Tracking Fumanya Footprints (Maastrichtian, Pyrenees): historical and ichnological overview

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ABSTRACT – The Fumanya tracksites (SE Pyrenees, NE Iberian Peninsula) are among the most important Cretaceous dinosaur track localities in the world. These sites have remained largely unstudied until 15 years after their discovery. They provide an exceptional record of sauropod (titanosaur) ichnology with nearly 3,000 footprints arranged in more than 50 trackways. The study of Fumanya sites is providing further refinements on titanosaur track morphology, stance, gauge and locomotion. Outcrop deterioration has deleted significant ichnological information that can be integrated in the present day dataset by means of the study of ancient pictures and measurements. Weathering and conservation studies provide conservation tools for the outcrop. The Fumanya site is integrated in a large Maastrichtian succession with plenty of other dinosaur remains (ichnites, bones and clutches) and other palaeoenvironmental indicators (plants, invertebrates, etc.). This reinforces the Vallcebre section as a key point to understand the diversity of the last European dinosaurs during the Maastrichtian and how their extinction took place.

Key words: *Fumanya, sauropod, tracks, Cretaceous, Pyrenees*

INTRODUCTION

At the end of the 1990s, the world-wide Late Cretaceous sauropod track record consisted of only four reported localities (Lockley et al., 1994). Among them, the Campanian-Maastrichtian Toro Toro, Cal Orcko and Fumanya sites were discovered during the 1980s but first maps and detailed data took a longer time to be published. Their very large size and the nature of their exposure hindered for many years a quantitative documentation. Nowadays, despite that new data from ancient and new localities have been reported (Lockley et al., 2002), the number of significant localities displaying Late Cretaceous sauropod trackways and footprints is almost the same.

Despite the early discovery of the Fumanya site in 1985, for almost ten years it underwent the absolute lack of interest by the scientific community and political institutions. The first scientific studies at the end of the 1990s aroused the social interest in dinosaurs in an area where those reptiles were almost unknown. To date, the scientific, social and cultural attributes of the site provide a unique location in order to study, explain and protect this palaeontological heritage. Current research has shown Fumanya to be one of the most significant evidence within the scarce Late Cretaceous sauropod track record. The aim of this paper is to report an overview of the site, its palaeoecological setting and the ichnological and conservation studies undertaken until now.

SITES LOCATION AND TERMINOLOGY

The Fumanya tracksites (Berguedà, NE Iberian Peninsula, fig. 1) are located 125 kilometres northwards from Barcelona city. The access to the sites is a mountain road (BV-4025) that runs from Coll de Fumanya (Fígols municipality) to Vallcebre village, north of the town of Berga, at the foothills of Serra d'Ensija mountain. The "Fumanya site" contains four different outcrop-localities at ancient open air lignite mines, along more than 1.5 kilometres on a continuous track-bearing surface. The whole set of outcrops cover an area of approximately 35,000 m^2 with nearly 3,000 tracks (Vila et al., 2005a). They have been named Fumanya South (the classical site referred in previous papers; UTM X: 400566; Y: 4670705; Z: 1,550 m), Mina Esquirol (UTM X: 400728; Y: 4671079; Z: 1,515 m), Fumanya North (UTM X: 401051; Y: 4671822; Z: 1,421 m), and Mina Tumí (UTM X: 400171; Y: 467335; Z: 1,458 m).

GEOLOGICAL / PALAEONTOLOGICAL SETTING

The continental Upper Cretaceous-Paleocene sediments that filled part of the southern Pyrenean basins are known as Tremp Formation (Mey et al., 1968) or "Garumnian" facies (Leymerie, 1862). The sediments of the Tremp Formation result from a Pyrenean progressive regression from marine to lagoonal and finally to entirely continental environments that took place basically during the Maastrich-

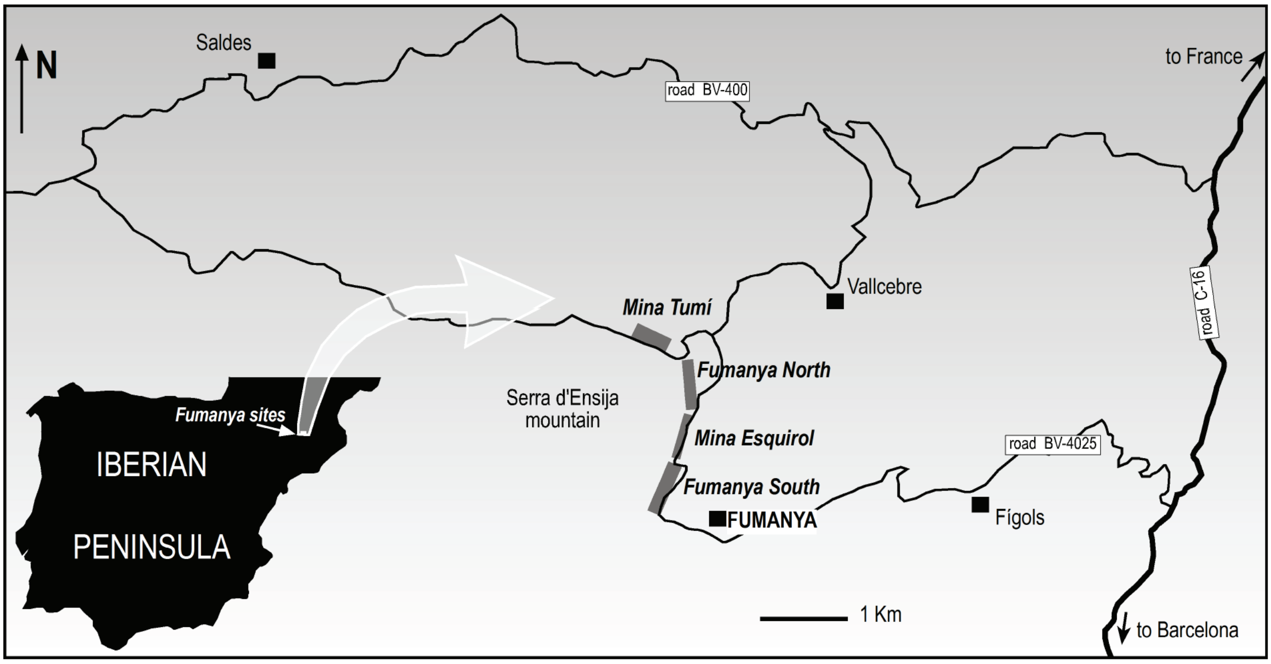


Figure 1 – Geographical sketch map with location of the Fumanya sites.

tian. At those times, the strata accumulated in an E-W foreland basin trough that was opened to the Atlantic ocean. This foreland basin was structurated in several basins, being Vallcebre the one where Fumanya outcrops are found. The regional stratigraphy of the south Pyrenean "Garumnian" sections displays up to four lithologic units (Rosell et al., 2001) which from base to top are: (1) a transitional Grey "Garumnian" (marls, coals, limestones and sandstones), (2) a fluvial Lower Red "Garumnian" (mudstones, sandstones, oncoliths and paleosols), (3) the lacustrine Vallcebre limestones and its equivalents and (4) an Upper Red "Garumnian" (mudstones, sandstones, conglomerates and limestones) deposited in several continental environments. The first and second units are Maastrichtian while the third and fourth are Tertiary.

For many years, the most abundant Late Cretaceous vertebrate record came from the Tremp basin, in outcrops found 60 km W of Fumanya (see review in Vila et al., 2006a). Along the Vallcebre syncline, where the Fumanya sites are located, dinosaur tracks and other vertebrate remains are found all over (1) and (2) lithologic units. The Fumanya tracksite is the very base of (1) unit, which deposited on top of shallow marine deposits. At the base of the unit, a 5 meter thick layer (the so called concrete level) is found, bearing on its top the "Fumanya" trackbearing surface. The transition of this level to the overlaying limestones with coals takes place after the overbeds, which are of centimetric thickness and weathers faster than the marly limestones of the concrete level. Above the concrete level and related overbeds, other three track bearing levels ("Mina Esquirol-1, -2, and-3") have also been distinguished (fig. 2). Magnetostratigraphic studies clearly show that the age of Fumanya sites is Lower Maastrichtian (Oms et al., 2007).

Primary geological research at the area focused on general structural and lithostratigraphic aspects (Vidal, 1871), including palaeontological research on marine invertebrate fossils from the carbonate crags that built up the Vallcebre syncline. The mining engineer L. M. Vidal performed the first palaeontologic prospects in the "Garumnian" at the end of the XIX century listing the invertebrate record from the transitional and continental "Garumnian" strata (Vidal, 1874 and subsequent works). Progressive economic interest in coal at the area yielded abundant fossil material from the lower Tremp Formation strata. Dr. Kühne (Berlin University) located promising fossiliferous levels at Tumí (Talens, 1955). In 1967 R. Aepler (Berlin University) reported data on the paleontology of the Vallcebre syncline (including first mention on dinosaurs in the area after egg findings). Since then a diverse list of findings, including molluscs, charophytes, plants, vertebrate bones and trace fossils has been reported in the continental Late Cretaceous strata of Fumanya and Vallcebre syncline.

HISTORY OF DINOSAUR ICHNOLOGICAL DISCOVERIES AND MAPPING ACTIVITIES

As at several other tracksites around the world (Parker & Balsley, 1989), coal mining quarry works at Fumanya permitted to unearth a unique track record. At Fígols-Fumanya-Saldes area the sub-vertical lignite-bearing levels located in the lower part of the Tremp Formation (transitional Grey "Garumnian" unit) were extracted over a century. Between latest 1970s and early 1990s mining company (CBSA) extracted lignites at open-air quarries and consequently unearthed multiple new "Garumnian" outcrops all over the

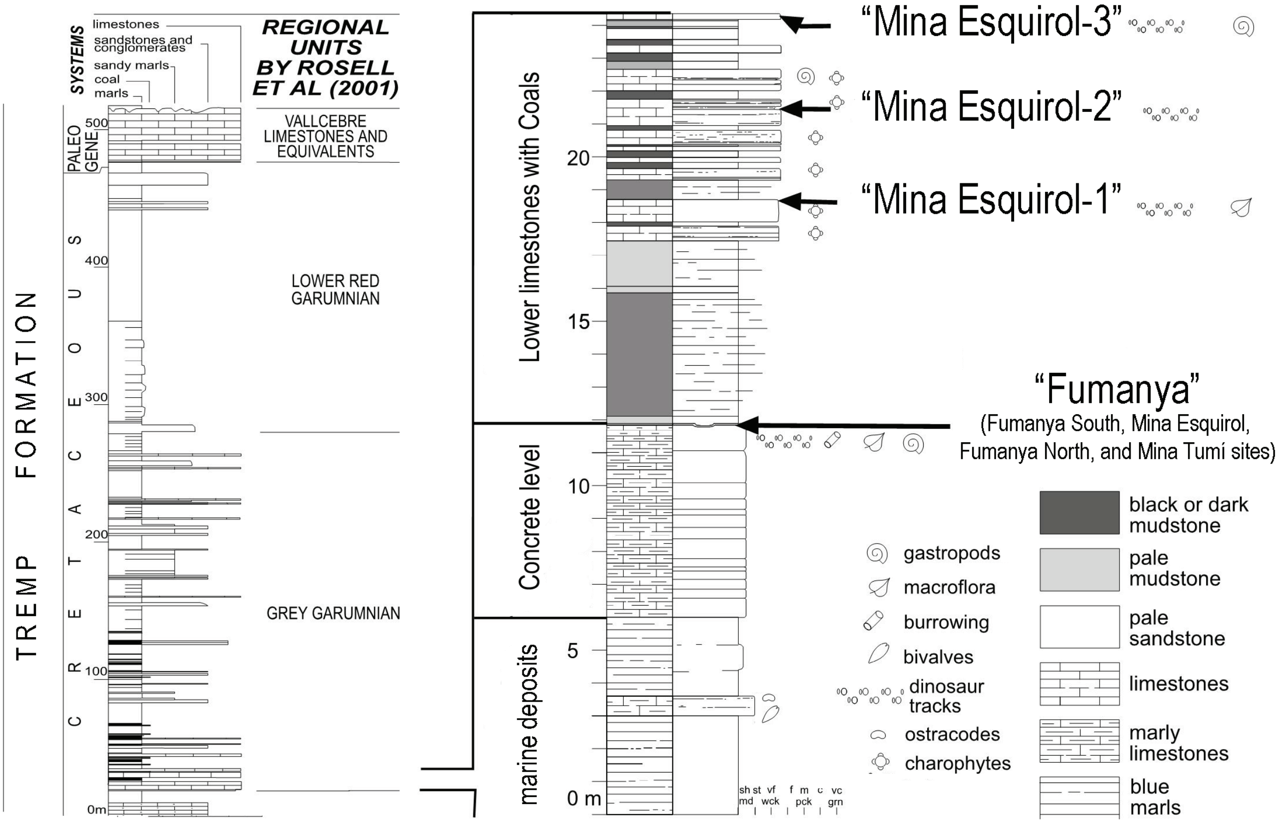


Figure 2 – Lithostratigraphic section of the lower Tremp Formation strata at Fumanya (with data from Aepler, 1967) with location of the four trackbearing levels at Mina Esquirol outcrop (right section).

Vallcebre syncline basin. However, neither palaeontological prospecting nor evaluating activities were undertaken during those years.

In the study of the Fumanya sites two periods can be differentiated: 1) the preliminary works related to the site discovery and 2) the studies by specialists. First period consisted of photographic documentation (fig. 3), sketching of several ichnites, discussions on the likely trackmakers, and very few measurements. The second period consisted of general and particular maps and photographs (Le Loeuff & Martínez, 1997a), initial measurements and detailed descriptions of particular tracks and trackways (Schulp & Brokx, 1999; Vila et al., 2005a) and discovery and approach to new tracksites (Vila et al., 2005b).

Lluís Viladrich i Pons (1957-2006), a teacher and an enthusiastic naturalist from Berga, is considered the discoverer of Fumanya, since he published the first report on the site (Viladrich, 1986). On March 31st of 1985 he and his wife were prospecting in that area when he observed some depressions in the quarry footwall that were likely to be produced by a big animal, probably a dinosaur. He informed Dr. J. V. Santafé, a vertebrate palaeontologist from *Institut de Paleontologia* "M. Crusafont", about the discovery. He was urged to inspect the purported dinosaur tracks. Finally, on October 3rd of 1986, Santafé among others visited the outcrop. After field observations they confirmed that depressions in the quarry seemed to be dinosaur footprints. Nevertheless in the early 1980s dinosaur ichnology in Spain was just an emergent discipline that did not have the current interest among vertebrate palaeontologists. The first preliminary observations were published in a local magazine (Viladrich, 1986). After that, nobody paid attention to the site for a long time.

After a decade, in 1996, Jean Le Loeuff (*Musée des Dinosaures,* Espéraza), together with geologist Albert Martínez-Rius and palaeontologists from Maastricht Museum of Natural History took multiple pictures and tried to assess quantitatively some tracks and trackways from Fumanya. Mapping difficulties only allowed to collect preliminary data from the north of Fumanya South site. They spread a 10 meters grid from the upper part of the wall and took pictures for mapping. They measured and described for the first time individual tracks, distinguishing pes and manus tracks. This work provided first strong evidence of titanosaurid tracks in the Upper Cretaceous of Europe by using spatial and temporal proximity criteria instead of ichnological-synapomorphy associated features (Le Loeuff & Martínez, 1997a, b). Meanwhile Anne Schulp (Maastricht Museum of Natural History), Wouter Brokx and Ilja van Nieuwpoort (Vrije Universiteit Amsterdam) continued the mapping works at the southernmost part of Fumanya South site. They also mapped tracks

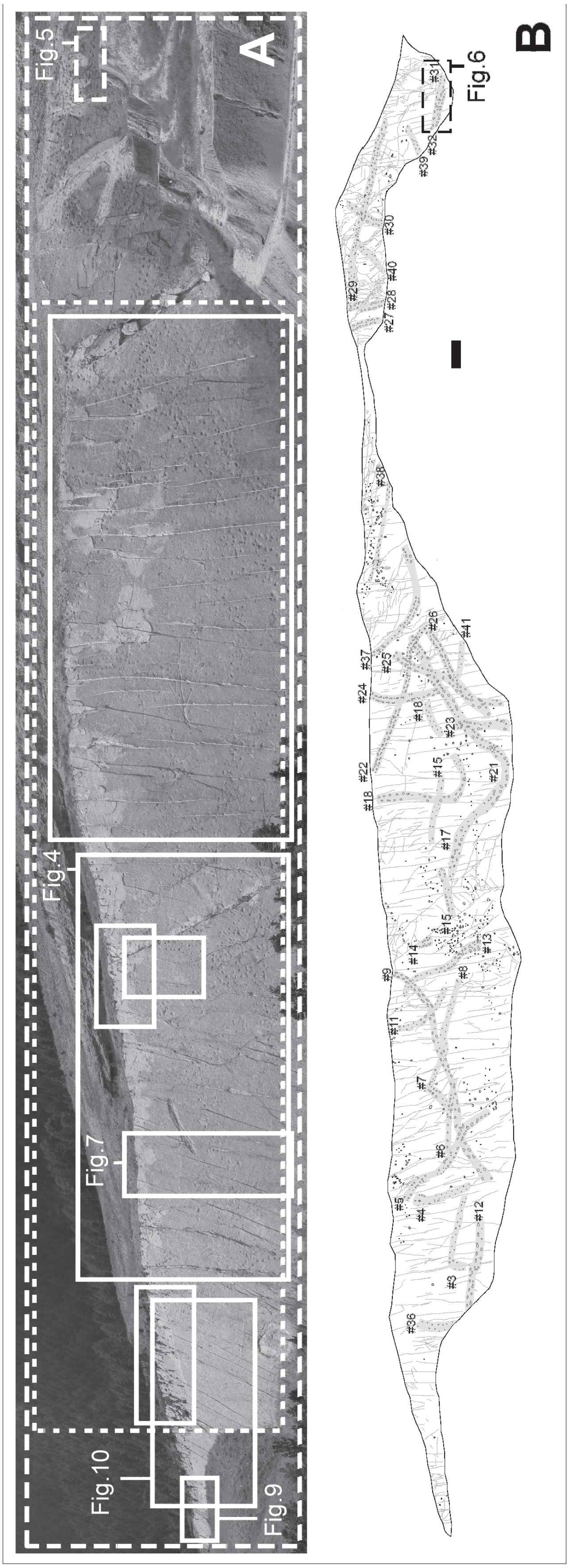


Figure 3 – A: Progressive mapping activities on the main Fumanya South site, from early eighties to recent. Solid line: early pictures (Viladrich, Ribera and Vicens); dashed line: Schulp & Brokx (1999)'s mapping; dashed bold line: 2002 mapping. B: Fumanya South mapping (2002) with location of trackways. Boxes indicate particular trackways figured in the text. Scale bar: 10 meters.

by setting a reference grid and taking photographs. Pictures were corrected for perspective distortion and fitted together in a composite map (Schulp & Brokx, 1999). Additionally Schulp and Brokx applied a strain correction to reconstruct the original trackway geometries. Twenty-six titanosaur trackways were recognized at the southernmost part of the site and 4 at the northernmost part (the longest trackway was over 80 m in length). They took multiple measurements (e.g. stride length, trackway width, pace angulation) and described particular manus and pes tracks.

Between 2002 and 2005 our team mapped Fumanya South, Mina Esquirol, Mina Tumí and the southernmost outcrops of Fumanya North sites by gridding the outcrop with ropes scaled at 5 m (instead of larger grids used in former studies). By doing so, we reduced the scale error after correcting photographs with appropriate software. At Mina Tumí and Mina Esquirol we also mapped surfaces using climbing equipment. From both Fumanya South, Mina Esquirol and Mina Tumí sites, we mapped up to fifteen new trackways, including notably well-preserved examples of manus-only (Vila et al., 2005a) and manus-pes trackways. We also attempted to map the vertical surfaces of Fumanya North site using a balloon with a photographic camera incorporated. Unfortunatelly, the results were not satisfactory and thus no trackway was mapped. From its southernmost part, we mapped for the first time a singular trackway formerly reported by Le Loeuff & Martínez (1997b).

At the end of 2005 collaboration between Institut Català de Paleontologia, University of Manchester and Universitat Autònoma de Barcelona favoured a new map of the outcrops, based on Light Detection And Range (LiDAR) scanning technology. The four vertical tracksites were mapped after acquiring 3D spatial data and the construction of Digital Outcrop Models (DOMs) of the localities (see details in Bates et al., 2008a).

LOSS OF ICHNOLOGICAL RECORD AND CONSERVATION STUDIES

Most of the studies on Fumanya sites (see Viladrich, 1986: p. 11; Le Loeuff & Martínez, 1997b: p. 152; Schulp & Brokx, 1999: p. 243; Oms et al., 2002, Vila et al., 2004) warned of the loss of ichnological record due to fast erosion. Nevertheless no track protection has been carried out except for the studies focused on rock decay and local conservation work (see below; Badia et al., 2005; Gamarra, 2005).

The altitude of the site (enhancing frost, rain, snow and temperature oscillation) produces important weathering

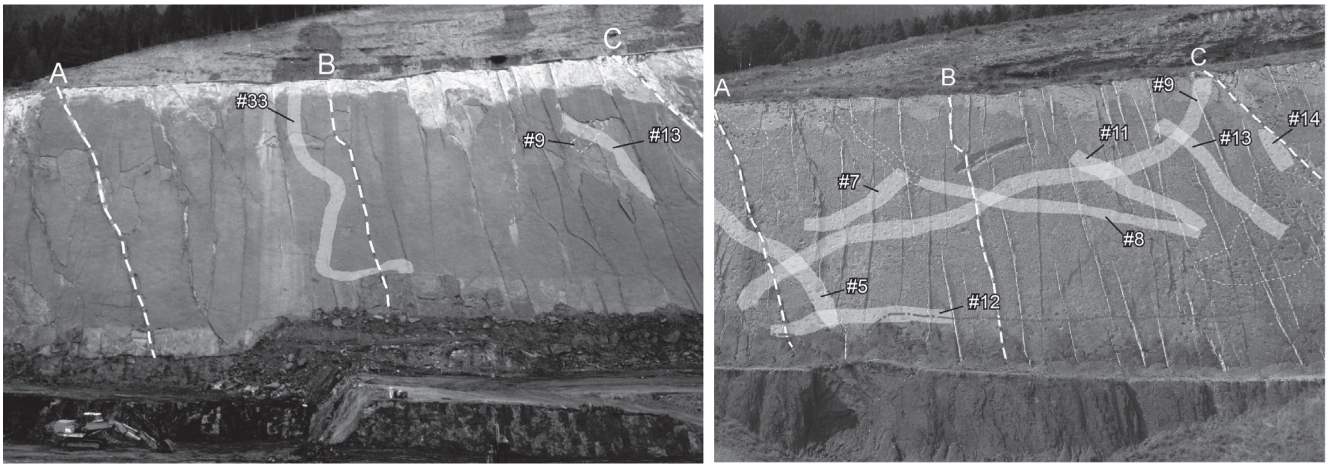


Figure 4 – Contrasting track occurrences on the main Fumanya South site at 1987 (left) and 2004 (right). Labelled joints allow comparison. 1987's photo modified from L. Viladrich.

and deterioration of the site. In less than ten years, the overbeds disappeared, leaving the underlaying sediments with only footprints preserved as undertracks. The comparison between early and recent pictures clearly shows the effects of degradation (Vila et al., 2006b). First pictures (after the discovery) show less tracks than later ones, which is likely to be related to a short-scale completeness of the sedimentary record. In 1985 only three trackways could be distinguished at the central part of Fumanya South site. In the middle nineties the same exposure depicted up to eight trackways (fig. 4). One of the early reported trackways (#33) was in fact preserved as overtracks in that overbed. The northernmost trackway, located close to the "C" labelled joint, was later mapped and numbered by Schulp & Brokx (1999) as trackway number 13. This is just an example of the first erosion phase in which the weathering of the upper overbed (with very few trackways preserved as overtracks) showed the underlying trackways. Thus, first reports of Fumanya South site (Viladrich, 1986) revealed few trackways because most of them were preserved below. From the early nineties to present day, all trackways have undergone a fast deterioration (Oms et al., 2002). One of the most striking examples is that reported in Vila *et al* (2004), showing an originally well-preserved trackway exposed in 2000 that completely vanished in four years (fig. 5). Up to date, no further tracks have been observed below Fumanya surface, thus being a finite paleontological resource. This strong erosion and the serious heritage loss fuelled a new project to study and protect the whole track complex.

Deterioration studies (see Alvarez et al., 2005 and Badia et al., 2005) show that the rock of the whole Fumanya surface (a marly limestone) undergoes a fast decay as a result of the interaction of atmospheric effects (rain, snow and frost) and rock microfracturation. The effect of large scale rock joints are also of crucial importance. Despite the general weathering of the site, on a microscopic scale, decay is shown to result from microfractures and the presence of soluble salts. Runoff does not allow film stability (of biological o or non-biological origin), so that rock is unprotected from environmental agents, therefore, decay is largely enhanced. Runoff also removes iron oxides or hydroxides generating areas of different colours. Microfractures act as a web enhancing the moving of several compounds such as gypsum, which separate microfracture as a result of its crystallization. In order to determine the most efficient treatment to be applied, several laboratory and *in situ* essays were carried out. *In situ* essays included the recovery of soluble salts, essays with consolidants and water-repellents and partial weathering mappings. Laboratory studies included petrological determinations, XRD, scanning microscope, vacuum absorption, free desortion in water, capillary suction, expansion, salts crystallization and product penetration. The obtained results permitted the selection of the ideal product for this rock type and the natural conditions of the site. Such studies and analyses gave the guidelines to carry out a small but successful protection of the manus-only titanosaur trackway from Mina Esquirol site. This trackway is regarded among the youngest described yet and provided an excellent example of the underprint phenomenon in the "swimming sauropod" debate (Vila et al., 2005a). Together with conservation studies, an engineering project for Fumanya South site has also been partially developed. This project includes topography, runoff control and proposals of talus modification. The detailed topography provides the frame where to plan any future project or action. The runoff control project includes the study of the hydrological regime, and the design of a set of ditches that stabilize the regolith above the site and captures runoff waters so that they cannot affect the site directly (runoff, infiltration, frost etc.) or indirectly (infiltration from within the rock).

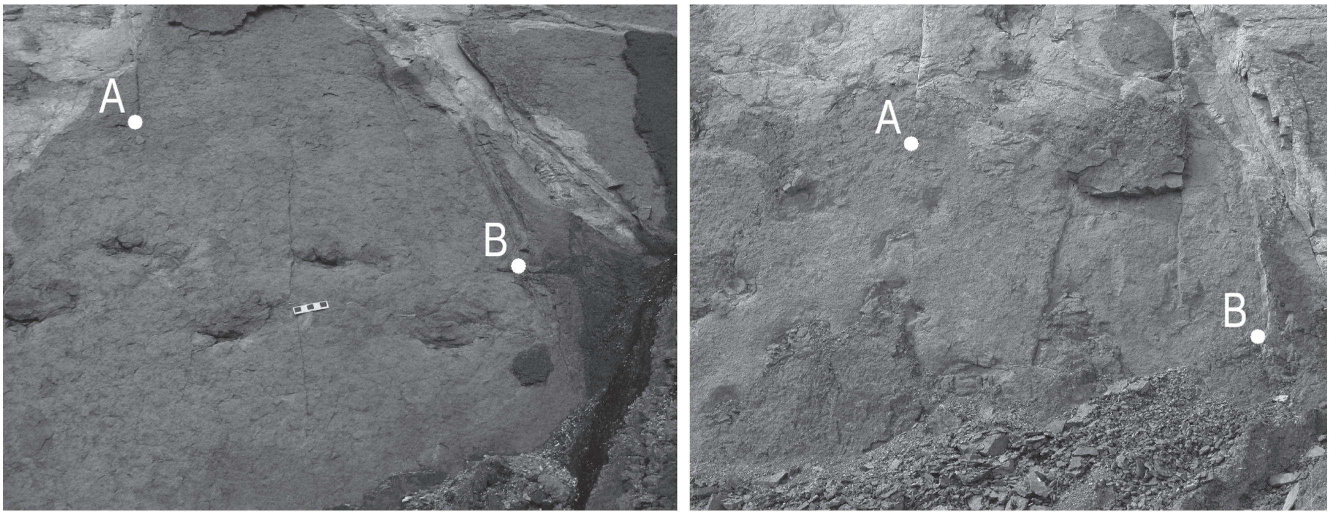


Figure 5 – Effects of track deterioration at Fumanya South site. Trackway #37 reported at September 2001 (left) and September 2004 (right). Labelled joints allow comparison.

Locality	Trackway number and equivalence	Track type	Reports
Fumanya South	#1*, #2*, #3, #4, #5, #6, #7, #8, #9, #10*, #11, #12, # 13, #14, #15, 16*, #17(= #21), #18, #19*, 20*, #22, #23, #24, #25, #26, #27, #28, #29, #30 [#13 and #29 correspond to "Group IV" and " Group II" from Viladrich (1986), respectively]	manus and pes trackways	Viladrich (1986) and pictures; Le Loeuff & Martínez (1997b); Schulp & Brokx (1999); present work
	#31 ["Group I" from Viladrich (1986)]	manus and pes trackway	Viladrich (1986) and pictures; present work (fig. 6)
	#32 ["Group I" from Viladrich (1986)]	manus and pes trackway	Viladrich (1986) and pictures; present work (fig. 6)
	#33 * ["Group III" from Viladrich (1986)]	manus and pes trackway	Viladrich (1986), and Ribera and Vicens pictures; present work (fig. 7)
	#34 * ["Group V" from Viladrich (1986)]	manus-only trackway	Viladrich (1986) and pictures; present work (fig. 8)
	#35 *	manus and pes trackway	Vicens pictures; present work (fig. 9)
	#36	manus-only trackway	Current studies
	#37	manus and pes trackway	
	#38 *	?likely theropod	Vila *et al*., (2004)
	#39	manus-only trackway	Current studies
	#40	manus-only trackway	
	#41	manus-only trackway	
Mina Esquirol	#42	manus-only trackway	Vila *et al*., (2005a)
	#43	manus-only trackway	Current studies
	#44	manus and pes trackway	
	#45	manus and pes trackway	
	#46	manus and pes trackway	
Mina Tumí	#47	manus and pes trackway	Vila *et al*., (2005b) and current studies
	#48	manus and pes trackway	
	#49	manus and pes trackway	
Fumanya North	#50	manus and pes trackway	Vila *et al* (in prep.)
	#51 * ["Group VI" from Viladrich (1986)]	undescribed	Viladrich (1986)

Table 1 – Numbered sauropod trackways from Fumanya sites (following Schulp & Brokx (1999)'s numerals). * indicates completely eroded trackways.

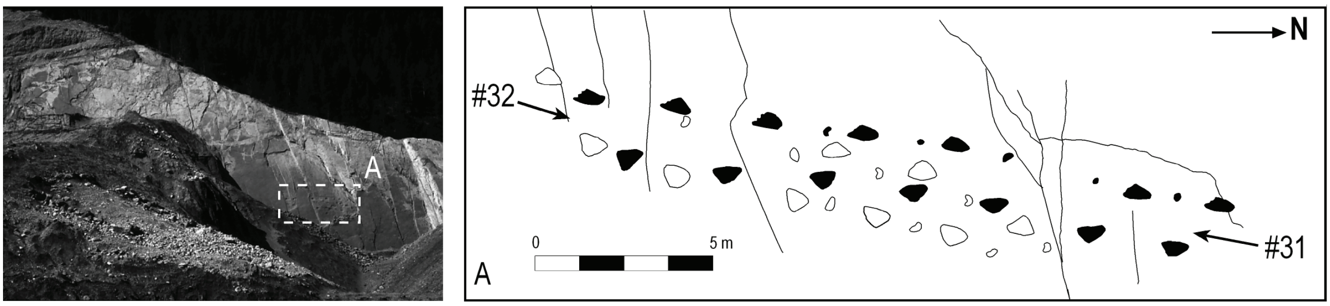
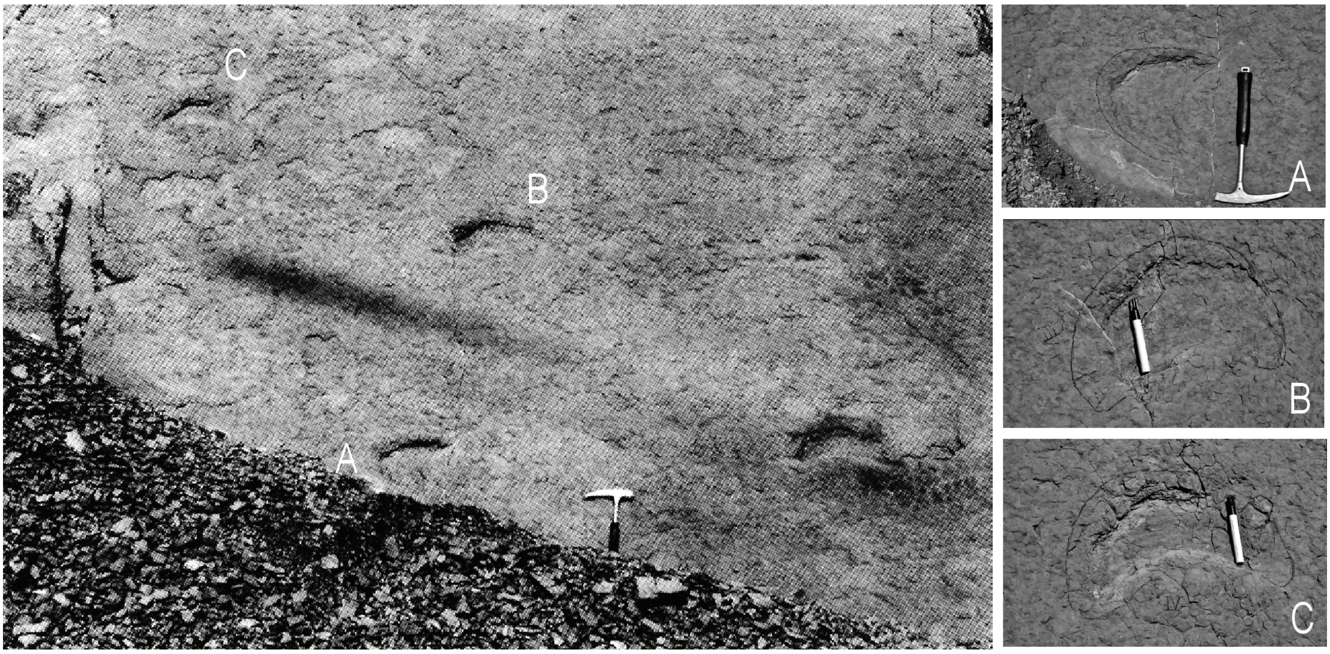


Figure 6 – Trackways #31 (black coloured) and #32 (white coloured) from the northernmost part of Fumanya South site. Arrows indicate walking direction. Photographies taken by L. Viladrich at March 1985.

Figure 7 – Trackway #33 from Fumanya South site at January 1987. Walking direction downwards. Photography courtesy of E. Vicens.



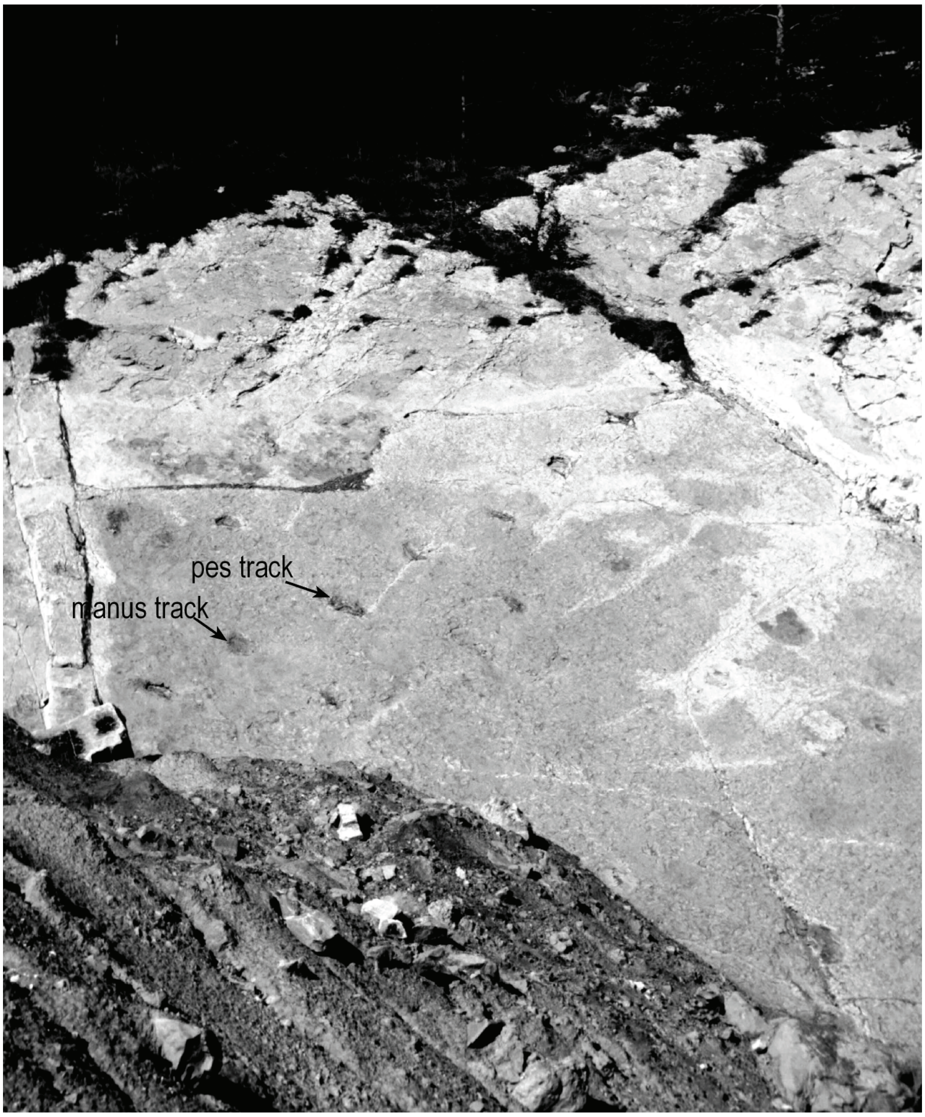


Figure 8 (top) – Trackway #34 from Fumanya South site. Particular tracks labelled in A, B and C. Scale: pen marker and hammer are 14 cm and 33 cm long, respectively. August 1986' photographs by L. Viladrich.

Figure 9 (left) – Trackway #35 from the southernmost area of Fumanya South site with location of manus and pes tracks. Walking direction upwards. 1987's photo modified from E. Vicens.

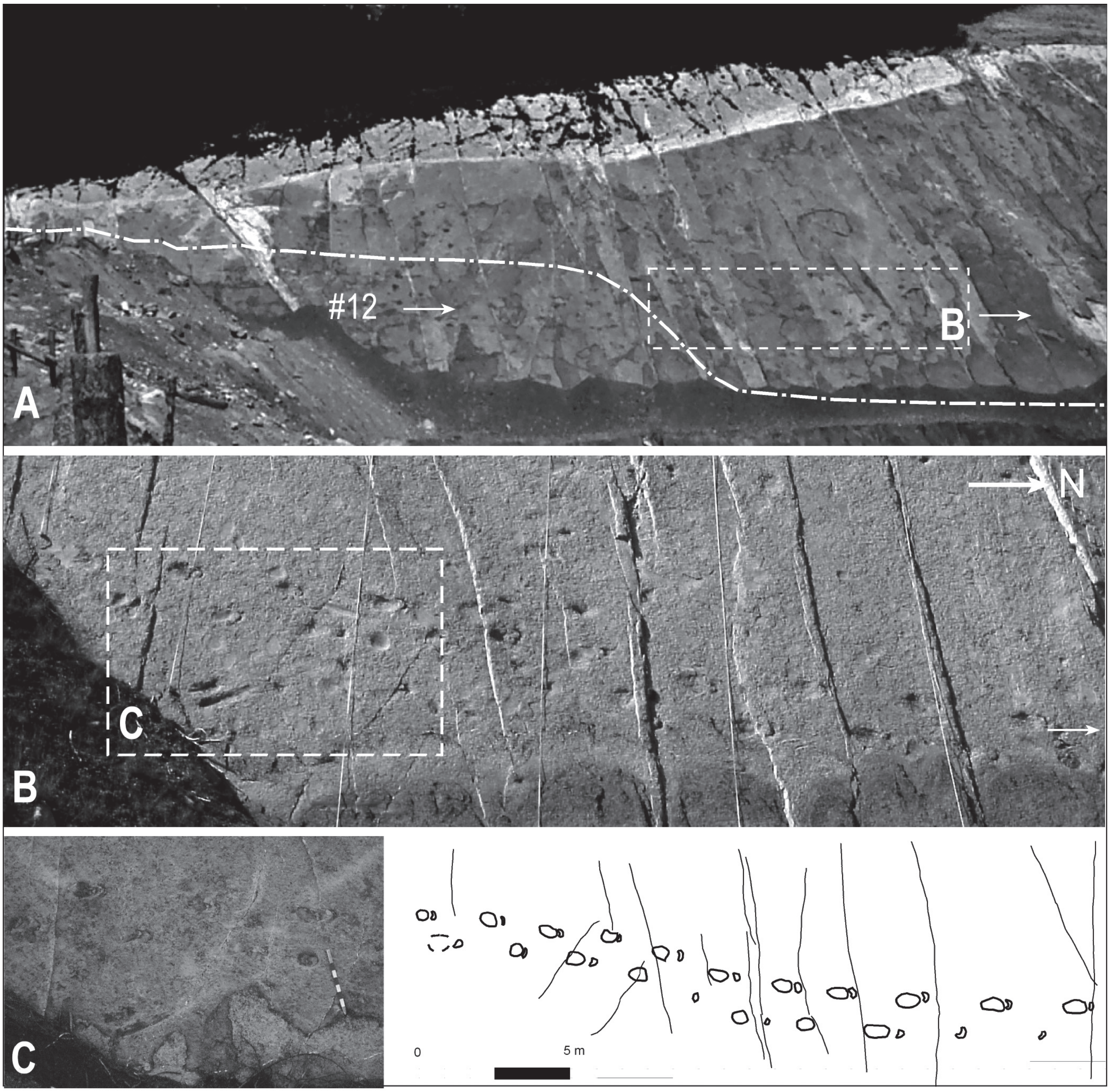


Figure 10 – Trackway #12 from the southernmost area of Fumanya South site. A, B and C: exposures at 1988, 2002 and 1995, respectively. Dashed line in A indicates recent exposure outline after covering the outcrop. Arrow indicates walking direction. Scale bar in C: 150 cm. A and C, courtesy of L. Viladrich.

NEW ICHNOLOGICAL DATA

Our mappings at Fumanya South, Mina Esquirol, Mina Tumí and the southernmost part of Fumanya North sites (carried between 2002 and 2004) have revealed up to 14 new trackways (#36 to #50; see table 1) that were not included in the previous studies. Such mappings allow us to compare present day outcrops with ancient pictures taken from 1985 onwards. In such comparison the mapping of penetrative rock joints turned out to be particularly useful. Thus 6 trackways (#31 to #35 and #51; see table 1) that are nowadays eroded (or preserved but not mapped) have been integrated in the present day dataset (in some cases even using old inedit measurements). In this paper we only consider those tracks reported and/or photographed by previous researchers (but not mapped) and are contrasted with our new mappings and data.

Viladrich (1986) referred tracks from trackways # 31 and # 32 as "Group I". The new mapping reveals that two different trackways can be distinguished from that area (fig.

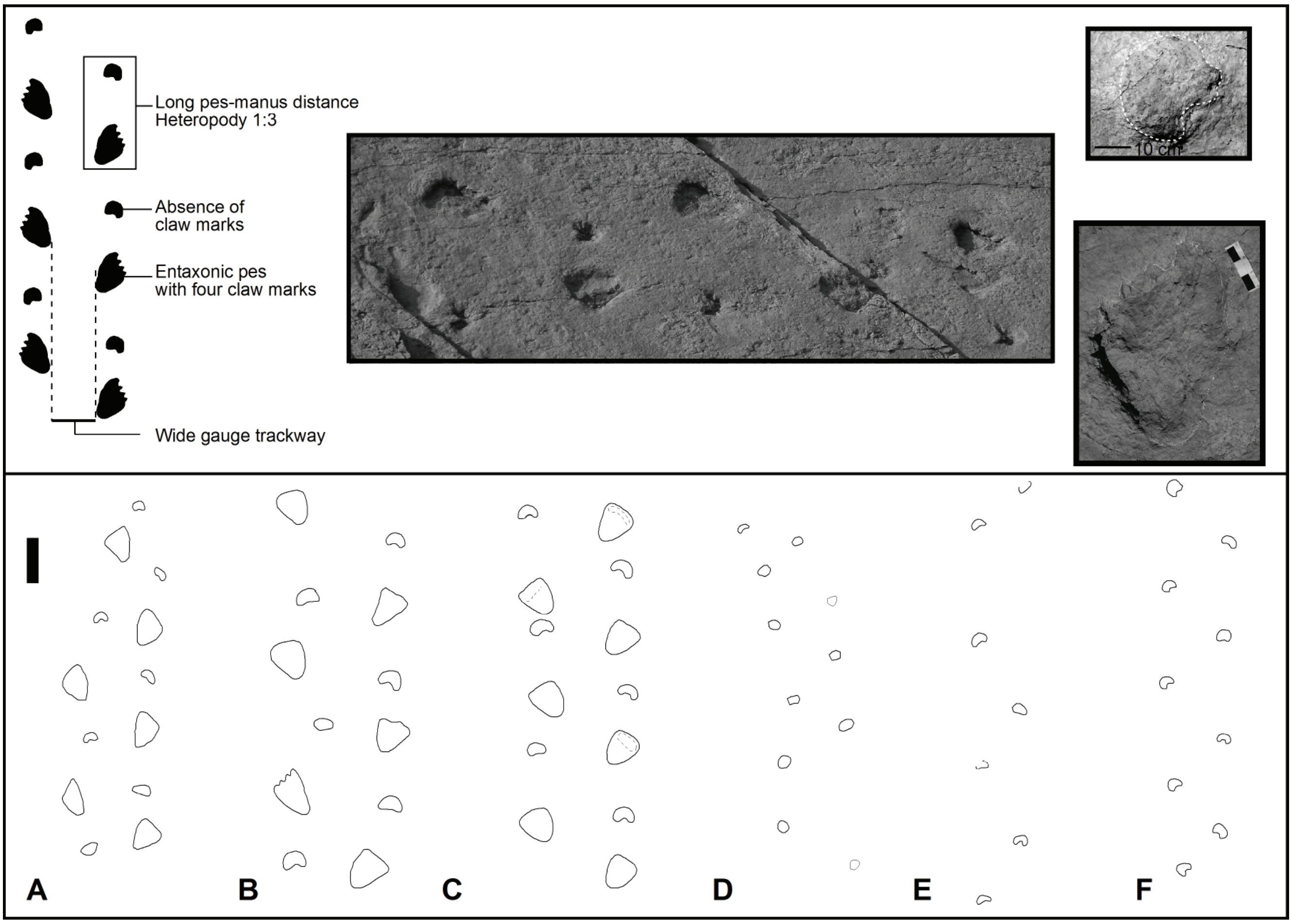


Figure 11 – General ichnological features recognized at Fumanya sauropod tracks and trackways. Titanosaur stylized trackway and examples of discrete tracks and trackways from Fumanya South (trackway and pes pictures) and Mina Esquirol (manus picture). Aspect of several manus-pes and manus-only trackway segments from Fumanya South (#32, #29, #36, #41; A, B, D and E, respectively), Mina Tumí (#47; C), and Mina Esquirol (#42; F, modified from Vila *et al*., 2005a). Walking direction upwards. Scale bar: 1 m.

6). Trackway #31 is composed by 14 pes tracks and 5 manus tracks and trackway #32 is composed by 8 pes tracks and 8 manus tracks. Mean stride length and inner trackway width are 254 cm and 107 cm and 235 cm and 104 cm, respectively. Best impressed manus tracks depict the typical manus print morphology (i.e. crescent, U-shape) and are outward orientated. Pes tracks (FLxFW= 72x37) are entaxonic and subtriangular in shape and some of them depict four claw marks. All of them are outward rotated. A southwards walking direction is recognized for #31 trackmaker and an opposite, northwards direction, is observed for the #32 trackmaker. On the basis of manus and pes track morphology and trackway pattern, both evidence are regarded as titanosaur trackways.

Trackway #33 corresponds to the track "Group III" described by Viladrich (1986). The most striking feature is the extremely sinuous trail showing at least four sharp turns (fig. 7). From the pictures we assume that the trackway (at the most complete exposure) was composed by approximately 80 tracks and a minimum total length of 40 meters. These tracks showed a clear heteropody. The biggest footprints (pes tracks) were longer (60-70 cm; Viladrich measurements) than wide and describe a zig-zag pattern along the trackway. Trackway width was about 120 cm (Viladrich, 1986). In front of big footprints there were smaller rounded tracks. The unusual track morphology is likely to result from an overtrack phenomenon (i.e., sediment infilling tracks). The general footprint arrangement and trackway pattern clearly resembles that of a quadruped big-sized trackmaker, probably a titanosaur sauropod.

Trackways #34 and #35 were located at the southernmost part of Fumanya South. The surface containing several tracks and trackways was exposed since 1985 but in 1992 that area was covered by rubble and currently none of them can be exactly placed. Trackway #34 corresponds to the tracks discovered and named by Viladrich (1986) as "Group V". Pictures of particular tracks (fig. 8A to C) show that they display an anteriorly convex shape describing a U-shaped (crescent) print with no claw marks. Both four footprints present a negative (outward) orientation and the trackway depicts a remarkable internal width. Track morphology and orientation, trackway pattern, and measurements resemble those taken in several manus tracks and trackways from Fumanya sites (Vila et al., 2005a). It is concluded that #34 can be regarded as a new manus-only titanosaur trackway instead of a biped trackmaker (Viladrich, 1986). Pictures taken from trackway #35 in 1986-1987 display tracks that were covered again or disappeared after erosion. From that picture we outline that the trackway was composed of 12 tracks displaying a zig-zag trackway pattern. Despite its poor state of preservation a clear heteropody is observed. As most of pes tracks in Fumanya, the anterior area of pes footprints is deeper impressed and outward rotated. Manus prints display a rounded shape in front of pes prints (fig. 9). A clear wide-gauge feature is recognized. Because of the general trackway pattern and footprints arrangement, we predict that trackway #35 represents a manus-pes sauropod trackway of a titanosaur trackmaker.

Additionally recent mapping and observations on the southernmost area of Fumanya South site provide new evidence for trackway #12, partially mapped by Schulp & Brokx (1999). Photographs show that the trackway was exposed for some years before being definitively covered. Recent mapping works and early pictures taken by L. Viladrich show that it continues southwards for more than 100 meters (fig. 10).

PALAEOENVIRONMENT AND OTHER COMPLEMENTARY FOSSIL RECORD

The general palaeoenvironmental interpretation of the main track-bearing level is based on sedimentological observations, invertebrate and botanic record, and track preservation. Track formation occurred on muddy sediment since detailed marks (e.g. claw marks) are rarely preserved and most of the tracks are roughly defined. It may have occurred over a short timespan because its state of preservation is really uniform and there are very few evidence of overprinting or eroded tracks. Preservation of tracks occurred by deposition of very fine laminated carbonate marls infilling the tracks (i.e. overbeds). They are internally organized in centimetric to milimetric laminations, free from coarse clastics, with virtually no tractive sedimentary structures, suggesting a deposition under sedimentary conditions of very low energy (Vila et al., 2005a). The top of concrete level and overbeds, where most of the tracks were impressed, is interpreted to have been sedimented in an extensive transitional mudflat under a subtropical humid climate.

This chapter describes the complementary paleontological record supporting such interpretation. Geochemical studies in progress are expected to provide further information.

Vertebrates

At Vallcebre syncline the bony record of vertebrates along the Tremp Formation strata was not identified until the second part of the XX century because of the lack of intensive and systematic prospects. Aepler (1967) made the first findings and noted the first unequivocal evidence (eggs, eggshells and bone fragments) of dinosaur remains at the basin. Ullastre and Masriera (1983) found an ornithopod bone fragment close to Peguera (see discussion in Pereda-Suberbiola et al., 2003) and Peitz (1999, 2000) used eggshells from Gósol (10 km NW of Fumanya) for microscopic analysis. Systematic prospects since 2002 have yielded a more extensive record of vertebrates (mainly dinosaur bones and trace fossils). Currently, an assemblage of dinosaurs (sauropods, theropods, and ornithopods), crocodiles, turtles, fishes, and vertebrate trace fossils (eggs and clutches) occur along the Maastrichtian succession, including those collected from the lower Tremp Formation levels. Recent digs at the area have yielded new theropod (teeth) and sauropod (mostly limb bones), turtle (postcranial) and crocodile (cranial and postcranial) material. Dinosaur eggshells and clutches have been documented in more than fifteen localities (Bravo et al., 2005), being some of them stratigraphically very close to the Fumanya surface. Detailed eggshell studies allowed the identification of two different megaloolithid oospecies (*M. siruguei*, *M. mammillare)* and *in situ* mapping and digging works yielded new data on clutch architecture and taphonomy (Vila et al., 2006d). New localities with hadrosaur and sauropod footprints have also been identified along the Maastrichtian succession (Vila et al., 2005c).

Invertebrates

The invertebrate fossil record from the Lower Tremp Formation levels and underlaying units at Fumanya and Vallcebre syncline represents an important element in order to assess the palaenvironmental context of the track-bearing levels. Right in contact with the overlaying Tremp Formation beds, shallow marine carbonate platforms strata (Terradets Formation) yielded a diverse and abundant invertebrate taxa composed by Cnidaria (e.g. *Heliastrea sp., Isastraea sp.*), Mollusca (e.g. *Hippurites radiosus*, *Monopleura figolina*, *Ostrea larva*, *Pecten sp., Turritella sp., Otostoma rugosa, Trochus sp.*) and Echinodermata (e.g. *Hemiaster sp., Cidaris sp.*), among others (Vidal, 1878). Rudist bioconstructions are common in these shallow marine facies. From the concrete level Babinot et al. (1983) and Feist & Colombo (1983) reported an ostracod assemblage composed by *Bairdia sp., Cytherella sp., Dolocytheridea, Dordonilla sp., Limburgina sp., Neocyprideis sp., Pteryigocythere sp.* and ?*Sphaeroleberis sp.* Thin layers dominated by oysters (e.g. *Saccostrea* and *Ostrea*) occur in-between the concrete level. The limestones with coals and neighbouring levels on top of the "concrete" bear characteristic bivalves (*Cerastoderma duclouxi, Corbicula laletana*, *Unio garumnica*) and gastropods (*Cerithium armonicum*, *Cerithium figolinum*, *Cerithium guzmanni*, *Cerithium isonae*, *Cosinia armata*, *Melanopsis crastina*, *Melanopsis serchensis*, *Pseudomelania* sp., *Pyrgulifera saginata*, *Pyrgulifera stillans*, *Deianira trillae*, *Lychnus repelini*, *Lychnus sanchezi*, *Lychnus vidali*)

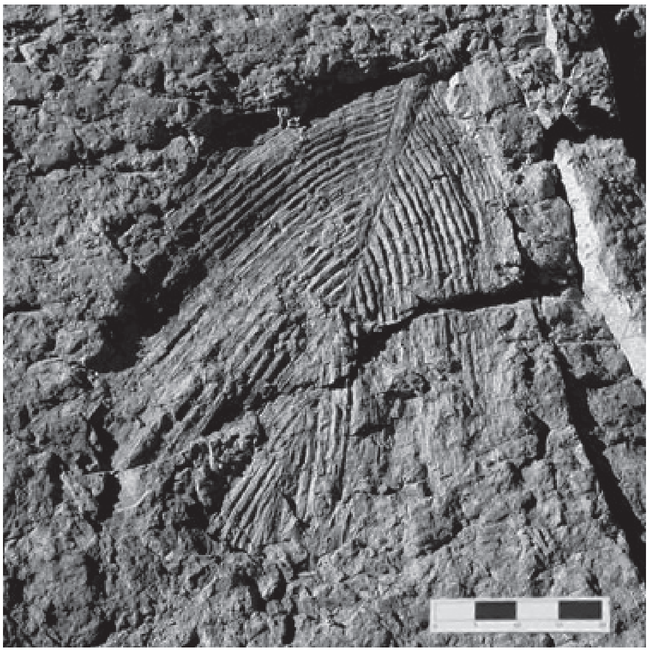


Figure 12 – Impression of palm leaf *Sabalites* cf. *longirhachis* (B-FUM015) from Mina Esquirol site. Scale bar: 20 cm.

(Vidal, 1871 and 1874; Calzada & Urquiola, 1994). These mollusc taxa were associated to different paleoenvironments (*Lychnus* was a terrestrial snail, *Unio* was a freshwater bivalve and the remaining taxa were typical of brackish waters) being interesting markers to elucidate paleoenvironmental parameters (e.g. water salinities). Some gastropods are found within the tracklevels (e.g. *Pyrgulifera* shells in tracklevel "Mina Esquirol-3" at Fumanya North site; (fig. 2) and impressions of *Pyrgulifera* in Fumanya South outcrop). This overall invertebrate record is in agreement with the origin of the concrete level in an extensive carbonate mudflat of marine-continental transitional environment.

Botany

The largest plant fossils found in the trackbearing level correspond to those of impressions of tree-trunks, palm leaves, conifer axes and angiosperm seeds (Gómez et al., 2007). These remains appear at all the sites where sauropod tracks occur (Fumanya South, Fumanya North, Mina Esquirol and Mina Tumí). To date at least 130 trunk impressions have been identified at Fumanya South and Mina Esquirol sites. The largest measured trunk is about 14 m in length and 12 to 40 cm wide. Most of the exposed leaves present fused segments and parallel nervadure corresponding to monocotyledons, specifically to palms (Family Arecaceae). The most complete specimens are those from Mina Esquirol site (B-FUM15 and B-FUM16). B-FUM15 (fig. 12) exhibits most of the lamina (75x41 cm) and B-FUM16 preserves the lamina (43x10 cm) and petiole (53 cm). These palm leaves are lanceolate-costapalmate and have been classified as *Sabalites* cf. *longirhachis*, being the most complete specimens found for this parataxon (Marmi et al., 2008). Similar palm leaf impressions have been found in the Grey "Garumnian" facies from other localities (Coll de Nargó and Tremp basins, both in Lleida province; Vicente, 2002; Marmi et al., 2008). In the levels above the "concrete", coals (see García-Vallés et al., 1993) indicate deposition in a forest-moor swamp environment probably in a subtropical humid climate.

Regarding charophytes, at least two species (*Peckichara cancellata* and *Microchara cristata)* have been identified by Feist & Colombo (1983) and Babinot et al. (1983) within the "Lower limestones with coals" unit. Recently, the genus *Feistiella* has also been reported in the Grey "Garumnian" facies of the Vallcebre syncline (Gómez et al., 2007).

SCIENTIFIC RELEVANCE AND SIGNIFICANCE

Fumanya tracksites are scientifically significant because of their ichnological record, age and location. A total minimum of 3,000 tracks, most of them aligned in 50 discrete trackways (both manus-only and manus-pes trackways; see table 1), have been identified to date. The carbonate fine grained original sediment where tracks were impressed increased the potential to preserve tracks as undertracks. Several examples of parallel trackways and the presence of multiple individuals at Fumanya South (Le Loeuff & Martínez, 1997b; Schulp & Brokx, 1999) and Mina Tumí sites report evidence of social behaviour. Occurrence of small trackways also allows comparison between adult and baby titanosaur trackmakers (Vila et al., in prep.).

This is the largest sample of sauropod ichnites in Europe in strata of any age. The other European localities with tracks ascribed to titanosaurs are those from Middle Jurassic at Oxfordshire (U.K.; Day et al., 2002) and Early Cretaceous at Istrian Peninsula (Croatia; Dalla Vecchia & Tarlao, 2000). Other titanosaur trackways are reported at South-America (Toro Toro, Cal Orcko, and Humaca; see Lockley et al., 2002 and references therein). Within this scarce titanosaur track record, Fumanya represents a unique location in order to characterize the latest titanosaur ichnites and correlate with the bony record. Localities from France (Le Loeuff, 1993), Romania (Le Loeuff, 2005) and Spain (Royo-Torres & Canudo, 2003) yielded multiple titanosaur bony remains though there is no evidence of significant new titanosaur tracksites.

Well-preserved trackways at Fumanya provide enough data to describe a distinctive trackway pattern characterized by 1) wide-gauge trackway (among the widest reported), 2) outward orientated entaxonic pes tracks with four claw marks, 3) U-shaped manus tracks without claw marks, 4) heteropody about 1:3, and 5) long manus-pes distance (Le Loeuff & Martínez, 1997b; Schulp & Brokx, 1999; Vila et al., 2005a and new observations; see fig. 11). Trackways can be assigned to *Brontopodus* type (Lockley & Meyer, 2000). Most of these features can be associated with moderate certainty to titanosaurs by using osteological synapomorphy based correlation (sensu Carrano & Wilson, 2001). The same authors argued that titanosaurs and some sister-taxa were the best candidates to make wide-gauge trackways because of their femoral shape and wip disposition (Wilson & Carrano, 1999). Examples of pedal and manual morphology in titanosaurs show at least four outward rotated metatarsials and a clear absence of manual phalanges in advanced titanosaurs (Apesteguía, 2005; Bonnan, 2005). Since saltasaurids exagerate the wide-gauge feature among sauropods (Wilson & Carrano, 1999) and the most complete specimens of Campanian-Maastrichtian sauropods (*Ampelosaurus atacis, Lirainosaurus astibiae*, and *Magyarosaurus dacus*) are regarded as advanced titanosaurs (i.e. lithostrothian titanosaurs; Upchurch et al., 2004) we suggest an advanced titanosaur affinity for the trackmakers of Fumanya. Other methods such as phenetic or coincidence (i.e. biostratigraphical) correlation were used to ascribe the trackways to sauropod and titanosaur taxonomic level, respectively (Le Loeuff & Martínez, 1997; Schulp & Brokx, 1999; Vila et al., 2005a).

As noted by Lockley & Meyer (2000; p. 238) "The Fumanya site acts as a window into the foot morphology and gaits of titanosaurids" and "... [preliminary reports] leaves a room for further detailed study of the individual trackways". Such detailed studies in progress are mainly focussed on describing three-dimensionally, tracks and trackways morphology (including calculations of load distribution within and through the footprints, cross sectional maps, statistical and multivariate analysis, etc.) (e.g. Bates et al., 2008b).

CULTURAL HERITAGE AND SOCIAL RELEVANCE

Besides the ichnological significance of these sauropod tracks and tracksites, the cultural and social relevance of Fumanya sites are remarkable. Nevertheless, administrative and legislative protection of the site is very recent. Under a legal point of view, the locality was not considered as a palaeontological site for governmental institutions until 2004. Because of the IDPI ("Icnitas de Dinosaurio de la Península Ibérica") proposal for a Natural UNESCO Worldwide Heritage (Andrés & Pérez-Lorente, 2005), several Pyrenean tracksites were evaluated and an administrative process was started. Nowadays Fumanya sites (Fumanya South, Mina Esquirol, Fumanya North, Mina Tumí and others) are regarded as BCIN (Cultural Good of National Interest; Resolution CLT/3492/2005), the maximum legal and protective statement in Spain. Furthermore, since 1993 the Catalan Cultural Heritage Law from the Generalitat de Catalunya (Catalan regional administration) avoids illegal fossil hunting in the area.

The cultural impact of the site within Berguedà and Catalonia is quite significant. From a cultural and social point of view, Fumanya has become an interesting site for tourists, schools, and universities. The nearest museum (Museu de les Mines de Cercs) organises guided visits to the main site, Fumanya South. As an example, during 2005 up to 1,740 people visited Fumanya South site (note that it just counts the organized visits) and about 2,000 people visited the M.A. (millions of years) palaeontology exhibition at Vallcebre. The exhibition displays didactic contents in order to explain basic ichnology, palaeontology and recent findings at the area. On the other hand, scientific and heritage relevance of the sites (associated with minery industry) permitted the organization of several meetings and symposiums focussed on minery and palaeontological heritage (V International Meeting on Geological and Minery Heritage, 2004), palaeoichnology (International Symposium on Dinosaurs and other vertebrates palaeoichnology, 2005), and palaeontology (III Young Researchers on Palaeontology Meeting, 2005).

CONCLUSIONS

A historical and ichnological overview outlines the following considerations:

1.- The Fumanya sites have remained largely unstudied until fifteen years after its discovery in 1985 by L. Viladrich. General information on the tracksite has been obtained from several research teams.

2.- Initial approaches revealed first data on trackmaker ichnology (general track and trackway morphology, trackmaker ascription). The current and future studies at Fumanya sites will provide further refinements on titanosaur track morphology, stance, gauge and locomotion.

3.- The sites provide an exceptional record of Maastrichtian sauropod ichnology with a total of nearly 3,000 footprints arranged in more than 50 trackways. Additional occurrence of small and parallel trackways allows comparison between adult and subadult trackmakers and inferences on social behaviour. Characteristic ichnological features refer to trackway width, tracks (manus and pes) arrangement and morphology. All trackways are wide-gauge (*Brontopodus*) and most probably represent the same taxon of trackmaker, titanosaur sauropods, based on a synapomorphy correlation.

4.- Outcrop deterioration has deleted significant ichnological information (5 trackways completely eroded) that can be integrated in the present day dataset after the study of ancient pictures and measurements. Comparison of present day outcrops with older pictures from 1985 onwards reveals six trackways that are at present time eroded or partially preserved. This record has been integrated in the present day dataset and is interpretated as manus-only and manus and pes titanosaur trackways.

5.- Weathering and conservation studies provide conservation tools for the outcrop. If no further investment is carried out in conservation, soon hardly any footprints will be visible.

6.- Fumanya is a site integrated in a large Maastrichtian succession with plenty of other dinosaur remains (ichnites, bones and nests) and other paleoecological indicators (plants, invertebrates, etc.). This reinforces Vallcebre section as a key point to understanding how dinosaurs were in the Maastrichtian and their extinction.

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