Cyclicity and Carbonate-Silicate Gel Interactions in Cretaceous Alkaline Lakes*

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Search and Discovery Article #51011 (2014)
Posted August 29, 2014

*Adapted from oral presentation given at 2014 AAPG Annual Convention and Exhibition, Houston, Texas, April 6-9, 2014

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Abstract

Mg-silicates are a prominent feature of many modern and ancient saline alkaline lake deposits, but whereas models for their distribution are well known, their influence on associated carbonates has not been considered. The cyclic distribution of various types of carbonates and Mg-clays in early Cretaceous lacustrine carbonates from the South Atlantic provides an insight into how evolving lake chemistries in highly alkaline settings control facies development. The cyclothems are typically sub-decametre scale, with component lithofacies arranged both in symmetrical and asymmetrical motifs. Laminated carbonates were deposited linked to short lived pluvial events, causing expansion of shallow lakes developed in rift settings, followed by evaporation which triggered Mg-silicate precipitation and calcite nucleation and growth. Where Mg-silicate deposition dominated textural development, calcite nucleated within gels to produce spherulitic textures. When the rate of gel precipitation decreased or ceased, calcite growth, now less inhibited, produced shrub-like calcites resembling those produced abiotically in modern travertines.

Physical reworking of these sediments led to the dispersion of the gels and the concentration of detrital carbonate components. The later behaviour of the Mg-silicates, where deposited and converted to clays, had a profound effect on porosity development. Limited criteria are available to indicate water depths for the lakes, but like modern shallow salt lakes such as the Great Salt Lake, tectonics had a significant control on facies development. Despite earlier proposals, evidence of microbial

processes producing carbonates in these Cretaceous lake deposits are rare and the application of facies models based on modern and ancient microbialite analogues maybe be misplaced.

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Cyclicity and carbonate-silicate gel interactions in Cretaceous alkaline lakes

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"Lacustrine sequences of all ages commonly show a cyclic arrangement of facies" (Talbot & Allen, 1996)

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Take away points

- Some of the facies in the Santos Basin Pre-Salt Barra Velha Formation are arranged in asymmetric **cyclothems**

- These are interpreted as **transgressive-regressive cycles** as shallow alkaline lakes freshened and then underwent progressive fractionation

- Following a pluvial, lowered pH phase, increased concentration in the lakes triggered the precipitation of Mg-silicates (initially as gels) within which **spherulites** grew

- Later, as the rate of Mg-silicate precipitation decreased, more extensive calcite nucleation resulted in the formation of **crystal shrub framestones**

- Subsequent **dissolution of the Mg-silicates** plus some primary porosity, produced reservoir quality in these unusual carbonates

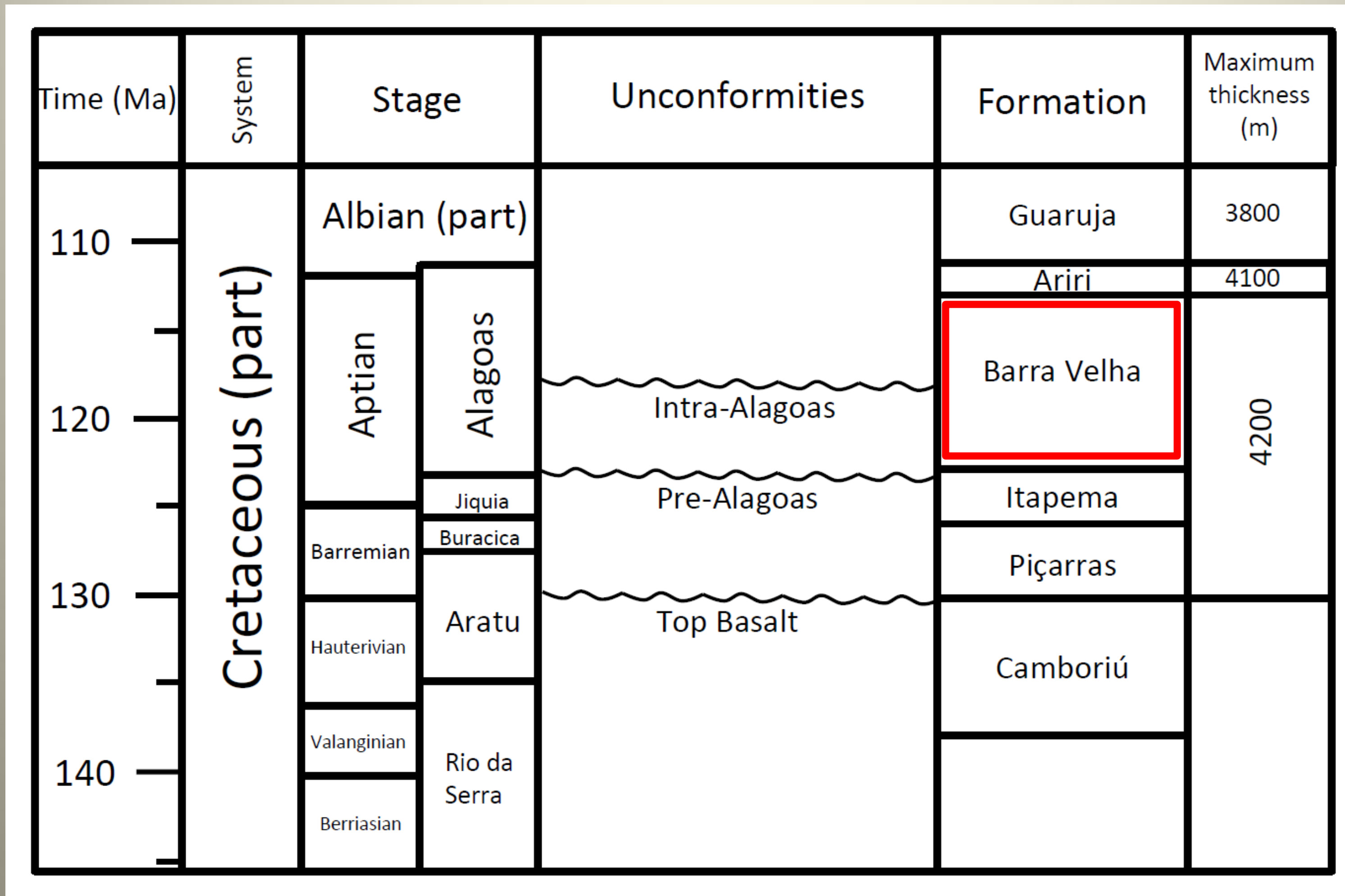
- Evidence for the direct microbial influence on carbonate formation is **extremely limited** so much so as to suggest the carbonates are abiogenic

Whatever explanation is proposed for the Barra Velha facies, it must address the fact that these non-marine carbonates are thick and are associated with a distinct and limited range of non-carbonate minerals. To date no analogues have been reported outside of contemporaneous South Atlantic basins.

If they had a **simple** origin – such as being just microbial, we should see other examples in the stratigraphic record.

There must have been something really unusual about some of the early Cretaceous closed system South Atlantic basins and we propose it was a unique interaction of carbonate and Mg-silicates in hyper-alkaline shallow lakes.

Early Cretaceous stratigraphy of the Santos Basin



(after Moreira et al. 2007, *Boletin Geociencias Petrobras*, **15**, 531-549.)

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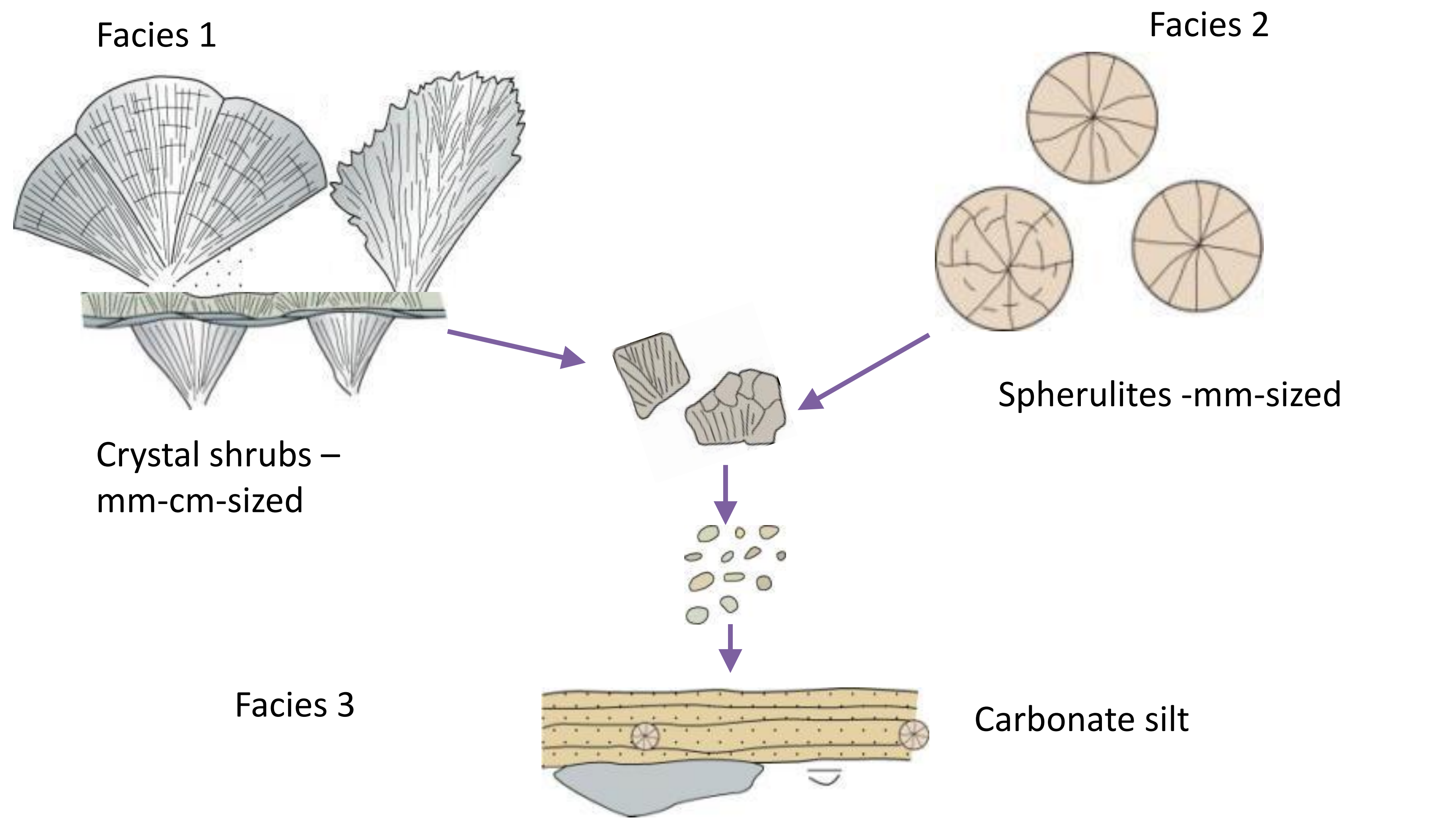
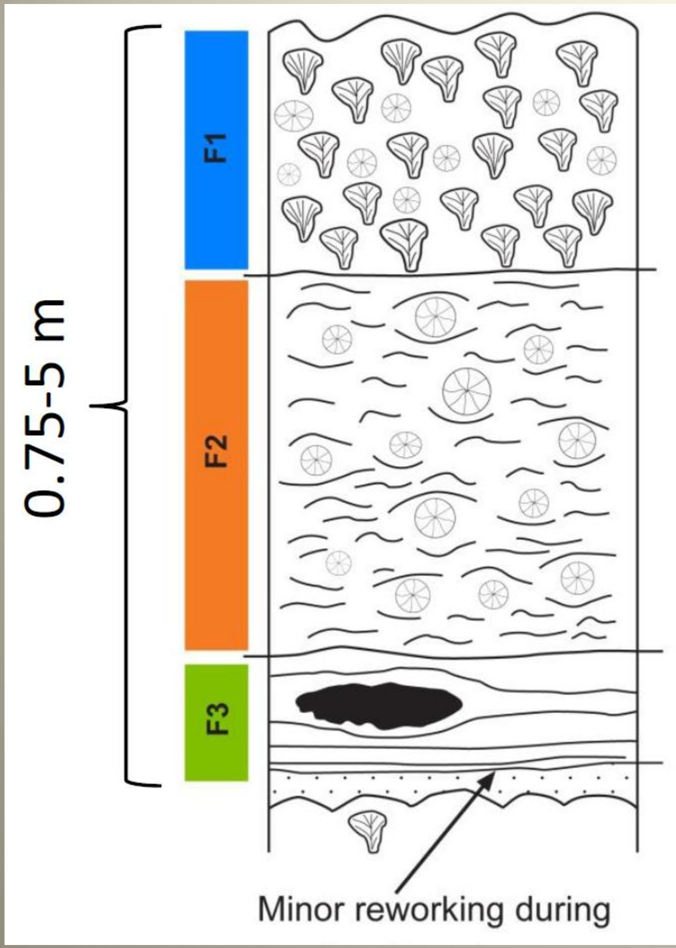
Barra Velha Fm carbonate components



The Cyclothems in the Barra Velha Fm



Facies 1: Crystal shrub framestones, with Mg-silicates or patchy traces of former Mg-silicates

Facies 2: Spherulite floatstones, with Mg-silicates or traces of former Mg-silicate matrices

Facies 3: Laminated calcimudstones with prominent ostracodes and vertebrate debris, early silica nodules

Are the cycles real?

Markov Chain analysis confirmed that facies transitions are non-random (facies are dependent on preceding facies)

And microbial structures?
How rare?

- microbial macrostructures which resemble classical stromatolites are rare (<0.5% of thickness of logged sections)
- as are microbial planar laminites (<1%)
- and oncoids (<0.1%)
- Microbial microstructures are very rare with as few as 0.05 to 0.1% of shrubs showing features such as microbial filament moulds

Origin of the shrubs –

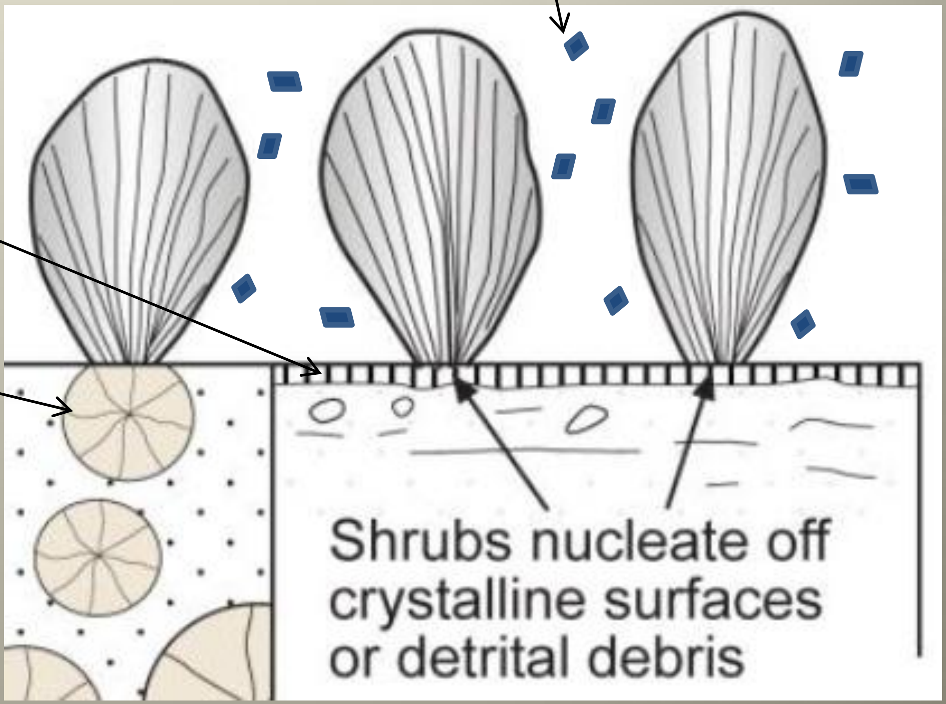
The shrubs closely resemble crystal shrubs (not bacterial shrubs) described from many travertines (thermal springs). This does not imply that thermal waters were involved in the precipitation of the Barra Velha Fm. shrubs but that like those in modern thermal springs, rapid precipitation occurred causing such effects as split-crystal growth. The lack of biotic features suggests largely abiotic origin.

Nucleation of crystal shrubs

The shrubs nucleated from thin fibrous crystal sheets, but also off spherulites as their growth became more asymmetric at some horizons

For images of shrubs from the Barra Velha Fm see Terra et al. (2010) Figs 16b,c; 17b,c and Dias (2005) Figs 9a & b.

“floating “dolomite rhombs

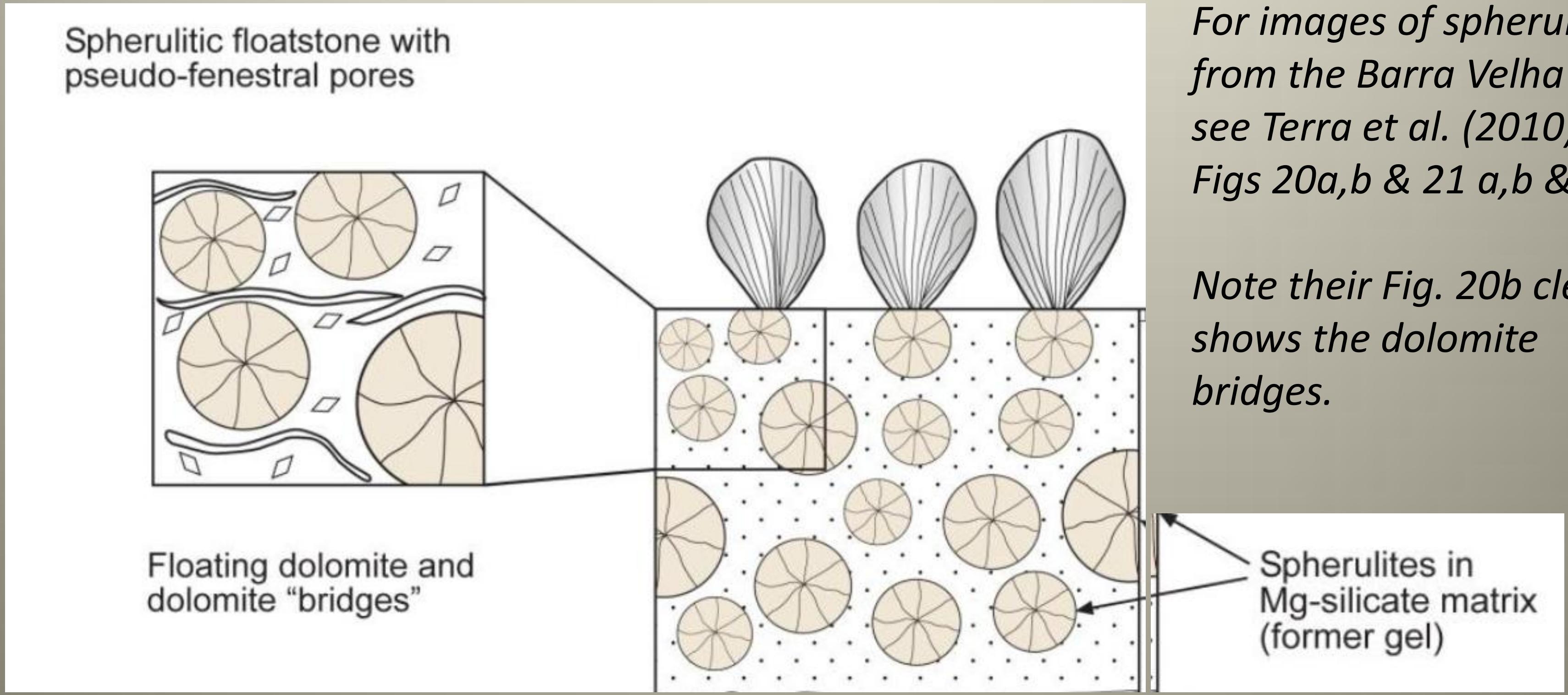


Spherulites with Mg silicate and dolomite matrices +/or pseudo-fenestral porosity

Spherulites, unless reworked, occur in two *in situ* associations:

1. Loosely packed in Mg-silicate matrices
2. In floatstone textures with the spherulites surrounded by porosity resembling fenestral porosity but associated with dolomite bridges.

In both cases a striking features is the presence of loosely arranged ("floating") dolomite rhombs.



For images of spherulites from the Barra Velha Fm see Terra et al. (2010) Figs 20a,b & 21 a,b & c.

Note their Fig. 20b clearly shows the dolomite bridges.

Origin?

Spherulitic carbonates are common features in microbial mats but are several orders of magnitude smaller than those seen in the Barra Velha

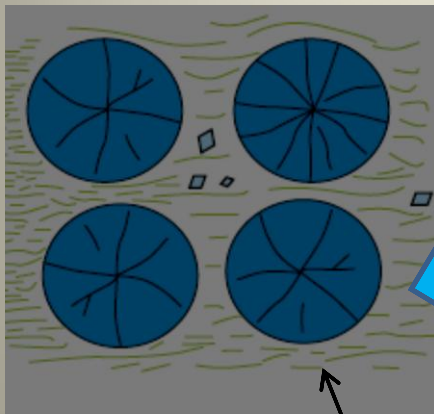
Spherulitic growth can be abiotic, and is favored by high levels of Mg and silica in highly alkaline solutions, coupled with rapid calcite crystal growth, in viscous media, with or without any microbial influence

The proposal is that the spherulites grew “floating” in a Mg-silicate gel associated with dolomite, from highly alkaline waters

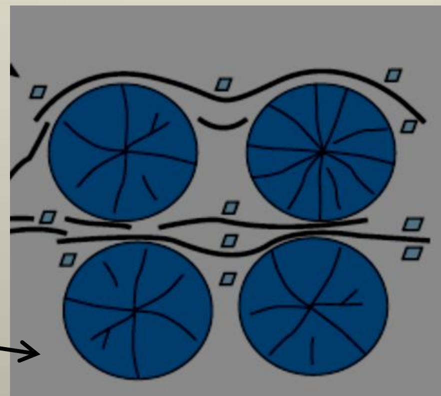
The silicates were later dissolved leaving the pseudo-fenestral porosity and dolomites bridges and rhombs.

Growth of spherulites in Mg-silicate gel, precipitation of dolomite rhombs in gel or between clay particles

Terra et al. (2010) Fig. 20b clearly shows the dolomite bridges and pseudo-fenestral porosity

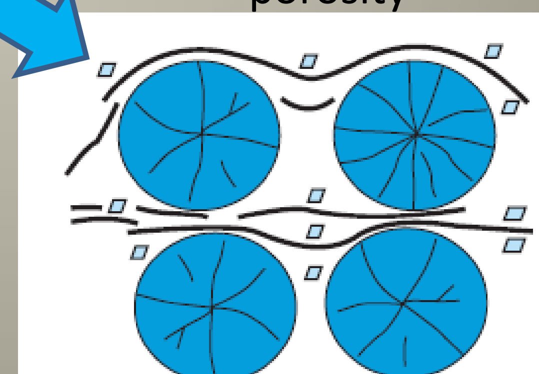


Gel matrix



Clay matrix

Decay of Mg-silicates to leave pseudo-fenestral porosity



Formation, after some compaction, of “dolomite” bridges producing pseudo-bindstone texture

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Facies 3 – laminated calcimudstones

•Laminated carbonate muds, composed of a fine detritus of spherulites and shrubs. They commonly contain prominent concentrations of ostracode carapaces, fine vertebrate remains and early silica nodules. Terra et al. (2010) Figs 23a,b show this facies.

Depositional origin of Facies 3:

•Detrital, finer grained - lower energy, deeper (lakes commonly have shallow wave base cf marine basins)

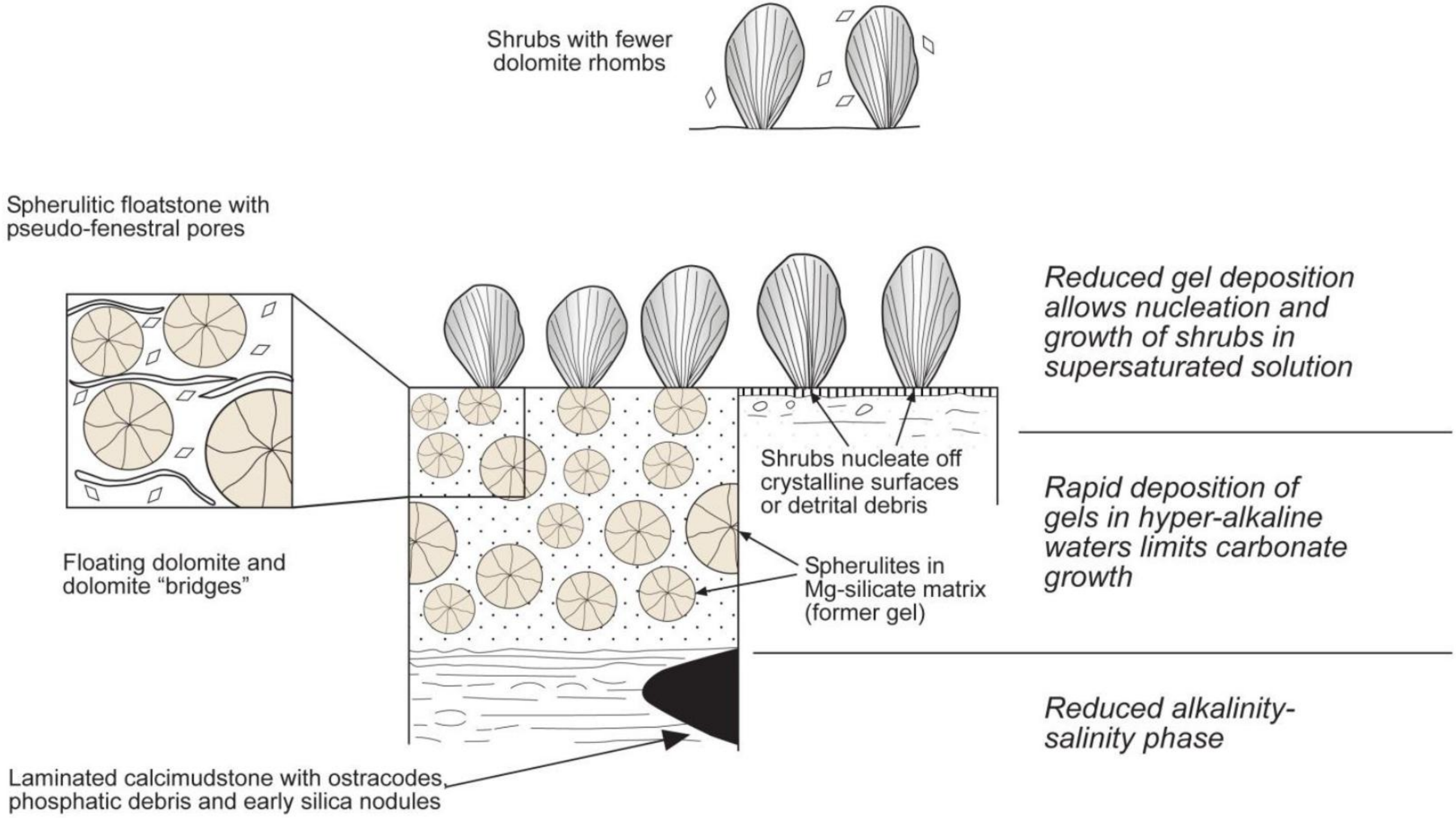
•Elevated concentrations of ostracodes suggest lowered salinities/alkalinities

•Influx of phosphatic debris - vertebrates invade during lowered salinity/alkalinity phases

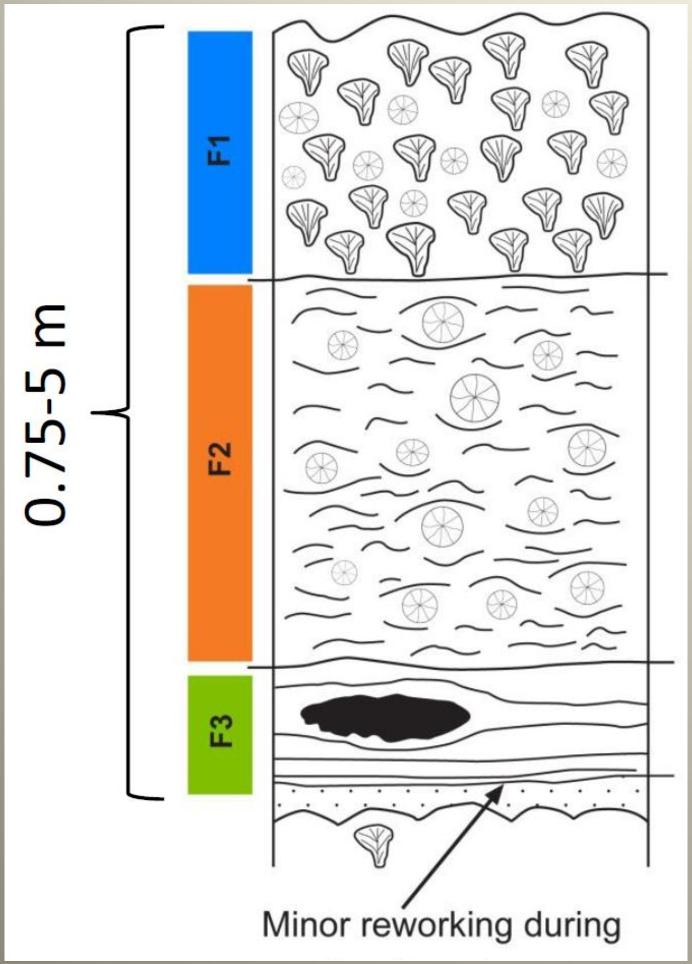
•Early silica nodule growth suggests lowered pH triggering silica precipitation

= influx of fresher waters, pluvial event, lake deepens, shoreline transgression

Textural "model"



Interpretation of the Cyclothems in the Barra Velha Fm



Facies 1: Crystal shrub framestones; rapid formation from probable low Mg/Ca fluids; some microbial influence? Lower rate of gel deposition

Facies 2: Spherulites floatstones with Mg-silicate matrices ; Mg silicates require pH >9,. Spherulites produced in Mg-silicate gels. Mg & Si rapidly depleted.

Facies 3: Laminated calcimudstones with prominent ostracodes and vertebrate debris, early silica nodules – flooding phase; reduced alkalinity-salinity allows influx of ostracodes and vertebrate nesting; also triggers silica precipitation as pH drops

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