

# Evidence of fluvio-deltaic interaction in the Triassic Red Beds of the Iberian Meseta (Almedina, Ciudad Real, SE Spain)

*Evidencias de interacción fluvio-deltaica en las Capas Rojas Triásicas de la Meseta Ibérica (Almedina, Ciudad Real, SE de España)*

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## ABSTRACT

Recent sedimentological research in the northwestern part of the Triassic Red Beds of the Iberian Meseta (TIBEM) reveals evidence of deltaic environments, contrasting earlier interpretations of a predominantly fluvial system. Fieldwork in the Almedina section (Ciudad Real, Spain) included stratigraphic analysis, architectural reconstruction, and paleocurrent measurements, identifying up to four facies associations (FAs): prodelta (FA-1), channel-mouth bar complex (FA-2), interdistributary bay (FA-3), and fluvial deposits (FA-4). The vertical succession reflects a prograding fluvio-deltaic system with distal subenvironments (prodelta and tempestites) transitioning upward to proximal settings (distributary channels, interdistributary bays and fluvial deposits). Tempestite deposits exhibit hummocky cross-stratification and wave ripples, inconsistent with purely fluvial interpretations. High bioturbation levels in distal deltaic facies contrast with scarce bioturbation in fluvial facies, further supporting the deltaic model. The studied deposits suggest an interplay of marine and fluvial processes, with NE-directed progradation dominating deposition.

**Key-words:** TIBEM, Almedina Facies Associations, Fluvio-deltaic system, prograding.

## RESUMEN

Investigaciones recientes en las Capas Rojas del Triásico de la Meseta Ibérica (TIBEM) han revelado evidencias de ambientes deltaicos en su margen noroeste, en contraste con interpretaciones previas que los consideraban exclusivamente fluviales. En la sección estudiada de Almedina (Ciudad Real, España), se analizaron secciones estratigráficas, elementos arquitectónicos y paleocorrientes, identificándose hasta cuatro asociaciones de facies: prodelta (FA-1), complejo de canales y barras de desembocadura (FA-2), bahías interdistributarias (FA-3) y facies fluviales (FA-4). La disposición vertical de estas facies indica un sistema fluvio-deltaico progradante hacia el NE, donde los ambientes distales (prodelta y tempestitas) dan paso a entornos más proximales (canales distributarios, bahías interdistributarias y depósitos fluviales). Las tempestitas, con estructuras como estratificación cruzada hummocky y ripples de oleaje, no coinciden con características típicas de ambientes exclusivamente fluviales. Además, la intensa bioturbación en las facies deltaicas distales contrasta con la escasez observada en los depósitos fluviales, lo que refuerza la interpretación deltaica. Estos depósitos reflejan la interacción de procesos marinos y fluviales, con una progradación dominante hacia el NE durante su depósito.

**Palabras clave:** TIBEM, Almedina, Asociación de facies, sistema fluvio-deltaico, progradante.

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## Introduction

Until recently, the sedimentological knowledge on the Triassic Red Beds of the Iberian Meseta (TIBEM, as defined by Viseras *et al.*, 2018) hadn't been updated. Moreover, no specific studies beyond regional surveys (López-Garrido, 1971; Fernández, 1977) have been published about its northwestern part, which is the focus of this article. Earlier studies generally described the TIBEM deposited in a fluvial environment (Fernández, 1977), but recent works have identified evidence of

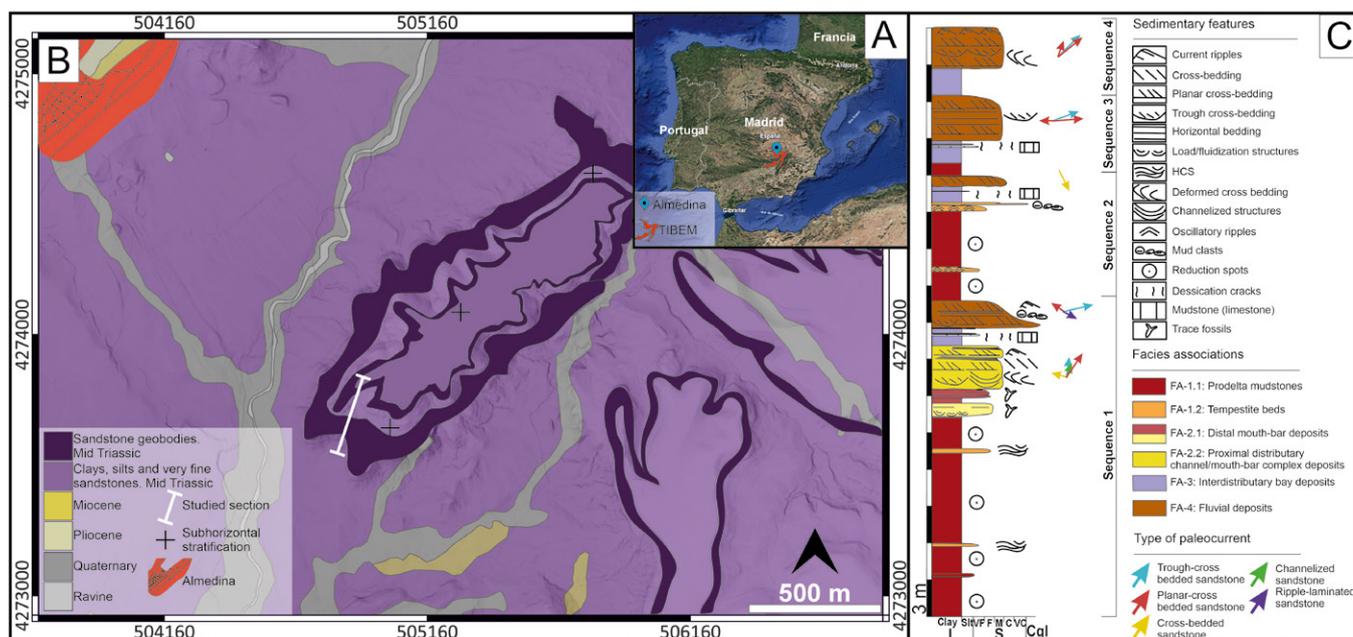
coastal and estuarine facies in the upper part of the Triassic succession, particularly in the eastern outcrops (Alcaraz outcrops, Yeste, 2020; Yeste *et al.*, 2024). This study presents the first evidence suggesting the presence of deltaic environments in the northwestern margin of the TIBEM.

## Geological setting

The Triassic Red Beds of the Tabular Cover of the Iberian Meseta (TIBEM) consist of a siliciclastic-dominated sedimentary succession. These deposits cover the

southeastern margin of the Iberian Massif, spanning over 4,000 km<sup>2</sup> (Fernández, 1977). The red beds primarily comprise sandstones, claystones, and siltstones, with minor occurrences of conglomerates, limestones, and marls, particularly in the study area. Their thickness varies between 50 and 400 meters (Fernández, 1977).

The earliest regional studies referred to the TIBEM as the "Chiclana del Segura Formation" (López-Garrido, 1971). Subsequently, four sequences (corresponding only to the emergent portion of the transgressive system tract) were identified (Fer-



**Fig. 1.- A) Location of Almedina’s Triassic outcrops. B) Geological map of the studied area and studied section (mean altitude of 850 m). C) Studied section at the Cerro Bogallo outcrop and its main sedimentary features. See color figure in the web.**

*Fig. 1.- A) Localización de los afloramientos triásicos de Almedina. B) Mapa geológica del área de estudio y sección estudiada (altura media de 850 m). C) Sección estudiada en el afloramiento de Cerro Bogallo y sus rasgos sedimentarios principales. Ver figura en color en la web.*

nández, 1977). It was not until more recent studies that its current nomenclature and focused analyses were established (e.g., Viseras *et al.*, 2018; Yeste *et al.*, 2019).

The palynological assemblage collected by Besems (1981) dated the TIBEM from the Ladinian (base) to the Norian (top), but precise dating remains challenging due to the scarcity of diagnostic fauna.

The studied section is located in Almedina (Ciudad Real, Spain, Fig. 1A), in the northwestern part of the TIBEM. In this area, the Paleozoic Hercynian basement and an unconformity formed by Mio-Pliocene tufas overlying the TIBEM are visible. The Triassic deposits include intervals of claystones, siltstones, and very fine sandstones, alternating with thicker geobodies of fine to medium sandstones (Fig. 1B and 1C).

### Methodology and data

A detailed sedimentological description, based on outcrop observations and measurements was developed at the Cerro Bogallo outcrop, located southeast of Almedina village. This involved logging the studied sedimentological column (Fig. 1), identifying and recording different lithologies, including grain sizes, sedimentary structures, and bioturbation types and degrees. Paleocurrents were also measured by identifying the orientation of different sedimentary structures. Measurements taken mainly from the fo-

resets of cross-bedding and cross-laminated structures. This sedimentological analysis allowed to identify the heterogeneity distribution, facies associations and architectural elements.

### Facies associations

Five different facies associations (FA) have been identified, based on its stratigraphic evolution:

#### FA-1: Prodelta deposits

This facies association was subdivided into two sub-associations:

- **FA-1.1: Prodelta mudstones:** It consists of reddish and greyish claystones and mudstones. Intervals can reach up to 7 meters in thickness and include siltstone beds up to 20 cm thick (Fig. 1C and 2A). These siltstone beds typically exhibit gradual bases and tops, but no clear sedimentary structures are visible. Reduction spots with dark nuclei are visible throughout the intervals of this association (Fig. 1C and 2A). FA-1.1 intervals are often interrupted by the deposition of FA-1.2 beds. A prodelta subenvironment is the most plausible interpretation. Evidence includes the fine-grained facies, abrupt interruptions by FA-1.2 beds, reduction spots (potentially indicative of organic matter accumulation), and occasional coarser siltstone beds (e.g., Ahmed *et al.*, 2014)
- **FA-1.2: Tempestite beds:** It includes

beds of very fine- to fine-grained sandstones with hummocky cross-stratification (HCS) and wave ripple-lamination. Beds range from 25 to 80 cm thick.

Wave ripple-lamination is common at the tops of beds in the lower section but becomes the dominant sedimentary structure in the upper section (Fig. 1C and 2B). Bases are sharp, while tops are more gradational, exhibiting fining-upward trends in the last tens of centimeters. This facies are typically interbedded within FA-1.1 intervals.

The presence of HCS and wave lamination, indicative of oscillatory and combined flows (Dumas and Arnott, 2006), indicates the deposition of these beds during storm events (Reolid *et al.*, 2014) in a subaqueous environment (shoreface).

#### FA-2: channel-mouth bar complex deposits (lower delta plain)

This facies association was subdivided into two sub-associations:

- **FA-2.1: Distal mouth bar deposits:** It comprises intervals up to 2 meters thick. The lower part contains massive, fine-grained sandstones that are highly bioturbated or horizontally to diffusely laminated (Fig. 2C). The upper part alternates between bioturbated reddish siltstones and very fine-grained, horizontally or current ripple-laminated sandstones (Fig. 1C and 2C). Load structures are present at the bases of massive sandstone beds.

These deposits represent the distal parts of a deltaic mouth bar (lower delta plain-delta front subenvironment). The massive, bioturbated sandstones indicate higher sand concentration, while alternating deposition of siltstones and sandstones suggest fringe zones with lower sand input (e. g., Van Yperen *et al.*, 2020). Also, the abundance of bioturbation supports the idea of a distal setting (lower delta front), where the energy is low enough to let benthic organisms to proliferate.

- **FA-2.2.: Proximal distributary channel/mouth bar complex deposits:** It is constituted by fine- to medium-grained sandstones with horizontal bedding, planar and trough cross-bedding, as well as ripple cross-lamination (Fig. 1C and 2D). Deformed cross-bedding and channelized structures are also present. These cycles, up to 3.5 meters thick, exhibit no

clear trends until the uppermost meter, where they are fining-upward. Sharp bases, occasionally erosive, transition to more gradual tops, often capped with current and/or oscillatory ripple lamination. Paleocurrents measurements indicate a dominant NE flow direction (30-40° NE).

The grain size, variety of sedimentary structures indicating high-energy conditions and the absence of bioturbation shows a more proximal depositional setting than FA-2.1, that could be interpreted as a proximal distributary channel/mouth bar complex (e. g., van Yperen *et al.*, 2020), set in the delta front and lower delta plain.

**FA-3: Interdistributary bay deposits (upper delta plain)**

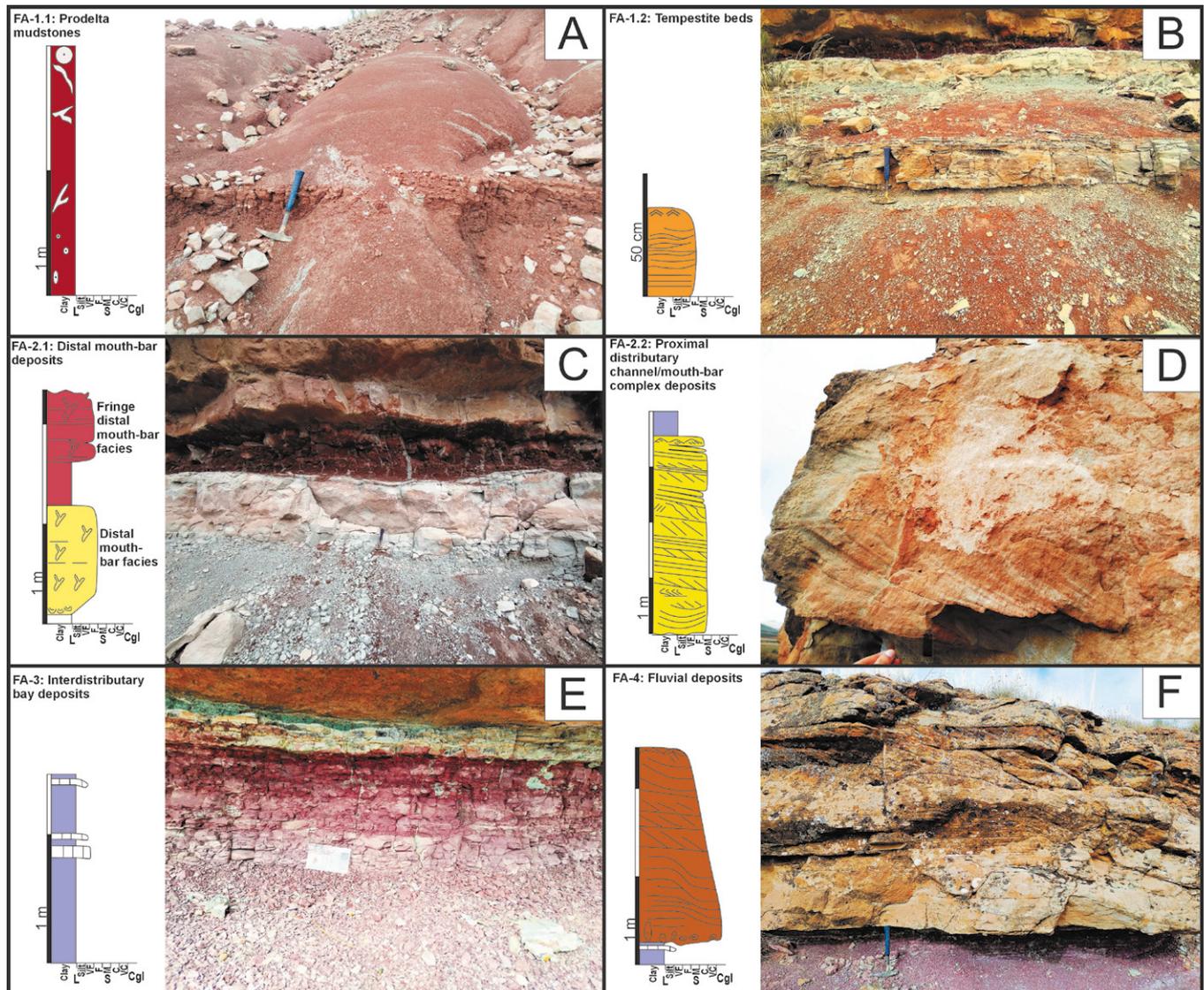
Consists of alternating purple mudstones and grey limestones (Fig. 1C and

2E). The limestones often exhibit fine laminations, desiccation cracks, and a nodular appearance.

The carbonate deposition indicates a shallow subaqueous environment conducive to carbonate precipitation. Desiccation cracks suggest cyclic subaerial exposure, while nodular textures may reflect incipient paleosols in partially submerged conditions (e. g., Andrews and Guo, 2024). This facies association is interpreted as an interdistributary bay setting (lower to upper delta plain).

**FA-4: Fluvial deposits (upper delta plain)**

Includes fine- to coarse-grained, planar and through cross-bedded sandstones within channelized geobodies (Fig. 2F). Conglomeratic lags, primarily com-



**Fig. 2.- Facies associations of the studied section and some examples (images) of the field aspect presented by each one (same legend as Figure 1). Scale is 8 cm width and hammer is 30 cm long. See color figure in the web.**

*Fig. 2.- Asociaciones de Facies de la sección estudiada y varios ejemplos (imágenes) del aspecto en campo presentado por cada una de ellas (misma leyenda que la Figura 1). La escala mide 8 cm de ancho y el martillo 30 cm de largo. Ver figura en color en la web.*

posed of mud clasts, are common (Fig. 1C). Cycles, up to 3.5 meters thick, display fining-upward trends, with rapid transitions from conglomeratic lags to sandstones at the base and from cross-bedding to current ripples in the uppermost part. Bases are erosive and sharp, while tops are gradual. Paleocurrent measurements (30–80° NE) indicate a dominant NE flow direction, with minor flow directions toward the SE, W, and NW.

The grain size, conglomeratic lags, channelized geobodies, and high-energy sedimentary structures indicate a fluvial environment in the upper delta plain (e. g., Bourquin *et al.*, 2009). Paleocurrent dispersion may reflect the influence of braid bars altering flow directions.

### Architectural stratigraphy and depositional model

The studied section represents a siliclastic, prograding fluvio-deltaic system (e. g., Zhao *et al.*, 2015), located in the northwestern TIBEM outcrops at Almedina, which predominantly prograded toward the northeast throughout its depositional history. The vertical stacking pattern of facies associations reflects this progradation, forming four coarseening-upwards and shallowing-upwards sequences (Fig. 1C). The basal sequence is the most complete, encompassing the full range of deltaic subenvironments. It begins with prodelta deposits, interstratified with tempestite beds characterized by HCS bedding and oscillatory ripple lamination. These prodelta deposits transition upward into distal mouth-bar deposits (lower delta front), followed by the proximal distributary channel/mouth-bar complex (upper delta front to lower delta plain). The sequence culminates with carbonate deposition in the interdistributary bay and is abruptly succeeded by fluvial deposits. In contrast, the upper sequences are incomplete, preserving only the prodelta fines, tempestite beds, and interdistributary bay deposits. These sequences reveal a trend of decreasing thickness in prodelta and tempestite facies upward, whereas interdistributary bay and fluvial deposits increase in thickness. This stratigraphic progression underscores the shallowing-upwards trend observed throughout the section.

The presence of tempestite beds interbedded with reddish claystones suggests a depositional system influenced by both fluvial and marine processes. Mo-

reover, the high degree of bioturbation in distal deltaic facies stands in stark contrast to the lack of bioturbation in fluvial facies, indicating a fluvio-deltaic depositional model for this part of the TIBEM.

### Conclusions

The northwestern outcrops of the TIBEM (Almedina, Ciudad Real), show evidences of a mainly siliclastic prograding fluvio-deltaic system with a main flow direction was towards the NE. An almost complete display of every deltaic subenvironment is represented in the facies associations that were studied (from prodelta to fluvial subenvironment). The presence of tempestite beds and the abundance of trace fossils typical of deltaic environments support this new interpretation of the studied succession.

### Author contributions

Sánchez-Guerra: work structure, methodology, data acquisition, figures, research/analysis. Yeste: work structure, methodology, editing, research/analysis. Gil-Ortiz and Rua-Alkain: editing, manuscript review. Cabello and Viseras: coordination, supervision.

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