

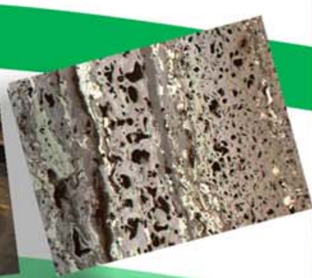

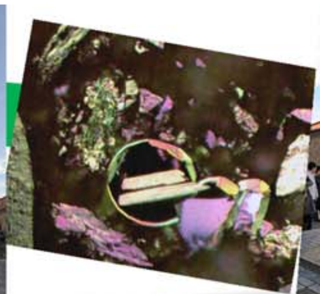


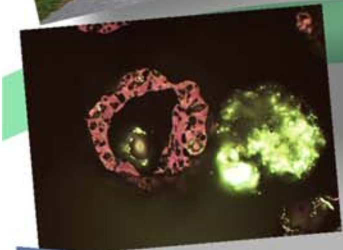

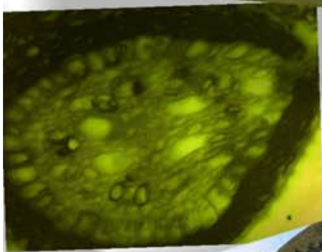

INTERNATIONAL CONFERENCE ON COAL AND ORGANIC PETROLOGY

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INTERNATIONAL COMMITTEE FOR COAL AND ORGANIC PETROLOGY • ICCP

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ASTURIAN JURASSIC COAST FIELD TRIP GUIDE

OVIEDO, SPAIN

SEPTEMBER 21-27, 2008

60TH MEETING OF THE INTERNATIONAL COMMITTEE FOR COAL AND ORGANIC PETROLOGY - ICCP

25TH MEETING OF THE SOCIETY FOR ORGANIC PETROLOGY - TSOP

GOBIERNO DE ESPAÑA | MINISTERIO DE CIENCIA E INNOVACIÓN | CSIC CONSEJO SUPERIOR DE INVESTIGACIONES CIENTÍFICAS

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Asturian Jurassic Coast

Field Trip Guidebook

J.C. García-Ramos, L. Piñuela, C. Aramburu, I. Suárez-Ruiz and J.I. Ruiz-Omeñaca,

International Conference on Coal and Organic Petrology

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Asturian Jurassic Coast
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García-Ramos[1,2], J.C., Piñuela[1,2], L., Aramburu[2], C., Suárez-Ruiz[3], I. and Ruiz-Omeñaca[1,2], J.I.

(1) Museo del Jurásico de Asturias, E-33328 Colunga, Asturias, Spain
(2) Dpt. of Geology, Oviedo University, E-33005, Oviedo, Asturias, Spain
(3) Instituto Nacional del Carbón (INCAR-CSIC), E-33011, Oviedo, Asturias, Spain

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The "Dinosaur Coast" refers to the section of the Asturian coast between the villages of Gijón and Ribadesella, which contains abundant footprints and fossil bones from dinosaurs and other Jurassic reptiles.

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Fig. 1. Index map of eastern Asturias and field trip route

The Jurassic World

The term "Jurassic" owes its name to the Jura Mountains, which extend along the border between France and Switzerland.

The Jurassic Period, which lasted about 55 m.y. (from 200 m.y. to 145 m.y. ago) is situated between the Triassic and the Cretaceous periods and constitutes the central part of the Mesozoic Era, in turn limited by two significant biological events: the latest Permian extinction (the most devastating of all known organic extinctions) at its beginning and the end of Cretaceous extinction (the most famous one because many dinosaur groups became extinct in it) at its close.

As regards dinosaurs, this was the time when big sauropods flourished as the dominant life-form. They appeared in the Early Jurassic and reached their peak and highest diversification in the Late Jurassic. Birds appeared in the Late Jurassic as well. Grass did not exist and flowering plants had not yet developed.

It was at the start of the Jurassic that the progressive breaking up of the supercontinent Pangea began, which gradually gave rise to the continents and water masses as they exist today. In that world there was an apparent lack of ice at the poles and the temperature differences between the polar and the equatorial regions were far less marked than nowadays.

The Jurassic rocks in Asturias

The most spectacular rock outcrops from the Jurassic in Asturias extend along a practically continuous segment of coast between Cape Torres (west of Gijón) and 2 km east of Ribadesella, limited in both cases by important faults which relate them to much older rocks belonging to the Palaeozoic Era (Fig. 2).

One way to order these rocks systematically consists in grouping them together in sets of similar features known as "formations". According to this criterion, the Jurassic rocks in Asturias can be ordered into different formations, from the oldest to the youngest (Fig. 3).

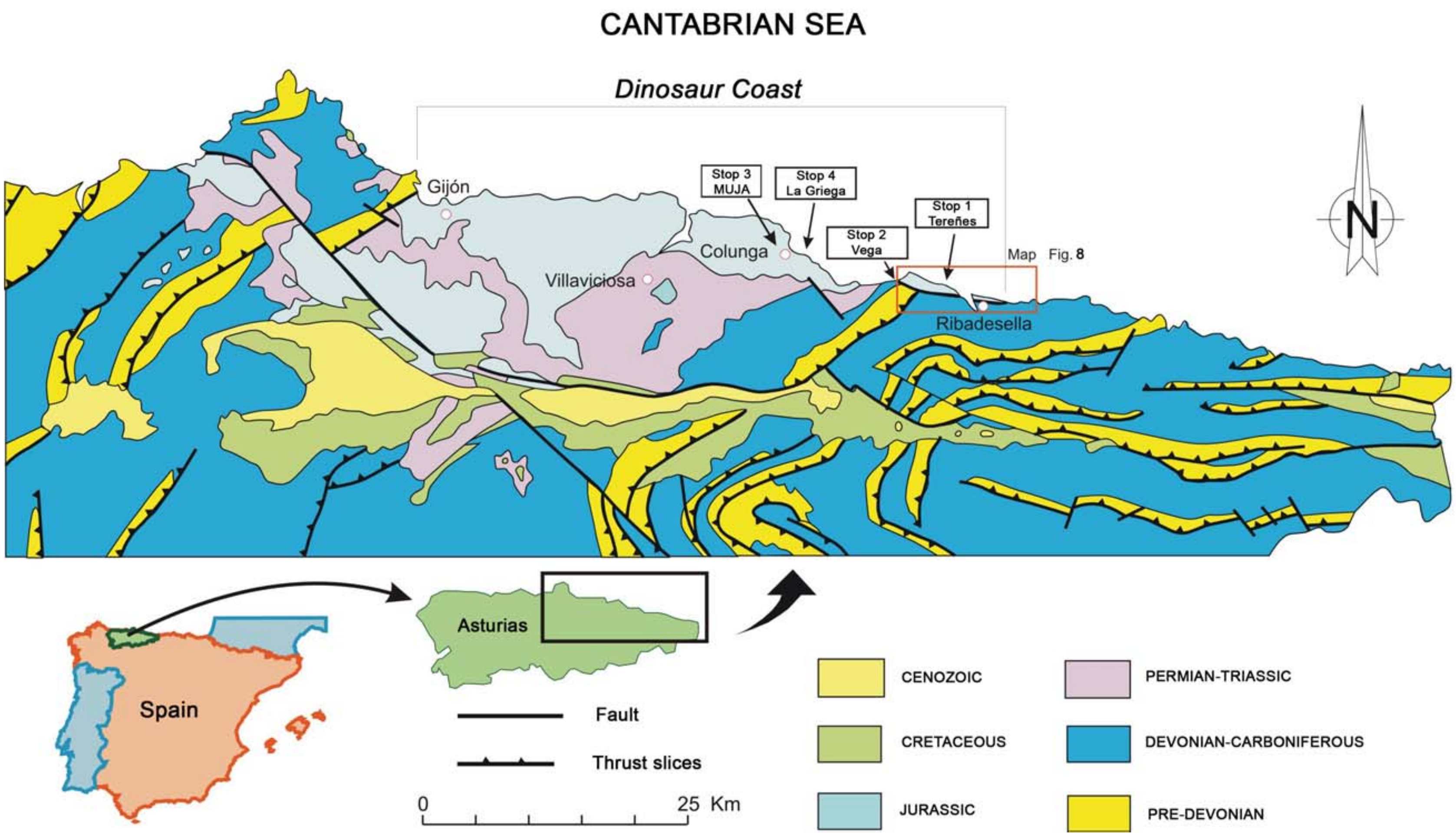

Fig. 2. Geological map of the easterrn Asturias section, including the situation of the three stops of field trip. After García-Ramos & Gutiérrez Claverol (1995).

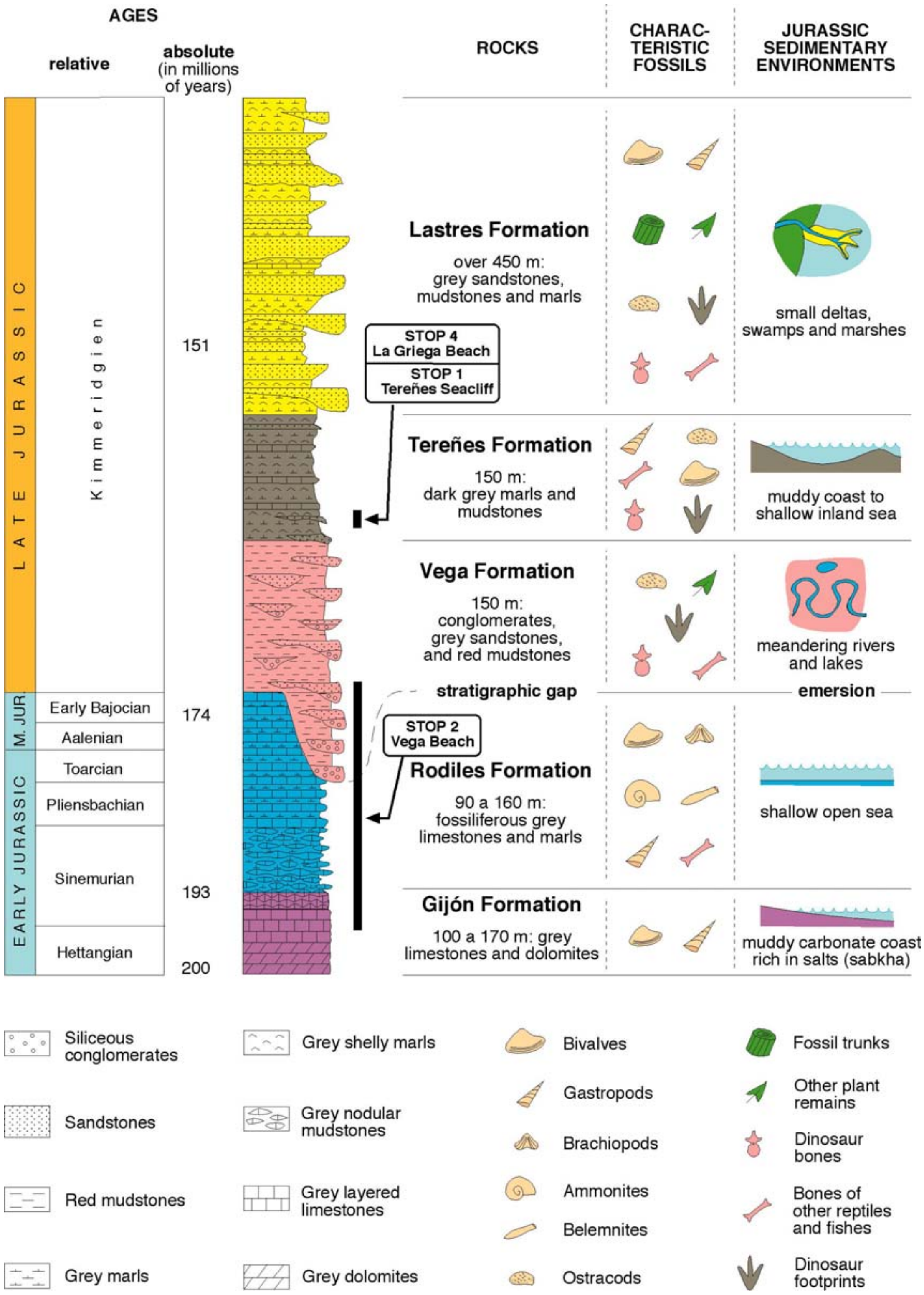

Fig. 3. Generalized stratigraphic succession of the Jurassic in the Colunga-Ribadesella area (García-Ramos *et al*., 2000).

Detailed study of these rock formations has allowed a reconstruction of the Jurassic landscape in Asturias (DVD 2003). This look back on the past, however, cannot be assessed in a general way, but through successive stages, as the landscape underwent many changes over a long period of time that lasted 65 million years.

The great marine invasion in the Early Jurassic

The Gijón Formation, which marks the beginning of the Jurassic history in our region, consists of limestones and dolomites which accumulated on a flat and irregular coast, rich in carbonate muds, in a mostly arid climate. This favoured the accumulation of salts. The relief was rather flat, without mountains, and the coastline was NW-SE oriented.

A bit later the sea level began to rise slowly, spreading all over the region, which sometimes was submerged down to depths of even 50 m. That sea displayed a rich and varied fauna with predominance of molluscs, brachiopods, crinoids, crustaceans and worms. Bivalves and cephalopods (ammonites and belemnites) were abundant among molluscs.There were also big sea reptiles, such as icthyosaurs and plesiosaurs, swimming in these warm waters. Evidence of these species has remained in their fossilized bones.

The most characteristic marine rocks from this first half of the Jurassic are the thick rhythmic successions, made up of limestone-marl alternations, like the ones cropping out on the seacliffs in Huerres (Colunga), Peñarrubia (Gijón), and on the beaches of Rodiles and Vega.

These rhythmites, known as Rodiles Formation, contain different dark grey marly levels (black shales), rich in organic matter which even generated oil. Remains of it have been preserved in the inside of some fossils and in small rock fissures.

The tectonic activity and the landscape in the Late Jurassic

At the outset of the Late Jurassic the landscape in Asturias underwent a drastic change which resulted in a quick uplift and emersion of the marine basin due to tectonic activity. This gave rise to an irregular relief, specially marked towards the southwest. Siliceous sediments originated in this part of the region and began to be deposited in the whole area. These sediments arose from the erosion of a relief of Paleozoic rocks exhumated by fault activity.

The material resulting from the erosion of this relief (gravel, sand, mud) was drifted by river courses to a coast which must have lain to the east of the region. This material makes up the Vega Formation nowadays.

The climate exhibited certain aridity at that time, judging both by the existence of carbonate fossil soils (caliches) gypsum levels and by the vertical arrangement of root traces, which evidences a low phreatic level.

This emersion, which resulted in a sudden shift from marine to continental conditions, became spectacularly displayed by a sharp contact between carbonate and siliceous rocks, such as that which can be observed nowadays in the Jurassic successions on the coastal cliffs in Huerres (Colunga), El Puntal and Santa Mera (Villaviciosa), Lastres and the beaches of Peñarrubia, La Griega, Vega and Ribadesella. This boundary represents a significant stratigraphic gap, because the absence of many rocks, of Mid and Upper Jurassic.

From this stage, on the dry land, we find the first evidences of dinosaurs: isolated bones and teeth in the conglomerate and sandstone beds of ancient Jurassic rivers, together with various footprints (ichnites).

In some of the inactive river channels and certain depressions between lay occasional small pools and fresh water ponds where bacteria, algae (charophytes) and ostracods proliferated. Nevertheless, most of these areas situated between channels remained in subaerial conditions and, as a result, their sediments were oxidized, which produced the typical reddish coloration of the Vega Formation strata.

A new rise of the Jurassic sea level from the northeast progressively flooded the central eastern part of the Asturian region. Here settled a low and irregular coastline, with plentiful dark muds rich in organic matter and variable proportions of sand borne by deltas. These flowed into a tideless inland sea, detached from the open sea by a threshold or barrier which served as protection against the storms at the time. Between this threshold and the coastline lay a large depression of stagnant brackish waters, at the bottom of which a great amount of dark grey and black muds was laid down.

The sediments which were deposited in these environments turned into the rocks that today make up the Tereñes Formation. These rocks contain abundant levels of dark-coloured mudstones, very rich in dense accumulations of shells of gastropods and bivalves (shelly beds).

The final episodes of the Jurassic history of the region, which gave rise to the rocks of the Lastres Formation, were characterized by an increase in the activity of the fluvial systems, which resulted in a bigger proportion of sand supplies on the coast, due to the activity of small deltas. This caused the littoral to extend even further north-east, though its previous NW-SE orientation remained unaltered.

Dinosaurs lived in those areas of dry land close to the coast, and on the coast itself, as can be inferred from the frequent findings of fossil bones and, especially, of footprints. The fossils found in Tereñes and Lastres Formations prove that the vertebrate fauna was rich and varied, including dinosaurs, crocodiles, turtles, flying reptiles (pterosaurs) and fishes.

In marshy and swampy areas of the coastal plain the vegetation was varied: from ferns to trunks over 11 m long and about 1 m wide. In some cases we can even notice the remains of petrified forests in which the stumps have kept their original position and preserved their roots.

The Jurassic landscape was very different from the landscape at the present time. Asturias was placed in the Upper Jurassic times at a paleolatitude about 33º N. The coast was not yet cliffed and it did not show the present west-east orientation, either. Moreover, the Cantabrian Mountains and the present inland reliefs did not yet exist. The formation of these mountain reliefs was due to the late Alpine Orogeny, which reached its peak about 30 million years ago, during the first half of the Tertiary Era, and it also caused the inclination that the Jurassic strata show nowadays.

Asturian Jet

The upright and drifted woody trunks of conifers (Fig. 4), fossilized and oil-impregnated, have produced jet, a variety of coal highly appreciated in jewellery which has been long exploited in Asturias, especially in the coastal area of the borough of Villaviciosa (Oles, Argüero, Quintes, Tazones, etc.).

The next summary on Asturias jet is taken of Suarez-Ruiz & Iglesias (2007). Jet is a gemstone of great beauty that has been used from prehistoric times to the present day. Due to the magical powers attributed to this stone, it has always been considered a mysterious gem. These powers include its protective and defensive properties as well its medical and chiromantic characteristics.

Fig. 4. Fossil tree-trunk with roots in upright position. Lastres Formation. Oles sea cliffs (Villaviciosa).

Several cultural trends, both pagan and Christian, converged in this black material in the Camino de Santiago (Saint James Way) between the 11th and 17th centuries. The “Camino de Santiago)” had tremendous significance in Europe because it was a crucible of culture and traditions as well as the most important vector of cultural trasition in those times. In this context, jet, once carved and polished in the form of various objects, served as a souvenir of the pilgrimage.

At present, jet is worked by artisan craftsmen, but using modern tools and modern designs in Asturias and Galicia (North-western Spain) to produce ornamental objects and jewelry goods mounted with silver, gold and coral. The final result is an exceptionally attractive product of high quality that is very much appreciated. Spanish jet, which successfully competed in the past with the well known jet from Whytby, England, is experiencing major difficulties at present related to its scarcity as a natural resource. As a result objects carved in jet are usually small in size and of a high price.

Asturian jet is a humic coal, conventionally assimilated to a variety of lignite coals. It is black in color, bright, light, compact, and relatively hard, with a fracture from cubical to conchoidal pattern, originating fragments with sharp edges. It is of a low density and susceptible to being carved and poslihed.

Petrological and geochemical studies of this material have shown that it has special and anomalous properties different to those of other coals. Asturian jet is a lithotype, the vitrain that is microscopically made up of only one maceral group: huminite/vitrinite. Some of the huminite (ulminite) has a relatively low intensity of fluorescence and shows very low reflectance (0.39%). The chemical composition of this coal is almost exclusively organic, with a negligible mineral matter content (1.08 ash, db), very low moisture (2.9%), sulfur and nitrogen contents (<1.5%) and a relatively high content in carbon (84.8%, daf) in volatile matter (54.0%, daf) and hydrogen (5.9%, daf). The final feature just mentioned is the rason for which it can be included in the category of perhydrous coals. Its perhydrous character justifies its high calorific value (8,163 kcal/kg), which is different to that normally attributed to lignites. Asturian jet is also characterized by a high proportion of aliphatic over condensed aromatic structures.

The hydrocarbons adsorbed by this coal were only retained in the porosity of its ulminite as it is shown by the very low porosity values.

Two mechanisms have been described to explain the effect of the hydrogenation processes in the increase of vitrinite reflectance. Asturian jet may be ascribed to one of the processes in which the increase in reflectance during its evolution was limited by inhibitor influence of the adsorbed oils. It is because of this that the huminite/vitrinite reflectance shows lower values in comparison to the real degree of evolution attained by this coal.

The modification of the textural properties of this coal (e.g. porosity) by the absorbed hydrocarbons prevents the oxygen from gaining easy access to the active centers of this coal. This explains the remarkable stability of jet, even after prolonged exposure to the air. As a result, Asturian jet remains unaltered over long periods of time.

Dinosaurs

The term "dinosaur" (terrible lizard) was coined by the British paleontologist Richard Owen in 1841. However, the first bones initially attributed to these unknown reptiles were found in several localities in the south of Britain in the 1820s.

Dinosaurs represented a particular group of land reptiles of great evolutionary success, which ruled our planet over a period of about 165 million years, extending from 230 m.y. (when they appeared in the Late Triassic) to 65 m.y. ago (time of their partial extinction at the end of the Cretaceous). This period of time corresponds to the greatest part of the Mesozoic Era. There were still 63 m.y. to go before the human race appeared on Earth.

Over their extensive lifespan, dinosaurs diversified and went through numerous evolutionary transformations. Moreover, they lived in a variety of ecological niches, all of them on dry land, though they could also sporadically wander into the waters of lakes, marshes, rivers and bays. Nevertheless, none of them were aquatic or could fly, unless avian dinosaurs.

A characteristic of dinosaurs is that their extremities emerge below their body, in a vertical orientation, whereas in most reptiles the extremities emerge laterally in an arched orientation.

Dinosaurs can be classified according to their pelvic structure in two distinct groups (Fig. 5): saurischians (reptile-hipped) and ornithischians (bird-hipped). The former include theropods (carnivorous, bipedal and three-toed) and sauropods (herbivorous and quadrupedal). Ornithopods (herbivorous, bipedal and threetoed; sometimes also quadrupedal) stood out among ornithischians, together with duckbilled, plated (stegosaurs), armoured (ankylosaurs) and horned dinosaurs (ceratopsians). All these were herbivorous.

According to their mode of locomotion, dinosaurs can be classified into bipeds and quadrupeds. The former, such as theropods and most ornithopods, walked upright like big flightless birds (ostriches), though some of them (certain ornithopods) could also move on their four limbs on the ground. In contrast, quadrupeds, such as sauropods, or horned, plated and armoured dinosaurs, moved on fore- and hindlimbs simultaneously.

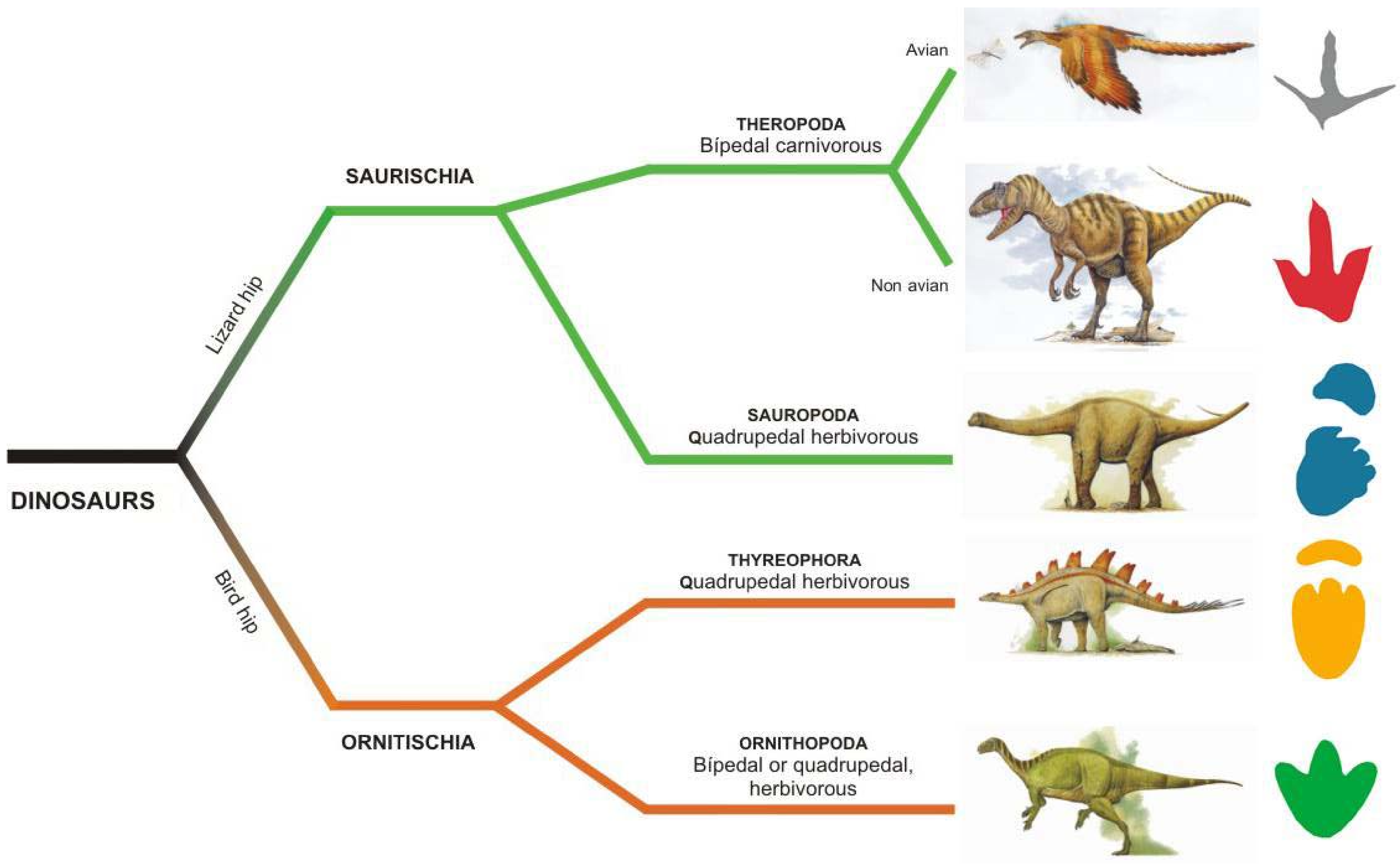

Fig. 5. Simple classification of dinosaurs represented in Asturias through bones and ichnological evidences.

Dinosaur Tracks

When moving on soft sediment (mud or sand) dinosaurs left a series of impressions called footprints or "ichnites". A set of footprints heading in a particular direction is termed a "trackway".

Footprints can provide valuable information about the behaviour of dinosaurs and the environment in which they lived. In addition, the study of tracks enables us to complete the data obtained from their fossilized bones.

Unlike bony remains, which need to be extracted from the rock and cleaned up for further study and classification in the laboratory, tracks often provide a more direct type of information through examination of the surface of the bed in which they occur. Tracks also indicate the exact place where the dinosaur walked, whereas bones are not always found where the dinosaur died, but were often transported by currents.

Among quadrupeds, the outstanding characteristic of sauropods and armoured dinosaurs was that they left pes footprints which were very different from manus footprints, both in shape and size. Hindfoot prints are bigger and they usually end in five very short toes, whereas forefoot prints seldom show finger impressions. On the contrary, other quadrupeds, such as horned dinosaurs, show only minor differences in the shape and size of tracks of their fore- and hindlimbs. In footprints from three-toed bipedals, the ends of the toes can be either rather blunt (ornithopods) or very sharp-pointed, corresponding to imprints of claws (theropods).

Careful study of the footprints can indicate if the dinosaur was small or large, herbivorous or carnivorous, whether it walked on two feet (bipedal) or both fore- and hindlimbs (quadrupedal), the approximate shape and number of toes/fingers on the hindfoot or forefoot, and if the print was from the left or right limb.

Various measurements can be made on the single prints (Fig. 6), such as length, width and depth for bipedal or quadrupedal dinosaurs; additional features such interdigital angles can be measured for tridactyl prints from theropod and ornithopod dinosaurs. In quadrupedal dinosaurs, it is also possible to measure the manuspes length and the manus-pes distance.

In the trackways (both from bipedal and quadrupedal dinosaurs), common measurements are the pace and pace angulation, the stride, footprint rotation (the angle the prints form with the midline of the trackway) and the internal and external width of the trackway. The body lenght, or glenoacetabular distance, is measured only for quadrupeds.

As a rule, quadrupedal dinosaur trackways are wider than those of bipeds, as a result of their different body structure. Moreover, trackway width is in turn inversely proportional to the length of limbs and to the animal´s movement speed.

Tracks fossilization

For a track to fossilize in a bed, a series of conditions must be previously met (Fig. 7). First of all, the composition of the sediment on which the track is created must be different from that which fills it afterwards. This happens, for example, when a dinosaur treads on mud leaving a hollow which is later covered by sand, resulting in a natural cast. Furthermore, it is essential that once formed the track should not be destroyed by erosive agents such as water currents or wave action. A track can also be altered by biological agents such as the steps of other dinosaurs.

When a dinosaur trod on soft ground, it caused a deformation not only on the upper bed but also on the immediately underlying strata, where it also created impressions of increasingly more diffuse and rounded shape called "undertracks".

The depth of a certain footprint will depend on the weight of the dinosaur as well as on the texture and composition of the sediment on which the animal treads. Thus, for instance, deeper tracks will be created on the soft mud of a pool than on the sand of a beach. Also, there will be differences between two sediments with the same composition but a different degree of moisture (for example, water-saturated mud or dry mud). In the former the depth of a track will be bigger and its contour more diffuse.

Dinosaur tracks in Asturias

Plain evidence of the abundance and variety of dinosaurs in Asturias in the Jurassic is provided by the numerous findings of footprints in the three formations of the Late Jurassic (Vega, Tereñes and Lastres), which crop out on the coastal cliffs in the boroughs of Villaviciosa, Colunga and Ribadesella.

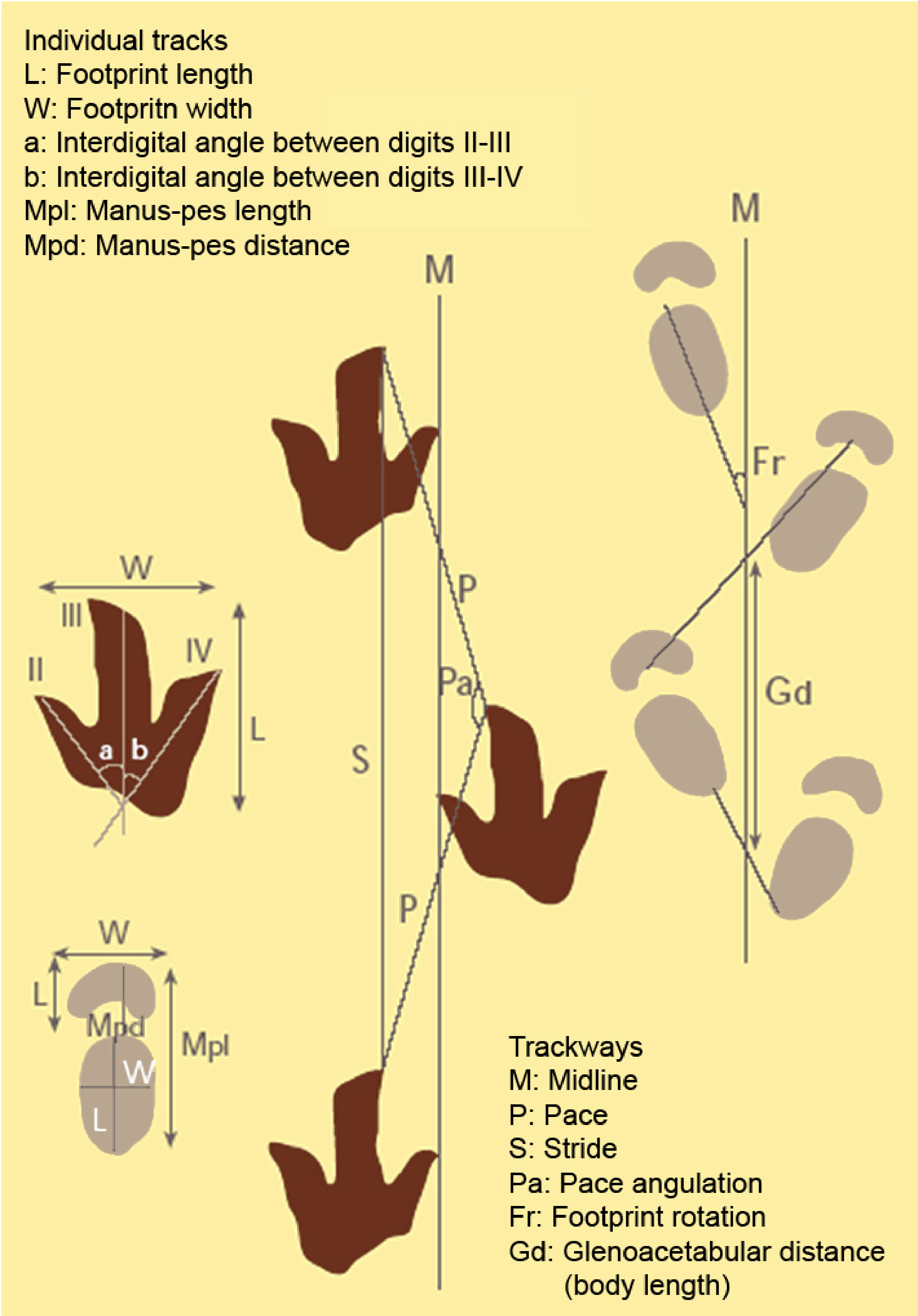

Fig. 6. Measurements used in describing bipedal and quadrupedal dinosaur tracks and trackways.

From an analysis of the tracks found in Asturias and comparison with other known sites, the following conclusions can be drawn:

- There is evidence of both bipeds (theropods and ornithopods) and quadrupeds (mostly sauropods and stegosaurs) in the region.

- The frequent occurrence of footprints preserved as natural casts in the outcrops often allows an accurate reproduction of the anatomical features of the fore- and hindfoot of the dinosaurs which created these tracks (claws, toe pads, irregular skin texture, and so on).

- Judging by the size of tracks, there were dinosaurs of very varied proportions in our region, from small ones to huge ones, as is the case of brachiosaurs.

- Some sauropod footprints such as those found on the beach of La Griega or on the Tereñes cliffs, are the biggest tracks known in Spain and are among the largest in the world.

- The woody parts of tree trunks, fossilized and hydrocarbon-impregnated, have produced jet, a variety of lignite highly appreciated in jewellery which has been long exploited in Asturias, especially in the coastal area of the borough of Villaviciosa (Oles, Argüero, Quintes, Tazones, etc.).

The main groupings of footprints appear around former deltaic areas on the coastal plain, especially inland, and on the banks of small deltaic channels next to their mouth, as well as in areas bordering marshes, swamps and lagoons situated between those channels.

Some of the footprints constitute rather long trackways, like the ones on the Oles cliffs, those west of Tazones and Tereñes, or those in Merón and Ribadesella beaches.

To sum up, this area can be said to represent the most important Jurassic site of dinosaur tracks in Spain. It is also the Spanish site with the largest number of quadrupedal dinosaur footprints (mostly sauropods and stegosaurs).

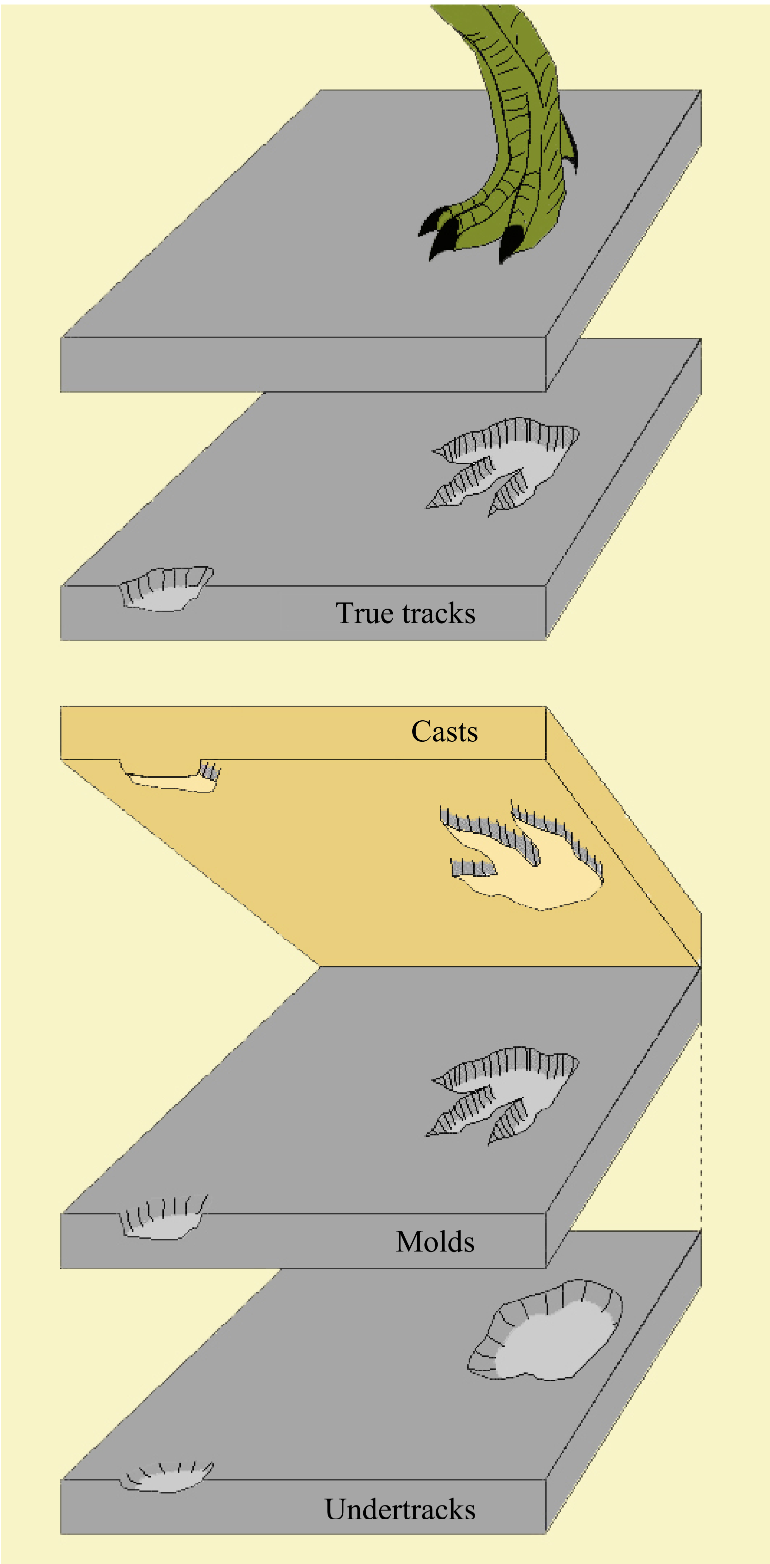

Fig. 7. Formation and preservation of footprints.

The Government of Asturias designated in 2001 the dinosaur footprints as a Natural Monument. The Asturian formations with dinosaur footprints, along with similar sites elsewhere in the Iberian Peninsula, are also candidates for designation as UNESCO Heritage Monuments.

STOP 1

Tereñes Sea Cliffs

Tereñes is a small village located 2 km at the west from Ribadesella (Fig.8). To start this route we take the road leading up to Tereñes until we reach a height where this road makes a sudden turn to the left, at the crossroads. From the information panel at this point, we take a narrow slightly sloping road, and about 200 m further down we turn right onto a path leading to the cliff. The cliff is made up of Tereñes Formation strata which slope seawards.

Dinosaur tracksites and lithological cycles

A number of dinosaur footprints levels are present here in a thin unit of about seven meters thick (Figs. 9 and 10; Piñuela *et al*., 2007)).

Once on the cliff we begin to walk eastward from the staircase. In the surface of a grey marly sandstone bed sloped towards the sea displays a large number of ichnites, among which we can distinguish several belonging to theropods and at least 4 parallel trackways (Figs. 11 and 12), very close together, made by ornithopodos (Fernández *et al.*, 2000; Piñuela *et al*., 2002) . This site is very important from a scientific point of view for three reasons:

- It is the first example in the Spanish Jurassic of gregarious behaviour in this group of herbivore dinosaurs.
- In the rest of the world, it is fairly rare to find ichnite sites which show a gregarious behaviour in ornithopods.
- The footprints were made by specimens of a larger size than any bone remains of specimens from this age known to date.

In the highest part, but in a lower bed, we can see another trackway of a large carnivorous dinosaur theropod, made up of 5 consecutive ichnites (Fig. 13).

A third lower bed close to it contains a number quadrupedal dinosaur footprints overlying spectacular mud cracks; an isolated footprint of this bed it can see in Fig. 14.

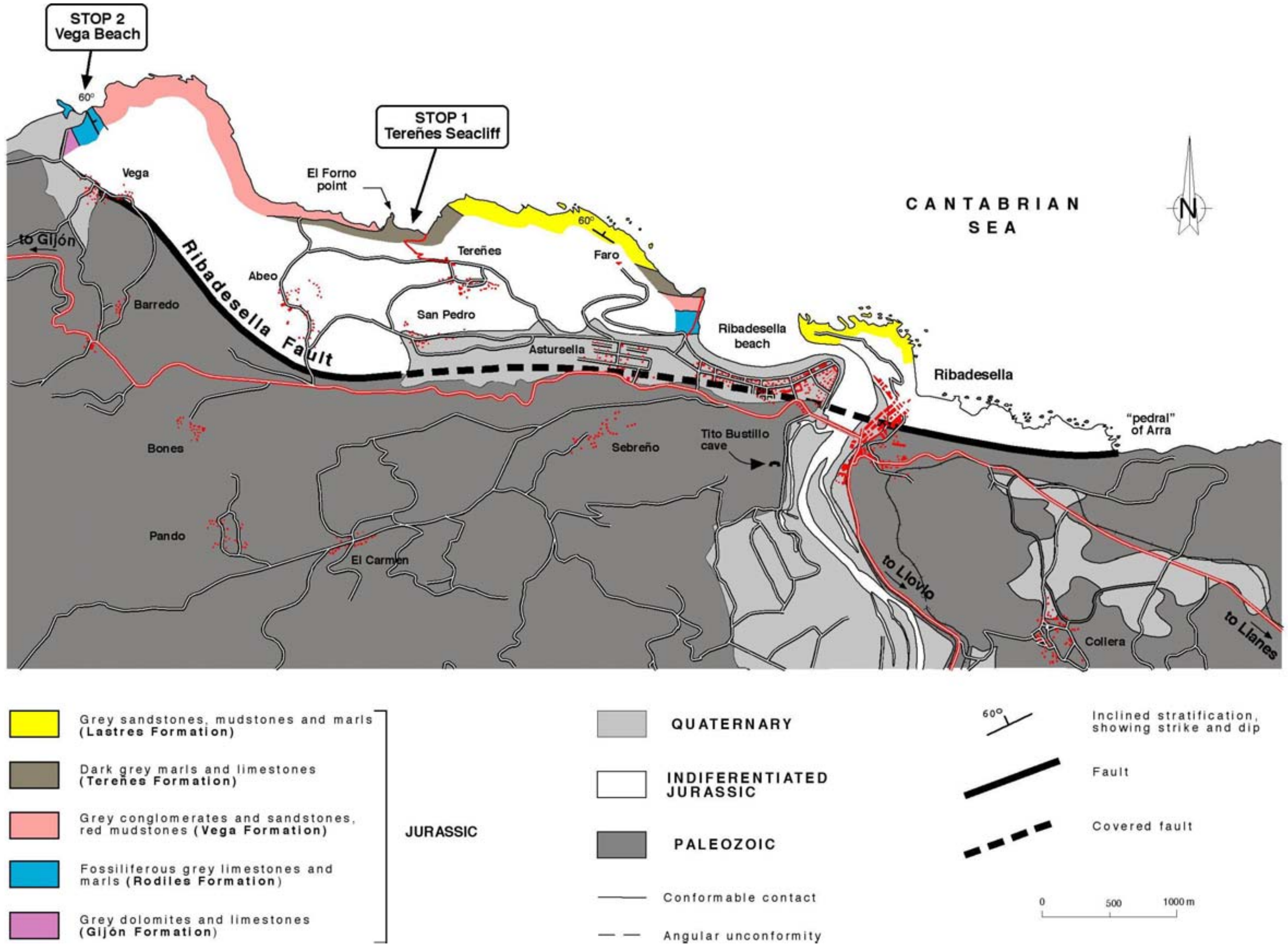

Fig.8. Geological map of the region close to Ribadesella, showing the situation of the first two stops of the field trip

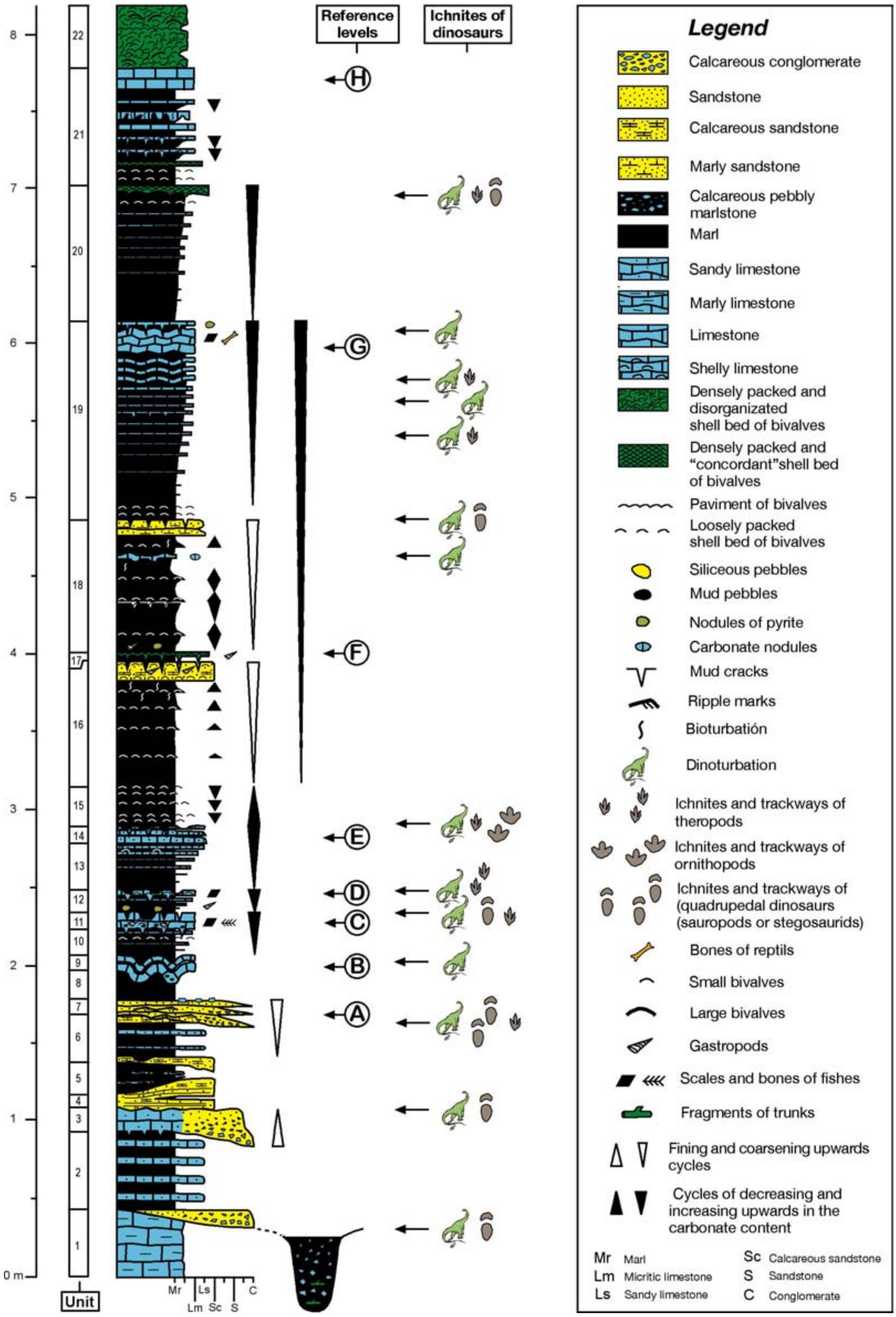

Fig. 9. Measured section showing the levels with dinosaur footprints in the Tereñes Formation (Tereñes sea cliffs)

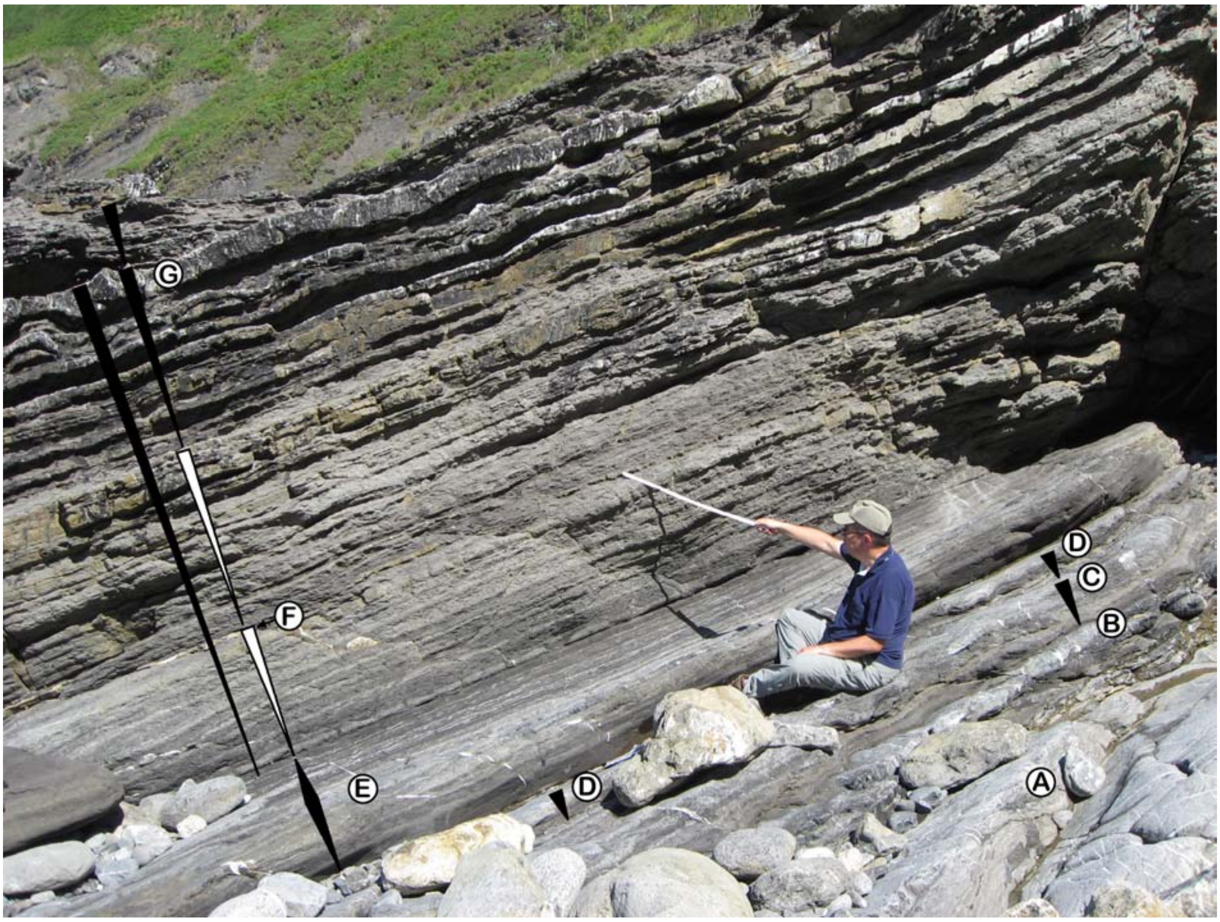

Fig. 10. View of the stratigraphic succession represented in Fig. 9, showing the sequences and reference levels there indicated.

Near to these tracks, but at the west from the access staircase, on the surface of a marly sandstone bed, we can see another trackway made up of 16 casts, preserved as high reliefs, most of them corresponding to hind feet (Fig. 15). At the start of the trackway, there is an exceptional example of a pair of forelegs of a quadrupedal dinosaur, probably a stegosaur. From the size of these footprints it could be a small adult dinosaur (a hip height of approximately 152 cm) or of a young individual.

Fig. 11. Parallel trackways attributed to bipedal and herbivorous dinosaurs (gregarious ornithopods) walking at the same time. Tereñes tracksite (Ribadesella). Level E in Figs. 9 and 10

Fig. 12. Ornithopod herd walking on a mud flat of Asturin Upper Jurassic coast. Dinosaurs like these produced the trackways in Fig.. 11

Fig. 13. Large theropod trackway. Tereñes tracksite (Ribadesella). Level D in Figs. 9 and 10

Fig. 14. Quadrupedal dinosaur footprint on the top of a fallen block of sandy limestone showing mud cracks. Level C in Figs. 9 and 10.

Nearby, in an isolated calcareous block with mud cracks are conserved two footprints, belonging to the same trackway, attributed to an ornithopod.

In a small bay situated 90 m southwest of the Peñón del Forno there is a reddish sandstone block (Vega Formation) fallen to the bottom of the cliff. On its now vertical stratification plane we see 17 casts of small three-toed footprints of bipedal dinosaurs, some of them, probably, belonging to ornithopods.

The total length of the walk along the base of the cliff is about 400 m. Apart from the footpritns the cliff also contains striking examples of Jurassic mud cracks.

Fig. 15. Trackway of a quadrupedal dinosaur, probably a stegosaur, showing manus and pes footpritns and a detail of a manus-pes set. Tereñes tracksite. Level A in Figs. 9 and 10

STOP 2

Vega Beach

From the coastal highway N-632, head west from Ribadesella 6 km until arriving near the village of Torre. From here, take the paved road 1.8 km to the Vega beach. A few meters from the eastern end of the beach parking lot, there are outcrops of limestones and dolomites of the Gijón Formation, upon which there is a series of alternating limestones and grey marls (Rodiles Formation). See Fig. 3

The Rodiles Formation, exposed in beds tilted towards the east, contains abundant marine fossils such as brachiopods, belemnites, ammonites, bivalves, etc.

The Lower Jurassic succession of Asturias was deposited in an epicontinental platform developed westwards to the Basque-Cantabrian Basin. This succession shows the evolution from carbonate-evaporite coastal sediments in the Late Raethian-Early Sinemurian to open platform lime mudstones and marls in the Pliensbachian and Toarcian. This evolution is interpreted as a major T-R cycle, which includes four black shale intervals (TOC up to 7% after Borrego *et al.*, 1997) developed at the late stages of the transgressive phase (Aurell et al., 2003).

Origin of Pliensbachian marl-limestone alternations

The Pliensbachian marl-limestone alternations represent deposition in the outer area of a storm-dominated carbonate ramp, which was opened to the north. The selected interval in Figs. 16 and 17 corresponds to most of the *davoei* Zone.

This outer ramp marl-limestone succession consists of elementary cycles of bioclastic levels followed by dark laminated intervals, which can be eventually burrowed. These were formed after several storm episodes. Elementary cycles are grouped in bundles that reflect cyclic changes on the carbonate exported from shallow platform areas and in the bottom oxygenation. These cyclic changes are tentatively related to orbital cycles in the Milankovitch frequency band (i. e., the short-eccentricity cycle). The compared analysis between primary cycles and the lithological profile shows that individual beds and marl-limestone rhythms are partly diagenetic in origin. However, many packages of marl-limestone rhythms, showing upwards thickening of limestone beds, have similar stratigraphic distribution than bundles of elementary cycles. These packages represent therefore the diagenetic enhancement of the primary lithological differences related to the progressive upward increase of the carbonate derived from shallow productivity areas (Bádenas et al., *in press*).

The absence of bioturbation episodes in several thick laminated intervals (black shales) could be explained by the existence of anoxic or subanoxic conditions. This fact could be due to the high sedimentation rates and/or deposition below the boundary of the deficient-oxygen waters in the relatively deep area.

Composition and organic evolution of Pliensbachian black shale levels

According to Suárez-Ruiz & Prado (1995), the organic fraction of these Pliensbachian black shale levels is composed of the mixed type of organic matter which corresponds to a type II Kerogen. It is composed of autochthonous material of aquatic origin (marine) which dominates over that from the continental origin, and comes from the phytoplancton and zooplancton as well as their degradation products. It mainly corresponds to alginite: (Lamalginite and Tasmanites, indicative of brackish waters), bituminite and different fragments of zooclasts as well as elements of the hystrichospherid group.

The allochthonous material is represented by pieces of continental vegetable origin which are scarce and reduced in size. They would be classified according to the established maceral groups by the ICCP as inertinite (fusinites and in lesser amounts semifusinites), huminite/vitrinite (humo/colinite and scarce humo/telinite), liptinite (microspores and few resinites) and products of mechanical and/or biochemical degradation. The main mass of these rocks is the organo-mineral groundmass, an undifferentiated mixture of organic and inorganic substances, over which the other figurated components, mentioned above, are found. Moreover, in the case of black shales with reflectance greater than 0.5%, different phases of hydrocarbons are highly fluorescent and solid bitumens have been identified.

The inorganic fraction of these black shales, identified by XRD is composed of calcite, quartz, pyrite, illite and in smaller amounts dolomite, ankerite, kaolinite and traces of feldspars.

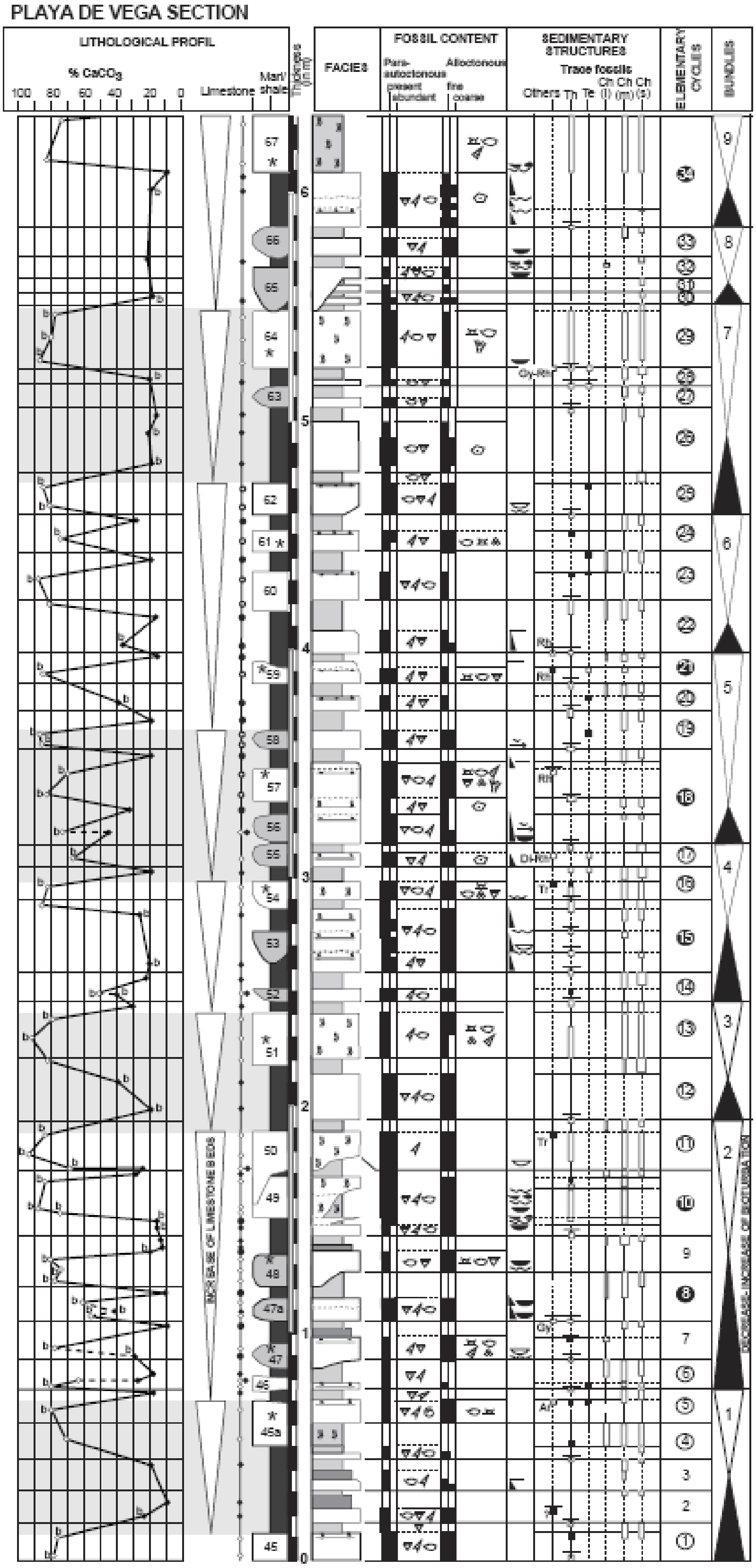
PLAYA DE VEGA SECTION
LITHOLOGICAL PROFIL
% CaCO3
Limestone
Marl/shale
Thickness (in m)
FACIES
FOSSIL CONTENT
Para-autoctonous
present
abundant
Alloctonous
fine
coarse
SEDIMENTARY STRUCTURES
Trace fossils
Others
ELEMENTARY CYCLES
BUNDLES
INCREASE OF LIMESTONE BEDS
DECREASE - INCREASE OF BIOTURBATION

Fig. 16. Detailed log of a part of the Rodiles Formation in the Vega Beach outcrop, showing lithological data and distribution of facies, elementary cycles and bundles (Bádenas et al., *in press*).

The degree of evolution presented by the organic matter from these black shales was achieved using the reflectance, spectral fluorescence data and the Tmax, HI, TOC parameters from Rock-Eval pyrolysis. The results obtained have permitted to define an organic evolution pattern corresponding to the catagenetic stage.

The organic fraction is evolved as indicate by the modification of rank parameters, which corresponds to the oil window or the oil generation phase. A gradual degradation of the organic matter occurs and its properties change. Therefore, it is not possible to identify all the organic components because they are degraded or they have been transformed into hydrocarbons. At the same time, the fluorescence properties of the organic components are modified showing reddish colours with lesser intensities. The organo-mineral groundmass has partially loss its fluorescence. The presence of different phases of hydrocarbons and oil traces having strong fluorescence are typically found in these levels. These black shales are source-rocks that have partially generated their hydrocarbons by natural evolution (Suárez-Ruiz & Prado, 1995).

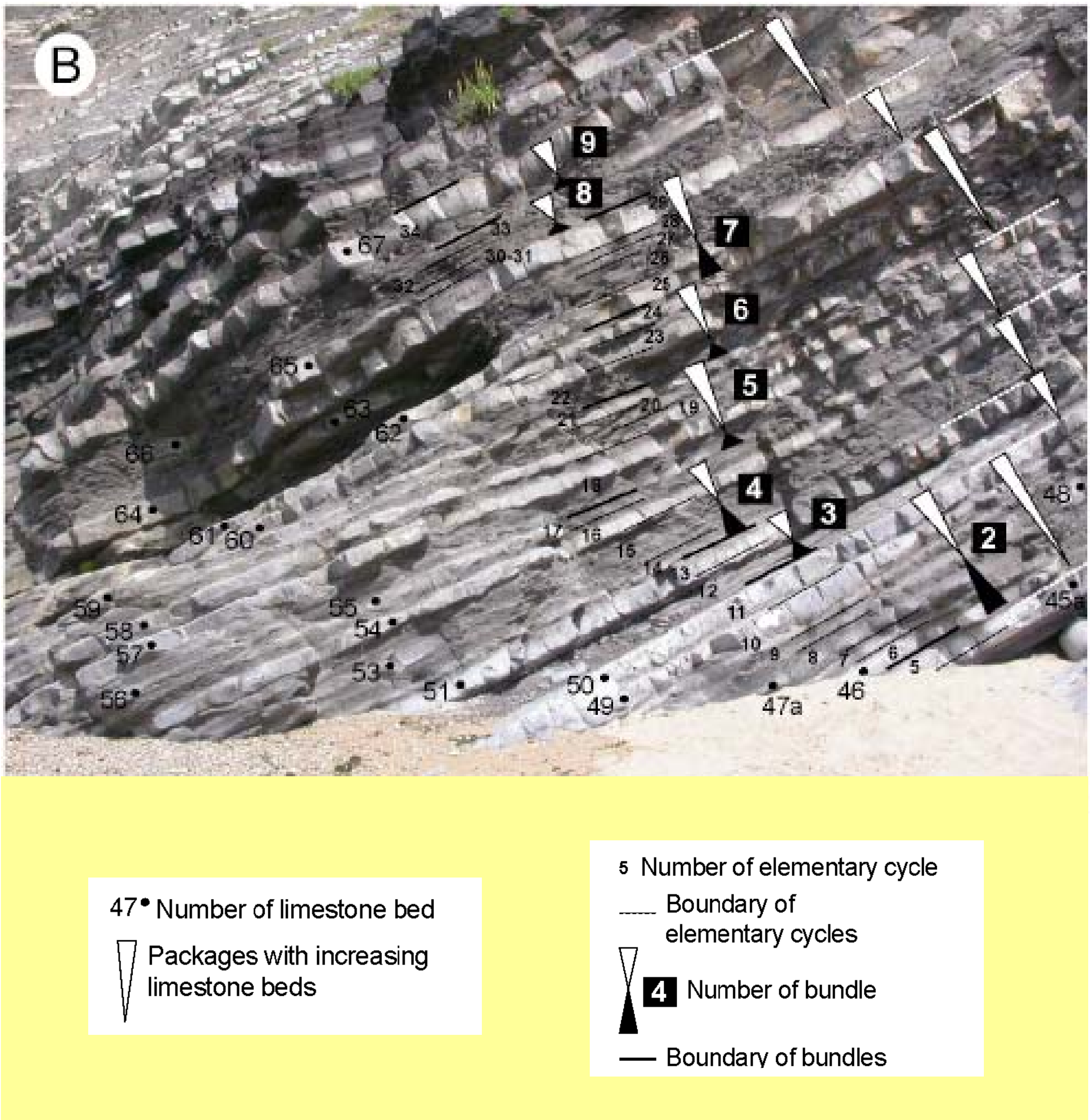

Fig. 17. Field view of a partial section of the Vega Beach marine series (Rodiles Formation) showing the distribution of primary cycles and lithological beds. (Bádenas et al., *in press*).

Dinosaur tracksite

Above this marine series of the Rodiles Formation there is a one-meter thick layer of conglomerate with siliceous clasts, and then alternating grey sandstones and red mudstones belonging to the Vega Formation. These deposits are fluvial in origin. Approximately 8 m above the conglomerate layer, there is a bed of sandstone tilted about 50° towards the northeast. At the base of this bed there are several tracks of tridactyl bipedal dinosaurs preserved as casts. At least one of them, the better preserved, corresponds to the left pes of a medium size theropod (Fig. 18).

In an isolated sandstone block of the same formation, a tridactyl ichnite around 11 cm long and wide can be seen. It has very slender digits with claws and with a very high interdigital angle. These characteristics make us think they were made by a theropod dinosaur very close to the birds or by a relatively big bird compared to what are known in the Jurassic fossil record (*Archaeopteryx*).

Fig. 18. Theropod footprint in a sandstone bed of the Vega Formation. Vega Beach section.

STOP 3

Jurassic Museum of Asturias (MUJA)

Inaugurated in 2004 on the coastal area of San Telmo, between the villages of Colunga and Lastres, the Jurassic Museum of Asturias (MUJA) is located at a strategic place on the halfway of middle point so-called “Dinosaur Coast”.

The MUJA, which belongs to the network of public museums of the Principado de Asturias, is a singular building in the shape of the three-toed dinosaur footprint, which houses a complete and didactic exhibition on the world of these fascinating reptiles and on the Jurassic Period in Asturias.

The building includes three large areas, each dedicated to one of the geological periods that form part of the Mesozoic: Triassic, Jurassic and Cretaceous.

The exhibition offer ample information on different aspects concerning the lives of dinosaurs and is complemented by three more modules: one dedicated to the geological history of the Asturian Jurassic and its fossil deposits, and two others dedicated to several aspects concerning the life and terrestrial ecosystems in those periods before and after the dinosaurs dominance.

Fig. 19. Aerial view of the Jurassic Museum of Asturias, with La Griega beach at the right margin

STOP 4
La Griega Beach

Dinosaur tracksite

La Griega beach is situated at the estuary of the Libardón River, between localities of Colunga and Lastres, close to the Jurassic Museum of Asturias (Fig. 19).

The route begins at the information panel situated on the right bank of the estuary, immediately beyond the bridge, close to the camping site.

Starting from here, we walk towards the cliff on the east side of the beach. About 500 m from the information panel, on the surface of a single reddish sandstone block, we observe two protuberances of decimetrical dimensions which correspond to natural casts of a manus and a pes print of quadrupedal dinosaurs heading in opposite directions (Fig. 20).

Fig. 20. Sauropod manus and pes footprints (natural casts) in La Griega Beach outcrop.

Following the very edge of the cliff for about 150 m, we come to a greyish sandstone bed, slightly sloping seawards. Its surface is cut across by small cracks of tectonic origin (joints) running in different directions, and several bipedal dinosaur footprints. Less than one metre higher up there is a grey limestone of the Tereñes Formation which contains minute gastropod fossils and a high number of dinosaur tracks.

The most outstanding feature of this site, what makes it really unique, is the presence of enormous prints made by dinosaurs feet in the form of several large, round-shaped hollows, with a diameter of 125 cm (Fig. 21 and 22). Their size makes them one of the largest prints found in the whole world. They were made by a sauropod of extraordinary dimensions. In the geological record, the skeleton of a dinosaur large enough to have made similar prints has yet to be discovered. The outline of the prints reveals peripheral bulges which would represent the calcareous mud pushed outwards and upwards by the footstep of the reptile. These ichnites were initially attributed to bipedal dinosaurs by German researchers in the eighties (Mensink & Mertmann, 1984). However, subsequent studies have contradicted this hypothesis and allow us to state confidently that the author of these huge ichnites was a gigantic sauropod which was crossing a shallow coastal pool (García-Ramos et al., 2000; 2002, 2004 and 2006; Lires *et al*., 2001; Lockley et al., 2007).

On the same surface, appears another trackway of 8 prints stretching about 5 m; one of this footpritns had been wrongly interpreted by the same German researchers (*op. cit.*) as belonging to a theropod. The estimated length of the trunk (140 cm) and the shape and size of the prints tell us that the animal responsible for this trackway was a small quadrupedal dinosaur, probably a sauropod (Lires *et al*., 2001; García-Ramos et al., 2002, 2004 and 2006; Lockley et al., 2007).

About 30 m further on we come upon an area of red sandstone of the Vega Formation containing vertical pale green-coloured root traces. They are evidence of fossil soils and represent the vegetated areas between Jurassic river courses.

Fig. 21. Excepcionally large fooprints of a quadrupedal dinosaur. La Griega Beach tracksite (Colunga).

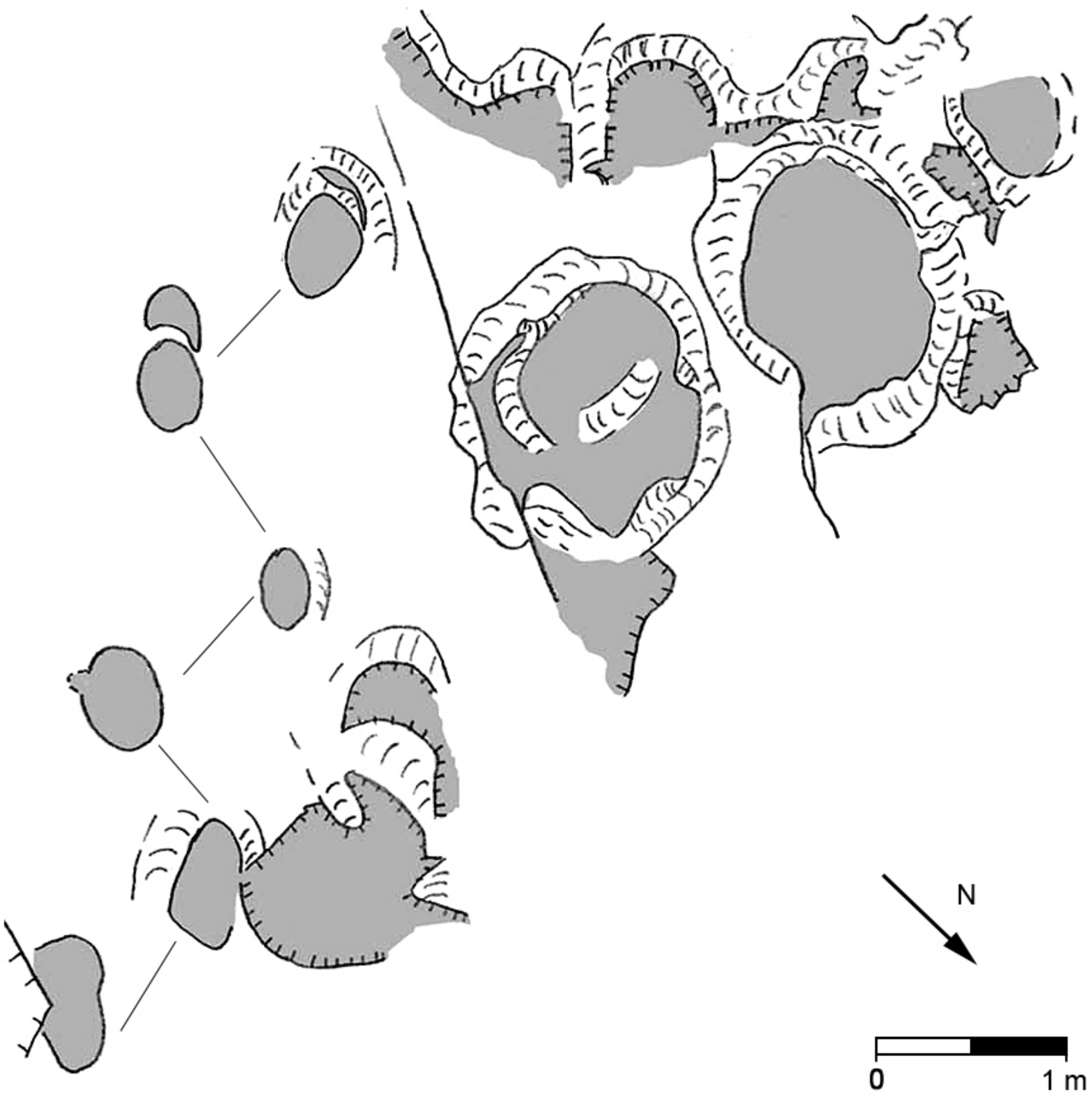

Fig. 22. Interpretative map of a part of La Griega Beach tracksite in which it is possible to see two quadrupedal dinosaur trackways.

Fig. 23. Sauropods walking on a mud flat. Dinosaurs like these made the giant footpritns of La Griega Beach tracksite.

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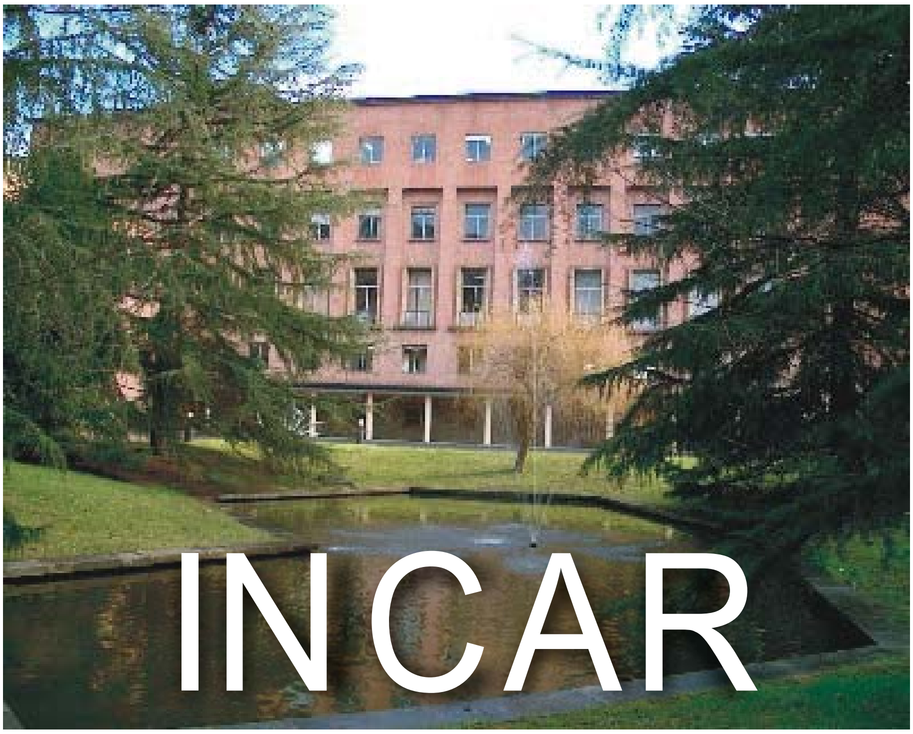
MUJA

MUSEO DEL JURÁSICO DE ASTURIAS



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