Hydrocarbon-seep Scenarios in the Western Mediterranean Margin during the Messinian Salinity Crisis: Onland Case Studies from the Italian Peninsula*

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Abstract

Brecciated fabrics extensively affect the carbonate units developed during the Messinian Salinity Crisis (MSC) of the Mediterranean Sea. In our study - a combined sedimentological, textural, and geochemical approach - we investigated the Messinian brecciated bodies in association with some key sections, representative of different geodynamic contexts. The study areas, cropping out in the Italian Peninsula, are located: in the Maiella foreland basin (Central Italy); in the Rossano and Crotone forearc basins (Calabrian Arc); and in the Caltanissetta foredeep basin (Sicily). Brecciation mainly affects microbial mudstones at different stratigraphic levels and always associated with the Messinian Erosional Surface (MES), and gypsum units to a minor extent.

From a sedimentological point of view, breccias variously consist of: patchy concretions, massive buildups and stratified thick bodies. They consist of fabric-retentive mud breccias, devoid of gravity segregation and any preferential distribution. From a textural point of view, they show scale- and lithology-independent patterns. Interestingly, the brecciated bodies are accompanied by fluid migration pathways occurring at various scales of observation. These characteristics clearly point to in situ brecciation phenomena, where hydrofracturing is held responsible for the widespread brecciation. The fluid-driven hypothesis was eventually endorsed by the 13C-depleted values (down to -43.7‰ PDB) yielded by the carbonates, pointing to the occurrence of hydrocarbon-enriched fluids involved in authigenesis, at least to a certain extent.

In view of that, there is no evidence to consider the upper Messinian breccias as a stratigraphic unit. Because the brecciated lithofacies are sealed by Lago-Mare deposits (late post-evaporitic), the age of this process is constrained to the early post-evaporitic phase.

By considering the different geodynamic settings of the investigated basins, we rule out a common tectonic trigger. Conversely, we suggest the major drawdown of the Mediterranean Sea recorded by the MES as the primary trigger for fluid migration: the high depressurization experienced by the sedimentary column after the removal of at least 1 km of water column, likely favored a catastrophic migration of

overpressured fluids from below. Similar data and interpretations, already suggested in the Tertiary Piedmont Basin, SE Spain and Northern Morocco, point to a regional extent of the event, that conceivably occurred throughout the Western Mediterranean margins in Messinian times.

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Hydrocarbon-seep scenarios in the Western Mediterranean Margin during the Messinian Salinity Crisis: onland case studies from the Italian Peninsula

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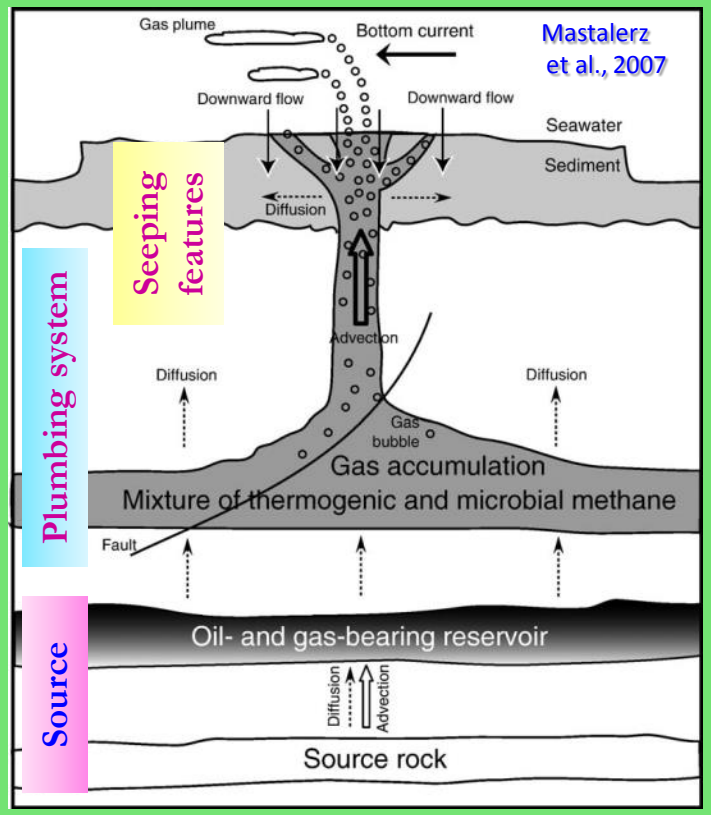
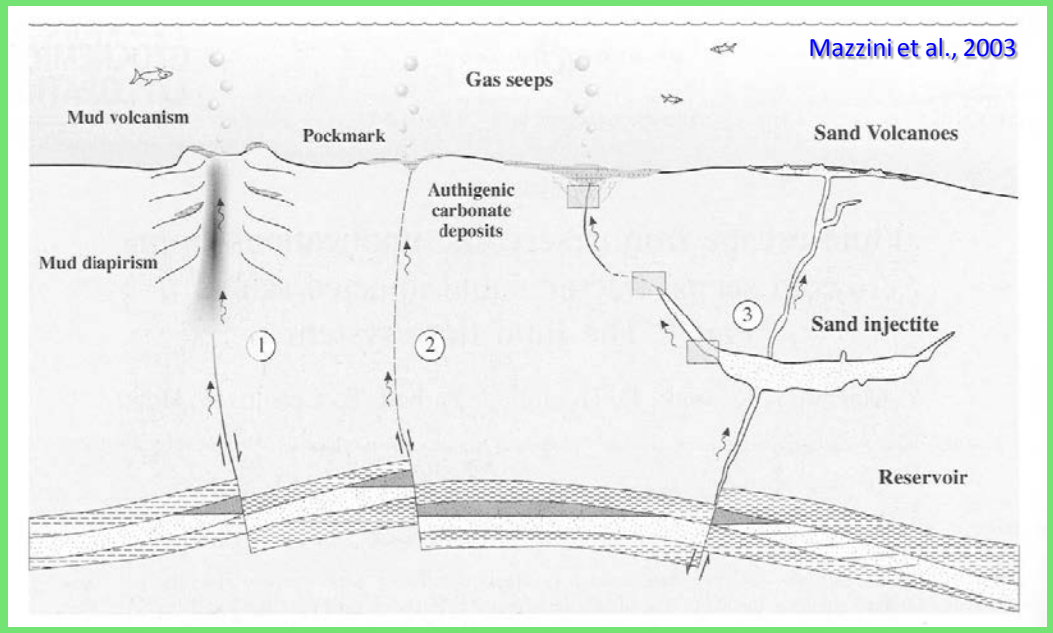
Paleo HC seeps

Submarine cold seeps refer to the seepage and venting of fluids involving gas, water and sediments (Taludaker, 2012)





What we look for in the geological record

Seafloor

Seeping features

- Chemoherms
- Pavements
- Slabs
- Boulder fields
- Polygenic chaotic breccias

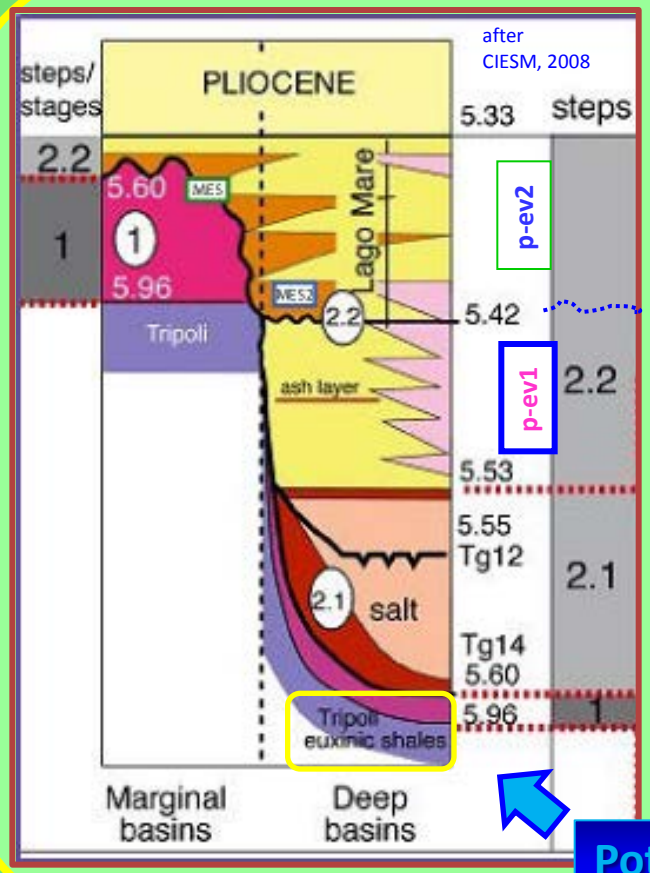
vs

Subseafloor

Plumbing system and Seeping features

- Chimneys
- Monogenic autobreccias
- (mega)concretions *devoid of chemoherms!*

The MSC "ingredients"



Potential source

Upward increase in continental water influxes and diffusion of Lago-Mare biofacies

Upper Evaporites (5.53 – 5.33 Ma)

2.2

Resedimented Evaporites (5.60 – 5.53 Ma) *

2.1

Brecciated Limestones (*Basal limestone*); clastics and salt in the deepest basins

MES

Lower Evaporites (5.96-5.60 Ma)

1

Potential trigger

Product of fluid seepage? WORKING HYPOTHESIS

*5.5320 ± 0.0074 Ma (Cosentino et al., 2013)

Breccias and basal limestones

The origin of the Brecciated Limestones is controversial; they are interpreted as:

A. An autobrecciated lithofacies of the Basal Limestone, that is composed of stromatolitic carbonates marking the onset of the crisis (*McKenzie, 1985; Decima et al., 1988; Pedley & Grasso, 1993; Guido et al., 2007*)

B. Resedimented breccias related to mass-wasting processes developed in the early post-evaporitic environment (*CIESM 2008; Manzi et al., 2010*)

Proposed triggers for brecciation in the Basal Limestone formation

A. doline collapse of lime mudstones during exposure to meteoric waters by dissolution of evaporitic minerals *(Pedley & Grasso, 1993 and ref. therein; Rouchy & Caruso, 2006)*
IN SITU BRECCIATION

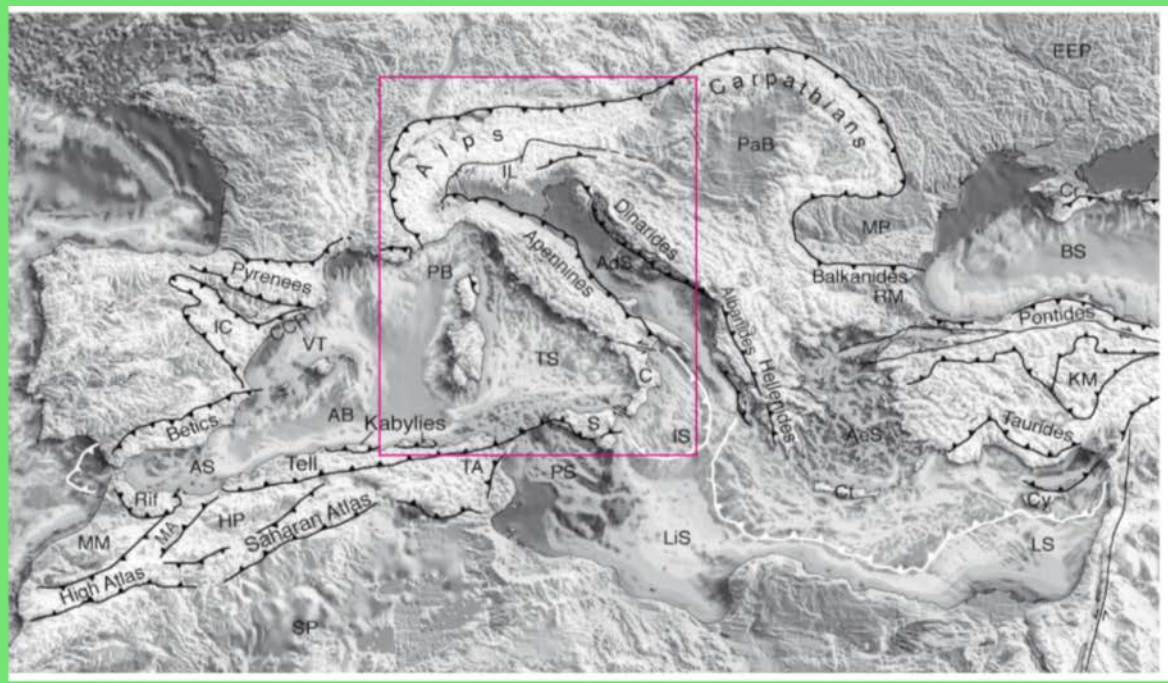
B. early erosion and sedimentation processes → mass-flow deposits *(Manzi et al., 2010)*
SECONDARY BRECCIATION

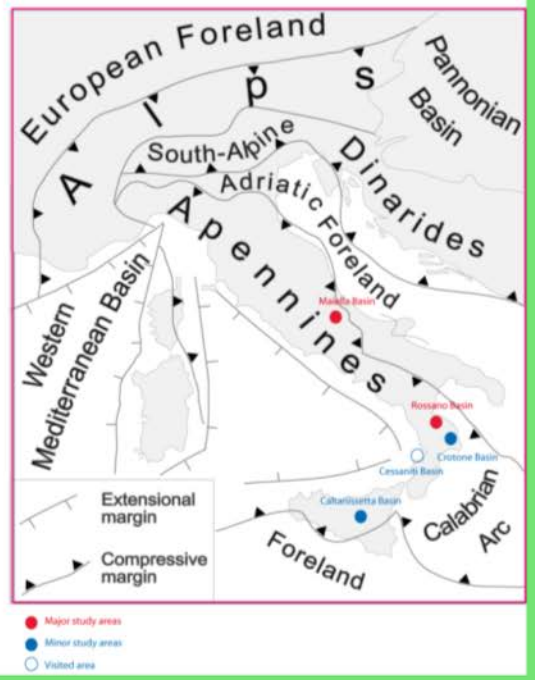
C. fluid-assisted brecciation *(Ryan, 2009; this study)*
IN SITU BRECCIATION

Sedimentological, textural and geochemical approach ($\delta^{13}C$, $\delta^{18}O$)

- ✓ Do the Brecciated Limestones represent the record of HC seepage?
- ✓ Trigger?
- ✓ An outcrop perspective in the study of cold seeps

Case studies





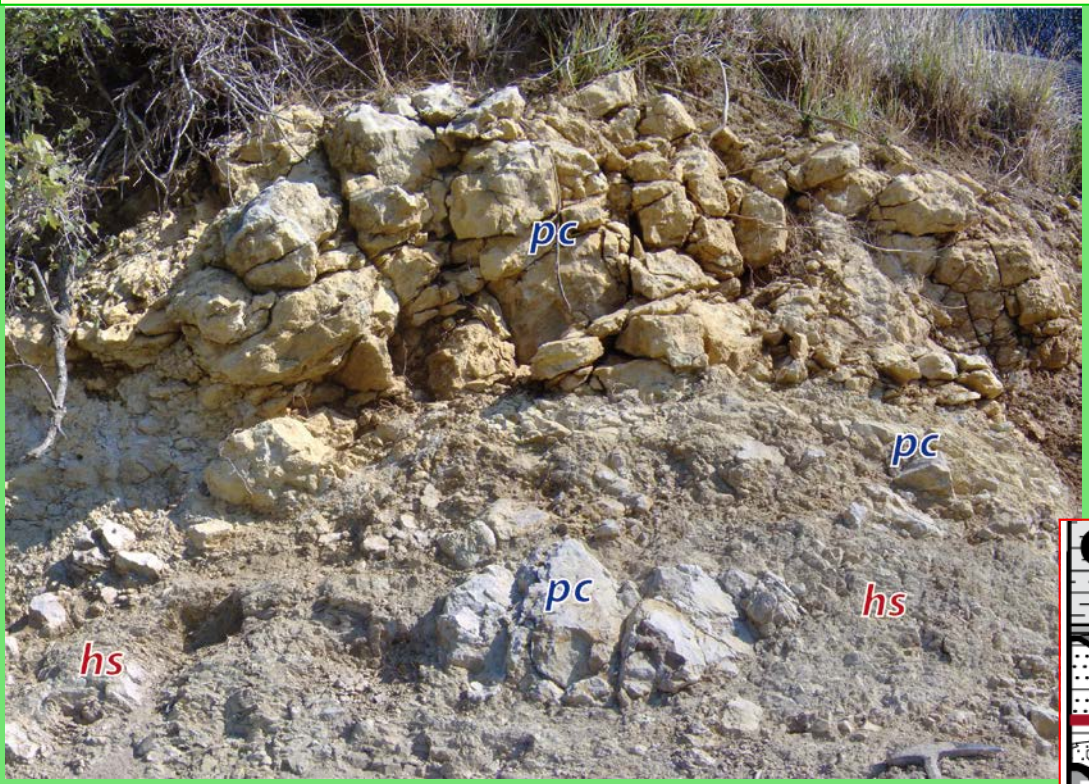
Different geodynamic settings in Messinian times

- **Maiella Basin**: marginal and shallow basin belonging to the Apulian **foreland** domain

- **Calabrian Arc** : **forearc** basins, that experienced a middle Miocene to middle Pleistocene regional NW-SE left-lateral strike-slip tectonic event (*Tansi et al., 2007*)

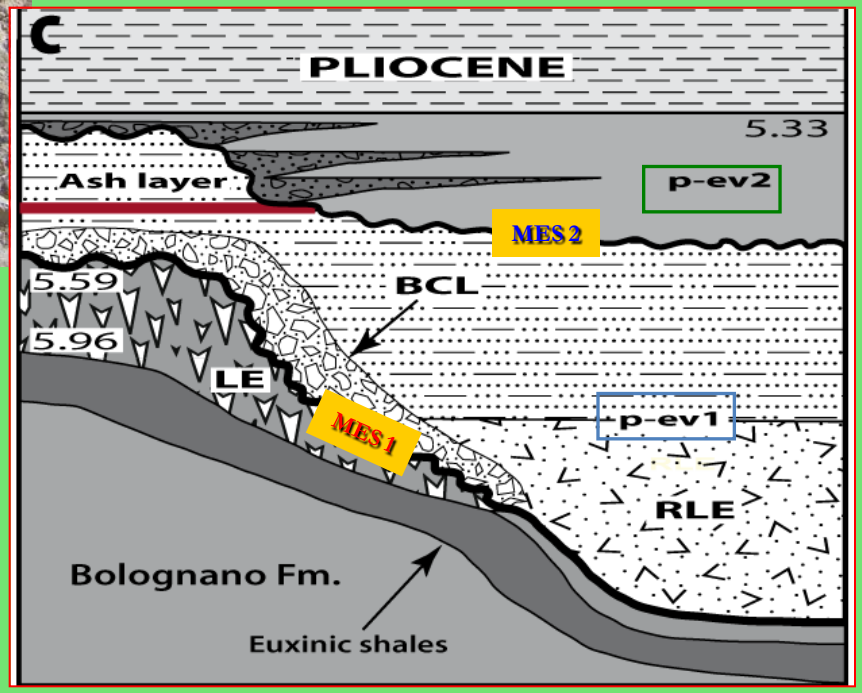
- **Caltanissetta Basin**: thrust-related synclines separated sub-basins of the main **foredeep** (*Butler et al., 1995*)

Maiella HC seep area



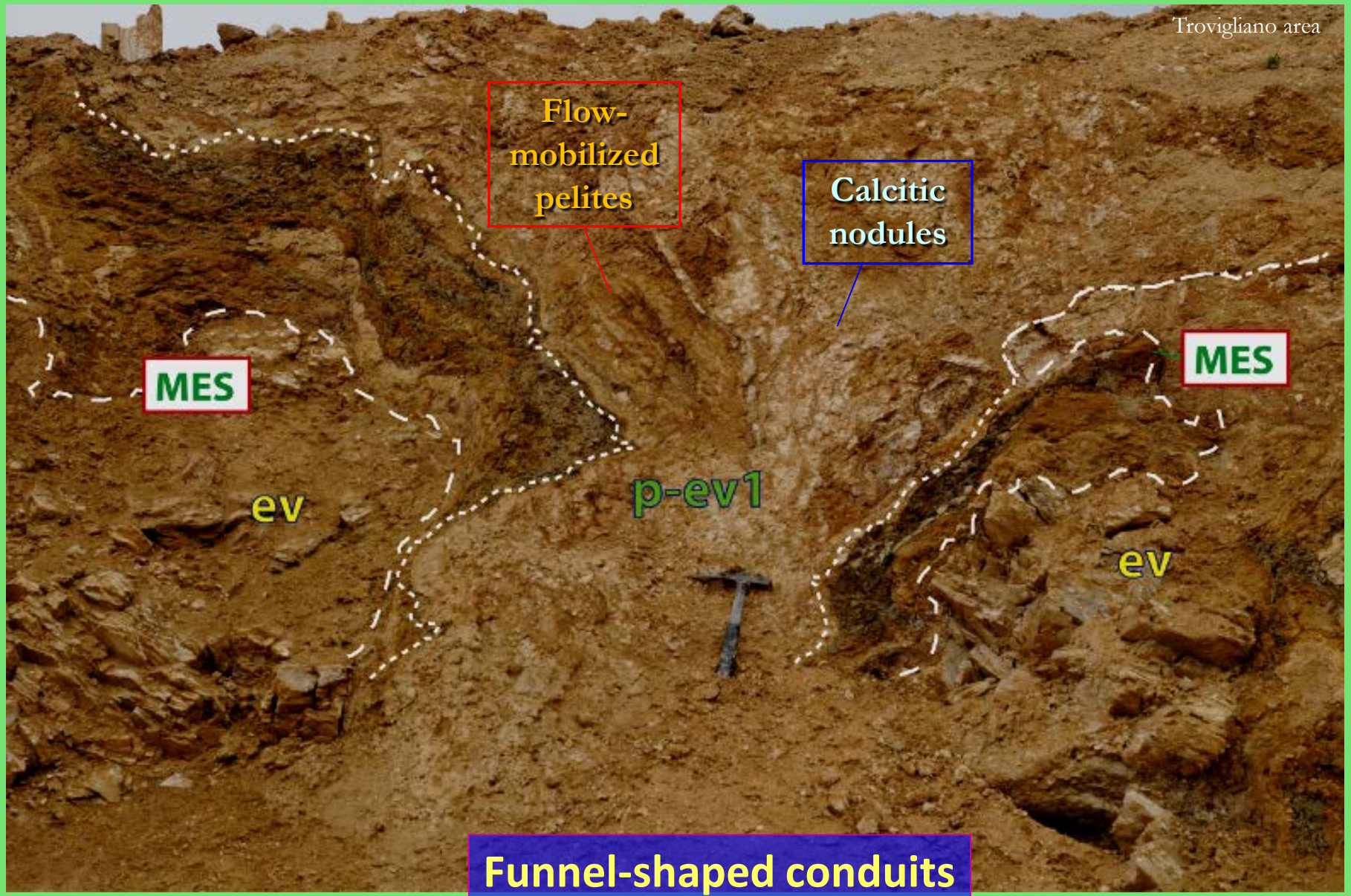
Patchily distributed authigenic limestones

- Major brecciated buildups: bedding-retentive breccias, devoid of gravity segregation and any preferential orientation
- Minor patchy breccias and concretions (pc) embedded in fossil barren marly-pelitic host sediment (*hs*)

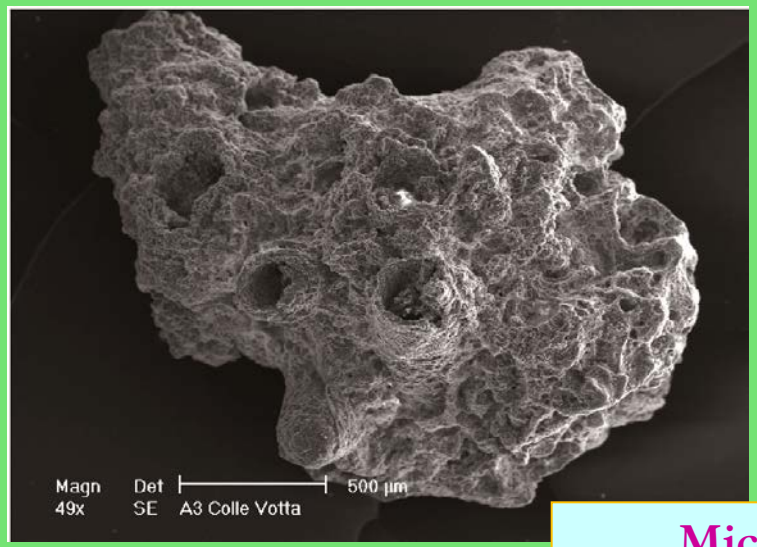


Iadanza et al., submitted

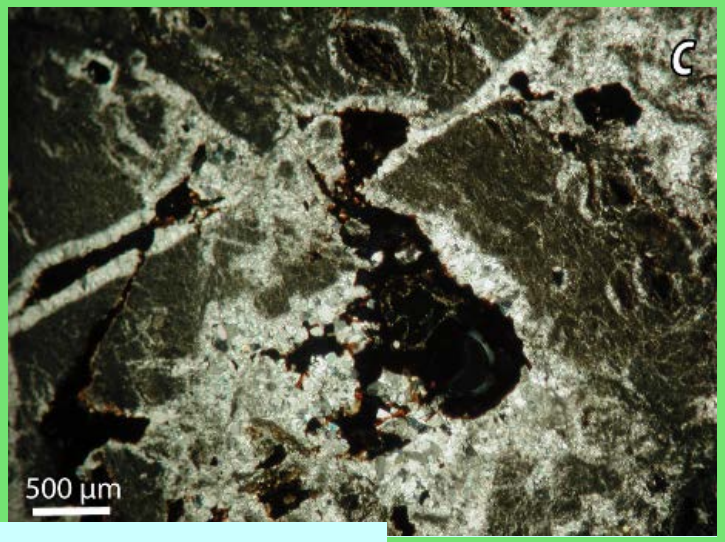
Maiella HC seep area



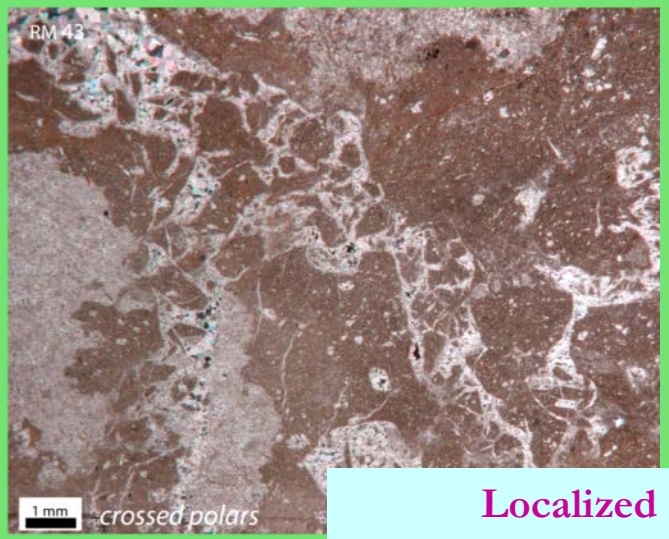
Maiella HC seep area



Micropipes



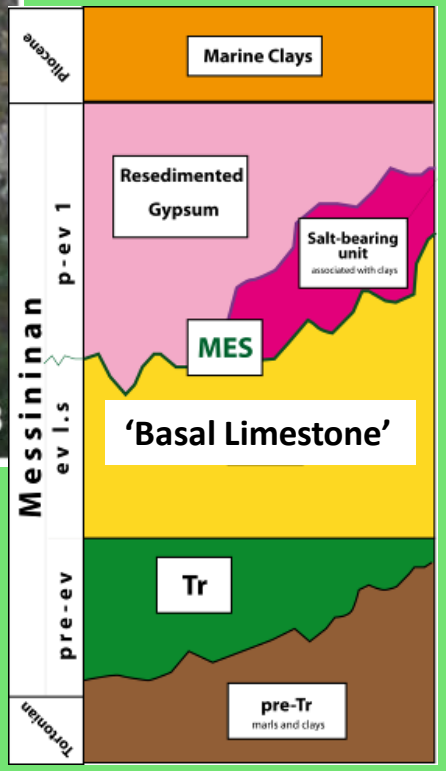
Tar micro-injections
fluidal microbial textures



Localized microbrecciation

Crotone and Rossano basins

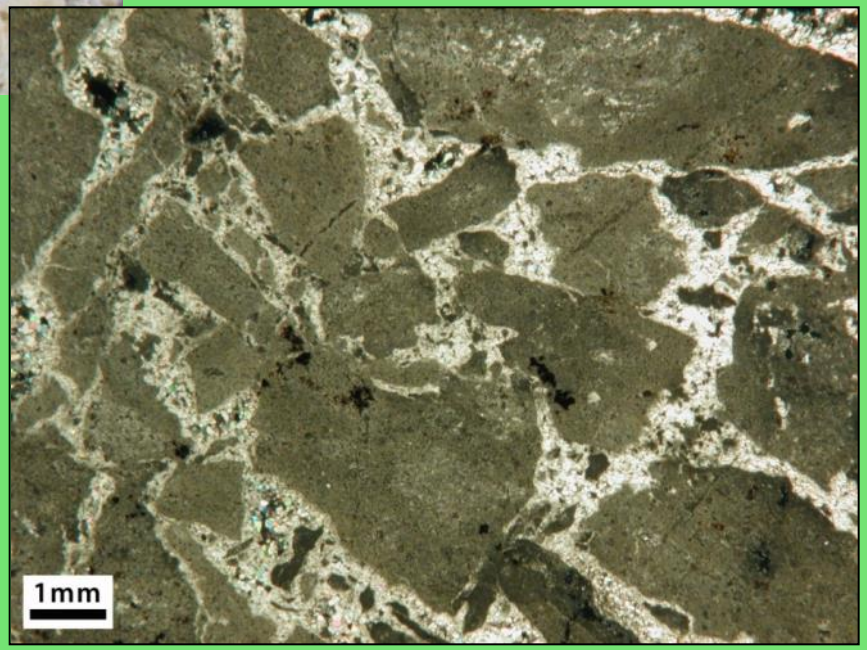
Alternation of thick-bedded massive carbonate beds and pelitic horizons



Breccias pass from a bedding-retentive pattern to a completely chaoticized fabric

Crotone and Rossano basins

Mosaic breccia

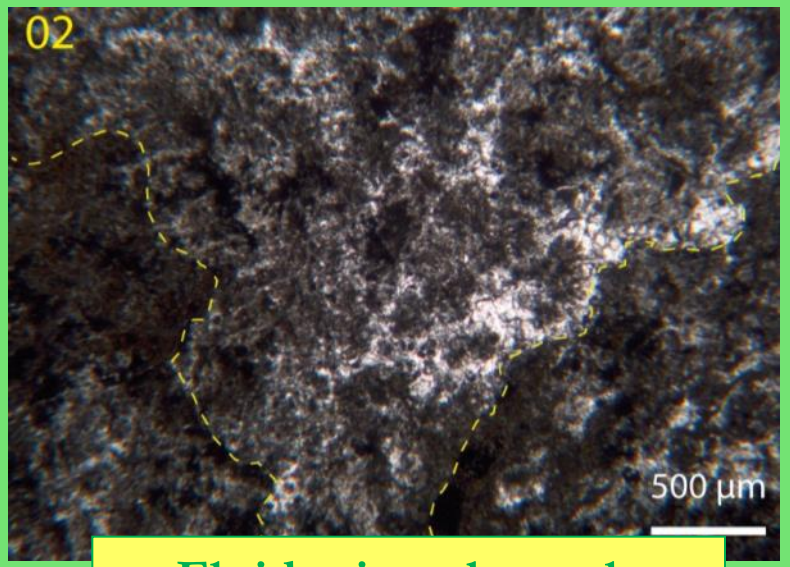


Jigsaw-like microtexture

Crotone and Rossano basins

Fluid migration meso-structures

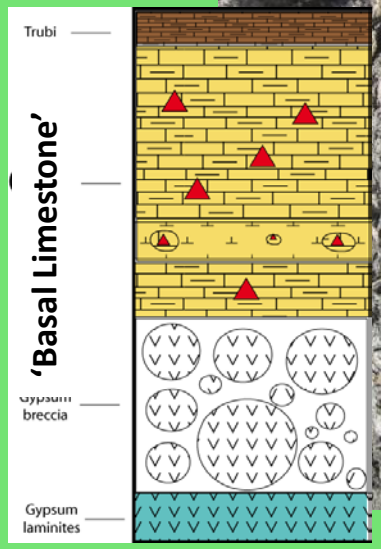
Flow-mobilized clotted peloidal microbialite



Fluid microchannels

Caltanissetta Basin

Massively stratified brecciated limestones, at places sulphur-bearing limestones



Caltanissetta Basin

Metric-scale chimney-like structure

Caltanissetta Basin

Cross-cutting relationships in silica-bearing limestones

Caltanissetta Basin

cylindrical concretions
(cm-scale pipes?)

fluidized concentric structures in gypsum
top view

Caltanissetta Basin

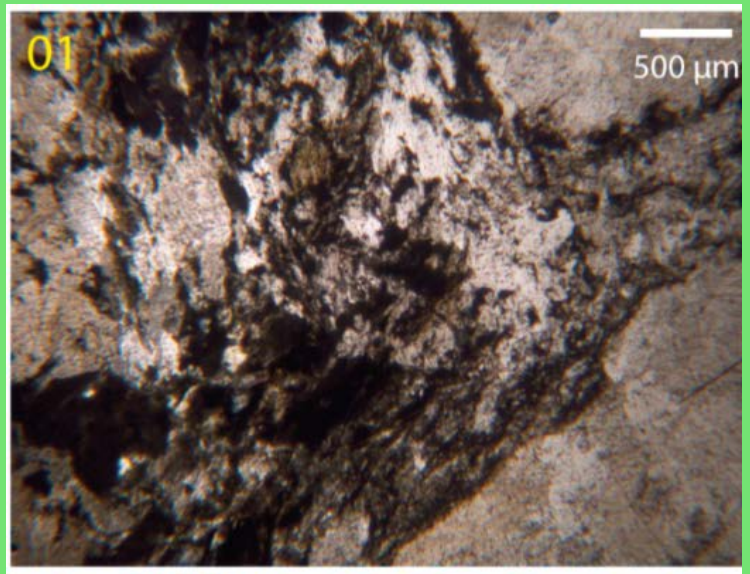
Different autobreccia types

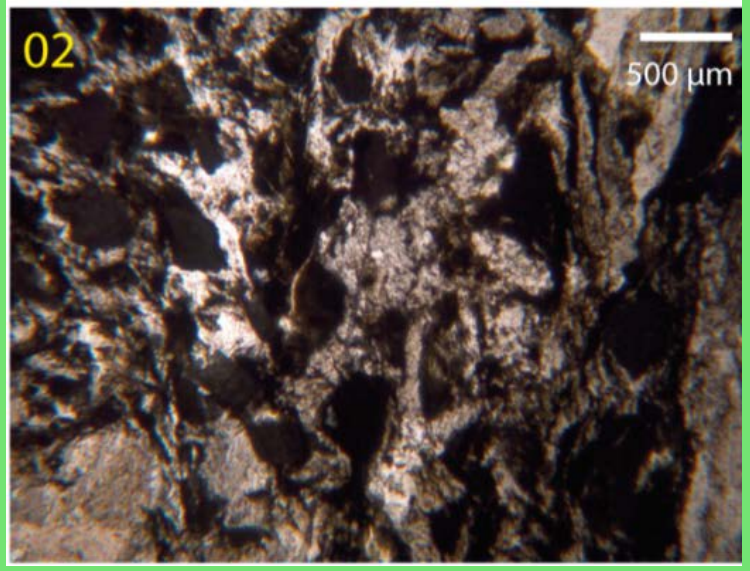

chimney type


massive

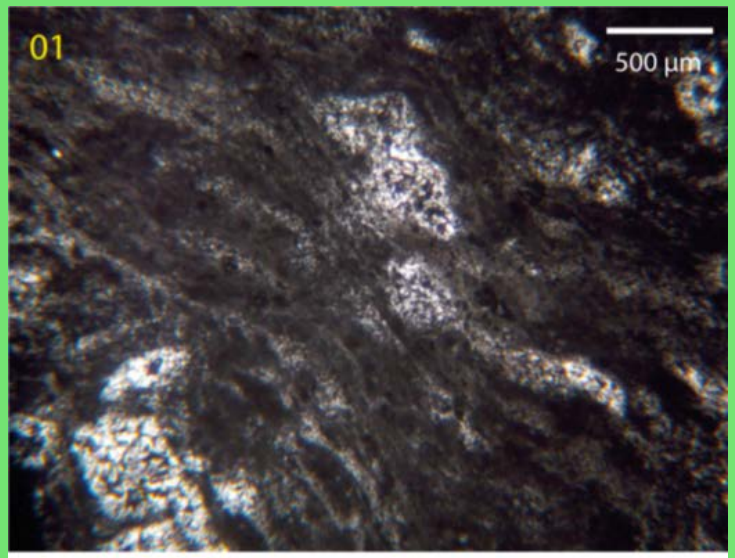

massively stratified

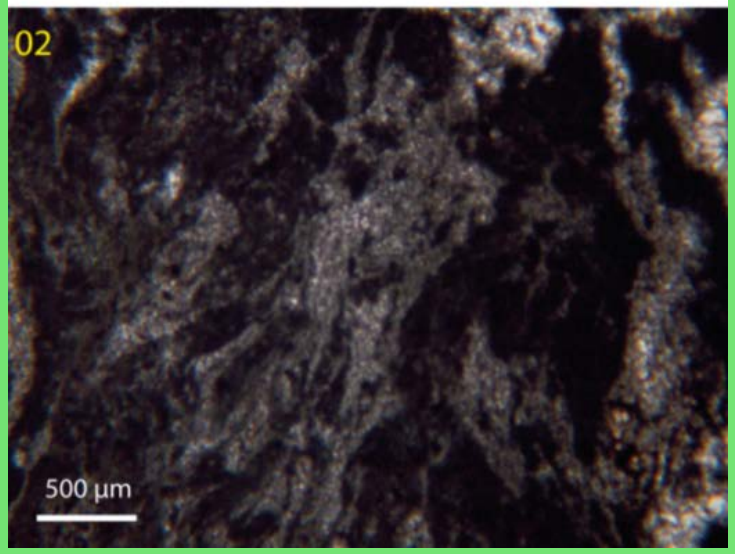
Caltanissetta Basin





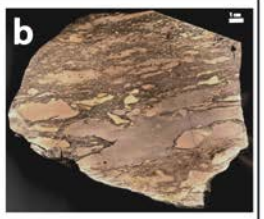
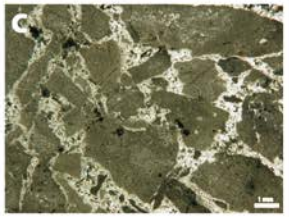
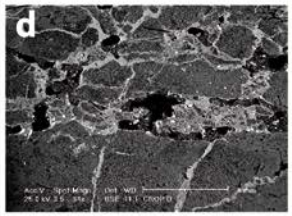
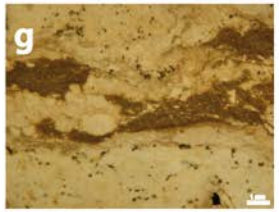
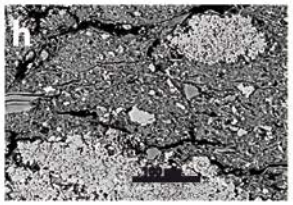
Gypsum - autobrecciated microtexture



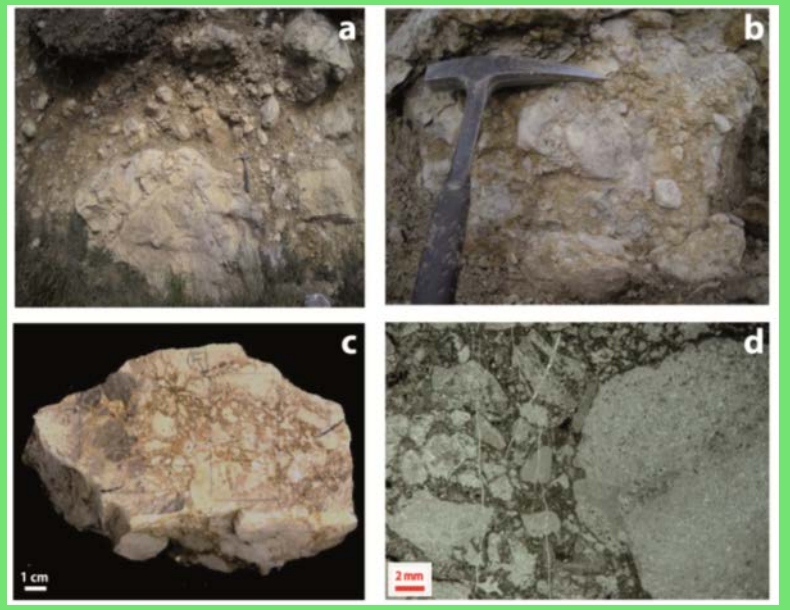


Flow-mobilized microbialite

Scale-independent fabric

Scale / Feature	OUTCROP	HAND SAMPLE	THIN/THICK SECTION	SEM view
BRECCIAS				
NODULES				

Rossano Basin



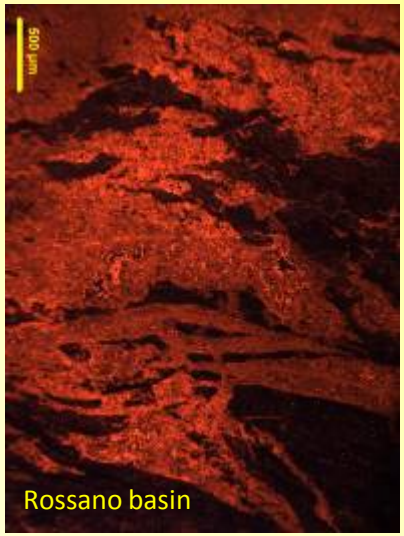
Maiella seep area

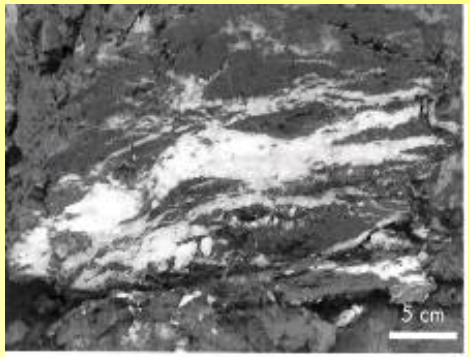
Lithology-independent brecciation

Brecciation in pelitic horizons
Rossano Basin

Autobrecciated Gypsum
Caltanissetta Basin

Fabric resembling GH-bearing sediments

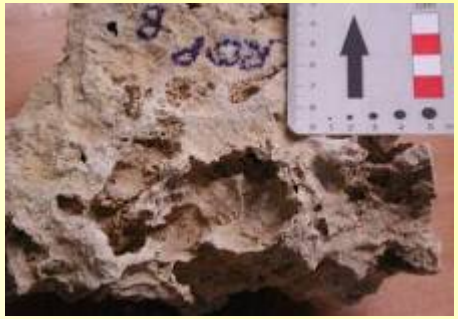




Photograph of pure white gas hydrate layers (containing >97% methane) infilling clayey sediment from Hydrate Ridge, on the Cascadia convergent margin off Oregon. (Courtesy of Erwin Suess and Antje Boetius.)

Former hydrate infilling clayey sediment?

Former hydrate-bearing moussy sediment?



Layered cement infillings *vs* gas hydrate infillings

MSC and seep-related geobodies

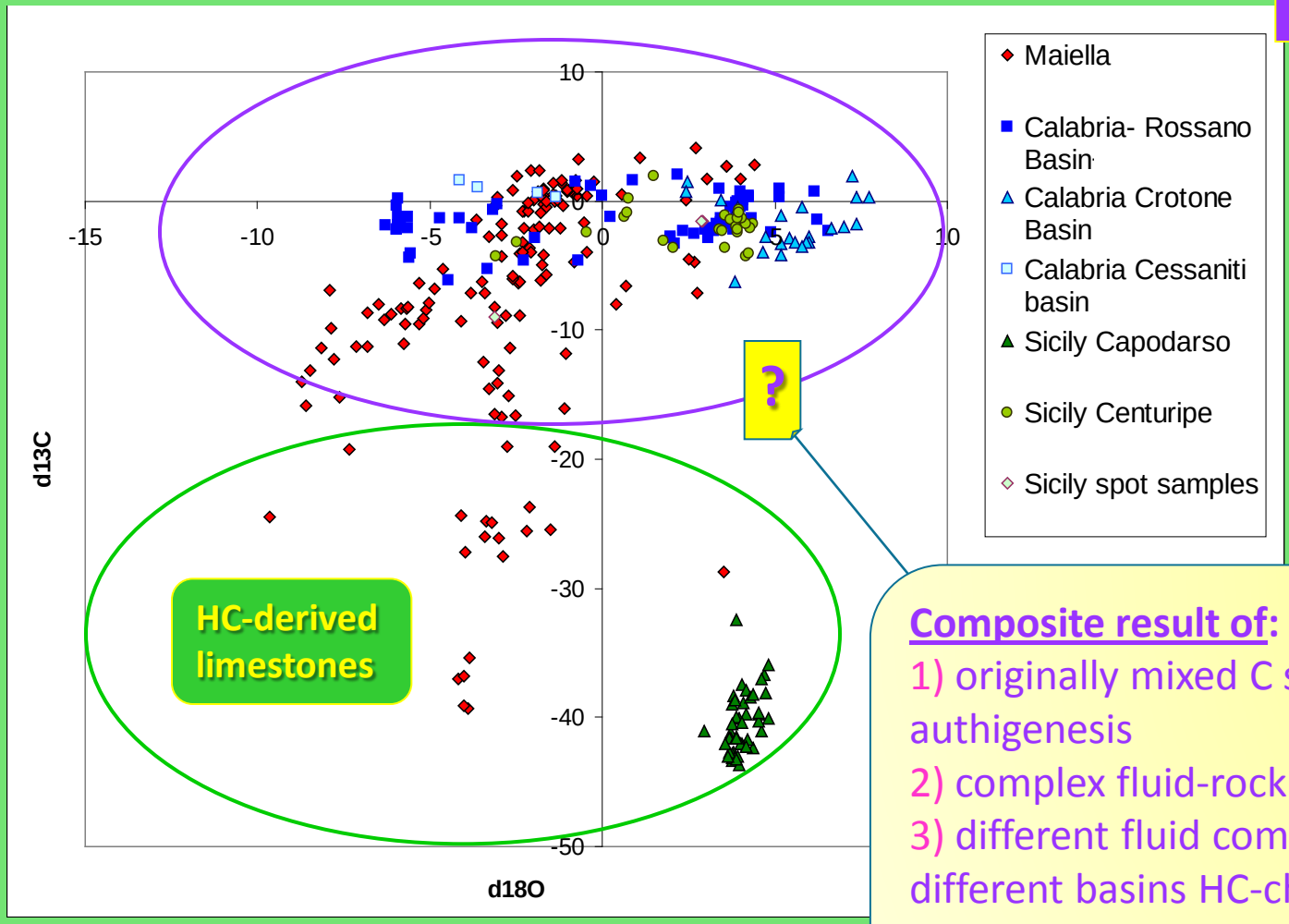
Textural patterns → Fluid-induced proxies

Primary fabric overprinting	In-situ brecciation (autobreccias)
Breccias showing jigsaw-like texture and scale and lithology - independent fabric	Overpressured fluid-permeated muddy sediment HYDROFRACTURING
Fluid migration pathways: cemented chimneys and micropipes v*s* feeder channels and flow-mobilized sediments	Sediment-prone *vs* mineral-prone seeps (sensu Roberts, 2001)
Fabric resembling gas-hydrate-infilling sediments	Gas Hydrates dissociation (?)

Geochemistry

Two "Mega-Ranges"

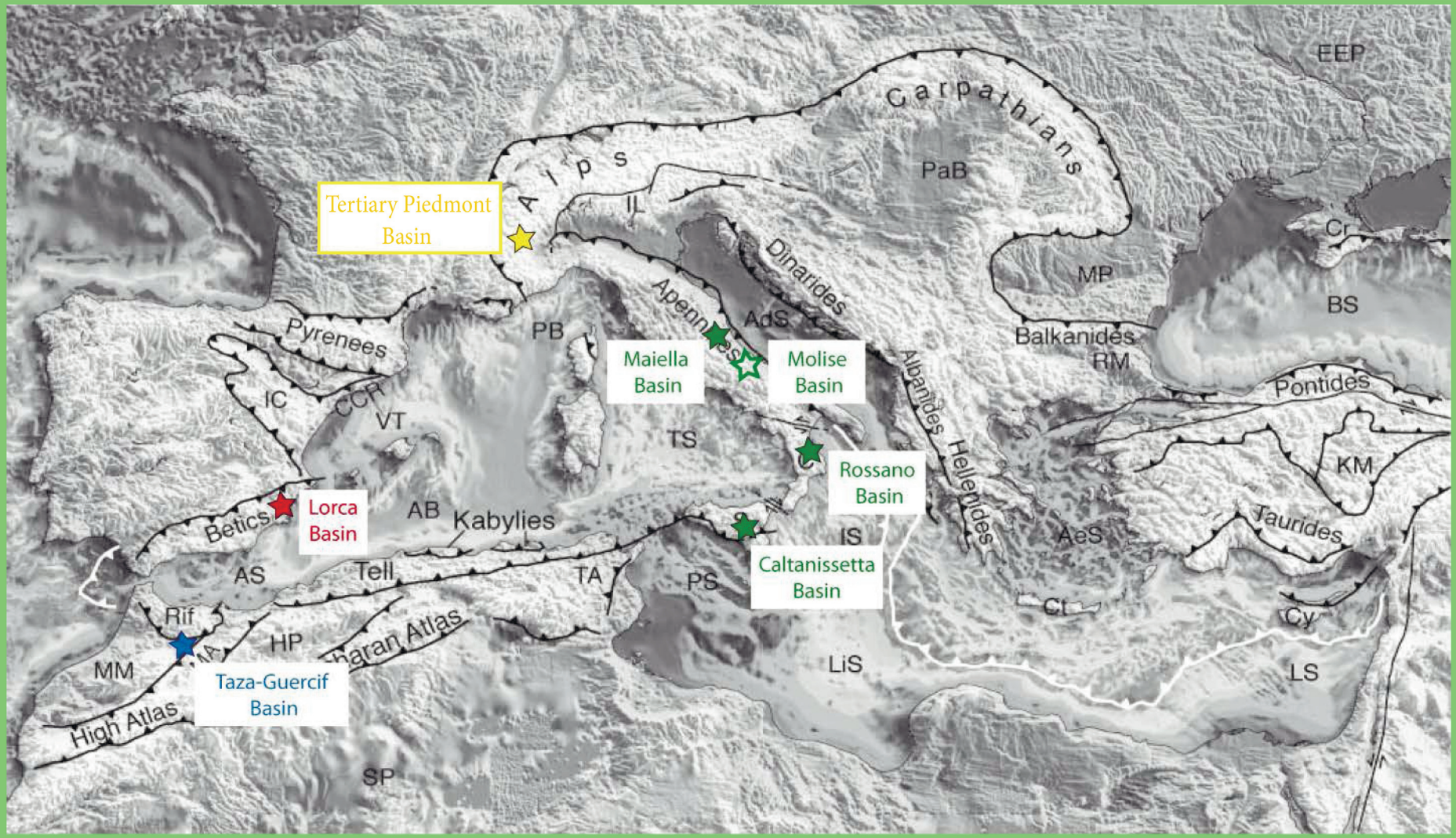
The nature of the fluids involved and the degree of fluid-rock interaction can be significantly different in each case study



Composite result of:

1) originally mixed C sources involved in authigenesis
2) complex fluid-rock interaction
3) different fluid composition in the different basins HC-charged *vs* saline(?)
4) Biodegradation of crude oil?

Western Mediterranean…



Pierre et al., 2002

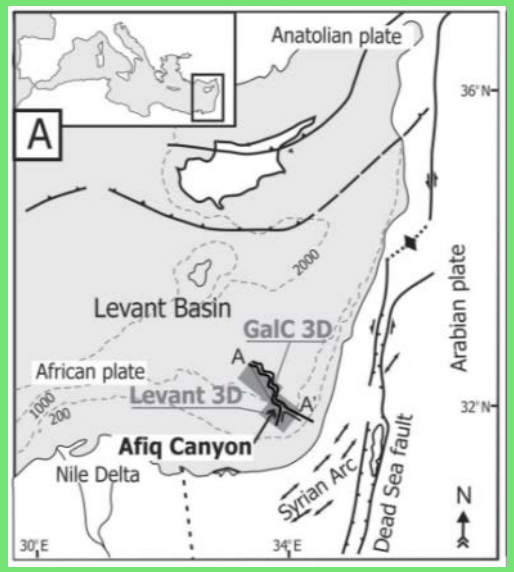
Pierre & Rouchy, 2004

Clari et al., 2009; Martire et al., 2010; Dela Pierre et al., 2010

present study; Iadanza, 2011; Iadanza et al., submitted

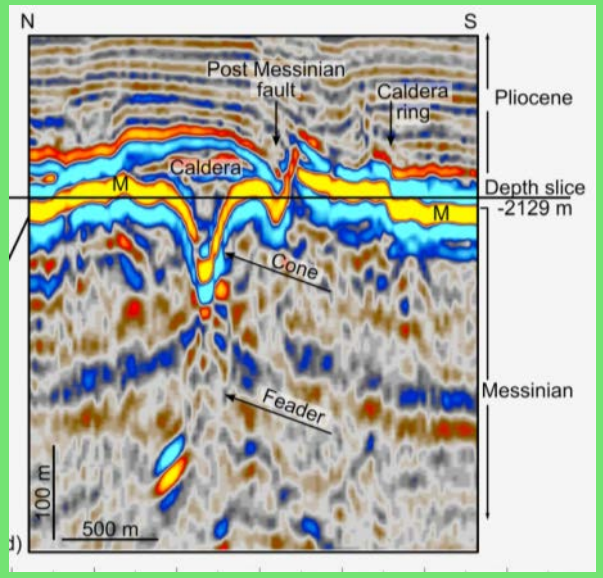
work in progress

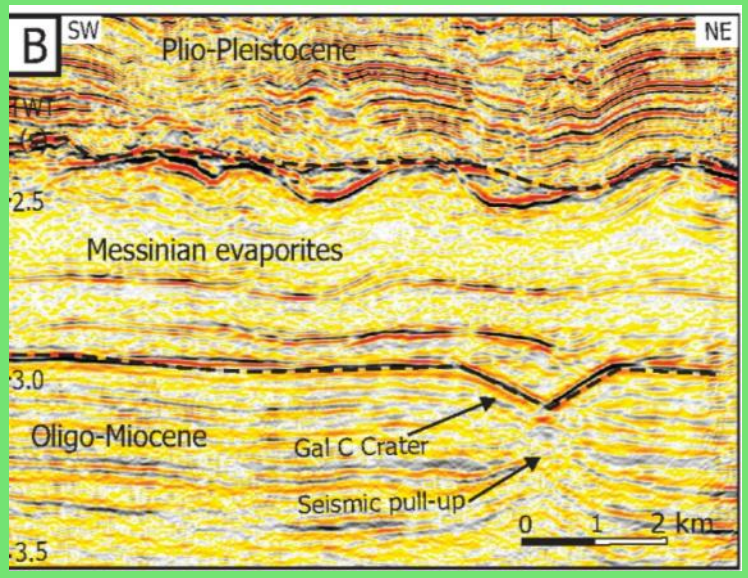
…and Eastern Mediterranean



"The great escape"

Pockmarks
in the
Levant Basin
(Lazar et al., 2012; Bertoni et al., 2013)





Concluding Remarks (1)

HC-seep?

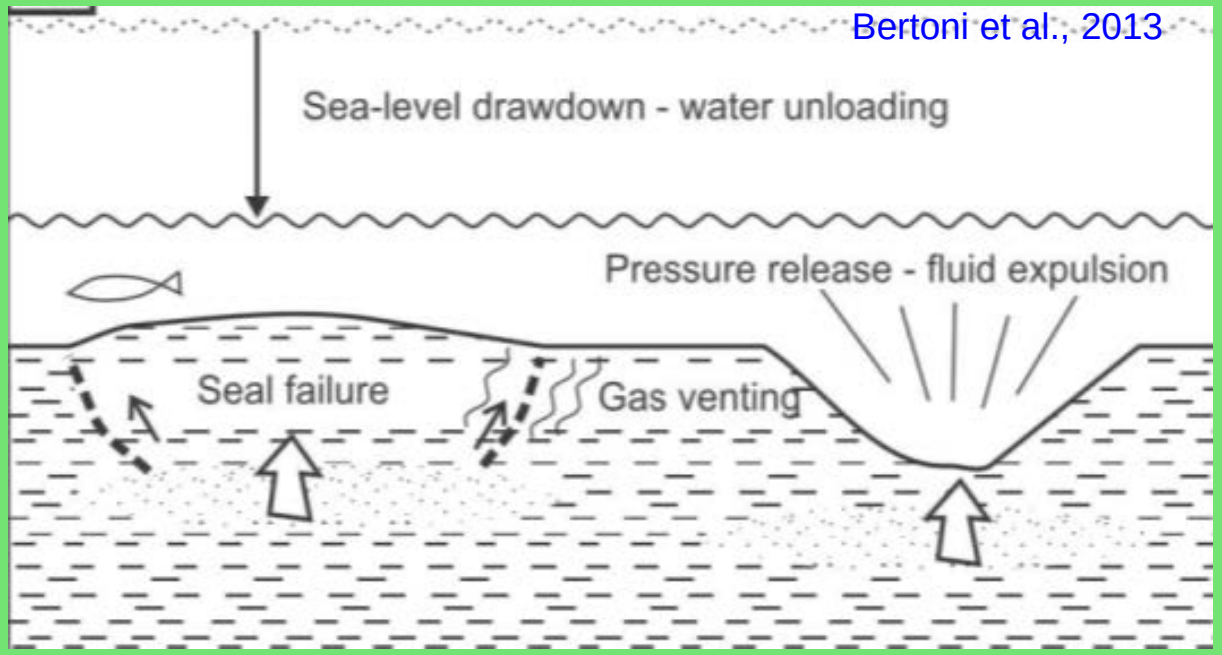
- The studied Messinian key sections in Italy show attributes of past cold seeps: autobreccias, authigenic limestones , chimney- and pipe-like structures, together with traces of fluid migration at different scales of observations, are interpreted to represent the vestiges of plumbing system and seeping features.
- The Messinian Brecciated Limestones do represent a record of seepage, though fluids were not everywhere HC-charged (uncertainties about source).

Trigger?

- The Messinian Brecciated Limestones occur in correspondence to different phases of the MSC → there is no evidence to consider the Messinian breccias as a stratigraphic unit (post-depositional brecciation).
- Conversely, the age of the brecciation event is constrained to the **early post-evaporitic phase** (Maiella area), following the **major drawdown** of the Mediterranean Sea responsible for the development of the MES.
- The high depressurization experienced by the sedimentary column after the removal of **at least 1 km of water column** likely favored a "sudden" migration of overpressured fluids from below.
- Site-specific tectonic settings may have locally enhanced the process, but it is not suggested to have acted as the main trigger.

Concluding Remarks (2)

Regional context



- Fluid and gas expulsion was an important process affecting the Mediterranean Basin during the Messinian Salinity Crisis, though with site-specific attributes and fluid-migration focus areas being separated by considerable distances.
- In this context, it has been also suggested that gas hydrates dissociation may have played a critical role (*Pierre & Rouchy, 2004; Dela Pierre et al., 2010; Martire et al., 2010; Lazar et al., 2012; Bertoni et al., 2013*)


Thanks for your attention