Bureau, D., 2016. Structural data, geomorphology and rock slides in the SW of Barles (The Alps of Northern Provence, France). *Boletín Geológico y Minero*, 127 (2/3): 613-624
ISSN: 0366-0176

Structural data, geomorphology and rock slides in the SW of Barles (The Alps of Northern Provence, France)

Dominique Bureau

MCF honoraire, Université Pierre-et-Marie-Curie-Paris VI,
17 rue de Trémeville, à Fromonvilliers, 45480 Autruy-sur-Juine, France.
dxbureau@wanadoo.fr

ABSTRACT

The Alps of northern Provence in France is a familiar area to European geologists because numerous, long field studies have been organized by European universities and private petroleum companies during the 20th century and the beginning of the 21st century. Nevertheless, geologists have made few comments on the consequences of some topographic slides and, more broadly, on the manner by which nature has sculpted the local geomorphology. After having set the local tectonic data (the thrust of the Blayeul Massif on an already folded para-autochtonous formation and locally up and down reversals in the area of the Heights of Chine and Proussier), a geological and geomorphological summary introduces a discussion on slides and slope formations; then the details of the morphology analysis lead us to the conclusions.

Key words: collapses, erosion, field geology, thrust speed, Alps

Datos estructurales, geomorfológicos y de deslizamientos rocosos en Barles sur-occidental (Alpes del norte de Provenza, Francia)

RESUMEN

Los Alpes del norte de Provenza en Francia son un área familiar a los geólogos europeos ya que se han organizado numerosos y largos estudios de campo tanto por universidades europeas como por compañías petroleras, tanto durante el siglo veinte como en los comienzos del siglo veintiuno. No obstante, los geólogos han hecho pocos comentarios sobre las consecuencias de algunos deslizamientos topográficos y, más generalmente, sobre la manera en que la naturaleza ha esculpido la geomorfología local. Después de describir los datos tectónicos locales (cabalgamiento del Macizo Blayeul sobre una formación para-autoctona ya plegada y con inversiones locales en el área de los altos de Chine y Proussier), un resumen geológico y geomorfológico introduce una discusión sobre los deslizamientos y la evolución de las pendientes; seguido de detalles del análisis morfológico que nos llevará a las conclusiones.

Palabras clave: colapsos, erosión, geología de campo, velocidad de cabalgamiento, Alpes

VERSIÓN ABREVIADA EN CASTELLANO

Introducción

Este trabajo presenta los resultados de la geología de campo concerniente a la región de Barles (20 km al norte de Digne, Alpes-de-Haute-Provence, Fig. 1). El objetivo es abordar las guías de la morfología local en relación con las estructuras superficiales. Barles está en el límite entre la zona alpina cabalgante desde el noreste a lo largo del Mioceno y la zona para-autoctona de carácter "dauphinois" con plegamiento este-oeste durante el Eoceno. La mayor parte de otros datos estructurales se han recogido en la figura 1. Estos se han completado precisando que las formaciones más resistente, Lias y Titónico, manifiestan una tendencia *a desplomarse hacia el sur. Esta tendencia está reforzada al nivel de la Clue de Pérouré, la más meridional, por movimientos sin-sedimentarios dando estructuras particularmente espectaculares en las formaciones terciarias (Fig. 2A y 2B).*

Datos estratigráficos y morfológicos

La masa cabalgante de Blayeul (Fig. 1) está compuesta por materiales del Retiense-Lias cuyo techo, aquí, es una lámina de Lias en posición inversa. El espesor de esta masa (unos 650 m, a menudo inaccesibles) comprende al menos una repetición tectónica. Dicha masa reposa sobre un Retiense de arenisca. El contacto no normal, en la base del precedente, está remarcado por una banda irregular de yeso del Keuper. La figura 1 muestra una semi-ventana al este de Barles. Está precedida de una barra de edad Retiense-Lias mostrando influencias pelágicas menores que en Blayeul. Progresando hacia el este se encuentran los yesos del Keuper que alcanzan los 200 m de potencia sobre un frente de 2 kilómetros. La erosión ha excavado una pequeña cuenca alimentada abundantemente por el Bès y dos voluminosos afluentes. A la entrada de la semi-ventana, se encuentra una zona fuertemente tectonizada constituida por afloramientos dislocados irregularmente y enterrados bajo los desplomes y productos del desmantelamiento de la masa de Blayeul. Más al este, un anticlinal erosionado deja aparecer la base del Trías en débil discordancia sobre el Estefaniense que después desaparece bajo el cabalgamiento al este de la Clue de Verdaches (Fig. 1). Al oeste de Barles, la inversión de la barra liásica (unos 250 m) está igualmente destacada en la figura 1; y produce la barra de Chine y las de Proussier (Fig. 1). Encerrando la cabecera de una segunda cuenca, está cerrada al sur por la creta calcárea del Titónico modelada por la Clue de Barles. Además un estrecho sinclinal ocupado por el Cretácico inferior recubierto por un Oligoceno discordante precede (Clue de Fontchande) un anticlinal irregular. Sobre su flanco sur, el Titónico está completamente invertido en la Clue de Pérouré donde está recubierto por un Oligo-Mioceno donde las primeras capas son verticales antes de ocupar progresivamente los espacios liberados por la erosión. Este corte muestra que antes de bascular 90 grados hacia el sur, el depósito eoceno estuvo afectado por un abarrancamiento torrencial sobre el Titónico entonces perfectamente vertical, mostrando de este modo la perennidad de los fenómenos erosivos. Este dispositivo corresponde al proceso de basculamiento hacia el sur del Titónico de Pérouré mostrando, a este respecto, la perennidad del movimiento tectónico. Los niveles terciarios del Velódromo (Fig. 2) se depositaron en una cuenca intramontañosa bordeada por la Clue de Pérouré. Ello muestra vivamente el adelgazamiento sinsedimentario hacia el sur-suroeste de las molasas correspondientes que se depositaron en medio salobre de una delgada rebanada de agua (Fig. 3A y B). Después de este período, el Bès, en sobreimposición tardía diseccionará el conjunto. Se aprecia que el conjunto de la serie está marcado por esquistosidades variables en intensidad así como en dirección. La estructura del conjunto y su historia ha llevado así a la implantación de una serie de cuencas retocadas progresivamente por una erosión regresiva en función de la formación de desfiladeros, los "clues", en las formaciones más resistentes.

La cresta de Proussier, desmantelamiento, deslizamientos y formación de pendientes

La cresta de Proussier, Retiense-Lias (Figs. 1 y 4), comienza al sur mismo de Barles. Si la microtectónica muestra una inversión precoz de la barra de Chine, este hecho no está demostrada por las barras de Proussier donde las inversiones no conciernen más que las partes más somitales (fase alpina propiamente dicha). Por su situación (Fig. 4A), la fracturación y juegos sucesivos de la cresta conducen a dislocaciones y excavaciones sobre sus dos caras dando un paisaje extremadamente abarrancado en sus partes bajas. Al este, el barranco de la Boulette se encaja profundamente en los yesos. Al oeste, los glacis están fuertemente afectados por el Bès, torrencial, que desprende las margas negras del Malm. La solifluxión resultante se manifiesta un poco más alta en la topografía. La fracturación conlleva fallas transversales y longitudinales (Fig. 4B) generalmente redireccionadas excepto en las zonas caídas. En la parte baja (Fig. 5A), las fallas sinsedimentarias, con mejor observación aquí, entrañan una red de variaciones de potencia que no corresponde sistemáticamente a fallas transversales (Fig. 5B). Ellas se acompañan de un juego senestral que contribuye a la dislocación de la barra. La cuestión de datación de los juegos se suma a la de la velocidad efectiva de fenómenos constatados y teniendo en cuenta su subordinación mutua (modificación de niveles de base, puesta al descubierto, alteración, socavación, desprendimiento, puesta en pendiente y desplazamiento). Al sur de la cota 1350 (Fig. 4), la mayor parte de la barra, afectada por las pendientes inversas cada vez más fuertes (70°), ve partir sus elementos en deslizamiento hacia el este, se rehabilitan por una falla transversa apoyándose directamente sobre el yeso. La presencia de loess en el seno de esta masa plantea la cuestión del origen de este material *(glaciar ?) así como la de la edad de su depósito y/o de su remodelación. Estos conjuntos hectométricos o kilométricos constituyen para otros lugares masas deslizadas sobre los glacis de desmantelamiento (Fig. 1, bajo la barra de Chine y al sur-oeste de la de Proussier). Estabilizadas sobre terrazas fósiles, se encuentran conservadas a cotas más elevadas que las cotas de barrera del valle por el Titónico antes del encajamiento de la Clue de Barles. No se deben confundir estas masas con aquellas que, bajo el Blayeul, han servido de jirón de acceso.*

Conclusiones

Las descripciones sucintas precedentes muestran que el papel de las claves de la evolución morfológica varía para las diferentes cuencas y las posibilidades de su orden de intervención en la erosión tienen causas generalmente conocidas. La pluviometría, la repartición local de las lluvias, las crecidas, las variaciones del nivel de base, la erosión sobre materiales de diferente textura, la abrasión y el transporte son parámetros cuya secuencia de intervención necesaria crean un gradiente de evolución. Si existe un gradiente de evolución de estructuras tectónicas, se supedita subyacente al precedente. La sucesión en cascada de las cuencas al sur de Barles es comparable a la sucesión de torrentes en relevo los unos de los otros. Igualmente la consistencia litológica asociada a deformaciones tectónicas diferentes modifica la cadencia de la evolución. La misma combinación tomada en orden inversa sucederá de tal modo que el resultado será sin duda diferente. Se puede considerar que la evolución morfológica, asociada a la constancia de la erosión, es más rápida que las modificaciones del material sedimentario a menudo rediseñado al estado de gel o de jirones irregularmente plásticos. La evolución morfológica es más rápida todavía que las deformaciones tectónicas (10 cm por año de desplazamiento medio). Así el cabalgamiento de Blayeul (1 mm por año) no ha podido intervenir de modo significativo en el curso de los períodos post-glaciares donde la intervención no puede ser descartada para otros lugares. Numerosas observaciones sobre los elementos dislocados, dispersos y algunas veces deformados han sido igualmente hechas en la semi-ventana de Barles. Estas no pueden estar bien desarrolladas aquí ya que el papel de la erosión interviene como factor determinante. En efecto, las cuestiones correspondientes preparan igualmente las respuestas a la cuestión del "cómo" en el posicionamiento de un cabalgamiento. El trabajo está lejos de estar acabado. Este no es sino un resumen de lo que todos los colegas han podido ver en la región de Barles.

Introduction

The manner in which geological phenomena is exposed in the countryside explains the choice of the Barles area (Fig. 1) for field trips or school field trip. The Paris School of Mines (France) was the first to organize such trips, later followed by other numerous universities. A part of the remarks and comments made in this text results from a common study only partly published so far. In the 20th century, the denudation of soil was the result firstly of cutting mountain oak trees for the decks of the French Royal Navy ("la Royale") ships, and secondly, walnut trees for World War I guns butts. This is why the government enforced re-forestation and soil stabilization laws. The re-forestation surrounding the Blayeul Massif in 1930 was massive, whereas that located at the southern entrance of the small town of Barles in 1950 had a more immediate purpose. The stabilization of soil was achieved through the reduction of torrential erosion, difficult to avoid on a low mountain morphology made up of very weak, soft outcrops. The socio-demographic evolution that has occurred since those former historic periods has been more significant during the 21st century. The dense population since the 17th century (370 victims were counted after a slumping near Barles-les -Sauvans), was reduced after World War I. New roads toward Dignes in the south and toward Seyne in the north east and the arrival of electricity in 1933 was not sufficient to maintain the previous industrious activity in Barles. Automobile use enabled a high frequentation of the area by people ignoring traditional requirements as regards sustainable mountain living. Short student field assignments have been reduced due to university budget cuts and have not been compensated by desk work on laptops. Moreover, countryside paths have been damaged. After these debasements, the cold winter of 1976 killed nearly all the parasites attacking the woody parts of the studied area. Since then, vegetal cover seems to have become very dynamic, generating the growth of bushes, and woody areas progressively conceal the details of outcrops. The Barles area, close to the border between thrusting alpine units (Goguel, 1963) from the NE (Miocene) and subalpine zones shaping a para-autochtonous EW folded unit (Eocene), itself surely detached (Debats *et al.*, 1972, Lemoine, 1972; Gidon and Pairis, 1986).

Structural data

The Blayeul thrust

The remains of the frontal thrust of the Blayeul Mountain makes a curve, widely opening toward the west, the intercutting of which with the para-autochtonous zone may be seen as a late, several kilometer-long bulge (Fig. 1). The thrusting mass, southward to Barles, is composed of a Rhetian-Lias formation of pelagic facies which looks very thick because it is formed of several slabs which can be seen under the Blayeul summit of the southern massif 2350 m high. The same disposition has developed in the NW Barles (Fig. 1). The contact shows a surface lubricated by Keuper gypsum. This contrast may contain outcrops, built of different exotic elements which are generally interpreted as displaced autochtonus slices (Grandjacquet and Haccard, 1973). More often than not, no gypsum remains visible. In the Barles area, the gypsum presents an important thickness of 100 m over a length of about 2 km. This accumulation is too limited to be the cause of the bulge. It can only come from a local decompression of a diapiric system. Muschelkalk and Bundsandstein, with a weak angular discordance on the Stephanian, are developing toward the east around 1065 m high, under the thrusting mass (Fig. 1).

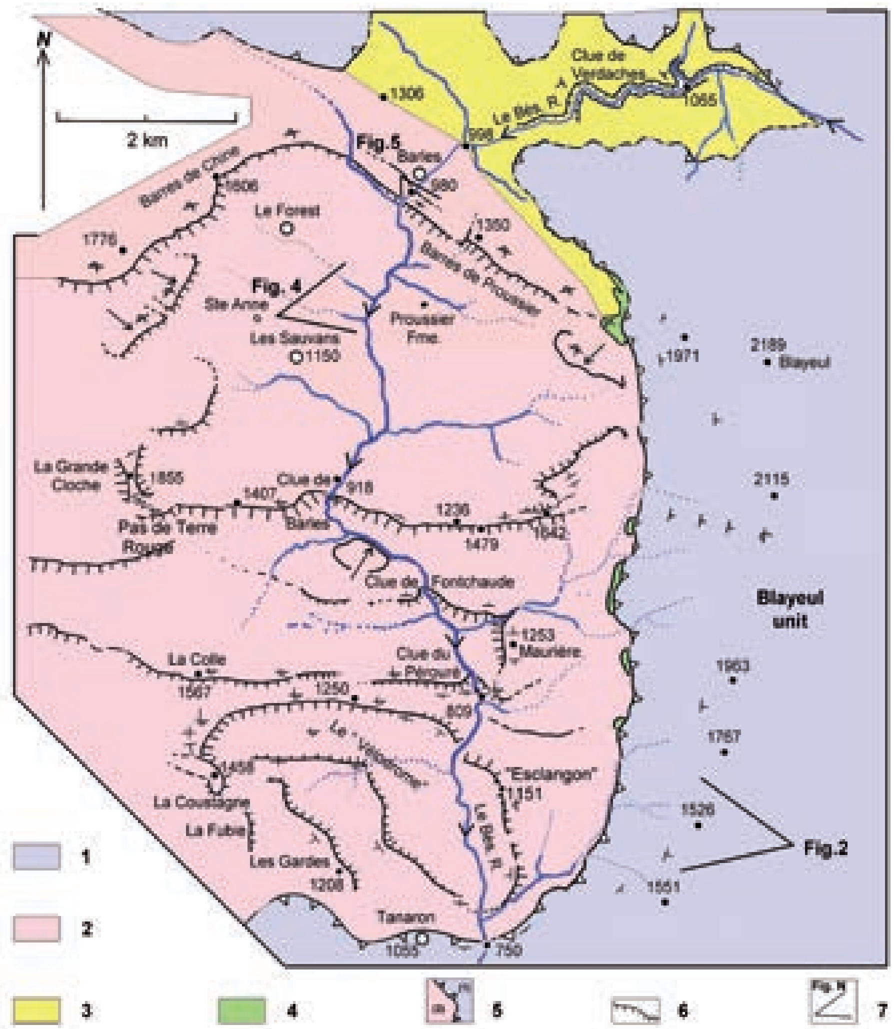


Figure 1. Topographic and structural sketches of the Barles area and of associated basins of the Bès torrent. The town of Digne is at 25 km in the south. Seyne-les Alpes village is 22 km towards the N-NE. 1.- The Blayeul allochtonus unit thrusted from NE (alpine period, Miocenian-present time); 2.- Folded para-autochtonus levels with EW axix (Pyrenean or eocenian period); 3.- Barles semi-window in the Blayeul thrusting unit; 4.- Displaced slice of autochtonus levels; 5.- *1* trusting unit over autochtonus *2;* 6.- Cliff ; 7.- Field for figure *N*.
Figura 1*. Bosquejos topográficos y estructurales del área de Barles y de las cuencas asocidas del torrente de Bès.*

Para-autochtonous positions

Under the thrust, looking towards the west, the Mesozoïc formation exhibits its successive stages. The Rhetian-Lias bank is vertical at the exit of Barles, then reverses and forms the Chine summit in the north and of the Proussier in the south. Along a north to south itinerary, located 1 to 2 km from the western part of the thrust, Upper Jurassic black marls succeed to Dogger carbonate banks which are associated with black marls in the overturn, locally affected by disharmonic movements (Coadou and Beaudoin, 1975); these marls evolve horizontally, then vertically after a fault, with the reddish Argovian layers passing into the vertical bank of the Tithonic where the "Clue of Barles" (meaning the gorge of Barles) is cut (Fig. 1). The top of this limestone is violently deformed and tends to overlap and is irregularly eroded. The old eroded surface is preserved because of a cover of brick-like red Oligocene deposits; not only on some low areas where they are deformed but also on high areas, such as in the north of the Grand Cloche or the Barri example. This Oligocene is observed until below the abnormal contact, easy to recognize because of multicolor gypsum. Oligocene deposition has levelled the previous morphology, later covered by layers which are progressively horizontal that can be seen further south. This shows the existence of significant pre-oligocenian erosion. The next narrow syncline, which is obviously overturned by later tectonics, carries on in the marly calcareous Valenginian strata and in the pale yellow Hauterivian schist. Rare remains of the other Middle Cretaceous stages show that they were systematically eroded during their deposition. Perhaps the Upper Cretaceous layers were not deposited in the area. Southward, the Tithonic reappearance occurs abruptly at the "Clue of Fonchaude" (hot fountain gorge, Fig. 1), in which only the lower part of the formation is present. It develops an anticlinal arch (Maurière, "the Moorish", Fig. 1) of which the southern flank is crumpled up by shearing producing slices within the previous Oligocene coatings. A reverse formation of the Upper Jurassic follows and is cut by the "Clue of the Pérouré" (the Pérouré gorge). This opens onto an Oligo-Miocene basin which ends to the south under the abnormal contact with the Blayeul formation, here represented by the slab of La Robine.

The synsedimentary deformations, which exist all along the different stages, become spectacular here (Fig. 2). An Oligocene channel is pasted vertically on the nearly horizontal reverse Tithonic, showing that the first Oligocene deposits occurred on the final strata of the Tithonic which was already vertical. But, all the layers of the Oligo-Miocene basin are touched by the continuation of the movement shown by the dip of the previously described channel at a time when contemporaneous contribution, deposition and accumulation were occurring and the penecontemporaneous erosion of it as well (Beaudoin *et al.*, 1970). The nearly-emerged Miocene (Fig. 3; Tessier and Gigot, 1989) has been completely overturned and the summit of the latest Mio-Pliocene Valensole formations is deformed (Fig. 2) and partially schistosed. These are forming sedimentary bevels, showing their progressive extension as they are covering simultaneously the eroded Miocene banks from Facibelle towards the west (Fig. 2B). On this surface shaped by a new erosion period, olistoliths are retained, some of them being hundred of metres wide, such as Coustagne, Fubie and Tanaron "Tower" (Gidon and Pairis, 1988). The average slope of this surface is looking towards the south and southwest, relatively weak in the north, to end locally nearly vertical in the south along the abnormal contact. The whole structure shows that the undermining of modern relief has been done during a later period with the help of a superimposition of the torrent, called Bès, stronger than now.

The succession of the modern basins was able to be differentiated as the regressive erosion attacked the natural dam formed by the Tithonic facies and by the Lias ones. This period is not really finished, as the Verdache Clue, upper Barles (Fig. 1), is very actively attacked and eroded. This comment can also be made for all the other "clues" (gorges) where erosion acts as a saw, the "Clue de Fontchaude" (hot fountain gorge) looking more fragile because of the thinning of the Tithonic layers by faults. This topography is dominated by the Chine and Proussier Heights.

The Proussier Heights

This relief, in its southern area, is the stratigraphic replica of the Chine one. It is composed of Rhetian-Hettangian-Sinemurian-Carixian-Domerian-Toarcian in a reversed position. The whole series is relatively thin, lying on marls and limestone of the Dogger formation which itself lies on the Upper Jurassic black marls. This last series lies under the Keuper gypsum which usually acts as a lubriciant under the thick Blayeul formation. They are very often marked by synsedimentary movements caused by variable important faults, leading to banks, as well as stages, changing thickness (Coadou and Beaudoin, 1975). The modern disposition shows that the reverse movement would result from a push coming from the

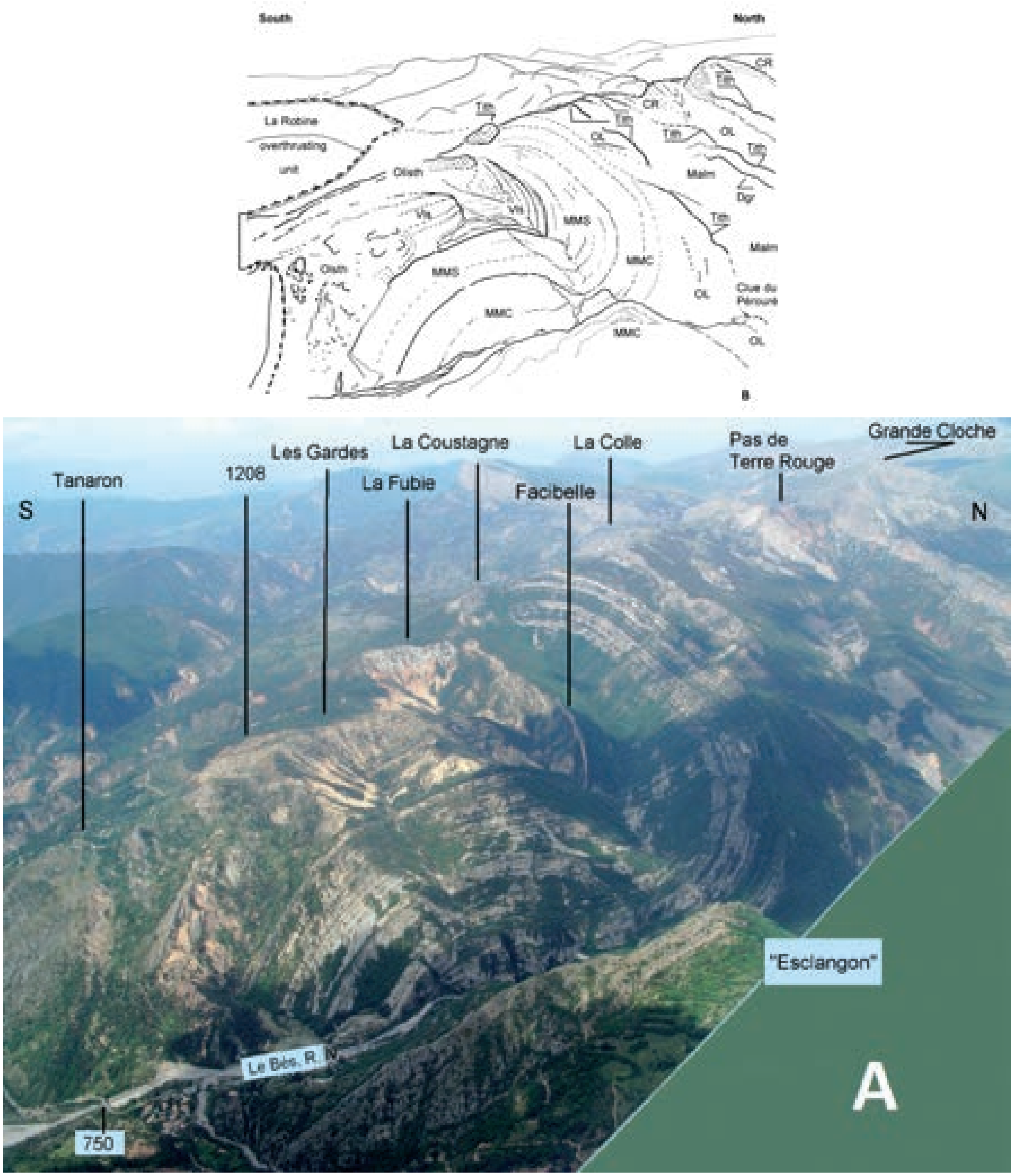


Figure 2. The deformations of the Tertiary and Quaternary deposits south of the "Pérouré Clue". A : The area is named by geologists the "Vélodrome". The centre of the deformation is near the centre of the photo. The Miocene, composed of conglomerate, sands and marls, forms an anticline along the Bès torrent, then a syncline, the northern limb of which on the right, turns on itself and fold back on its own core. The superposed layers follow the movement until the Valensole formations, well layered on the left, between two reworked masses of Oligocene and grey molasse. The successive bevelled layers underline the simultaneity of the extension of the deposits and of the erosion of the existing deformed layers; conglomerates and sands can also be seen in the strong thickness variations of the Miocene. From nearly zero on the left, this Miocene is 900 m thick in the centre of the photo. B : Panoramic sketch : from left to right : Olisth : Olistholith formation; Vls Valensole formation (Pontian = Upper Miocene/Lower Pliocene); MMS: molasse with marl and sands (cupped by white Facibelle banks) and MMC: molasse with marl and conglomerates (Lower Miocene), OL: Oligocene, CR: Lower Cretaceous, Tith: Tithonic facies including Berriasian), Malm: Malm, Dgr: Dogger

Figura 2. *Las deformaciones de los depósitos del Terciario y Cuaternario al sur de la Clue de Pérouré. A. El área es llamada por los geólogos el Velódromo. B. Bosquejo panorámico.*

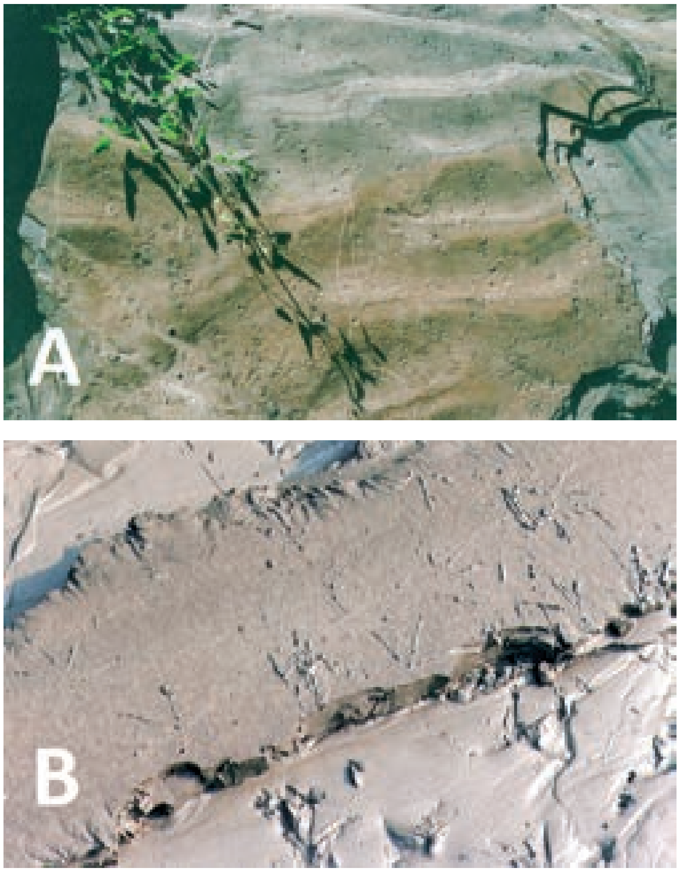


Figure 3. The base of the marly conglomeratic Miocene. A: Example of a half-emerged facies which may develop in all MMC facies; bird foot prints, small birds, or in other cases herons, sea-gulls, etc. B: Taiwan coastal basin; modern print of a heron on a variable plastic support: very plastic in front, hardened in the centre and semi-plastic in the back ground.

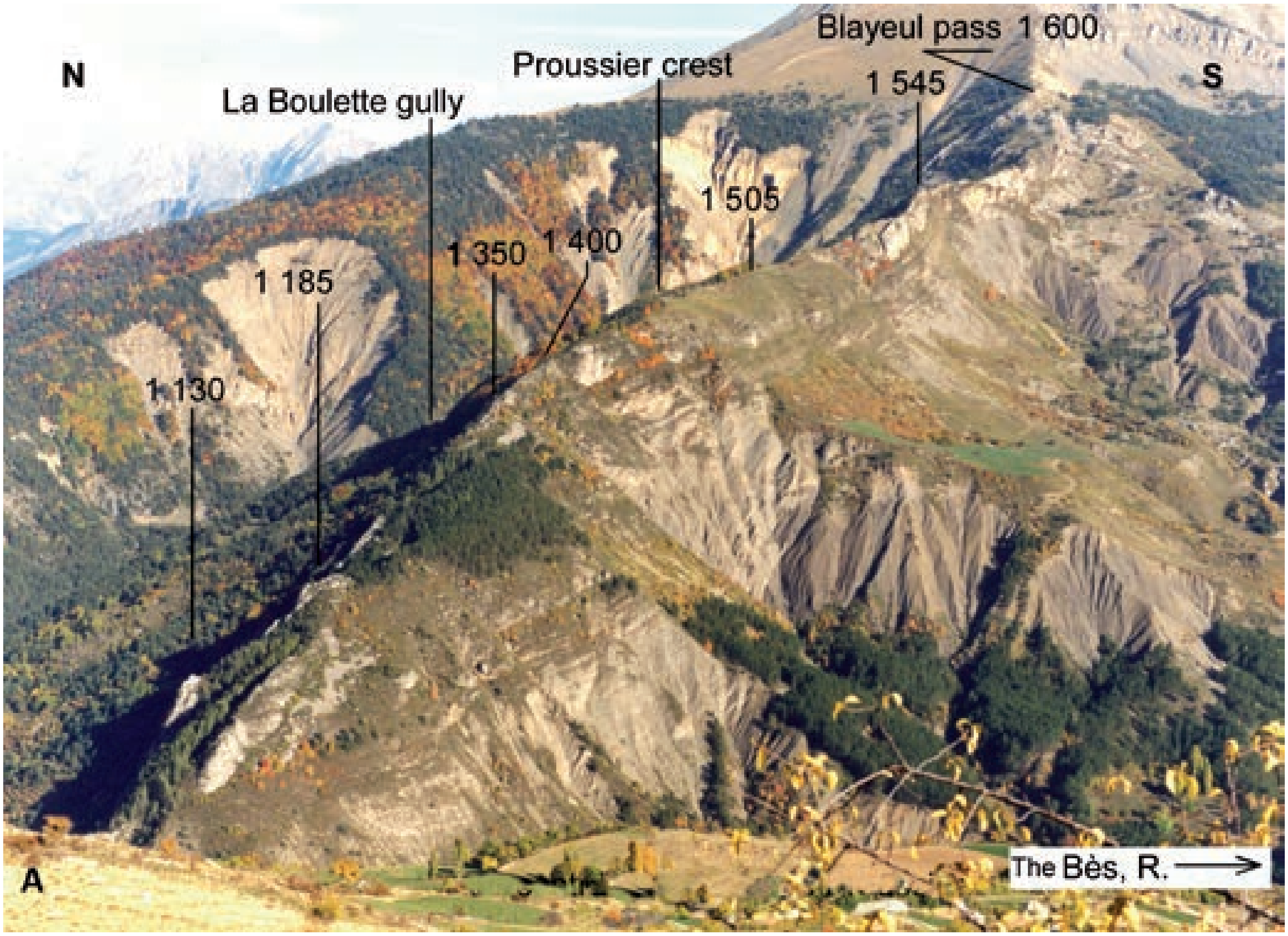
Figura 3. *La base del Mioceno margoso conglomerático. A: Ejemplo de una facies medio emergida que se puede desarrollar en todas las facies MMC. B: Cuenca costera de Taiwan; marca moderna de una garza sobre un soporte de plasticidad variable. Muy plástico en el frente, endurecido en la parte central y semi-plástico al fondo.*

north for the Chine Heights. Microtectonics proves that the overturn of the Chine Bar would have come first, before the Blayeul thrust. This fact has not been demonstrated for the Proussier one, the reversal of which being only limited and involved on the highest parts (alpine phases themselves).

Geological overview and geomorphology

The western face of the Proussier Bar has been largely eroded by the Bès torrent in the upstream Barles Clue basin (Fig. 1), erosion which is particularly active south of Barles (Fig. 4) under the accumulated deposition of the cuttings of the Chine Heights. The eastern face is actively excavated in the gypsum of the Boulette gully, the top of which has a slope of 37°, so 600 m of altitude for 1 500 m of track (Figs. 4 and 5). The bilateral attack is evidenced by the presence of a sinuous and subvertical fault on the Boulette side which cuts the synsedimentary accidents (Figs. 1 and 5), and which makes the gypsum appear vis-à-vis of the Proussier series. The sweeping imposed by the undercutting in the western area reflects the strata of the series, caused by the fault, which appears longitudinal, parallel to the direction of the rocky heights. Thus, on this eastern face, one can observe some dislocation favoured by synsedimentary faults and partially by a rocking movement which is responsible for mass slides, as individual slides of decametric blocks, the whole emerging from the slope that forms a large part of the outcrops on this flank between 1000 and 1 400 m high (Fig. 4). This can also be observed from the north, downwards to the foot of the Proussier Heights, where the Bès torrent crosses it (Fig. 5).

The main transport of debris (blocks of less than 1 metre up to ballasts, main mass of the flow, and broken stones) is due to the strong but late rejuvenation of secondary faults from SW towards the NE, transverse to the direction of the Heights (Fig. 1 to 4). They currently show a high dip towards the north, faults which do not seem to belong to the previously described synsedimentary extensional fault family. The separation between their two compartments of the most northern fault, passing under hill 1 350, is very spectacular on the western side by the Dogger inclusions in the hinge. These stuffings present axes, linked to the upward movements of the southern compartment which is underlined by the relief of hill 1 350, badly named Eagle Rock (in fact, a hill of 1 185 m). This implies that the concerned sedimentary masses were still receiving a non-negligible cover during the throw of the fault, and the vertical one can be estimated at more than 150 m and nearly joined the Hettangian banks. Other faults, nearly parallel to those called secondary, contribute to the same effect with a lesser throw, each of them giving a limited, yet systematic, uplift of the southern compartment. The northern transverse fault, with a sinuous track, and its associates, cut again the previous fault in non-precisely defined areas, because of forests, often interrupted by slope deposits and gravity slides. The dating of each free movement would be necessary to know, but there are too many unknowns to correlate them, e.g. late movements. Invisible in the Boulette gully crossing, the track of the southern fault cannot be clearly seen towards the north-east, except in contact with the Keuper gypsum with cyclopean



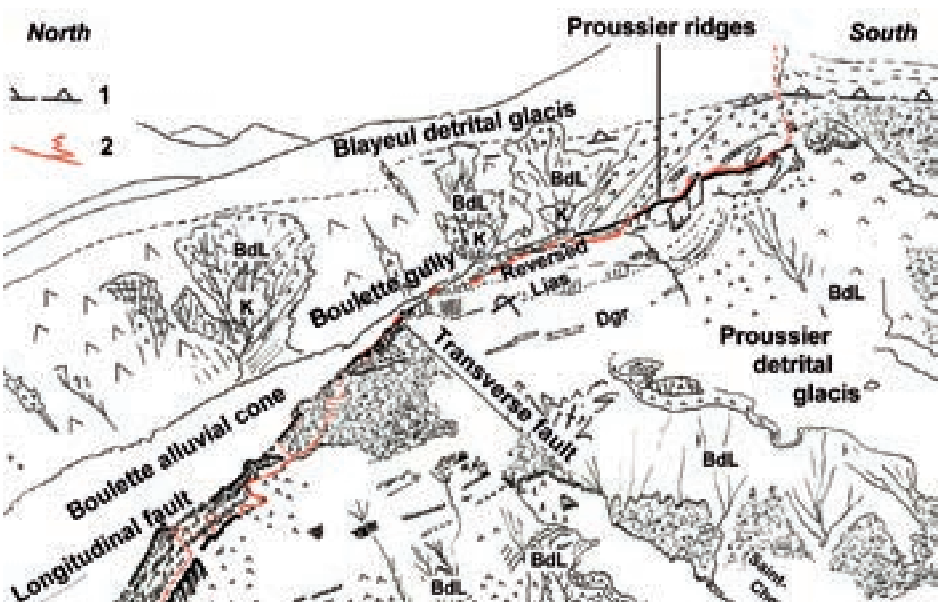


Figure 4. The Proussier Heights seen from St-Anne. A: The Bès Valley and the Proussier Edge which hide the bottom of the "la Boulette" gully. The background is mainly made of Blayeul slope formation, summit of more than 2,000 m; (a) longitudinal fault, (b) transverse fault. B: General disposition of all slope formations under the Proussier edge; only the upper part of it has been named the Proussier Ridges. The Saint-Chevalier gully underlies the track of the northern fault, transverse to the chain. (K) Keuper; (Dgr) Dogger; (Bdl) badlands.
1.- Overthrusting surface; 2.- Footpath

Figura 4. *Las Proussier Heights vistas desde St-Anne. A: El valle del Bès y el Proussier Edge que ocultan el fondo del barranco "la Boulette". B: Disposición general de todas las pendientes de las formaciones bajo el borde Proussier; sólo la parte más alta se conoce como las Proussier Ridges.*

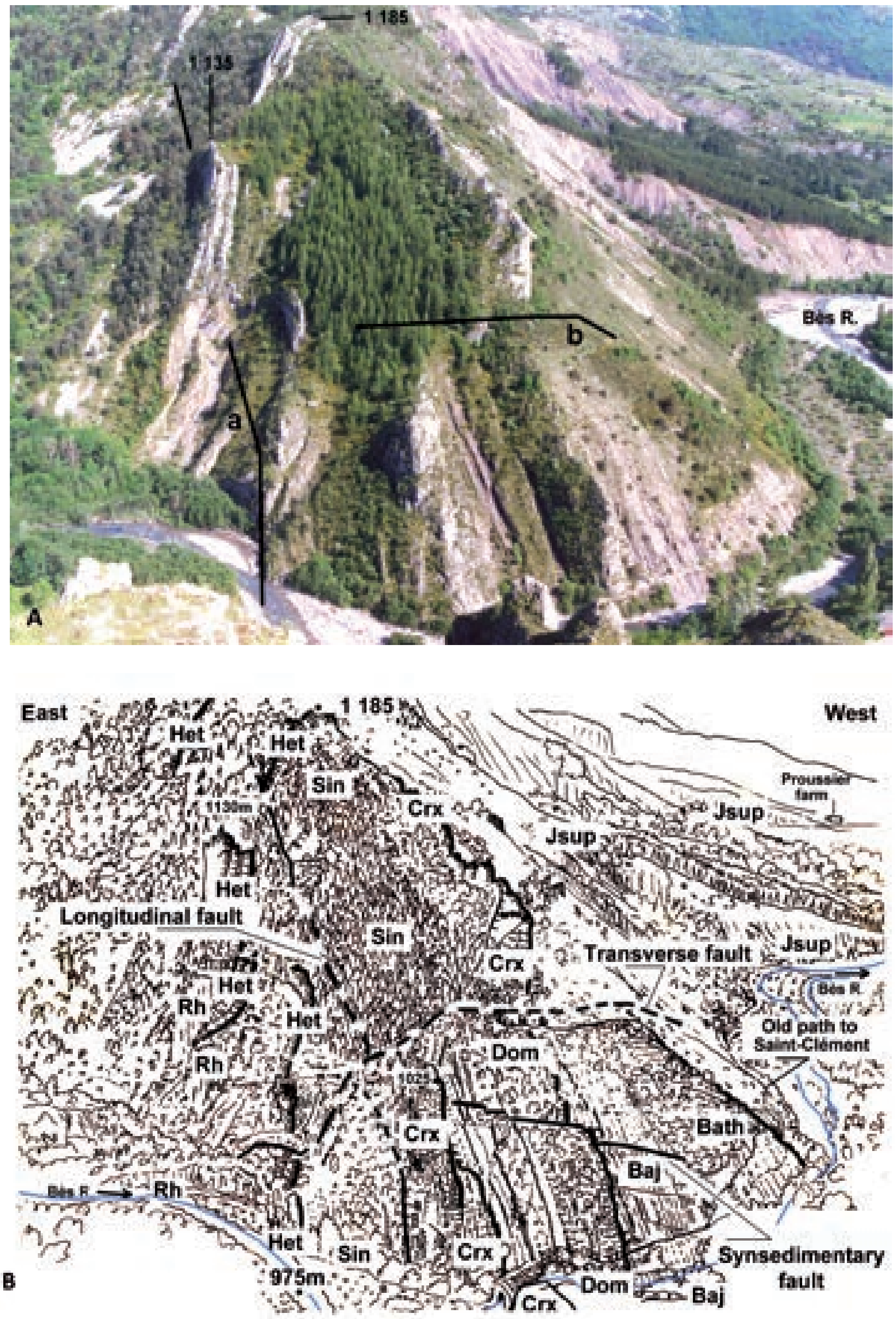


Figure 5. Northern side of the basal part of the Proussier Heights, between the Bès and the 1 185m spot height. A: Landscape (taken) from the Hettangian northern summit. B: Sketch with legends showing the vertical, eroded, tilted and slid down layers by the Bès erosion.
Rh: Rhetian ; Het: Hettangian, Sin: Sinemurian, Crx: Carixian, Dom: Domerian, Baj: Bajocian, Bath: Bathonian, Jsup: Upper Jurassic but different from the final carbonates.
Above the crest and below the "Jsup", the slopes are made up of debris, big enough to resist the Bès torrent erosion. The cut-out part in the Carixian is related to a transverse fault which has contributed to the Hettangian mass slide (hill 1 130m); one dislocated base block of it is lying down, its side on Rhetian. The longitudinal fault cuts the Carixian base and climbs on the left up to the foot of hill 1 185 m outcrop. This longitudinal fault is clearly seen on the right bank of the Bès torrent. A synsedimentary fault, right below, is one of the oldest evidences of the substratum instability of the area.
Figura 5. *Lado norte de la parte basal de Proussier Heights, entre el Bès y el punto de cota 1 185m. A: Paisaje visto desde la cumbre norte de Hettangian. B: Bosquejo con leyendas mostrando capas verticales, erosionadas, basculadas y volteadas por la erosion del Bès.*

breccia formed in the Muschelkalk, where the ancient outcrops start. The throw seems then to explain the presence of ancient levels and also, in a number of places, surface irregularities of the abnormal contact. Both the question about the date of the overturn of the Liasic suite (Eocene ?), and the date of the important movement of the transverse faults can be raised. These observed movements would contribute to define one element of the realization of the bulge of the nappe in the areas here described.

South of hill 1350 m

The 1350 m hill is the last point of the Proussier Bar seen from the Barles town centre in a southerly direction. It used to be, for Barlatan young people, an emblematic finish line of a race that was happening during the French National holiday every July 14. The summit is formed by Carixian banks with an eastern dip of 50 to 70° and which grows towards the south. These banks have undergone more and more marked slides that finish, in the most unstable area, in a mass slide of a part of the banks of the already reversed rock successions. A new path goes through this area which is less dangerous than the passage by the hill 1350 m. The evolution is accomplished over a short distance, less than 400 m, and it is striking for the observer because it stops abruptly at a transverse fault at the foot of hill 1350 m. What are the physico-chemical mechanisms acting during the rocky bank reversal? Although there are recrystallisations of the rocky mass, few calcite small veins are visible, giving no microtectonic evidence. These small veins show that the tectonic conditions have changed. The absence of possible marly walls is due to the distension and dislocations evidenced by the banks *after* their progressive aerial position then destabilizing attacks on the undermined side, giving an active relief with cliff and slope below. On the other side, this act may lead to morphological fattening and retain sliding elements remaining in equilibrium, despite the dip and slope value. Water meanders, or their remnants, have not been observed. On the other hand, the presence of a reddish eolian deposit or loess, sometimes abundant, is observed under the biggest boulders, which are moving downslope or ready to be pushed down. This loess is a light soil, which may be rich in organic matter with silt-size grains.

In Beauce province, south of Paris, the loess is still depositing, coming from the Sahara, since the Burdigalian age. The only peri-glacial origin of the Proussier loess is difficult to reconcile with the necessary aerial winnowing and its apparent organic rich composition. An audacious explanation has been given: this could be due to the mixture and grinding of the vegetal cover with soils during the installation of the thrust.

Collapses, field slides and slope formations

The collapses, more or less important, annually interrupt the roads in the area for limited periods. They are always the consequence of the destabilizing work on rocky masses which roads and railways have been cut into. The consequence of slides and mass or not mass movements, of collapses, belong to another scale regarding their importance over time. In most cases, it is possible to identify the geological strata from which the boulders or the masses are coming. The date of slides is seldom given. If undermining is the most common cause suggested, the conditions of the undermining are not so well known, particularly the relative speed of alteration-erosion-abrasion compared to the displacement speed of the rocky masses, sliding on slopes or thrusting, which is revealed by the accumulation of the breaking down towards the slope. In other occurrences, the observer can only notice the superposition of the involved formations and not the speed of relative displacement. A GPS sensor, on the Blayeul thrusting mass, shows positive movement of a millimetre per year, without knowing if this value takes into account the reworking, the erosion being very active at the foot of its western flank which is very abrupt. Here we have only the altitudes where the displaced boulders are now, and the sill altitudes of the basins in which they are located. In the affected area (Fig. 1), the hecto- or kilometre scale boulders seem, for the most part, to be still attached for dozens of years. We will only conclude that they started their displacement when the Pérouré Tithonic relief, already in position close to the modern one (vertical and oriented W-E, Fig. 1), was largely indented by a limited exposure in its central gully. The average altitude would have been around 1250 m, an altitude above which it is rare to find pebbles. Indeed, the altitude of sliding boulders is always higher than a hundred metres. This fact distinguishes those from previously detached boulders and slides, after having progressed again after the “Clue de Barles” the previous sill of the basin which climbs until the entrance of Barles village has been excavated out with a lowering of nearly 500 m. These relative datations show that the phenomena have occurred when the basins, located downstream, have started their excavation; this fact places the phenomena as forming after the Mio-Pliocene Valensole formation because they deeply cut it further to the south. For the other easily seen and closed elements, the northern part of the Proussier Bar relief is the most exposed to the undermining, stormy rains provoking floods and abrasions, equally important as brutal, inside an enormous debris mass, lying on also low attacked resistant layers (“Badlands”).

Conclusions

The evolution keys of the morphology in the studied area are the same as for the other basins which have been formed downstream of Barles. The responsible phenomena evolve by already known common rules. The morphological transformations occur with a higher speed than the modifications of the sedimentary material, even faster than most of the tectonic deformations. In the best occurrence, the advance of a thrusting front, linked to a huge compression, is about 10 cm per year in modern conditions (half the value of the opening of the Pacific Ocean). If alteration, erosion and scouring out occur as in Taïwan for example, the apparent advancement of the front slows down without being perceived by people living in the area, except for earthquakes. It is the same for inhabitants living in other more instable areas such as Bolivia, or less frequently for people living in the south of the Hautes Alpes Département. The simultaneity of the tectonic action on a much larger area is due to a perspective effect linked to human scale. On the other hand, the result of these deformations, accumulated phase after phase, gives a structure to the sedimentary mass, distributing geographically and geometrically soft or hard formations, whether dislocated or not (Bureau, 1983, p. 245; Bureau, 1986, p. 315 and 326). The erosion carries on its action at the same rate as the subsurface when it arrives at the surface. Yet, if erosion has its own rules, it must really act in accordance with those of geology. The active motions in the structured Barles area comply by these principles. The Bès torrent flow, pluviometry, rain spreading on each basin and flood, erosion starting again and abrasion as a function of base level of each basin. It does not appear useful to inventory all the factors and parameters, intervention and succession of which create a geographic gradient like the one reflected by the image which, at a lower scale, would describe the course of a torrent without describing the bank’s evolution. Lastly, the relation between the advancement of a nappe and the disaggregation of its thrusting front remains to be investigated further. The superimposition which led to the modern Bès torrent has been described. As a water flow takes the lower passage and as erosion is regressive, it is generally the lower water flow which wins. This is the way to explain the localization of the Bès passage through the Robine unit (Fig. 2B) in the southern area of the described zone. The analysis of the connected area between the Blayeul mass and the Robine unit shows a long flexure along the linking up zone. It is underlined by vertical dips, easily seen on a scale of dozens of metres. This flexure has had a sufficient impact to have represented the possible weak point of the slightly metamorphosed marls, a weak point which has made the settling down of the Bès torrent possible on the lower part of the thrusting material. The impact of the Quaternary glaciations has not been presented. Freezing and, above all, melting and refreezing, have provoked a complementary fracturing, making easy an important removal and an abrasion during their final phases. The hypothesis that a little glacier could have been responsible for the few off-centre excavated small valleys on the Tithonic heights of the Barles Clue, is quite probable; and it is clearly true that the breaking up during deglaciations could have provoked gigantic abrasion in the Alps valleys and caused an intense morphologic cleaning away in the Bès valley (Jorda, 1980). The upper Bès Basin and all the surfaces of Barles area constitute the origins of extremely important flows of sediment loaded waters. These latter would have rolled several-ton boulders without any difficulty, as in the Chamonix example (a village below Mont Blanc) where the modest torrent carried away houses some years ago. It will have required nearly 14000 years to stabilize the post-glacial temperature. During the same time, the Blayeul which is a living geological structure, will have moved only 150 m forward, adding this volume to the other ones to be towed away.

The results exist, the question about “how?” calls for further research.

Acknowledgments

No doubt that this text does not come from a large consensus between colleagues who have worked in the Barles area. It is simply an attempt to remember students and field-trip leaders work, and so thus pay homage to Professor Michel Durand Delga for his great scientific probity. I deeply thank Robert Bourrouilh for accepting this paper on Barles that he has known very well for several years and where he used to teach Parisian students in field geology. I am also very grateful to Françoise G. Bourrouilh-Le Jan, to Professor Donn S. Gorsline and Romain R. Bureau for their translation of the text into English.

References

Beaudoin, B. Gigot P. Haccard D. 1970. Flysch et molasses, approche sédimentologique. *Bulletin de la Société géologique de France* (7), XII, 664-672.

Bureau, D. 1983. Dynamique structurale des blocs basculés de l'Est Algérien. *Annales de la Société Géologique du Nord*, CIII, 231-246, 15 fig.

Bureau, D. 1986. *Dynamique structurale : Evolution méso-zoïque et devenir orogénique de la partie septentrionale du Fossé Saharien (Sud-Ouest Constantinois et Aurès, Algérie).* Thèse de Doctorat d'Etat, Université Pierre-et-Marie-Curie-Paris VI, 779 p., 153 fig., 3 tb., 1 carte h-texe.

Coadou, A. and Beaudoin, B. 1975. Pulsations tectoniques et rythmes sédimentaires associés dans le bassin sub-alpin méridional au Jurassique inférieur et moyen. IXe *Congrès International de Sédimentologie Nice,* thème 5, 49-60.

Debats, J.-M. Lagabrielle, R. and Taponnier, P. 1972. Un exemple de superposition de deux phases de plissements dans les chaînes subalpines de la région de Digne. *Géologie Alpine,* 48, 2, 179-185.

Gidon, M. and Pairis, J.-L. 1986. Problèmes d'autochtonie et de charriage aux confins méridionaux du dôme de Remollon (environs de Turriers, Alpes de Haute-Provence). *Géologie de la France*, 4, 417-432, 9 fig.

Gidon, M. and Pairis, J.-L. 1988. La structure des environs de Digne (chaînes subalpines méridionales, Alpes de Haute-Provence) : un exemple d'interférence entre l'avancée d'une nappe épiglyptique et la sédimentation sur son front. *Comptes Rendus de l'Académie des Sciences de Paris,* 307, 1283-1288.

Goguel, J. 1963. Les problèmes des chaines subalpines. In: Livre à la Mémoire du Professeur P. Fallot, *Mémoire hors série de la Société géologique de France,* II, 301-308.

Grandjacquet, C. and Haccard, D. 1973. Mise en évidence de la nature sédimentaire et de l'âge néogène de certaines séries de « Cargneules » et de gypse des chaînes subalpines méridionales ; implications structurales. *Comptes Rendus de l'Académie des Sciences de Paris,* 276, 2369-2372.

Jorda, M. 1980. Le glaciaire quaternaire des Alpes de Haute-Provence. « Montagnes et Montagnards ». *Revue de Géographie alpine,* 183-194.

Lemoine, M. 1972. Rythme et modalités des plissements superposés dans les chaînes subalpines méridionales des Alpes occidentales françaises. *Geologische Rundschau,* 67, 3, 975-1010.

Tessier, B. and Gigot, P. 1989. A vertical record of different tidal cyclicities. An example from the Miocene Marine Molasse of Digne (Haute Provence, France). *Sedimentology*, 36, 5, 767-776.

Recibido: febrero 2014
Revisado: enero 2015
Aceptado: junio 2015
Publicado: julio 2016