BACTERIAL ORIGIN OF SELECTED PHANEROZOIC RED CARBONATE ROCKS

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THE PROBLEM...

PIGMENTATION ORIGIN?

detrital biological chemical
Red limestones are rare but precious …

- **griottes** Devonian S-France, Viséan N-Spain
- ‘**red marbles**’ Devonian (Frasnian), Belgium
- **Ammonitico Rosso** Jurassic, N-Italy, S-Spain
- ‘**red marble**’ Devonian, Czech Republic
- **red condensed series** Devonian, Morocco
- **red lenses in slope** Carboniferous, N-Spain

*cathedrals, castles, Versailles, Trianon*…
... how can we explain the red colour that made the stone so scarce?

XVIIIth-XIXth centuries: red = iron (Delhaye, 1908)

- the iron is detrital (Reijers, 1985), transported from the continent, then mixed with the carbonate matrix during sedimentation...
- its concentration and degree of oxidation produce colour variations (reddish)

Later on (1964-1988)

A relation between ferruginization/palaeogeography/climate is the fashion: washed equatorial laterite soils provide great quantities of iron oxides... thus the red limestones are used as palaeoclimatic indicators!
oxygenation degree? (in non clastic rocks)

- red limestones are found in oxidized facies
- green limestones indicate reducing conditions
  both indicate shallow waters

red silicified limestones (lydites)
indicate deep environments
with minimum amounts of iron and oxygen!
... but they are not reduced...
the Fe content of red limestones of biotic origin is comparatively low 1 to 2 %, often < 1 %

...therefore this content is not responsible of the coloration
There is no direct relation between oxygen content and overall iron oxidation...
Thus the colour is not necessarily linked to shallow water marine environments where oxygen is abundant
sedimentation is in a NORMAL OPEN MARINE facies

red limestones are formed in calm environments, with low levels of oxygen
Iron bacterial filaments on a shell (photonic microscopy)

Filamentous iron bacteria (TEM)  
F = Fe
Inner = ferric iron deposits

Intermediate = bacteria heavily incrusted with Fe deposits

Outer layer = bacteria non incrusted poorly or with Fe deposits

more Recent examples

Montacuta ferruginosa

Gillan 2001
In the Phanerozoic

inframicrometric hematite crystals coating bacterial filaments

Italian Ammonitico Rosso Jurassic
Italian Ammonitico Rosso Jurassic
Italian Ammonitico Rosso Jurassic

benthic bacterial mats up to 20%
Microscopic morphologies of the iron constructions

- infillings of original fossil cavities
- calcite replacement of dissolved echinoderm plates
- infillings of bioperforations
- bacterial/fungal filaments
- ‘hedgehogs’ and ‘erythrospheres’
- massive hematite coating around microfossils
- simple or multiple biofilms
- microstromatolites (exogens ou endogens, crenulated or not...)
- oncolites

..... non exhaustive ....
OBSERVED MICROFACIES OF DIFFERENT AGES AND LOCALITIES
CZECH REPUBLIC, LOWER DEVONIAN

20 µm

0.1-0.6 µm

Praguian, Czech R., Mamet et al 1997

0.2 µm

2 µm
Asymmetrical growth of Fe-stromatolites on two sides of an altered echinodermal plate.

The two other sides are devoid of coating.
ANTI-ATLAS, MOROCCO LOWER-UPPER DEVONIAN
Filamentous iron bacteria

Iron encrustation (25-50% Fe)

Sheath

Diameters: 1.5-4 µm

[MEB]
Iron-bacteria
(Siderocapsa-like, Sphaerotilus-Leptothrix-like in the internal sediments of Receptaculites Rochefontaine quarry, Franchimont, Philippeville Massif (Boulvain et al. 2001))
BALEAS GRIOTTES, SPAIN, CARBONIFEROUS

with endostromatolites

and microstromatolites
Infillings of original fossil cavities, biofilms

also bryozoan, gastropods, ostracods, tentaculids ...
SIERRA DEL CUERA, SPAIN, CARBONIFEROUS

Infillings of original fossil cavities, biofilms
SIERRA DEL CUERA, SPAIN, CARBONIFEROUS

Infillings of bioperforations

Brachiopods, Pelecypods, Bryozoans, Foraminifers
Infillings of bioperforations and filaments (‘cactus’)
SIERRA DEL CUERA, SPAIN, CARBONIFEROUS

‘Erythrospheres’
ROSSO AMMONITICO, ITALY, JURASSIC

Microstromatolites-Oncolites

Fe hardgrounds

with dichotomous filaments

Fe hardgrounds

1mm

100µm

25µm
ROSSO AMMONITICO, SPAIN, JURASSIC

Calpionellids

Holothuroid sclerite
ROSSO AMMONITICO, SPAIN, JURASSIC

Holothuroid-Ophiuroid packstone
first conclusion

hematite is not dispersed at random but follows regular patterns...

BIOsediementary pathway?
1. Today they are associated with Fe and/or Mn deposits. $O_2$ and pH values determine the iron solubility in aqueous solutions.

2. The neutrophile iron bacteria are associated with the oxic/anoxic interface - *Sphaerotilus, Leptothrix, Gallionella, Beggiatoa* ...

3. Iron biomineralization is linked to the production of EPS - exopolymeric substances = sheaths or capsules rich in polysaccharides forming the main part of the bacterial mats. The Fe$^{+++}$ is passively precipitated in the EPS of the Recent bacterial films.
Iron bacteria with an Fe++ sheath. The Fe++ ions are oxidized to Fe+++ within the EPS matrix. The 1 to 2 µm thickness is indicated.
in the past, coccoid and bacillar bacteria associated with other microfossils formed mineralized biofilms
MEB observations
X1000, x35000...

• simple and regular filaments
• simple filaments with regular constrictions
• dichotomic filaments with constrictions
• concentrations of regular sphaerules

diameter: \( \leq 2 \mu m \)
with submicronic hematite in the sheath

These morphologies are suggestive of iron bacteria
Irregular filamentous forms (10'µm), sometimes forming a network and associated with spores

These morphs suggest the presence of FUNGI IMPERFECTI
DEEP BASIN

LITTORAL

SWB  FWWB  TALUS  RED CARBONATE ROCKS with IRON-BACTERIA

today ±200m
turbidites

SECOND CONCLUSION

... if iron bacteria are present, iron hydroxides are linked to an oxic/anoxic gradients in poorly oxygenated waters and independent of light
Further diagenesis will transform the micrite into a porous microspar. Iron hydroxides are now hematite.
WHAT TO REMEMBER?
not a curiosity
BACTERIAL FILAMENTS ARE WIDESPREAD
Bajocian, SHP, France, Prétat et al. 2000
FUTURE RESEARCH ...