Istituto di Geologia Ambientale e Geoingegneria

Scuola Estiva di Geomorfologia, Ecologia e Biologia in Ambiente Marino e Insulare

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Emissioni sottomarine nelle Isole Pontine

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OUTLINE

- Introduction on submarine fluid emissions
- Geology of the western Pontine Archipelago
- Fluid emissions and the Zannone Hydrothermal Field
- Methods
- ZHF-giant pockmarks: seabed morphology
- ZGP seabed morphology, fluid emissions, fluid geochemistry and extremophilies
- ZGP seabed types and deposits (alteration - mineralization products)
- ZGP shallow seismic stratigraphy (buried hydrothermal features)
- Genetic models proposed for ZGP and ZHF systems
- Concluding remarks

Submarine fluid emissions

Hydrothermal vents: hot fluids (e.g., CO2, H2O, H2, H2S, SO2) – Mid ocean ridges, volcanic arcs, back-arcs and intraplates -

Chimneys, domes, craters, pockmarks, authigenic crusts, massive sulfides

Cold seeps: low T fluids - hydrocarbons and brines (e.g., CH4) – continental margins and deep sea fans-

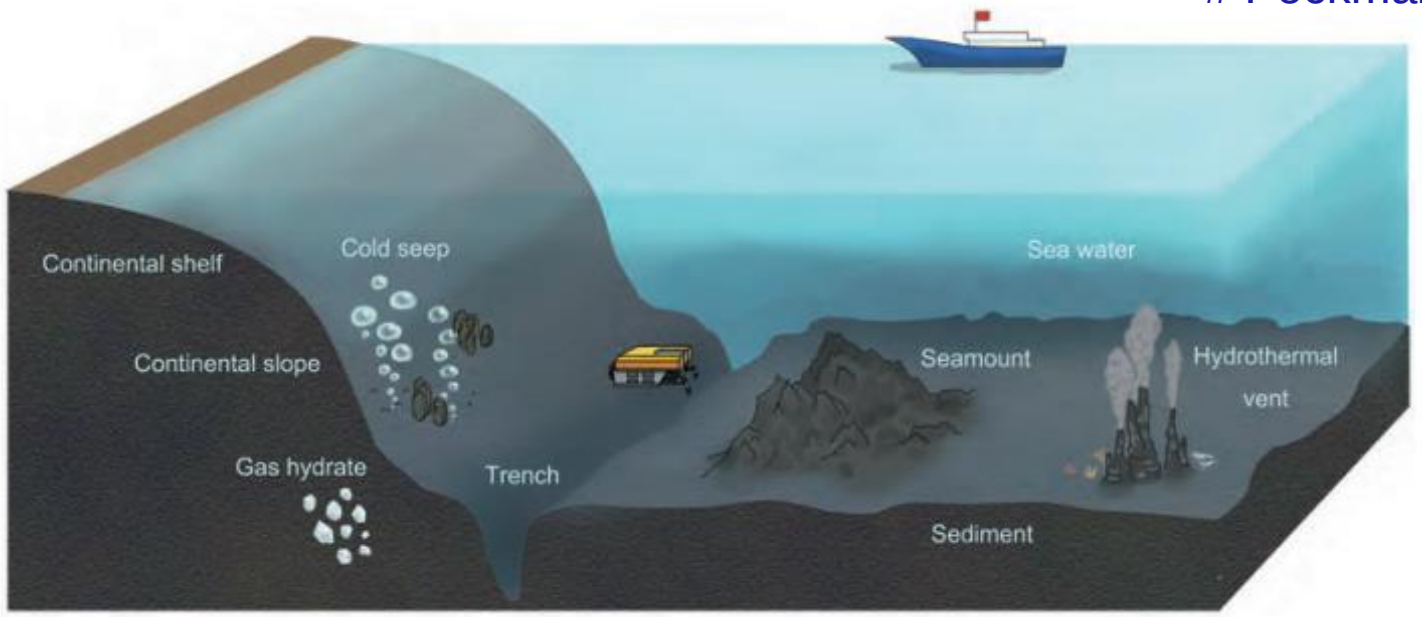
Pockmarks, mud volcanoes, diapirs, brine pools, authigenic carbonates (e.g., mounds) and precipitates, gas hydrates

also submarine groundwater discharge – shelf –

Pockmarks, collapse structures, slides, gullies

and from microbial CH4 – e.g., **deltaic systems**

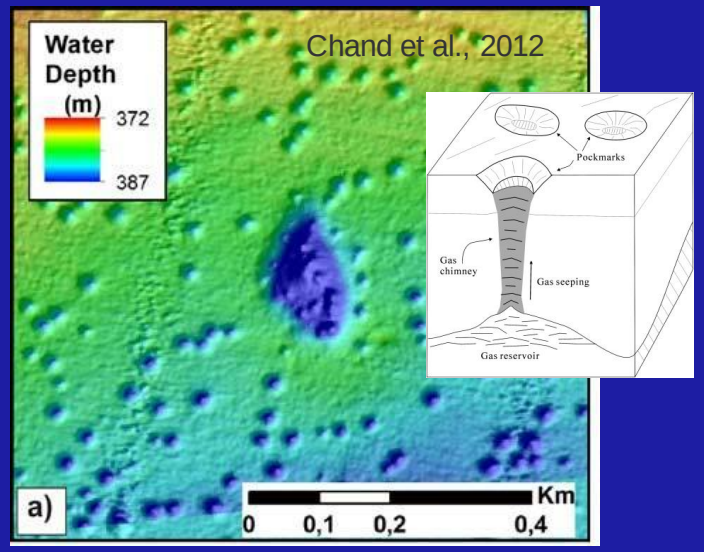
Pockmarks, authigenic carbonates, mud volcanoes



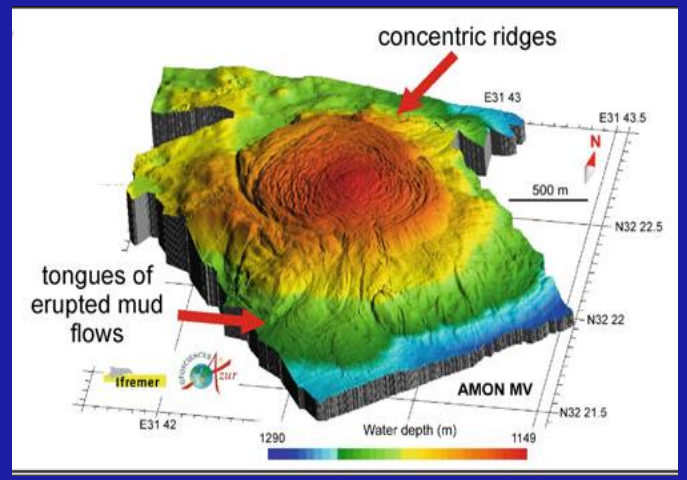
Both play an important role in **matter and energy exchange** between the lithosphere and the hydrosphere, influencing seabed ecosystems and greenhouse gas concentrations

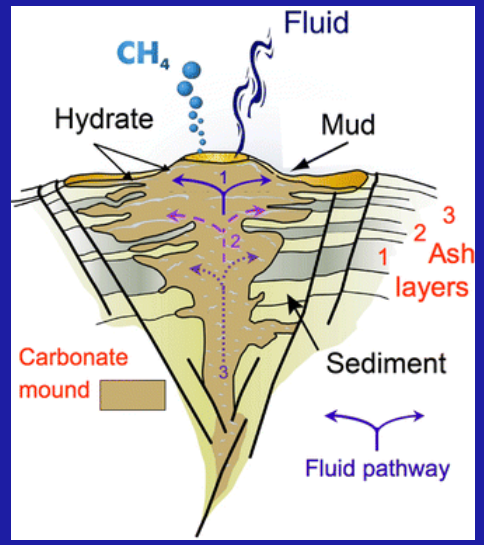
Cold seeps

Pockmark field (Barents Sea)



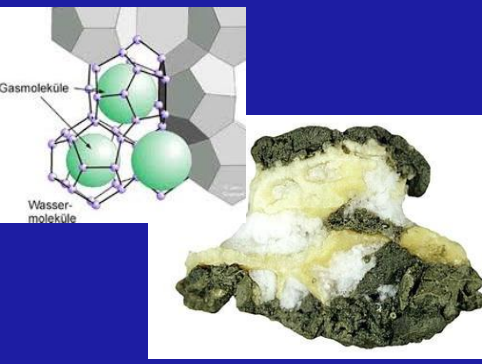
AMON Mud Volcano (Nile Fan)
(Dupre et al 2008)



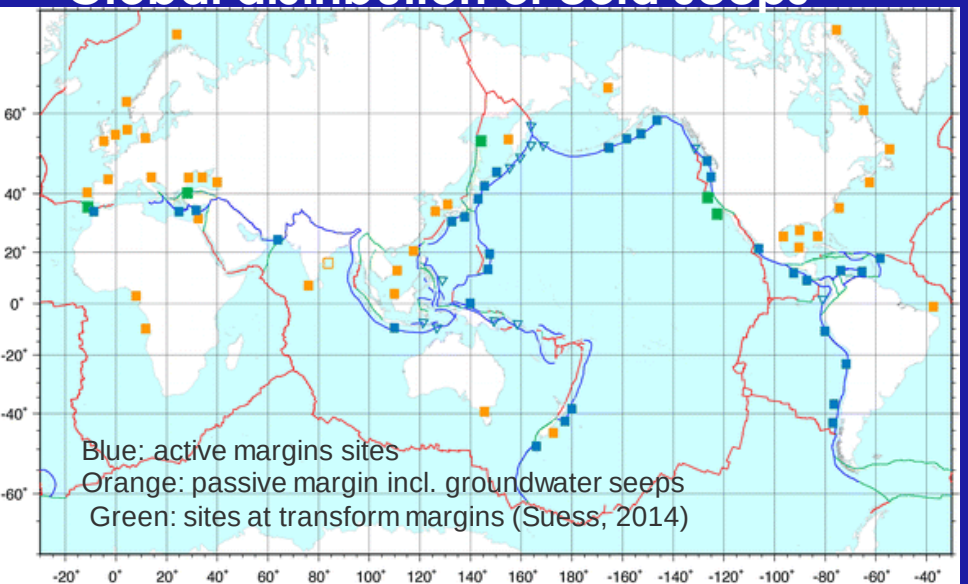


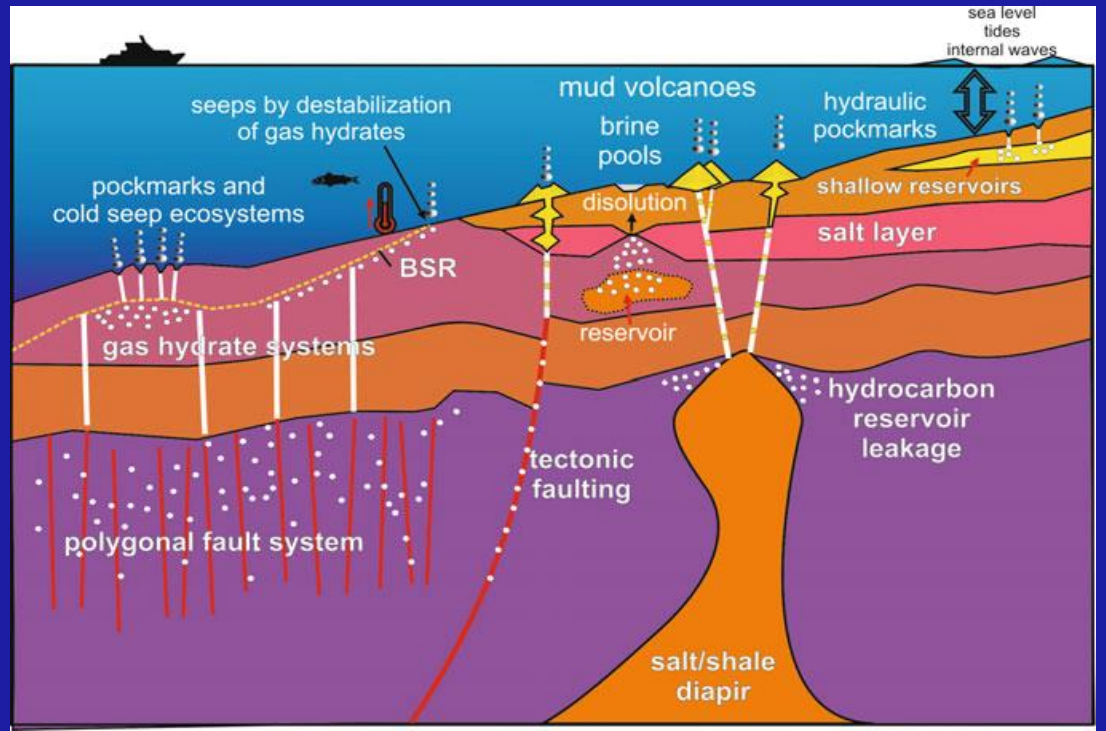
Mud volcano with carbonate core
(Suess, 2014)

Mud with
gas hydrate
and aragonite



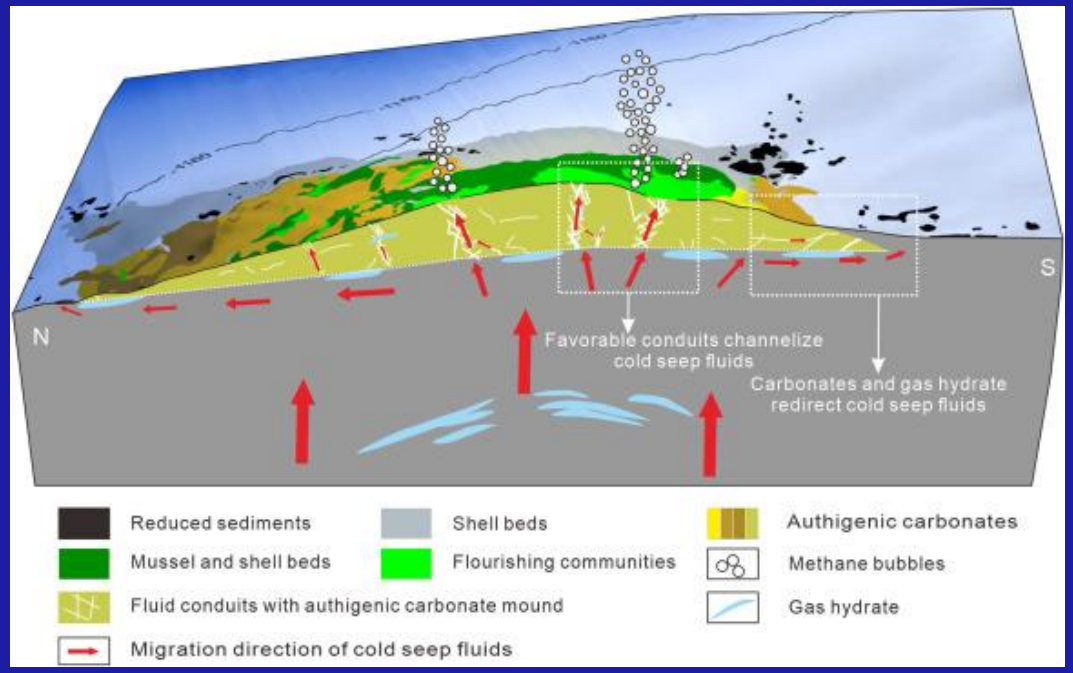
Global distribution of cold seeps



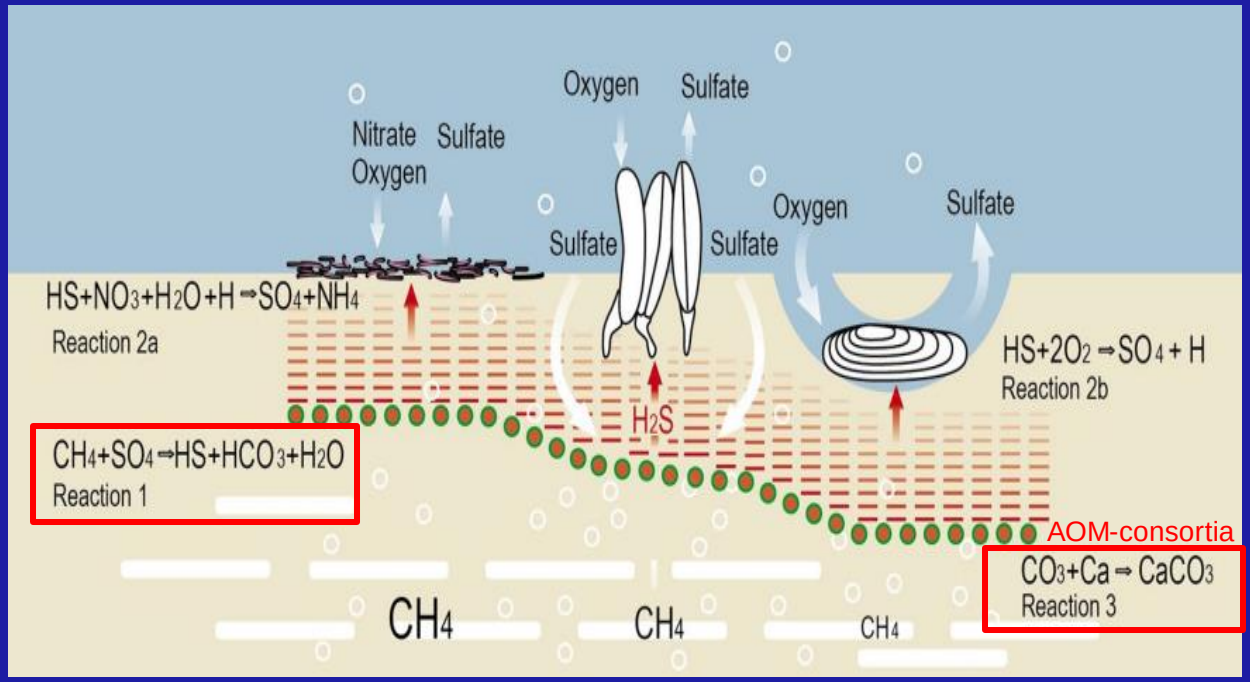


Cold seeps on a continental margin

ang et al., 2021

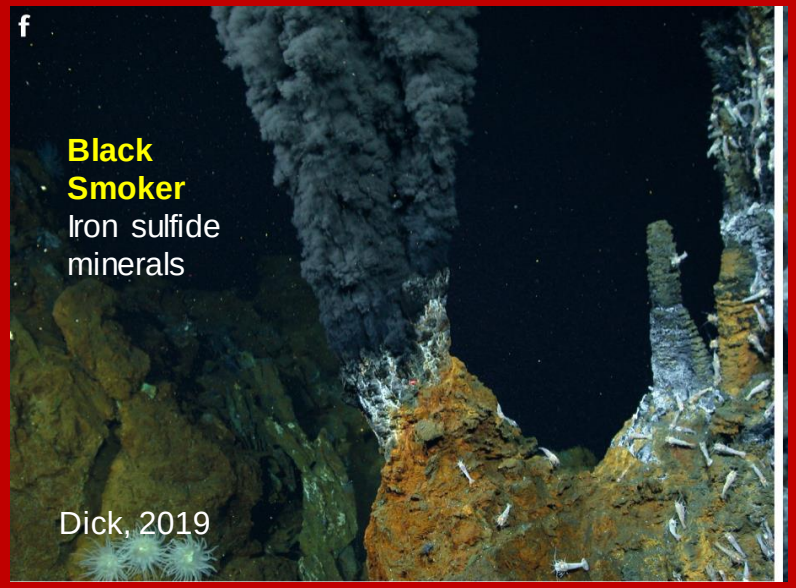


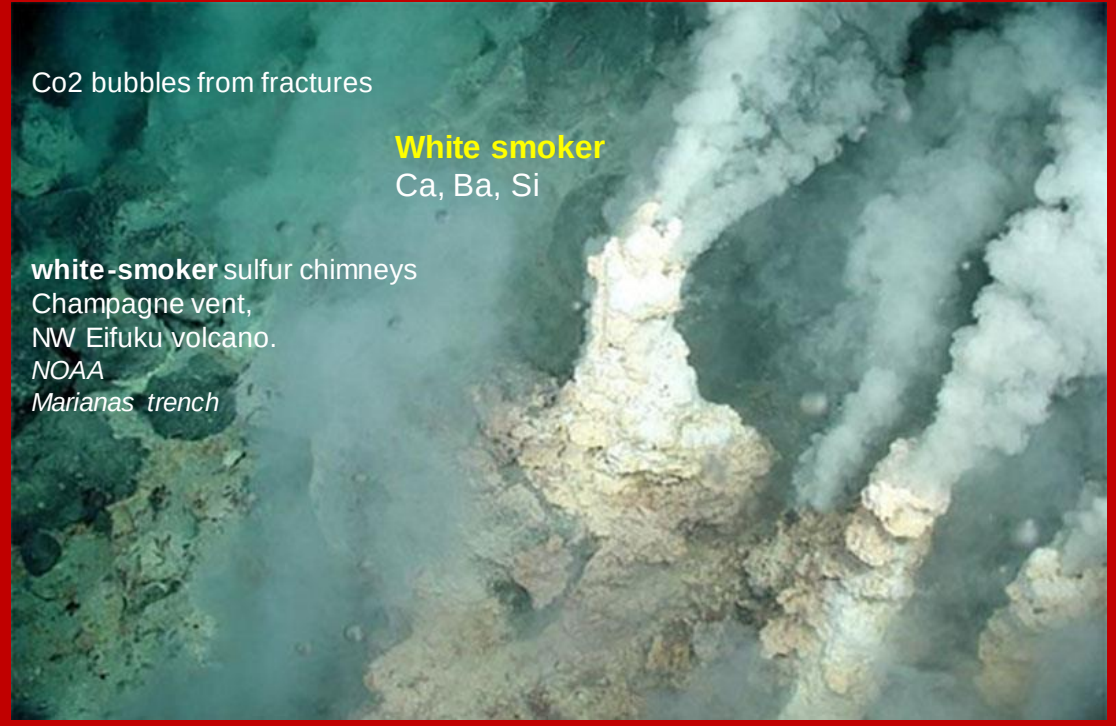
Carbonate precipitation by anaerobic oxidation of CH_4



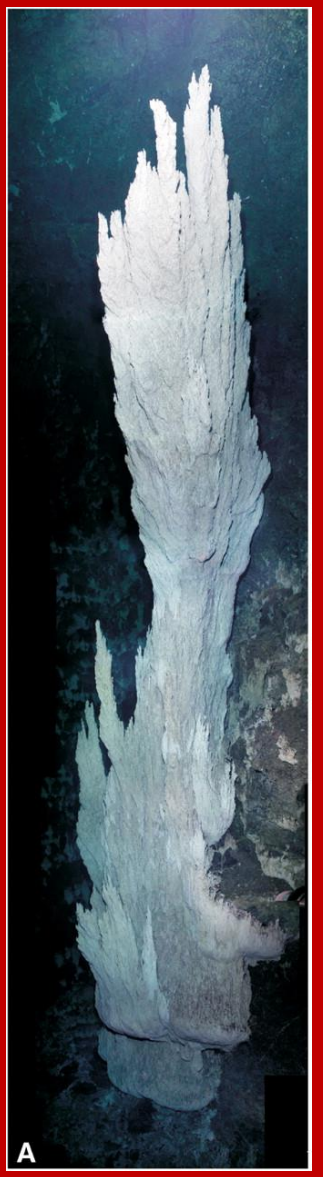
Buried gas hydrates and free gas supply methane to AOM-consortia. CHEMOAUTROPHIC BACTERIA
AOM consume seawater sulfate in oxidizing methane (R1) producing hydrogen sulfide and bicarbonate;
hydrogen sulfide rises to the seafloor and is oxidized in microbial mats (R 2a) or by macrofauna (R2b) using O2 or nitrate;
in the process calcium carbonate precipitates (R3).

Hydrothermal vents

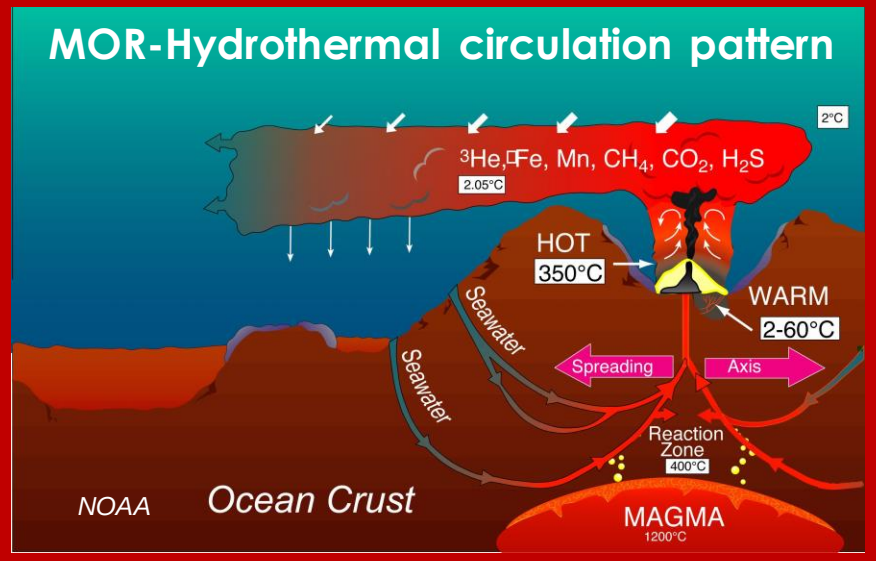




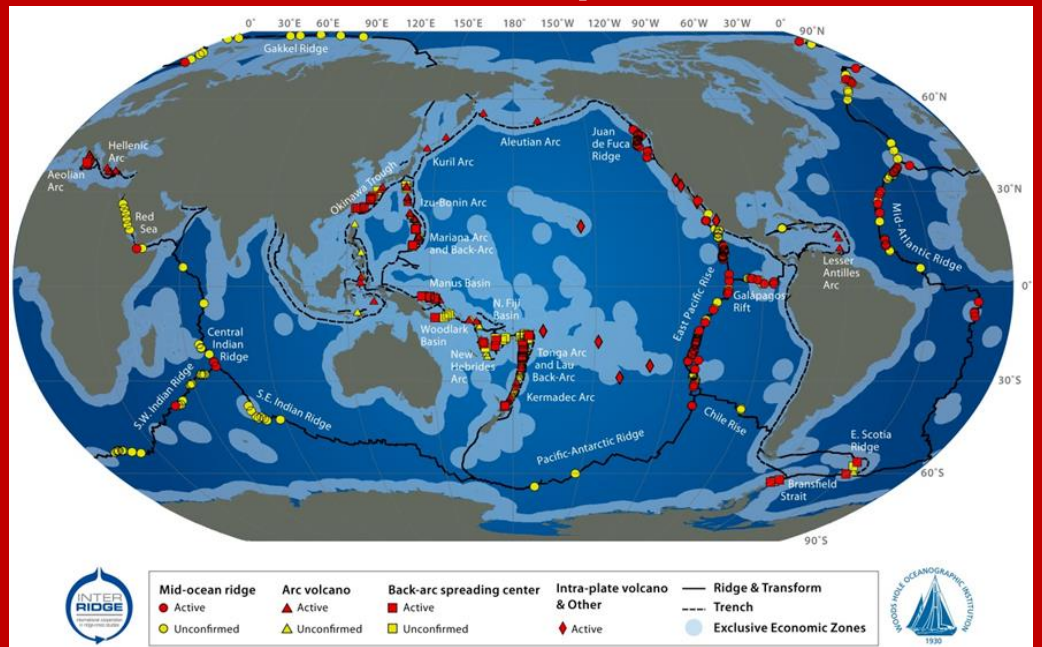
Carbonate Chimney (Lost City)



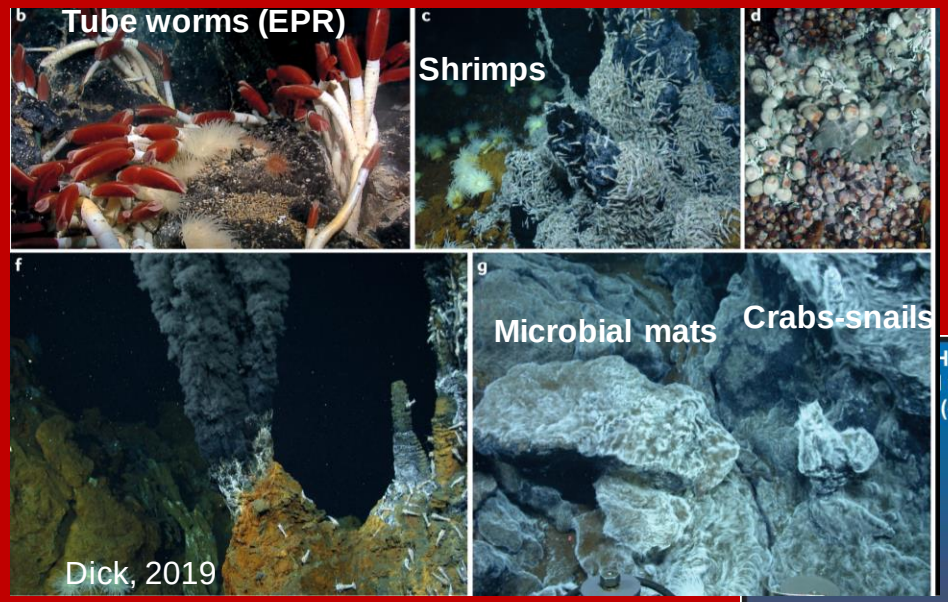
Fromm serpentinite cliff Mid Atlantic Ridge

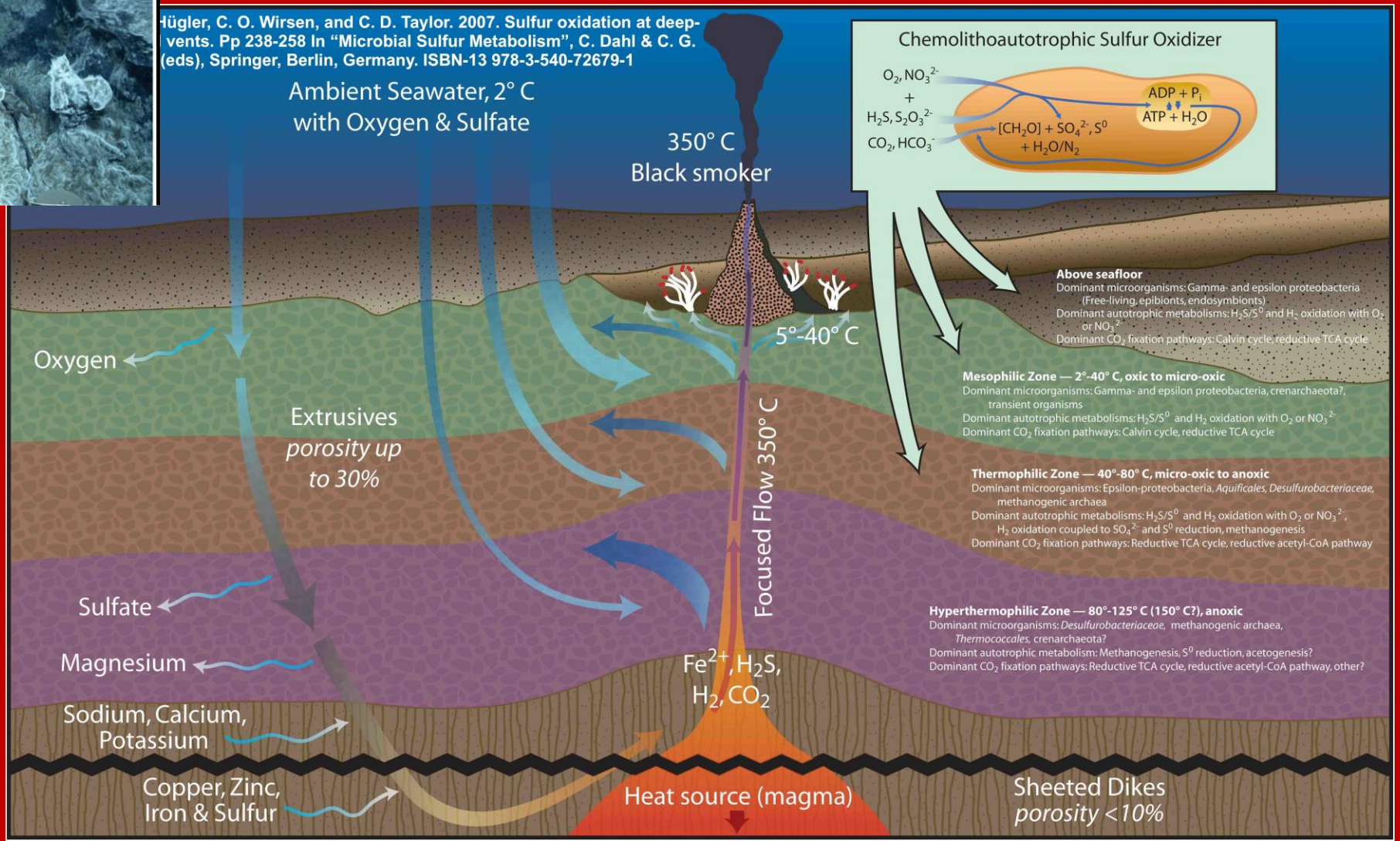


Global distribution of hydrothermal vents



Hydrothermal vent chemosynthetic communities *extremophiles*



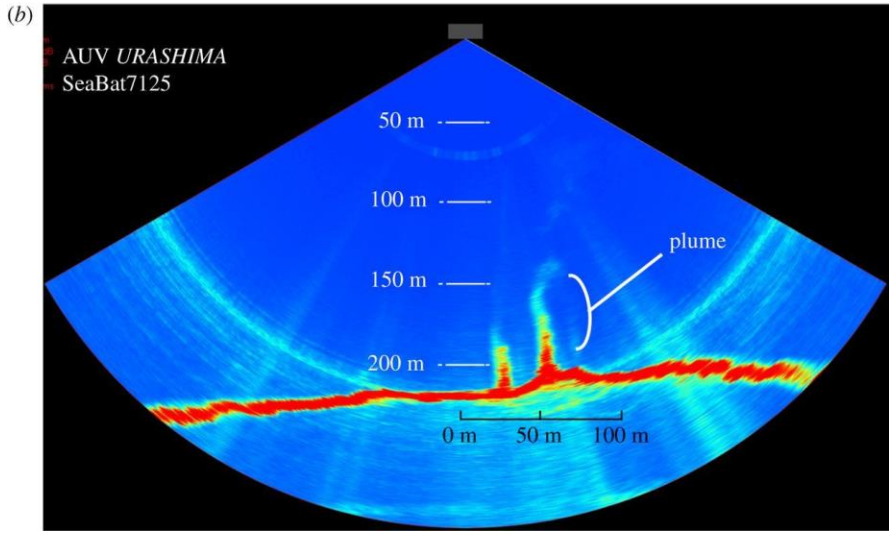


Detection of active fluid emissions

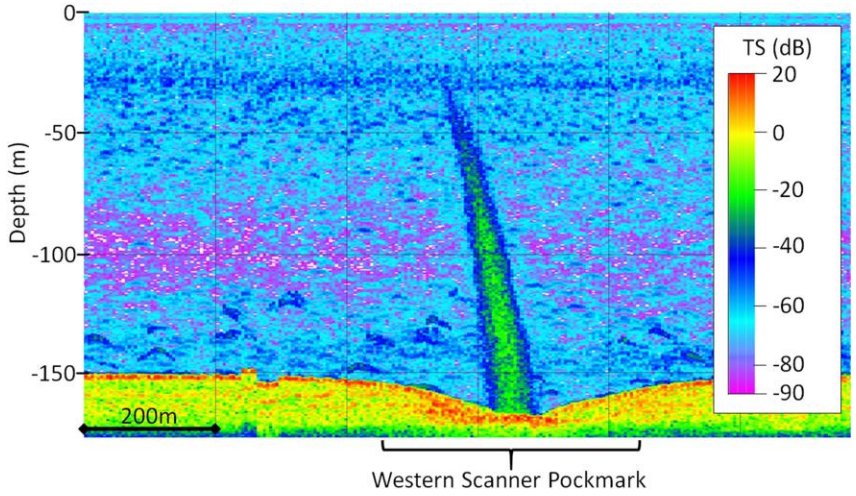
"Hunting for active vents"

Fluid emissions in the water column: acoustic plumes, flares, bubbling

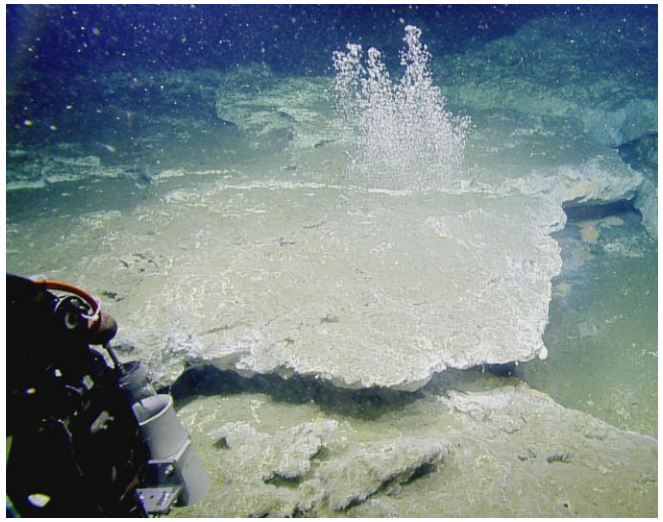
Multibeam water column data, echo-sounders, side scan, seismic profiles, ROV, CTD.



MBES by AUV
Yaeyama Knoll, Okinawa trough
(Myazaki et al., 2017)



Scanner Pockmark
CH4 plume from
18kHz single beam
(Li et al., 2020)

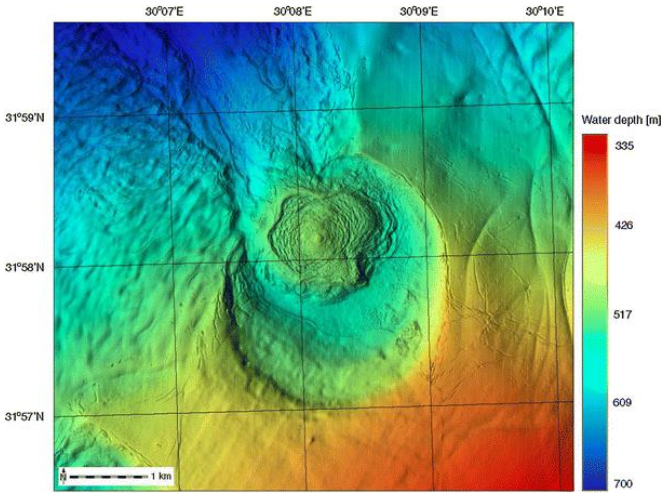


CH4 bubble stream from
ROV
Oregon coast
(Oregon State University)

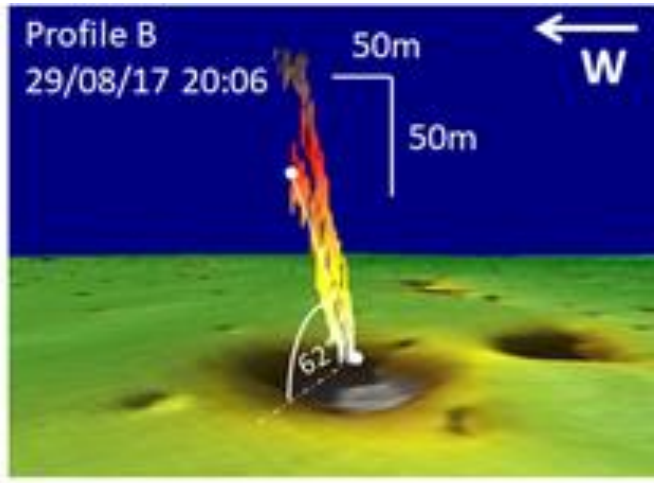
Detection of fluid emission seabed structures and fluids

Seabed fluid emissions: structures (e.g., carbonate mounds, pockmarks, mud volcanoes by hydrocarbon gases), venting fluids (brine pools)

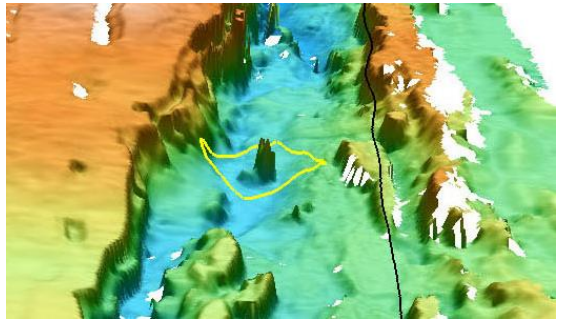
Multibeam, Side scan, seismic profiles, ROV



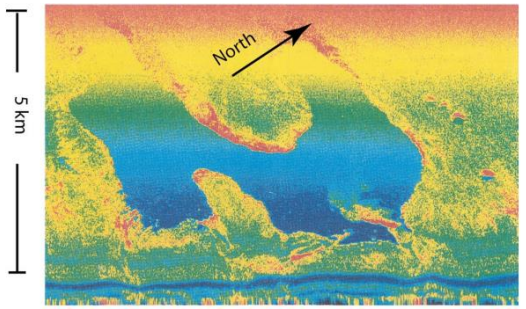
North Alex Mud Volcano
mud ponding, breached crater rim and outflow structures
Nile fan



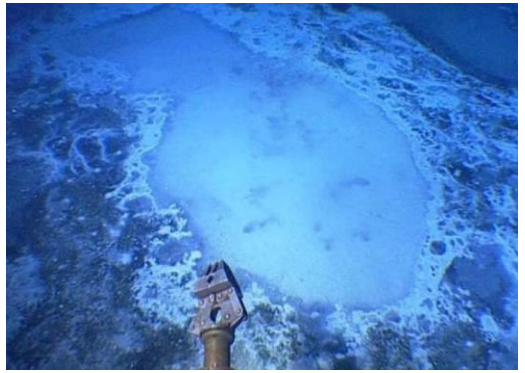
Scanner Pockmark
CH4 plume from EM710 Data (Li et al., 2020)
North Sea



Meybò Hydrothermal chimney
AUV multibeam data (MBARI, 2012)
Gulf of California



L'Atalante Brine Pool
side scan data (Suess, 2014)
Mediterranean Ridge, estern Mediterranean



MV: Menas Caldera Brine Pool
ROV (Suess, 2014)
off Nile, estern Mediterranean

Fluid emissions may or may not have a surface expression

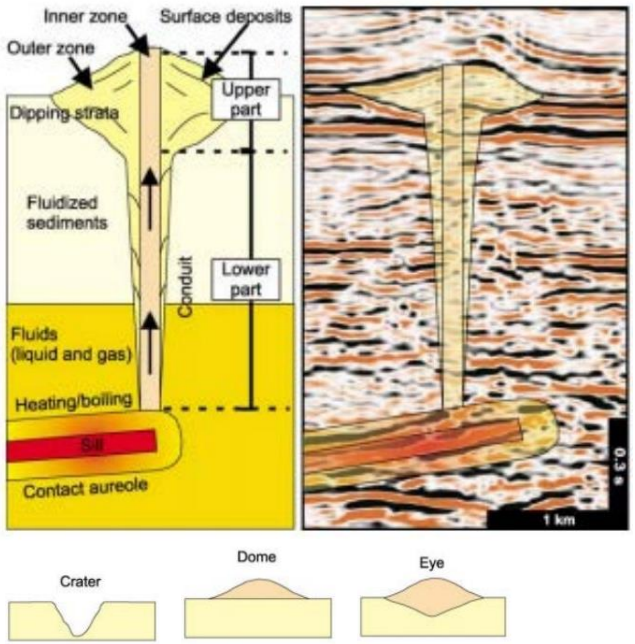
Detection of fluid emissions in the subsurface

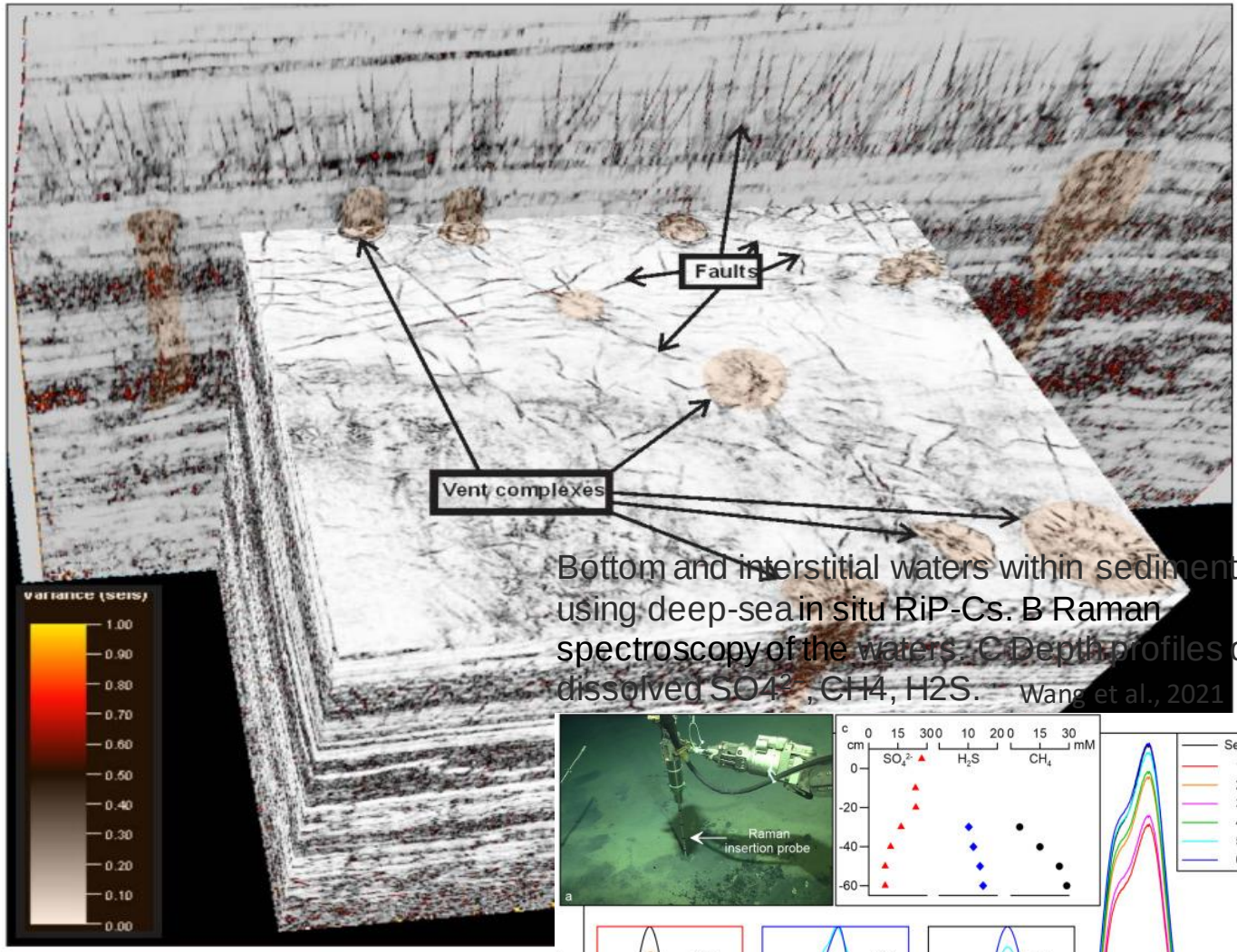
Fluid emissions within sediment: buried structures (e.g., pockmarks, pipes, mud diapirs),

Zones with gas-charged sediment (acoustic turbidi zones, bright spots), bottom simulating reflectors

Seismic profiles, In situ-measurements

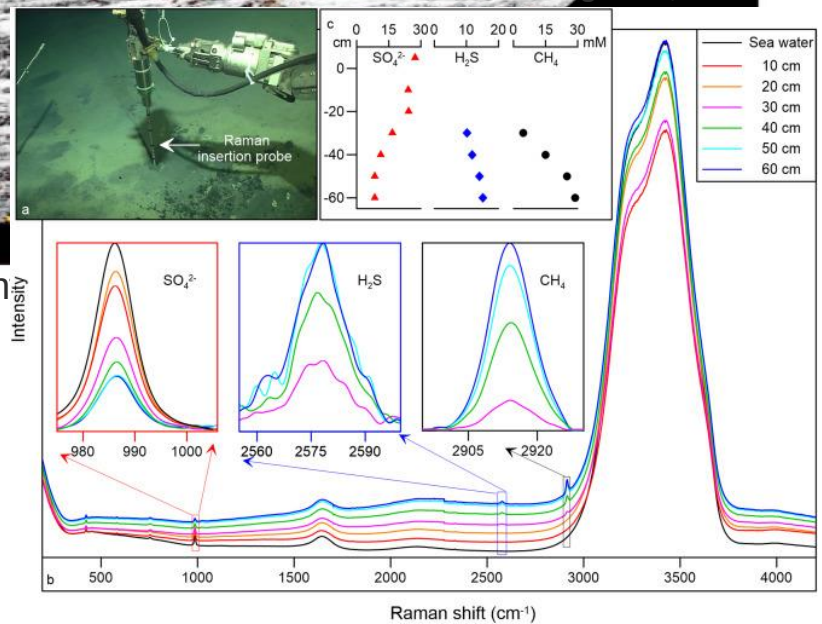
Seismic expression of a **hydrothermal vent complex HVC** (Voring Basin, Norwegian margin).
The upper part of the HVC is a crater-, dome- or eye-shaped and is connected to the termination of a sill by a conduit with disturbed seismic data in the lower part. Planke et al., 2005.



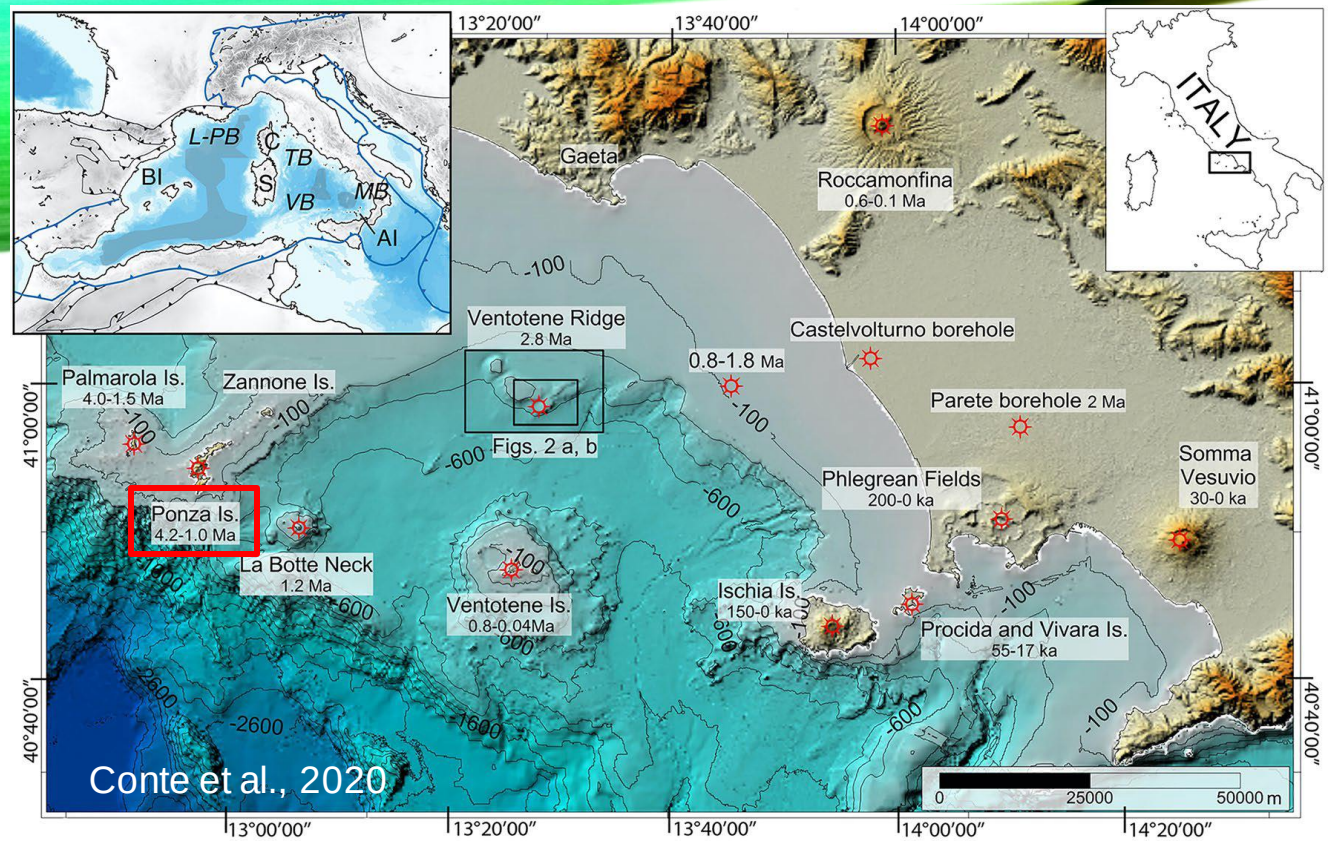


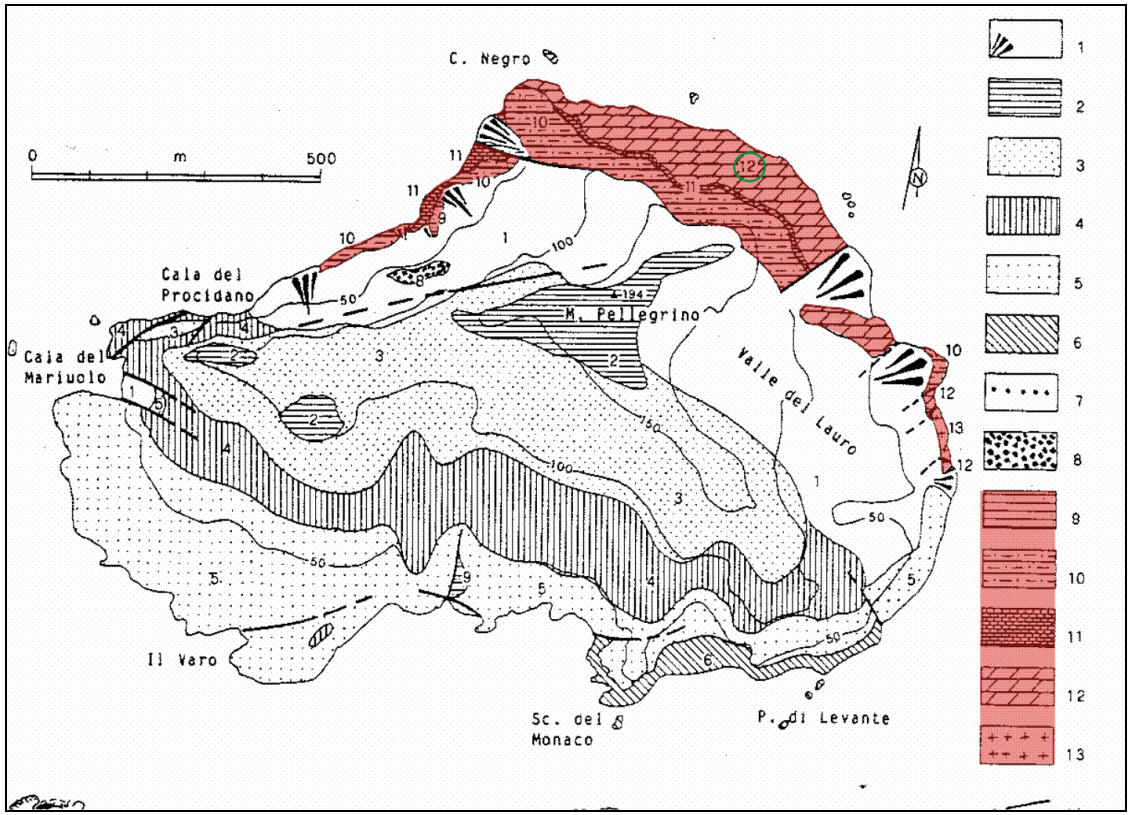
Variance cube showing faults and ven
Njone, 2014

Bottom and interstitial waters within sediments using deep-sea in situ RiP-Cs. B Raman spectroscopy of the waters. C Depth profiles of dissolved SO_4^{2-}, CH_4, H_2S. Wang et al., 2021



THE WESTERN PONTINE ARCHIPELAGO





Pliocene calc-alkaline rhyolites above

Meso-Cenozoic sedimentary units:

9: Barren clays and marls with gypsum (Messinian?);

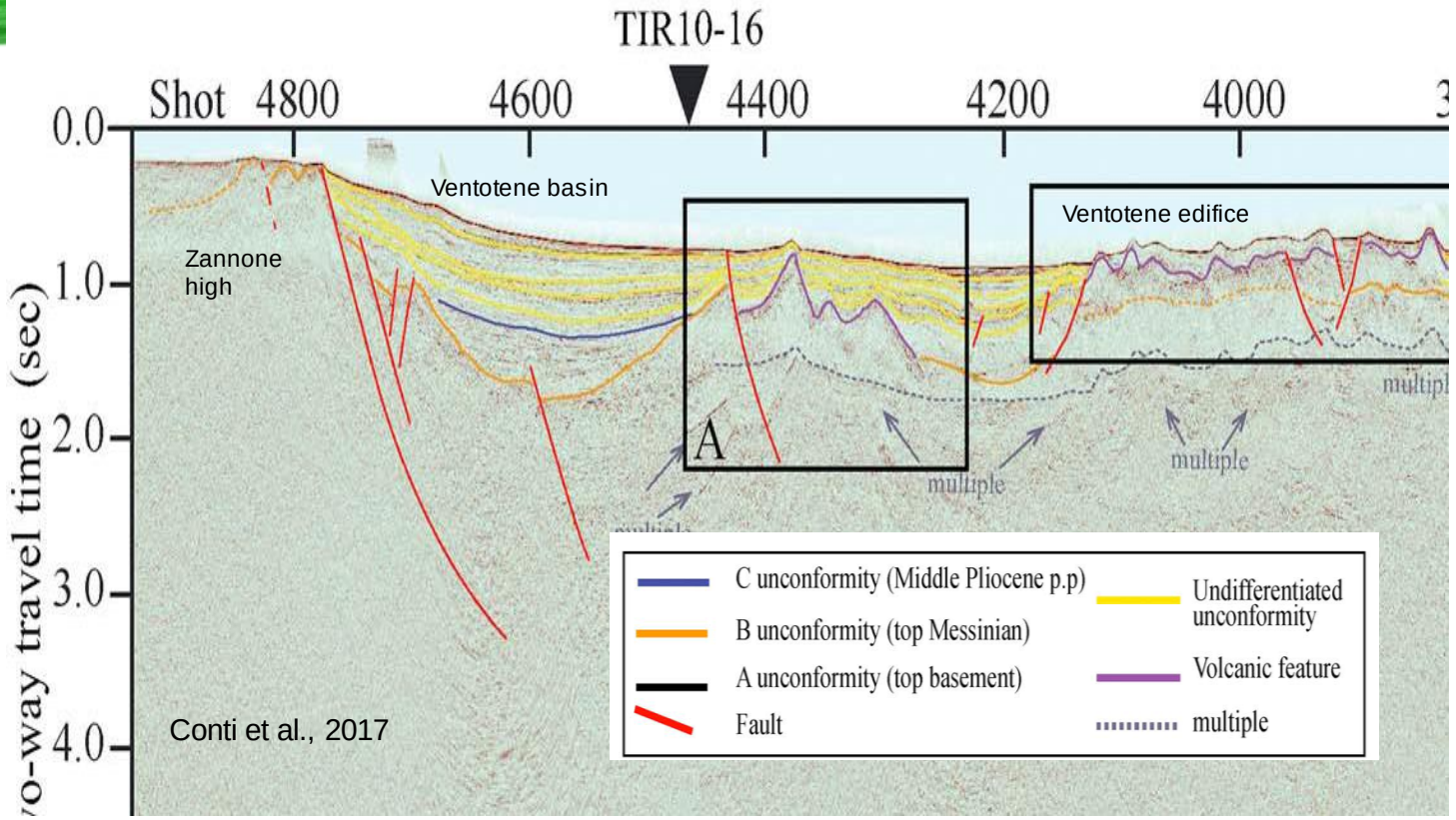
10: Argillitic Flysch (Miocene);

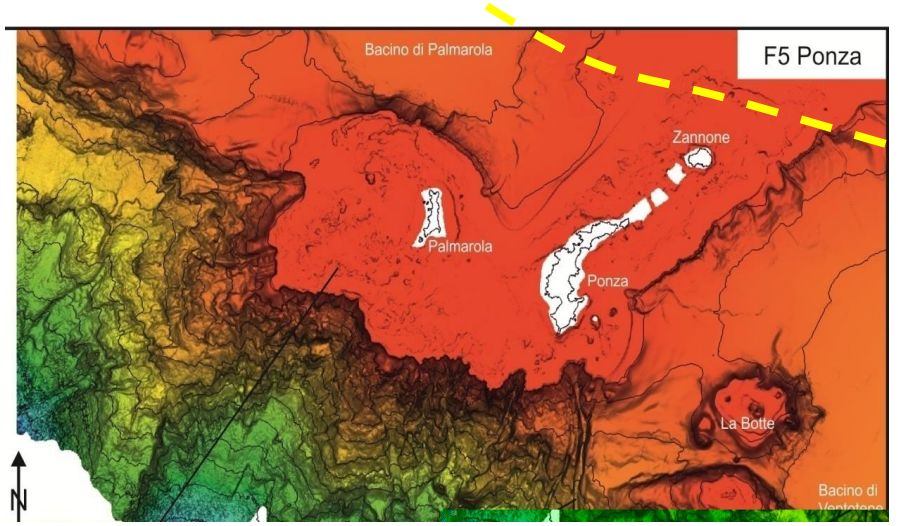
11: Scaglia unit (Upper Creta.-Eocene);

12: Dolomites, dolomitic Limestones, marls with stromatolites (Trias);

13 Quarzitic sandstones and phillites (Paleozoic?);

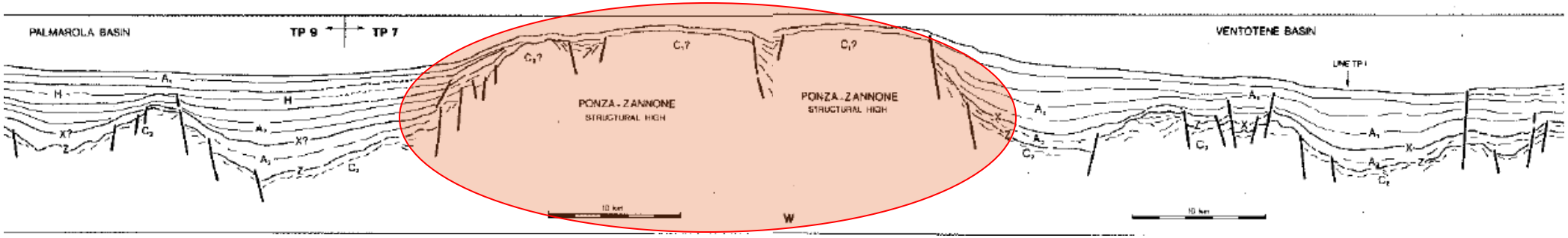
THE PONZA-ZANNONE STRUCTURAL HIGH



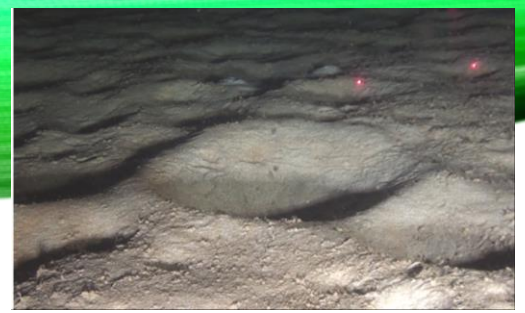


Volcanic/magma-rich rifted Plio-Pleistocene sedimentary margin

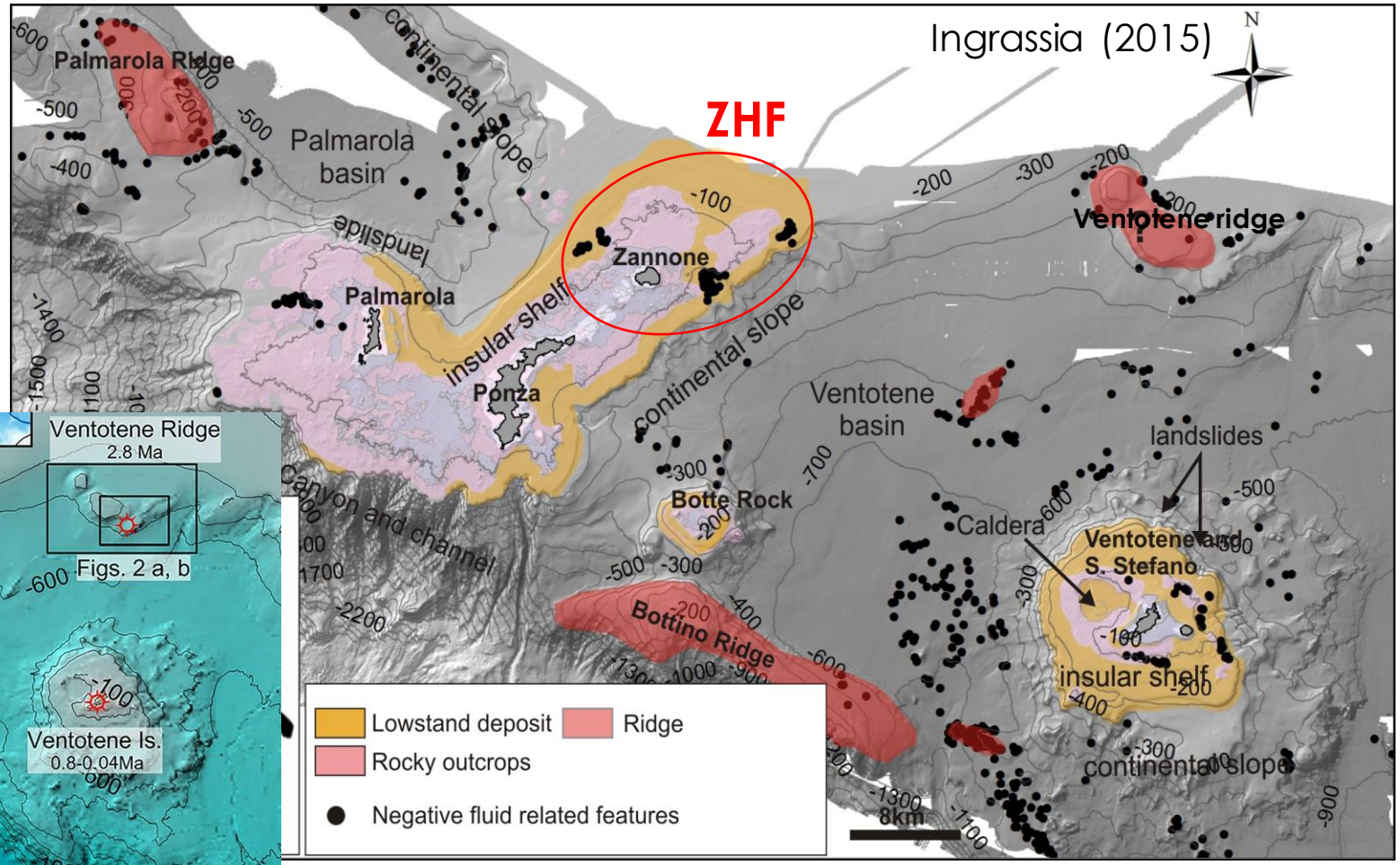
Zannone high: Faulted Meso-Cenozoic sedimentary rocks and Rhyolites

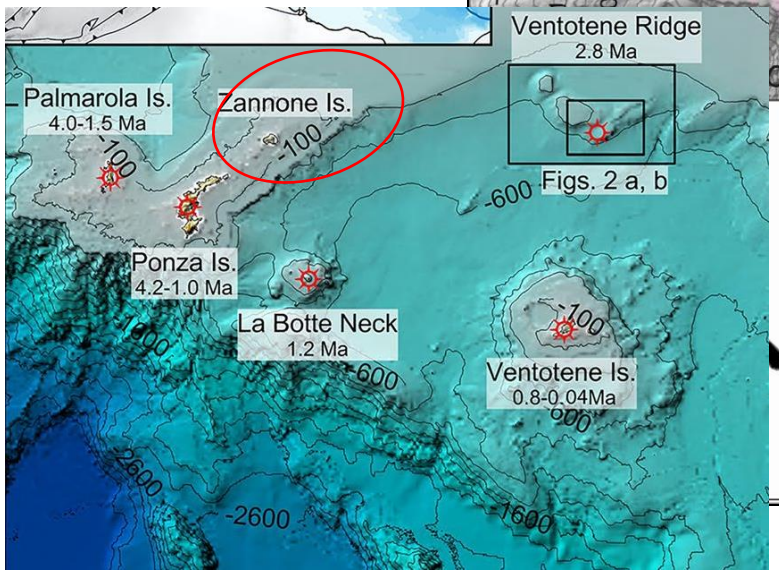


DETECTION OF SEABED FLUID EMISSION STRUCTURES - POCKMARKS -

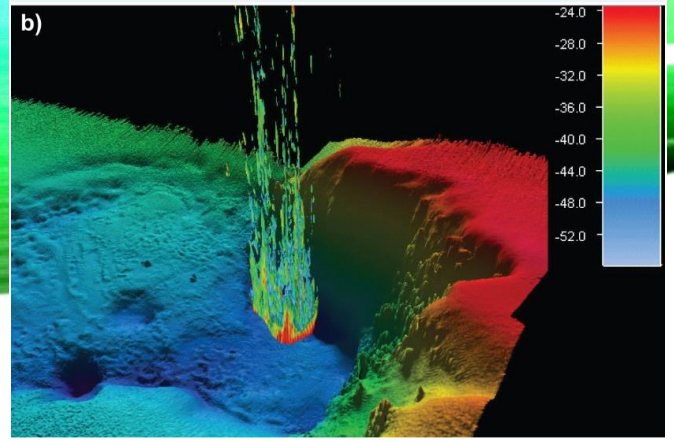


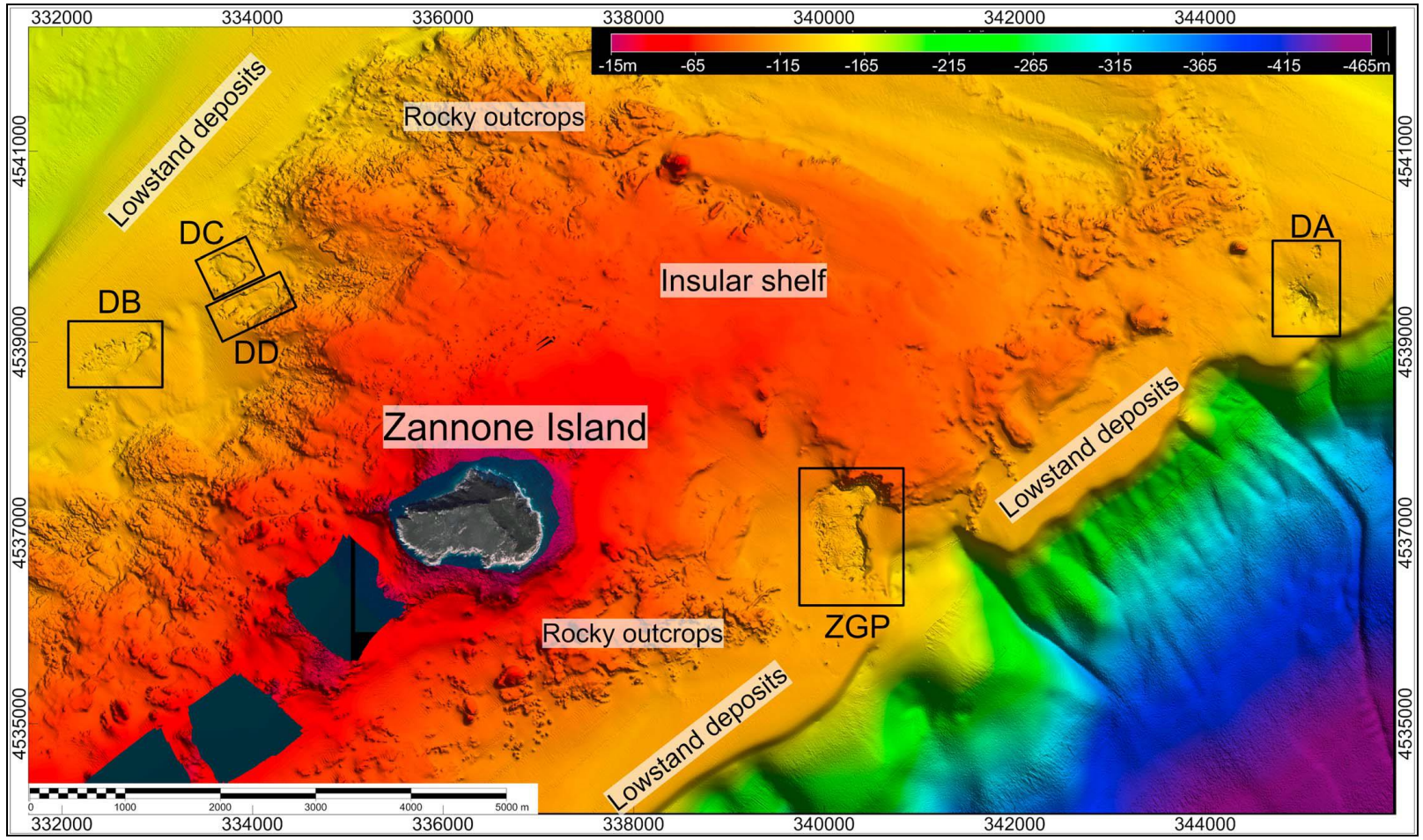
>1000 pockmarks mapped between -65 and -1200 m by MB bathymetry





THE ZANNONE HYDROTHERMAL FIELD





- Ongoing and polyphased hydrothermal activity, fluid migration across faulted substrata
- Seabed morphological expression favored by low sedimentation rates: 5 giant pockmarks on the Po-Za high
- Alteration and mineralization processes
- Shallow water extreme environment with bacterial mattes and non-calcareous foraminifera

METHODS

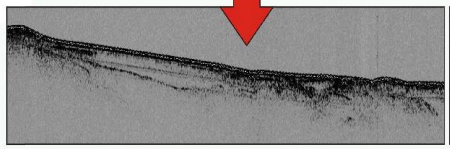
multibeam

side scan sonar

chirp

sparker

morphology and lithological complexity



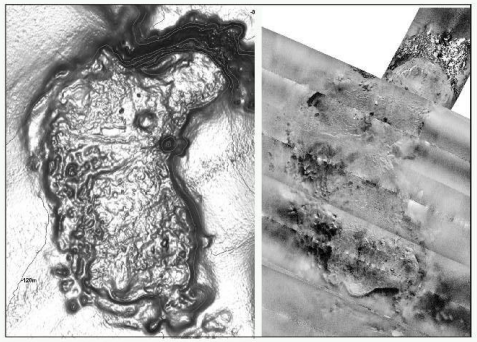
subsurface architecture and gas evidences

grab

sediment types

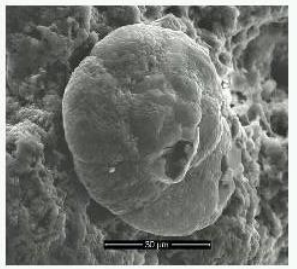
SURFACE EVIDENCES

SURFACE EVIDENCES



SURFACE EVIDENCES

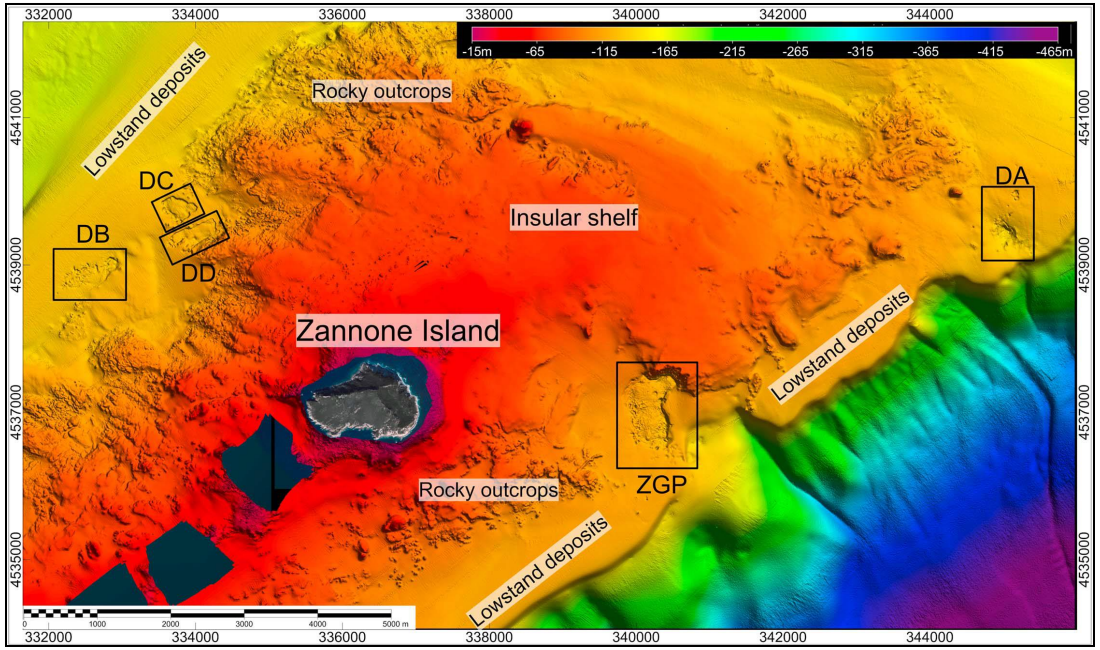
ROV



SEDIMENTOLOGICAL, MINERO-PETROGRAPHIC, PALEONTOLOGICAL ANALYSES

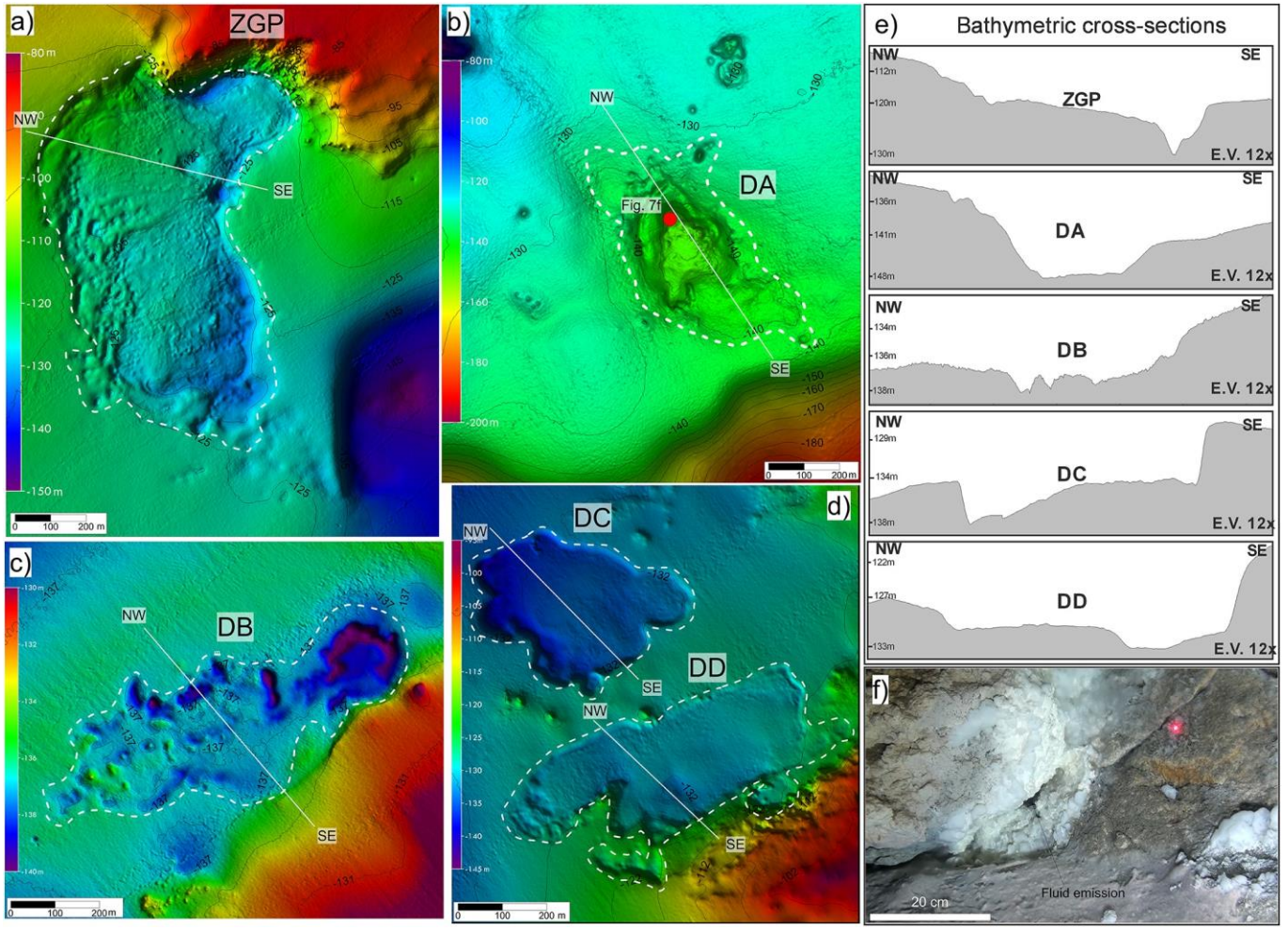
BIOLOGICAL AND GEOCHEMICAL ANALYSES

GIANT POCKMARKS



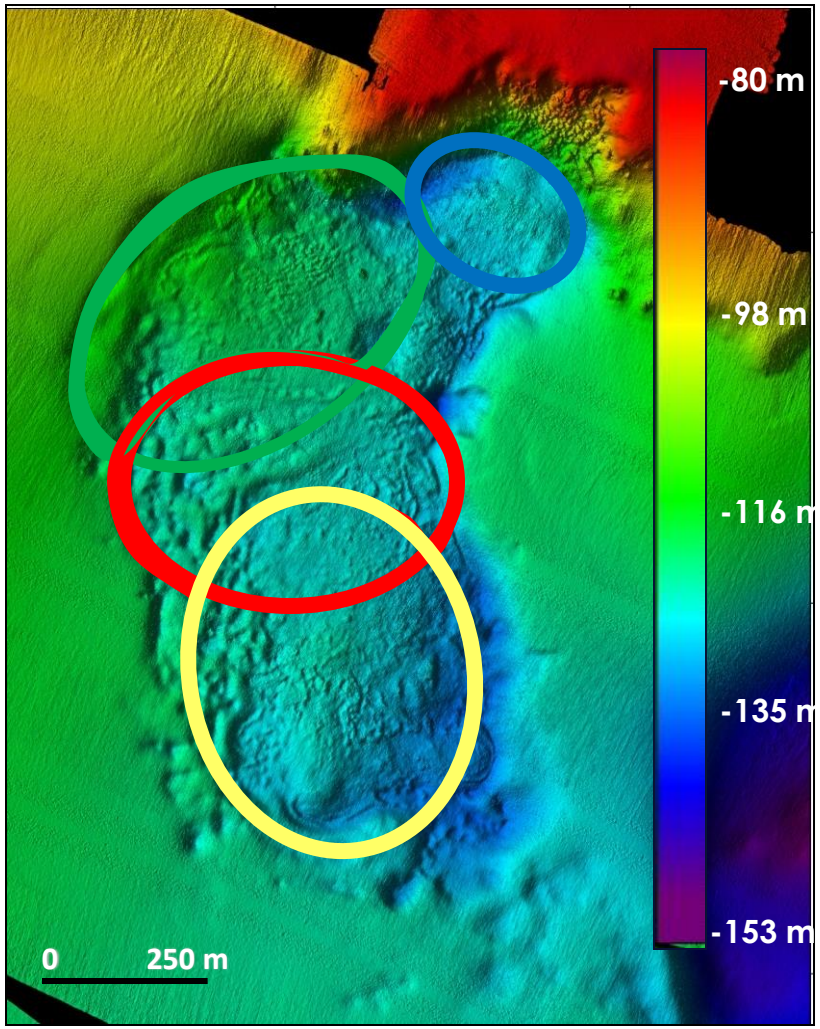
5 giant pockmarks 10-15 m deep
at about -130 m

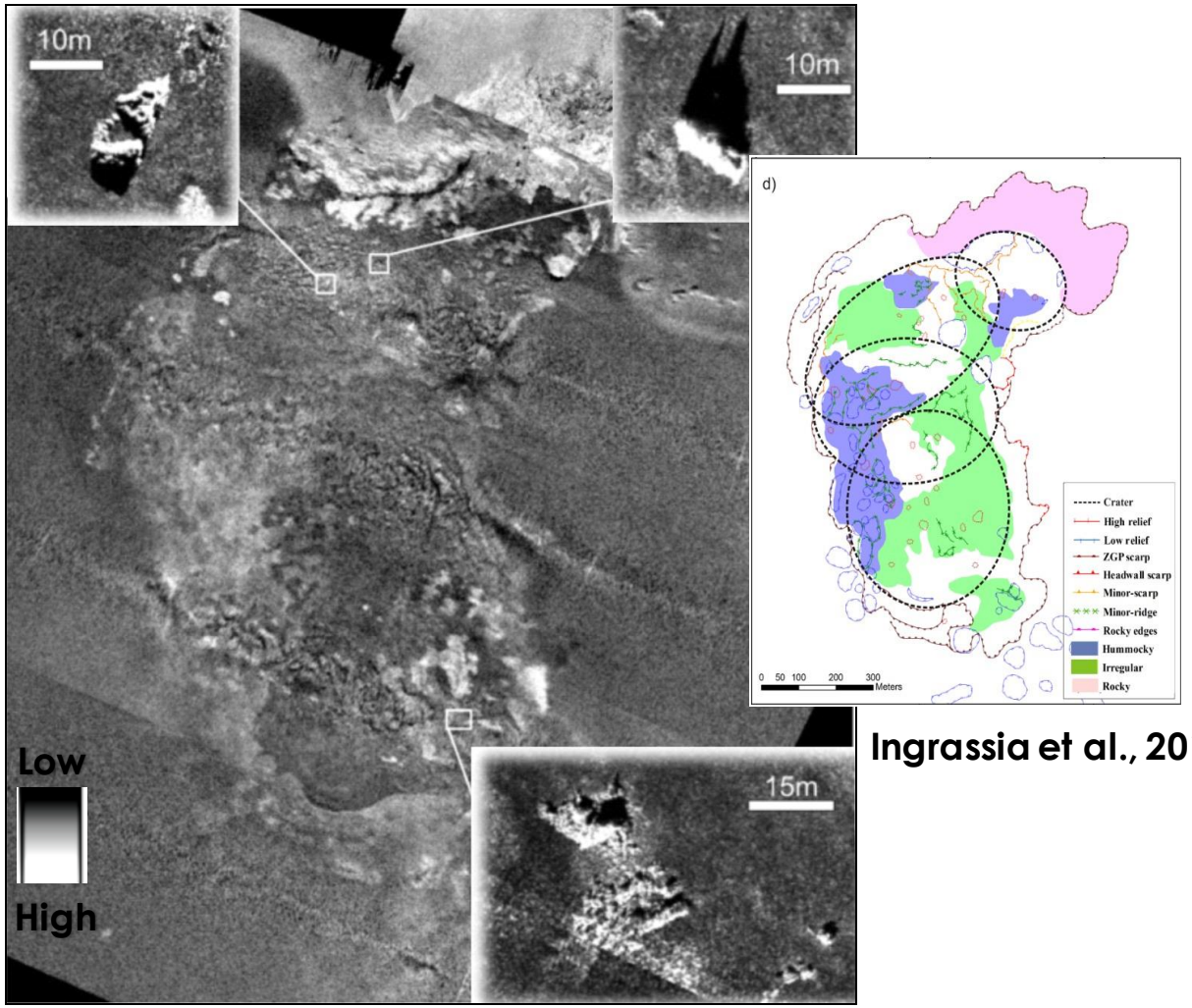
EASTERN FLANK: ZGP and DA
WESTERN FLANK: DB-DD



Martorelli et al., 2016

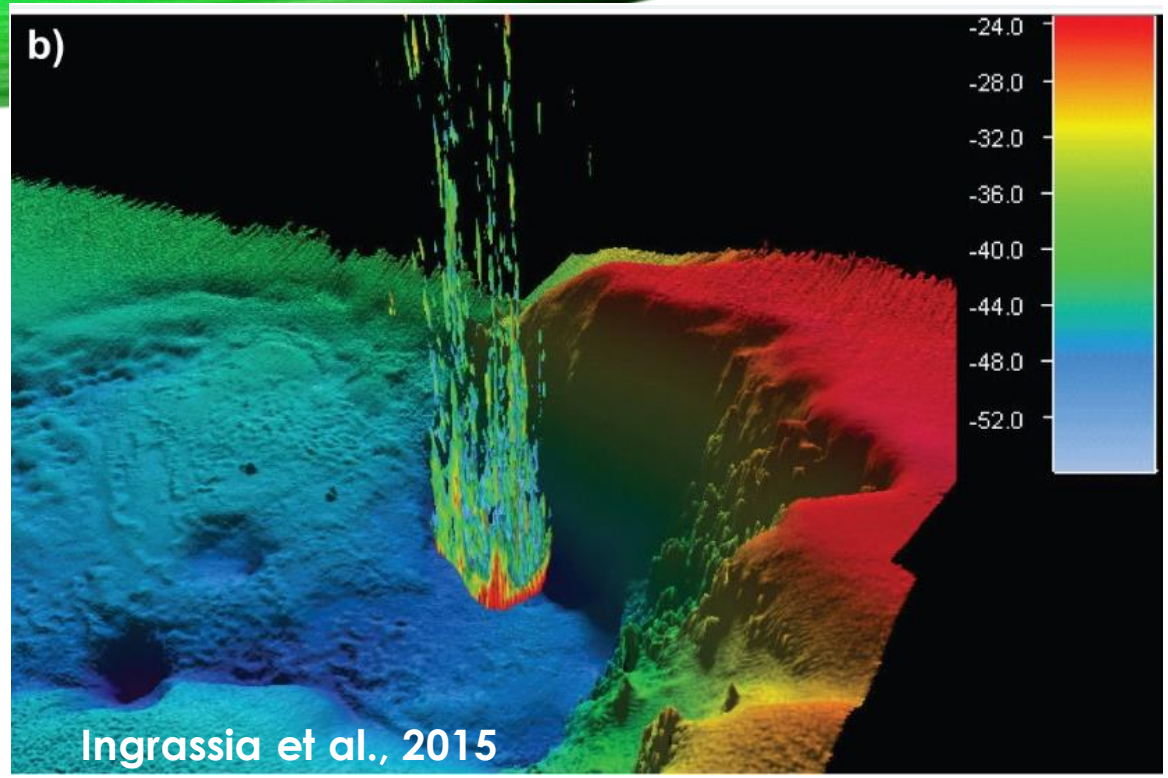
THE ZANNONE GIANT POCKMARK (ZGP)

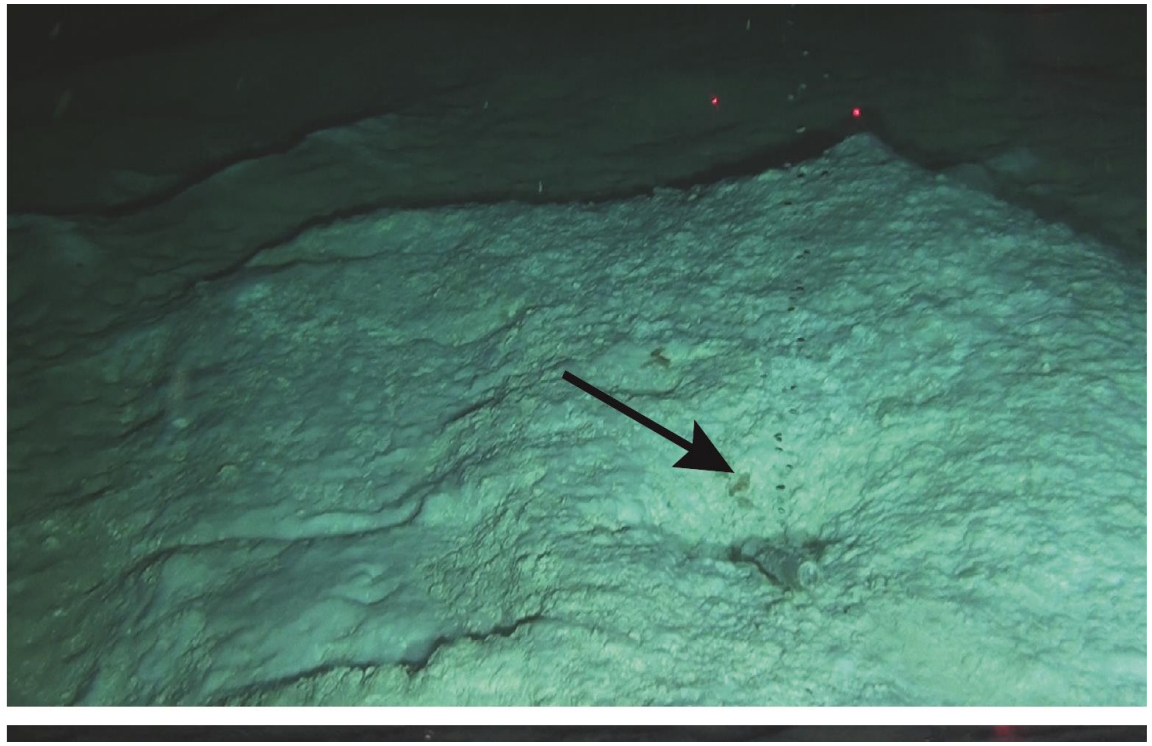




Ingrassia et al., 2015

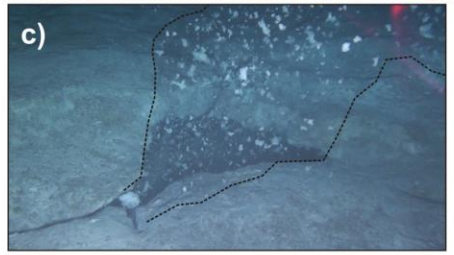
ZGP – FLUID EMISSIONS IN THE WATER COLUMN





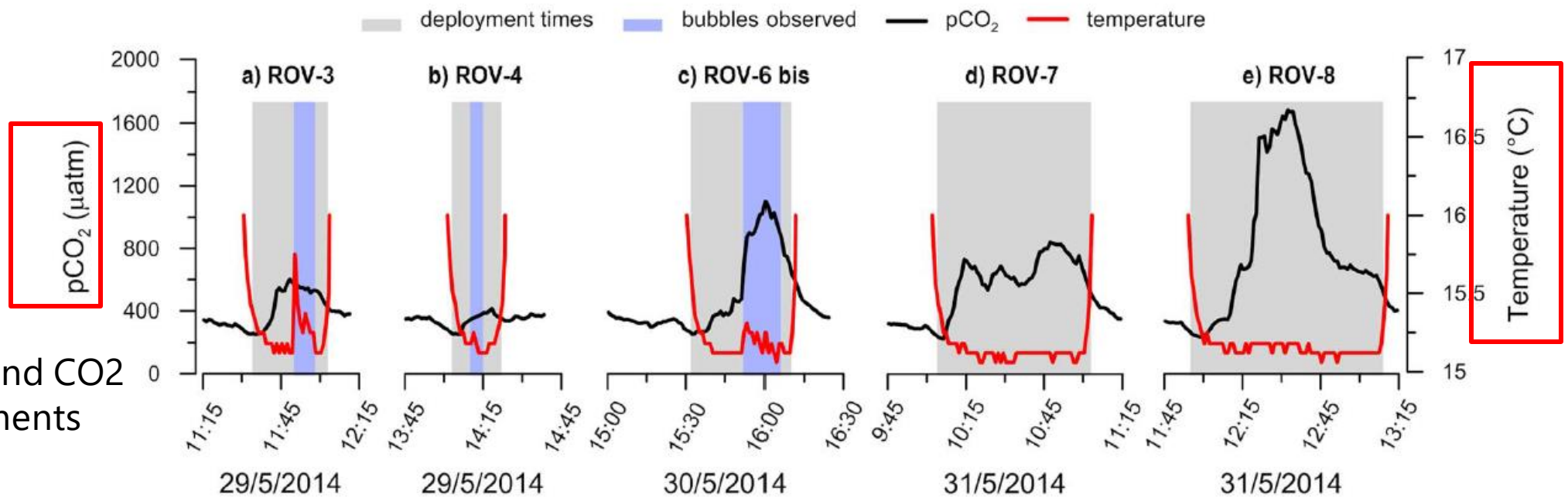
ZGP – FLUID EMISSIONS FROM THE SEAFLOOR

Different discharge modality

Rate	Seafloor morphology	Discharge modality
slow → moderate → rapid		diffuse seepage ↓ pockmarking seafloor
		continuous bubble streams ↓ lithified sediments
		continuous fluid cloud emissions ↓ authigenic crusts

ZGP – FLUIDS GEOCHEMISTRY

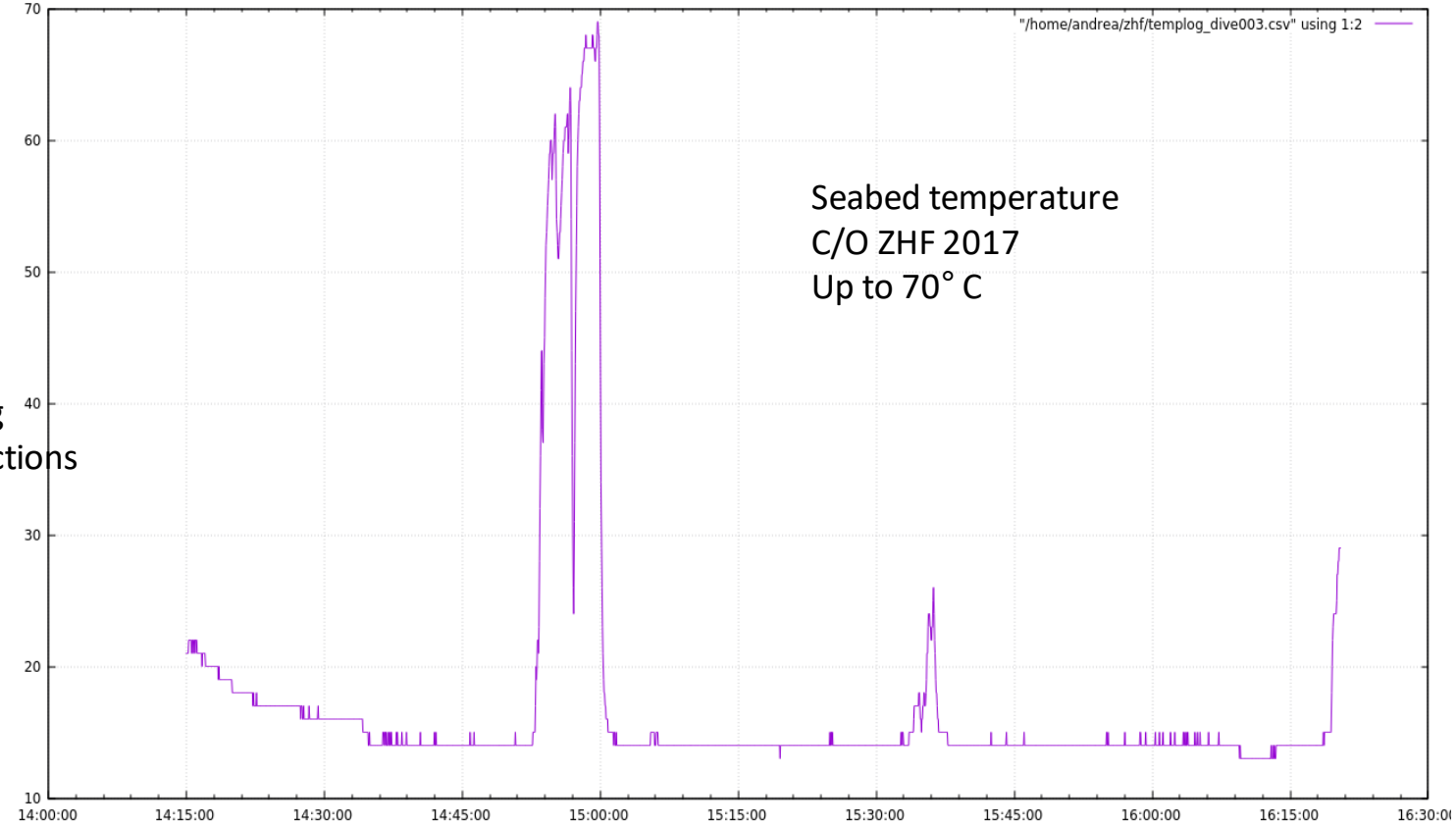
						Bubbling Gases								
#	Sample Depth	He	H_2	O_2	N_2	CO	CH_4	CO_2	He/Ne	R/Ra	R/Ra_c	Error	$\delta^{13}C_{CO2}$	$\delta^{13}C_{CH4}$
11	BT1-129 m	7.9×10^{-3}	7.0×10^{-4}	12.25	33.40	1.9×10^{-4}	2.6×10^{-4}	50.94	7.71	3.49	3.60	0.02420	n.a.	-43.70
12	BT1-129 m	8.2×10^{-3}	9.0×10^{-4}	11.34	31.87	1.3×10^{-4}	2.6×10^{-4}	55.08	7.11	3.50	3.62	0.02434	n.a.	n.a.
13	BT4-127 m	5.8×10^{-3}	bdl	12.75	30.28	1.9×10^{-4}	1.9×10^{-4}	54.22	5.47	3.41	3.56	0.02395	n.a.	n.a.
14	BT4-127 m	6.4×10^{-3}	bdl	13.62	35.98	bdl	2.1×10^{-4}	48.93	10.19	3.48	3.56	0.02394	n.a.	−43.63



In-situ T and CO2 measurements

ZGP – SEABED TEMPERATURE

WATER temperature
C/O ZHF 2017
Up to 60° C
Italiano et al., 2019
Enriched in major ions (e.g., K, Na, Mg)
«concentrated seawater»
likely due to boiling.
Mg is slightly depleted for precipitation of Mg secondary minerals during water-rock interactions



Seabed temperature
C/O ZHF 2017
Up to 70° C

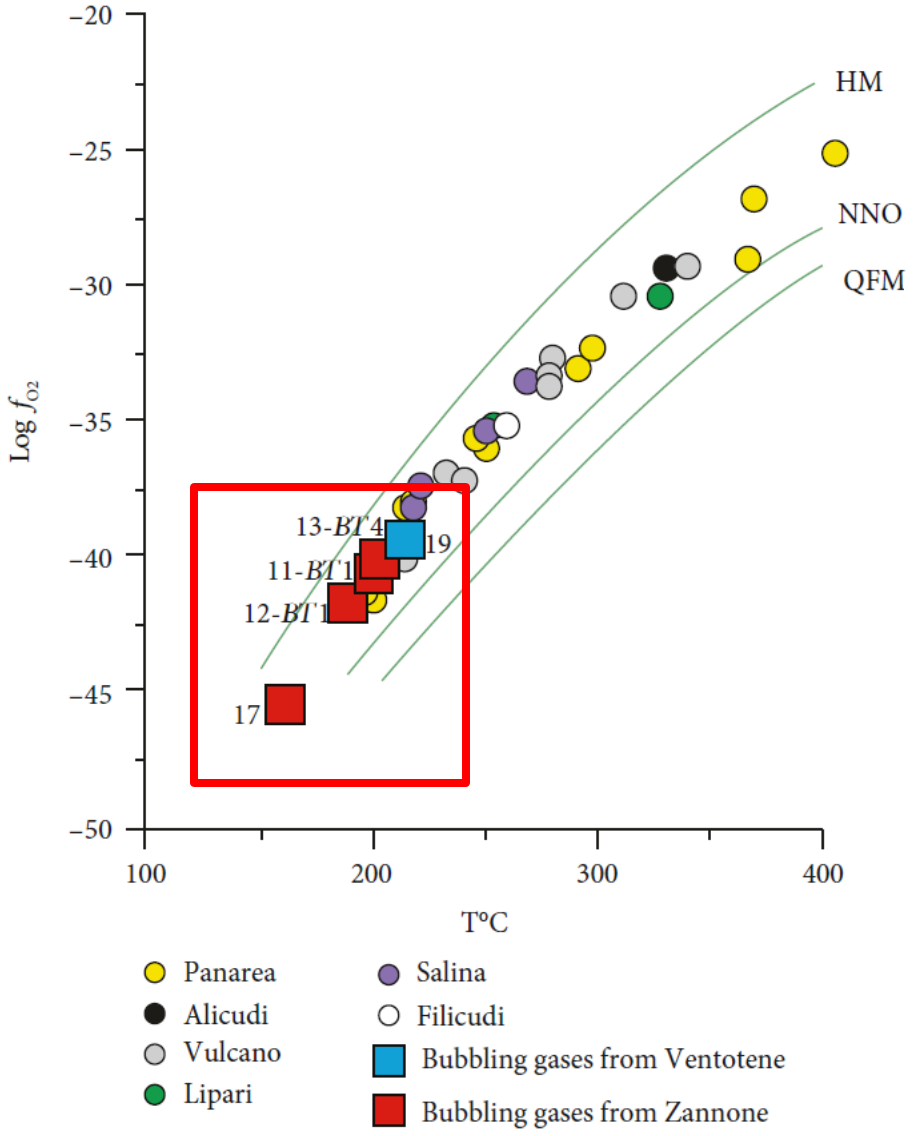
CO2 dominated degassing with magmatic signature and contribution of mantle volatiles >> residual magma batches similar to Pleistocene trachyites

Reservoir conditions (equilibrium zone: fluids re-equilibrate at T-P conditions)

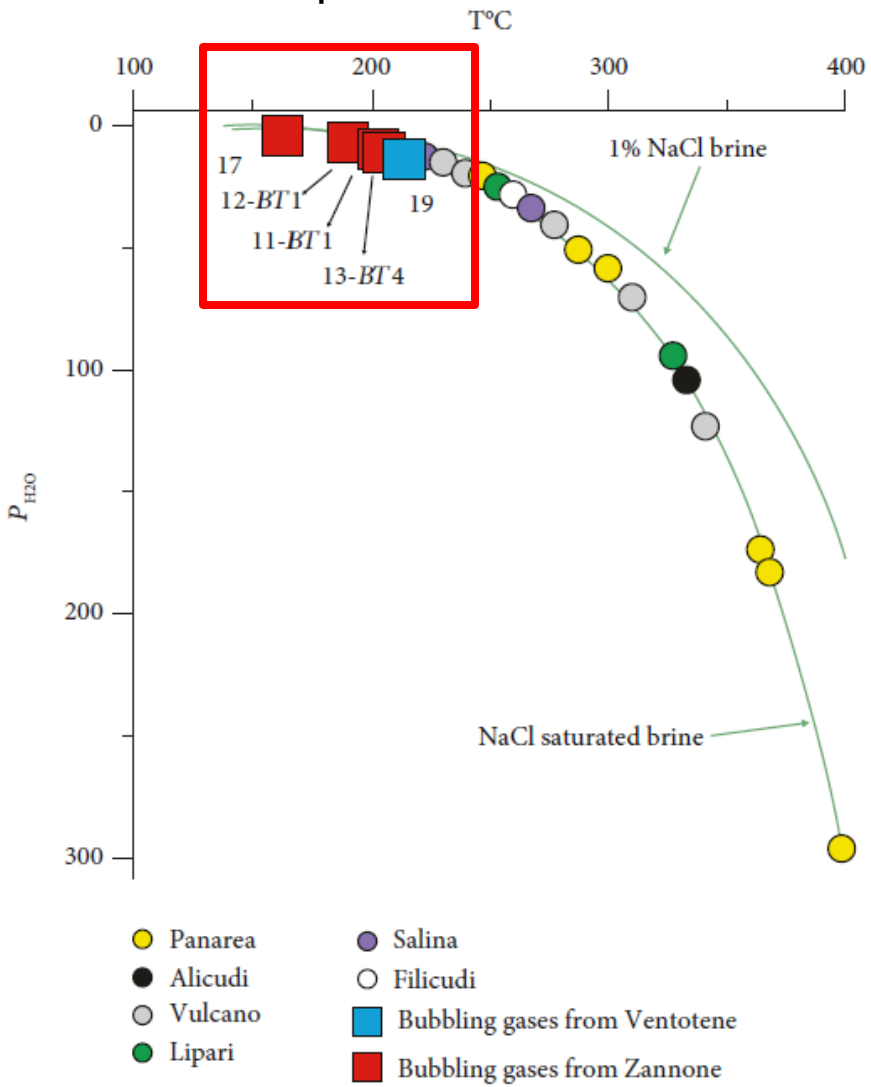
Equilibrium TEMP and PH2O (RESERVOIR T and P; equilib. zone)

Teq= 150-200°

PH20eq= 5-18 bar

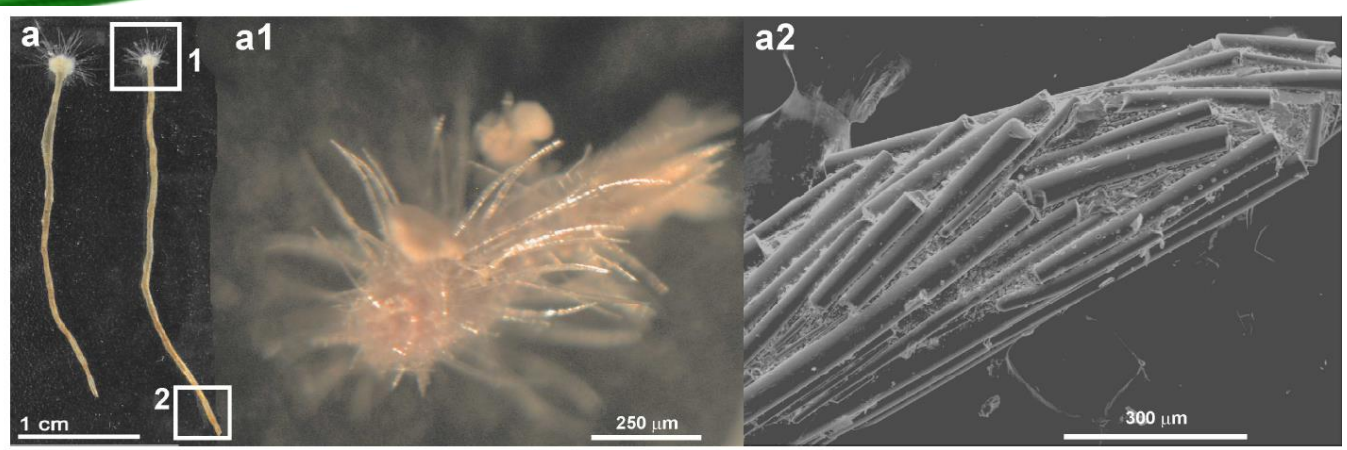


Italiano et al., 2019



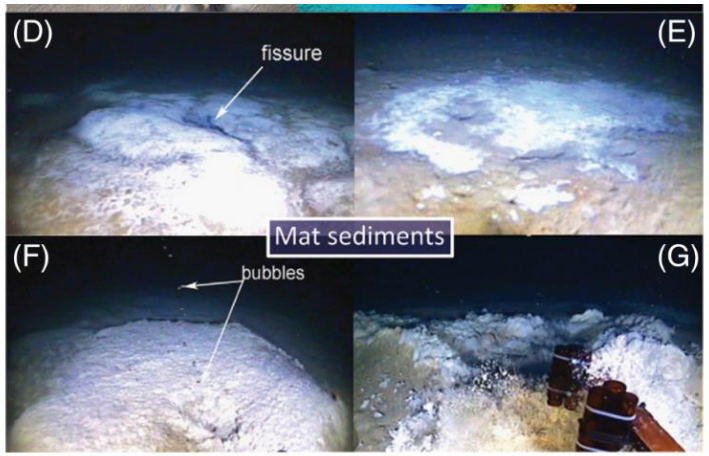
ZGP – BENTHIC FORAMS AND BACTERIA

Di Bella et al., 2018



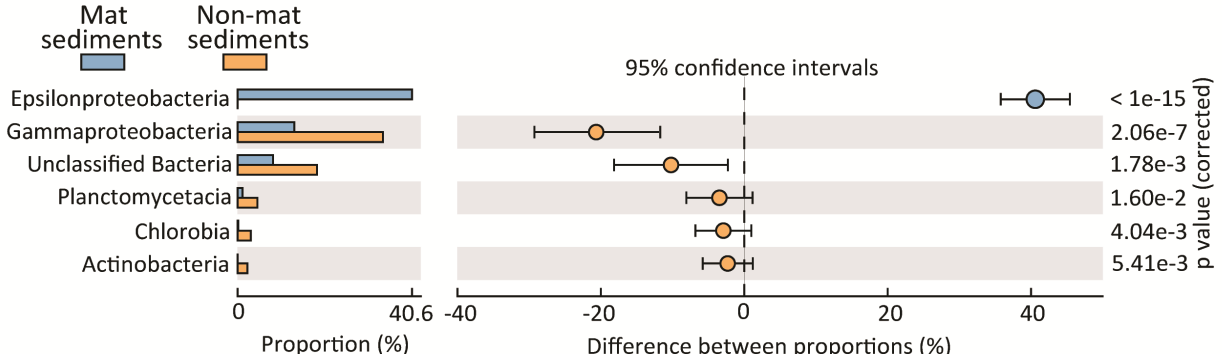
NON CALCAREOUS TESTS

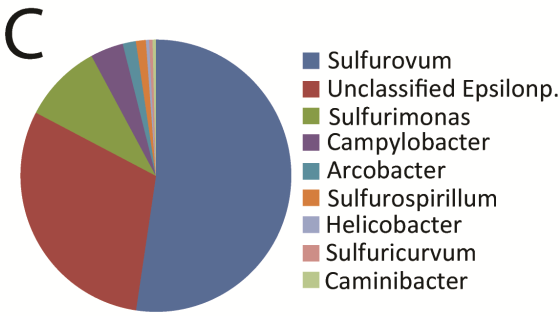
SPICULOSIPHON OCEANA



EG., SULFUR-OXIDIZING BACTERIA (SULFUROVUM GEN.) AND ASSOCIATED VIRUSES

Rastelli et al., 2017

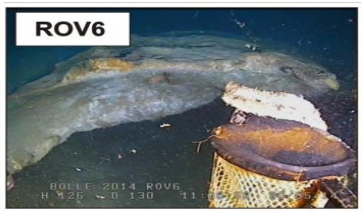




ALTERATION-MINERALIZATION PRODUCTS:
CLUES FOR THE SUB-SEAFLOOR STRUCTURE

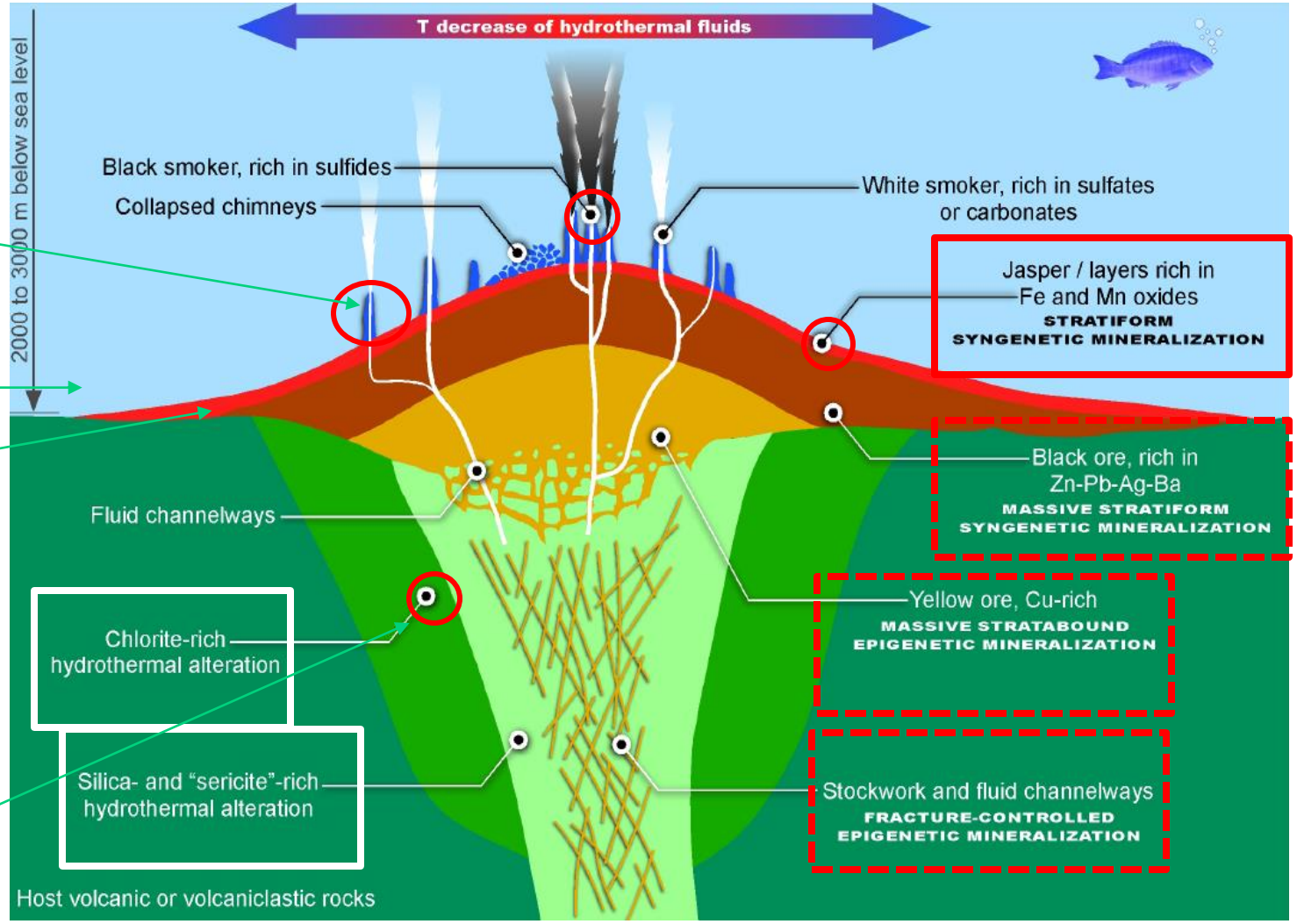
Mineralized sediment

Small chimneys

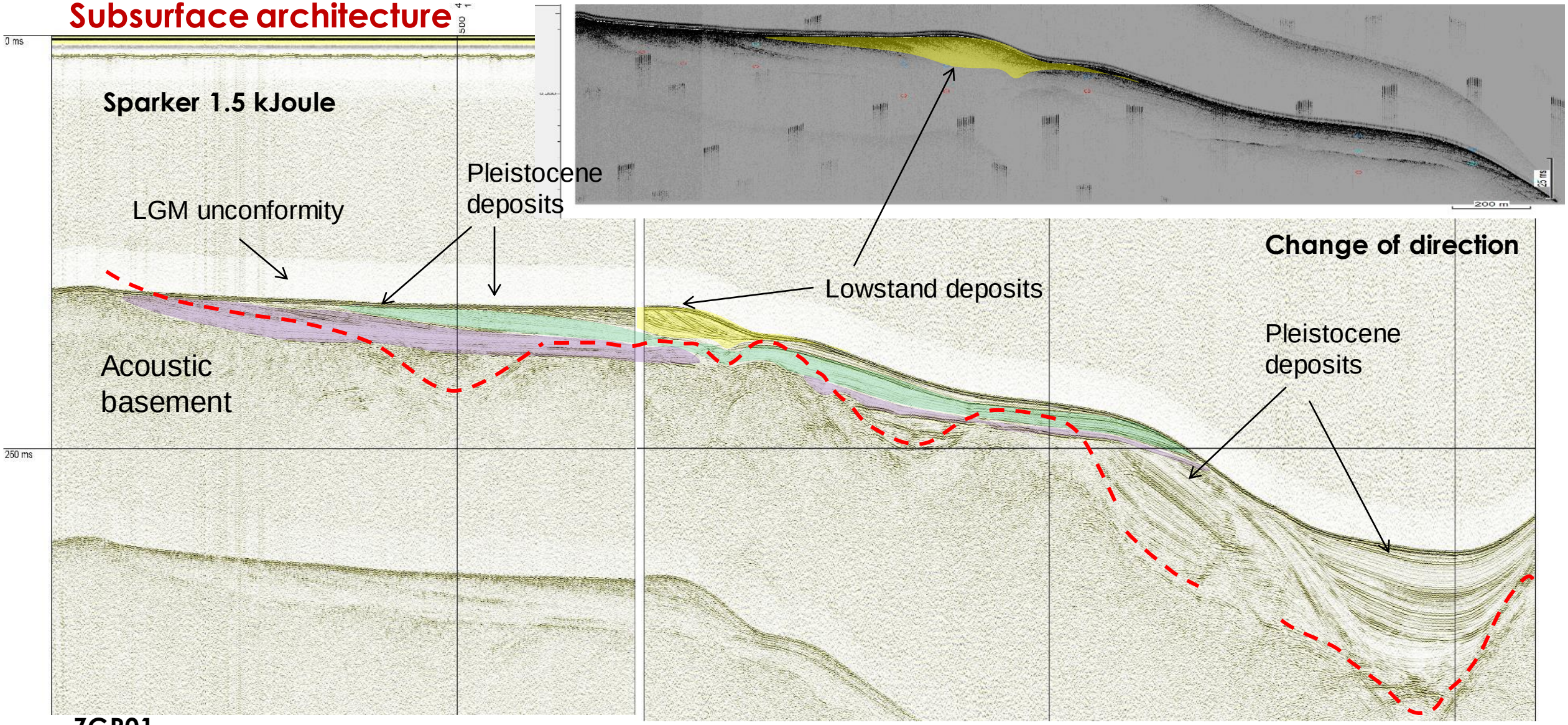


SYNGENETIC MINERALIZATION Authigenic crusts
(NATIVE SULFUR AND SULFUR-CEMENTED SANDS)

ALTERED RHYOLITE CLASTS (SERICITE TO PYRITE-CHLORITE FACIES) HYDROTHERMAL BRECCIAS BY HYDROTHERMAL ERUPTIONS



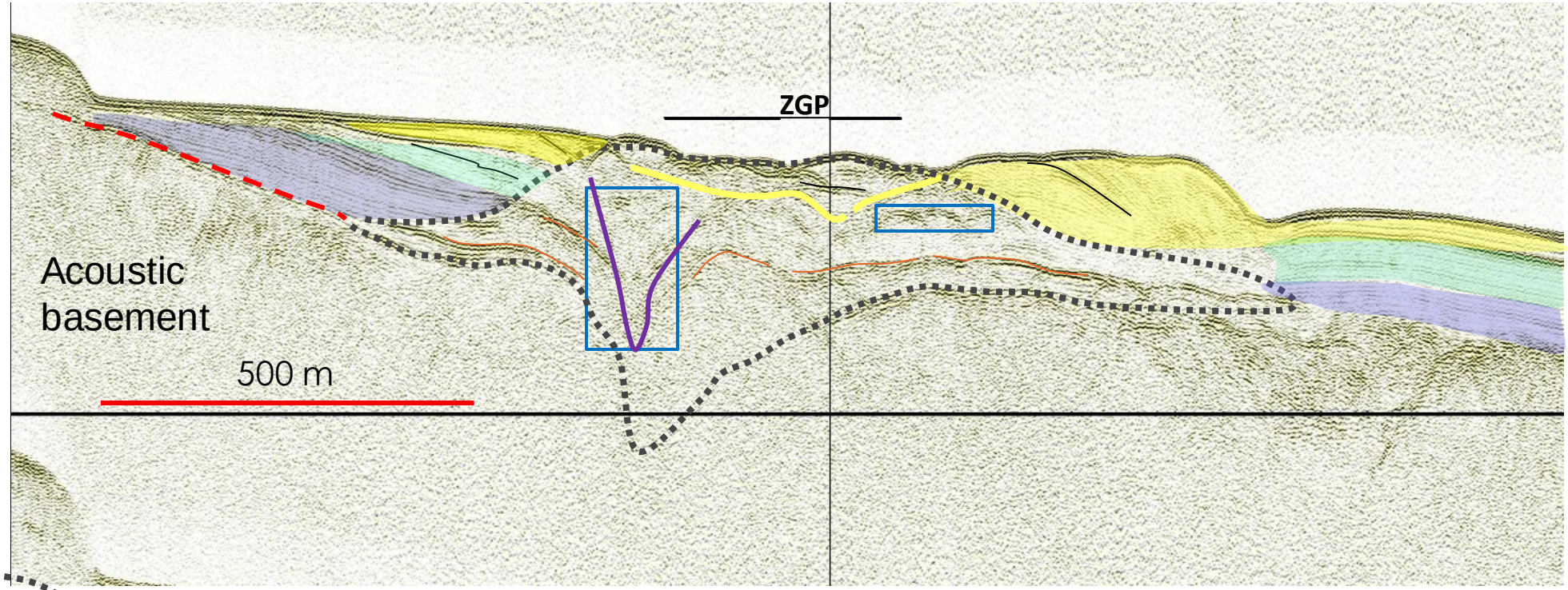
Subsurface architecture



ZGP01

Outside of ZGP: Standard stratigraphy

ZGP06
Inside ZGP



Eye-shaped zone with acoustic anomalies

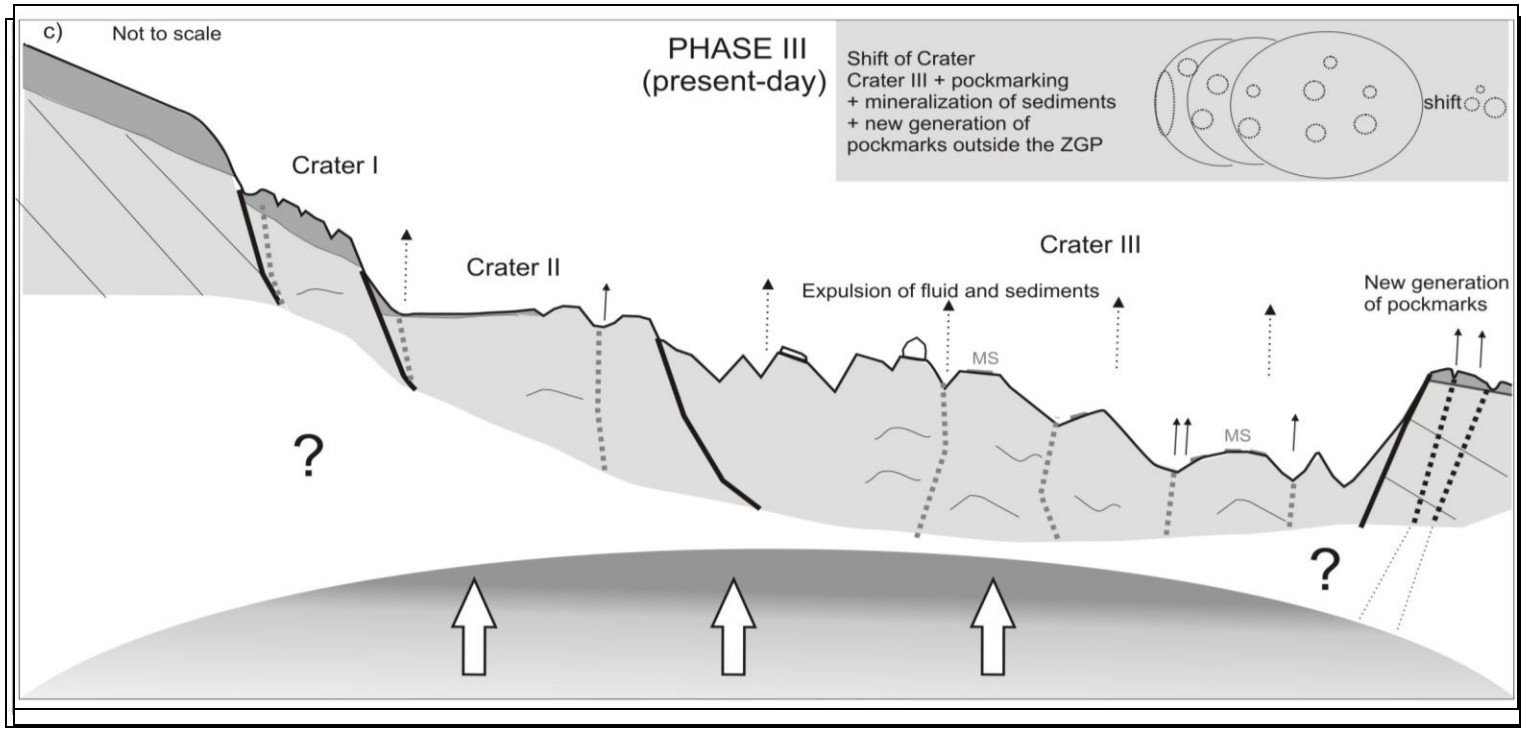
Acoustic blanking: fluids

Chaotic reflections: sediment disruption

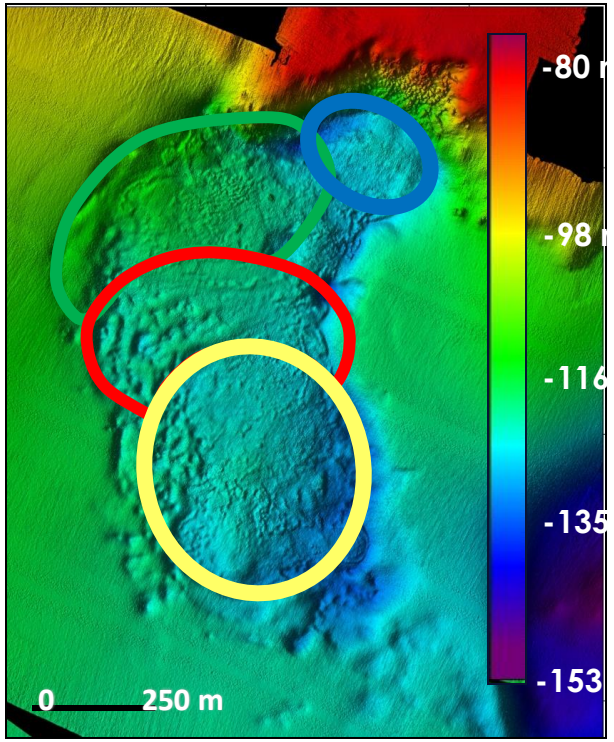
Hyperbolae: hard pavements, complex morphology (pockmarks)

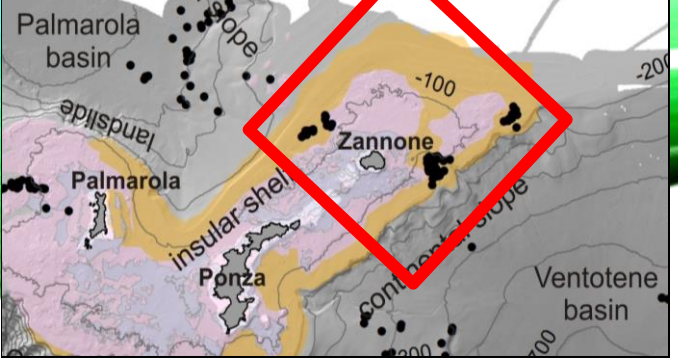
Bright spots: gas- charged sediment

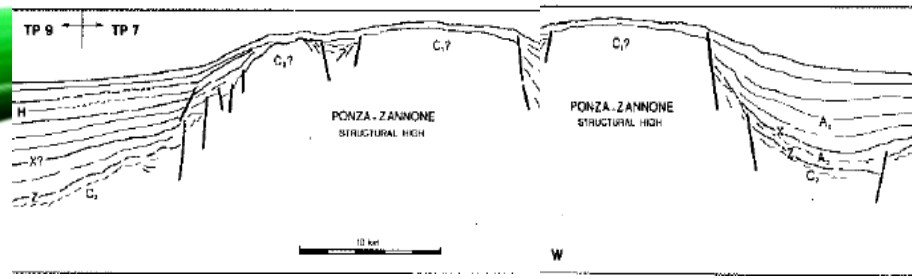
GIANT POCKMARK GENETIC MODEL



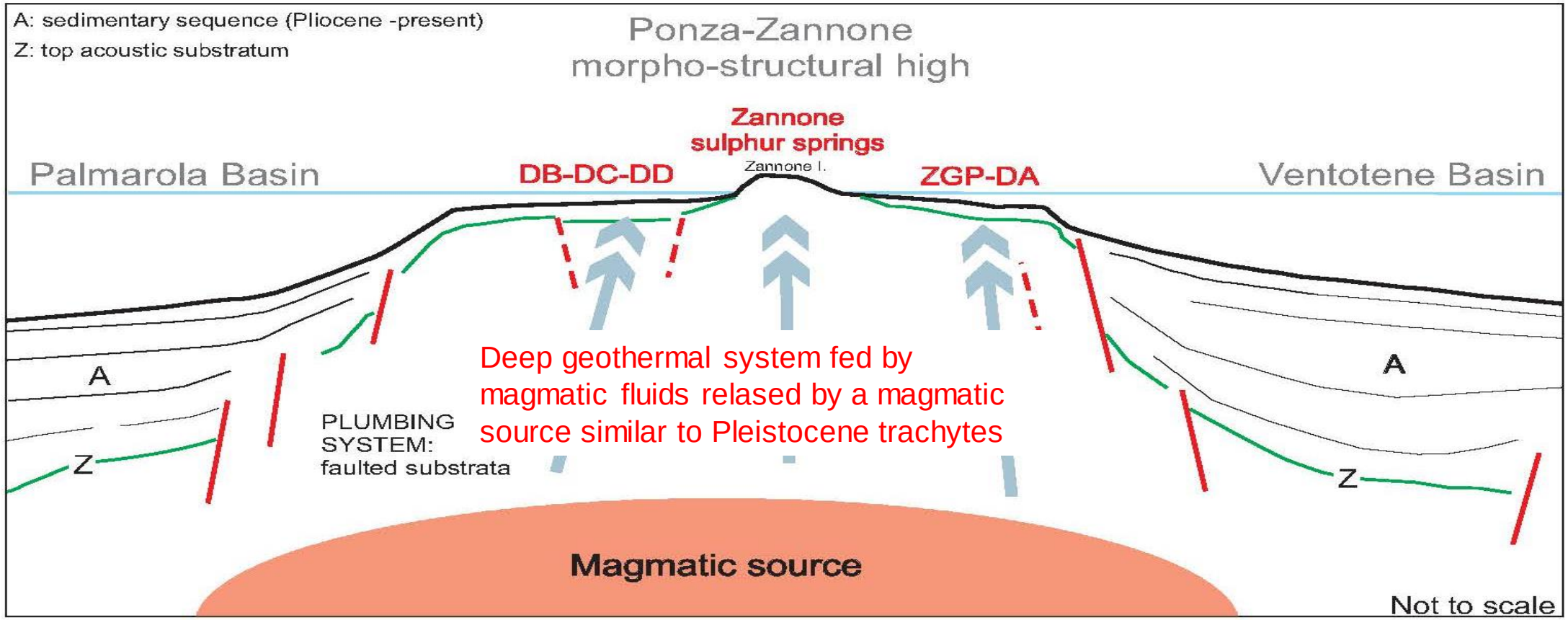
Ingrassia et al., 2015







ZHF GENETIC MODEL



Upper part: volcanic felsic rocks and Pleistocene sedimentary deposits hosting mounded/eye-shaped hydrothermal complexes

Lower part: sedimentary rocks and continental crust

CONCLUDING REMARKS

- The ZHF represents a shallow hydrothermal system with a deep magmatic source, fluids rise through the faulted basement of the Zannone high; polyphased activity
- Highly heterogeneous seabed including pockmarks, hard pavements and mounds, diffuse seepage and punctual emissions
- The ZGP hosts extreme environments related to vent activity (high temperature, acidic condition) with bacterial mattes, absence of calcareous forams and peculiar agglutinated species (*Spiculosiphon oceana*) at the seabed
- Mineralizations and alteration products are consistent with hydrothermal facies of felsic volcanics hosting massive sulfides;
- Altered rhyolite clasts and pockmarks suggest occurrence of hydrothermal eruptions
- First models on the origin of giant pockmarks, the ZGP hydrothermal complex and the ZHF hydrothermal system