and Aspres Massifs and spread out their load as alluvial fans in the Prades Basin. The simultaneous deposition of many size classes may be a consequence of the sudden decrease of slope on the fan, and of rapid changes in run-off.

*Age.*

As with the other deposits, the evidence concerning the age of the Ternère Formation is both weak and indirect, and accordingly the question of its age is still controversial.

Firstly, there is the fact that the Ternère Formation overlies both the Codalet and Marquixanes Formations, and that it is separated from them by a disconformity.

Secondly, Bourcart had already observed that on the Col de Ternère, the Ternère Formation overlies arkosic sands and a clay layer, which because it contains glauconitic grains he thinks to represent at least part of the marine Plaisancian. He therefore correlates the Ternère Formation with the lacustrine or post-Plaisancian Pliocene.

Thirdly, the relation to the Ille Sands must be considered. These sands, as we will point out below, date at least partially from the very end of the Pliocene or the earliest Quaternary (Villafranchian). It can be argued that they replace the Ternère Formation in a downstream direction. Both are fluvial formations with many points in common, although there are also some differences. It would indeed be surprising if the Ternère Formation, which ends at the Col de Ternère, had no downstream continuation, and the Ille Sands, occurring 3 km downstream, had no upstream equivalent. But this is by no means a proof of their being contemporaneous.

In any case, there is sufficient evidence that the Ternère Formation dates at the most from the very end of the Pliocene and is separated by a long time interval from the Codalet and Marquixanes Formations.

As to the Escaro Formation, field evidence seems to indicate a gradual transition into the Ternère Formation, though at some places it seems to underlie the latter. If they were at least partly contemporaneous, the Escaro Formation too would date from the end of the Pliocene, but it might be that its deposition started earlier. What the conditions in the basin were between the time of the Marquixanes Formation and that of the Escaro Formation remains unknown.

If the age-relations as set forth above are approximately correct, it remains a curious fact that some of the conditions which caused the deposition of the Codalet Formation at the beginning of the Pliocene, recurred towards the end of the Pliocene during the deposition of the Escaro Formation. Nevertheless, there were also important differences: the valleys in the source-area had become much deeper, there were very few remnants of true red soils which occasionally reached the basin, and for the remainder we may presume a red-yellow soil.

On the other hand, conditions at the end of the Pliocene or the beginning of the Quaternary also differed greatly from the present ones: the Canigou Massif was much lower and at least partly covered by yellow soils, whereas at present, and the same applies to the later Quaternary when the fluvial terraces were formed, it rises steeply to altitudes above 2000 m and supplies hardly any clayey material. This means that, probably towards the beginning of the Quaternary, strong movements must have occurred which raised the Canigou Massif and deformed the basin sediments. Other arguments for these movements will be brought forward in the discussion of the Ille Sands.

## THE FLUVIAL BEDS: ILLE SANDS

These sands are not situated inside the Conflent Basin, but at the inner margin of the Roussillon, near the place where the river Têt leaves the Conflent. They are treated here because they may be of approximately the same age as the Ternère Formation and replace the latter downstream.

In aspect they are somewhat different (fig. 10). They show an alternation of well-bedded, more or less cemented, coarse sands and gravels (or rather conglomerates), with in the lower part some clayey to silty layers. The sands and gravels present various characteristics of fluvial deposits, such as gravelly or sandy lenses, current bedding, channelling etc.

*Grain size.*

Although there is sorting into separate layers of different composition, such as coarse gravels (maximum size of the pebbles about 30 cm), fine gravels, and coarse and finer sands, the sands of a single layer are not well sorted in themselves. The coarse sands often contain some 10 % silt and 5—10 % clay, and the finer sands are still less sorted, having 30—45 % of particles smaller than 50 $\mu$.

Such badly sorted sands are especially typical of rivers with strongly varying run-off, i. e. braided rivers according to Doeglas (1948). Sudden decreases in velocity compel such rivers to deposit many size-classes together. The climate must have been characterized by occasional rains, alternating with dry times, as is evidenced by gypsum crystals in the fine-grained layers. The clay is mainly illitic, with traces of kaolinite, as could be expected from what we know of the clays of the Conflent Basin.

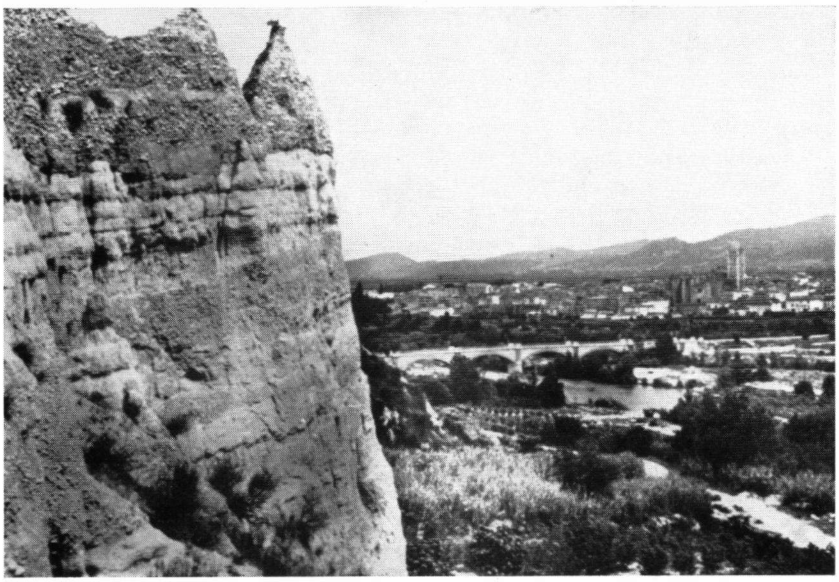

Fig. 10. Escarpment in Ille Sands. In the background river Têt, the town of Ille, and part of the Roussillon.

*Falaise dans les Sables d'Ille. A l'arrière-plan la Têt, la ville d'Ille et une partie du Roussillon.*

*Roundness.*

The roundness of the pebbles is typically that of river deposits (Tricart & Schaeffer 1950), with maxima in the 200—300 or 250—350 roundness classes. There is a great spread in the roundness values, which range from below 100 (broken pebbles) to over 600, indicating a considerable variation in transport distances. No differences were observed in the roundness values of granites and gneisses, notwithstanding the foliation of the latter.

*Pebble composition.*

This is much more similar to the composition in the present river Têt (Tricart 1958) than to that of the deposits in the Conflent Basin. Granite is first and foremost, which is only natural since the deposit adjoins the large granite massif of Quérigut-Millas, and the river that supplied the sediment will have run, like the present river Têt, for a considerable distance alongside this massif.

Gneisses take second place, and the same varieties as those found in the Vernet Basin occur here. Micaschists and quartzes are present in smaller quantities.

Obviously, the pebble composition clearly reflects the rocks occurring in the Conflent. Part of the pebbles may have derived from the basin deposits, but fresh rocks will also have been supplied, which is particularly obvious for the granites.

This is also illustrated by a local deposit somewhat upstream from the outcrops of the Ille Sand. In contrast to the latter, the pebbles here consist only of granites; this is clearly an old alluvial fan of a tributary coming from the granite massif which at this place poured into the main stream that supplied the Ille Sands.

*Heavy minerals.*

These present an even more varied picture than the pebble composition. All samples contain a great variety of minerals, in varying percentages. Zoisite often attains the highest values (up to 35 %, with one exception in which andalusite is present with 57 %), but zircon, tourmaline, saussurite, garnet, epidote, and alterite are usually present in quantities varying between a few percent and some 15 %. Obviously, the mineral assemblages of a great many rock types occurring in the source area are mixed here, the variations being dependent on which tributary supplied most of the sediment at any given moment.

*Deformation.*

The Ille Sands and conglomerates were tilted and warped after their deposition. The whole formation exhibits dips varying from a few degrees to 37°, mainly in a southeasterly direction, the greater dips occurring on the northern border. These are not primary dips because, apart from their being too steep, the deposits are not alluvial cones supplied by the granite massif in the north but ordinary fluvial deposits supplied from the south-west. Moreover, at some places they are clearly separated from the adjoining granite by faults.

*Age.*

The Ille Sands is the only one of the formations investigated which has yielded some fossils. In the clay layers near Ille, which are intercalated in the sands, remains of *Dicerorhinus etruscus* (Falc.) [5]) have been found which, together with the pollen assemblage, point to an Upper Pliocene to Villafranchian age (Florschütz & Menéndez Amor 1960). The same clay also yielded the new species *Azolla pyrenaica.* These finds throw a new light on the sequence of events in this area. The Ille Sands overlie, near Neffiach, marine deposits dated as Plaisancian, and were considered by Bourcart to represent a continental equivalent of these deposits, dating from about the same time.

It now appears that the Ille Sands are younger, dating from the end of the Pliocene or the transition towards the Quaternary. This means that they are younger than (or at the most contemporaneous with) the uppermost layers of the lacustrine Pliocene. The tectonic movements which warped these deposits may, thus, date from about the beginning of the Quaternary. This is still somewhat younger than was thought by Bourcart, who already observed that the "Pliocène lacustre", overlying the marine Pliocene, took part in the gentle folding of the Roussillon deposits.

It may well be that the deformation of the deposits of the Conflent Basin

[5]) These remains of Dicerorhinus were found by the employees of the Ille brick works, who brought them to Mr. Iché, teacher at Ille. They have been identified at the Geological Museum at Leyden by Mr. H. Loose.

also dates at least partially from this time, and that contemporaneously with it the Canigou Massif and probably also the mountains to the north of the basin have risen in relation to the Conflent Basin. These movements must have initiated the Quaternary cycles of erosion, and have probably continued for some time (see also Llopis Lladó 1946).

## QUATERNARY TERRACES

Quaternary terraces of the river Têt are well developed in the Prades Basin where the river could easily remove the Pliocene deposits. They are found at 100 m, 40 m, 25 m, and a few metres above the present river course, running more or less parallel with it. In the Vernet Basin there are, of course, no terraces of the Têt because it runs outside the basin in a narrow epigenetic gorge, but the tributaries which cross the basin from south to north have developed some terraces in which three to four levels can also be distinguished.

Clearly, at the time of their formation the tectonic disturbances referred to above, and the profound topographical changes initiated by them, were already long past, and the topography, except for continued valley-deepening, was not very different from the present one. This also appears from the pebble composition and the heavy mineral assemblages, which are similar to those of the present rivers. Some regional tilting may still have been active, because the terraces of the tributaries in the Vernet basin distinctly converge downstream.

The grain-size distribution of the sands in these terraces is, however, different from that of the present rivers as a result of glacial climate. The sands are poorly sorted, with silt and clay percentages of 20—35, and in some finer-grained layers all size classes can be present in almost equal amounts. These are clearly sediments of glacial braided rivers with strong and sudden variations in run-off. The pebbles are less rounded than in the present river beds, supposedly because of strong frost action.

## CONCLUSIONS AND SUMMARY

1. Coarse sediments of Pliocene and Quaternary age have accumulated in local deeper basins within the oblique rift valley in the Eastern Pyrenees. Sedimentological data permit certain conclusions on their mode of deposition, the relief and climate in the source areas, and on epeirogenic movements during and after their deposition.
2. The oldest basin deposits, forming the Codalet Formation, are red beds with angular particles of micaschists, occurring along the southern border of the Prades Basin. They are derived from red soils formed in a humid and warm climate on the micaschists adjoining the basin on the south, and were deposited mainly from mud-flows initiated on the slopes of the basin, which at this time began to subside. According to Bourcart, this formation dates from the end of the Pontian or the early Pliocene.
3. The Marquixanes Formation, along the north flank of the basin, consists of arkosic sands with angular granite pebbles, supplied from the granite massif at the northern margin of the basin, and formed in a dryer climate.
4. The Escaro Formation constitutes the main mass of the basin sediments. The unsorted material contains huge boulders supplied by the Canigou Massif, which was much less high than at present and partly covered by yellow to

red soil. The mode of deposition was not unlike that of the Codalet Formaton, but there are indications of occasionally more normal fluvial transport. Towards the east the Escaro Formation passes into a torrential deposit, the Ternère Formation, which unconformably overlies both the Codalet and Marquixanes Formations. As to age, the Escaro and Ternère Formations may be equivalent to the uppermost lacustrine Pliocene or to the Ille Sands.

5. The Ille Sands and conglomerates, which occur near the eastern outlet of the Conflent Basin, are fluvial deposits dating from the end of the Pliocene or from the Villafranchian.
6. All these deposits are affected by tectonic movements. The basin sediments have been folded into a wide syncline, partly bordered by faults. These movements must date from the transition from the Pliocene to the Pleistocene, and were accompanied by a strong rise of the adjoining mountain blocks.

# RÉSUMÉ

## SÉDIMENTATION PLIOCÈNE ET QUATERNAIRE DANS LE CONFLENT, FOSSÉ INTRAMONTAGNEUX DANS LES PYRÉNÉES ORIENTALES

Cette contribution contient quelques résultats d'études sédimentologiques sur les dépôts pliocènes at quaternaires remplissant le fossé qui traverse les Pyrénécs orientales en direction oblique. Les données sédimentologiques pourront fournir quelques indications sur les conditions de dépôt et sur la provenance de ces assises, ainsi que sur le climat.

Pour les couches rouges de Codalet, remplies de fragments de schiste, l'opinion de Bourcart selon laquelle elles ont été formées par des coulées boueuses, est confirmée. Elles proviennent de sols rouges formés avant le Pliocène sur les schistes du Paléozoique Ancien.

Les arkoses de Marquixanes, contenant des cailloux de granite, indiquent un climat plus sec. Ces deux dépôts datent, selon Bourcart, du début du Pliocène.

L'assise d'Escaro, à grands blocs, montre la transition de déposition par coulées boueuses vers une sédimentation fluviale. La différence entre la composition des cailloux et des minéraux lourds de ce dépôt et celle dans les dépôts actuels montre que les conditions étaient bien différentes: le massif du Canigou était bien moins élevé qu'aujourd'hui et en partie couvert de sols jaunes, parfois même rouges.

L'assise de Ternère, qui en partie remplace celle d'Escaro vers l'E, est plutôt un produit de sédimentation torrentielle. Il est probable que ces deux assises datent de la fin du Pliocène et même qu'elles pourront être contemporaines des Sables d'Ille.

Ces dernières sont des dépôts fluviaux typiques. Les intercalations argileuses ont fourni un ensemble pollinique et des fragments d'os de Rhinoceros etruscus (Falc.) qui indiquent un âge fin-Pliocène ou Villafranchien.

Tous ces dépôts ont été affectés par des mouvements tectoniques, déjà décrits antérieurement, qui ont accompagné la surrection de la chaîne pyrénéenne pendant le Pliocène et le début du Quaternaire.

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