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An Interdisciplinary Approach for Interpreting the Paleoenvironment of the Upanema Member, Alagamar Formation (Lower Cretaceous), Offshore Potiguar Basin, Brazil

Mirian Costa Menegazzo[1], José Gedson Fernandes da Silva[2], Bruno Rafael de Barros Pereira[3], Eduardo Henrique Roesner[3], Cecília Cunha Lana[4], and José Ricardo Maizatto[3]

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Abstract

To better understand the paleoenvironment of the Upper Aptian Upanema Member, Alagamar Formation (offshore Potiguar Basin), an interdisciplinary analysis of core samples from well 3-RNS-159-RN was performed. It involved interpreting facies associations, defining ichnofabrics, and inferring conditioning patterns, combined with petrographic and palynological data to characterize depositional environments and paleoclimatic aspects. Using ichnofacies and ichnofabric characterization methods, the trace fossils were categorized into nine groups. The Mermia and Scoyenia ichnofacies, specific to non-marine environments, were identified, as well as the Skolithos ichnofacies, which occur in marine, coastal, and non-marine settings. The results show deposition in channels and floodplains during high accommodation conditions and rapid aggradation, with initial hydromorphic paleosol development. The evidence for this hypothesis includes: (1) Basic characteristic of trace fossils: one of the basic principles of ichnology is that trace fossils represent the in-situ record of biogenic activity and do not undergo secondary displacement, consequently revealing an intimate relationship with the host substrate. These characteristics highlight the application of trace fossil studies for paleoecological and paleoenvironmental reconstructions, as emphasized by various authors. (2) Non-marine context: the recognition of the non-marine ichnofacies *Scoyenia* and *Mermia* characterizes a non-marine context for the cored interval from Upanema, as well as the sedimentological, paleoecological, and petrographic data. (3) Terrestrial context: subaerial exposure is evident in deposits showing the Scoyenia Ichnofacies, characterized by trace fossils with meniscate fill (*Taenidium barretti* and *Scoyenia gracilis*), produced by terrestrial insects. (4) Influence of pedogenetic processes: evidence includes organic fragments with cellular structures, root traces exhibiting siderite/ferroan dolomite and ankerite on the exterior, with the interior filled with fine-grained material or irregular voids, and nodules of pyrite and siderite. The characteristics of the root traces found indicate the presence of plants in waterlogged areas, i.e., poorly drained paleosols. Palynological data indicate the great dominance of spores from hygrophilous plants, such as spores of the genus *Cicatricosisporites*, as well as psilate and verrucate trilete spores, and notable percentages of perisporate spores (*Crybelosporites* spp. and *Perotilites* spp.) produced by

hydrophilous plants. The interdisciplinary analysis provides evidence of deposits associated with channel fill, abandonment, crevasse splay and interdistributary bays within a deltaplain. These deposits suggest a poorly drained area, flat/smooth relief and hygrophilous and hydrophilous vegetation with prolonged periods of flooding and feature coniferous vegetation in the higher interior regions, as indicated by the prevalent presence of *Araucariacites* pollen, the most representative genus of the upland humid flora. The study conducted has significant implications for understanding an exploratory frontier area and demonstrates the applicability of interdisciplinary analysis in the development of depositional models.

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1.Petrobras / Exploration, 2. Independent Researcher, 3. Universidade Federal do Rio de Janeiro/Museu Nacional, 4. Petrobras / CENPES

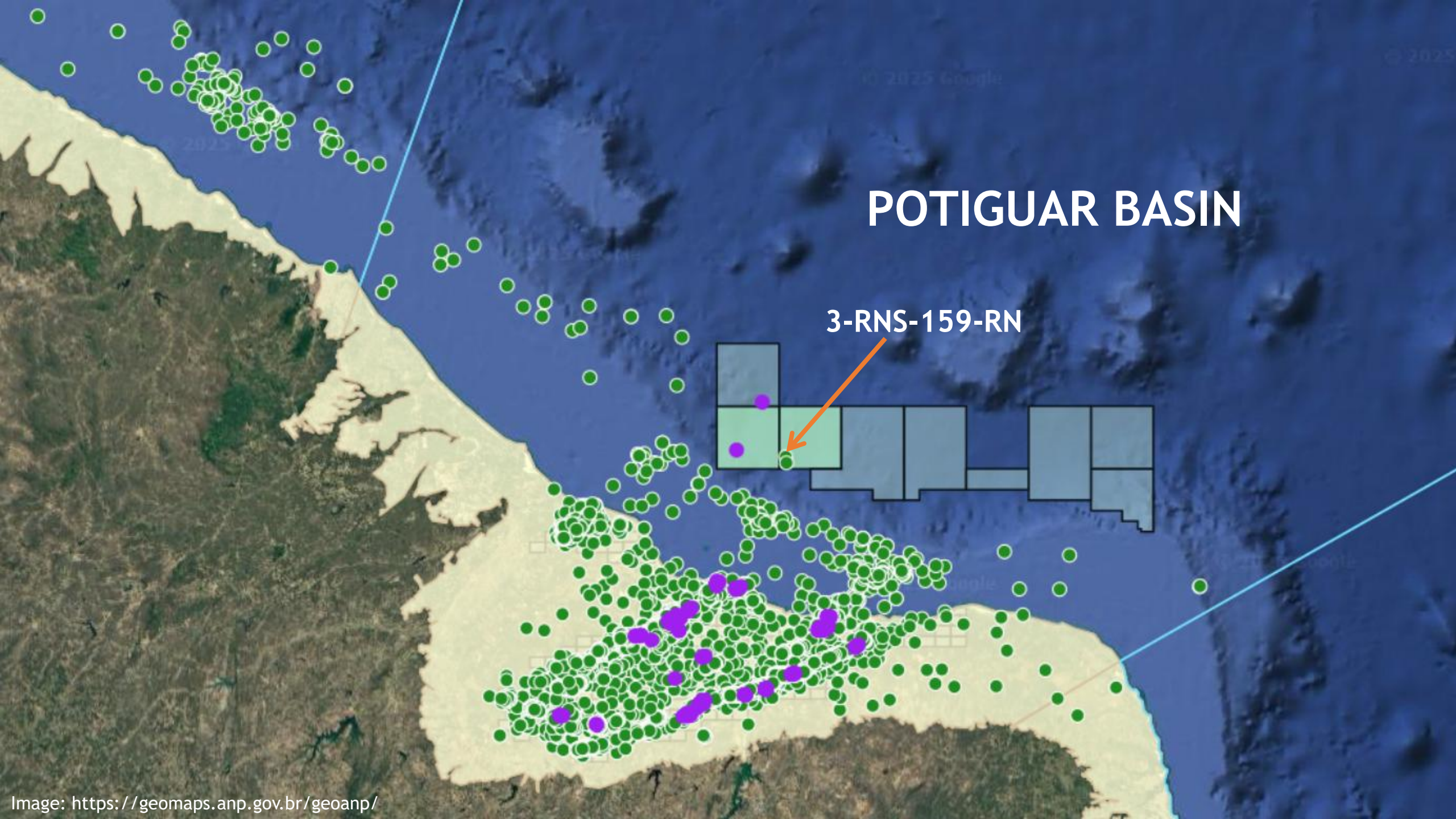
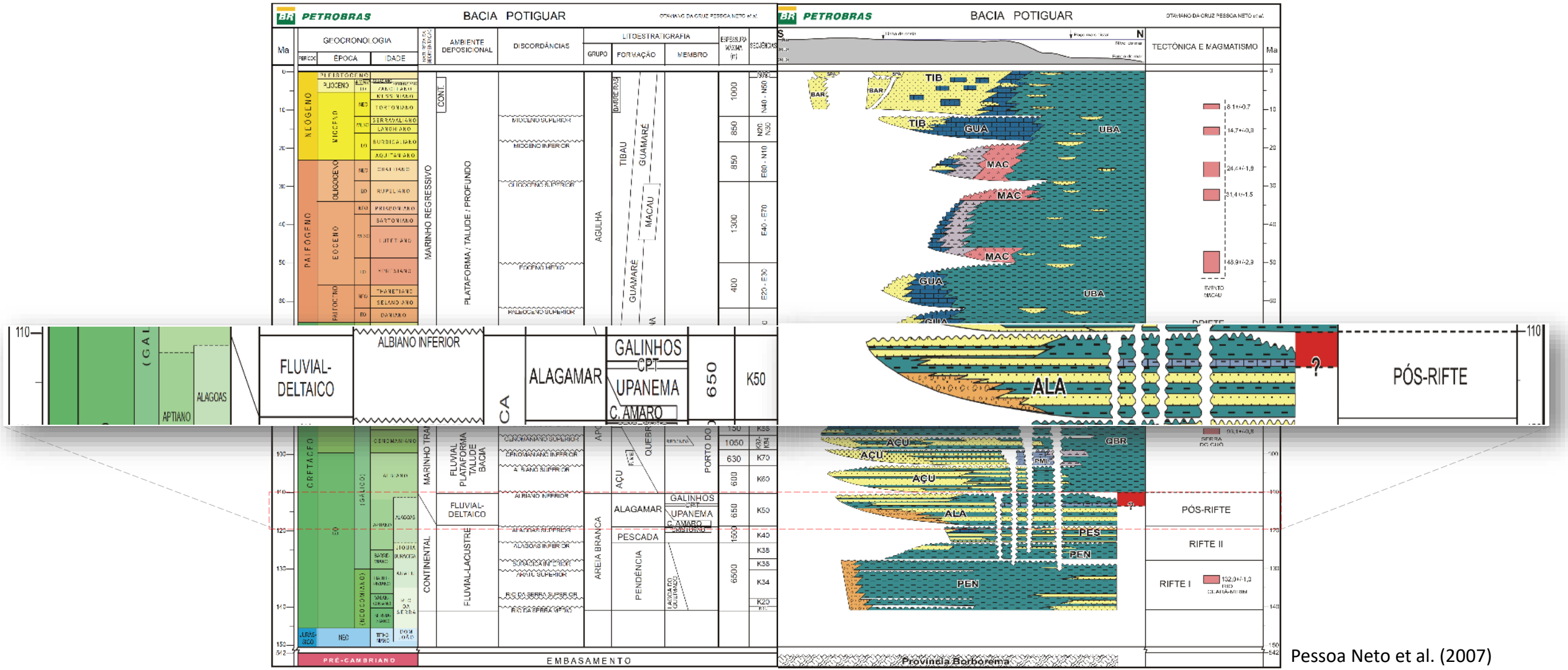


Image: https://geomaps.anp.gov.br/geoanp/

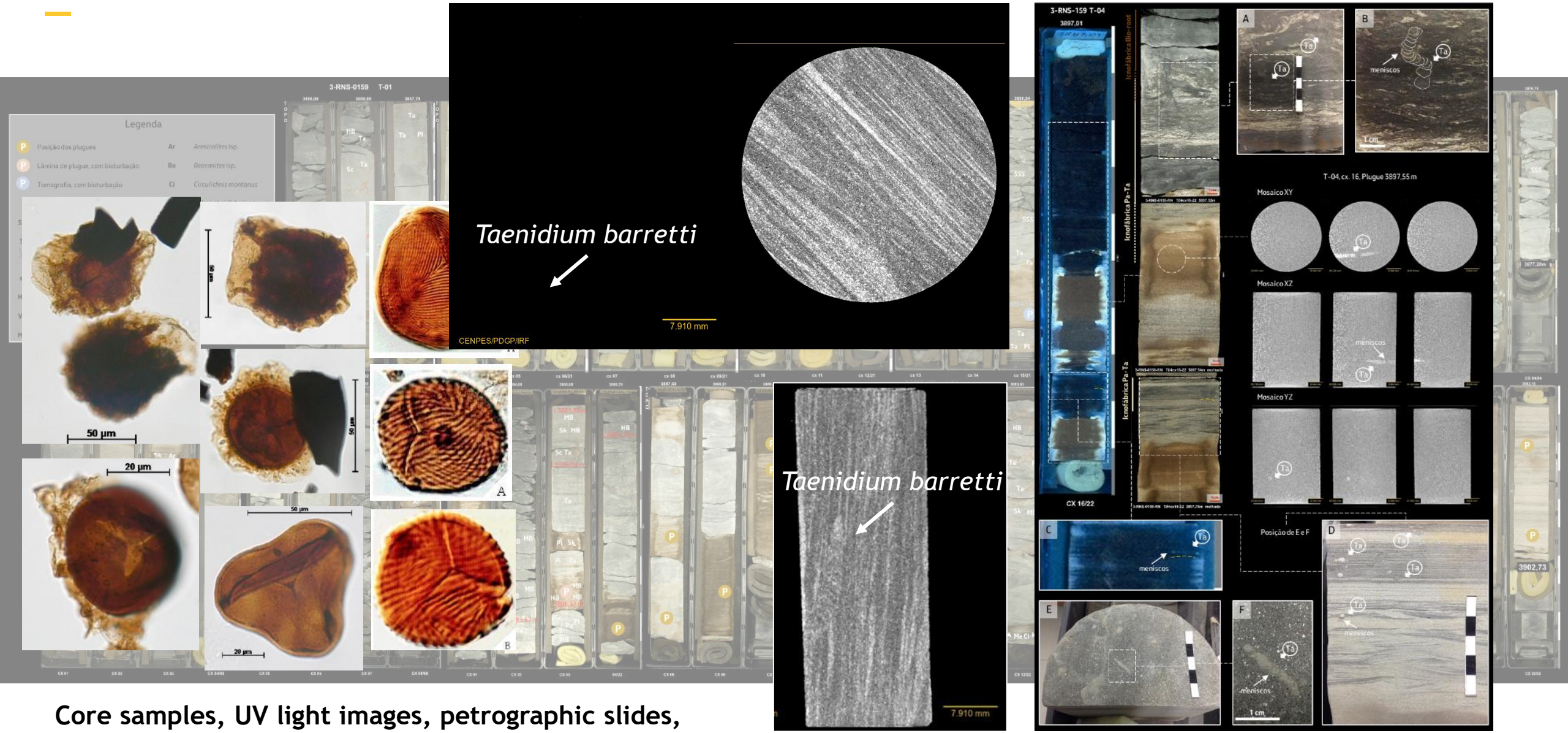
Stratigraphic Objective

Upanema Member - Alagamar Formation - Potiguar Basin - Brazil



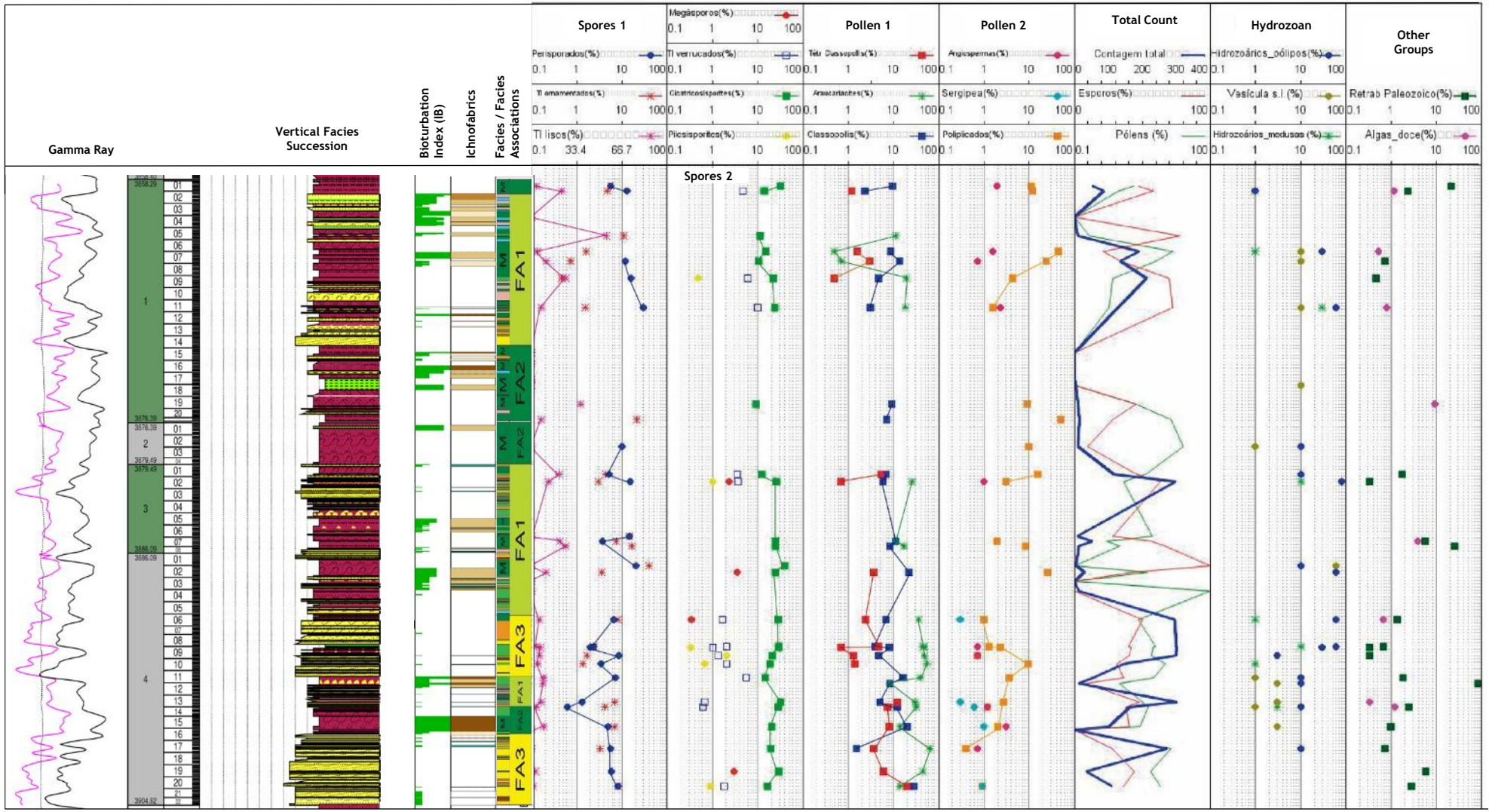
Pessoa Neto et al. (2007)

Dataset

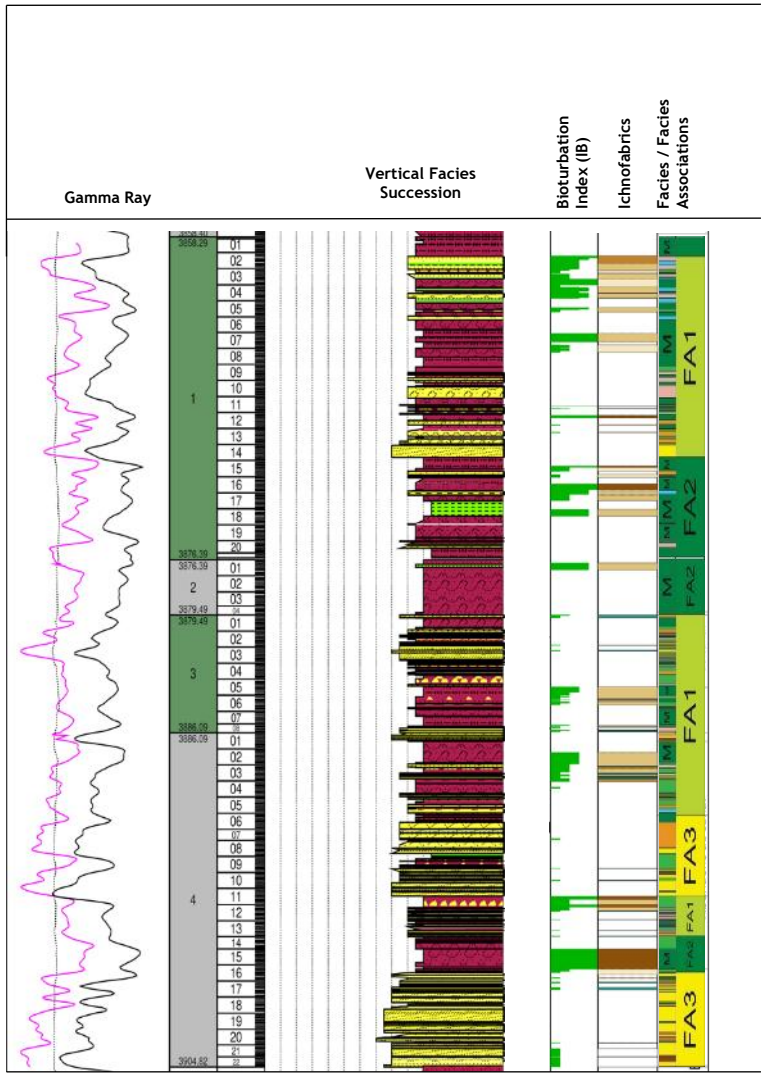


Core samples, UV light images, petrographic slides, tomography images and videos, palynomorphs

Results


Gamma Ray
Vertical Facies Succession
Bioturbation Index (IB)
Ichnofabrics
Facies / Facies Associations
Spores 1
Spores 2
Pollen 1
Pollen 2
Total Count
Hydrozoan
Other Groups
Megásporos(%)
Contagem total
Esporos(%)
Pólens (%)
Hidrozoários_pólipos(%)
Vesícula s.l. (%)
Hidrozoários_medusas (%)
Retrab Paleozoico(%)
Algas_doce(%)
FA1
FA2
FA3

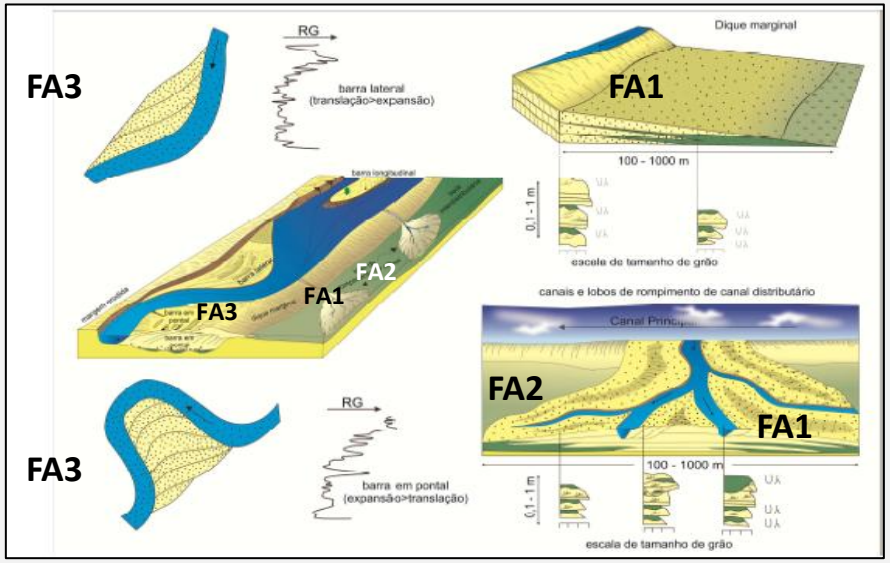
Facies Association



FA1: Overbank, levee, channel, and crevasse splay deposits

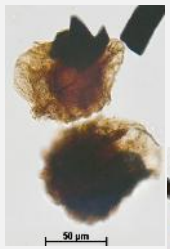
FA2: Overbank and abandoned distributary channels, interdistributary bay muds with pedogenic influence

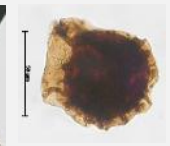
FA3: Point bars, distributary channel fill and abandonment, interdistributary bay deposits

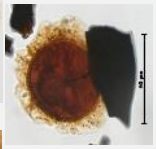


Palynology

Palynological data indicate the great **dominance of spores from hygrophilous plants**, such as spores of the genus *Cicatricosisporites*, as well as psilate and verrucate trilete spores, and **notable percentages of perisporate spores** (*Crybelosporites* spp. and *Perotilites* spp.) **produced by hydrophilous plants.**

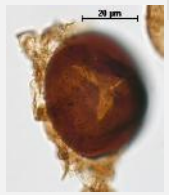




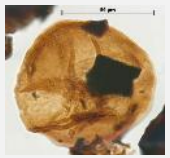


Spores

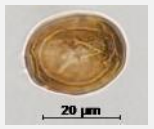
Pollens

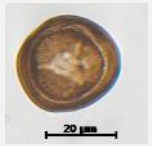


Hygrophilous pteridophytes
Spores of Marsiliaceae + Bryophytes + Algae:
Crybelosporites, *Perotrilites* + *Aequitriradites*
('Perisporate Group') + *Pediastrum*/*Chomotriletes*

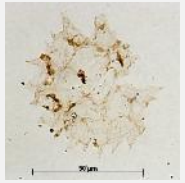


Araucariacites: pollen from arboreal terrestrial vegetation occurring at altitudes between 200/600 m and 1500 m under humid climatic conditions.

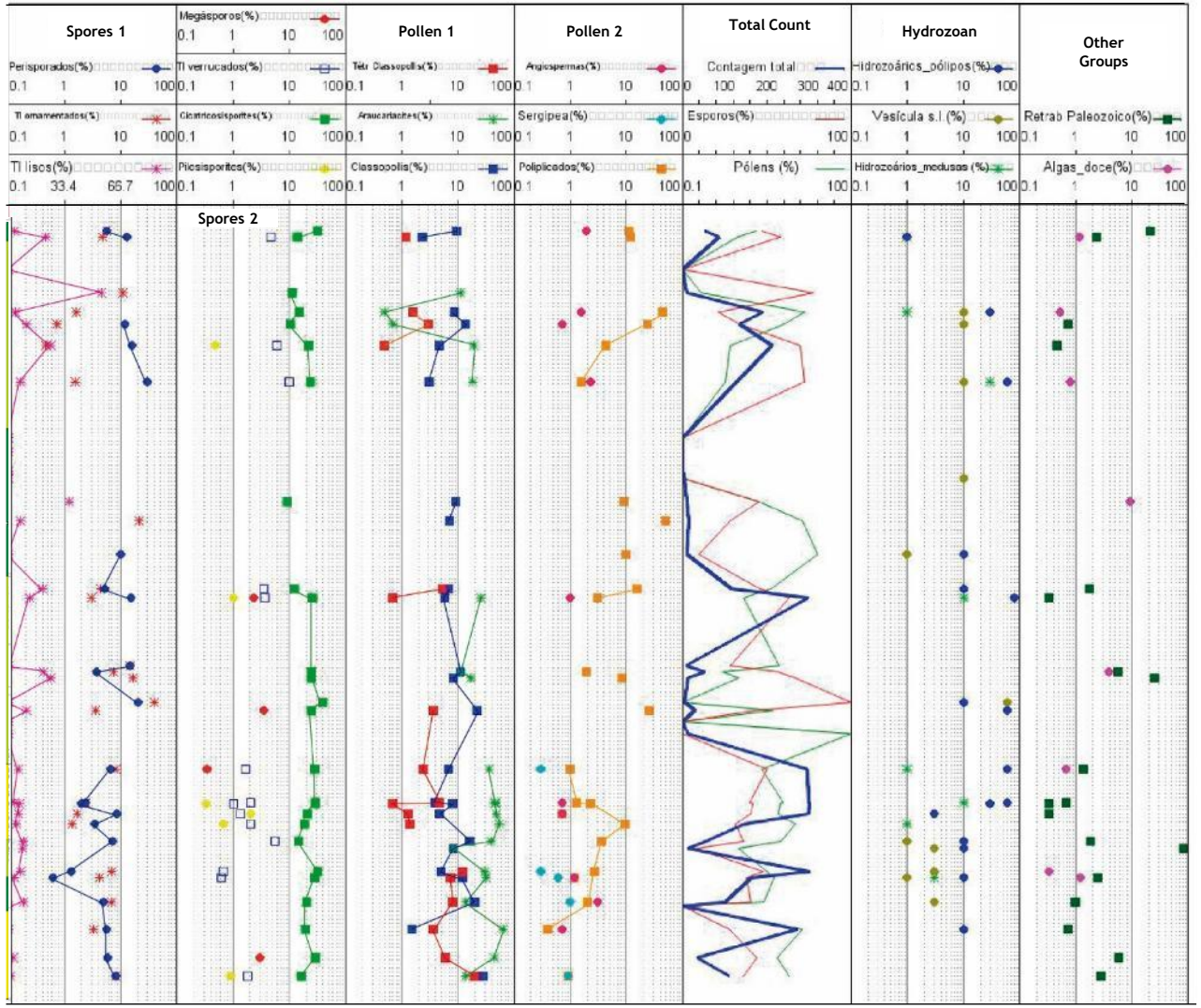




Classopollis **and** **polyplicate-type pollen**: pollen from terrestrial shrub vegetation, typically found in coastal areas or along lake margins, under semi-arid to arid climatic conditions.



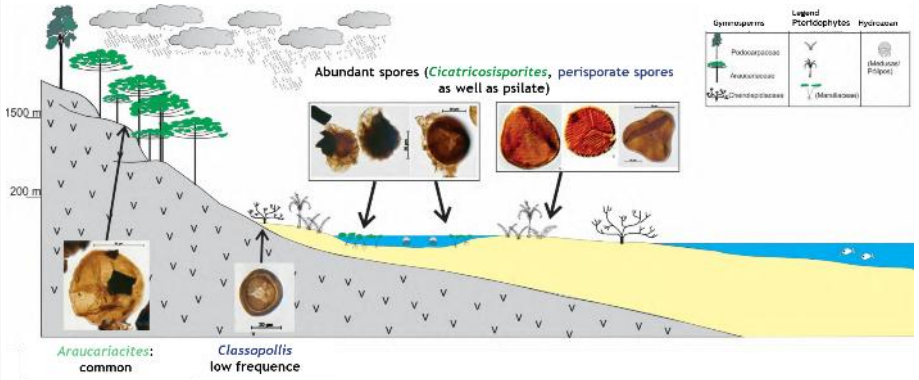
Freshwater algae: ***Pediastrum***, ***Scenedesmus***, ***Chomotriletes***

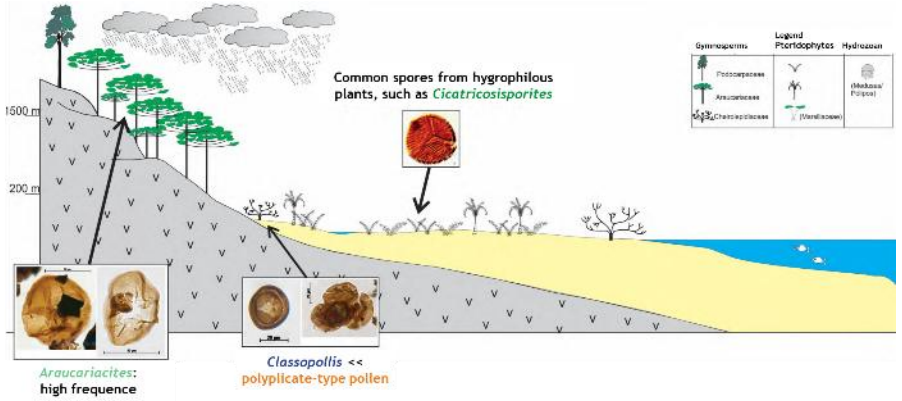


Palynology

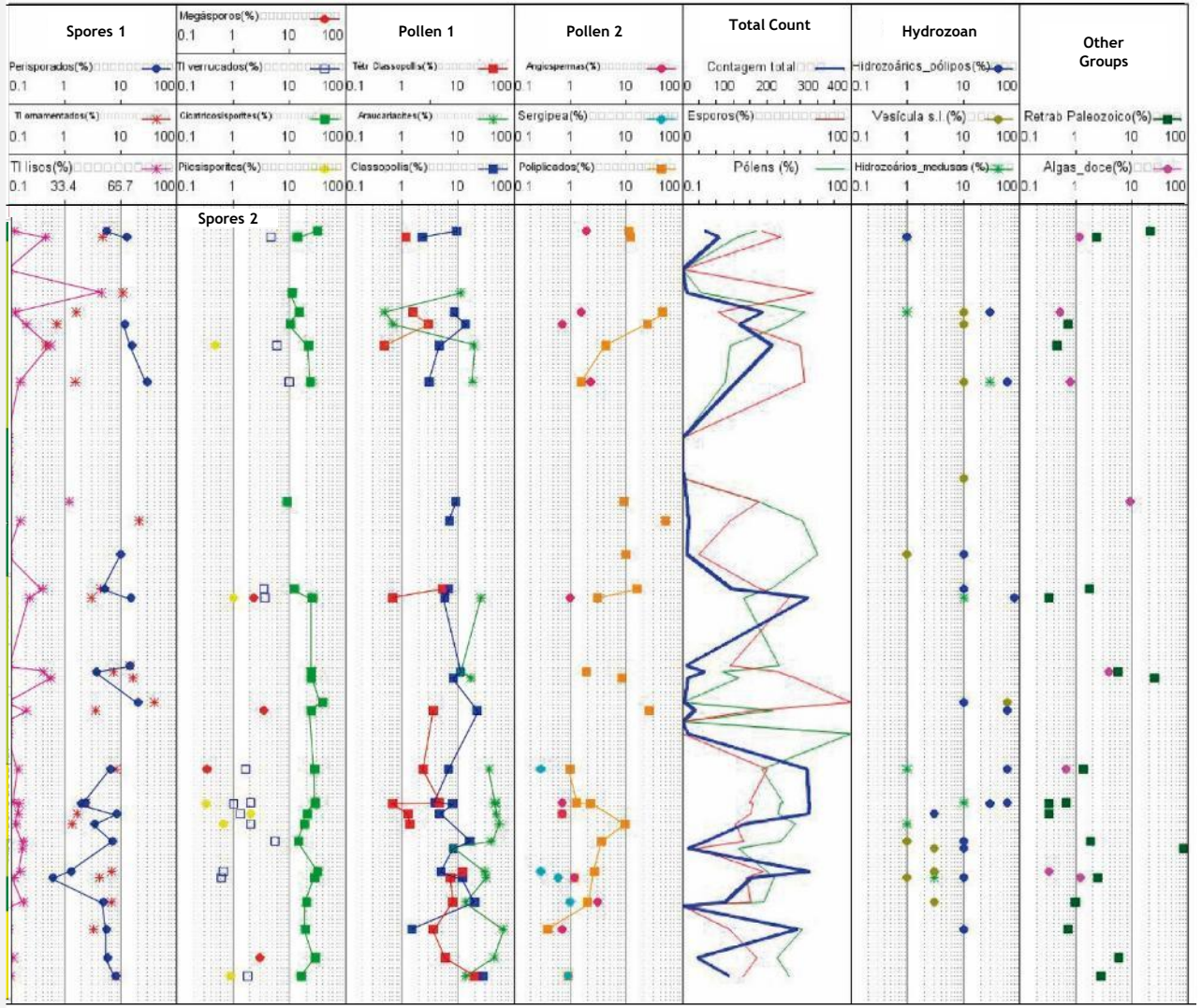
A **continental environment** is well characterized in the Aptian cored section based on the diversified and **abundant non-marine palynological assemblage** which is in good agreement with the **absence of any in situ marine microfossils.**

Araucariacites, indicative of highland vegetation, is the dominant terrestrial pollen genus in the areas surrounding the depocenter. This assemblage suggests **warm and humid climatic conditions**.

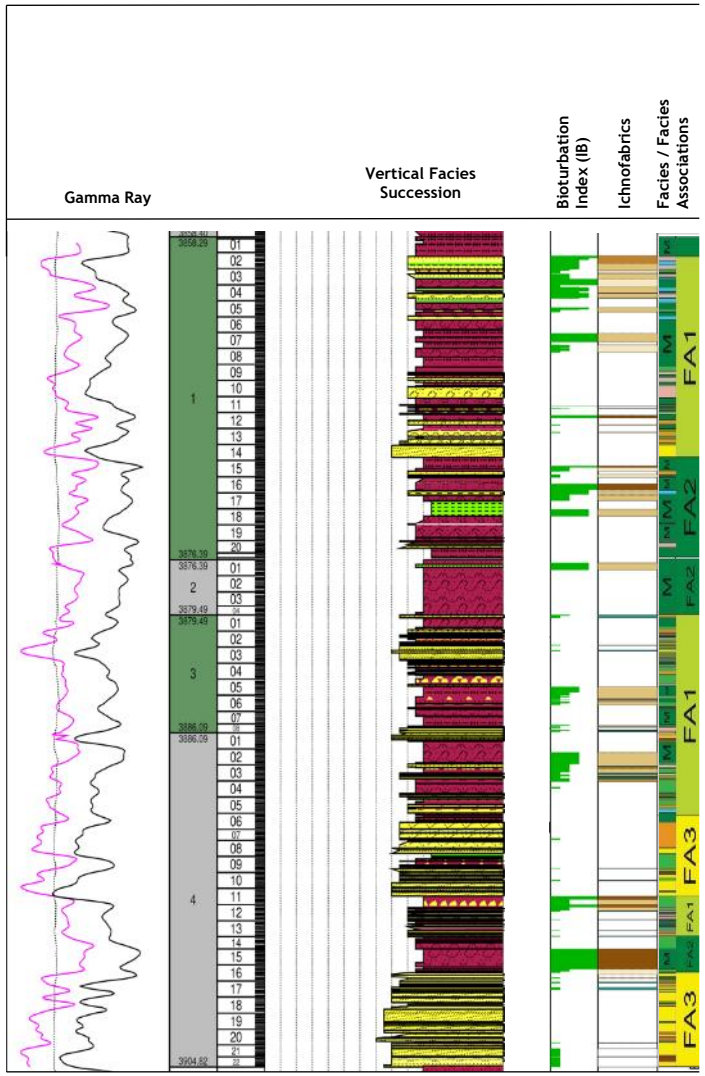




From the base to the top of the cored section, there is **a progressive increase in spore-producing sources** (hydrophytes and hygrophilous plants) and a corresponding **decrease in the proximity of pollen-producing sources**, particularly those of Araucariacean types.



Ichnology

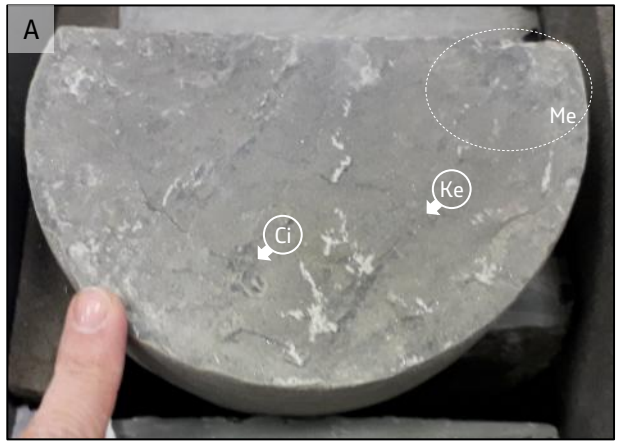


	Ichnofabric	Lithofacies	Interpretations
Ichnofacies *Mermia*	*Mermia* (Me2)	Contact between AMFon/cv and Ple	Low-energy subaqueous conditions in a non-marine environment.
	Impoverished *Mermia* (Me1)	Contact between AMFdf and Ple/pp and Aftg and Ple.	Low-energy subaqueous conditions in a non-marine environment.
Ichnofacies *Skolithos*	*Arenicolites - Palaeophycus* (Sk1)	AMFbi, AMFbi/df, AMFon/cv, AFba AMFcv/bi/df, AMFcp.	Opportunistic colonization during brief colonization windows. Structures produced under subaqueous conditions ranging from moderate to high energy.
	Skolithos (Sk2)	AMFpp, AFpp, AMFcv, AMFon/df, AMFon, AFsg.	Structures produced under subaqueous conditions of moderate to high energy within an aggradation setting.
Ichnofacies *Scoyenia*	*Palaeophycus - Taenidium* (Pa-Ta)	AFpp, Ple/df, AMFa_bi, AMFcv, Pbi, Pbi/df, Pdf, Ple, Ple/df.	Colonization by pioneer or opportunistic organisms during temporarily favorable conditions (energy and oxygen availability).
	Taenidium 1 (Ta1)	AMFpp, AMFan, Ple_bi.	Opportunistic or pioneer colonization on substrates that may be moist but lie above the water table.
	Taenidium 2 (Ta2)	AMFa_bi, AMFdf, P, Pbi, Pbi/df, Pdf, Ple/bi, Ple/bi/df, Ple/df.	Similar to Ta1 but indicating a longer colonization window.
	Scoyenia (Sc)	Ple/df, Ple/bi/df, AMFbi.	Evidence of subaerial exposure with a higher degree of substrate desiccation.
	Bioturbated, with trace roots (Bio-root)	Pbi/df, Ple/df, Pbi.	Gleyed protosol, that is, an incipient hydromorphic paleosol.

Ichnology

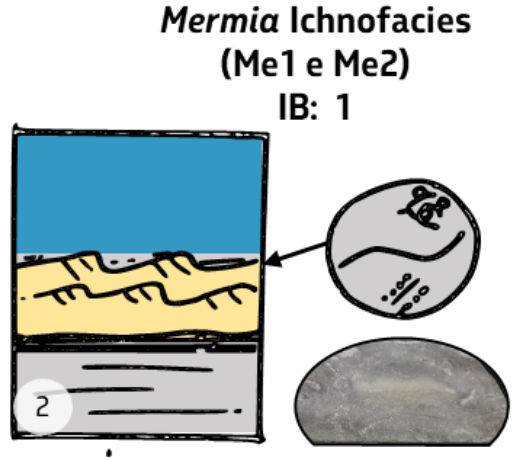
The *Mermia* Ichnofacies indicates permanently subaqueous, oxygenated, and low-energy conditions, typically associated with marginal lacustrine deposits and floodplain environments.

	Ichnofabric	Lithofacies	Interpretations
Ichnofacies *Mermia*	*Mermia* (Me2)	Contact between AMFon/cv and Ple	Low-energy subaqueous conditions in a non-marine environment.
	Impoverished *Mermia* (Me1)	Contact between AMFdf and Ple/pp and Aftg and Ple.	Low-energy subaqueous conditions in a non-marine environment.



Mermia (Me2)

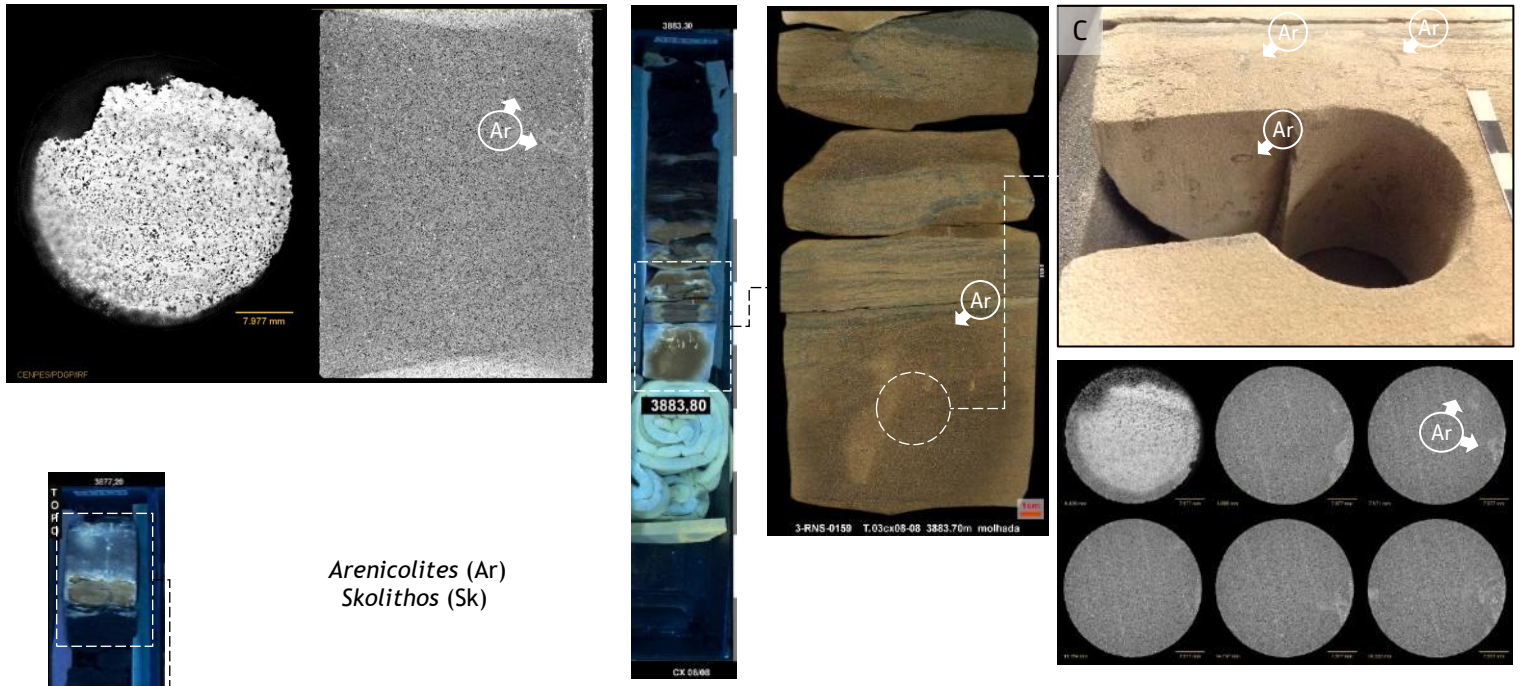
Impoverished *Mermia* (Me1)



- ***Mermia carickensis* (Me):** Grazing and/or locomotion structures produced by vermiform organisms and/or mosquito larvae.
- ***Keirkalia multipedia* (Me):** Locomotion structure attributed to an arthropod.
- ***Circulichnis montanus* (Ci):** Feeding traces produced by vermiform organisms.
- ***Helminthoidichnites tenuis* (He):** Grazing traces likely produced by nematomorphs or insect larvae.

Ichnology

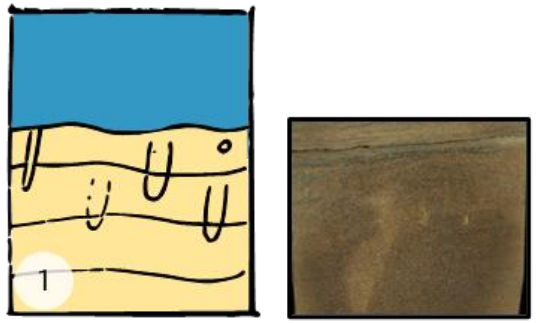
The *Skolithos* Ichnofacies is typically recorded in non-marine environments with moderate to high energy, such as shallow lacustrine deposits, fluvial bar tops, or crevasse splay deposits.



Arenicolites (Ar)
Skolithos (Sk)

	Ichnofabric	Lithofacies	Interpretations
Ichnofacies *Skolithos*	*Arenicolites - Palaeophycus* (Sk1)	AMFbi, AMFbi/df, AMFon/cv, AFba AMFcv/bi/df, AMFcp.	Opportunistic colonization during brief colonization windows. Structures produced under subaqueous conditions ranging from moderate to high energy.
	Skolithos (Sk2)	AMFpp, AFpp, AMFcv, AMFon/df, AMFon, AFsg.	Structures produced under subaqueous conditions of moderate to high energy within an aggradation setting.

Skolithos Ichnofacies (Ichnofabrics Sk1 e Sk2)
IB: 1-2

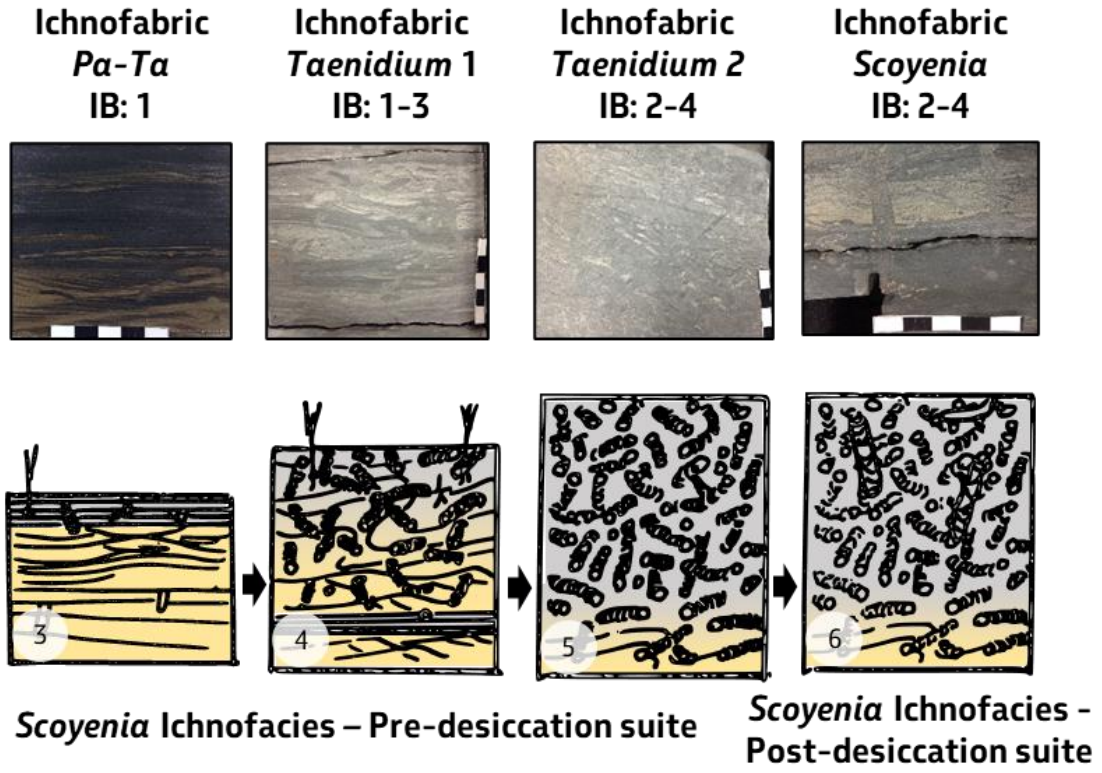


Moderate to high energy

Ichnology

The *Scoyenia* Ichnofacies is typical of sediments that are periodically exposed or intermittently flooded, commonly occurring in fluvial and lacustrine systems. In fluvial settings, it is found in floodplain deposits, while in lacustrine environments, it is restricted to lake margin areas. It is also present in poorly developed paleosols.

	Ichnofabric	Lithofacies	Interpretations
Ichnofacies *Scoyenia*	*Palaeophycus* - *Taenidium* (Pa-Ta)	AFpp, Ple/df, AMFa_bi, AMFcv, Pbi, Pbi/df, Pdf, Ple, Ple/df.	Colonization by pioneer or opportunistic organisms during temporarily favorable conditions (energy and oxygen availability).
	Taenidium 1 (Ta1)	AMFpp, AMFan, Ple_bi.	Opportunistic or pioneer colonization on substrates that may be moist but lie above the water table.
	Taenidium 2 (Ta2)	AMFa_bi, AMFdf, P, Pbi, Pbi/df, Pdf, Ple/bi, Ple/bi/df, Ple/df.	Similar to Ta1 but indicating a longer colonization window.
	Scoyenia (Sc)	Ple/df, Ple/bi/df, AMFbi.	Evidence of subaerial exposure with a higher degree of substrate desiccation.

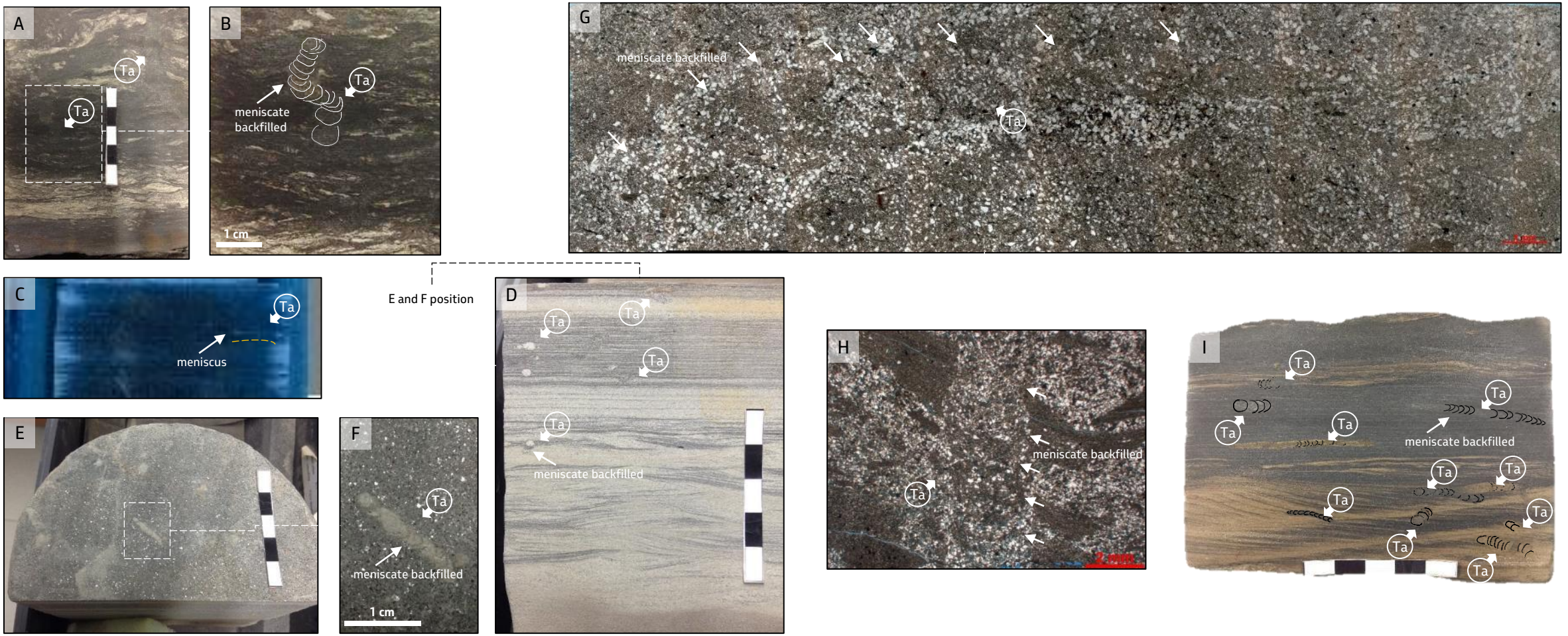


Taenidium barretti (Ta), *Scoyenia gracilis* (Sc), *Beaconites* (Be)
Other components: *Planolites* (Pl), *Palaeophycus* (Pa) and root traces

It is currently recognized that various insects produce meniscate traces, including Tipulidae larvae, true bugs, cicada nymphs, beetles, and both larvae and adults of ground beetles.

Ichnology

Scoyenia Ichnofacies



Taenidium barretti (Ta), *Scoyenia gracilis* (Sc), *Beaconites* (Be). Other components: *Planolites* (Pl), *Palaeophycus* (Pa) and root traces

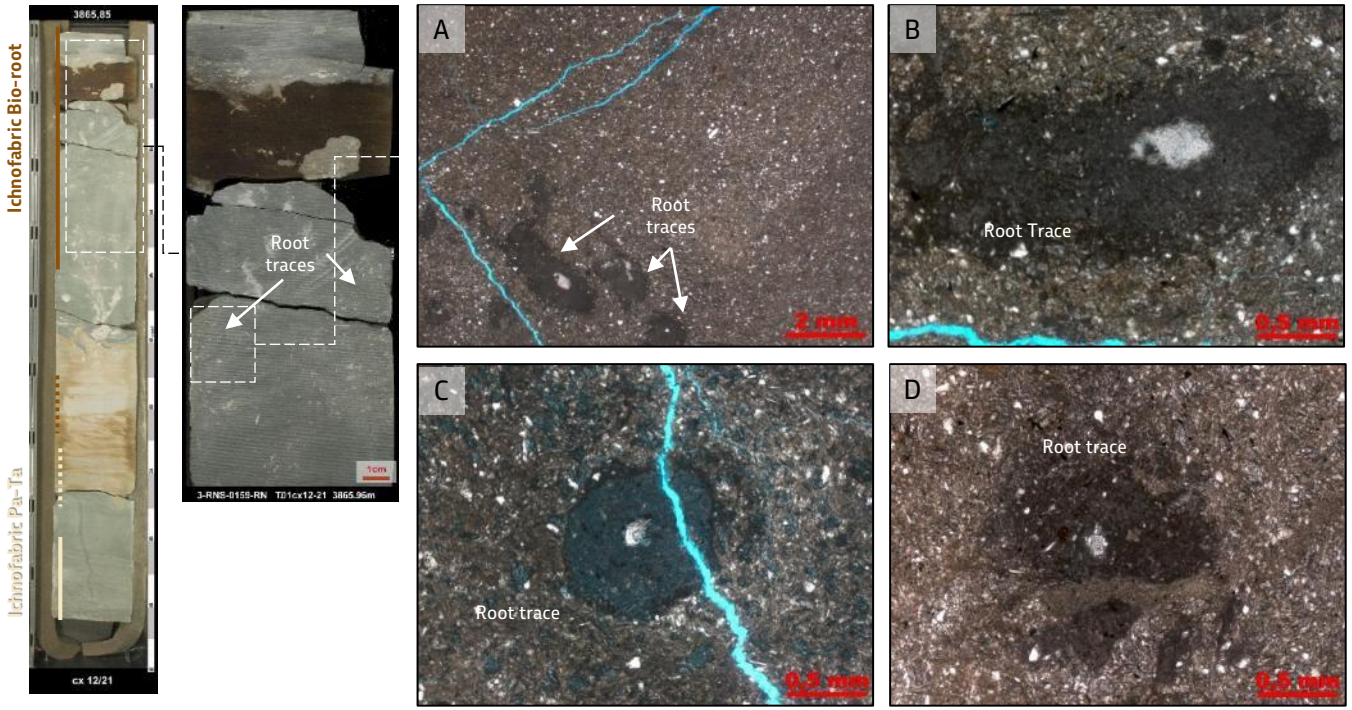
It is currently recognized that various insects produce meniscate traces, including Tipulidae larvae, true bugs, cicada nymphs, beetles, and both larvae and adults of ground beetles.

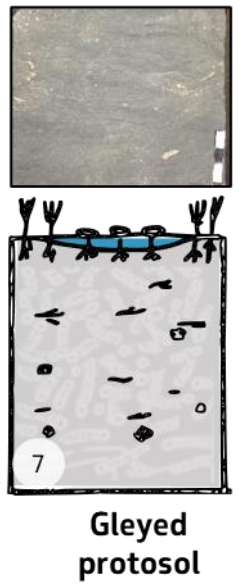
Ichnology

Gleyed Protosol
(following classification of Mack et al., 1993)

The intervals classified as Bioturbated with root traces consist of massive siltstones with gray to greenish-gray coloration; laminations are rare and typically exhibit deformation.

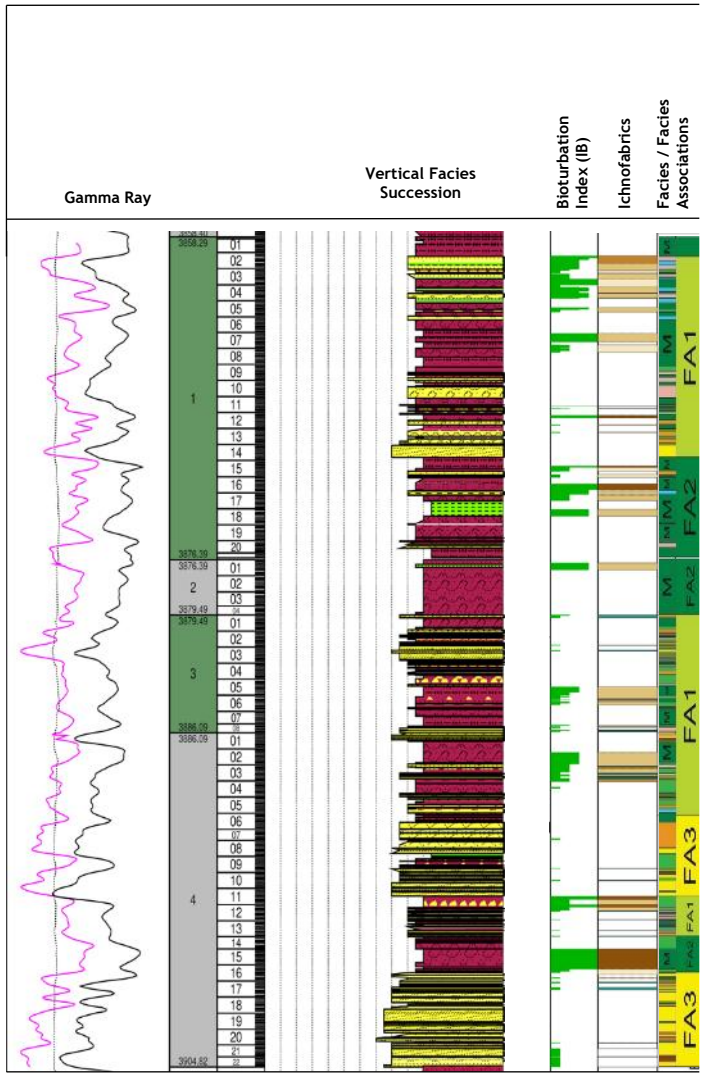
	Ichnofabric	Lithofacies	Interpretations
	Bioturbated, with trace roots (Bio-root)	Pbi/df, Ple/df, Pbi.	Gleyed protosol, that is, an incipient hydromorphic paleosol.





- Texture is disrupted by bioturbation;
- Dispersed tiny root traces;
- Presence of slickensides and carbonized plant fragments;
- Irregularly shaped nodules of siderite, ferroan dolomite, ankerite, and pyrite.

Ichnology and facies associations



At the top, predominance of:

CREVASSE CHANNELS

- **Thicker intervals of very fine to fine-grained sandstones** with lamination and cross-stratification, lacking bioturbation;

CREVASSE SPLAY

- **Fine-grained sandstones** exhibiting ripple marks and/or soft-sediment deformation structures, associated with the ***Sk1* ichnofabric**;

FLOODPLAIN WATERBODIES

- **Upward-fining successions** capped by occurrences of the Mermia ichnofacies;

FLOODPLAIN MUDSTONES / PALEOSOLS

- **Very fine-grained sandstones and siltstones**, moderately to intensely bioturbated, displaying the *Taenidium* 1 (Ta1) and *Taenidium* 2 (Ta2) **ichnofabrics**;
- **Fine-grained sediment packages** containing *Taenidium* 2 (Ta2) and ***Scoyenia* (Sc)** ichnofabrics, along with intervals of **gleyed protosol** represented by the **Bioturbated with root ichnofabric**.

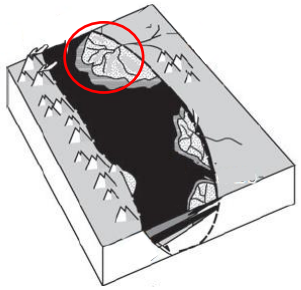
At the base, predominance of:

CHANNEL DEPOSITS

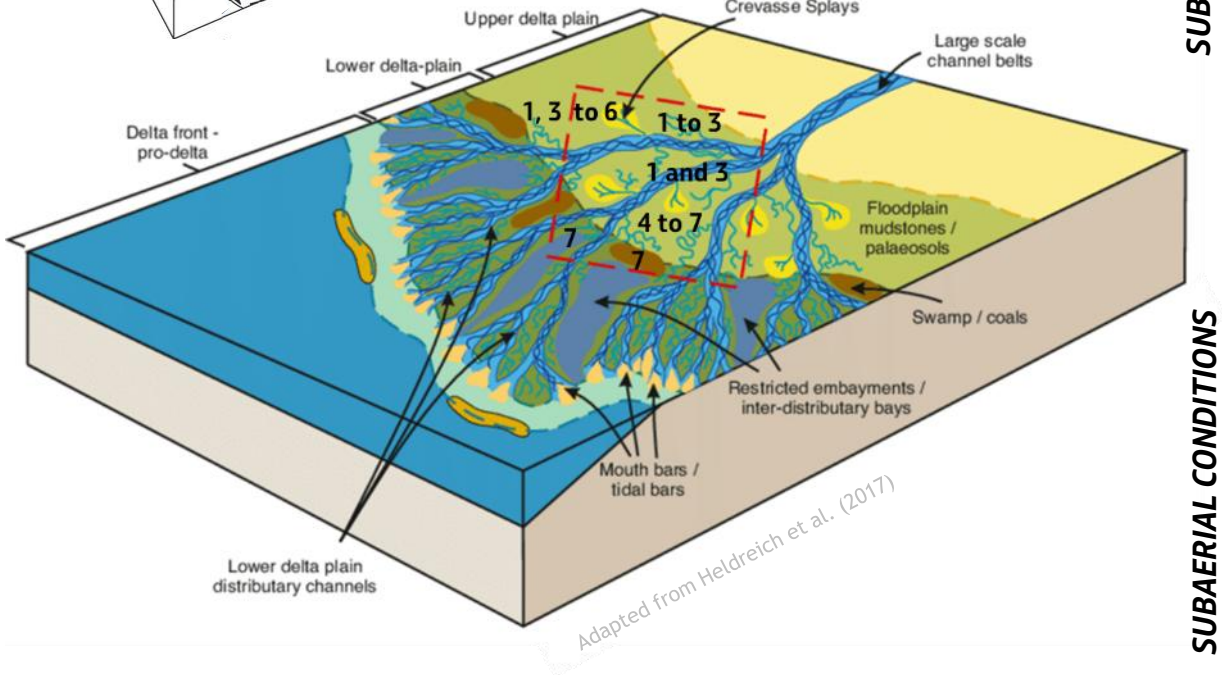
- **Sandstones with cross-stratification and current ripples**, associated with the ***Skolithos* ichnofacies**, indicative of subaqueous conditions with moderate to high energy.
- **Localized occurrences of the *Palaeophycus-Taenidium* (Pa-Ta) ichnofabric** suggest episodes of non-deposition followed by rapid subaerial exposure.

	Ichnofabric
Ichnofacies *Mermia*	*Mermia* (Me2)
	Impoverished *Mermia* (Me1)
Ichnofacies *Skolithos*	*Arenicolites - Palaeophycus* (Sk1)
	Skolithos (Sk2)
Ichnofacies *Scoyenia*	*Palaeophycus - Taenidium* (Pa-Ta)
	Taenidium 1 (Ta1)
	Taenidium 2 (Ta2)
	Scoyenia (Sc)
	Bioturbated, with trace roots (Bio-root)

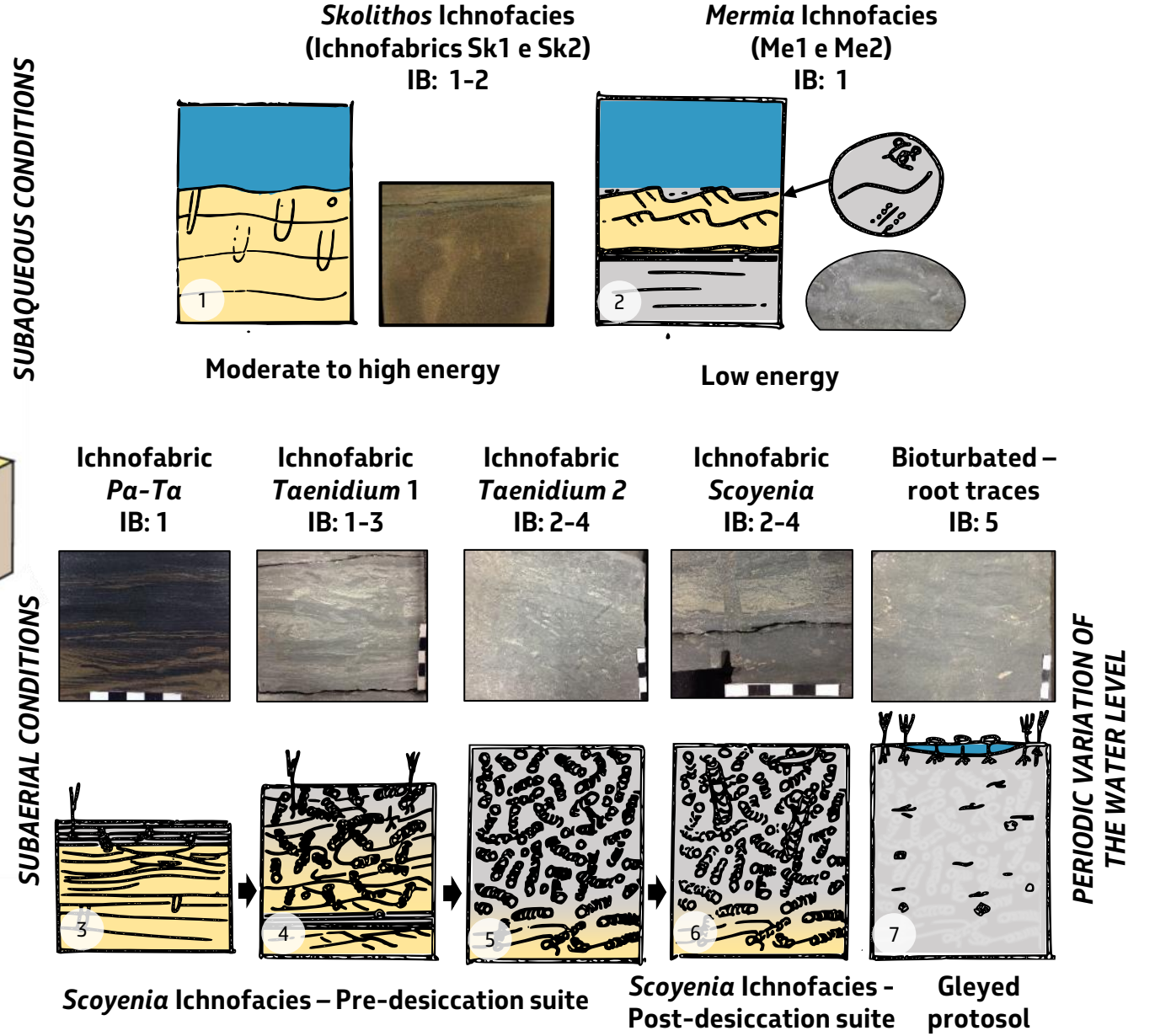
Ichnology



Implications for the paleodepositional model.

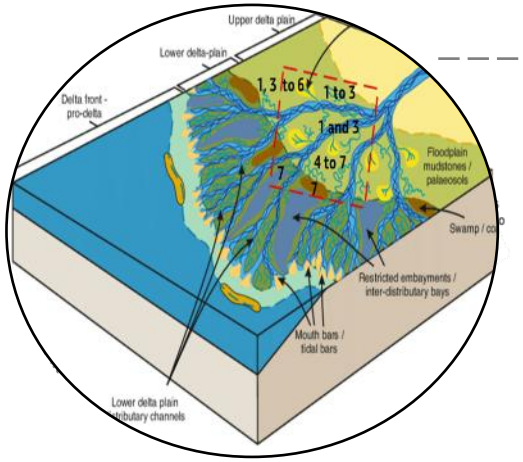


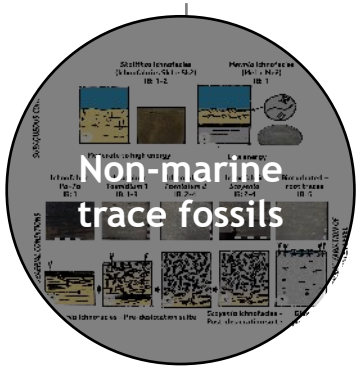
The analyzed interval is characterized by deposition in channels and floodplain environments under high accommodation conditions during a phase of rapid aggradation, with incipient development of hydromorphic paleosols.



The evidence supporting this hypothesis includes:

The interdisciplinary analysis provides evidence of deposits associated with channel fill, abandonment, crevasse splay and interdistributary bays within a deltaplain.

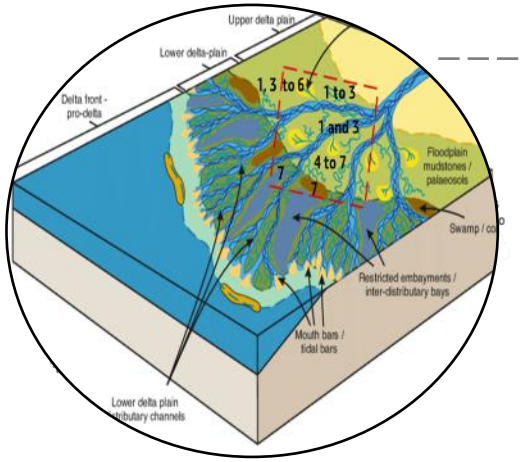


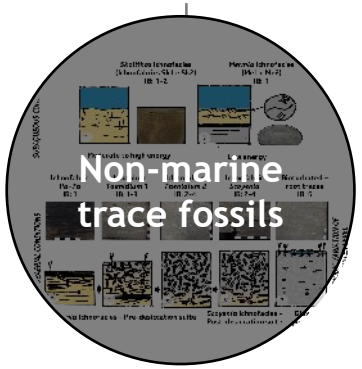


Non-marine environmental conditions: In-situ records of non-marine biogenic activity, represented by the *Scoyenia* and *Mermia* ichnofacies, along with non-marine palynological assemblages.

The evidence supporting this hypothesis includes:

The interdisciplinary analysis provides evidence of deposits associated with channel fill, abandonment, crevasse splay and interdistributary bays within a deltaplain.

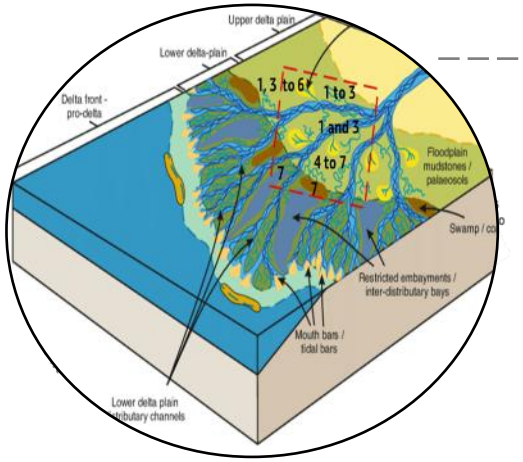


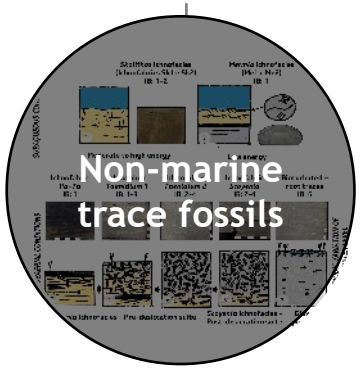


Terrestrial context: Subaerial exposure is indicated by deposits exhibiting the *Scoyenia* ichnofacies, characterized by meniscate-filled trace fossils such as *Taenidium barretti* and *Scoyenia gracilis*, typically produced by terrestrial insects.

The evidence supporting this hypothesis includes:

The interdisciplinary analysis provides evidence of deposits associated with channel fill, abandonment, crevasse splay and interdistributary bays within a deltaplain.

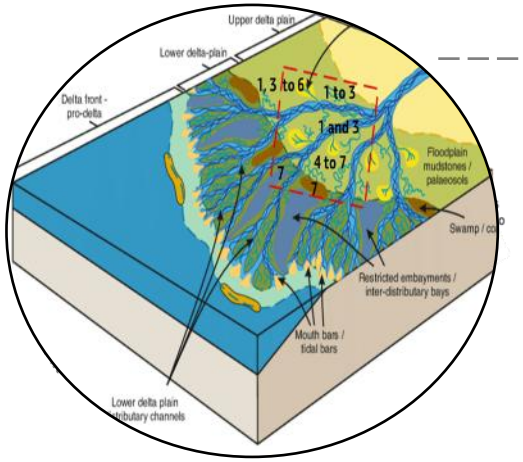


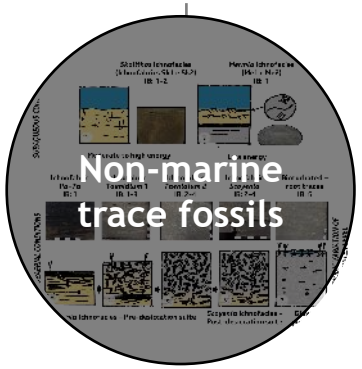


Influence of pedogenic processes: Supporting evidence includes organic fragments with preserved cellular structures, root traces coated externally with siderite, ferroan dolomite, or ankerite, and internally filled with fine-grained sediment or irregular voids. Additional indicators include pyrite and siderite nodules. The morphology and mineralization of the root traces suggest colonization by plants in waterlogged conditions, consistent with poorly drained paleosols.

The evidence supporting this hypothesis includes:

The interdisciplinary analysis provides evidence of deposits associated with channel fill, abandonment, crevasse splay and interdistributary bays within a deltaplain.





All these interpretations are integrated with the interpretation of the facies association.

This study highlights the critical role of interdisciplinary geological analysis in reconstructing the depositional paleoenvironment of the investigated interval. It also reinforces the enduring relevance of fundamental geology and comprehensive datasets for improving the understanding and predictability of deposits in frontier exploration areas.

Illustrative images: Satellite view and flooded areas of the Selenga River delta (in the background), Lake Baikal, Russia.
https://boydnorton.photoshelter.com/image/I0000QctTw3_NR0I