Uncovering a Salt Giant

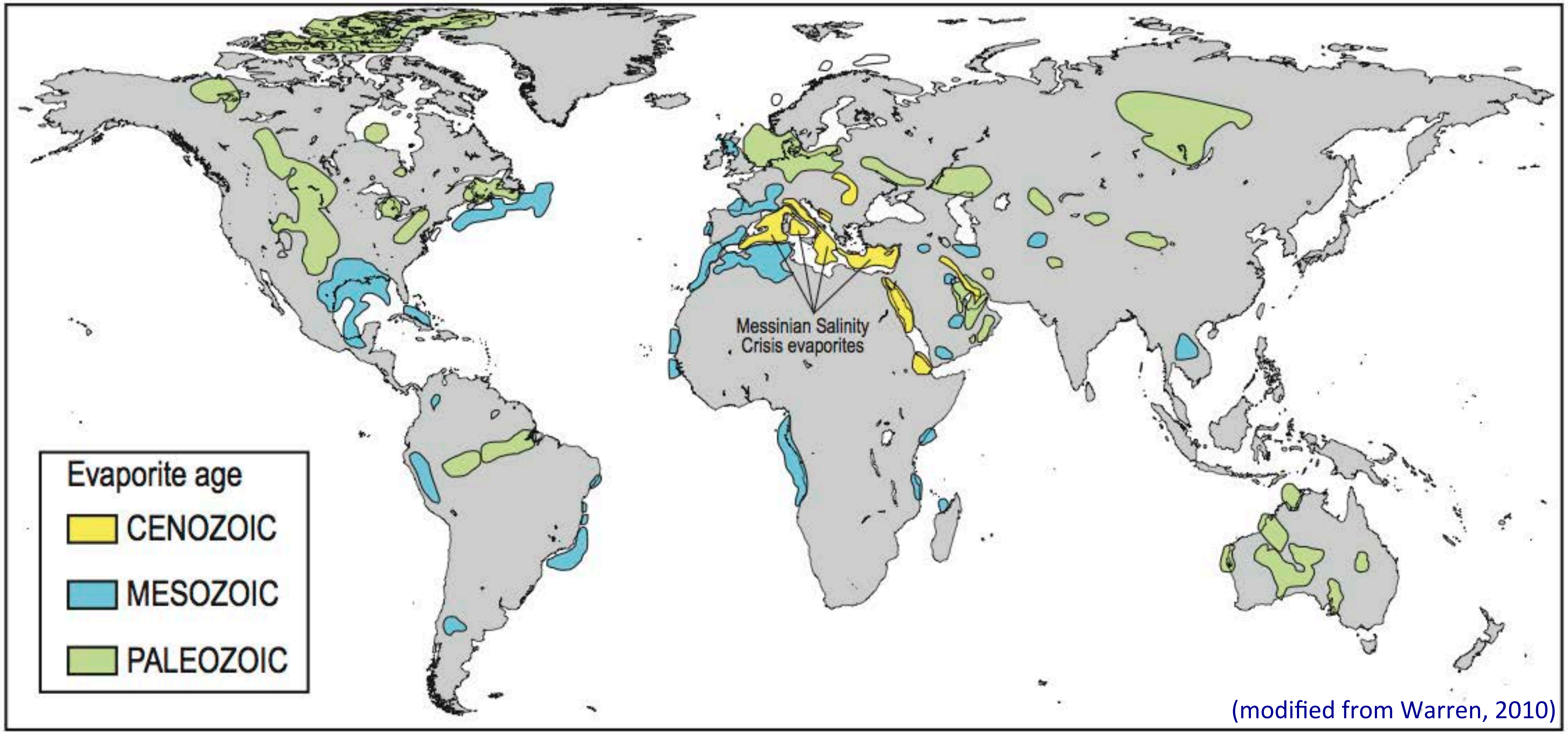
Umbrella proposal of the Deep-Sea Record of Mediterranean Messinian Events (DREAM) multi-phase drilling project

Angelo Camerlenghi, Giovanni Aloisi, Sierd Cloetingh, Hugh Daigle, Gert DeLange, Rachel Flecker, Daniel Garcia-Castellanos, Zohar Gvirtzman, Christian Hübscher, Wout Krijgsman, Junichiro Kuroda, Johanna Lofi, Stefano Lugli, Agnès Maillard-Lenoir, Yizhaq Makovsky, Vinicio Manzi, Terry McGenity, Andrea Moscariello, Marina Rabineau, Marco Roveri, Francisco Javier Sierro, Nicolas Waldmann

…….and many others

Presented by A. Moscariello

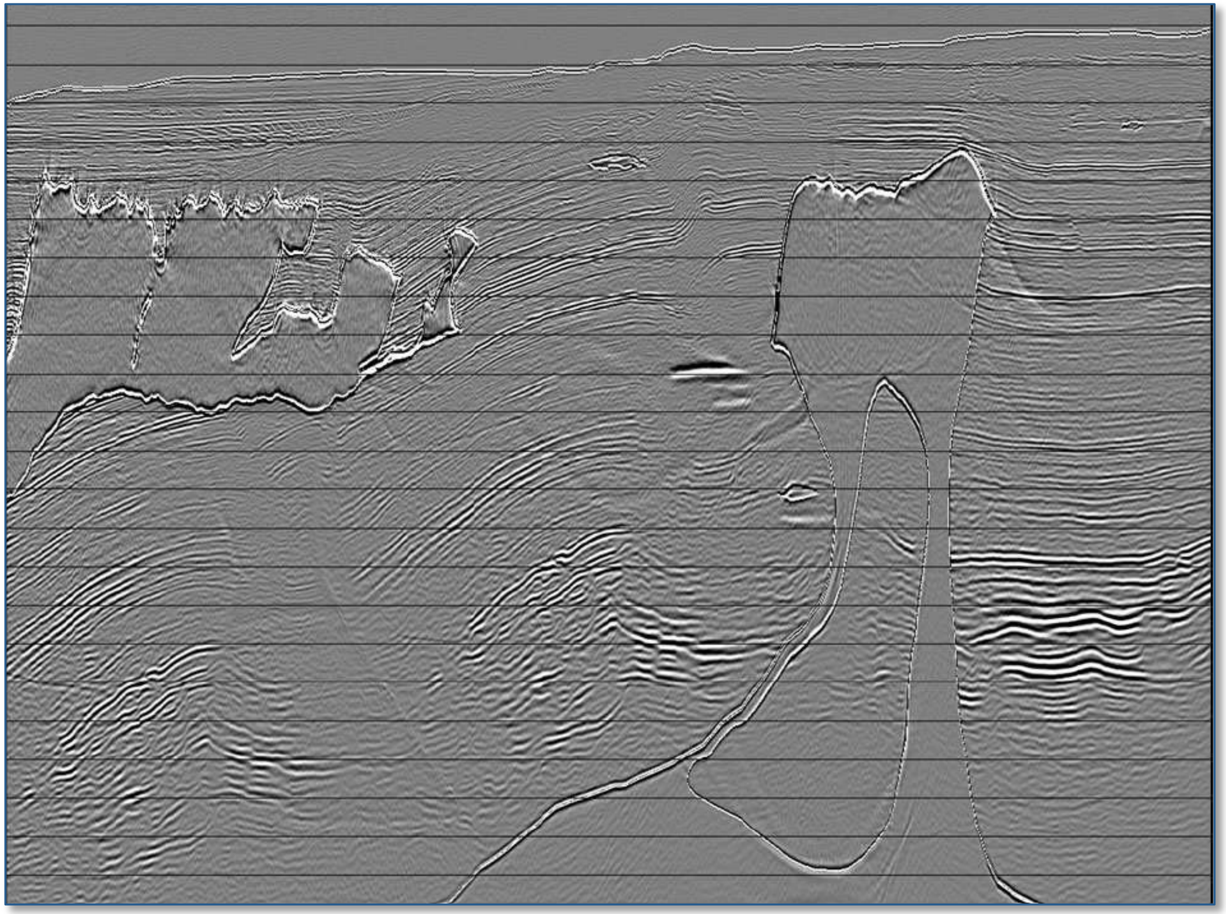
Geographical and temporal distribution of salt giants giants



(modified from Warren, 2010)

Saline giants are found only in the most recent 600 million years of Earth history. The first great change in oceanic salinity (from an inferred value 1.5 to 2 times the modern value) probably occurred during the latest Precambrian when huge quantities of salt were sequestered from seawater in giant Neoproterozoic evaporite basins (Knauth, 2004).

Most salt giants in the geological record are old and have typically experienced intense deformation (Davies and Engelder, 1985; Hudec and Jackson, 2007).



Images courtesy Cristian Hübscher, Hamburg

They are commonly the focus of applied research by the petroleum industry because of:

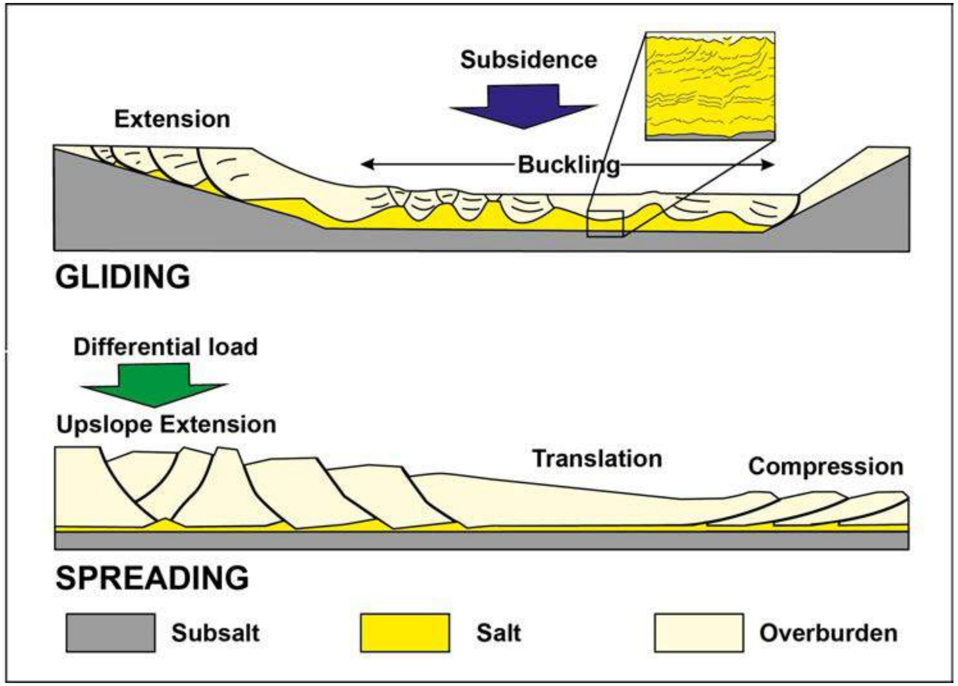
- **sealing capacity** of salt rock
- the recurrent association with **structural traps** for hydrocarbon fluids,
- **perturbations to *in situ* stresses** associated with salt bodies.

Images courtesy Cristian Hübscher, Hamburg

Besides the industrial interest: The global importance of salt giants

- Salt giants are the **sedimentary expression of extreme environmental events of global relevance**, often resulting from a combination of deep earth-system dynamics and climatic forcing.
- Salt deposition **impacts the structural, chemical and biological evolution of the sedimentary basins** in which it accumulates, and affects global ocean salinity.
- Because of the variety of chemical environments, **salt giants have the potential to harbour an unprecedented diversity of microbial life** with exceptional metabolic activity.

- Being almost free of any overprinting by plate-tectonic processes, **young salt structures reflect almost pure salt tectonics caused by differential load and gravitational spread.**
- Quantitative understanding of salt dynamics and associated fluid flow is fundamental to the **assessment of submarine geohazards, and O&G exploration & production risks**.



End-member conceptual models for early salt deformation caused by basin subsidence and marginal tilt (gliding), and caused by differential load.

Gliding is considered to have started during the salt deposition phase creating internal salt deformation.

Despite their global occurrence and general importance within the global Earth system, **there is currently no complete stratigraphic record through an un-deformed salt giant.**

Similarly, **there is a significant lack of knowledge about the factors controlling salt giants deposition, their early evolution, the impact that thick salt deposition exerts on the isostatic response of continental margins and on sub-salt formations.**

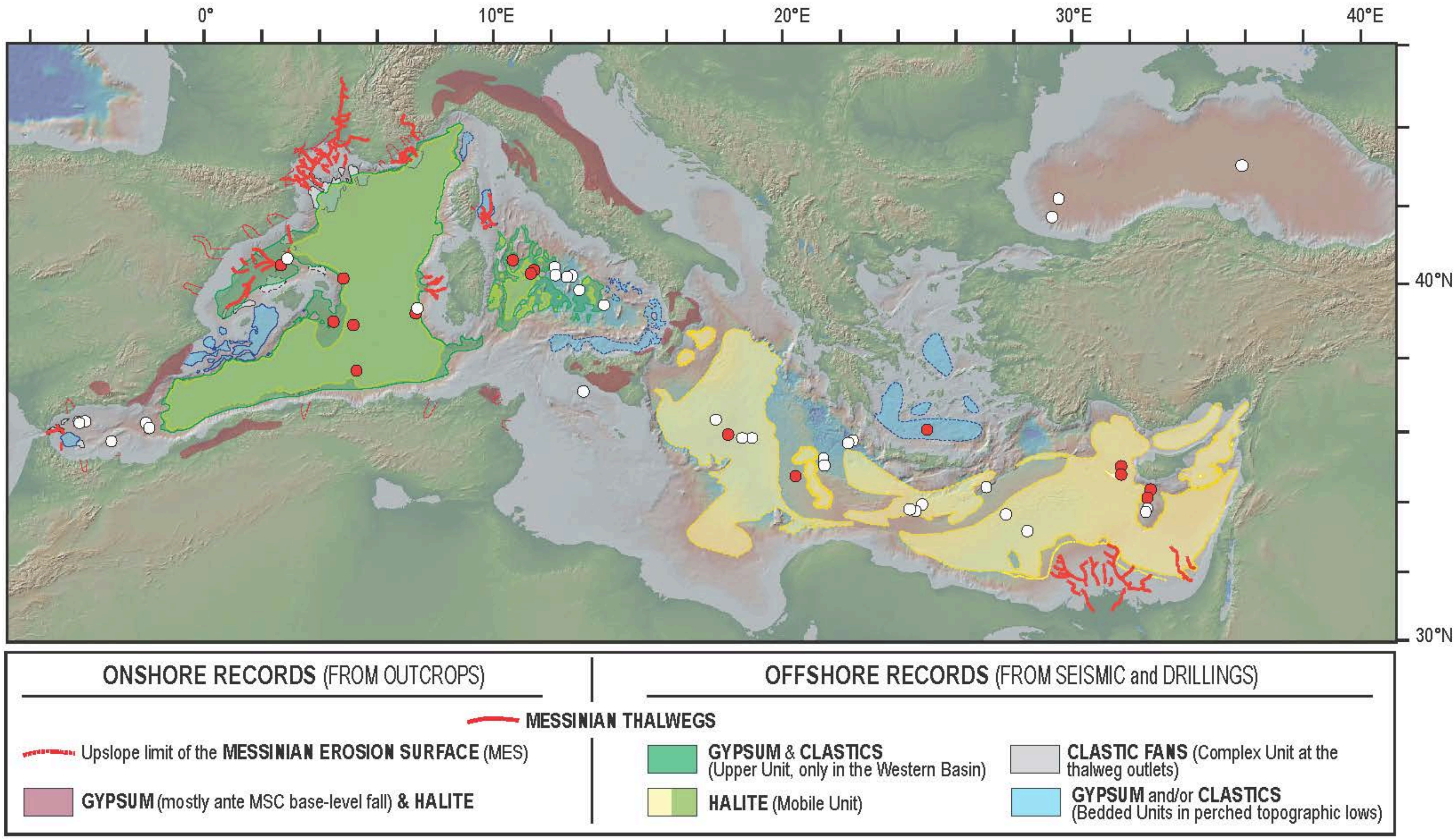
Drilling the **Messinian salt giant in the Mediterranean** represents a **unique opportunity to understand the sedimentary history, stratigraphy, biosphere and fluid dynamics of a salt giant in a state close to its original depositional configuration**.

This is a novel concept for scientific drilling in sedimentary basins and addresses fundamental questions posed in the **IODP (International Ocean Discovery Program)** Initial Science Plan and beyond.

IODP INTERNATIONAL OCEAN DISCOVERY PROGRAM

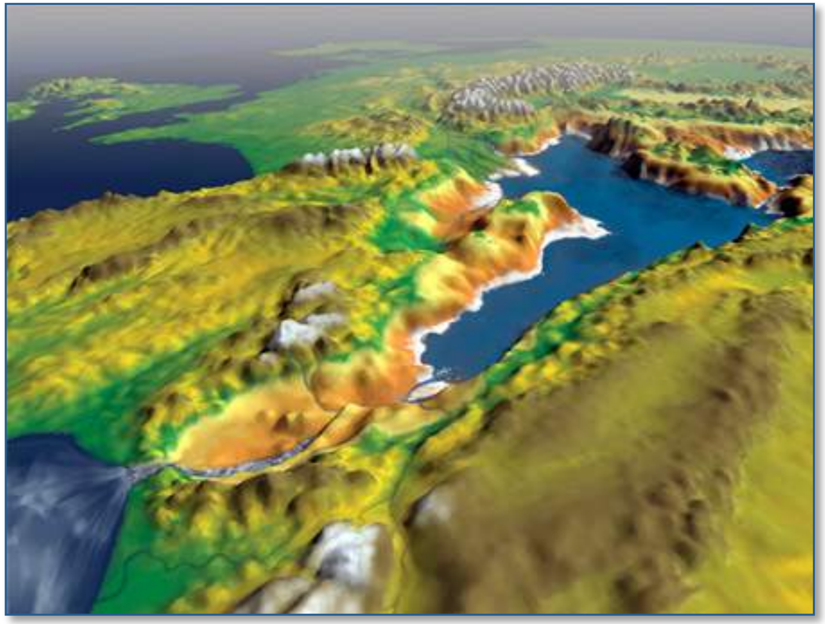
http://www.iodp.org

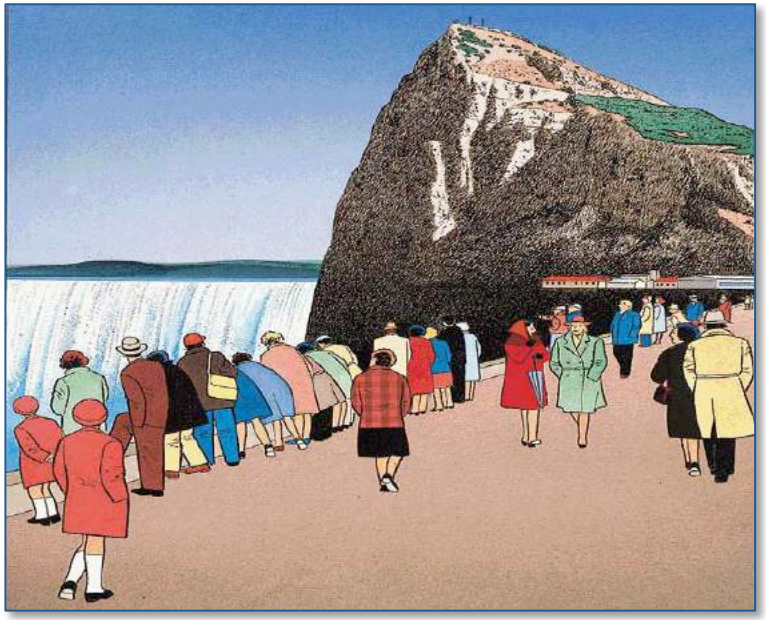
About **6 million years ago** the Mediterranean Sea was transformed into a **giant saline basin**, one of the largest in the Earth's history and



Lofi et al., in preparation, modified after Maillard et al., 2011

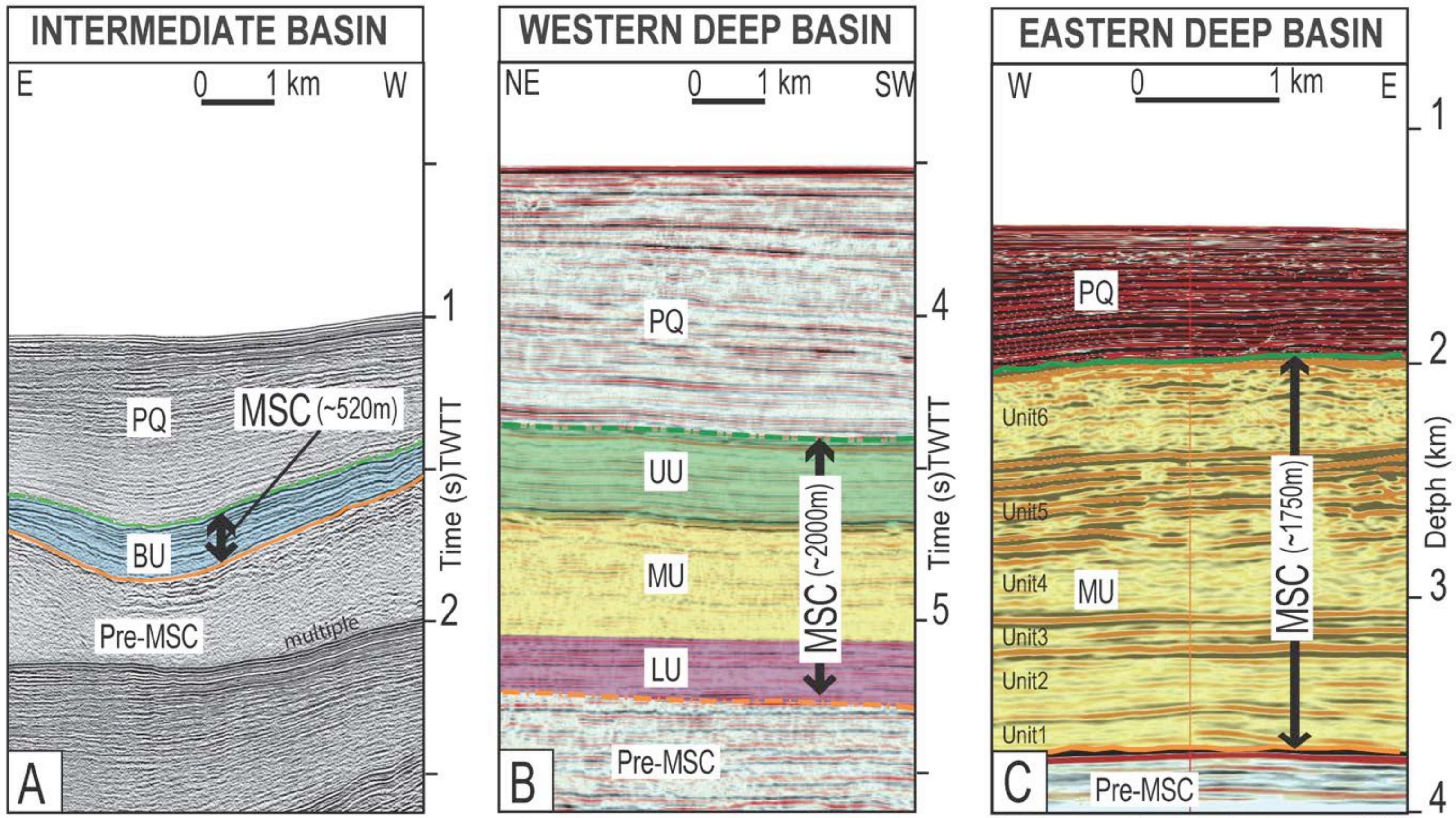
- More than 10^6 km^3 of salt (6% of the dissolved oceanic salt) accumulated, locally exceeding a thickness of 3 km in the deep basins.
- This extreme, but geologically brief event (640 ka, 5.97 – 5.33 Ma), changed the chemistry of the global ocean and had a permanent impact on both the terrestrial and marine ecosystems of a huge area surrounding the Mediterranean.
- Increasing Mediterranean salinity was driven by tectonic restriction of exchange with the Atlantic Ocean and modulated by the impact of climatic precession on surface water salinity.





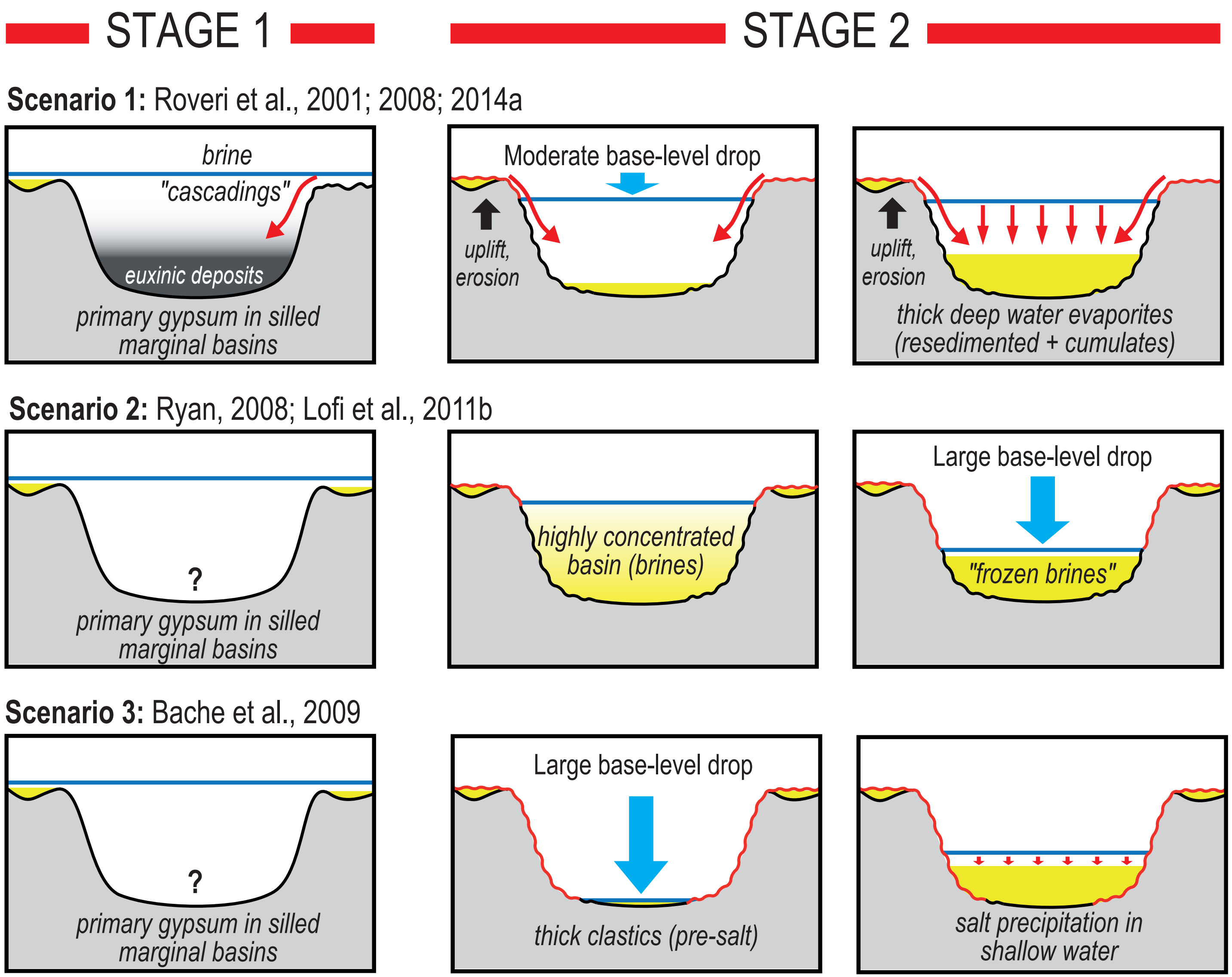
Left: A view of the desiccated Mediterranean basin during the Messinian Salinity Crisis Source: http://www.wired.com/wiredscience/2009/12/mediterranean-flood. Right: Artist's impression of the Early Pliocene Gibraltar Strait flooding (©1986 Guy Billout, first published in The Atlantic Monthly).

Seismic markers of the Messinian Salinity Crisis



Messinian seismic markers on the Mediterranean continental margins (Balearic Promontory) (A) and in the deep Mediterranean Basin: Western Mediterranean (Provençal Basin) (B), and Eastern Mediterranean (Levant Basin) (C). PQ: Pliocene-Quaternary; BU: Bedded Unit; UU: Upper Unit; MU: Mobile Unit; LU: Lower Unit (after Lofi et al., 2011a).

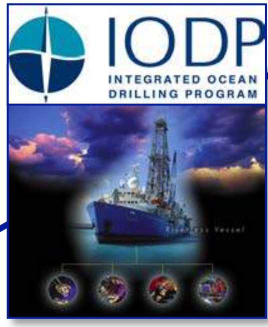
Three (simplified) conceptual scenarii

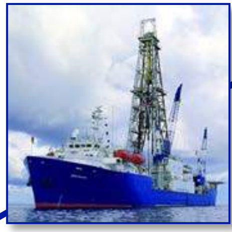


October 2003

The Integrated Ocean Drilling Program (IODP) starts

October 2023





ODP
1985-2003

DSDP
1968-1983

MOHOLE
1958-1966

October 2013

The International Ocean Discovery Program (IODP) starts

Exploring the Earth Under the Sea

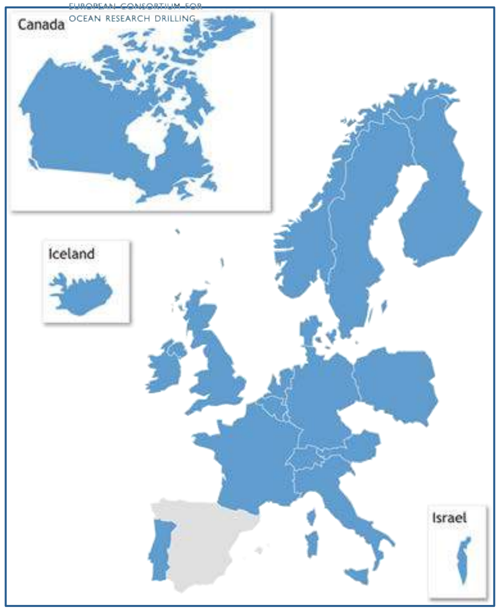
The international Ocean Discovery Program

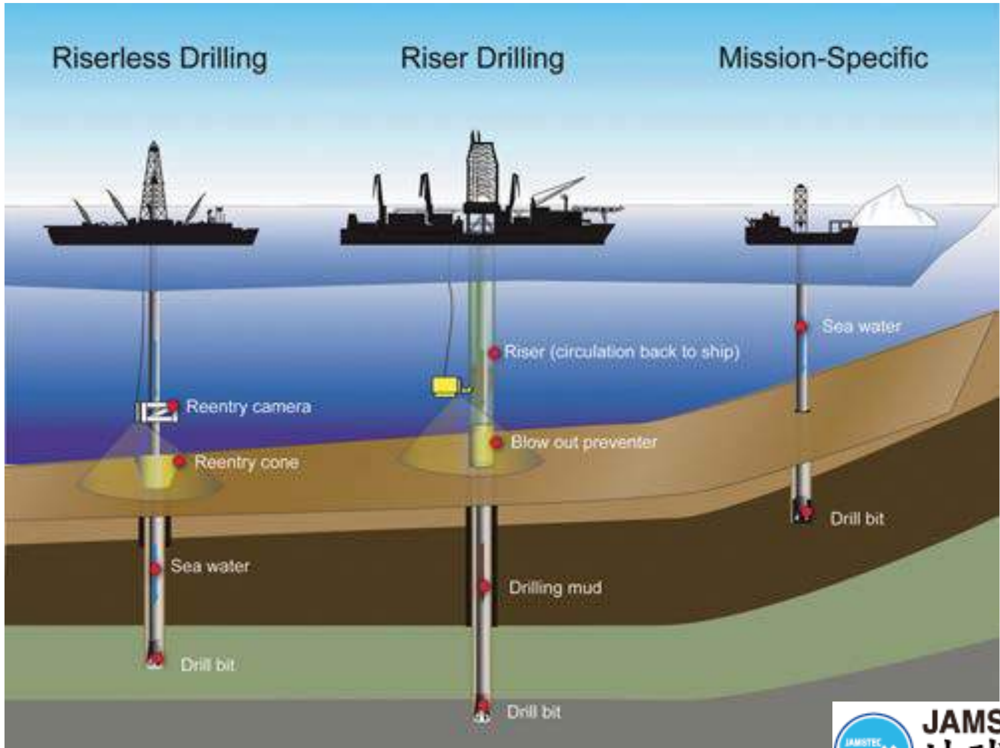
Implementing Organizations (IOs)

USIOU.S. Implementing Organization
http://www.iodp-usio.org/
● Consortium for Ocean Leadership
● Texas A&M University (TAMU)
● Lamont-Doherty Earth Observatory, Columbia University (LDEO)

CDEX The Center for Deep Earth Exploration
http://www.jamstec.go.jp/chikyu
● Japan Agency for Marine-Earth Science and Technology (JAMSTEC)

ESO ECORD Science Operator
http://www.eso.ecord.org/
● British Geological Survey
● University of Bremen, Germany
● European Petrophysics Consortium (EPC)
University of Leicester (EPC Coordinator), U.K.
Université de Montpellier, France
RWTH Aachen University, Germany



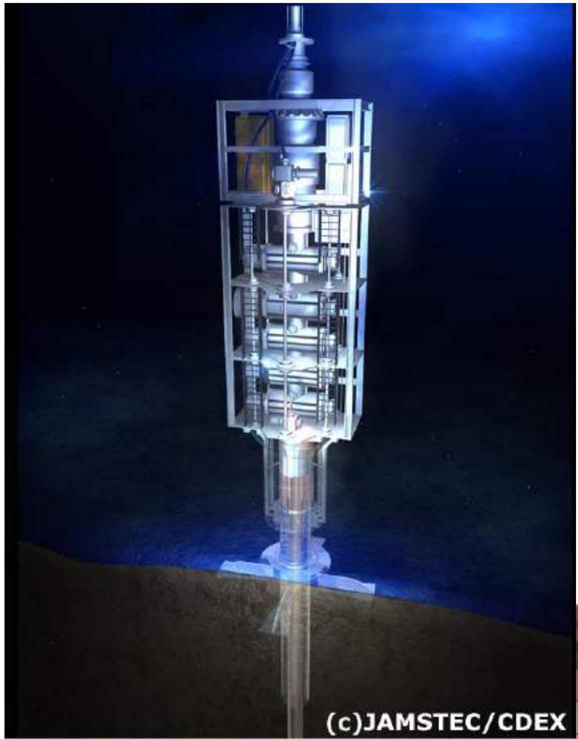


ECORD
European Consortium for Ocean Research Drilling

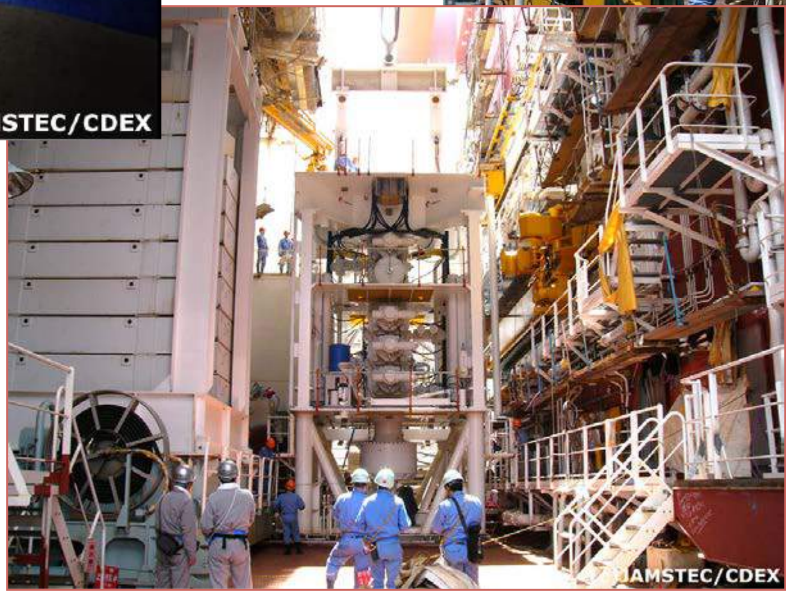
icdp

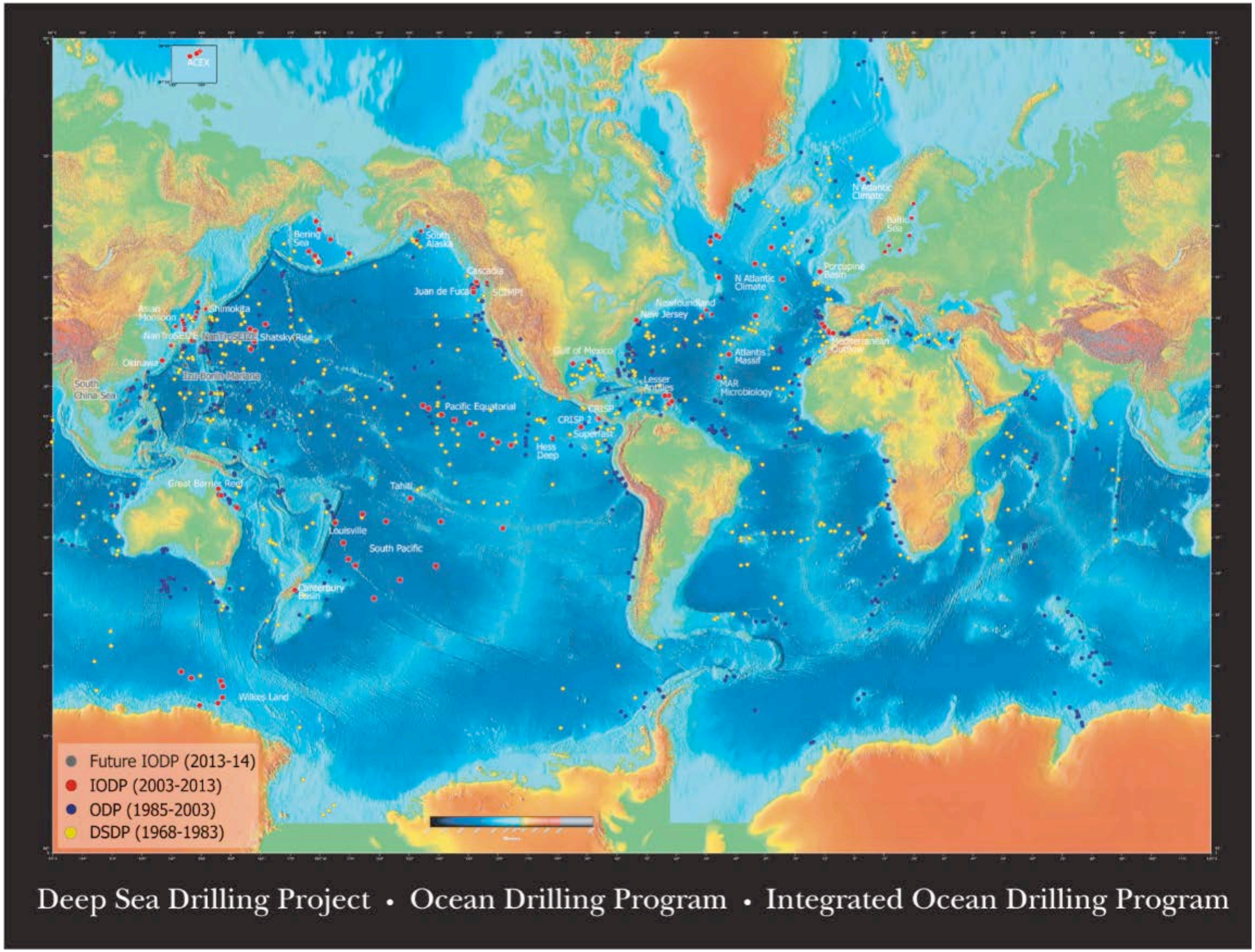
JAMSTEC
地球深部探査センター
CENTER FOR DEEP EARTH EXPLORATION

IODP
INTEGRATED OCEAN DRILLING PROGRAM

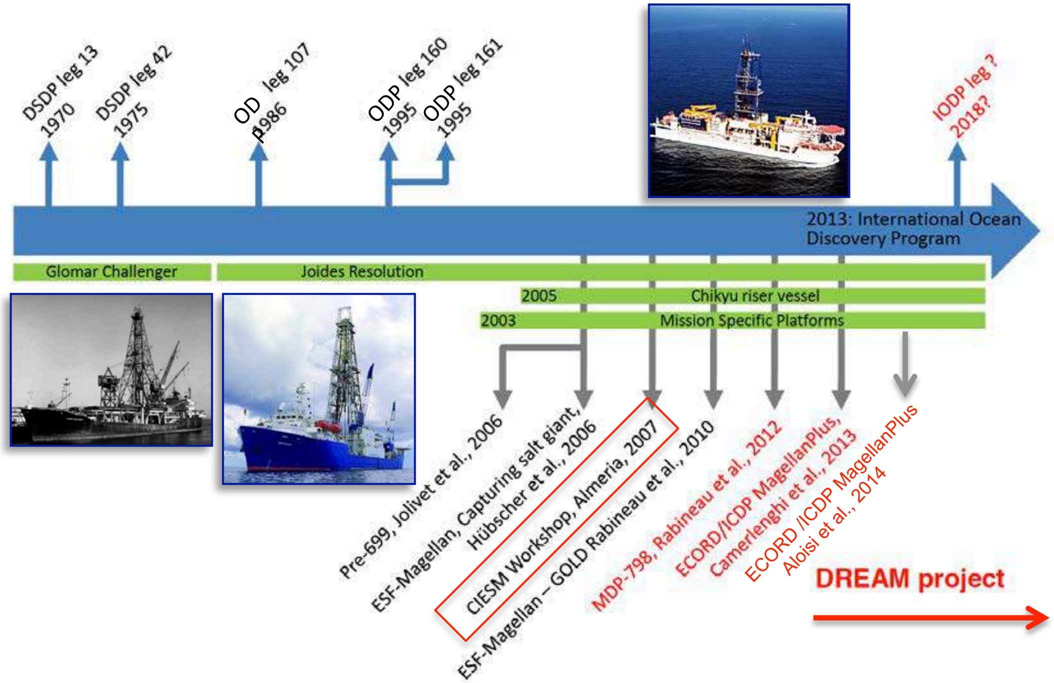

(c)JAMSTEC/CDEX


(c)JAMSTEC/CDEX


JAMSTEC/CDEX


ACEX
Bering Sea
South Alaska
Cascadia
Juan de Fuca
Shimokita
Asian Monsoon
NanTroSEIZE
Shatsky Rise
Okinawa
Izu-Bonin-Mariana
South China Sea
Pacific Equatorial
Gulf of Mexico
New Jersey
Newfoundland
Lesser Antilles
CRISP
CRISP 2
Superfast
Hess Deep
Atlantis Massif
MAR Microbiology
N Atlantic Climate
Porcupine Basin
Baltic Sea
Mediterranean Outflow
Great Barrier Reef
Tahiti
Louisville
South Pacific
Canterbury Basin
Wilkes Land
Future IODP (2013-14)
IODP (2003-2013)
ODP (1985-2003)
DSDP (1968-1983)
Deep Sea Drilling Project • Ocean Drilling Program • Integrated Ocean Drilling Program

Drilling MSC - TIMELINE

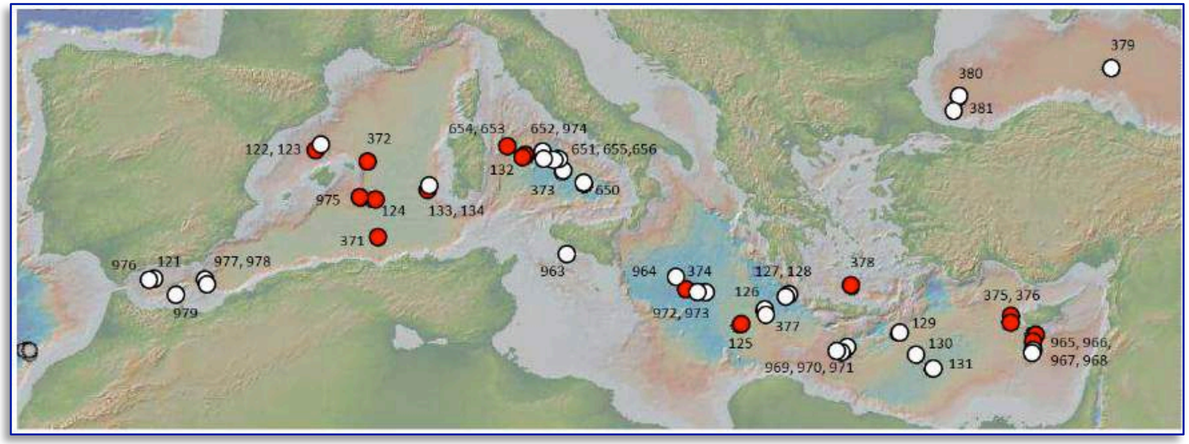


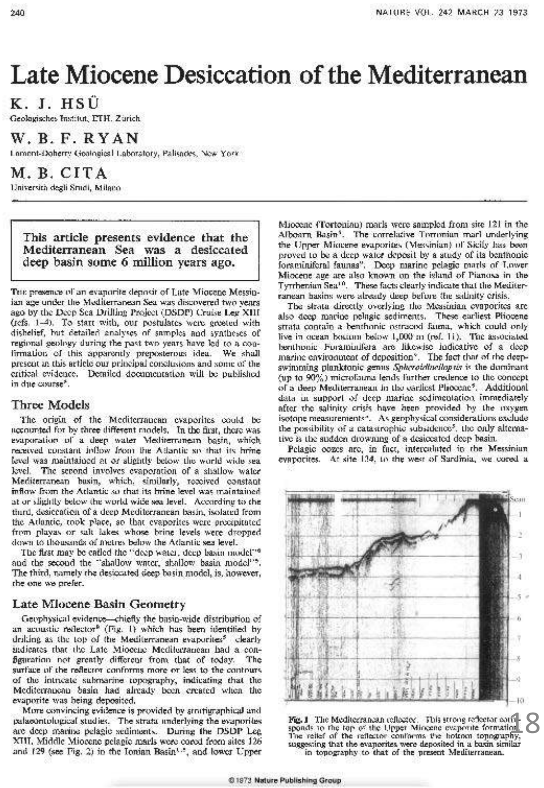
ECORD Science Support & Advisory Committee

ECORD/ICDP – MagellanPlus Workshop Series Program
http://www.essac.ecord.org

Brisighella (Ravenna) Italy
May 05 – 08 2013

IODP ECORD icdp JAMSTEC 地球深部探査センター CENTER FOR DEEP EARTH EXPLORATION MEDGATE





240 NATURE VOL. 242 MARCH 23 1973

Late Miocene Desiccation of the Mediterranean

K. J. HSÜ
Geologisches Institut, ETH, Zurich

W. B. F. RYAN
Lamont-Doherty Geological Laboratory, Palisades, New York

M. B. CITA
Università degli Studi, Milano

This article presents evidence that the Mediterranean Sea was a desiccated deep basin some 6 million years ago.

The presence of an evaporite deposit of Late Miocene Messinian age under the Mediterranean Sea was discovered two years ago by the Deep Sea Drilling Project (DSDP) Cruise Leg XIII (refs. 1–4). To start with, our postulates were greeted with disbelief, but detailed analyses of samples and syntheses of regional geology during the past two years have led to a confirmation of this apparently preposterous idea. We shall present in this article our principal conclusions and some of the critical evidence. Detailed documentation will be published in due course[5].

Three Models

The origin of the Mediterranean evaporites could be accounted for by three different models. In the first, there was evaporation of a deep water Mediterranean basin, which received constant inflow from the Atlantic so that its brine level was maintained at or slightly below the world wide sea level. The second involves evaporation of a shallow water Mediterranean basin, which, similarly, received constant inflow from the Atlantic so that its brine level was maintained at or slightly below the world wide sea level. According to the third, desiccation of a deep Mediterranean basin, isolated from the Atlantic, took place, so that evaporites were precipitated from playas or salt lakes whose brine levels were dropped down to thousands of metres below the Atlantic sea level.

The first may be called the "deep water, deep basin model"[6] and the second the "shallow water, shallow basin model"[7]. The third, namely the desiccated deep basin model, is, however, the one we prefer.

Late Miocene Basin Geometry

Geophysical evidence—chiefly the basin-wide distribution of an acoustic reflector[8] (Fig. 1) which has been identified by drilling as the top of the Mediterranean evaporites[5] clearly indicates that the Late Miocene Mediterranean had a configuration not greatly different from that of today. The surface of the reflector conforms more or less to the contours of the intricate submarine topography, indicating that the Mediterranean basin had already been created when the evaporite was being deposited.

More convincing evidence is provided by stratigraphical and palaeontological studies. The strata underlying the evaporites are deep marine pelagic sediments. During the DSDP Leg XIII, Middle Miocene pelagic marls were cored from sites 126 and 129 (see Fig. 2) in the Ionian Basin[1,2], and lower Upper Miocene (Tortonian) marls were sampled from site 121 in the Alboran Basin[3]. The correlative Tortonian marl underlying the Upper Miocene evaporites (Messinian) of Sicily has been proved to be a deep water deposit by a study of its benthonic foraminiferal faunas[9]. Deep marine pelagic marls of Lower Miocene age are also known on the island of Pianosa in the Tyrrhenian Sea[10]. These facts clearly indicate that the Mediterranean basins were already deep before the salinity crisis.

The strata directly overlying the Messinian evaporites are also deep marine pelagic sediments. These earliest Pliocene strata contain a benthonic ostracod fauna, which could only live in ocean bottom below 1,000 m (ref. 11). The associated benthonic Foraminifera are likewise indicative of a deep marine environment of deposition[5]. The fact that of the deep-swimming planktonic genus *Sphaeroidinellopsis* is the dominant (up to 90%) microfauna lends further credence to the concept of a deep Mediterranean in the earliest Pliocene[5]. Additional data in support of deep marine sedimentation immediately after the salinity crisis have been provided by the oxygen isotope measurements[4]. As geophysical considerations exclude the possibility of a catastrophic subsidence[5], the only alternative is the sudden drowning of a desiccated deep basin.

Pelagic oozes are, in fact, intercalated in the Messinian evaporites. At site 134, to the west of Sardinia, we cored a

Fig. 1 The Mediterranean reflector. This strong reflector corresponds to the top of the Upper Miocene evaporite formation. The relief of the reflector conforms the bottom topography, suggesting that the evaporites were deposited in a basin similar in topography to that of the present Mediterranean.

Since 1970:

- **50 sites, 120 holes**
- **13 km of cores**
- **44-84% of core recovery**
- **Technological limitation (no riser)**

DEEP-SEA RECORD OF MEDITERRANEAN MESSINIAN EVENTS (DREAM)

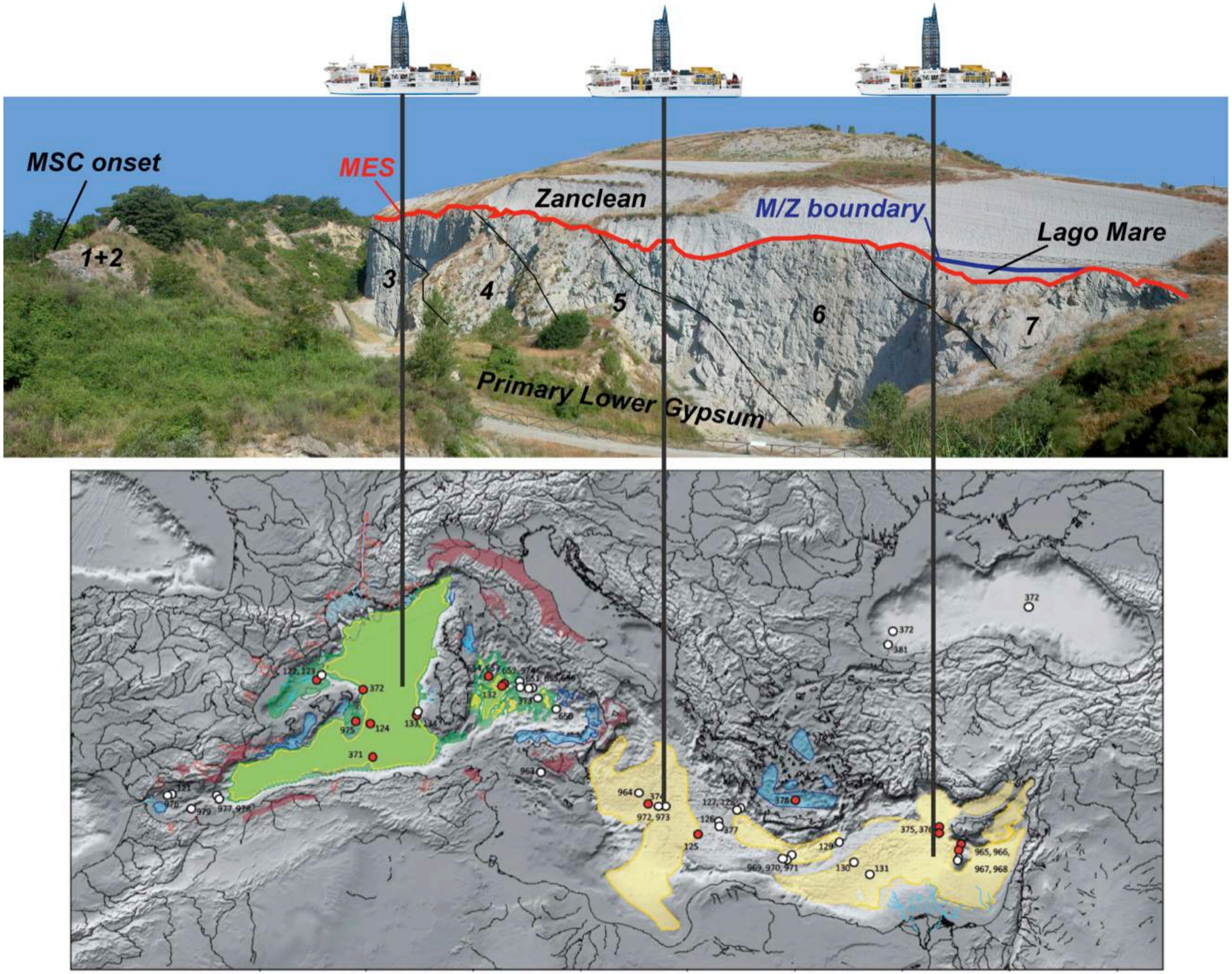
The purpose of the DREAM Workshop was to:

- **gather three generations of scientists** (those who participated in the discovery, those who are presently actively involved in research, and the next generation)
- **identify locations for multiple-site drilling** (including riser-drilling) in the Mediterranean Sea
- Identify a strategy to **solve the several open questions still existing about the causes, processes, timing and consequence at local and planetary scale of the Messinian Salinity Crisis (MSC).**

Brisighella (Ravenna) Italy

37 scientists and 13 students/young post docs

37 scientists and 13 students/young post docs


MSC onset
MES
Zanclean
M/Z boundary
Lago Mare
1+2
3
4
5
6
7
Primary Lower Gypsum

DREAM ACTION PLAN emerged from the two ECORD Magellan+ Workshops (Brisighella and Paris):

Proceed with the submission of:

Umbrella proposal of the Deep-Sea Record of Mediterranean Messinian Events (DREAM) multi-phase drilling project:

Uncovering a Salt Giant
(Camerlenghi et al.)
Submitted on April 1st 2014.

4 related scientific drilling proposals:

DREAM: Deep-Sea Records of the MSC (Lofi, Camerlenghi et al.)
What are the causes, timing and emplacement mechanisms of the MSC salt giant?

Deformation and fluid flow in the MSC salt giant (Hübscher et al.)
What are the factors responsible for early salt deformation and fluid flow across and out of the halite layer?

Probing the Salt Giant for its Deep Biosphere secrets (Aloisi et al.)
Do salt giants promote the development of a phylogenetically diverse and exceptionally active deep biosphere?

Probing deep Earth and surface connections (Rabineau et al.)
What are the mechanisms underlying the spectacular vertical motions inside basins and their margins?
(link with TOPO EUROPE)

Drilling Proposal 1:

DREAM: Deep-Sea Records of the MSC
(Lofi, Camerlenghi et al.)
to be submitted on October 1st 2014 (pre-proposal)

The main objectives of the DREAM pre-proposal will be to answer the following overarching question:

What are the causes, timing and emplacement mechanisms of the MSC salt giant?

Drilling Proposal 2:

Deformation and fluid flow in the MSC salt giant
(Hübscher et al.)
to be submitted on October 1st 2014 (pre-proposal)

The main objectives of the DREAM pre-proposal will be to answer the following overarching question:

What are the factors responsible for early salt deformation and fluid flow across and out of the halite layer?

Drilling Proposal 3:

Probing the Salt Giant for its Deep Biosphere secrets
(Aloisi et al.)
to be submitted on October 1st 2014 (pre-proposal)

The main objectives of the DREAM pre-proposal will be to answer the following overarching question:

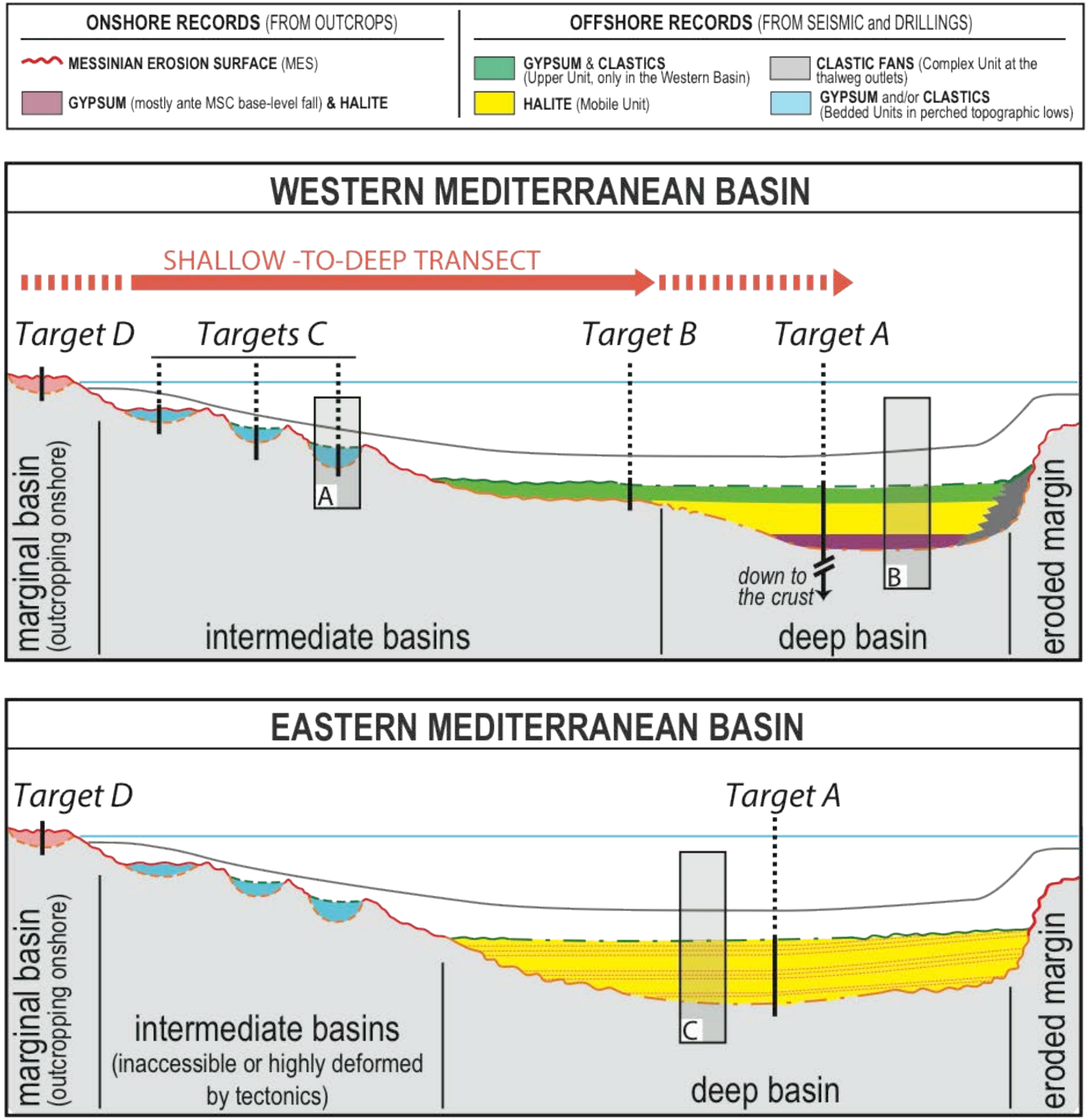
Do salt giants promote the development of a phylogenetically diverse and exceptionally active deep biosphere?

Drilling Proposal 4:

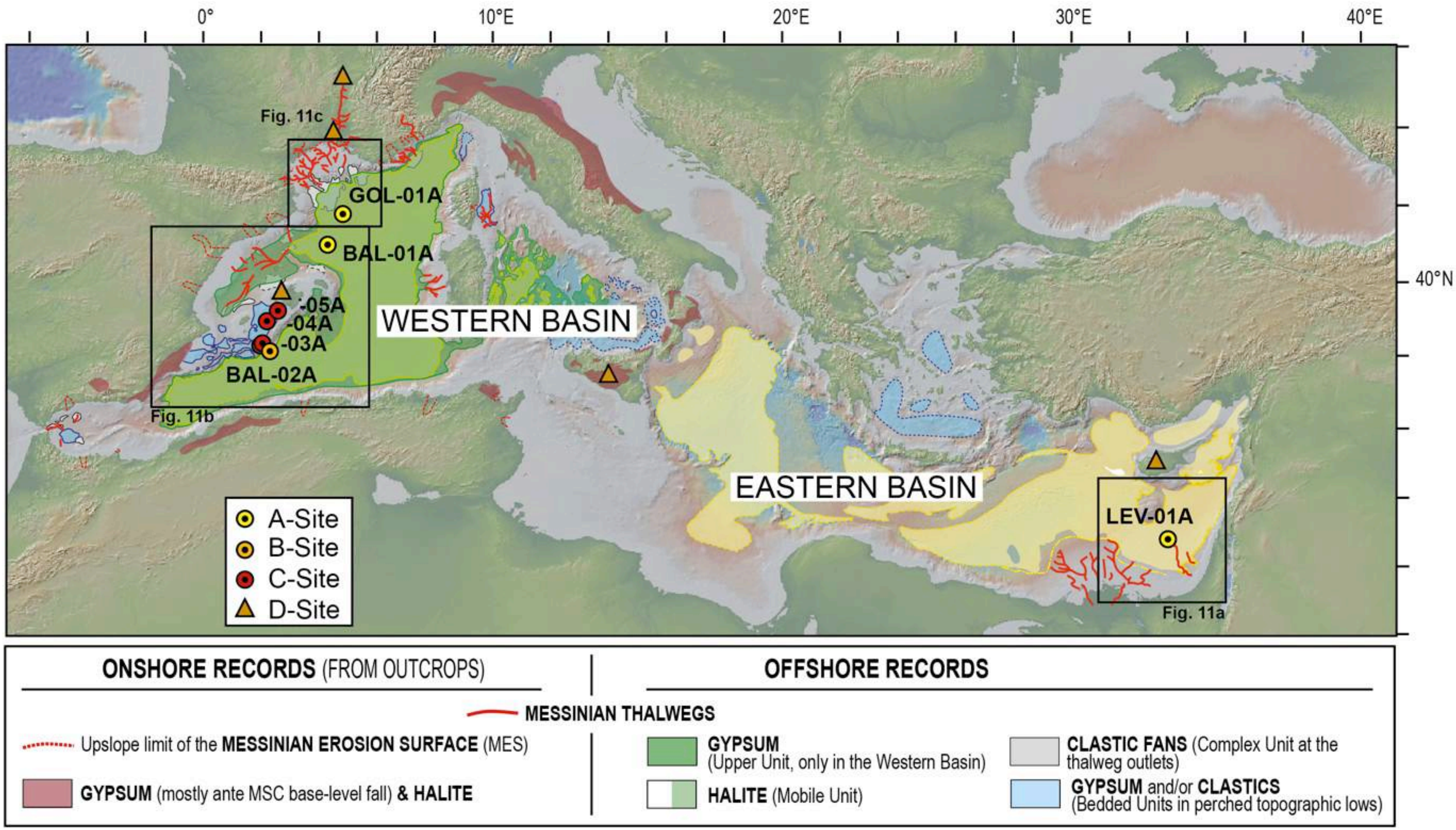
Probing deep Earth and surface connections
(Rabineau et al.)
submitted on April 1st 2014 (pre-proposal)

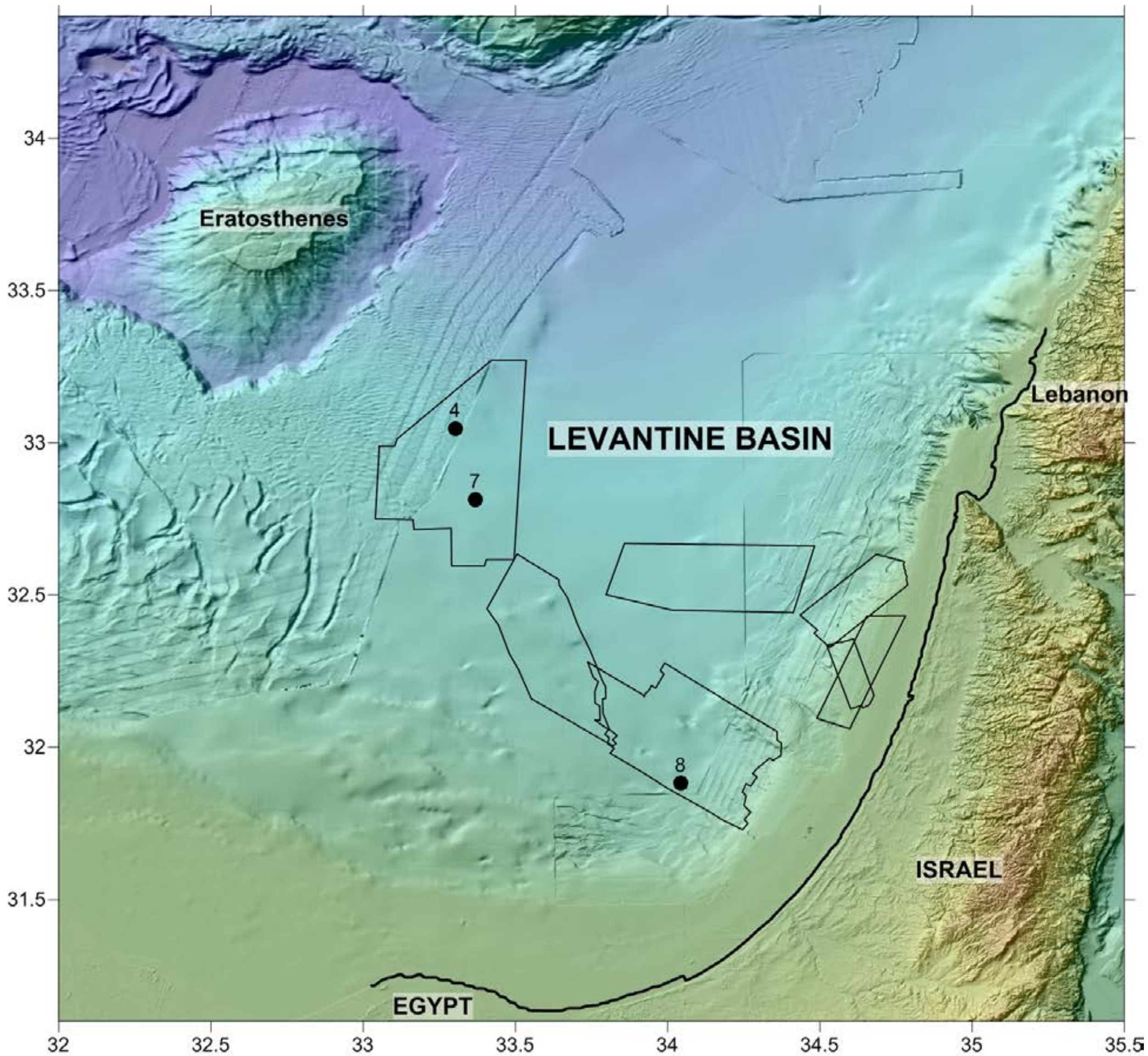
The main objectives of the DREAM pre-proposal will be to answer the following overarching question:

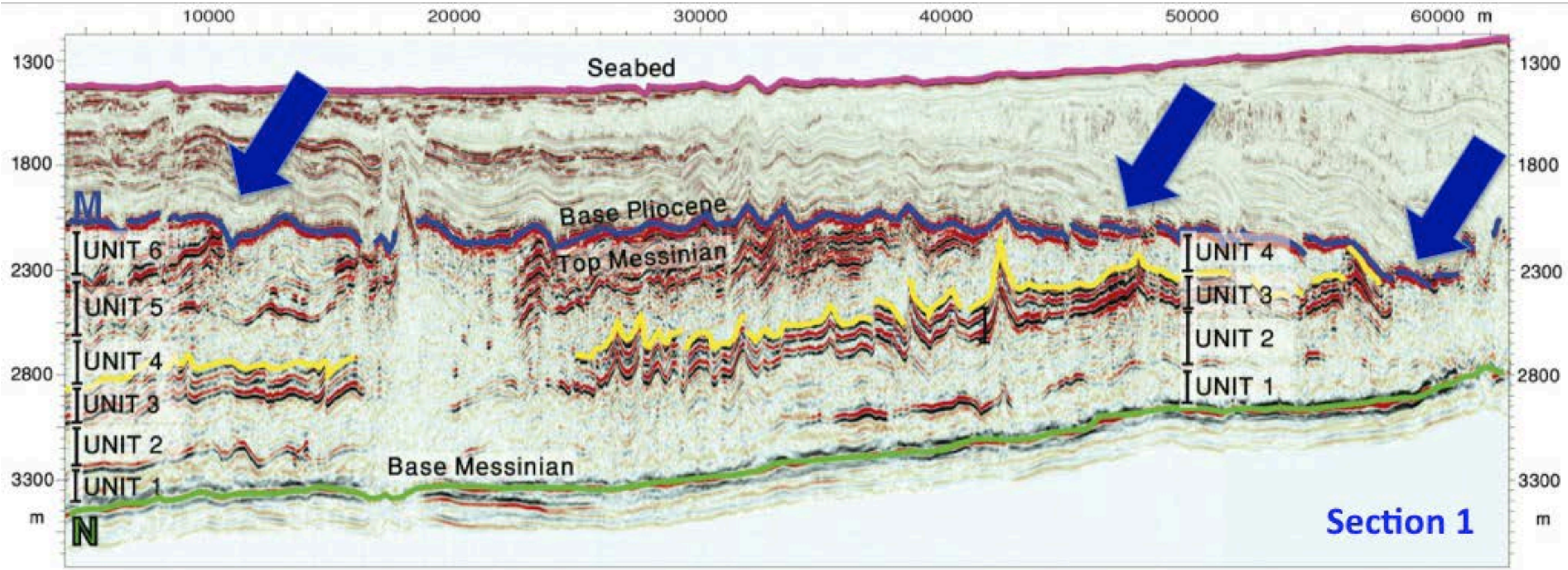
What are the mechanisms underlying the spectacular vertical motions inside basins and their margins?

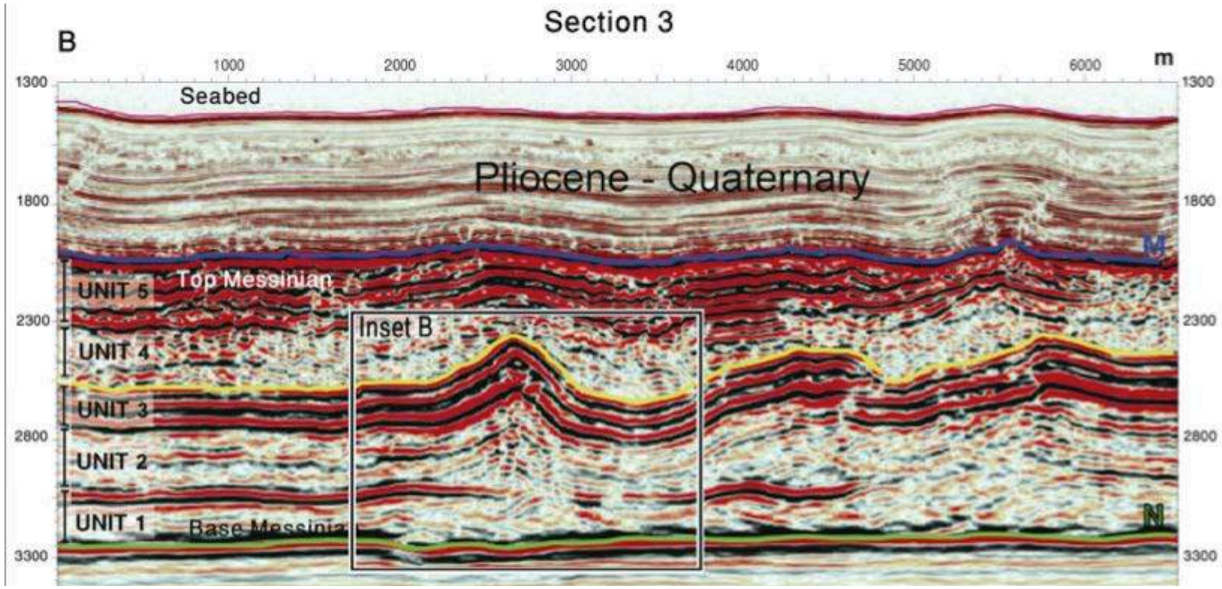


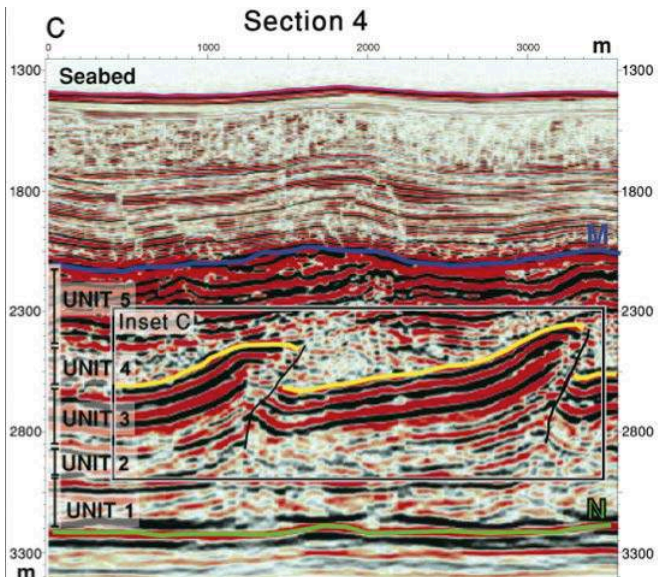
(Lofi et al.,2011)

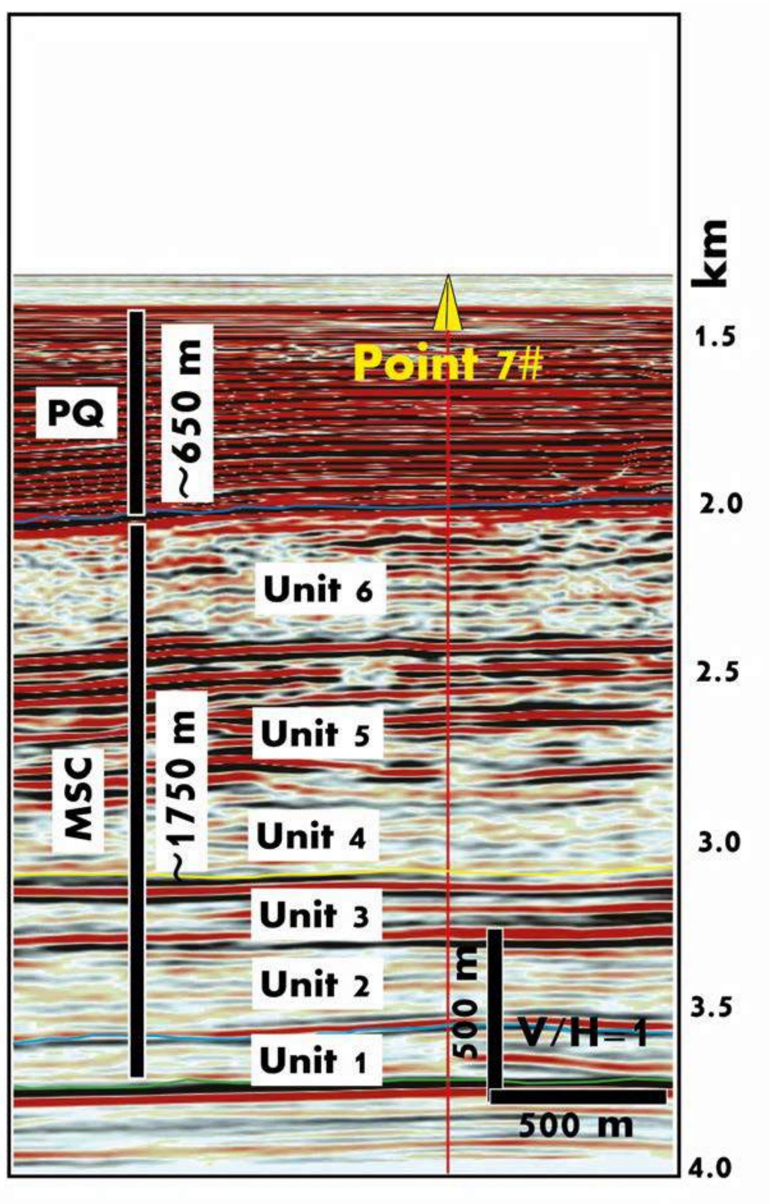

0°
10°E
20°E
30°E
40°E
40°N
Fig. 11c
GOL-01A
BAL-01A
-05A
-04A
-03A
BAL-02A
Fig. 11b
WESTERN BASIN
EASTERN BASIN
LEV-01A
Fig. 11a
A-Site
B-Site
C-Site
D-Site
ONSHORE RECORDS (FROM OUTCROPS)
OFFSHORE RECORDS
MESSINIAN THALWEGS
Upslope limit of the MESSINIAN EROSION SURFACE (MES)
GYPSUM (mostly ante MSC base-level fall) & HALITE
GYPSUM (Upper Unit, only in the Western Basin)
HALITE (Mobile Unit)
CLASTIC FANS (Complex Unit at the thalweg outlets)
GYPSUM and/or CLASTICS (Bedded Units in perched topographic lows)

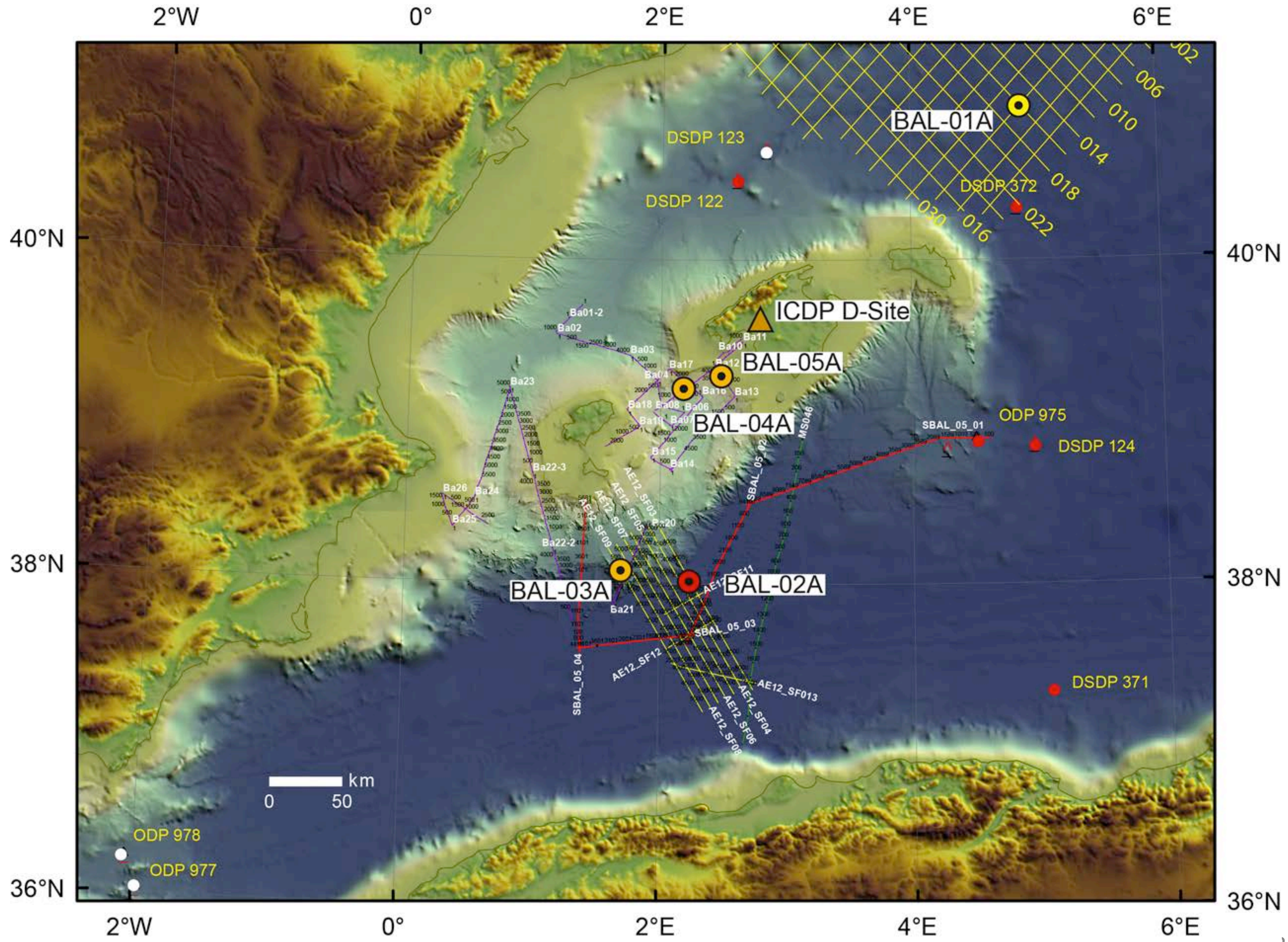

34
33.5
33
32.5
32
31.5
32
32.5
33
33.5
34
34.5
35
35.5
Eratosthenes
LEVANTINE BASIN
Lebanon
ISRAEL
EGYPT
4
7
8

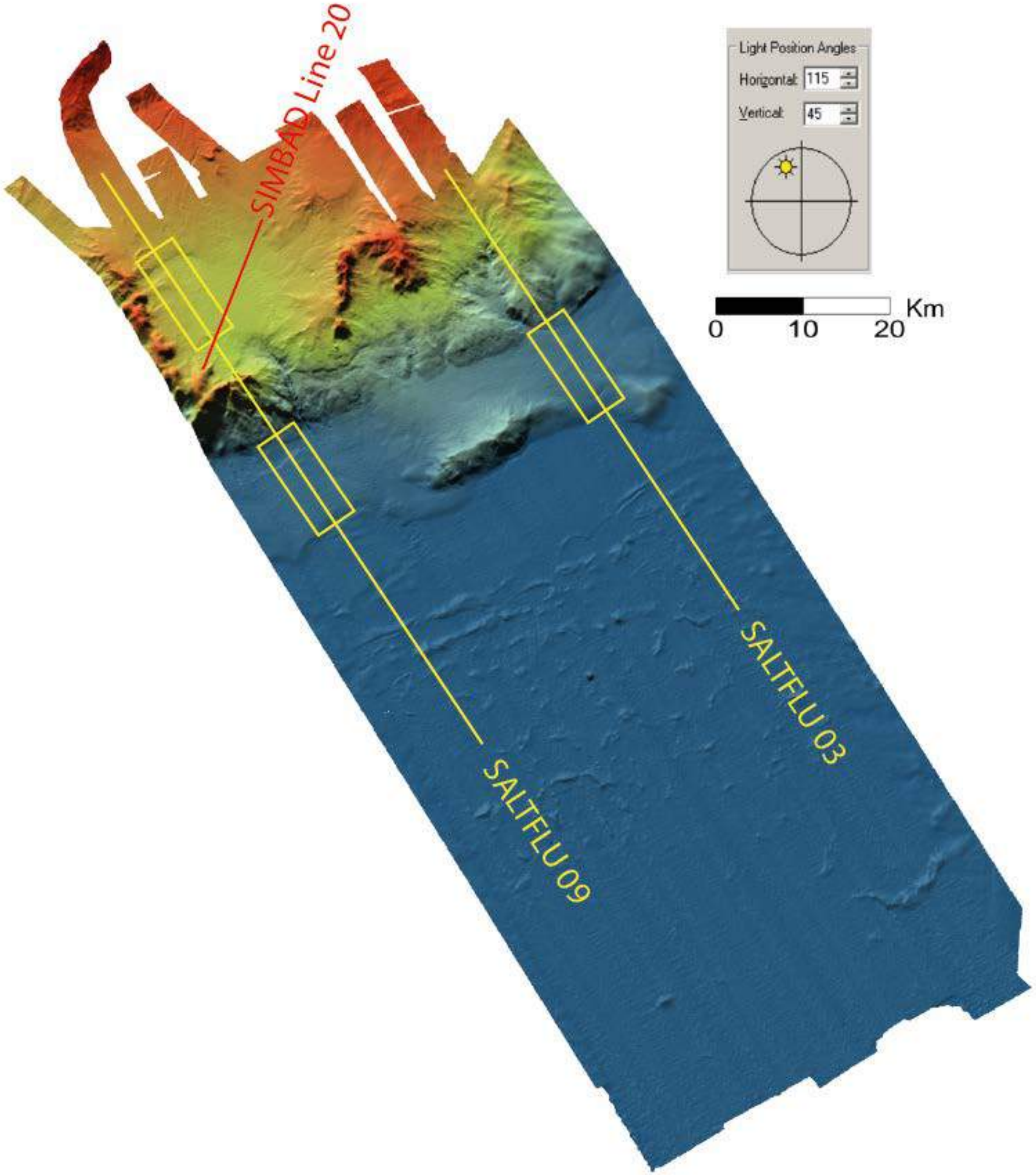

10000
20000
30000
40000
50000
60000 m
1300
1800
2300
2800
3300
m
Seabed
M
Base Pliocene
Top Messinian
UNIT 6
UNIT 5
UNIT 4
UNIT 3
UNIT 2
UNIT 1
Base Messinian
N
Section 1

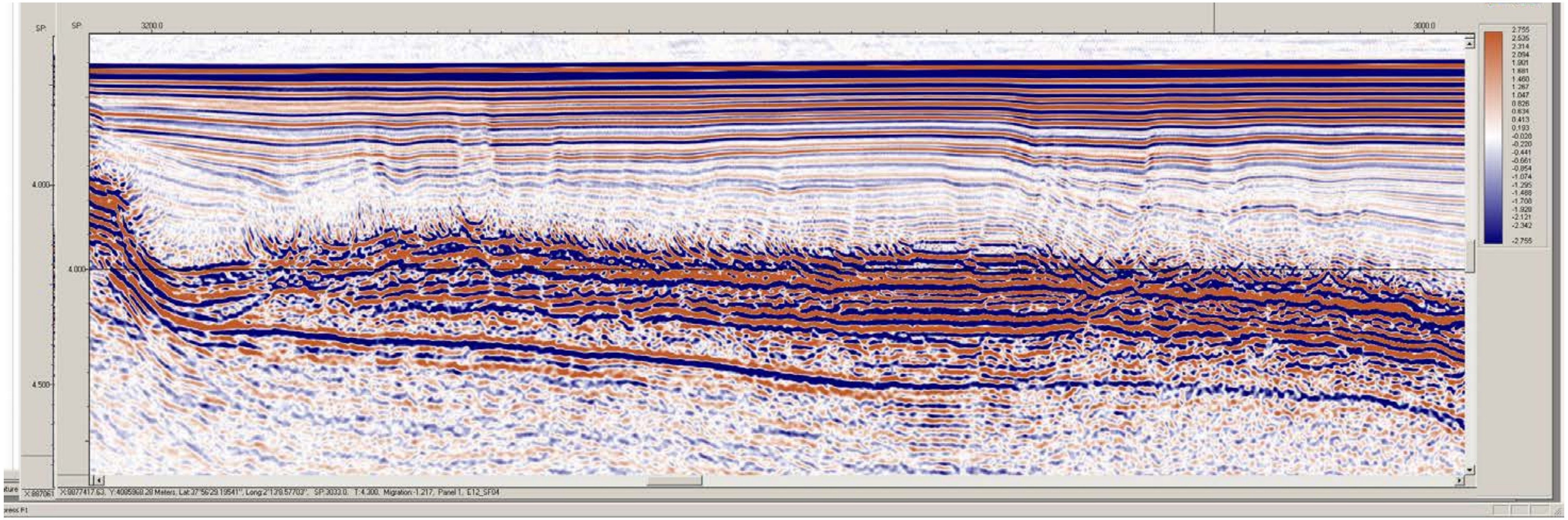

B
Section 3
1000
2000
3000
4000
5000
6000
m
1300
1800
2300
2800
3300
Seabed
Pliocene - Quaternary
Top Messinian
M
UNIT 5
UNIT 4
UNIT 3
UNIT 2
UNIT 1
Inset B
N

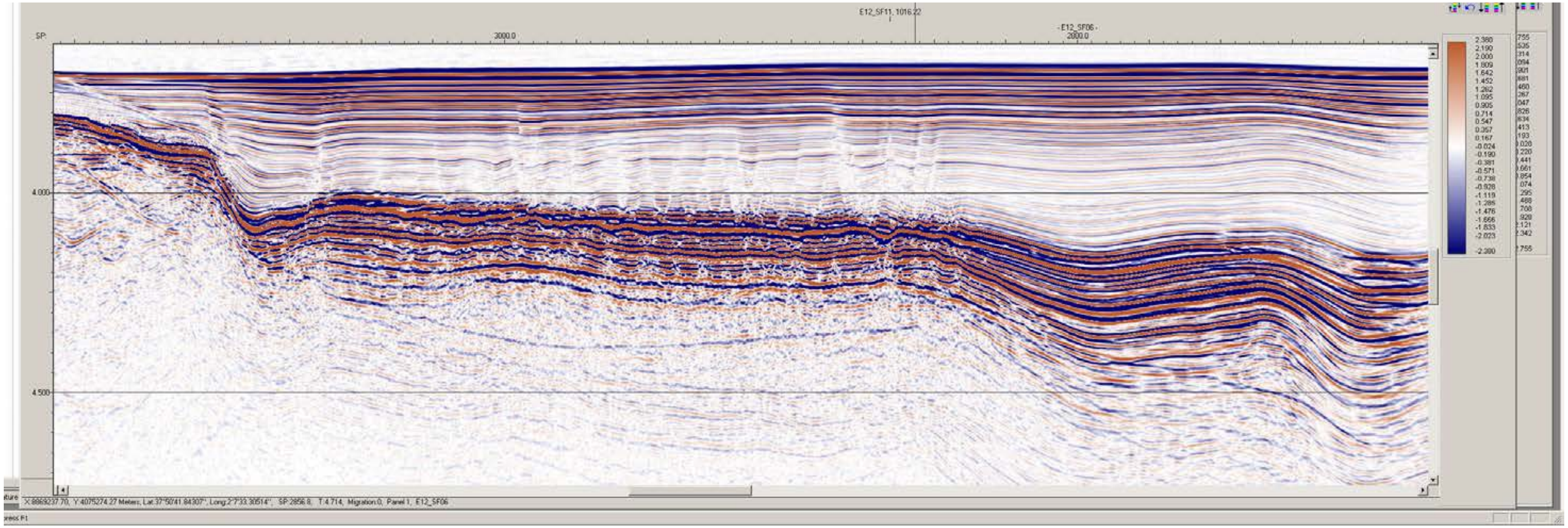

C
Section 4
1000
2000
3000
m
1300
1800
2300
2800
3300
m
Seabed
M
UNIT 5
Inset C
UNIT 4
UNIT 3
UNIT 2
UNIT 1
N

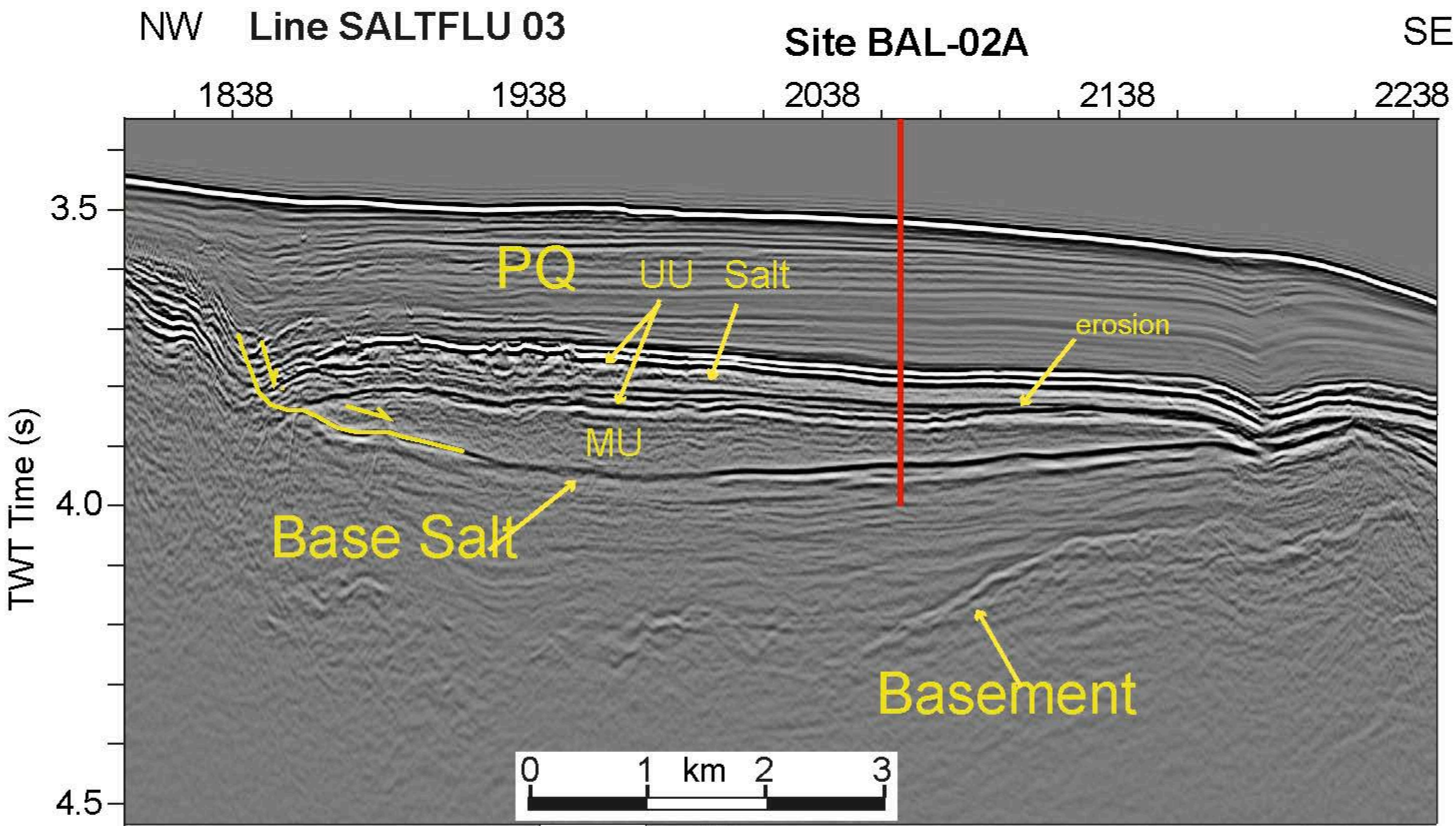

km
1.5
2.0
2.5
3.0
3.5
4.0
Point 7#
PQ
~650 m
MSC
~1750 m
Unit 6
Unit 5
Unit 4
Unit 3
Unit 2
Unit 1
500 m
V/H=1
500 m

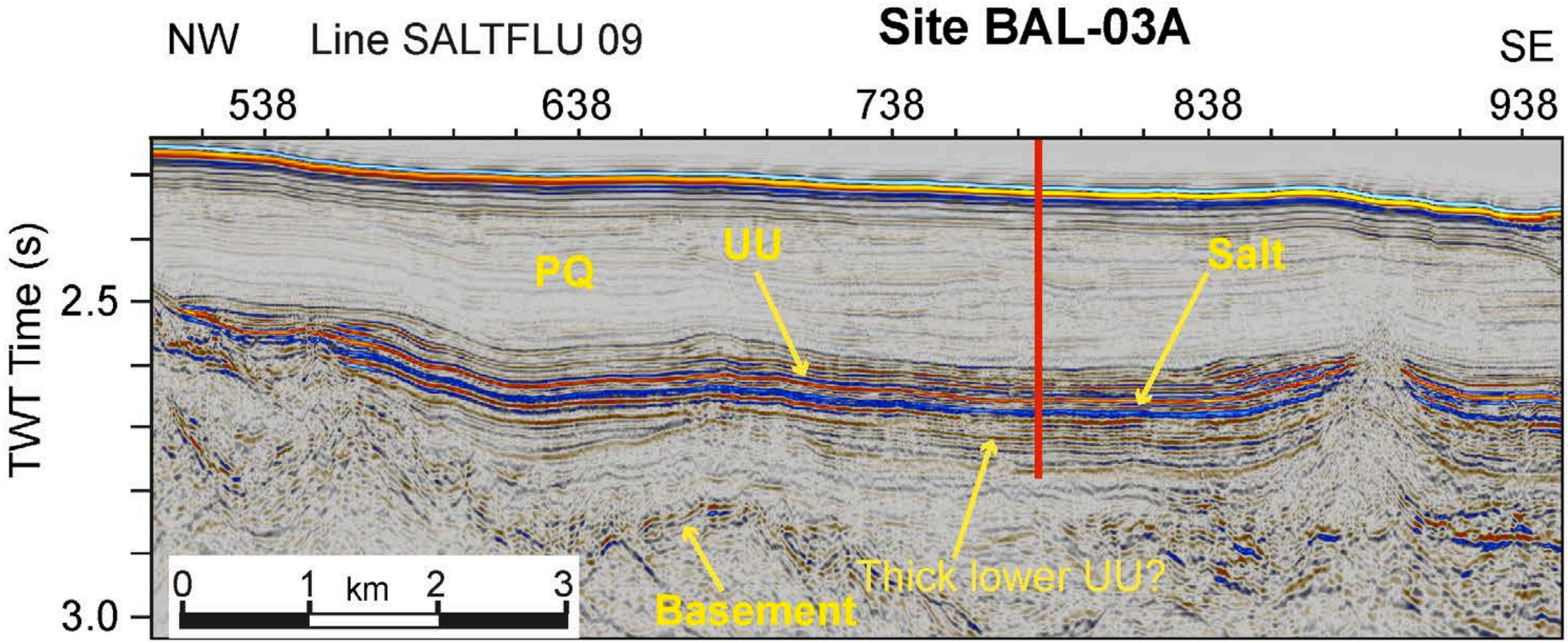

2°W
0°
2°E
4°E
6°E
40°N
38°N
36°N
BAL-01A
BAL-02A
BAL-03A
BAL-04A
BAL-05A
ICDP D-Site
DSDP 123
DSDP 122
DSDP 372
DSDP 124
DSDP 371
ODP 975
ODP 978
ODP 977
km
0
50
SBAL_05_01
SBAL_05_02
SBAL_05_03
SBAL_05_04
MS048
AE12_SF12
AE12_SF013
AE12_SF04
AE12_SF06
AE12_SF08
AE12_SF03
AE12_SF05
AE12_SF07
AE12_SF09
006
010
014
018
022
016
030

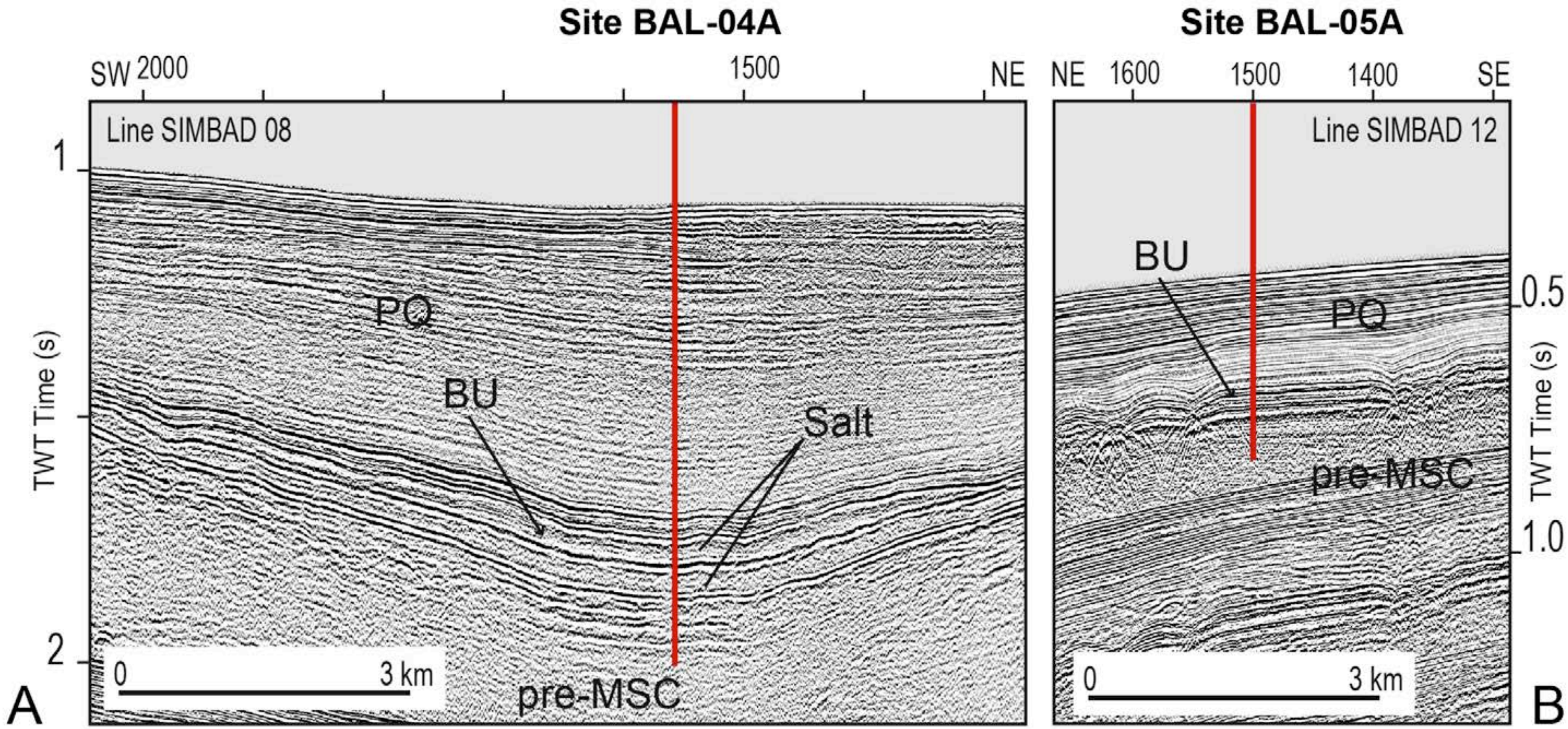

SIMBAD Line 20
Light Position Angles
Horizontal: 115
Vertical: 45
Km
0
10
20
SALTFLU 03
SALTFLU 09

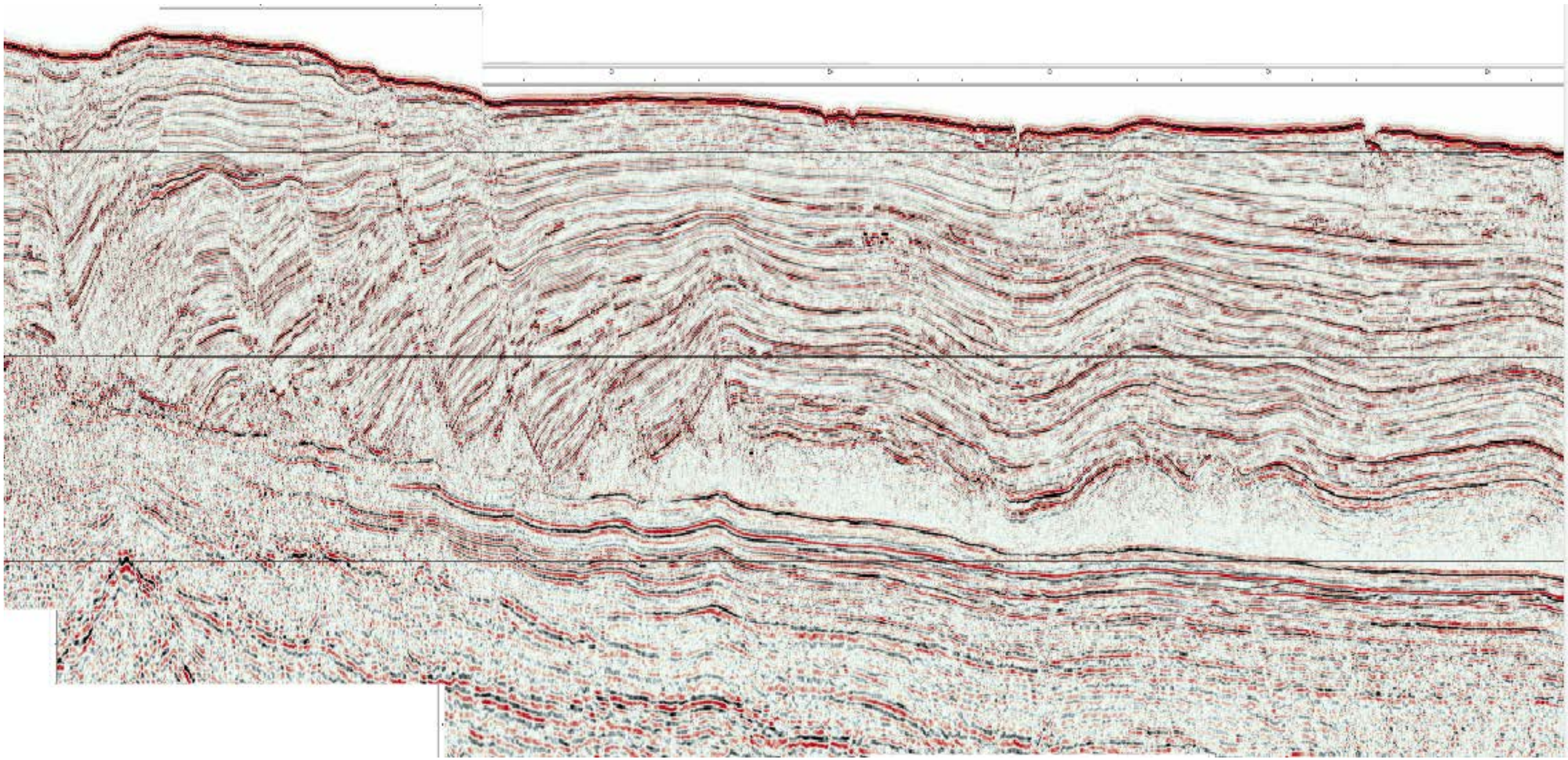

SP:
3200.0
3000.0
4.000
4.500

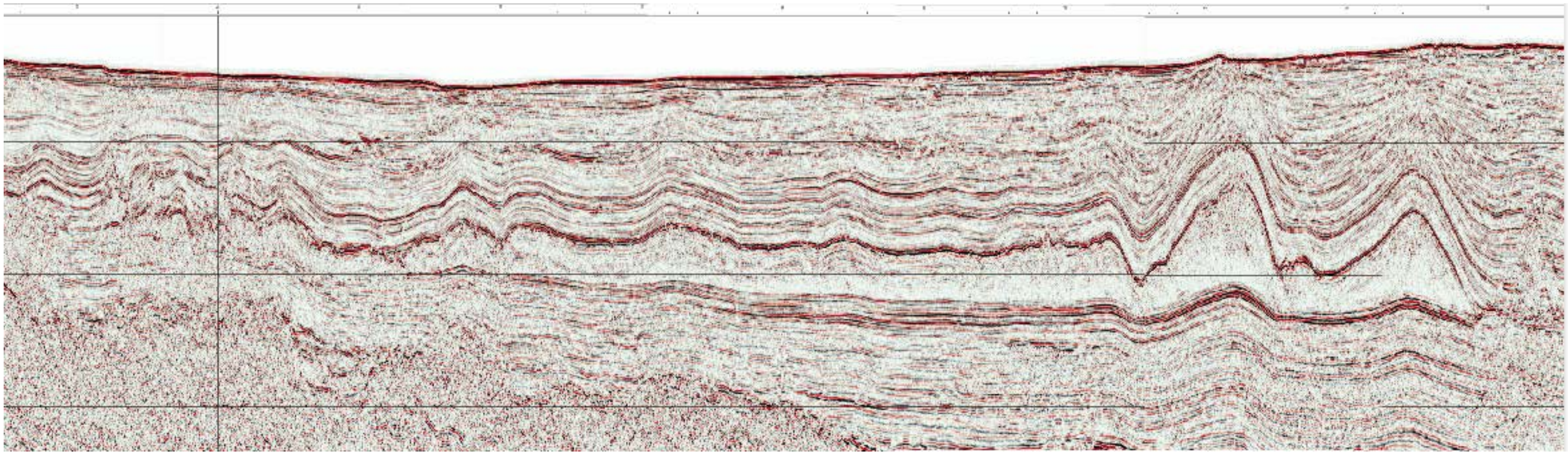

SP:
3000.0
E12_SF11, 1016.22
E12_SF06
2000.0
4.000
4.500

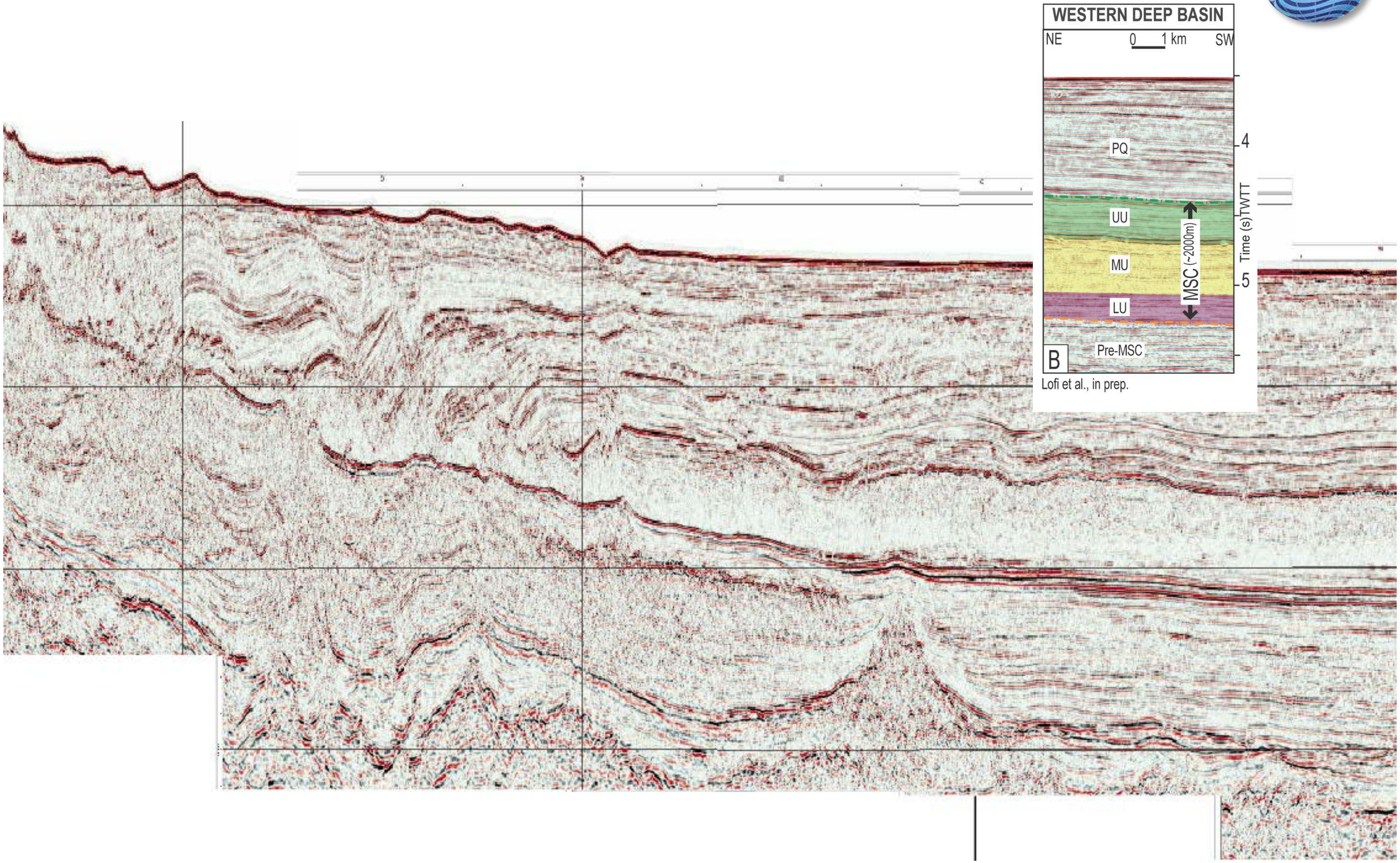

NW
Line SALTFLU 03
Site BAL-02A
SE
1838
1938
2038
2138
2238
3.5
4.0
4.5
TWT Time (s)
PQ
UU
Salt
erosion
MU
Base Salt
Basement
0
1
km
2
3

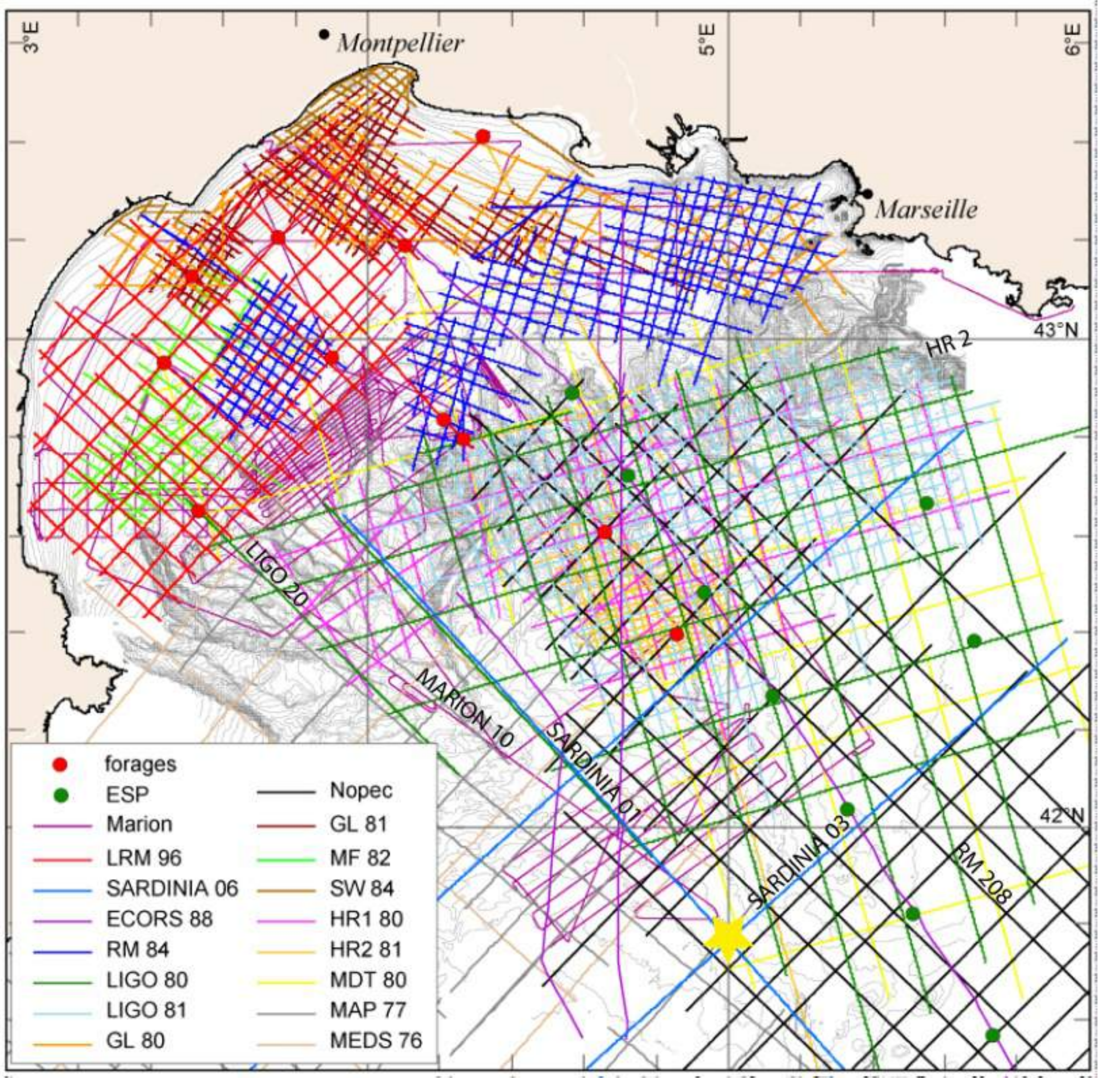

NW
Line SALTFLU 09
Site BAL-03A
SE
538
638
738
838
938
TWT Time (s)
2.5
3.0
PQ
UU
Salt
Thick lower UU?
Basement
0
1
km
2
3

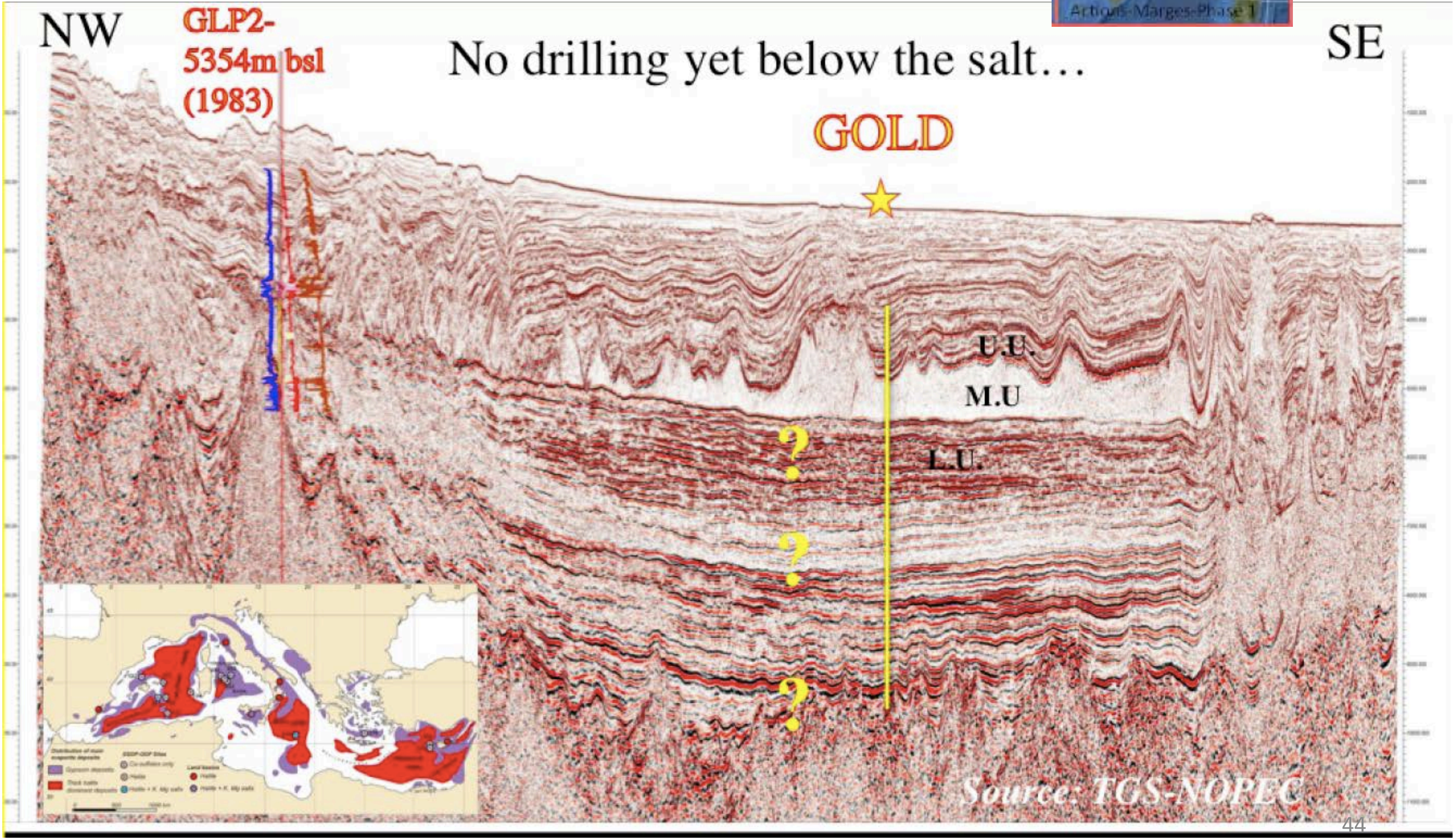

Site BAL-04A
SW 2000
1500
NE
Line SIMBAD 08
1
2
TWT Time (s)
PQ
BU
Salt
pre-MSC
0
3 km
A
Site BAL-05A
NE 1600
1500
1400
SE
Line SIMBAD 12
BU
PQ
pre-MSC
0.5
1.0
TWT Time (s)
0
3 km
B



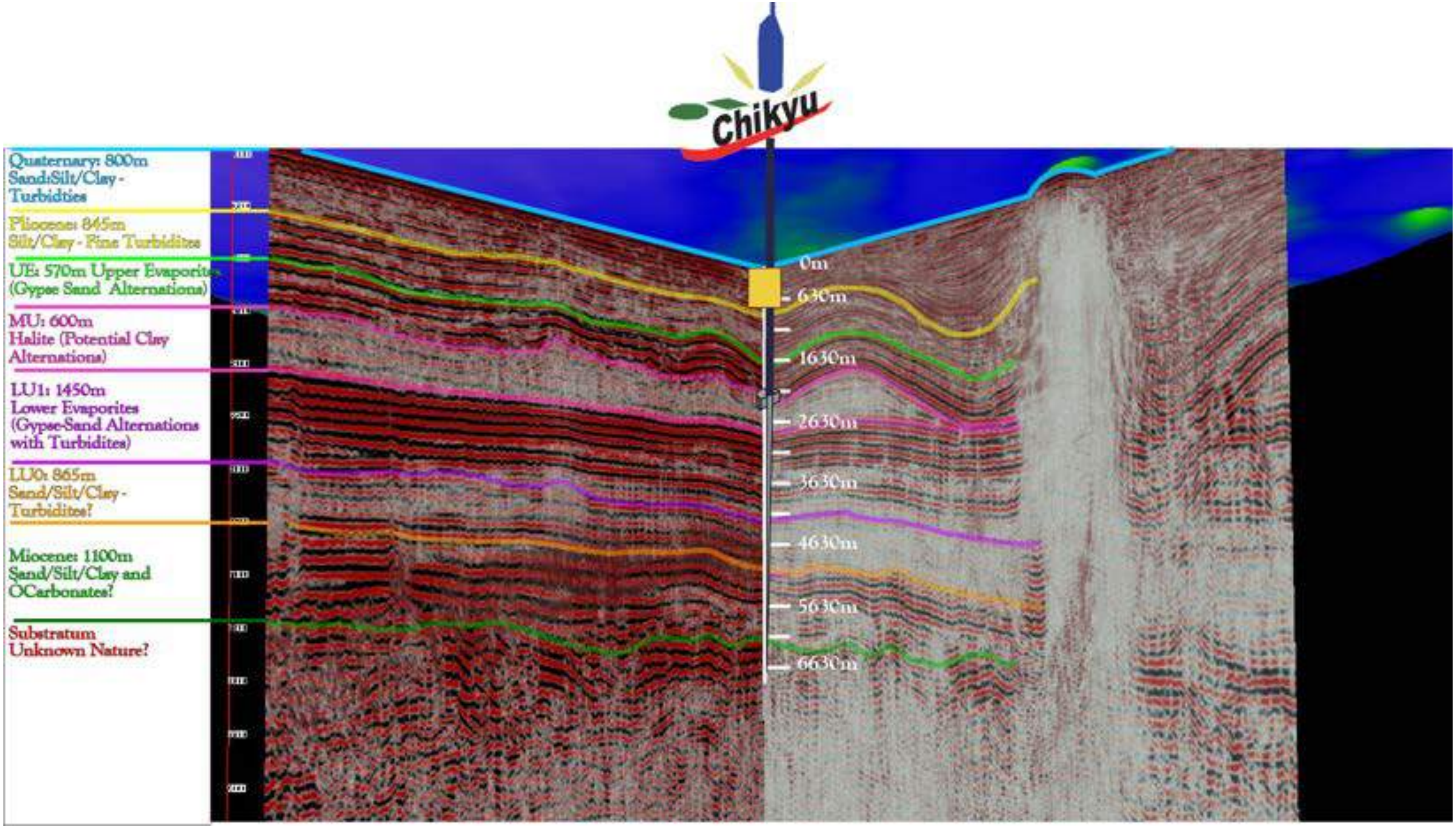



WESTERN DEEP BASIN
NE
0
1 km
SW
PQ
UU
MU
LU
Pre-MSC
MSC (~2000m)
4
5
Time (s)TWTT
B
Lofi et al., in prep.


3°E
5°E
6°E
Montpellier
Marseille
43°N
42°N
HR 2
LIGO 20
MARION 10
SARDINIA 01
SARDINIA 03
RM 208
forages
ESP
Marion
LRM 96
SARDINIA 06
ECORS 88
RM 84
LIGO 80
LIGO 81
GL 80
Nopec
GL 81
MF 82
SW 84
HR1 80
HR2 81
MDT 80
MAP 77
MEDS 76



Courtesy M. Rabinueau and the GOLD Project



Courtesy M. Rabinueau and the GOLD Project

Multiple-platform drilling

- **Riser drilling** (D/V Chikyu) for deep basin sites
- **Riserless drilling** (D/V JOIDES Resolution) for Mediterranean margin sites and erosional surface sites.
- **Mission Specific Platform (MSP) drilling** or ICDP drilling rigs in very shallow water or on land.

LIMITING FACTORS

- **Water depth** (presently 2500 m)
- **Hazard to drilling:** stress in the salt rock inducing rapid deformation, and possible overpressure in the pre-salt formations.
- **Logging while drilling** (LWD) and **geochemical logging** s**ide-wall coring** in salt.

- **Links with oil and gas industry** are considered of primary importance for the success of DREAM
- **Site survey**