The Dinosaur Footprints in the Vicinity of Ribadesella[*]

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The dinosaurs were particular group of reptiles among which about 340 different genera are known. The size as well as the weight of these organisms is extremely variable, and contrary to what we sometimes think, we frequently refer to them as large reptiles. Their extreme dimensions vary between the ***Mussaurus*** found in Argentina, the smallest currently known, with dimensions no larger than a modern thrush (Charig 1984), and the gigantic ***Brachiosaurus,*** almost 13 meters high, which weighed about 80 tons. Nonetheless, in 1972 various bones belonging to an even larger dinosaur were found in Colorado, which was informally named ***Supersaurus***, some 25-30 m in length, about 17 m in height and weighing about 70 tons. Finally, and in the same area, an even larger dinosaur was discovered in 1979, known by the familiar name of ***Ultrasaurus***, more than 30 m in length and weighing some 130 tons.

Their character was also variable, and there existed both ferocious and meek types, also types with different feeding strategies (herbivores and carnivores), different postures, whether at rest or walking (bipeds and quadrupeds), including both agile and clumsy individuals. The majority of them lived on firm ground, even though many could venture into swampy areas, lakes, marshes, deltas, estuaries, etc.

The name "dinosaur" does not correspond in reality to a scientifically recognized taxonomic group, because the group includes two distinct orders that were established long ago: the Ornithischia (with a bird-like pelvis), and the Saurischia (with a reptile-like pelvis); even though there is no doubt that both groups are related to one another, being members of a larger group, the subclass Archosauria, they also have characteristics in

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common with other orders of this subclass, for example with the pterosaurs (flying reptiles) or the crocodiles.

The dinosaurs lived during most of the Secondary or Mesozoic Era, specifically from the beginning of the Upper Triassic (231 million years ago) until the end of the Cretaceous (65 million years ago); their period of existence on earth was about 166 million years (fig. 1).

The extinction of these organisms, as well as that of a significant number of other creatures and plants, defines the end of the Secondary Era; this chronostratigraphic boundary is one of the most important from a biological perspective since there exists then an abrupt change in the fossil record.

During their period of existence, dinosaurs populated all the large land masses. As is known, in the beginning of the Triassic these consisted of a unique supercontinent named Pangaea, which began to break up at the end of that period into big plates, which progressively became widely separated from each other, giving way to seas and oceans in between all the time becoming wider and deeper, until reaching the present situation. The study of the progressive separation of these continental masses is of vital importance, giving what controlled the migration, expansion and distribution of many living creatures, among them the dinosaurs.

The fossils and footprints of this latter group have been found in all parts of the earth in which Mesozoic sedimentary rocks deposited in continental and coastal environments appear at the surface. The fact that large areas exist in which these strata have not been located must be because these layers were, in many parts of the world, previously exposed by erosion and eliminated; or a large part of those layers found at the present time were covered again by other younger strata and are no longer visible at the surface.

Traces of the Footsteps of Dinosaurs

Much of what is known today about dinosaurs is due to the study of their fossil remains, as much from their skeletal parts, preserved at the present time though process of burial and mineralization, as from other lines of fossil evidence representing the activity of these organisms, such as coprolites, footprint traces or ichnites, and the impressions of other parts of their body.

The study of fossil tracks constitutes a branch of geology known as ichnology.

In the case which interests us, the importance of the study of these tracks is due on the one hand to the large abundance of ichnites compared to the number of preserved fossil bones, the latter moreover being dispersed and fragmentary. As is logical, each organism produces a large number of footprints during its lifetime as a consequence of its activity, while its skeleton will only be fossilized in the most favorable case, moreover requiring a series of specific conditions such as: rapid burial, suitable pH, low energy in the sedimentary environment, etc., in order to be preserved completely "in situ" without suffering a process of fragmentation and transportation.

On the other hand, from the study of the tracks of these reptiles, we can derive data on their behavior and mode of life, as well as the environmental conditions such as the climate, sedimentary medium, etc., that prevailed in that epoch.

With respect to the present preservation of dinosaur footprints in sedimentary rocks, there exist two fundamental types and several others that are less common. The type that appears depends to a large degree both on the type of sediment on which the animal stood, often sandy or muddy, and on the type that later filled the depressions they had made (fig. 2).

Depending on these variables, the footprints we observe at present will be situated in the upper part of the strata in negative relief, or in the lower part of the same as infilled bulges, frequently as sandstone (natural molds).

Their morphology and dimensions (length, width, and depth) will depend on the one hand on the weight of the body introduced through the feet of the trackmaker organism, and on the other hand on the type of substrate on which the dinosaur stood; if it was made on a soft or muddy substrate, the depth of the depression would be greater than if it walked over a sandy one.

The combination of parameters described above, together with various others such as the distances between two or more preserved tracks attributable to the same individual, or the total width of the preserved trackway, permits us to infer many of the morphological characteristics of these reptiles, such as their behavior or type of activity at given moments in their life (figs. 3, 4 and 5).

In this way it is possible to obtain a series of data points about these dinosaurs, such as their approximate size and weight, speed of progression, feeding types, body posture at rest or during progression (bipedal or quadrupedal), the environment in which they developed, type and characteristics of the feet, and taxonomic designation to a given group or family, etc.…

When a series of consecutive tracks, or a trackway, shows up, the task of the ichnologists consists of taking a series of measurements such as the length of the stride and step, width of the trackway, pace angulation, interdigital angle, degree of anterior-posterior variation in the relief of the footprint, etc.

The pace angulation is formed by the lines that unite the three identical points of reference on three consecutive hind or front footprints. The stride is understood as the distance between a fixed point on a footprint of the same foot. The step is the distance projected on the midline, between the tracks of right and left front (or hind) feet. The length of the stride is generally the same in the case of the two consecutive front and back footprints, but the length of the step can differ greatly.

The characteristics of an inefficient walker are a wide trackway and short steps; by contrast, a trail with long steps is proof of the presence of an efficient and agile walker that can move quickly.

Nonetheless, a trackway more intermediate in either width or stride could just as easily indicate an inefficient or an efficient walker progressing at a relatively slow speed. Equally, a bipedal dinosaur is more agile to the degree that the interdigital angle of the hind footprints is less, and vice versa.

Based on this type of data as well as on other complementary osteological data obtained from fossil skeletons (Alexander 1976; Farlow 1981; Thulborn 1982), the conclusion has been reached that the fastest dinosaurs were smaller sized bipeds, which could run at maximum speeds reaching 35-40 km/h. Larger bipeds (both herbivores and carnivores), would have had normal or slow progression, which in extreme cases would reach a light trot (15-20 km/h). Finally the majority of quadrupeds were slow walkers, up to 6-8 km/h, although some sauropods could reach 12-17 km/h and exceptionally some ceratopsians reached 25 km/h.

In a general way, the size and weight of the individuals can be determined on the basis of the degree of deformation of the sediment on which they stood (figs. 6 and 7), as well as taking into account the morphology and dimensions of the resulting footprints (fig. 8).

The feeding type can be deduced from the general outline of footprints in trackways, which can facilitate classification in a particular group with known habits. The outline of the ends of the toe is also significant: thus, for example, carnivorous bipeds such as theropods create tridactyl impressions that end in sharp claw marks, whereas in some herbivores such as ornithopods, which are also bipeds, the ends of the toes are blunt. In the case of quadrupedal herbivores such as sauropods, only the innermost toe, or the first three digits in the best preserved cases, may end in claw marks, though not as sharp as those of the theropods.

The disposition of the body, whether at rest or in progression, can be interpreted on the basis of the variation, form, and configuration of the impressions that compose the trackway. Often it is also possible to differentiate the footprints of right and left feet, as seen in the case of many bipeds; the steps of these latter forms, which are often tridactyl, tend to display a morphology that reflects the characteristics of the digitigrade type typical of theropods and some ornithopods.

On the other hand, those of the quadrupeds often present a more rounded outline, being more equidimensional in appearance, especially if they are attributable to individuals of the infraorder Sauropoda; in the case of those quadrupeds that behave as such only occasionally, the disposition of the steps reminds us in general of bipeds, given that this is their most habitual gait.

As far as the reconstruction of the environment in which the dinosaurs of given area lived, it is reconstructed through paleogeographic studies based primarily on sedimentological and paleoecological data.

As far as questions of social behavior are concerned, one can say that the footprints of both herbivores and carnivores are known in groups with the same orientation of progression (indicating herds), and also with a structured herd pattern, with the younger ones and the babies in the center protected by the adults, showing gregarious behavior.

Dinosaur Footprints in the Region of Ribadesella

In the region of Ribadesella, sedimentary rocks of various types and ages outcrop abundantly at the surface (fig. 9). The oldest are from the Paleozoic or "Primary" Era (Cambrian, Ordovician, and Carboniferous) and the youngest from the Quaternary. As far as the deposits laid down during the age of dinosaurs are concerned (the Mesozoic or "Secondary" Era), with the exception of a small portion of the Triassic in the northwestern area, they are represented in their entirety by rocks of Jurassic Period, which appear predominantly in the northern part of the region, specifically between Vega beach in the west and La Arra cove in the east. This latter site constitutes the eastern border of the Asturian Jurassic, separated by a fault from other much older limestones of Carboniferous age (fig. 10).

The age of the different footprints from around Rio Sella, which are associated with the Upper Jurassic, could be between 150 and 156 million years in age.

A very favorable condition for the discovery of dinosaur tracks in this region is the great abundance of deposits of this age in the steep cliffs of the coast, especially between the beaches of Vega and Santa Marina, and the mouth of the Rio Sella and the Arra rocks (figs. 11, 12, 13, and 14).

The present high rainfall of the region, the intense marine erosion, especially during intense winter seasons, and the steeply inclined cliff, causing movement and relatively rapid change with successive landslides and displacement of blocks by the swell, permit the discovery of new footprints as well as the destruction or burial of others in a relatively short period of time. This latter adverse circumstance requires a continual search, as well as a rapid "in situ" study of discoveries, or an eventual collection of the same for a later study in the laboratory, when feasible.

The constant dynamics of the cliffs presently constitutes one of the decisive factors in evaluating the track-bearing outcrops of Ribadesella, as well as some of the other coastal districts (Colunga, Villaviciosa, and Gijon); moreover, if we take into account the large number and variety of forms, as well as the excellent state of preservation, it would not be an exaggeration to consider them among the most interesting discovered in Spain to date.

Nonetheless, it is known that dinosaur tracks occur in other localities in the peninsular part of the northern region, belonging to the provinces of Lérida, Logroño, Sonia, and Burgos. The cliffs of the Portuguese coast have an equal number of excellent examples, especially those of Cabo Mondego and Lagosterios (north of Cabo Espichel).

The first discoveries of footprints of these Mesozoic reptiles occurred in 1975 after a detailed geological survey of the coastal cliffs of Asturia between the approximate longitude of Gijon and Ribadesella. In the following years, the first, though preliminary, results on these tracks were published (Garcia-Ramos and Valenzuela 1977 a, b and 1981; Valenzuela 1979).

Currently, the number of observations, measurements, photographs, and sketches have increased significantly, allowing us a more complete and general picture of the diversity of these reptiles, their mode of life, and the ancient environment in which they lived.

The dinosaurs must have frequently been in our region during the Jurassic, judging by the abundance and variety of their traces preserved in the sediments, as well as the fragments of bone found. At present, these discoveries appear to be widely dispersed, and the notable references, many of them old, to the teeth of ***Megalosaurus*** as well as some other fragments of bone found recently are still unclassified. Among those pertaining to contemporary animals more or less related to the dinosaurs, we will mention references to the skeletal remains of plesiosaur paddles (marine reptiles), as well as some ichthyosaur vertebrae (pisciform marine reptiles).

Among the signs of their activity, especially prominent here are the footprints of bipeds (fig. 16) as well as quadrupeds (fig. 17); both have been found not only as a multitude of isolated footprints, but also as various traces that we easily recognize as the trails walked by the animals, thanks to the successive impressions of the hind and/or front feet progressing in a given direction (figs. 18 and 19).

In addition to this type of evidence, other examples have been found that, although scarce in number, confirm the existence of these reptiles in Asturias: tracks produced by the tail dragging over the substrate, and fecal remains or coprolites.

The overall analysis of the dinosaur tracks of Ribadesella, as well as the remains from the Upper Jurassic of Asturias, show us that during this period there existed very diverse populations belonging to the principle groups into which these reptiles are subdivided (figs. 20 and 21).

Thus, at least the presence of abundant examples of the suborder Theropoda (carnosaurs and probably coelurosaurs), the order Ornithopoda and the infraorder Sauropoda has been detected.

The finds of the footprints of these latter quadrupedal reptiles (fig. 22), are relatively common in these strata and are especially interesting given that, until now, very few references to them exist in the whole world; the reason relates to their problematic preservation, since their characteristic morphology still is not very revealing, fundamentally because of the small size of their digits in relation to the sole of the foot; their shape is partly reminiscent of living elephants.

In consideration of size, the tracks of Ribadesella are very variable; the smallest known up to now are about 15 cm; those of larger size, like some appearing on the cliffs at Terenes, approach 65 cm based on the maximum dimensions of each.

The Paleogeography of Asturias During the Late Jurassic

The paleogeographic situation that existed during the Upper Jurassic in the area which is now Asturian territory was substantially different from today. To the south and southeast of the region there was an emergent area with alluvial siliciclastic deposits, corresponding to a network of fluvial distributaries with low flow regimes, which in its distal part reached the coastline situated to the north and northeast. The transition to the marine environment was a setting for small deltas. Vegetation was abundant and the climate warm and humid: for example, it is known that there were no ice caps in the polar regions in this epoch.

On the other hand, the area that today is Asturias must then have occupied a paleolatitude of around 25-35 degrees.

In the continental areas closest to the shoreline there were often lacustrine and swampy environments, the latter with woody vegetation (figs. 23 and 24), in basins lateral to the various fluvial channels that fed the deltas. Near the outlet to the sea were many very shallow and saline ponds and lagoons, whose substrates were colonized by an abundant invertebrate fauna dominated by gastropods, crustaceans, and bivalves (clams).

The coastline was low and irregular, practically lacking tides and affected by very limited wave action (figs. 25 and 26); in front of the shoreline a small arm of inland seaway extended, separated from the open ocean by a protective barrier; this latter was situated several kilometers north of the present coast.

The importance of the dinosaur footprints of Asturia, and those of Ribadesella in particular, both from the purely scientific viewpoint as well as for education and culture, has been confirmed and recognized by the Spanish Institute of Geology and Mineralogy by recently including them among various Points of Geological Interest (Puntos de Interes Geologico: P.I.G.) catalogued in this district (Agueda et al., 1985; Elizaga et al., 1984 a, b, and 1985), as part of a much broader geological context.

Finally it remains to point out that while it is necessary to make the Natural Geological Heritage known to the community so as to make them aware of its value and significance, this publication always carries with it a certain risk of damage, not so much from utilization by tourists and recreational visitors, but from the actions of collectors and exploiters. Due to this it would be very desirable that the local and regional administration would realize the timely opportunity for a study aimed at protecting and conserving said outcrops, simultaneously developing an adequate educational program that includes information about the importance of the discoveries and the geological significance of source.

FIGURES

FIG. 1. Geological time scale.

FIG. 2. Process of formation of a footprint and its natural cast.

FIG. 3. Marly limestone showing a footprint that belongs to the left foot of a medium-sized bipedal dinosaur. Terenes cliffs.

FIG. 4. Tridactyl footprints attributable to two small bipedal dinosaurs. Preserved as reliefs on the surface of a sandstone belonging to an ancient fluvial system. Cliffs around Punta de la Sierra.

FIG. 5. Footprint belonging to a tridactyl bipedal dinosaur of medium to large size, seen at the foot of the path that descends the Terenes cliffs.

FIG. 6. Strong deformation of the strata caused by a dinosaur footstep of medium to large size. Below the point where the reptile foot stepped, a pronounced thinning of the sandy beds is observed, as well as a thickening and rupture of the beds in the adjacent zone to the left. Cliffs between Punta Covachera and Ribadesella lighthouse.

FIG. 7. Deformation structures caused by footsteps of medium-sized dinosaurs, preserved as natural casts at the base of the sandstone bed. Cliffs at the end of Grua avenue.

FIG. 8. Tridactyl footprint made by a small bipedal dinosaur. Natural cast preserved on a sandstone bed. Cliffs east of Vega beach.

FIG. 9. Geological map of the area around Ribadesella.

FIG. 10. View of Jurassic cliffs from the top of Corvero Hill looking east. The furthest part of the cliff, at left, is formed by Carboniferous limestones similar to those forming the mountains behind them.

FIG. 11. Cliff at the east of Vega beach. First, on the right of the photograph, we can see alternating limestones and marls accumulated in Jurassic marine environments. Above them, with partially red coloration, there are sandstones and claystones belonging to ancient fluvial deposits, where some of the dinosaur tracks appear. This combination represents a magnificent example of a marine platform that has been raised up.

FIG. 12. Cliffs formed by Jurassic rocks in the area around Ribadesella. View from Corvero Hill, looking west.

FIG. 13. Partial view of Ribadesella (Punta del Arenal). Behind it, we can see a pronounced calcareous ridge coinciding with the fault that brings Jurassic rocks, buried here by beach sands and dunes, in contact with the Carboniferous. Above these latter rocks one observes the ancient marine platform, partially eroded by karstification processes.

FIG. 14. General view of the Jurassic outcrops of the Terenes cliffs in which some of the dinosaur tracks shown in the photographs have been found. In the background, we can see the calcareous Sueve massif, formed by Paleozoic rocks.

FIG. 15. General view of the cliffs in the area round Ribadesella, formed by marls, sandstones, and limestones belonging to the Upper Jurassic. In fig. 18, we can see a detail of the strata situated in the foreground part, which show dinosaur tracks.

FIG. 16. Tridactyl impression made by the left foot of a bipedal dinosaur of medium size, preserved as natural cast in sandstone. Cliffs of the area around Punta de la Sierra.

FIG. 17. Footprint made by a quadrupedal dinosaur. Terenes cliffs.

FIG. 18. Bedding plane in the cliffs at the base of Somos Hill. We can see several trackways made by quadrupedal dinosaurs.

FIG. 19. Marly stratum with mud cracks where a dinosaur trackway is impressed. Terenes cliffs.

FIG. 20. Natural casts of two tridactyl footprints belonging to small bipedal dinosaurs (probably ornithopods), at the base of a sandstone bed. Terenes cliffs, a little west of Penon del Forno.

FIG. 21. Footprints belonging to a small bipedal dinosaur (probably an ornithopod). Casts preserved at the bottom of a sandstone bed. Cliffs in the eastern end of Vega beach.

FIG. 22. Depressions on a marl bed formed by quadrupedal dinosaurs (probably sauropods). The irregular morphology, without clear outlines, is caused by the initial plastic conditions of muddy substrate where they stepped. Cliffs between Punta Covachera and Ribadesella lighthouse.

FIG. 23. Accumulation of uprooted tree trunks on the surface of a marly bed. The bigger ones are up to 11 meters in length. Cliffs between Punta Covachera and Ribadesella lighthouse. Scale, 2 meters.

FIG. 24. Transverse section of a fragment of fossil tree, mostly replaced by carbonate and pyrite. The concentric growth rings are seen in great detail. Terenes cliffs. Scale in cm.

FIG. 25. Top of a sandstone bed where ripple-marks produced by currents are preserved. Cliffs between Punta Covachera and Ribadesella lighthouse.

FIG. 26. Example of a fish specimen partially preserved on the surface of a sandstone bed showing ripple-marks. Cliffs at the foot of La Guia hermitage.