THE DEPOSITION OF THE GREEN SANDSTONES (BAJO BARREAL FORMATION- LATE CRETACEOUS) AND THEIR TAPHONOMIC IMPLICATIONS[1]

Jorge F. R. Rodríguez*

**Departamento de Geología, Facultad de Ciencias Naturales,*
Univ. Nac. de la Patagonia "San Juan Bosco". Km 4
9005 Comodoro Rivadavia- Chubut

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ORIGINAL ENGLISH ABSTRACT. A conspicuous psammitic section within the upper part of the Lower Member of the Bajo Barreal Formation is known as the "Areniscas verdes" (Green sandstones). In this study the sedimentological and taphonomic characteristics observed at Estancia Ocho Hermanos are considered. From a sedimentological point of view, they are tabular bodies, commonly multihistorical, with planar bases, generally with parallel stratification. Most of the fossils are found in the upper 25 m of the Lower Member, associated with the "Areniscas verdes".

The most noticeable descriptive features related to the conservation of the remains are: 1- Isolated materials of greatly differing sizes predominate; 2- Presence of some well preserved articulated remains; 3-The majority of the remains are suspended in the sandstones and not at the lithological interphases; 4-Isolated and well preserved remains. The group of evidences allow for the postulation of a system of ephemeral streams, of high regime, sheetlike and violent; alternate with long periods of little sedimentation during which paleosols developed. It is suggested that the remains are associated with the "Areniscas verdes" due to their genesis, that allowed a rapid burial of the remains. The lower and middle part of the Lower Member, and the Upper Member have scarce remains, probably due to a slow sedimentation rate and to the development of paleosols.

The heterogeneities in the preservation models could be explained essentially because the flows could take the remains from overbank environments, generally without producing great changes in their preservation state. It is suggested that the ephemeral currents generate their own taphonomic mode. It is interpreted that the articulated sauropod (UNPSJBPV 920) was rapidly covered by sediments, probably without transport.

INTRODUCTION AND GEOLOGIC SETTING

The mountainous areas of south-central Chubut province consist mainly of a succession of Cretaceous units, deposited in continental environments, with important pyroclastic participation that form part of the infilling of the Golfo San Jorge basin.

The following work is based on sedimentological and paleontological evidence from the Bajo Barreal Formation.

The Bajo Barreal Formation, included in the Chubut Group, overlies the Castillo Formation and underlies and interfingers laterally with the Laguna Palacios Formation. In it two members are recognized (Sciutto, 1981). Hechem et al. (1989, 1990) subdivide the Bajo Barreal Formation into three depositional sequences denominated from the lowest to

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highest KBB1, KBB2 (equivalents of the Lower Member) and KBP (Upper Member + Laguna Palacios Formation).

From the first explorations of the highlands the existence of fossil vertebrate remains was recognized, mainly of dinosaurs. In this work the sedimentologic and taphonomic evidence is compared and related, with the purpose of obtaining a more complete and precise paleoenvironmental interpretation. Recent works evidence the consistent tendency to integrate sedimentologic and taphonomic data in the interpretation of fluvial systems (Dodson, 1971; Miall, 1983; Koster, 1987; Behrensmeyer, 1988). A hypothesis is suggested to explain the distribution of the fossil remains in the section.

The study is focused on the outcrops of Estancia Ocho Hermanos, from where important remains of Cretaceous vertebrates come. Most of the materials mentioned in this publication come from work made by personnel of the Universidad Nacional de la Patagonia “S. J. B.” during several campaigns that extend from end of the year 1984 up to 1992. The author has participated in these campaigns of search and extraction of fossil remains, at the same time performing sedimentologic observations and a lithofacial analysis of the considered unit (Rodríguez, 1992).

GEOGRAPHICAL LOCATION

The work area is located in south-central Chubut province, about 50 km to the northwest of the town of Sarmiento, to the southwest of the Bajo Guadaloso (Fig. 1A). It is a small area with very good outcrop, a few km to the north of the entrance of the Estancia Ocho Hermanos.

PALEOENVIRONMENTAL CHARACTERISTICS

The Bajo Barreal Formation has been studied by several authors, the majority oilmen and from the company YPF. In this way, it has an important sum of information.

Hechem et al. (1989, 1990) consider that the Lower Member is constituted by deposits generated by ephemeral currents and floodplains, rivers braided proximally and volcaniclastic processes; and the Upper Member by deposits of ephemeral currents and floodplains.

In the area of Estancia Ocho Hermanos, Rodríguez (1992) interprets that the low part of the Lower Member represents the sedimentation of channeled and unconfined ephemeral currents intermingled with fine floodplain sediments, with the development of paleosols at times of scarce sedimentation and formation of shallow lagoons in times of flooding.

Gradually upwards it is observed that sandstones begin to predominate over the fine sediments (Fig. 1B), to culminate the Lower Member with multihistoric sandy bodies ("green sandstones") interpreted as the progradation of proximal facies.

The Upper Member is constituted principally of fine floodplain deposits, with sandstones generated by ephemeral currents, and it is interpreted that it begins with a flood surface.

Pyroclastic material is abundant, especially in the Lower Member, and contributed to the agradation of the system.

DESCRIPTION OF THE SANDSTONES

They are known informally by the name of "green sandstones", a conspicuous sandy section, developed in the high part of the Lower Member (Fig. 1B) of the Bajo Barreal Formation. These sandstones present great areal extension and have been observed in many of the profiles of the Sierra de San Bernardo. In Ocho Hermanos these sandstones associate with bioturbated tuffs and tuffaceous mudstones. The bioturbated tuffs usually present limited extension, due to erosion produced by the currents that deposited the sands.

The green sandstones are characterized from the sedimentologic point of view by the following (Fig. 2):

-Green color, grain size of fine to thick, in areas conglomeradic, and abundant pyroclastic participation.

-The most common structure is fine parallel stratification, while some massive banks are observed. In certain cases they present planar crossbedding and low angled troughs. Some banks show deformational structures.

-Presence of fragments of bioturbated tuffs (paleosols), of up to 20 cm and with limited transport,"suspended" in the sandstones.

-They form bodies of high width/depth relationship (tabular).

-Multihistoric bodies with relicts of intercalated paleosols.

The base of the bodies is planar or almost planar, sometimes with a thin thickness of fine conglomerate.

DESCRIPTION OF THE MODES OF PRESERVATION

The Bajo Barreal Formation is the Cretaceous unit that has produced most vertebrate remains in the Golfo San Jorge basin. One of its important localities, probably the most important, is the area of Estancia Ocho Hermanos. From this locality comes an interesting but poorly studied Cretaceous vertebrate fauna.

It is normally complex to define and interpret the taphonomic characteristics of a unit, essentially due to the abundance and interrelation of variables that can act between the death and burial of a vertebrate.

Although in the case of the unit in study, the documented abundance of remains of taxa is not large, it is considered that the information regarding the modes of preservation of the fossil remains allows one to construct, with sedimentologic data, a coherent interpretive scene.

In the area of Ocho Hermanos the outcrops are very good, for one can study the column almost without interruption. The lateral extension of the exposures facilitates sedimentologic investigation as much as paleontological prospecting. The vertical profile has approximately 245 m, of which 142 correspond to the Lower Member. The great majority of the fossil bones have been found in the highest 25 m (Fig. 1 B) of the Lower Member, inside the “green sandstones” (the author has been able to observe that this situation seems to repeat in the several sections that outcrop to the north and east of the Cañadón de la Horquetas, about 40 km to the northeast of the studied locality). It is observed that the remains are scarce and isolated in the lower and middle part of the

Lower Member, and in the Upper Member, while in the upper part of the Lower Member they are abundant.

With regard to the preservation of the fossil remains one can say the following:

- The "green sandstones" are those that preserve the great majority of the fossil remains discovered.

- The most common discoveries are isolated remains, corresponding to bones of very different sizes. The largest bones are sauropod femora, humeri, and vertebrae, the smallest teeth (of dinosaurs and crocodiles), phalanges, or fragments. Lag concentrations have not been observed. In general the remains, although abundant in these sandstones, do not seem to form important concentrations. In spite of being isolated remains, many times their state of preservation is very good, preserving delicate structures and indicating little abrasion.

- The articulated materials correspond to three discoveries. One exaample is a right hindlimb (without the foot) of a carnivorous dinosaur (*Xenotarsosaurus bonapartei*, Martínez et al., 1986) that seemed "suspended" in the sandstones.

A second discovery corresponds a sauropod dinosaur of medium size described as *Epachthosaurus sciuttoi* (Powell, 1990) and that includes several dorsal vertebrae articulated to part of the sacrum, plus some disarticulated remains in the proximity (this material was found in a campaign directed by Dr. José F. Bonaparte, of the Museo Argentino de Ciencias Naturales "Bernardino Rivadavia"). In this case the bones are in a very hard sandstone, due to calcareous cementation.

A third discovery corresponds to an exceptionally preserved skeleton, as much for its grade of articulation as for its position.

It is the articulated skeleton of a medium-sized sauropod that lacks some anterior dorsal vertebrae, the neck, the head, and the distal part of the tail. This material, that has not been studied in detail (a preliminary communication can be seen in Martínez et al., 1990), is deposited in the Universidad Nacional de la Patagonia "S. J. B." under the repository number UNPSJB PV 920. Although it cannot be known with certainty, it is probable that the neck and head were preserved, but have been eroded in recent times, since the actual surface of erosion affected part of the dorsals and scapular girdle. The skeleton was resting on its stomach (prone position), with the arms extended, both hind legs flexed under the body and the tail extended back and curved toward the right (Fig. 3 A). The thickness of the body in the preserved position measures approximately 1 m (Fig. 3 B) from its ventral to dorsal limit, and the effect of compaction should be kept in mind.

- A remarkable fact is that the great majority of the remains were preserved suspended in the sands (Fig. 2), and not in the base of the bodies or lithologic interfaces.

- From the "green sandstones" come abundant teeth of dinosaurs (carnivores and herbivores) and some of crocodiles. Many of the carnivore teeth show very well preserved lateral serrations. In some teeth wear facets are observed.

All of these characteristics suggest limited transport of the materials (Rigby, 1987).

INTERPRETATION

For the" green sandstones", from the sedimentologic point of view, the existence of tabular bodies of planar base, filled with sandstones with parallel or massive stratification are indicative of unconfined currents of high regime. The presence of important thicknesses of sandstones with deformational structures indicates the sedimentation of large quantities of sand in short periods. The absence of lags and the presence of large fragments of paleosols indicate limited transport of the transported materials. All of this permits one to interpret the existence of currents of high regime with abundant load, ephemeral and of violent character, that moved in sheets (sheet floods). These deposits have been attributed to ephemeral systems (Hechem et al., 1989; Rodríguez, 1992), comparable to those described by McKee et al. (1967) and Tunbridge (1981, 1984).

Their genesis can be related to increases related with rain, although volcanic activity should have influenced a large amount of sedimentation. The “green sandstones” have similarity with some of the facies described by Smith (1987) for a system strongly influenced by volcanic contribution.

The “green sandstones” include fragments of paleosols. It is interpreted that between the successive events that deposited the sands, important lapses could have occurred, in which the cumulative material (with pyroclastic contribution) was made into soil. The flooding followed, eroding the paleosols, incorporating their fragments. Lenticular sandstones interpreted as channeled ephemeral currents and tuffaceous mudstones are also associated.

The heterogeneity in the size of the preserved remains, as well as the predominance of suspended remains and absence of lag type deposits, indicate great transport capacity, but limited selection of the transported material, suggesting larger density than normal flowing currents.

The existence of articulated remains and very well preserved isolated materials (vertebrae, teeth) indicate limited transport for the currents, that can be interpreted as quick sedimentation.

The position of the articulated skeleton (UNPSJB PV 920) indicates that it probably was preserved where it died. Voorhies (1981) documents similar positions in skeletons of rhinoceroses (*Teleoceras*) from the Miocene of Nebraska that died in situ by a fall of volcanic ash. Dodson (1971) describes the dispositions of skeletons that probably floated, and they are different from that of the considered skeleton. Finally, the excellent grade of articulation can only be explained by a quick burial (Dodson, 1971; Koster, 1987). In synthesis, this discovery suggests the sedimentation of an important thickness of sediments in a brief period, soon after of the death of the animal.

As is seen, the sedimentologic evidence as well as that related to the preservation of the fossil remains suggests similar interpretations for the genesis of the green sandstones.

The proposed environment implies that most carcasses were exposed for important time intervals, facilitating the separation and destruction of the remains. This is consistent with the predominance of isolated remains in the “green sandstones”.

Probably, in times of flooding, the materials were collected by ephemeral currents from overbank environments or dry beds, for these the state of preservation of the

remains is more a reflection of their previous history than of the processes that buried them. This interpretation allows one to explain the heterogeneity in modes of preservation in similar sands related laterally or vertically. In the moment of the flooding the remains were incorporated and deposited with the sands, being able to preserve articulated materials of animals that died a short time before. It is considered that it is in fact the existence of ephemeral currents depositing important thicknesses of sand that is the main cause of preservation of remains in the green sandstones because their burial was rapid. The remains had a better chance of escaping destruction in overbank environments, where they were covered by a larger thickness of sediments than in the section of the soil (Behrensmeyer, 1975).

At the moment it is considered that the deposits generated by the currents are those that have more possibility to preserve remains (Koster, 1987).

In the Hell Creek Formation the existence of fluvial systems highly dependent on rains has been interpreted, and as in Ocho Hermanos, the fossils are mainly associated with deposits generated by currents, and not with the overbank fines (Rigby, 1987).

The lower and middle parts of the Lower Member present, on the contrary, a great scarcity of preserved remains. It seems certain that organisms existed in the area, since their sporadic and isolated remains are found in the section. Many causes can concur to explain this. The sandy deposits are less abundant, and of smaller thickness, commonly represented by isolated bodies. The existence of abundant paleosols is also a factor that hinders preservation of remains, since on one hand there is no rapid burial, and on the other, pedogenesis would destroy the few preserved remains (Behrensmeyer, 1975; Koster, 1987). A simple model proposed by Behrensmeyer (1988) considers the relationship between the rate of sedimentary accumulation and the quantity and quality of preserved bones.

If the sedimentation is too slow, accumulations of remains have little chance to be preserved, since they will be disintegrated (by the sum of biologic activity and weathering) before they can be buried. If some remains were able to reach burial, they would be destroyed by pedogenesis, due to scarce sedimentation. If sedimentation is too rapid, time is insufficient for bones to accumulate.

The abundance of paleosols and fine sediments in the middle and lower parts of the Lower Member make one think that their cause was too slow sedimentation. Even with smaller participation of paleosols, the Upper Member seems to corrrespond to the same.

Other explanations may be found in adverse paleoecologic conditions, for example greater volcanic activity, as could be indicated by the larger participation of tuffaceous banks.

In this way, even constituting the areas near to Ocho Hermanos a sector of proximal sedimentation (for the Bajo Barreal Formation) of the basin, given the involved environments (Hechem et al., 1989), that are not very favorable for the preservation of bony remains (Koster, 1987), we have preservation of fossils due to floods in sheets (flash floods) that quickly buried the remains.

Given the absence of concentrations of remains in specific layers (bonebeds), there is no evidence to argue for the existence of catastrophic events that generated mass death, although it is known that sedimentary processes and/or biological agents can disperse or eliminate a mass death association (Koster, 1987). It should be clarified,

however, that methodical excavations looking specifically for “bonebeds” have not yet been made.

Behrensmeyer (1988) proposed the concept of taphonomic mode (taphonomic mode) and differentiated two different taphonomic modes for fluvial systems.

The existence of at least three articulated and well preserved examples (2 partial); the presence of sauropod dorsal vertebrae with their structure of thin laminae largely conserved, and the absence of associations of remains with thick channel base facies, allow one to differentiate the taphonomic mode of the Ocho Hermanos remains from the channel lag mode (Behrensmeyer, 1988). The characteristics of the preserved remains resemble more the channel fill mode, but their sedimentologic attributes are different, due to the particularities that characterize the genesis and deposits of the ephemeral currents.

Ephemeral currents probably generate a particular taphonomic mode, with characteristics partially overlapping with the modes proposed by Behrensmeyer (1988), that only can be characterized with a larger quantity of data. However, some of its possible characteristics are the following:

- Existence of heterogeneity in the size of the materials associated with the sandstones.

- Strong heterogeneity in modes of preservation, from isolated and worn remains to practically complete skeletons.

- Remains distributed in all the thickness of the banks, without predominance of concentrations in the base of the bodies.

CONCLUSIONS

- The levels bearing the great majority of the remains of the Bajo Barreal Formation in Estancia Ocho Hermanos are the “green sandstones” of the high part of the Lower Member.

- The sedimentologic characteristics and the evidence obtained from the preservation of the remains, allow one to interpret that the “green sandstones” were deposited by ephemeral currents, of high regime, mainly sheetlike that reached high density in certain cases and that deposited important thicknesses in short periods of time.

The most interesting taphonomic evidence is:

1 - The extreme variety in modes of preservation, from worn isolated fragments, to a quite complete and articulated skeleton, conserved in similar lithologies and at limited distance from each other (limited in both the areal and thickness senses).

2 - The heterogeneity in the size and abundance of the isolated remains preserved “suspended” in the sandstones.

- It is suggested that the fact that the remains are preserved in the high part of the Lower Member is in fact due to the processes of accumulation of the green sandstones, that allowed a rapid burial of the materials. The low and middle parts of the Lower Member, on the contrary, include ephemeral flows in general isolated and with less thickness, suggesting more distal areas of the system.

On the other hand the abundance of paleosols indicates prolonged periods of exposure and destruction of remains by pedogenic processes.

- Most of the remains would be collected by ephemeral currents in times of flooding, from overbank environments. These currents did not have great power of selection due to the speed of the process, and possibly to a density somewhat larger than normal flowing currents. Although they could affect the state of preservation of the remains, the heterogeneity in modes of preservation seems to correspond more to the previous history of the materials in overbank environments than the effects of ephemeral currents.

- Ephemeral currents probably generate their own taphonomic mode, and some of its possible characteristics are suggested.

- It is interpreted that the articulated sauropod (UNPSJB PV 920) died and was quickly buried (probably without any transport) by an important thickness of sediments accumulated by ephemeral currents.

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FIGURE CAPTIONS

Figure 1: A - Location map. B - Generalized stratigraphic column of the Bajo Barreal Formation in Estancia Ocho Hermanos. (The arrow represents the larger fining-upward cycle that encompasses the Lower Member and culminates in the “green sandstones”).

Figure 2: Schematic column with some banks of “green sandstones”. Abbreviations: AV, “green sandstones”; FT, tuffaceous mudstones; and TB, bioturbated tuffs. References as in Fig. 1.

Figure 3: Schematics that show the position in which the articulated sauropod was found (UNPSJB PV 920). A – Dorsal view. B – Transverse section traverse immediately forward of the pelvis, C - Lateral view of the right hindlimb. Abbreviations: F, femur, P, pelvis.