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The Upper Oligocene of Montgat (Catalan Coastal Ranges, Spain): new age constraints to the western Mediterranean Basin opening

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ABSTRACT

The Oligocene deposits of Montgat are integrated in a small outcrop made up of Cenozoic and Mesozoic rocks located in the Garraf-Montnegre horst, close to the major Barcelona fault. The Oligocene of Montgat consists of detrital sediments of continental origin mainly deposited in alluvial fan environments; these deposits are folded and affected by thrusts and strike-slip faults. They can be divided in two lithostratigraphic units separated by a minor southwest-directed thrust: (i) the Turó de Montgat Unit composed of litharenites and lithorudites with high contents of quartz, feldspar, plutonic and limestone rock fragments; and (ii) the Pla de la Concòrdia Unit composed of calcilitharenites and calcilithorudites with high contents of dolosparite and dolomicrite rock fragments. The petrological composition of both units indicates that sediments were derived from the erosion of Triassic (Buntsandstein, Muschelkalk and Keuper facies), Jurassic and Lower Cretaceous rocks (Barremian to Aptian in age). Stratigraphic and petrological data suggest that these units correspond to two coalescent alluvial fans with a source area located northwestwards in the adjoining Collserola and Montnegre inner areas. Micromammal fossils (*Archaeomys sp.*) found in a mudstone layer of the Pla de la Concòrdia Unit assign a Chattian age (Late Oligocene) to the studied materials. Thus, the Montgat deposits are the youngest dated deposits affected by the contractional deformation that led to the development of the Catalan Intraplate Chain. Taking into account that the oldest syn-rift deposits in the Catalan Coastal Ranges are Aquitanian in age, this allows to precise that the change from a compressive to an extensional regime in this area took place during latest Oligocene-earliest Aquitanian times. This age indicates that the onset of crustal extension related to the opening of the western Mediterranean Basin started in southern France during latest Eocene-early Oligocene and propagated southwestward, affecting the Catalan Coastal Ranges and the northeastern part of the Valencia trough during the latest Chattian-earliest Aquitanian times.

KEYWORDS **Catalan Coastal Ranges. Compression. Alluvial fan. Chattian. Micromammal. Catalan Intraplate Chain.**

INTRODUCTION

The field work, that finally led to the writing of this paper, was done as part of a PhD thesis (Parcerisa, 2002) linked with a research project funded by the Dirección General de Enseñanza Superior e Investigación Científica of Spain (PB97-0883) whose principal researcher was Francesc (Cesc) Calvet. One of the main objectives of the PhD thesis was to describe the evolution of the central part of the Catalan Coastal Ranges (Collserola high) during Miocene times from the petrological composition of several Miocene deposits surrounding this high (Fig. 1). With this goal in mind, we began to work, together with Cesc, on the study of the detrital rocks of presumably Miocene age, cropping out close to the Montgat town (Fig. 2).

Previous studies of these deposits had assigned them different ages, from Miocene to Pliocene, thus they were considered as deposited in an extensional tectonic regime (Depape and Solé Sabarís, 1934). Almera (1902) reported the presence of some plant remnants (*Salix angusta*) indicative of a Tortonian to Pliocene age. From petrographic and tectonic criteria, Depape and Solé Sabarís (1934) inferred a Late Miocene age. Finally, Vicente (1964, 1971) after a compilation of the plant remnants found in the studied area, proposed a Tortonian to Messinian age.

According to Guimerà (1984), Anadón et al. (1985), Fontboté et al. (1990), Roca (1996) and Roca et al. (1999), in the Catalan Coastal Ranges the transition from the contractional building of the Catalan Intraplate Chain to the extensional opening of the western Mediterranean, took place during Late Oligocene times. The assigned late Oligocene age for this change was based on the presence of an small outcrop of Lower Oligocene deposits (Campins basin; Fig. 1) still affected by a contractional deformation (Anadón, 1986), and from the presence of Aquitanian to Burdigalian age rocks in the lowermost dated syn-rift deposits (Cabrera and Calvet 1996; Roca et al., 1999; Cabrera et al., 2004). The lack of dated upper Oligocene and lowermost Aquitanian deposits in the Catalan Coastal Ranges has prevented to precise the age of the beginning of the extensional deformation in this area. As the western Mediterranean began to open due to the extensional movement of major NE-SW faults located along the Gulf of Lion, the Catalan Coastal Ranges and the Valencia coast (Roca et al., 1999), any improvement in the dating and structural characterisation of the beginning of this extensional deformation can be especially useful in order to understand the formation of the western Mediterranean. Thus, the discovery of an upper Oligocene outcrop in the Catalan Coastal Ranges is essential to improve the understanding of the palaeogeographic and tectonic evolution of the central part of the Catalan Coastal Ranges and the western Mediterranean during Cenozoic times.

From all these premises the scope of this paper is twofold: 1) to characterize the stratigraphy, petrography, structure and age of these new dated Oligocene deposits, and 2) to integrate the obtained results in the Cenozoic evolution of the Catalan Coastal Ranges in order to specify the end of the contractional deformation of this area and the beginning of the extensional deformation, which led to the opening of the western Mediterranean.

MATERIALS AND METHODS

In order to know the extent and structure of the Oligocene deposits a detailed (1:5,000 scale) geological mapping was made westwards of the Montgat town and six stratigraphic sections were carried out to recognize the main sedimentary features of these deposits. Transmitted light microscopy was used for the petrographic study on 65 samples of mudstones, sandstones, limestones and conglomerate pebbles. Point-count analyses on thin sections of conglomerates and sandstones were performed using the Gazzi-Dickinson's method (Gazzi, 1966; Dickinson, 1970) to made a provenance analysis from detrital modes (Ingersoll et al., 1984). Finally, in order to find micromammal fossils and to date the deposits, about 30 kg of a mudstone bed were washed and sieved.

GEOLOGICAL SETTING

The Catalan Coastal Ranges extend over 250 km along the northeastern coast of Spain, between the Ebro Basin (southern foreland of the Pyrenees) and the Valencia Trough (Fig. 1). In their central part, the Catalan Coastal Ranges are composed by two parallel mountain chains, the Prelitoral and the Litoral ranges separated by the Vallès-Penedès Basin (Figs. 1 and 2). The Prelitoral Range consists of a Palaeogene major anticline with multiple NW-directed thrust sheets overthrusting the Ebro Basin which is cut southeastwards by the Vallès-Penedès major normal fault. The Litoral Range is a Neogene horst structure tilted towards the NW that, striking along the coast, does not show noticeable Cenozoic internal deformation. The Vallès-Penedès Basin developed on top of the lower parts of the NW side of the Litoral horst close to the major SE dipping normal fault (Vallès-Penedès fault) that separated this basin from the Prelitoral Range. To the SE, both, the Catalan Coastal Ranges and the Litoral horst are bounded by another major extensional fault, the Barcelona fault, which is parallel to the coast and separates them

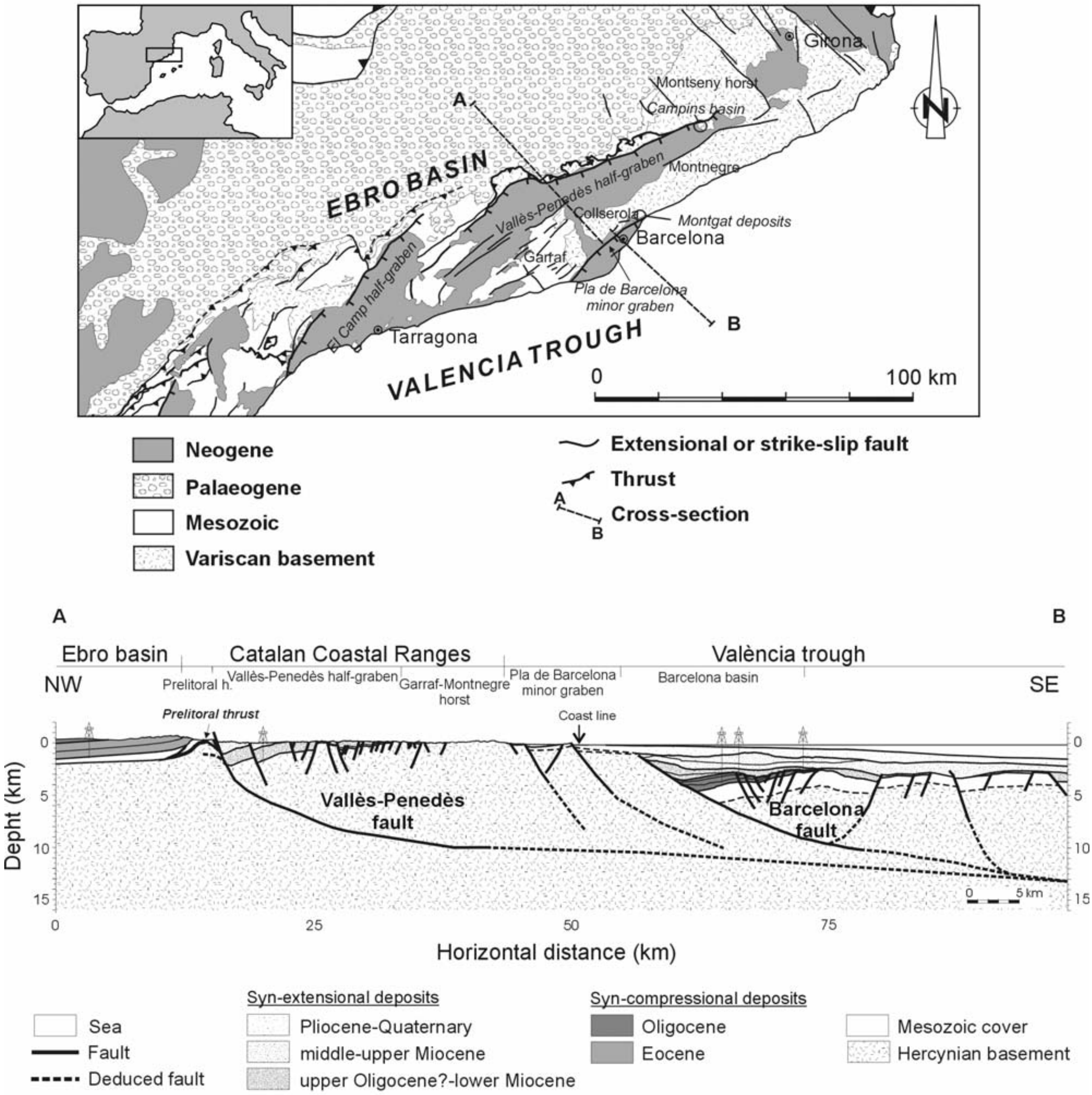

FIGURE 1 | **Geological and structural sketch of the Catalan Coastal Ranges with a cross-section showing the tectonic structure of these ranges.**

from the offshore Barcelona Basin (Fig. 2). Close to this major fault, in its footwall, there are some minor Neogene grabens (as the Pla de Barcelona basin where the city of Barcelona is located) superimposed to a Variscan basement and thin Mesozoic cover affected by northwest-directed contractional structures. The Montgat outcrop is located precisely in this contractionally deformed fringe developed close to the Barcelona fault along its footwall block.

The evolution of the Catalan Coastal Ranges during Cenozoic times has been roughly divided into two stages (Fontboté, 1954; Fontboté et al., 1990; Roca, 1996): a Palaeogene compression phase and a Neogene extensional stage. During the Palaeogene, N-S compressive stresses related to the development of the Pyrenean orogeny led to the inversion of the older Vallès-Penedès fault (Guimerà, 1984) and probably also of the Barcelona fault (Gaspar-Escribano et al., 2004) which bounded previously former Mesozoic basins. The obliquity between compressive direction and these ENE-WSW-striking faults resulted in the development of a thick-skinned system of a NNW-directed thrusts with a left-lateral strike-slip component (Anadón et al.,

1985) which has been referred to as the Catalan Intraplate Chain.

Starting in the Oligocene, extensional collapse of the Catalan Intraplate Chain related to the opening of the Valencia Trough led to a general rearrangement of the region into horsts and grabens (Roca and Guimerà, 1992), as it stands today. Whereas large parts of the Catalan Coastal Ranges were uplifted as a result of the Valencia Trough rift shoulder effect (Gaspar-Escribano et al., 2004), extensional activation of upper crustal-scale Barcelona and Vallès-Penedès faults governed the development of subsiding half-grabens in the Catalan margin filled by thick Oligocene to Neogene successions (e.g. Roca et al., 1999; Cabrera et al., 2004).

Located in the Garraf-Montnegre horst, in the footwall of the ENE-oriented normal faults that bound northwestwards the Pla de Barcelona graben, the Cenozoic deposits recognised near the town of Montgat form two small outcrops (less than 300 m^2) which are partially covered by undeformed Quaternary deposits. In the southeastern outcrop, these Cenozoic deposits unconformably overlay both the Variscan basement and a thin Mesozoic cover. The Variscan basement is made up of Devonian dolomites and limestones, Silurian black shales and Upper Carboniferous to Permian granitoids (Vaquer, 1973; Gil Ibarguchi and Julivert, 1988; Enrique, 1990; Julivert and Duran, 1990) and the Mesozoic cover is constituted by Triassic limestones, dolomites and locally siliciclastic and evaporitic rocks, ascribed to Buntsandstein, Muschelkalk and Keuper facies (Virgili, 1958; Marzo and Calvet, 1985).

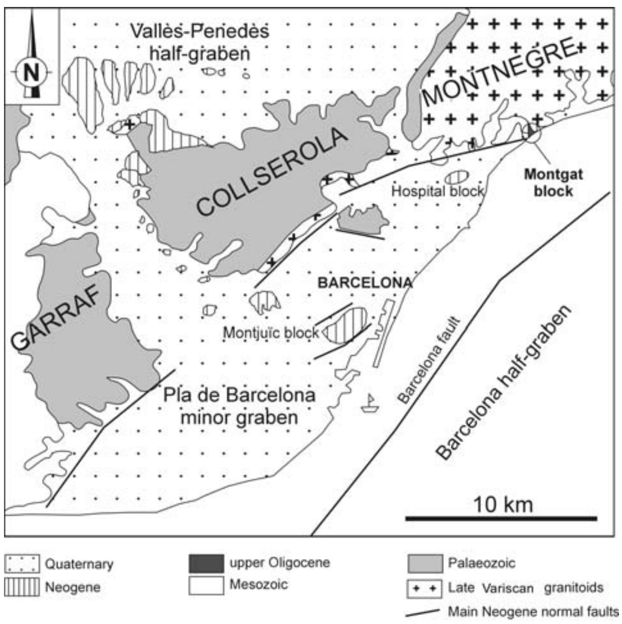

FIGURE 2 | **Geological and structural sketch of the Pla de Barcelona.**

STRUCTURE

The Cenozoic deposits of Montgat, are strongly deformed by contractional structures (folds, thrusts and strike-slip faults). Bounded northeastwards by a major NW-SE oriented thrust which dips to the NE, its structure could be simplified as a major syncline cut by a southwest-directed thrust and N-S oriented strike-slip faults (Fig. 3). The syncline has an overturned northeastern limb and its axis is 276/44º north-oriented; an orientation which is roughly parallel to the strike of the thrust that separates two well-differentiated stratigraphic units in the Cenozoic deposits of Montgat. The N-S oriented strike-slip faults are mainly dextral and mainly dip eastwards. They separate blocks in which the Cenozoic unconformably overlies different stratigraphic levels (Triassic or Palaeozoic) which are always younger in the hangingwall block. This denotes that these faults result from the inversion of normal faults that were active before the Cenozoic sedimentation.

STRATIGRAPHY AND PETROGRAPHY

Two different stratigraphic units separated by an E-W oriented thrust can be distinguished in the Cenozoic materials of Montgat: the Pla de la Concòrdia Unit located to the south in the footwall block and the Turó de Montgat Unit located to the north in the hangingwall block of the thrust (Fig. 3).

Turó de Montgat Unit

This unit integrates the northeastern parts of the eastern Montgat Cenozoic outcrop and unconformably overlies the Variscan basement (mainly Silurian shales and Upper Carboniferous-Permian granites). It can be divided into three subunits (Fig. 4): the basal, the middle and the upper subunits.

The *basal subunit* is made up of a 4 m thick massive breccia deposits (Fig. 4A) containing pebbles of limestone, shale and porphyry rock fragments (Table 1).

The *middle subunit* is 25 m thick and consists of massive poorly sorted conglomerates with some thin interbedded sandstone layers (Fig. 4B and 5C). The conglomerates are lithorudites with pebbles of shale, granite and limestone fragments and minor amounts of quartz (Table 1). Sandstones, which are arkoses (Fig. 6), are mainly made up of quartz, feldspar and biotite grains (Table 2).

The *upper subunit* is 40 m thick and is made up of interbeds of conglomerates, grey sandstones and red

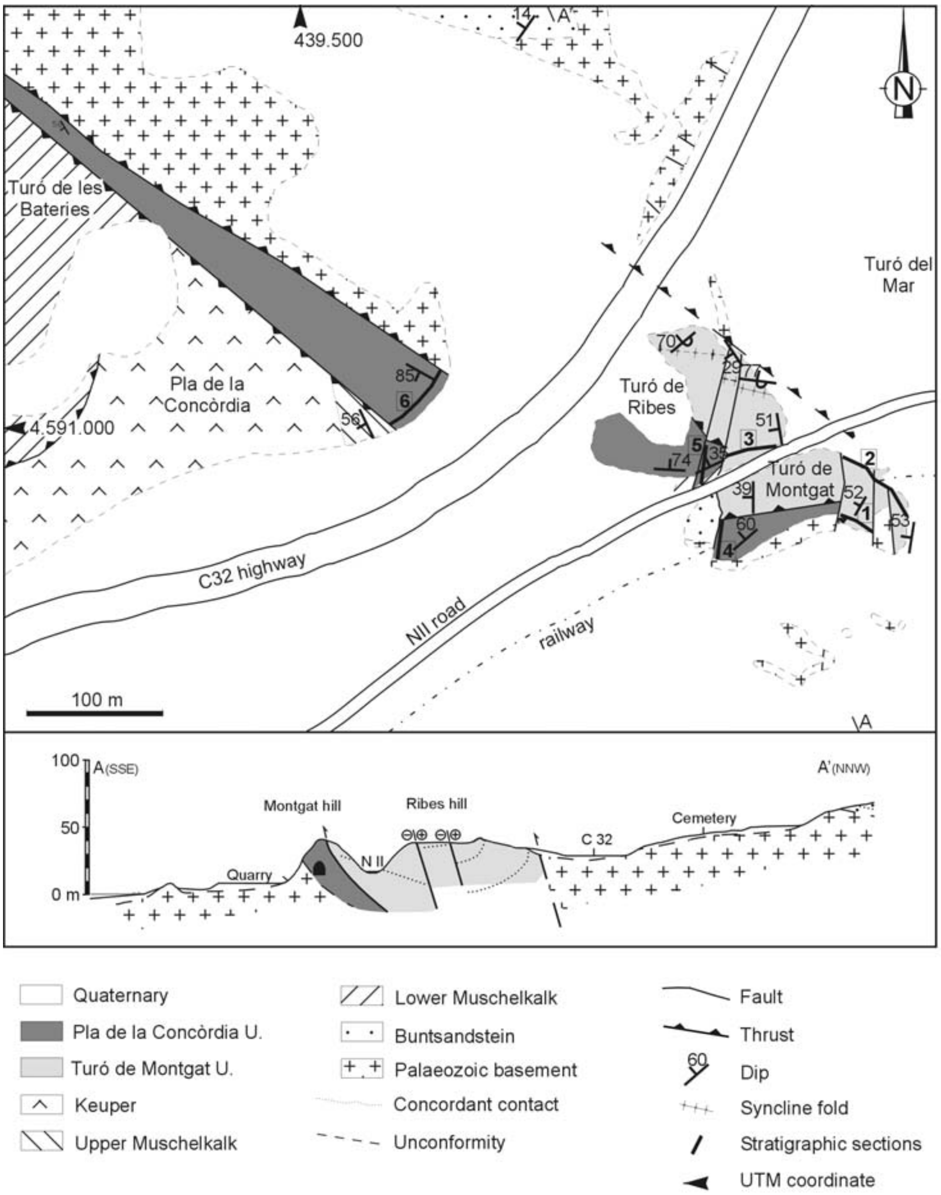

FIGURE 3 **Geological map of the Montgat area with the location of the stratigraphic sections shown in Fig. 7.**

mudstones (Fig. 4C). Conglomerates are lithorudites with abundant intraformational oncolithic fragments (Table 1) and sandstones are litharenites made up of limestone rock fragments, quartz and feldspar grains (Fig. 5A; Table 2). Conglomerates and sandstones have a petrological composition similar to those of the underlying middle subunit, although in the lower parts they could be exclusively made up of limestone rock fragments deriving from the Mesozoic cover (Table 1).

It is interpreted that the basal subunit deposits record a colluvial environment, the middle subunit a proximal alluvial fan environment and the upper subunit a medium to distal alluvial fan environment.

Pla de la Concòrdia Unit

Located southwestwards of the previous unit, the Pla de la Concòrdia Unit unconformably overlies Triassic (lower Muschelkalk) and Devonian limestones. It can also be divided into three subunits.

The *basal subunit,* which consists of breccia deposits (Fig. 4D) with limestone rock fragments (Table 1) crops out locally and is always less than 2 m thick.

The *middle subunit*, made up of a 2 m thick bed of grey marls and a 3 m thick bed of thin laminated brown limestones, is only present in one of the stratigraphic sections carried out in this unit. The limestones contain fossils from plant and charophyta stem fragments and ostracoda valves. These beds belong to the interval where plant remnants previously used to date the Montgat Cenozoic materials, were collected (Almera, 1902; Vicente, 1964, 1971). In the lower part of the limestone bed there is a thin layer of drab coloured breccia mainly made up of limestone rock fragments (Tables 1 and 2; Fig. 6).

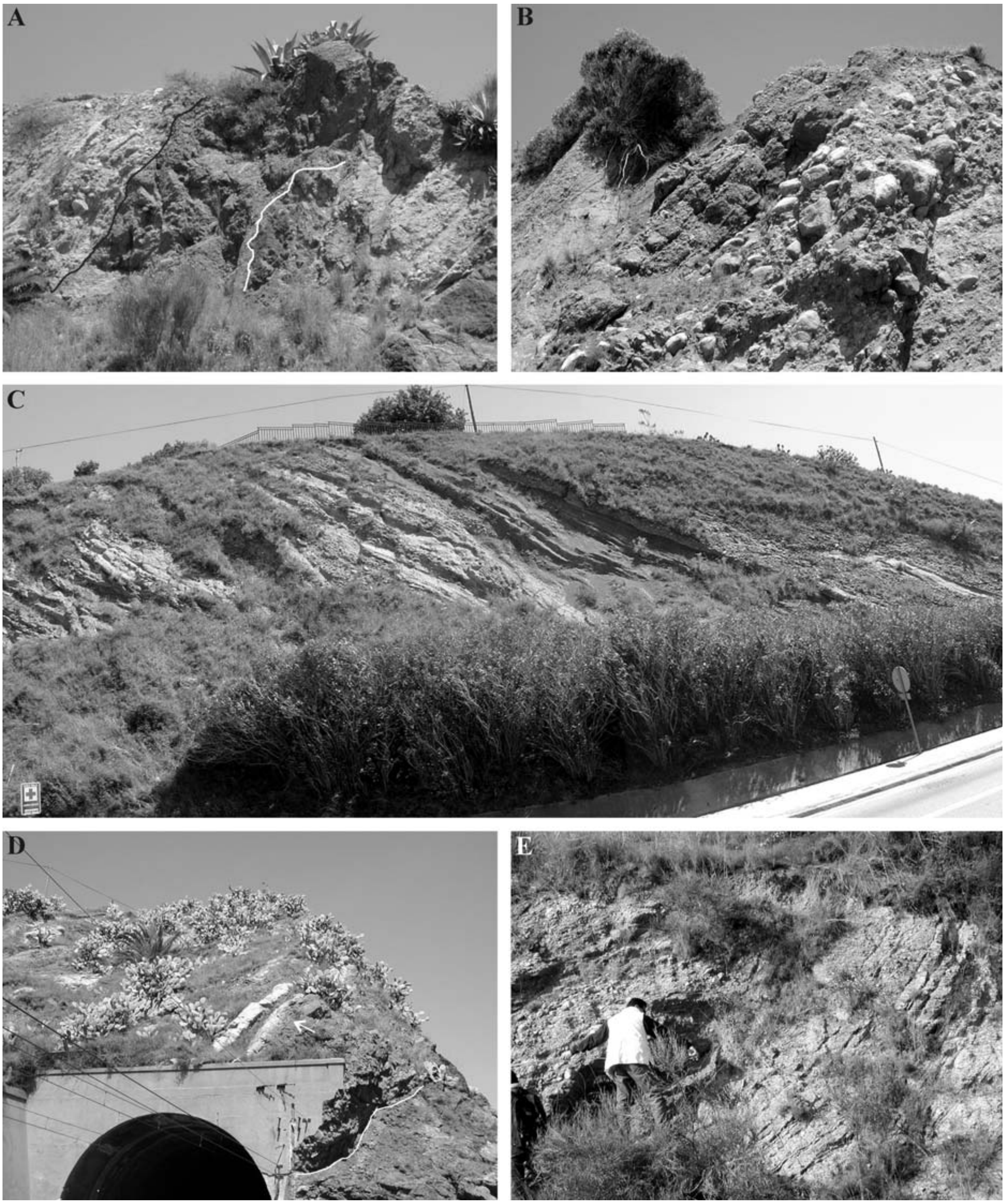

FIGURE 4 | **Field views of the Turó de Montgat Unit (A to C) and the Pla de la Concòrdia Unit (D and E). A) Detail of the basal subunit unconformably overlying Silurian shales (white line) and underlying the middle subunit (black line). B) Conglomerates of the middle subunit with some interbedded sandstone layers. C) Two thick conglomerate and sandstone beds separated by red mudstones in the upper subunit. D) Unconformable contact (white line) between Devonian limestones (right) of the basement and the basal subunit (left). Above the basal subunit appears the upper subunit made up of calcrete deposits (white arrow). E) Interbedded conglomerate, sandstone and mudstone beds forming the upper subunit.**

TABLE 1 | **Modal compositions of representative conglomerates of Cenozoic deposits of Montgat. NCE: Non carbonate extrabasinal components; CE: Carbonate estrabasinal components; CI: Carbonate intrabasinal components.**

Unit	**Turó de Montgat Unit**												**Pla de la Concòrdia Unit**							
	Basal	**Middle**				**Upper**							**Basal**	**Mid.**	**Upper**					
Sample	**MG a**	**MG b**	**MG c**	**MG d**	**MG e**	**MG f**	**MG g**	**MG h**	**MG i**	**MG j**	**MG k**	**MG l**	**MG m**	**MG p**	**MG n**	**MG o**	**MG q**	**MG r**	**MG s**	**MG t**
Components	**%**	**%**	**%**	**%**	**%**	**%**	**%**	**%**	**%**	**%**	**%**	**%**	**%**	**%**	**%**	**%**	**%**	**%**	**%**	**%**
NCE	**10**	**70**	**60**	**45**	**50**	**—**	**—**	**50**	**10**	**30**	**55**	**65**	**10**	**—**	**85**	**—**	**—**	**—**	**—**	**—**
Quartz	—	5	5	5	5	—	—	5		5	10	10	—	—	—	—	—	—	—	—
Metamorphic RF	5	30	10	20	20	—	—	20	10	25	20	20	8	—	50	—	—	—	—	—
Porphyry RF	5	20	15	—	15	—	—	15	—	—	15	20	2	—	10	—	—	—	—	—
Granite RF	—	15	30	20	10	—	—	10	—	—	8	10	—	—	25	—	—	—	—	—
Red sandstone RF	—	—	—	—	—	—	—	—	—	—	2	5	—	—	—	—	—	—	—	—
CE	**90**	**30**	**40**	**55**	**50**	**100**	**100**	**45**	**90**	**25**	**25**	**30**	**90**	**100**	**15**	**100**	**100**	**100**	**100**	**—**
Grains.-Wackes.	—	—	10	35	15	—	—	10	—	—	10	10	—	—	7	—	—	5	5	—
Dark dolosparite	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	20	—	15	70	—
Brown dolosparite	90	20	10	10	20	—	—	5	—	—	5	10	90	—	8	—	—	—	—	—
Dolmicrite/Micrite	—	10	20	10	15	100	100	30	90	25	10	10	—	100	—	80	100	80	25	—
CI (Oncolithic)	**—**	**—**	**—**	**—**	**—**	**—**	**—**	**5**	**—**	**45**	**20**	**5**	**—**	**—**	**—**	**—**	**—**	**—**	**—**	**100**
Grain mode (cm)	**25**	**10**	**30**	**15**	**15**	**Mc**	**Mc**	**10**	**3**	**10**	**30**	**5**	**30**	**5**	**5**	**3**	**3**	**5**	**3**	**2**
Sorting	**M to P**	**M to P**	**M to P**	**M to P**	**M to P**	**M**	**M**	**M**	**M**	**M to P**	**M to P**	**M**	**M to P**	**M to P**	**M**	**M**	**M**	**M**	**M to W**	**W**

Sorting: P: Poor sorted; M: Moderately sorted; W: Well sorted.

The *upper subunit* is more than 50 m thick and consists of drab coloured conglomerates with some interbedded sandstone and mudstone layers (Fig. 4E). Locally, in its lower parts, it also includes a 1 to 1.5 m thick bed of grey limestones (Fig. 4D) formed by low amounts of limestone rock fragments in a micritic matrix. Conglomerates and sandstones of this subunit are lithorudites and litharenites made up of limestone rock fragments (Figs. 5B and 5D) and low percentages of intraformational oncolithic clasts (Tables 1 and 2). However, two beds of this subunit show a quite different composition: one is exclusively made up of oncolithes (Fig. 5E) and the other has a very similar petrological composition to the Turó de Montgat Unit conglomerates (Table 1). Moreover, a mudstone bed of this subunit contains mammal fossils (Fig. 7).

From a sedimentological point of view, it is interpreted that: (i) the basal subunit deposited in a colluvial environment; (ii) the middle subunit deposited in a lacustrine environment and; (iii) the upper subunit deposited in a medium to distal alluvial fan environment, where conglomerates and sandstones constitute channel deposits and mudstones constitute flood-plane deposits. The micritic limestones are interpreted as calcretes developed in these flood-plain (Parcerisa et al., 2007).

Provenance of detrital sediments

Petrological analysis carried out in the conglomerates (Table 1) and sandstones (Table 2) of these two Cenozoic units show that detrital grains are lithologically very heterogeneous and that they derive from different source rocks. Four main typologies have been recognized which could be associated to the erosion of different stratigraphic levels (Tables 1 and 2): 1) monocrystalline and coarse polycrystalline quartz grains, which could have been derived from Upper Carboniferous-Permian granites/porphyries, veins within Cambro-Ordovician metamorphic rocks, or detrital grains of the Triassic formations; 2) fine polycrystalline quartz grains, which could have been derived from metamorphic rocks; 3) feldspar and mica grains, which could have been derived from granites and porphyries; and 4) rock fragments deriving from granites, porphyries, black shales (Silurian), mottled shales (metamorphic aureole of the Upper Carboniferous-Permian granite), red sandstones (Triassic) and limestones/dolostones.

In turn, the limestone/dolostone rock fragments show different features and are interpreted to be derived from different formations: 1) monocrystalline and polycrystalline calcite, which were presumably derived from several formations, but some anhedral polycrystalline grains may be equivalent to Lower Cretaceous (Barremian) calcitized dolomites cropping out in the Garraf high (Artoles Fm.; Nadal 1999); 2) micritic calcite, which could have been derived from Muschelkalk and Lower Cretaceous (Barremian) limestones; 3) bioclastic grainstones and packestones containing orbitoid fossils are distinctive of the Lower Cretaceous limestones (Barremian to Aptian); 4) dirty dolosparites derive from Devonian dolostones; 5) dolosparites with relict oolithic textures deriving from Jurassic dolostones (Esteban, 1973); 6) dolomicrites derived from Triassic materials (Muschelkalk limestones); and 7) fine dolosparites derived from Lower Cretaceous formations.

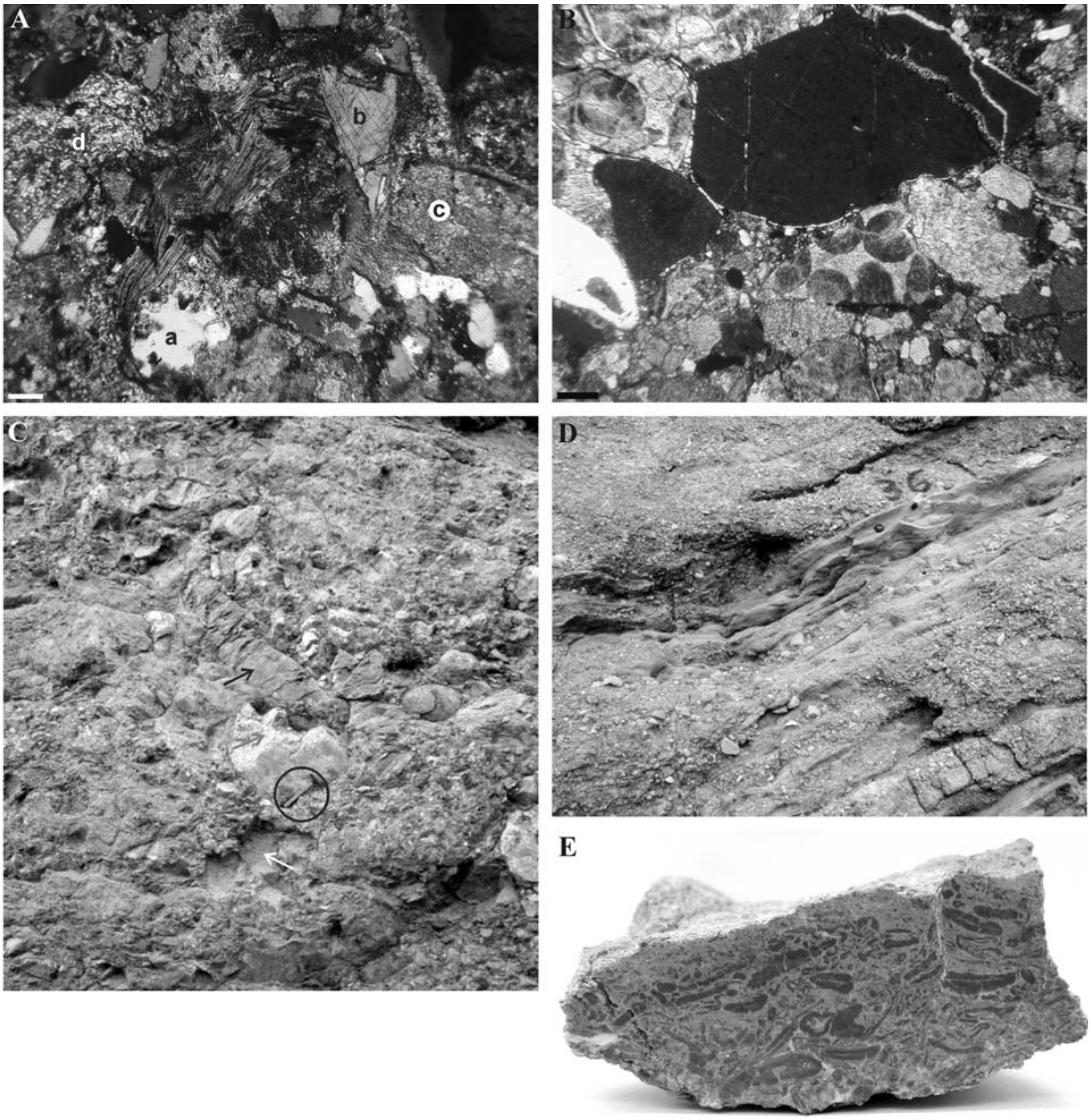

FIGURE 5 **Details of the conglomerates and sandstones of the Turó de Montgat Unit (A and C) and Pla de la Concòrdia Unit (B, D and E). A) Sandstone of the upper subunit with a deformed biotite grain surrounded by quartz (a), feldspar (b), limestone rock fragment (c) and metamorphic rock fragment (d) grains. Cross polarized light. Scale 100 µm. B) Sandstone of the upper subunit made up of dolomite limestone rock fragments. Plane polarized light. Scale: 150 µm. C) Conglomerates of the middle subunit with rock fragments of porphyry (black arrow), limestone (grey arrow) and granite (white arrow), note hammer for scale. D) Conglomerate of the upper subunit exclusively made up of limestone rock fragments. E) Hand sample of a microconglomerate formed by intraformational grains (oncolithes). Horizontal length: 8 cm.**

The Turó de Montgat Unit is composed of igneous, metamorphic and limestone rock fragments deriving from the Variscan basement and the Mesozoic cover, while Pla de la Concòrdia Unit is mainly made up of limestone/dolostone rock fragments of the Mesozoic cover, and also from Devonian limestones and dolostones. The upper subunit of the Pla de la Concòrdia has some conglomeratic layers with the typical petrologic composition of the Turó the Montgat Unit and vice versa. These features indicate that the Turó de Montgat and Pla de la Concòrdia units had a specific and different source area but, occasionally, the source area of each unit supplied detrital sediments to the other unit.

Chronostratigraphy

Two damaged upper molars of a theridomorph rodent of the genus *Archaeomys* (Fig. 7) have been found in a

TABLE 2 **Modal compositions (Ingersoll et al., 1984) of representative thin sections of Cenozoic sandstones of Montgat.**

	Turó de Montgat Unit				Pla de la Concòrdia Unit		
	Middle subunit	Upper subunit			Middle subunit	Upper subunit	
SAMPLE	**MG-1** %	**MG-14** %	**MG-17** %	**MG-21** %	**MG-27** %	**MG-35** %	**MG-45** %
Detrital components	**51.8**	**82.5**	**76.0**	**72.0**	**90.3**	**89.6**	**94.9**
Detrital quartz	26.8	5.6	23.8	23.6	2.4	2.5	0.4
Detrital K feldspar	11.2	1.8	9.3	10.9	0.2	—	—
Detrital plagioclase	3.1	1.4	4.3	8.7	—	—	—
Chert	1.4	—	—	—	—	—	—
Fillite fragment	1.6	—	0.7	3.5	1.0	0.4	—
Schist fragment	1.0	1.2	1.7	0.9	0.2	—	—
Prophyr fragment	0.2	—	2.6	1.5	—	—	—
Siltite fragment	—	—	0.2	—	—	—	—
Fragment micrític	0.4	6.4	0.9	0.2	21.3	3.1	2.2
Monocrystalline Cc	—	—	0.4	0.9	—	3.1	2.2
Policrystalline Cc	—	6.4	0.4	0.2	0.2	—	—
Bioclastic Packs.-wackes.	—	—	—	—	2.0	—	—
Oolithic grainst.	—	1.6	0.2	0.4	0.2	—	—
Microcrystalline Dol	—	16.8	1.3	5.4	19.5	23.7	18.8
Monocrystalline Dol	—	2.6	2.2	1.5	1.8	6.9	2.7
Policrystalline Dol.	—	30.3	4.5	4.3	15.5	25.7	31.0
Dirty polycrist. Dol	—	0.8	—	—	3.8	1.8	2.0
Dol RF oolithic phantoms	—	—	—	1.7	6.6	16.3	18.0
Oncolite	1.4	—	3.7	3.3	10.6	1.2	—
Muscovite	0.6	—	0.7	—	—	—	—
Biotite	3.9	0.6	3.9	2.8	—	—	—
Chlorite	—	—	3.7	0.9	—	—	—
Zircon	0.2	—	—	—	—	—	—
Siliciclastic matrix	—	2.0	3.9	1.3	0.2	—	—
Carbonatic matrix	—	5.0	7.6	—	4.8	4.9	17.6
Total diagenetic	**47.2**	**16.8**	**22.6**	**25.6**	**8.0**	**8.1**	**4.3**
Pseudomatrix	0.2	2.6	3.7	2.1	—	—	—
Epimatrix	4.6	3	8.3	15.5	—	—	—
Cements	42.4	11.2	10.6	8	8	8.1	4.3
Porosity	**0.8**	**0.6**	**0.9**	**1.7**	**1.6**	**2.2**	**0.8**
Intergranular	0.6	0.6	0.9	0.9	1.4	0.8	0.8
Fracture	0.2	—	—	0.9	0.2	1.4	—
Cemented (%)	**41.1**	**9.8**	**9.9**	**7.2**	**8.0**	**8.2**	**4.3**
Intergranular volume (%)	**41.7**	**17.4**	**22.0**	**10.2**	**14.7**	**15.3**	**22.7**
Grain size	**M-C**	**M-Cong**	**M-Vc**	**C-Vc**	**Mc-Cong**	**C-Mc**	**Mc-Cong**
Sorting	**M**	**P**	**M-P**	**M**	**M-P**	**M-P**	**M**

Sand size: M: medium; C: coarse; Vc: very coarse.
Conglomerate size: Mc: microconglomerate; Cong: Conglomerate.
Sorting: P: poorly sorted; M: Moderately sorted.

mudstone layer of the upper subunit of the Pla de la Concòdia Unit (Fig. 7). Although fragmented, these two upper molars display a derived design, with a simplified dental pattern and high hypsodonty. This pattern enables one to assign the specimens from Pla de la Concòdia Unit to an advanced member of the genus. The first members of *Archaeomys* are reported from levels assigned to the biochronological unit MP 25 (*Archaeomys gracilis* SCHLOSSER) corresponding to Rupelian-very early Chattian ages (Barberà et al., 2001). *Archaeomys gracilis* has been previously reported from the site of Can Quaranta (Campins Basin; Anadón and Villalta, 1975; Arbiol, 1993). However, the specimens from Pla de la Concòdia Unit are clearly more derived, within the rank of variability of the most advanced species in the genus, such as *A. muemliswilensis* MAYO, *A. helveticus* VIANEY-LIAUD or *A.*

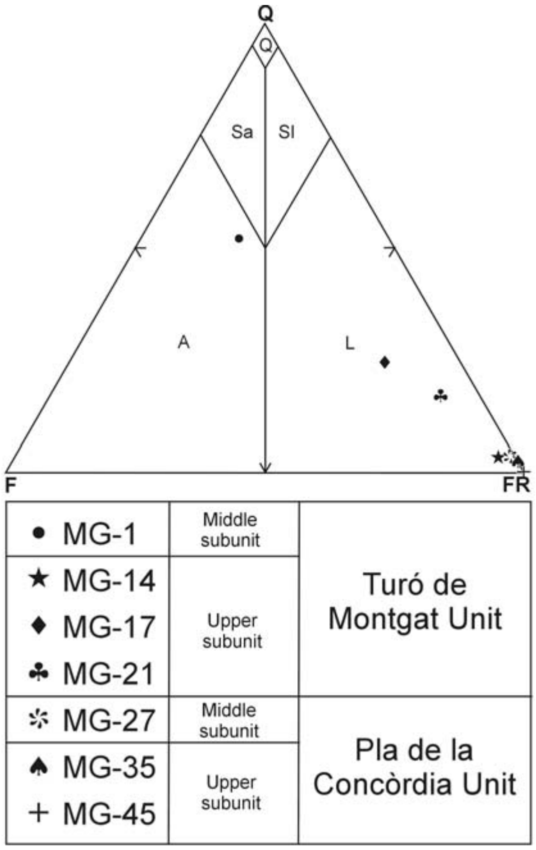

FIGURE 6 | **Triangular Q-F-Fr plot (Dott, 1964) of Montgat sandstones. Q (quartzarenite), A (arkose), L (litharenite), Sa (subarkose) and Sl (sublitharenite).**

laurillardi BRAVARD. The range of these species cover from MP 27 to MP 30. According to the magnetobiostratigraphic correlation established in the Ebro Basin (Barberà et al., 2001), the age of the Pla de la Concòdia layers would range from the base of chron 8 to the top of chron 6, that is, between 27 to 23 Ma. In any case, the Pla de la Concòrdia Unit is clearly Chattian in age.

Separated from the Pla de la Concòrdia Unit by a thrust, the age of the Turó the Montgat Unit is relatively uncertain. However, there is evidence regarding the possible contemporarity of Pla de la Concòrdia and Turó de Montgat units: 1) a similar sedimentological evolution with colluvial environments in the basal parts evolving upwards to medium and distal alluvial fan environments, and 2) the presence of some interbedded conglomerates in Turó de Montgat Unit with the characteristic composition of Pla de la Concòrdia conglomerates and vice versa (Fig. 7 and Tables 1 and 2). Thus, the Turó de Montgat and Pla de la Concòrdia units are thought to be two contemporary and attached alluvial fans with two different source areas. The Turó de Montgat alluvial fan was located towards the east with Palaeozoic and Mesozoic rocks in the source area and the Pla de la Concòrdia alluvial fan was located towards the west with a source area exclusively constituted by Mesozoic rocks (Fig. 9). Consequently, we can infer that both Turó de Montgat and Pla de la Concòrdia units are coeval and Chattian in age.

DISCUSSION

Constitution of the adjacent palaeohighs during Chattian times

Taking into account the general palaeogeography of the area during Oligocene times (Roca et al., 1999) we can assume that source areas of the Pla de la Concòrdia and Turó de Montgat units were located in the boundary of the present Collserola and Montnegre highs. From the analysis of detrital grains in sandstones and conglomerates (Tables 1 and 2) we can deduce that the Mesozoic partly covered Collserola and Montnegre highs during Chattian times (Fig. 9). This Mesozoic cover almost includes Triassic, Jurassic and Lower Cretaceous rocks, which now only crop out in the Garraf high and in some minor Triassic outcrops located in the Collserola and Montnegre highs close to the Pla de Barcelona (Fig. 2).

AFT thermal histories show a noticeable cooling event during Neogene times, which reveals an important exhumation of pre-Cenozoic rocks in the Prelitoral and Litoral ranges (Gaspar-Escribano, 2003; Juez-Larré, 2003; Gaspar-Escribano et al., 2004). Thus, during Neogene times the Mesozoic rocks, which covered Collserola and Montnegre highs were almost totally eroded and deposited in the Barcelona and Vallès-Penedès half-grabens. The removal of the Mesozoic cover was very rapid since the Upper Burdigalian detrital deposits of the Vallès-Penedès half-graben and the Serravallian detrital deposits of the Montjuïc block are exclusively made up of Variscan basement rock fragments (Parcerisa, 2002). This Mesozoic cover was less than 2 km thick (Juez-Larré, 2003) and progressively decreased towards the north, disappearing in the Montseny-Guilleries area (Anadón et al. 1979; Nuñez, 2002; Gómez-Gras et al., 2004).

Age of the compression-extension tectonic regime transition

Roca et al. (1999) and Cabrera et al. (2004) made a general tectonic evolution of the Catalan Coastal Ranges during Oligocene and Neogene times. From existing outcrops, seismic lines and log data they deduce that the transition from compressional to extensional tectonic regime took place during Upper Oligocene times. In the Barcelona half-graben, Roca et al. (1999) deduce that latest Eocene to Oligocene deposits were deposited in a compressional regime prior to the sedimentation of Aquitanian deposits in a extensional regime. The Montgat sediments record the last stages of the compressive event which formed the Catalan Intraplate Chain and constitute the sole sedimentary record of this event in the Pla de Barcelona area.

In the Vallès-Penedès half-graben, the transition is constrained by the thrusted and folded Rupelian deposits of Campins (Anadón and Villalta, 1975; Anadón, 1986; Anadón and Utrilla, 1993) and the first deposits associated to normal faults which are Aquitanian(?) to Burdi-

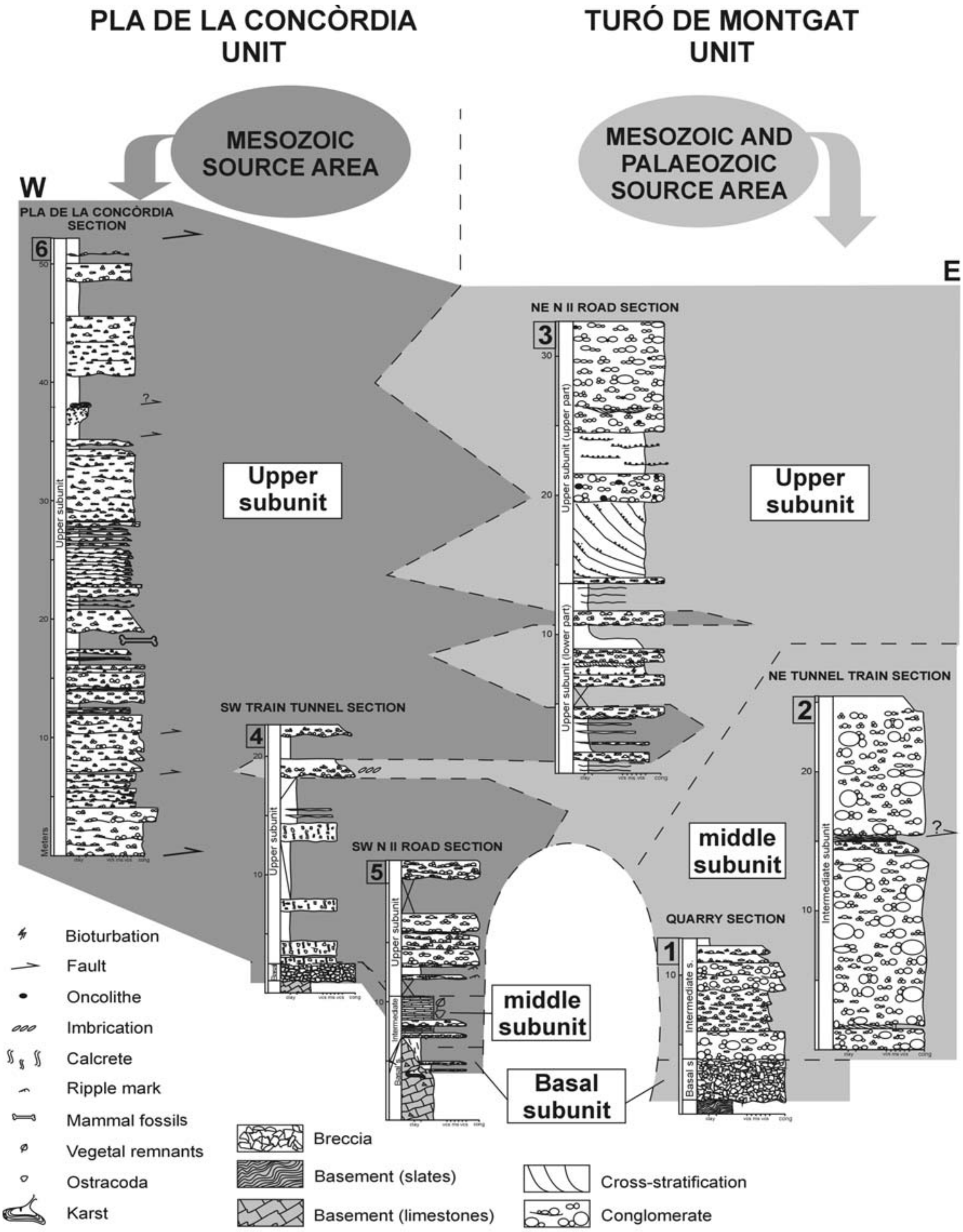

FIGURE 7 | **Correlation panel showing the stratigraphic sections carried out in Turó de Montgat and Pla de la Concòrdia Units. Some conglomerate beds of the Turó de Montgat Unit are interbedded in the Pla de la Concòrdia Unit and vice versa.**

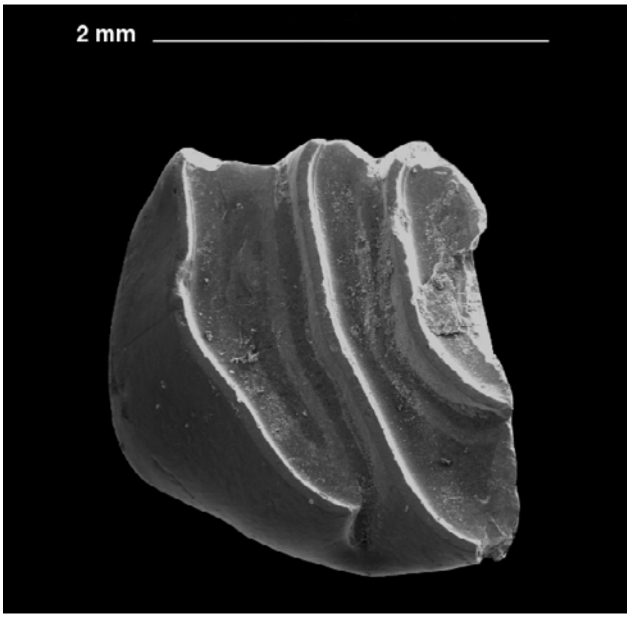

FIGURE 8 | **Fragmented lower m 1-2 of the theridomorph rodent *Archaeomys* sp. from Turó de Mongat.**

galian in age (Cabrera and Calvet, 1996). Nevertheless, the age of the upper parts if the Campins deposits may also be Chattian, since Rupelian dated deposits of Campins are overlain by more than 300 m of Oligocene materials.

Regionally, the Montgat materials were probably deposited at the north-western edge of the Oligocene Barcelona piggy-back basin, which was buried 6,000 m deep via the extensional motion of the Barcelona fault (Roca et al., 1999; Gaspar-Escribano et al., 2004; Cabrera et al., 2004). This extensive phase configured the present structure of the area with the Garraf-Montnegre horsts, the Pla de Barcelona minor graben and the offshore Barcelona half-graben. Furthermore, the presence of compressive deformed Oligocene materials (Campins and Montgat outcrops) clearly indicates that an important post-early Oligocene compressive deformation took place across the northwestern block of the Barcelona fault. The Chattian age of the Montgat materials allows to constrain the Palaeogene compression of the Catalan Coastal Ranges at least until the Late Oligocene and reinforces the hypothesis that offshore Oligocene deposits of the Barcelona basin were deposited in a compressional tectonic regime as a piggy-back basin (Roca and Guimerà, 1992; Roca et al., 1999; Gaspar-Escribano et al., 2004). The compressional fracturing of Montgat deposits was probably linked to the activity of the Barcelona fault, indicating that this fault was active almost since Chattian times and probably was also active during the formation of the Catalan Intraplate Chain.

The other Cenozoic deposits cropping out in the Pla de Barcelona correspond to some minor Neogene out-

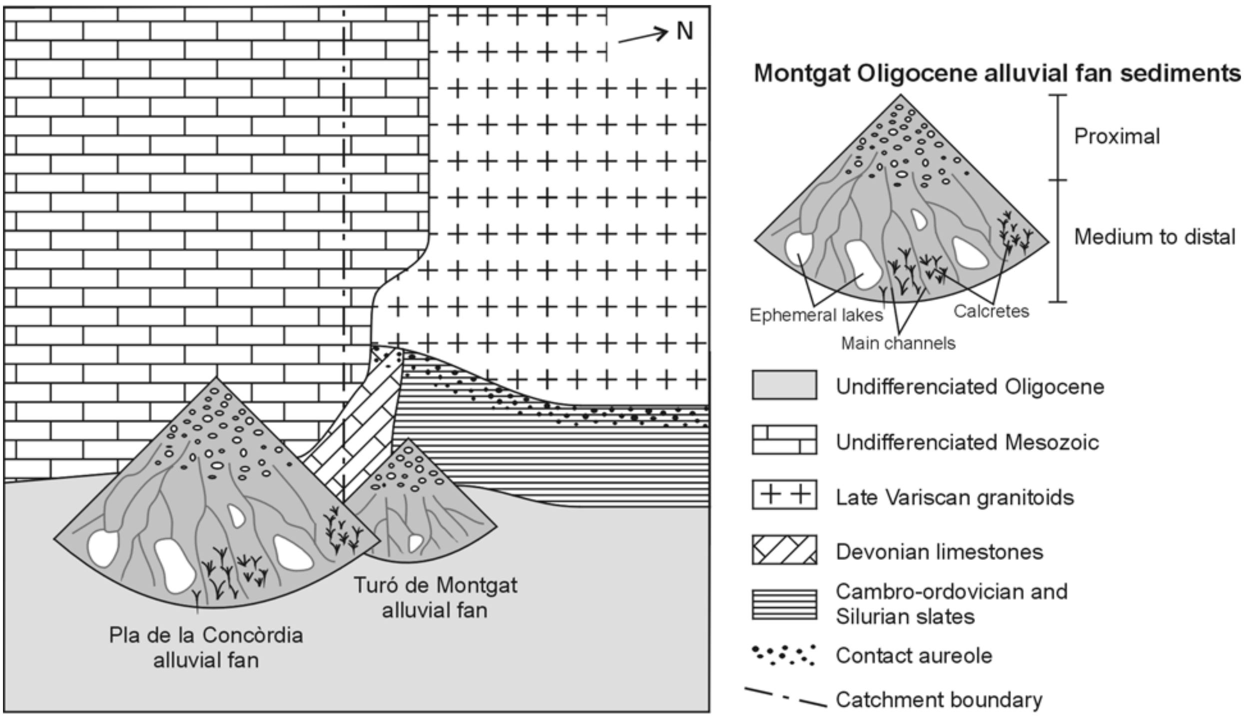

FIGURE 9 | **Palaeogeographical sketch of the Montgat area during Chattian times, showing two adjacent alluvial fans (Turó de Montgat and Pla de la Concòrdia units respectively) and their catchment areas.**

crops which were deposited in an extensive tectonic regime surrounded by Quaternary and Pliocene deposits. The Neogene outcrops correspond to two tilted blocks which form small hills in the Plio-Quaternary Barcelona plain (Fig. 2): the Montjuïc block, attached to Barcelona city and constituted by mudstone, sandstone and conglomerate beds deposited in a deltaic environment during Serravallian times (Gomez-Gras et al., 2001) and the Hospital block, located between Santa Coloma de Gramenet and Badalona cities and constituted by red sandstone and conglomerate beds deposited in alluvial fan environments. A post-Langhian age has been proposed for the Hospital block deposits by fossils located in a thin interbedded layer of marine limestones (Vicente, 1999) and by the petrologic features of their conglomerates and sandstones (Parcerisa, 2002). These Neogene outcrops constitute the first evidence of the formation of the Pla de Barcelona minor graben and constraint the age of the tectonic inversion in the Pla de Barcelona area between the Chattian and the Serravallian.

CONCLUSIONS

The Montgat deposits are significant to unravel the western Mediterranean evolution due to: (i) the occurrence of strong contractional deformation affecting them; and (ii) the micromammal fossil that allow its dating.

The studied deposits can be split into two separate units with different petrographic features: the Turó de Montgat and Pla de la Concòrdia units. Although former studies assigned Miocene to Pliocene ages to the studied materials, the finding of micromammal fossils in the upper part of the Pla de la concòrdia Unit indicates that these deposits are Chattian in age.

The Turó de Montgat Unit is mainly made up of lithorudites and litharenites with high contents of rock fragments deriving from the Variscan basement, while the Pla de la Concòrdia Unit consists of calcilitharenites and calcilithorudites with limestone rock fragments mainly deriving from the Mesozoic cover. The petrological composition of these two units indicates that, during Chattian times, the central part of the Garraf-Montnegre horst (Collserola and SE Montnegre highs) was still covered by a widespread Mesozoic cover integrated at least by Triassic, Jurassic and Lower Cretaceous rocks.

The strong contractional deformation with thrusts, overturned synclines and strike-slip faults affecting the Chattian deposits of Montgat, as well as the presence of Serravallian deposits along the Pla de Barcelona deformed by extensional events (Vicente, 1999; Gómez-Gras et al., 2001; Cabrera et al., 2004), reveal that the central part of the Garraf-Montnegre horsts was affected by a compressional tectonic regime between Chattian and Langhian-Serravallian times. Considering that, in the neighbouring Barcelona and Vallès-Penedès half-grabens, the syn-rift lowermost sediments are Aquitanian in age, the age of the compression event could be restricted to the latest Upper Oligocene (Chattian). The obtained age for the contractional deformation of the Montgat deposits allows to confirm that the contractional building of the Catalan Intraplate Chain was still active during the Chattian times. Moreover, the opening of the València trough (i.e. of the western Mediterranean) along the central part of the Catalan Coastal Ranges was developed shortly after deposition of the Montgat deposits.

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