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TerMEx - Terra Mediterranean Earth Science Experiment

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Terra Mediterranean Earth Science Experiment

Draft white paper

(june 2010)

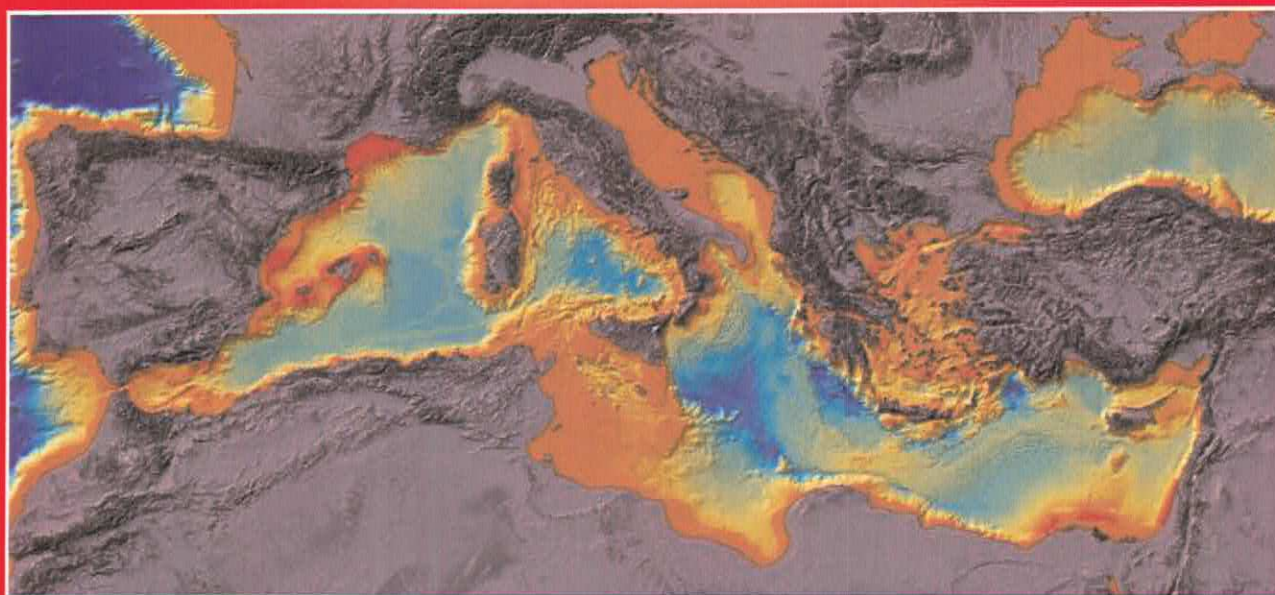




Illustration de couverture

L.Brosolo et J. Mascle, 2008, Shaded bathymetry of the Mediterranean Sea,
in "Terre Planète mystérieuse" co-edition Insu/ le Cherche Midi, p. 80-81.

MISTRALS

The present white paper of the TerMEx programme (Terra-Mediterranean Earth Science Experiment) results from a French initiative, launched in 2008 by a French network federating the main public Earth Sciences centres* in France in the scope of a wider working group known as "MISTRALS".

In addition to the TerMEx programme, the "MISTRALS" programme includes other initiatives aimed at the study of the hydrosphere (HyMEx = Hydrological cycle in the Mediterranean Experiment, MerMEx = Marine Ecosystem Response in the Mediterranean Experiment), atmosphere (ChArMEx = Chemistry-Aerosols Mediterranean Experiment), surface interfaces (SICMED = Surfaces and Continental Interfaces in the Mediterranean Experiment), paleo-environments (PaleoMEx = Mediterranean Paleo-Experiment) and biodiversity (BioDivMEx = Biodiversity in the Mediterranean Experiment), also at the scale of the Mediterranean realm.

*

INSU: National Institut of Earth Sciences and Astronomy (coordinator)

MESR-DGRI: Ministry of Research

MEEDDM: Ministry of Environnement

ANR: National Agency for Research

BRGM: French Geological Survey

CEA: Atomic Energy Center

Cemagref: National Agriculture Center

CIRAD: International center for Agriculture development

CNES: National Spatial Agency

CNRS: National Center for Scientific Research

InEE: Institut of Ecology and Environment

InSHS: Institut for Human and Social Sciences

IFP: Institut for Innovation, Energy and Environment

Ifremer: French Institut for Marine Studies

INRA: National Institut for Research in Agronomy

IRD: Institut for Research and Development

Météo-France: National climate and forecasting Institut Cordialement



MISTRALS

Mediterranean Integrated Studies at Regional And Local Scales
(Chantier Méditerranée)

AXE

TerMEx

Terra Mediterranean Earth Science Experiment

Draft white paper

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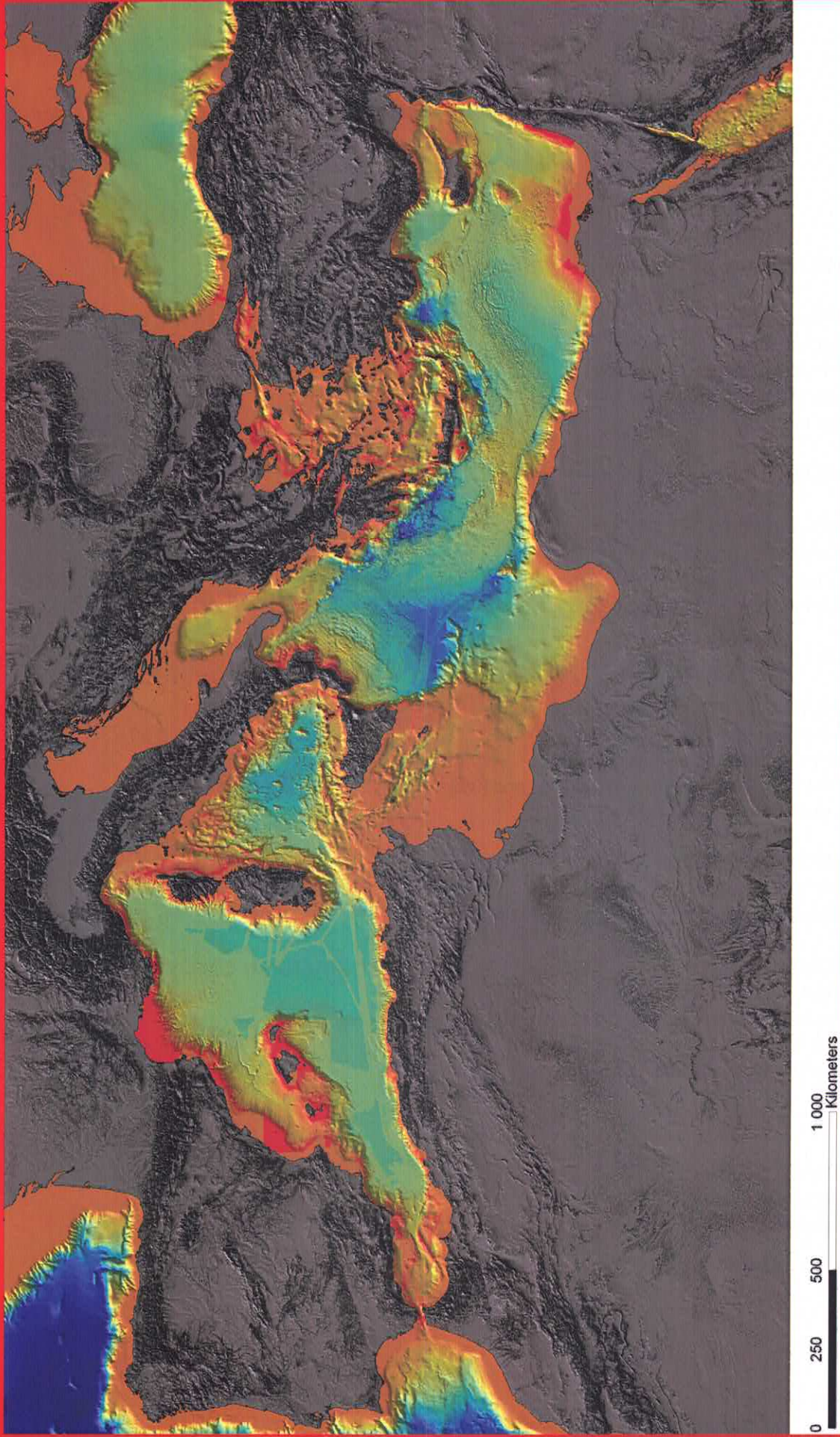
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Table of contents

SUMMARY/BACKGROUND of the TERMEX PROGRAMME	p 7
1- Challenges	p 7
2- Scientific issues	p 9
3- Tools and dedicated work flows	p 11
4- International perspectives	p 13
5- Estimated budget	p 13
INTRODUCTION	p 15
1- PAST and PRESENT GEODYNAMICS	
1.1- Subduction and mantle dynamics	p 20
1.2- Crustal dynamics	p 22
1.3- Topography, erosion/sedimentation and sedimentary processes	p 26
Figures	p I, VI
2- NATURAL HAZARDS and RISKS	
2.1- Seismic hazards and risks	p 30
2.2- Volcanic hazards and risks	p 33
2.3- Gravity-driven slope failure hazards and risks	p 36
2.4- Coastal hazards and risks	p 37
3- ENERGY and WATER RESOURCES	
3.1- Energy resources	p 40
3.2- Water resources	p 42
4- PALEO-ENVIRONMENTS, PALEO-CLIMATES, MEDITERRANEAN ECOSYSTEMS, and their FUTURE EVOLUTION	
4.1- Paleo-environments, paleo-climates, Mediterranean ecosystems and their evolution	p 46
4.2- The Messinian salinity crisis	p 48
Figures	p VII, XII
5- OUT-REACH	
5.1- Geological parks	p 52
5.2- Geological atlas of the Mediterranean	p 52



L. Brosolo et J. Mascle, 2008, Shaded bathymetry of the Mediterranean Sea, in "Terre Planète mystérieuse" co-edition Insu/ le Cherche Midi, p. 80-81.

Summary

1

Challenges

The understanding of the overall dynamics of the Mediterranean realm represents a major concern for its populations, as well as for other nations who are depending on its energy, mineral and other natural resources, as well as its manpower and economy. Preservation of the environment and assessment of natural risks (such as seismic hazards) and anthropic risks are two important concerns that must be kept in mind when exploiting Mediterranean resources. Dealing with these concerns would require a good understanding of the many parameters controlling resource distribution and the genesis of natural hazards and risks. Therefore, the Mediterranean system as a whole needs to be better understood, from the dynamics of the lithosphere and underlying mantle up to its interactions with the climate and anthropic activities.

The TerMEX project will address two sets of major challenges, i.e. societal challenges associated with natural hazards, resources and climate change), as well as scientific challenges such as the deep Earth dynamics, its interactions with climate, and the overall evolution of the Mediterranean ecosystems. Research projects of the TerMEX programme will be undertaken in the framework of a circum-Mediterranean cooperation.

Further discussions with other European and circum-Mediterranean countries will be required to improve this draft of the white paper, which has been prepared at the initiative of the French earth sciences community. The international workshop scheduled in June 2010 in Paris will aim at federating the different national Earth Sciences communities from Europe and circum-Mediterranean regions, and ranking their main priorities, before submitting more focused proposals to the various national and international funding agencies, as well as potential industrial sponsors (i.e. both national and international companies). The TerMEX programme will provide a bridge between the various Earth Sciences communities around the Mediterranean, with the objective of setting up the data base, sharing the costs of data acquisition and processing, as well as to securing a better technological transfer between Northern and Southern European countries, North Africa and the Middle East.

HAZARDS

The Mediterranean realm comprises about 450 million inhabitants, who are exposed to various natural hazards, including seismic, volcanic and gravity-driven hazards. All these hazards must be precisely identified, recorded and quantified. We must also understand the various parameters controlling these natural hazards in order to provide a better assessment and prediction. This will require the monitoring and modelling of the various processes involved, both onshore and offshore. A better knowledge and assessment of natural hazards is indeed crucial for the long-term security of circum-Mediterranean communities.

RESOURCES

The current partitioning of natural water and energy resources is quite unbalanced between the northern, eastern and southern margins of the Mediterranean. For instance, water resources are plentiful in the north, whereas hydrocarbon resources are mainly distributed in the east and in the south. This implies a permanent redistribution, exchange and transportation of circum-Mediterranean natural resources, and requires an implementation of their sustainable development. We need to understand better the processes controlling the distribution and regional concentration of natural resources in order to improve their exploration and production. More specifically, the Mediterranean realm is characterized by more or less semi-arid climatic conditions and increasing demographic pressure, which have a major impact on the access of the populations to sufficient and good-quality water resources.

DEEP EARTH DYNAMICS

Since the Late Cretaceous, subduction and slab retreat represent the main driving processes of deformation in the Mediterranean. Alternatively, collisions between Europe, Africa and smaller continental blocks have led, at a regional scale, to a relatively complex tectonic pattern. Therefore, we must focus our attention on the interactions between mantle and surface processes to improve our understanding of the role of both subduction and collision in past and currently active deformation in the Mediterranean domain. Individual structures, as well as past and present processes, must be studied at the most appropriate scales, both vertically (i.e. down from the crust to the upper and deep mantle) and horizontally (i.e. from outcrop scale up to one thousand km), on geologically significant time ranges.

INTERACTIONS BETWEEN THE DEEP EARTH, SURFACE PROCESSES AND CLIMATE

The Mediterranean Sea is characterized by numerous straits, which can be alternatively open or partially or totally closed, thus controlling the communication and exchange of waters between numerous sub-basins as well as with the World ocean. Because these water passages can be easily interrupted by ongoing geodynamic processes and climate changes, the whole Mediterranean environmental sphere is constantly impacted by interactions between the deep Earth and the global climate.

CLIMATE CHANGE

Today, the Mediterranean region is recognized as a major hotspot for biodiversity. It is worth mentioning that climatic changes identified in this region during the Tortonian (i.e. 10 Ma. ago) form one of the best analogues for comparison with the current global warming. Therefore, it becomes of great interest to understand how this climatic change impacted the Miocene flora, which was initially dominated by trees and taxa associated with a dominantly forested environment, and which was progressively replaced by landscapes dominated by grass and shrubs. In this context, it is also very important to study the climatic and biodiversity changes associated with glacial-interglacial stages of the Late-Pliocene and Pleistocene (i.e. from 3.6 to 2.5 Ma.).

TRANS-DISCIPLINARY INTERACTIONS

The TerMEx programme will require an excellent international coordination between teams from the various countries surrounding the Mediterranean, as well as with other European countries involved in the study of past and present-day processes, as well as risk and resource assessments in this part of the World. Trans-disciplinary interactions/collaborations will be also required between Earth scientists, experts in surface fluids (i.e. hydrology, oceanography and climate), research teams involved in environmental and social sciences, as well as with the end users (i.e., international, national and regional agencies, urban communities and industry).

2

Scientific issues

PAST, PRESENT AND FUTURE GEODYNAMIC EVOLUTION

Convergence between Africa and Europe is slower than 1 cm per year. However, faster displacements ranging up to 10 cm/year have been recorded in the past. These contrasted velocity values probably relate to the dynamics of individual subducted slabs, whose retreat is eventually interrupted by episodes of slab detachment. Slab retreat ultimately impacts surface dynamics, and is likely to induce both distension and compression. In such a context, can we document, for instance, whether the lateral escape of Anatolia and rifting in the Gulf of Corinth result from slab retreat, or from the collision between the Arabian and Eurasian plates. How does this process control the current seismicity of the Gibraltar Arc and Northwestern Africa? To what extent have subduction and inherited lithospheric features contributed to the geodynamic evolution of the Mediterranean domain? How can we account for the seismicity of the Northern Ligurian margin, which displays surficial passive-margin characteristics, but has nonetheless been impacted by strong historical earthquakes? Clearly, identifying the respective contributions of subduction and collision in these processes still requires careful investigations at the appropriate spatial and temporal scales. It is becoming crucial to understand the forcing factors of deformation in the Mediterranean, extending down from the crust to the deep mantle, as well as the coupling between the convective mantle and the lithosphere, in order to model the behaviour of lithospheric blocks in active seismogenic zones.

NATURAL HAZARDS

Mediterranean regions associated with high seismic, volcanic or gravity-driven hazards, i.e. Northwestern Africa, Italy, Greece and Turkey, are also highly populated. Therefore, we must not only study in more detail the faults currently active in these regions, but also their paleo- and historical seismic records. This also implies monitoring their current seismicity using a sufficient number of multi-parameter recorders. Ultimately, the understanding and further prediction of seismic failure would require a better knowledge of the mechanical behaviour of active faults, which is as yet only approximated. Brittle failure is likely to operate differently, depending on whether the overall dynamics of the studied area is controlled by subduction, strike-slip or distension. Therefore, we must set up instrumented in situ laboratories specifically adapted to each of these types of fault, and perform modelling of their brittle failure as well as gravitational sliding, taking into account the local structure and real geological boundary conditions. We also need to study the impact at different scales of the geological structures on the seismic waves which will ultimately cause damage at the Earth's surface. Seemingly, we must implement a regional alert system to detect tsunamis and prevent related damages at the scale of the Mediterranean. Vulnerable areas will be targeted for this type of monitoring, i.e. the Aegean region and the Hellenic subduction zone, where earthquakes of magnitude 8 are likely to occur, the Messina and Gibraltar straits, where strong historical earthquakes have occurred, as well as Northwest Africa, which is also characterized by frequent earthquakes and dense urban populations. Areas with moderate seismic activity, but where devastating earthquakes have occurred in the past, will be also targeted, especially in highly populated areas such as the Ligurian coast and the French Riviera, where surficial damage could be also extremely important.

RESOURCES

The largest fresh water reserves of the Mediterranean realm are currently found in the orogenic domains of Southern Europe, including the Apennines, Carpathians and Alps, as well as their adjacent foreland basins (i.e., the Rhône, Pô and Danube basins). On the other hand, the largest hydrocarbon resources identified to date are located in the Eastern Mediterranean offshore (i.e. in the Nile deep-sea fan), as well as North Africa (i.e. in Libya and Algeria). Such an asymmetric distribution should stimulate joint studies involving the various circum-

Mediterranean countries to improve assessments of the fresh water and hydrocarbon resources of the Mediterranean realm as a whole. A large part of the Mediterranean offshore still represents a frontier area for HC exploration in the Central and Western Mediterranean domains, i.e., in the deep Ionian and Algerian basins, respectively. Special attention will be paid to the study of subsurface karsts, since the Messinian crisis has strongly impacted their morphology and distribution. Indeed, many deep karsts remain under-explored and could still contain large hydrocarbon or fresh water reserves. Because the salinity of numerous coastal aquifers is currently increasing, due to demographic pressure and climate change, further work will be focused on the transition between terrestrial and marine environments, in order to better understand and monitor the temporal, lateral and vertical variations at the interface between saline, brackish and fresh water tables.

PALEO-ENVIRONMENTS, PALEO-CLIMATES, MEDITERRANEAN ECOSYSTEMS AND THEIR FUTURE EVOLUTION

The relative isolation of the Mediterranean may have a locally negative impact on its environment, because this increases its vulnerability. However, this isolation also provides ideal conditions for accurate mass balance studies, estimating the budget of sedimentary transfers and addressing environmental issues. For instance, the Mediterranean domain behaves as a closed system, in which it is possible to draw up a spatial and temporal mass balance between erosion and sedimentation. This is because all the sediments derived from erosion of the onshore domain are rapidly redeposited within the adjacent offshore. Such boundary conditions are also extremely important for differentiating between tectonic and climatic forcing. Ultimately, drastic environmental changes are potentially recorded in the sedimentary successions of the Mediterranean basins, i.e. during the Messinian salinity crisis. This record provides well documented analogues for studying the impact of rapid tectonic and climatic changes affecting the short and medium-term evolution of highly sensitive environments. The continuous Plio-Quaternary sedimentary records of the Mediterranean also represent a unique geological archive for studying climate changes and related forcings, with numerous sapropel and tephra horizons being likely to yield very accurate dating. High-frequency climate variations have been precisely recorded in the Western Mediterranean basin, as a result of eustatic variations and coeval changes in the thermo-haline circulation. In the Eastern Mediterranean basin, by contrast, the sedimentary records are directly impacted by monsoon processes. High subsidence rates account for thicker deposits in the Rhône and Nile deep sea fans, which thus form a unique archive for high-resolution studies, ranging down to sub-orbital scales, as demonstrated by cores collected in the Gulf of Lions during the PROMESS-1 cruise, and which deserve to be extended by deeper drilling.

3

Tools and dedicated work flows

FIELD STUDIES, OFFSHORE SURVEYS AND IN SITU MEASUREMENTS IN NATURAL LABORATORIES

- Field work (structural geology, petrography, geochronology, biostratigraphy, sedimentology, paleomagnetism, seismotectonics, paleoseismicity, historical seismology and electromagnetic surveys).
- Upgrading and integration of permanent networks of seismological recorders.
- Upgrading and integration of permanent and dense temporary networks of geodesic stations (GPS).
- Implementation of a complete bathymetric map of the Mediterranean. Coverage of the deep offshore is already relatively well advanced, but various sectors still merit further acquisitions. However, further bathymetric surveys should also be carried out in shallow water domains where seismic and gravitational hazards have been identified.
- 3D seismic acquisition in areas targeted for drilling, recording of regional deep seismic and high-resolution 2D seismic reflection and magneto-telluric profiles both offshore and onshore, as well as across coastal areas and up to adjacent foothills where this is required. Mediterranean subduction zones have so far only been poorly imaged by reflection profiles. High-resolution seismic tomography will be dedicated to the study of the crust, lithospheric mantle, and extending down into the lower mantle, combining both onshore seismic networks and the deployment of ocean-bed seismometers (OBS). As a follow-up of Topo-Iberia, similar projects could be initiated along the northwestern (Topo-Maghreb) and northeastern margins of Africa (including the Saharan Atlas and Saharan flexure, Sirte basin, Cyrenaica and Western Desert of Egypt) and Levant, in order to characterize the crustal and mantle structure of the Mediterranean margins as well as the lateral transitions with stable cratonic portions of the African and Arabian plates.
- Ultra-deep offshore drilling (involving the use of Chikyu-type drilling platforms), as well as more conventional shallower wells, aimed at resolving targeted questions such as the occurrence and distribution of potential resources and reserves beneath the Messinian salt in the Western Mediterranean, or the paleoclimate records and deep biosphere in both the Western and Eastern Mediterranean.
- Further heat flow studies.
- Integrated petrophysical, petrological and geochemical studies of mantle rocks (i.e., exhumed mantle and xenoliths associated with volcanic suites), in order to obtain better constraints for the geological interpretation of geophysical records and geodynamic models.
- Prospection of deep karstic aquifers by means of air-borne electromagnetic surveys and offshore high-resolution seismic reflection.

AIR-BORNE AND SATELLITE SURVEYS

- Remote sensing of electromagnetic signals originated from the planet Earth (visible domain, IR, UV, radar band C, L, X, micro-waves).
- Systematic processing of interferometric radar images for targeted areas within the Mediterranean domain.
- Acquisition of a regional data base of optical images covering the Mediterranean domain, to perform short-, medium and long-term studies:
 - Correlation of optical images taken before and after earthquakes or volcanic eruptions.
 - Compilation of a high-resolution MNT covering the entire Mediterranean domain, by means of a series of SPOT images.
 - Long-term monitoring of geomorphology, anthropic impact and erosional processes, especially in vulnerable coastal areas, dedicated also to the short, medium- and long-term evolution of the coast line itself.
- Use of high-resolution Lidar air-borne surveys in specific test areas.

FURTHER MEASUREMENTS AND ANALYTICAL STUDIES IN RESEARCH LABORATORIES

- Geodynamic and palinspastic reconstructions of stages in the past evolution of the Mediterranean domain

and simulation scenarios for the future (from -70 Ma up to +10 Ma).

- Paleo-climatic and paleo-environmental reconstructions for the same time intervals, as well as for shorter periods (focussing on the last 1-2 Ma).
- Erosion/sedimentation budgets.
- 3D modelling of lithosphere dynamics, surface processes, interactions between surface processes and mantle dynamics, as well as between geodynamic processes and climate.

LONG-TERM MONITORING, DATA BASES AND NUMERICAL TOOLS

- Implementation of in situ laboratories for the monitoring of highly vulnerable or characteristic areas (natural hazards).
- Funding instrumental networks for the monitoring of tides and longer term sea-level variations.
- Increase the number of subsurface environmental observatories, using shallow wells.
- Pooling of available databases with easy access to the circum-Mediterranean and European scientific community.
- Compilation and acquisition of a high-resolution bathymetric coverage of the Mediterranean region.
- Providing the interested scientific community with powerful visualisation and quantitative tools.

4

International perspectives

The TerMEx programme aims at the study of the Mediterranean realm as a whole. TerMEx is targeting the international circum-Mediterranean and European community. Indeed, the Mediterranean domain forms a unique geological entity with complex 3D interactions; this implies that its current architecture and evolution should be studied at the scale of the entire basin, while also covering the bordering countries, i.e. including its oceanic domain and continental margins, as well as its lithosphere and underlying mantle. In adjacent parts of North Africa and the Middle East, the transition between the Alpine-Mediterranean lithosphere and the stable African and Arabian cratons also needs to be better documented. Pilot areas exposed to specific natural hazards will also justify dedicated studies:

- In the Western Mediterranean, specific targets will thus include the Betics, Gibraltar Arc, Rif and Maghrebides, the Gulf of Lions, the transition between the Franco-Italian Alps and the Ligurian basin, the Balearic Islands and Catalonia.

- In the Central Mediterranean, specific targets will also include the Apennines, Sicily and the Eolian Islands.

- In the Eastern Mediterranean, further projects will aim at the study of the Aegean, the Marmara Sea, the North Anatolian Fault, the Gulf of Corinth, the Hellenic volcanic Arc, the Levant Fault, the Ionian Islands and the Egyptian margin.

The TerMEx programme will not only require a European-level coordination, but must also involve Earth scientists from North Africa (South Mediterranean margin) and the Middle East (East Mediterranean margin).

Numerous other European initiatives already address some of the TerMEx objectives, and we need to tailor this new programme so as to avoid duplication, and instead consolidate the existing projects. Among these projects, we can mention:

- Topo-Europe (<http://www.geo.vu/~topo/>), which already comprises the TopoMed programme (<http://www.insu.cnrs/f1454doc.bockelmann-resume2008-v2.doc>), coordinated by the University of Utrecht.

- EMSO-ESONET (European Multidisciplinary SeaFloor Observatories), coming under the scope of ESFRI (European Strategy Forum of Research Infrastructure): European initiative involving sub-marine observatories and aimed at continuous monitoring of the activity of circum-European oceanic margins.

- EPOS (European Plate Observatory System), also in the framework of ESFRI. This programme comprises five components (observatory network, observatories dedicated to targeted objectives, network of laboratories involved in the study of rock properties and minerals, data bases and integration of data, high-speed computing systems);

- MEDREF: extension of the EUREF GPS network across the Mediterranean, also linking the EUREF network (<http://www.epoch.oma.be/>), which has been active for more than ten years, with the AFREF initiative (<http://geoinfo.uneca.org/afref/>), which is currently being implemented.

5

Estimated budget

Current estimates for the next 10 years: 400.106 Euros (400 M€).



INTRODUCTION

The daily life of Mediterranean peoples has regularly been affected by devastating earthquakes, volcanic eruptions and tsunamis. In other respects, the diversity of its landscapes that is, the geological features, climates and environments, has contributed to the development of a succession of famous circum-Mediterranean cultures. For instance, the results of the monsoon in Ethiopia and along the Nile Valley have contributed to the rise of the ancient Egyptian civilisation, whereas the high density of Aegean islands led to the development of navigation and the spread of Hellenic culture. Water recharge in the Apennines facilitated the growth of the ancient city of Rome, as indicated by the direct correlation between periods of accelerated construction of water pipes and the economic booms recorded in the history of this city. In the Mediterranean as well as worldwide, deltas have favoured the development of cities and agriculture.

The Mediterranean represents a unique geological feature. Its present-day landscapes reflect a geological history extending over more than 100 Ma., if we also take into account the evolution of the former Tethys Ocean. The geological evolution of the Mediterranean has shaped both its sub-marine and continental morphology. The progressive isolation of the Mediterranean waters and their partitioning into a number of sub-basins result from a long geodynamic evolution, controlled predominantly by an incipient convergence between Eurasia and Africa. About 30-35 Ma ago, this long-lasting convergence led to the collision between the two supercontinents. The collision between Europe and Africa has continued up to the present day, in a context of a dominantly cooling climatic trend [over the past 2-3 Ma], despite the more or less cyclic occurrence of short phases of warming. The Mediterranean, as we know it today, developed during this last period, characterized by its particular subduction dynamics, coeval with mountain building processes and the development of localized extensional basins.

The geological archives of the Mediterranean contain a comprehensive record of major paleo-environmental crises, resulting from both geodynamic (i.e. deep Earth processes) and climatic forcing. Unravelling these crises can lead to a better understanding of the various parameters controlling the regional climate,

the dynamics of the oceanic waters and Mediterranean biodiversity, as well as the interactions between these parameters. The most spectacular crisis occurred during the Messinian, 5.6 Ma ago, when the mean sea level of the Mediterranean dropped to 1 500 m below the present-day reference level, leading to the deposition of a salt layer more than 1 km thick. During the Messinian event, the Mediterranean rivers incised deep subaerial canyons, which were subsequently filled by marine sediments during the Lower Pliocene transgression. Circum-Mediterranean karsts, which are known to store large volumes of fresh water, were not only also greatly impacted at the onset of the Messinian marine regression, but also during the Lower Pliocene rise of sea level. In the same way as before the Messinian crisis, the present-day Mediterranean comprises a number of narrow straits, which facilitate the isolation of individual sub-basins from the World Ocean, sooner or later leading to their complete drying up. Since the Messinian event, the circulation of water masses has remained restricted, as indicated by the repeated deposition of sapropels in the Eastern Mediterranean. Throughout the Plio-Quaternary period, the entire Mediterranean was strongly affected by global climatic changes. In the Eastern Mediterranean, anoxic episodes led to the deposition of organic-rich horizons, mainly because of the stagnation of its deep waters. The same process still operates seasonally in the Adriatic, where it is possibly amplified by anthropic activities.

Earthquakes and volcanic eruptions represent the most spectacular events resulting from the dynamics of the deep Earth. However, we need to improve our understanding of the links between deep and surface processes to better predict or mitigate the consequences of these natural hazards. On the northern margin of the Mediterranean, natural landscapes have been progressively deforested, inducing slope instabilities, while the seasonality of Mediterranean oceanic and atmospheric water exchanges accounts for short episodes of very heavy and devastating rainfall. Mediterranean communities are all facing natural hazards such as flash floods, which are even likely to increase in areas where the natural resources, vegetation and drainage have been damaged by human activities, or remain inadequately managed. In order to preserve such vulnerable environments and pro-

tect Mediterranean populations from geological hazards, we must better understand the dynamics of the Mediterranean system as a whole, so we can predict its short and medium-term evolution.

Contrasted geographic and climatic conditions differentiate the northern, eastern and southern margins of the Mediterranean. For instance, the African plate is gently subsiding and being progressively subducted beneath Eurasia in the east, whereas Eurasia is becoming uplifted, developing positive topography above the subduction zones. Such asymmetry accounts for a coeval partitioning in fresh water and energy resources: fresh water is dominantly present in the north, whereas hydrocarbon reserves are more abundant in the south. Even though the overall Mediterranean climate is partly controlled by the global climate evolution, local conditions have developed as a response to the topography and therefore also to the geodynamics.

The Mediterranean is a very vulnerable area, with an estimated population of 450 million. Any growth in population in this region will dramatically increase pressure on the marine and coastal environments in terms of access to water resources and pollution, making the climatic and seismic hazards even more alarming. We can already measure the strong impact of human activities on the ecosystems, coastline stability and water resources. The fresh water supplied by the major rivers is no longer enough to balance evaporation, with the result that the advection of Atlantic oceanic water is becoming the main contributing factor for maintaining a constant sea level in the Mediterranean. The main gateway for water exchanges with the global ocean is indeed located at the Gibraltar Strait, despite some minor influx eventually coming from the Suez canal. Therefore, any pollution of the Mediterranean Sea is likely to become of greater concern than in the open ocean.

An understanding of the Mediterranean system and its environmental feed-backs will require work at various temporal and spatial scales. The TerMEx programme will aim at studying all the components of this complex system, including the dynamics of the deep mantle and lithospheric deformation as well as surface processes, assessing the incidence of these components on the evolution of sedimentary basins, natural hazards, fresh water and energy resources, as well as on the overall Mediterranean climate.

Such an integrated project for the Mediterranean as a whole is expected to provide a strong benefit for the end-users and circum-Mediterranean communities, because of its multi- and trans-disciplinarity, multi-ob-

jectives and multi-scales approach. It will require the integration of local and supra-regional scales over time, which are relevant for long-lasting processes such as mantle flow and crustal dynamics, which take place over millions of years, or instantaneous events such as devastating earthquakes and tsunamis. The Mediterranean climate is also changing according to a more or less cyclic pattern on various time scales. The TerMEx programme should help to unravel the respective roles of Earth dynamics and external forcing on the evolution of the climate of the Mediterranean and adjacent land masses.

TerMEx will be the first attempt to carry out such an integrated programme at the scale of the Mediterranean realm. Although a few pioneer studies have already been undertaken to implement integrated data sets at the scale of the Mediterranean, these projects were limited to restricted groups of scientists or individuals, or focused only on a single targeted event such as the Messinian. Hence, the aim of TerMEx will be to address major societal concerns such as security and resources, by considering the main driving forces as being deep and surface Earth dynamics and its interactions with climate.

This programme will require strong interactions among various disciplines, in order to discriminate the main parameters controlling the Mediterranean landscapes. Because of its ambitious scope, societal implications and trans-border complementary approach between northern, eastern and southern countries, TerMEx will require a close partnership between the European community and other circum-Mediterranean countries. Although, trans-Mediterranean collaborations already exist, at this stage they remain dominantly bilateral. The success of the TerMEx programme will thus depend on its ability to generate a truly trans-Mediterranean network of exchange and collaboration, involving most if not all the individual research centres involved in the study of this area. International workshops must be organized as soon as possible with the various countries likely to participate, to identify and rank – following joint consultation - the scientific and societal priorities and long-term strategies for collaboration, technological transfer and training, as well as fundings.

The current strategic topics of TerMEx include:

- 1) Past and Present Geodynamics
- 2) Natural Hazards and Risks
- 3) Water and Energy Resources
- 4) Paleo-environment, paleo-climate, Mediterranean ecosystems, sedimentary dynamics and their future evolution
- 5) Out-Reach

The first topic (Geodynamics) has strong links with topics 2, 3 and 4. Indeed, crustal, lithosphere and mantle architecture as well as Mediterranean dynamics to a certain degree drive our understanding of hazards and the distribution of resources, i.e. the location of earthquakes and land slides, the generation of magmas, the generation and trapping of hydrocarbons, as well as the formation and evolution of fresh-water aquifers. This topic must be coordinated with ongoing European projects such as Topo-Europe and Topo-Med from ESF, which have partly overlapping objectives and scientific communities in common.

TerMEx will also benefit from collaborations with the HyMEx and PaleoMEx programmes of the "MISTRALS". Past environmental crises are indeed likely to help in evaluating the main parameters controlling the water budget in the Mediterranean region. Conversely, a better understanding of the modern budget of fresh and marine waters, providing a basis for measuring all the key parameters, should help in unravelling the past evolution of the Mediterranean, especially during well identified crises.

The expected societal feed-back of the TerMEx programme will be very important. For example, we anticipate that the results obtained will contribute to a better management of natural risks, as well as a sustainable development of the resources by the circum-Mediterranean countries. Otherwise, numerous earthquakes and recurrent climatic changes have been reported in the ancient literature, making it also necessary to collaborate with the human sciences community, i.e. paleographers, historians and archeologists, so the value of these old records can be added to the overall assessments of risks and hazards.

A crucial task shared by all the main themes and sub-projects of TerMEx (as well as EcoMed), will be to set up an efficient network of data bases, which should indeed be interconnected with easy access, if not actually free of charge, to the scientific community as a whole, including any type of public data dealing with the Mediterranean (i.e. digital topography, bathymetry, seismicity and seismic profiles, when in the public domain, 3D tomography, well data, when in the public domain, gravimetry, magnetics, paleoclimatic records, etc...). This task alone is quite ambitious, although it could benefit for already existing national initiatives such as have been developed in Italy (Geological Society), and in France (BRGM):

In this context, the BRGM, which has the duty of maintaining the French geological archives, has proposed to implement the existing data bases compiled by French teams in the Gulf of Lions, the Ligurian margin, the Nile Delta and the Middle-East (MEBE consortium), ensuring their long-term digital conservation and accessibility to the public by means of updated software. The user interface should remain simple, i.e. geoportal whereby scientists can export and store their own geo-referenced data, and make them available for use by the entire community. Free software such as Google Earth could be used to plot the data on maps. The first step should be to identify existing data bases and the persons in charge of their conservation. It would then be necessary to define the required criteria for inter-operability (INSPIRE format), edit a catalogue and implement a user interface. BRGM is proposing here to allow cheap access to its 3D geomodeler (since it is now owned and distributed by a private company), but other initiatives/suggestions/propositions are of course welcome.



1. PAST and PRESENT GEODYNAMICS

1.1.

Subduction & mantle dynamics

Recent work has demonstrated the importance in Mediterranean tectonics of slab retreat dynamics in subduction zones. In fact, a large part of Mediterranean tectonics could result from the flow induced by slab retreat in the underlying mantle. Thus, it appears we should probably look for the origin of the movements not only laterally, but also beneath the lithosphere. It has also been suggested that the Neogene volcanic activity of North Africa and Western Europe resulted from a remobilization of subducted material accumulated beneath the upper mantle. A global vision of Mediterranean geodynamics and associated subductions should therefore encompass the underlying mantle as well as the peripheral continental domains. Moreover, modelling crustal deformation in areas with important seismic hazards requires an understanding of the stresses applied to the system boundaries, including the mantle structures and processes which strongly influence surface phenomena. The situation can vary considerably, depending on whether deformation is controlled exclusively by lateral loading or via an underlying mantle flow. With its coupled approach, combining surface observation and deep-structure imaging, the TerMex programme should be able to provide answers to this crucial question.

Horizontal movements on system boundaries are very slow. Africa is moving obliquely towards Europe at a maximum rate of 1 cm/year. However, geological data and spatial geodesy surveys have revealed the presence of much faster crustal displacements over the subduction zones. Thus, the velocity of the westward translation of Anatolia towards Eurasia reaches 2.5 cm/year and continues to increase nearer to the Hellenic trench. This movement might result from the collision with Arabia, through an extrusion-type mechanism. But other patterns are suggested that involve the detachment of African slabs under Turkey and Greece. Tomography reveals a discontinuity in the slab under Western Turkey, and probably also under the Peloponnese, which could have led to a rapid opening of the Aegean Sea during the Miocene. However, what is the significance of the recent opening of the Gulf of Corinth and the extension of the

North Anatolia Fault into the Aegean area? In the western and central Mediterranean, the latest data suggest that back-arc basins, such as the Tyrrhenian Sea, could have opened at a rate of 12 cm/year during the last 2 to 3 million years. Once again, such rates cannot be attributed to the Africa/Eurasia convergence. The retreat of the slab under the Apennines and Calabria is probably responsible for this tectonic phenomenon. In the westernmost part of this domain, the opening of the Sea of Alboran raises similar questions.

Current mantle structure and dynamics under the Mediterranean are also largely inherited from the subduction of the Tethys and the region's evolution during the Neogene, after the Africa-Eurasia collision. Observing mantle structures could therefore constrain, not only on current Mediterranean geodynamics, but also concerning its evolution since the Mesozoic. The first indications provided by mantle tomography concern slab geometry. In theory, these data can be confronted with the tectonic history of the region to build up a pattern of development of their geometry over the course of time. However, currently available images have a very poor spatial definition and lack sufficient homogeneity to allow us to link surface events with observations such as slab rupture or detachment. Only by extending higher-definition 3D images with greater continuity to neighbouring areas will it become possible to relate slab behaviour in the upper mantle to crustal tectonics, in the hope of revealing possible correlations between this behaviour and deep mantle convection. Several ongoing programmes, (Thales was Right, Simbaad and Medusa) are beginning to provide us with such images of the mantle in the Aegean area. Similar campaigns should be undertaken in the central and western Mediterranean. These higher-resolution tomographic models should help us understand slab behaviour over longer periods of time. They should also improve our visualisation of subduction geometry under Crete, Calabria and Gibraltar, three zones where high-magnitude earthquakes occur.

The acquired data should also provide us with images

of lithospheric structure and thickness variations in the adjoining continental areas. Combining transfer functions with seismic anisotropy will allow us to constrain mantle flows at the base of the lithosphere. For instance, the relief of the Moroccan Atlas partly results from lithospheric thinning over a rather narrow zone, but we have not yet been able to achieve a precise definition of the overall deep architecture of this region. This thinning could result from a combination of erosion of the lithosphere with mantle flow coming from the Canary Islands hotspot and feeding the Mediterranean upper mantle, in relation with the opening of the Alboran Sea.

The northern part of the African continent, as yet poorly instrumented, should benefit from more attention in future research operations. Indeed, given its northward displacement, the African plate may overlap deeper structures which are inherited from subduction. Little is known about these structures as geophysical instrumentation is poorly developed in this area. However, the presence of broad-scale volcanism (Atlas, Hoggar, Tibesti, Darfour, etc...) could

indicate the existence of former oceanic material, deeply buried during the Africa-Eurasia convergence. A combined seismic imaging and geochemical study of subsurface North Africa (volcanism and xenoliths) should allow us to investigate the deeper structures related to the ancient geological history of the Mediterranean, and explore the complex interactions between mantle flows and instabilities generated by the subduction of old oceanic slabs.

Finally, slab dynamics, and more particularly the periods of detachment and break-up, are expected to produce surface relief variations (migration of depocentres and changes in basin geometry) as well as lead to a geochemical signature of the magmatism. To determine the erosion-sedimentation budget, as mentioned further below, it will be necessary to take account of these deep processes when interpreting the data. As regards the magmatic aspects, the study of key areas such as western Anatolia should allow us to characterize the impact of slab rupture on the chemical composition and setting of the magmatism.

ACTIONS 1.1

High-resolution seismic tomography of the upper mantle, or even of the lower mantle in the central and western Mediterranean and beneath North Africa (Atlas, Maghrebides, North-African hotspots and associated lithospheric structures).

Crustal tomography of key areas such as the interplate contact between Crete and the Peloponnese, or beneath Calabria and Gibraltar.

Assessment of sedimentary basin evolution, migration of relief and depocentres.

Assessment of magmatism: chemistry and position of active centres over time.

Combined petrology and geochemistry study: petrophysics of mantle rocks expelled by volcanism or exhumed in order to constrain the geophysical observations and geodynamic models.

Reinforcement of permanent seismic observation networks (including an offshore extension with EMSO and probably KM3) and continuous GPS monitoring.

Acquisition of a high-resolution DTM (digital terrain model) of the whole Mediterranean area within the framework of an agreement with SPOT-images.

1.2. Crustal dynamics

All the structural components of geodynamics are involved in the geological history of the Mediterranean: subduction zones (Gibraltar, Calabria, Greece and Cyprus), collisional chains (Alps, Dinarides, Hellenides, etc...), accretionary prisms (Calabria prism, Mediterranean Ridge), major strike-slip faults (transcontinental: North Anatolian Fault, Levant Fault; or submarine: Hellenic faults), rifting and back-arc oceanic opening [Ligurian-Provençal basin and Gulf of Lions, Tyrrhenian Sea, Aegean Sea (although not really on the same scale as the other structures mentioned here) and Alboran Sea]. The complex geometry of the system means that the various geodynamic settings can follow each other fairly rapidly in time. For instance, the passive margins of North Africa and North Liguria are now once again under compression. In the case of the Algerian margin, we are currently witnessing the possible onset of a future south-dipping subduction zone. As for the North Ligurian margin, the deformation dynamics is most often interpreted as resulting from an incipient north-dipping subduction; however, current evidence points towards the existence of an extensional deformation field in the north of the Alpine domain, which raises the question of a possible interaction between distension and compression from the high Alpine chain to the adjacent basins. We should also investigate the part played by gravitational tectonics on a crustal scale. Similarly, the Rift of Corinth only appeared 2-4 Ma ago on a particular segment of the former mountain chain. The complexity of these structures is confirmed by surface geology studies. Spatial geodesic surveys, particularly GPS, provide us with fairly accurate instantaneous displacement fields, and the kinematics at the boundaries of the Mediterranean area are reasonably well constrained. In all the cases mentioned above, it is often the structural geometry and its evolution in time at crustal level which remain problematic. Hazard quantification requires the estimation of activable fault surfaces, but possible correlations between surface and deep structures are most often unknown. Even for the Africa-Europe plate boundary, which can be studied on land, we still do not know the precise location of the deformation.

For smaller areas, such as the Rift of Corinth, the internal geometry at depth remains poorly understood. What is the meaning of the gently north-dipping microseismic zone observed beneath the western part of the Gulf? Does it merely represent the detachment of a thick unit of fluid-rich cataclasites or fluid migration from the underlying slab? Similarly, offshore from Crete and the Peloponnese, the geometry of the interplate contact in the Hellenic trench remains unknown, even though it is the only Mediterranean region where earthquakes with magnitudes greater than 8 are reasonably likely to occur. Similarly, in the Sea of Crete, very little is known of the nature of the substratum or the history of its formation. In the central Mediterranean, debate continues regarding the possible influence on regional seismic activity of Ionian Sea subduction under Calabria and the Apennines due to slab retreat. This is an important issue, particularly since the area has already suffered major earthquakes (for example, Colfiorito and Assisi in 1997 with magnitude 5.9). The same question arises regarding the subduction of the Atlantic under the Gibraltar arc in the Gulf of Cadiz and its possible connection with the Lisbon earthquake (1755, magnitude 9). Similarly, the present-day deformation process of the North Algerian margin is the source of major devastating earthquakes such as Boumerdes (2003, $M=7.3$), Orleansville (1954) and El-Asnam (1980). Despite this intense seismic activity, the crustal-level geometry of the onshore and offshore faults responsible for these earthquakes remains uncertain. The problem is even more acute in areas of moderate seismic activity such as North Liguria, where extremely destructive earthquakes are rarer (Imperia, 1887), but where seismic risks are important given the area's vulnerability.

Therefore, we need to improve our imaging of active-fault geometry, our understanding of their position with respect to crustal structures, and discover which crustal structures are reactivated. The inherited structures should be clearly identified to specify the location of active deformation with respect to the pre-existing structures. Will deformation be preferentially localised on the boundaries between crustal

areas of contrasting nature, such as the continent-ocean boundary? How are the old faults remobilized in present-day deformation processes? In areas such as the Algerian or Ligurian margins, where passive margins undergo renewed compression, does the active deformation remobilise the ancient structures of the margin or does it become concentrated along newly formed faults that cut across the older structures?

Amongst the major earthquakes in the Aegean, those that regularly affect the North Anatolian Fault have recently demonstrated their devastating potential. To understand the dynamics involved in major transcontinental strike-slip faults, we need to take into account the prolongation of the North Anatolian Fault into the Aegean Sea, its connection with the Cephalonian Fault, the position and dimensions of active faults in the Marmara Sea as well as the exact history of this basin's formation.

To date, the mechanisms involved in continental crust distension remain poorly understood. However, the Mediterranean provides us with some particularly interesting examples that are currently the object of numerous studies, both offshore and onshore. The Gulf of Corinth is a good example of rifting initiation, providing us with a textbook case of high-speed active rifting. The nature of the ocean-continent transition in the Gulf of Lions and offshore Liguria and Corsica, as well as crustal thinning mechanisms, have been debated for many years, but we lack direct data on the nature of the crust and the subsidence history. Similarly, field studies in the Aegean and Betic metamorphic core complexes (MCC) have led to a partial description of their evolution and suggest mechanical models for their emplacement; however, the stumbling block remains the position of these complexes within the structure of the present-day crust. What are the relationships between the gently-dipping detachments observed on the roof of these MCCs and the more recent steeply-dipping faults? As yet, this question remains unanswered. Finally, the resistant part of the lithosphere in these domains is usually represented by the mantle. Improved knowledge of crustal dynamics necessarily requires a better understanding of mantle behaviour, and therefore a comprehensive taking into account of deep structures and surface observations.

Similarly, the processes leading to mountain building, through subduction and collision, are currently the object of intense research activity in the Mediterranean area. One of the advantages of this area is that its overall geology is well known, so researchers can rely on a solid basis. Moreover, since the rate of the

Africa-Eurasia convergence is rather slow, structures remain relatively well preserved during chain formation. Finally, the very complexity of African margin geometry prior to collision means that the Mediterranean chains display varying stages of development. This enables us to study the various stages of chain formation, all the way through to their destruction through erosion and post-orogenic distension. The Mediterranean framework could lead us to discover original answers to currently controversial issues, such as high-pressure rock exhumation, the influence of distension within mountain chains, lithospheric flexure, the transition from subduction to collision, the role of crustal rheological changes during collision, etc....

Evidently, geological field studies are indispensable, but they cannot resolve all these questions and we require more extensive research involving major logistical resources to address these issues from a critical point of view. We propose to focus on several large-scale regional seismic profiles with deep investigation and major deep-drilling programmes. Offshore drilling in the Mediterranean will have to penetrate the Messinian salt layer to reach the deeper structures. This will involve using riser drilling technology (IODP = Integrated Ocean Drilling Programme), the only feasible method when managing the safety issues inherent to the possible presence of hydrocarbons under the salt.

Thermomechanical modelling will allow us to test the various models and explore the variables controlling crustal rheology (P-T conditions, role of fluids at depth, as well as part played by the lithospheric and sublithospheric mantle, etc...). Indeed, it is important to determine the appropriate rheological parameters with respect to the spatial and time scales considered. Thermomechanical modelling is the most suitable way of progressing from experimental data to real-life parameters. This modelling will rely on in situ laboratory results to determine, using a long-term multidisciplinary approach, the various hydro-thermo-chemo-mechanical coupling phenomena involved (Rift of Corinth, North Anatolia Fault, Alto-Tiberina Fault, Campi Flegrei, etc...).

3-D geometrical modelling of the main interfaces [upper/lower crust, Moho., base of lithosphere] requires the use of modern tools such as 3D editors.

To integrate these data into new models, we will need to devise palinspastic reconstructions taking into account kinematics, relief evolution, climate/tectonics interactions, heat-flow evolution, sedimentation and erosion. They could include a projection extending 1-

10 Ma into the future.

Detailed field work will be required to back up this research work, especially when new data needs to be acquired or when old data has to be reconsidered. This will make use of various techniques: structural

analysis, geomorphology, seismotectonics, geodesy, metamorphic petrology, mantle-rock studies, radiochronology, biostratigraphy, paleomagnetism, sedimentology, etc. Indeed, our understanding of crustal deformation depends on the precise determination of tectonic history.

ACTIONS 1.2

Particular emphasis should be placed on determining offshore crustal structures and their link with known onshore crustal structures. Marine exploration requires the acquisition of geophysical data, which should then be interpreted according to the calibration of samples obtained by drilling at varying depths

At least five deep and very-deep drill holes could be considered for the following areas: Gulf of Lions, Gulf of Corinth, Southern Crete, Northern Crete (Sea of Crete) and Sea of Alboran. To prepare for these drillings, 3D seismic blocks are indispensable (3D is requested by IODP). Several projects are already under way, notably the SPIRAL programme which involves the shooting of four major deep profiles across the Algerian margin.

Other shallower drill holes should yield important data on deformation history. Drilling could be considered in the Sea of Marmara, for instance. The IODP project, which involves using adapted platforms to carry out 7 drill-holes (maximum penetration of 2000 m) in the Gulf of Corinth, should also provide this type of information. Similar drillings in the Gulf of Lions could yield important data on the Quaternary sedimentary series dating back to more than 500,000 years BP, the period already investigated by the PROMESS drill hole.

These drill holes need to be positioned on major trans-Mediterranean seismic profiles, such as Ecors, which extend both offshore and onshore: Gulf of Cadiz-Alboran Sea, Gulf of Lions-North Algerian margin, Libyan margin-Sea of Crete-Cyclades-Rhodopes mountains, Argentera Massif-Ligurian Basin. This raises the issue of the quality of the seismic data available in France. The quality of existing profiles for Mediterranean subduction zones is far poorer than for the profiles available in circum-Pacific subduction zones or the Equatorial margins. It is unfortunate that the nearest subduction zones are the very ones where the least imaging has been undertaken.

Geological and geophysical field campaigns are required when the data available is too fragmented or obsolete: they should include structural analysis, geomorphology, paleoseismology, metamorphic petrology, direct mantle studies when possible, paleomagnetism, radiochronology, paleothermometers, biostratigraphy, and sedimentology. Determine the paleostress fields on the shelves (as requested by industry) Seismic profiling (sub-surface and deep seismics, reflection and wide-angle), tomographic and magnetotelluric imaging, characterization of fluxes through geochemical studies of fluids circulating in the faults, study of present-day deformation using seismological and GPS studies (notably within the TopoEurope programme and its TopoMed component, but also in association with HYMEX to acquire water-content data from the various layers of the atmosphere); INSAR or SPOT imaging will be also very useful.

Bathymetric mapping of the entire Mediterranean domain. This has already begun and most deep areas have been mapped. The data have already been integrated into a GIS (Geographic Information System) which will be accessible via the TerMex portal. Shallow areas, however, have not yet been covered. Multibeam bathymetry acquisition takes much longer time in shallow areas. This should really be undertaken as most offshore seismic and gravity-driven slumping risks concern areas near the coast. Offshore territoriality problems are likely to arise in this case, and this legal issue should be addressed beforehand.

Mapping of active offshore and onshore faults, publication of a constantly updated atlas. Imaging of the southern and eastern domains of the Mediterranean and understanding the functioning of faults in these domains are essential objectives for the TerMex project. Given the quality of data in the southern and eastern domains, the characterization of slip-rates and return times of major earthquakes is particularly important. In the Western Mediterranean, knowledge concerning recently identified active faults (Algerian margin, Alps and Northern-Ligurian margin) will need to be improved given the vulnerability of these areas and despite the difficulties of studies in settings with low rates of deformation (TopoMed project).

Dating of active fault systems using radiometric techniques (cosmogenic isotopes: uranium/ thorium/ helium, etc.)

In situ laboratories of the EPOS programme (European Plate Observatory System): Concentration on a single site of long-term multidisciplinary observations in order to identify couplings on various time scales at the boundaries of tectonic plates or lithospheric (or crustal) blocks: Rift of Corinth, North-Anatolian Fault and Sea of Marmara, Alto-Tiberina Fault in the Apennines, Campi Flegrei, margins of the Africa-Eurasia plate in Gibraltar.

Paleothermometry studies for "Source-to-Sink" studies (history of relief denudation).

Geodynamic reconstructions of the past and scenarios for the future (-70 Ma to +10 Ma). Creation of a 3D time-evolution model integrating kinematics, relief, sedimentation and climate change. This will require a collaboration with paleoclimatologists; Dionisos-type codes (IFP) will be used to reconstruct the geometry and nature of sedimentary bodies. Concerning the Mediterranean, markers associated with the Messinian crisis (Gilbert-type deltas and salt onlaps, for instance) will allow a quantification of vertical movements, both offshore and onshore, over the past 5.6 Ma. Salt tectonics also record local tectonic phenomena (amplification, guiding or modifications in structural style). A fine-scale and systematic study of these markers would allow us to obtain a fairly reliable picture of the Mediterranean 5.6 Ma ago, thus permitting an even more accurate prediction of the evolution of the Mediterranean system.

Study of the subsidence history of Mediterranean basins and quantification of its tectonic component.

1.3.

Topography, erosion/sédimentation/ and sedimentary processes

Sedimentary basins record all sorts of changes in boundary conditions: lithosphere movements as well as climate changes. These records occur on different scales in time and space, which must be differentiated in order to distinguish tectonic signals from climate signals. Sedimentary basins also represent reserves of water, energy and mineral resources. A major objective is the study of couplings between deep and surface processes, as well as between temporal and spatial scales. In fact, many European teams are currently working on coupling thermomechanical codes for lithospheric deformation with erosion/sedimentation modelling codes.

As far as sediment transfer is concerned, the Mediterranean Basin has been partly or completely isolated from the World ocean for the past 30 Ma. All erosion products derived from coastal mountain chains around the Mediterranean are transported towards the onshore or offshore basins, along with sediments coming from the plateaus of East Africa (via the Nile, which rises in the Ethiopian Highlands, over 5,000 km away from the Levant Basin). The circum-Mediterranean continental margins are the site of active sedimentation, expressed either by the accumulation of widespread silico-clastic deposits known as turbiditic systems, or by erosion-related phenomena due to the down-cutting of canyons or the reworking of pre-existing deposits by submarine slides. Turbiditic systems are particularly well developed in the estuaries of major rivers such as the Rhone or the Nile, but they can also be found offshore from minor coastal rivers subject to exceptional flood regimes as occurring in the basins of Liguria, Corsica or the Maghreb. These sedimentation and erosion phenomena are controlled by several factors, operating on different scales in time and space. The nature and volume of detrital inputs from neighbouring continents are regulated by climate variations which control the erosion, release and transport of particles on the continent. In addition, glacio-eustatic changes control both the redistribution of detrital inputs on the margins and location of depocentres. During their accumulation, sedimentary bodies can also be reworked by more localized phenomena. Thus,

the recent systematic exploration of continental margins has revealed the importance and intensity of fluid releases, highlighted by extrusive phenomena in mud volcanoes or more diffuse effects in sediments with “pockmarks”. Finally, tectonic activity linked with the local geological setting, the dynamics of the lithosphere or the presence of a mobile substratum (sub-compacted clay, Messinian salt) induces either ductile or brittle deformation which can even be expressed at the sea-bed. Hence, the assessment of erosion/sedimentation budgets between offshore and onshore requires a detailed analysis of the impact of these different factors (intensity, frequency and rate) and their recording in marine sediments on various scales in time and space. The only way to achieve this is to improve our understanding of particle-transfer hydrodynamic processes and the impact of tectonics on the emplacement of new deposits or the deformation of pre-existing deposits; each of these events also needs to be accurately dated. The only possible loss of sediments from the system is through subduction of part of the sedimentary pile under the basal detachment layer of the accretionary prisms. Knowledge acquired on the Gulf of Lions margin (Western Mediterranean) and the Nile margin (Eastern Mediterranean) indicates that it is possible to quantify sediment volumes based on seismic profiles calibrated by stratigraphic data and dating. By drilling a series of deep wells, we should be able to quantify the volumes of sediment accumulated over time and compare the evolution of this sedimentation with the history of circum-Mediterranean mountain ranges and climate variations. This type of approach implies a comprehensive knowledge of topography and bathymetry as well as the availability of seismic profiles dedicated to sedimentary studies and an accurate dating of sediments. Currently established databases for the Gulf of Lions and the Nile margin, or those provided by the MEBE programme, could serve as initial models for this project.

To establish a sedimentary budget for the Mediterranean, we should not only be able to quantify eustatic effects and sedimentary fluxes, but we should also quantify the carbonate production that could mask

terrigenous supply (for instance, on seismic images). The various topographic wavelengths should also be extracted and correlated with local or more global processes (dynamic topography). In a foreland basin, for instance, what are the respective roles of gravity-driven deformation (salt, clay), crustal deformation, lithospheric flexure, possible slab detachment and purely sedimentary or climatic events? Particular attention should be paid to currently onshore sedimentary basins which extend under the sea, such as the Miocene/Pliocene basin in the south-east of Spain. Rigorous marine seismic studies could also supple-

ment the deep onshore investigations (chronology, structural and spatial arrangement of deposits). This dual approach will yield 3D models that can then be readily exported.

Major research efforts should be devoted to dating methodology (C14 and other radiometric methods, biostratigraphy, tephrochronology and palynology) to achieve an improved control of deposition and subsidence rates. All available methods should be used for the dating and quantification of landforms.

ACTIONS 1.3

Ultra-deep drilling and the major trans-Mediterranean seismic profiles considered above will be used to establish these erosion/sedimentation budgets.

Locally, shallower drill holes could yield important data on sedimentary series. As far as the Quaternary period is concerned, this would involve drillings in submarine deltas and lacustrine sediments (Sea of Marmara, Sea of Crete, Rift of Corinth, Black Sea).

Erosion/sedimentation budget on a Mediterranean-wide scale: the sedimentology community should be keen to support this project, particularly colleagues working on large-scale budgets.

Comparison of sedimentary records from the Nile and Rhone deltas covering the Pliocene and Quaternary: emplacement of terrigenous deposits in contrasted tectonic and climatic environments. The "Nile Experiment" and ECORD (European Consortium for Ocean Research Drilling)

Study of the feasibility and potential hazards of geological storage of CO₂ under the Messinian salt.

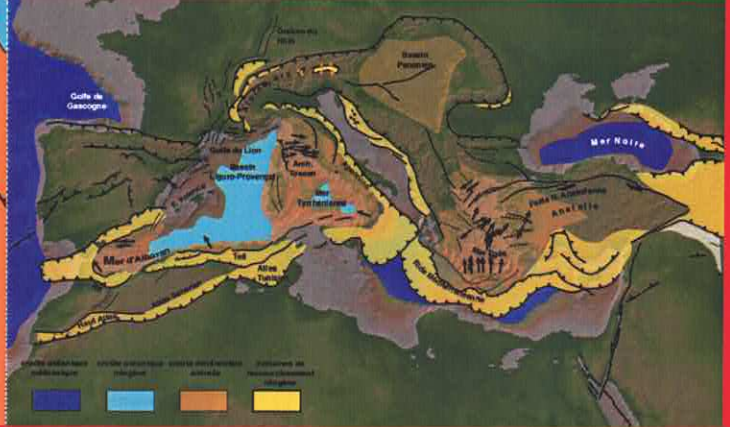
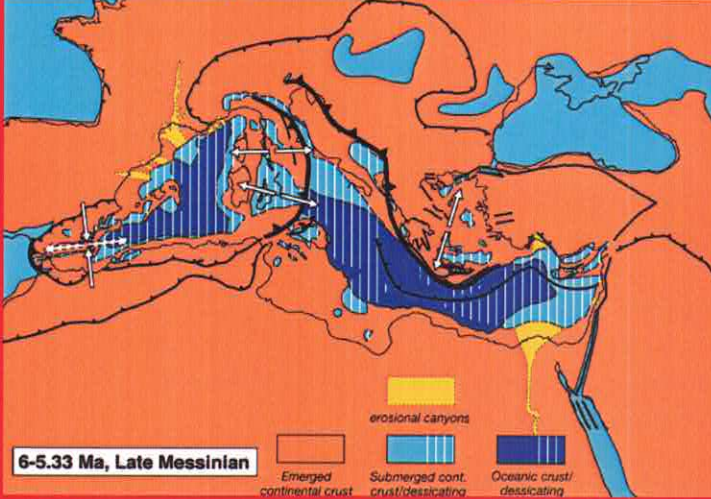
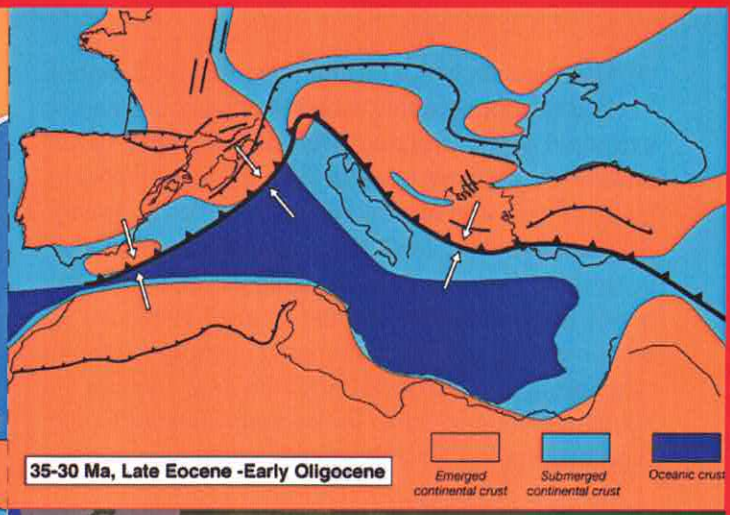
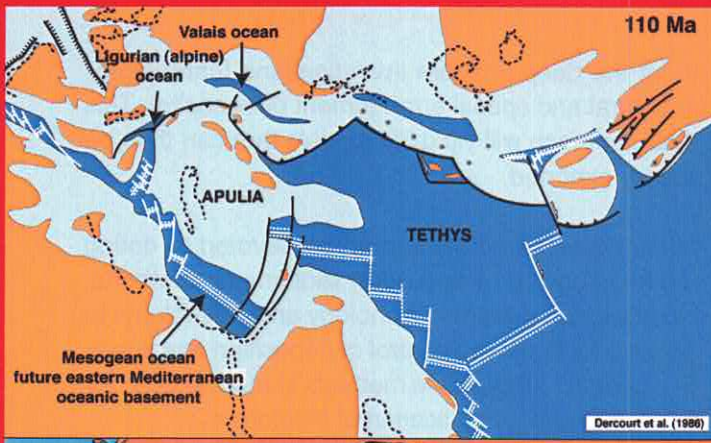
Detection of possible hydrocarbon-bearing systems under the Messinian salt.

The bathymetric coverage of the Mediterranean should be supplemented, particularly in shallow areas, using onboard resources and dedicated tools.

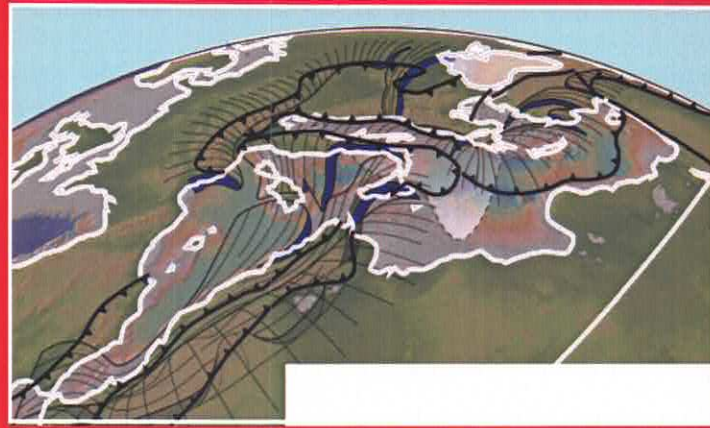
Regarding onshore topography, a comprehensive and detailed DTM of the entire region should be acquired and made available to all via the database.

Systematic study of relief evolution, dating of the formation of the main landforms.

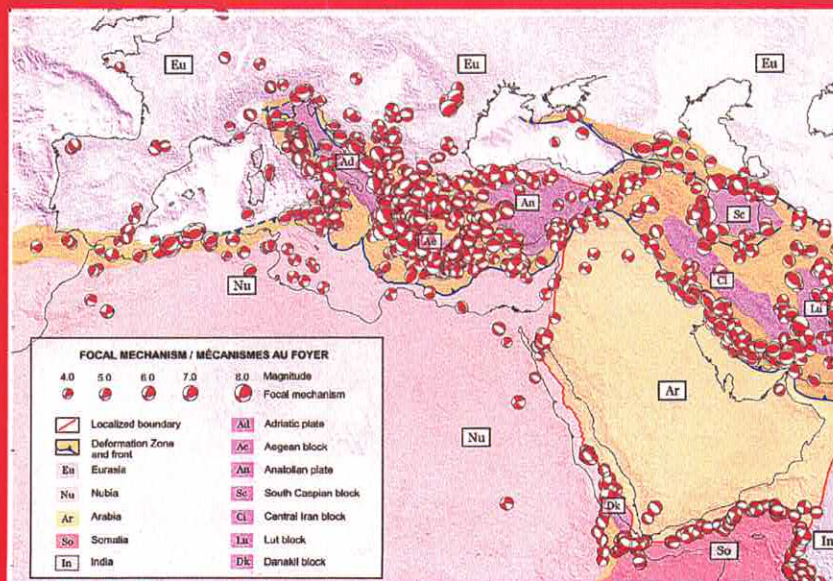
The geodynamic reconstructions mentioned above should take into account the evolution of relief and sedimentation.



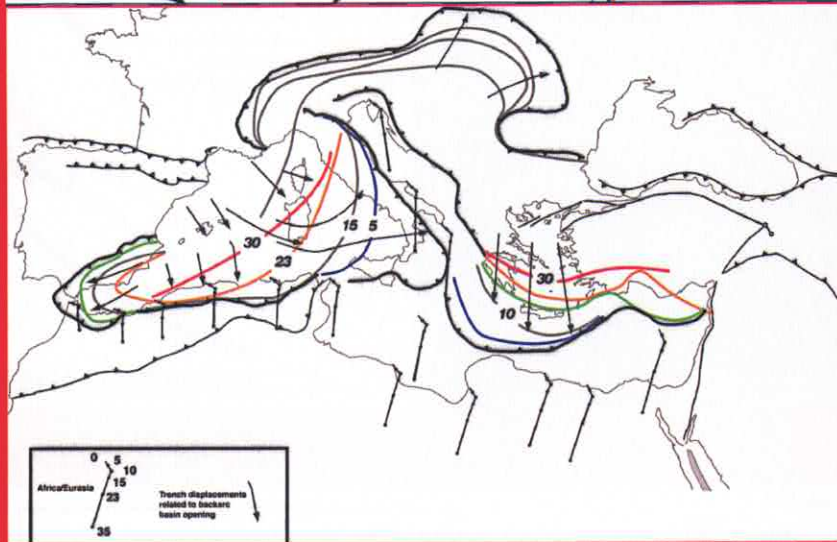
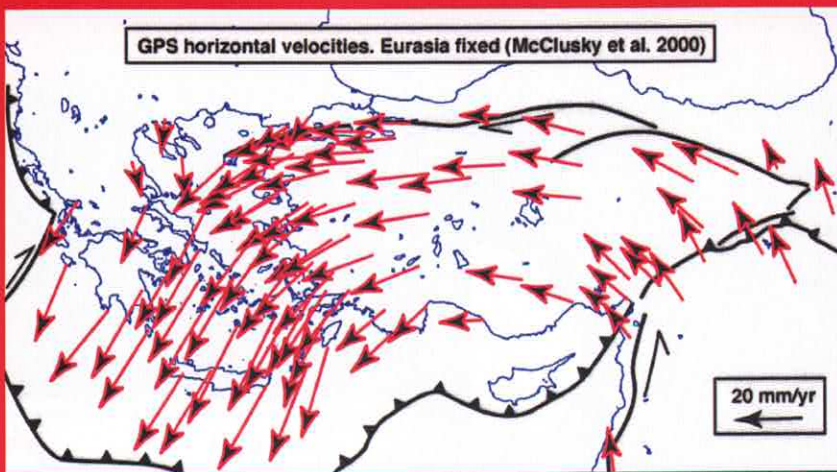
From the Tethys Ocean to the Mediterranean. (Dercourt et al. 1986, Jolivet et al. 2006, 2008)



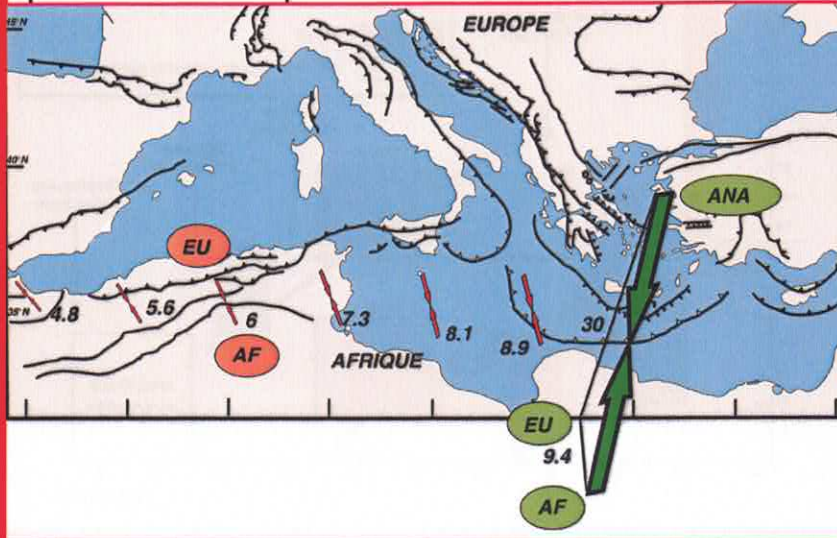
Mediterranean slabs. (Jolivet et al. 2009)



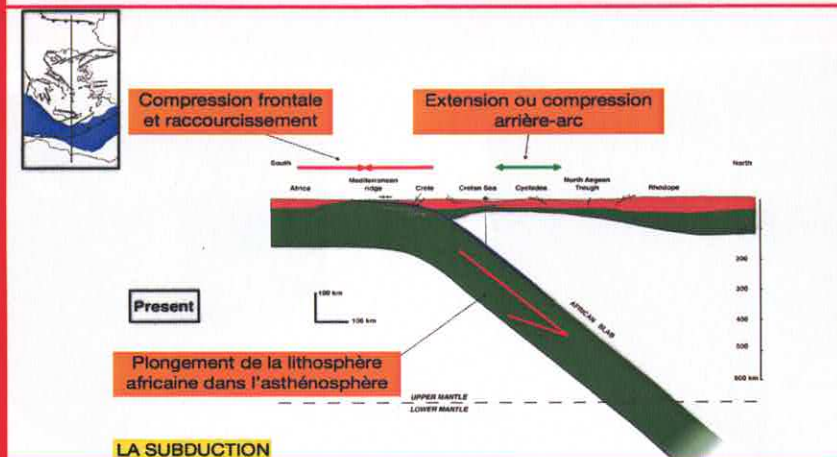
Chamot-Rooke in Barrier et al. 2004



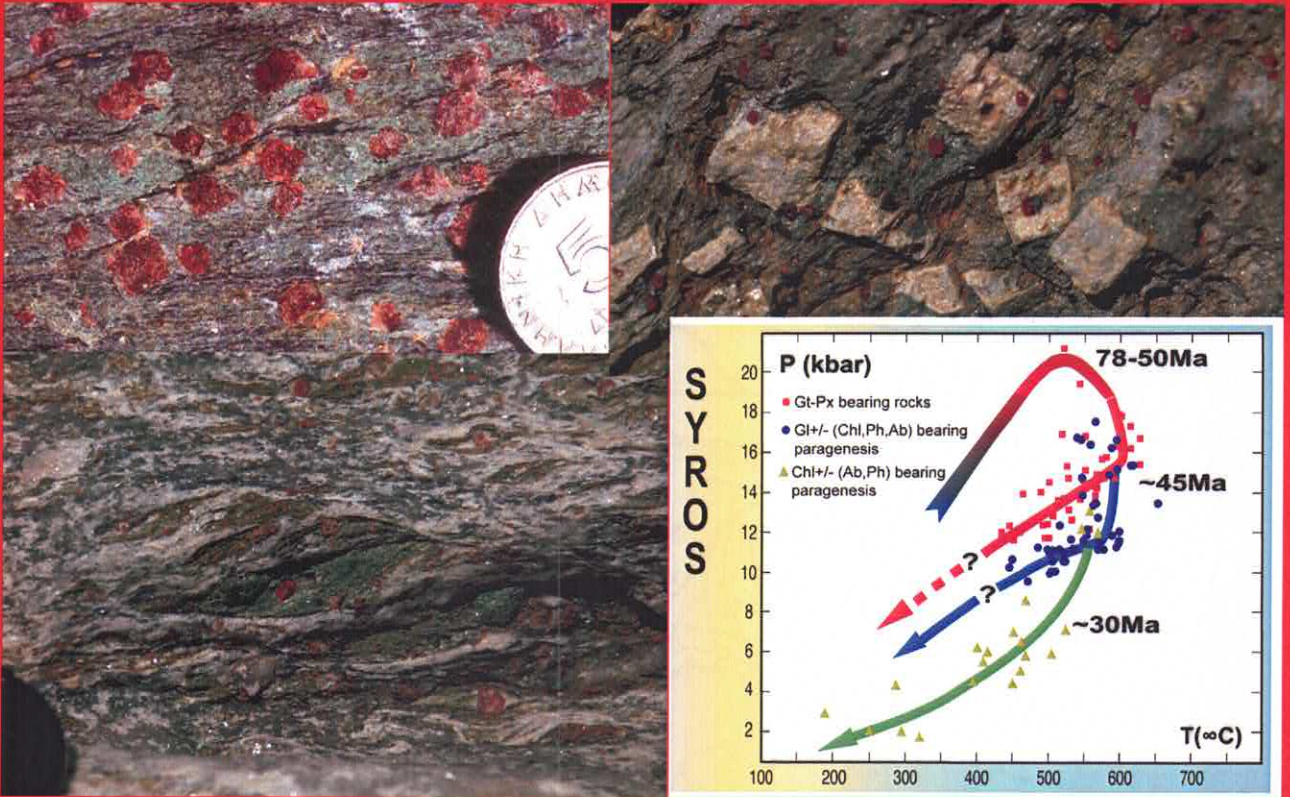
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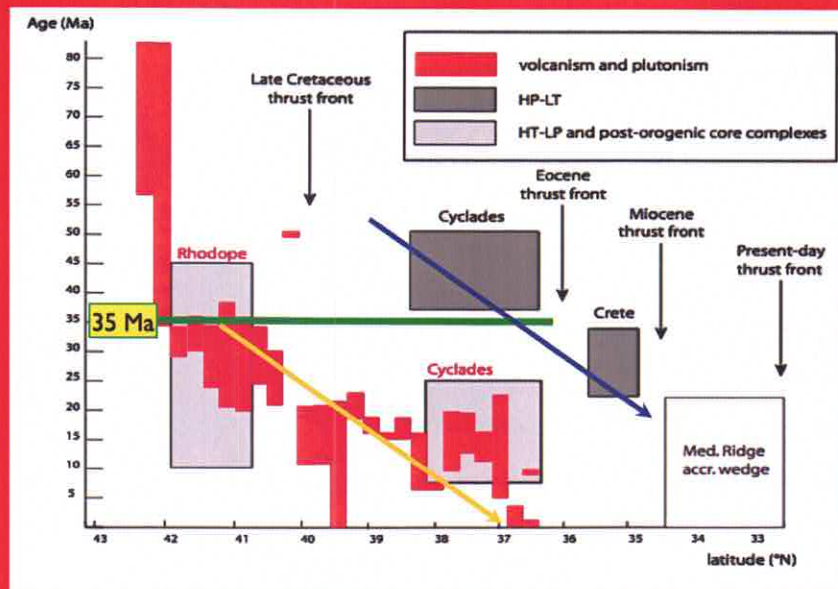
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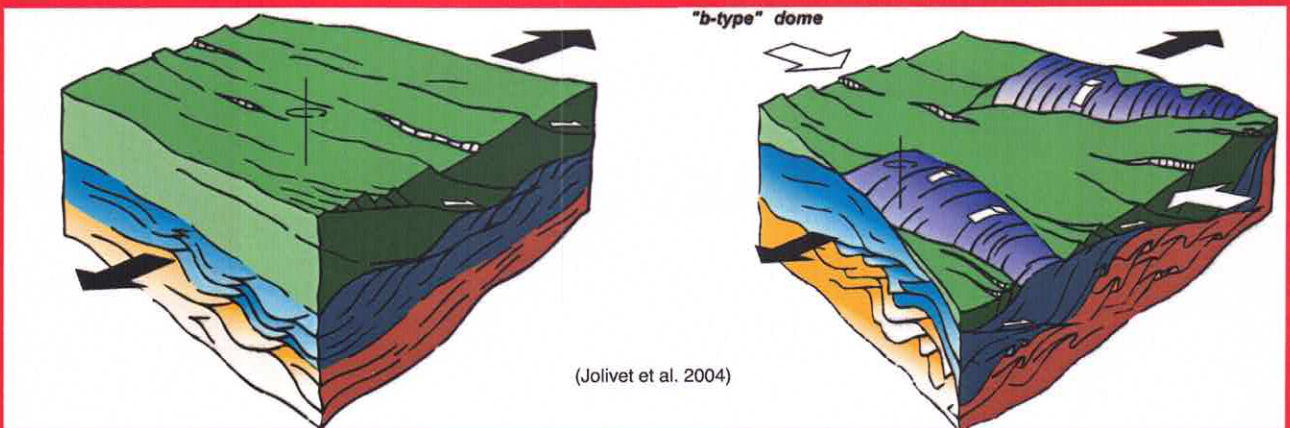
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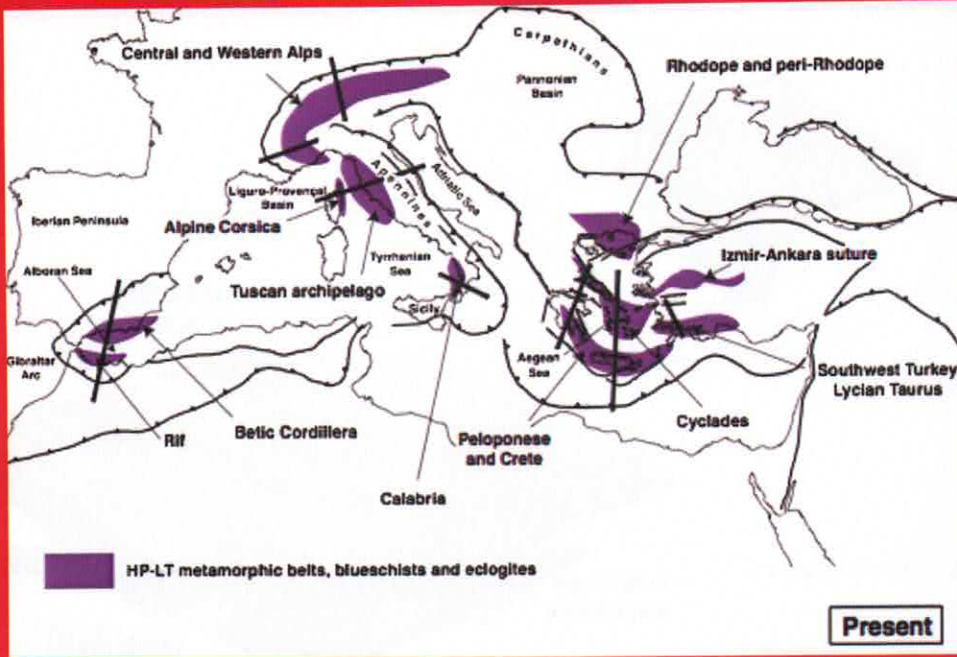
(Pictures : Jolivet Syros Island, Trotet et al. 2001)



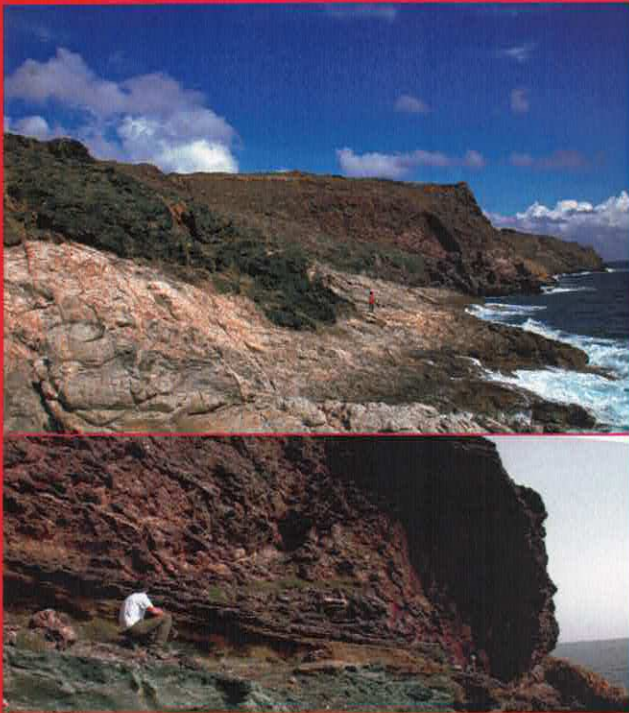
(Jolivet et al. 2008)



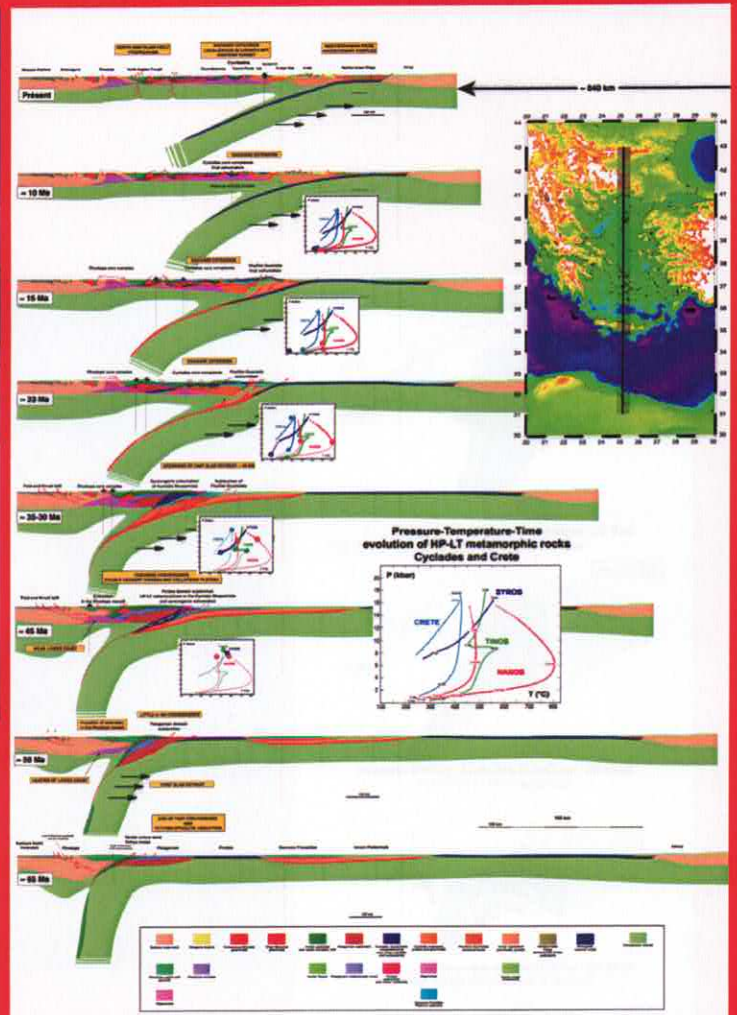
(Jolivet et al. 2004)



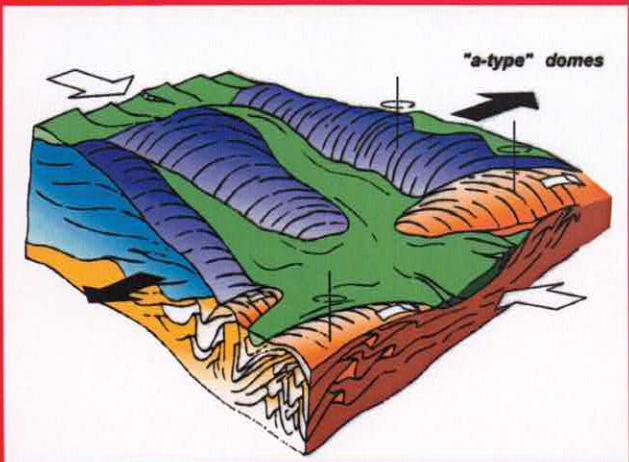
(Jolivet et al. 2003)

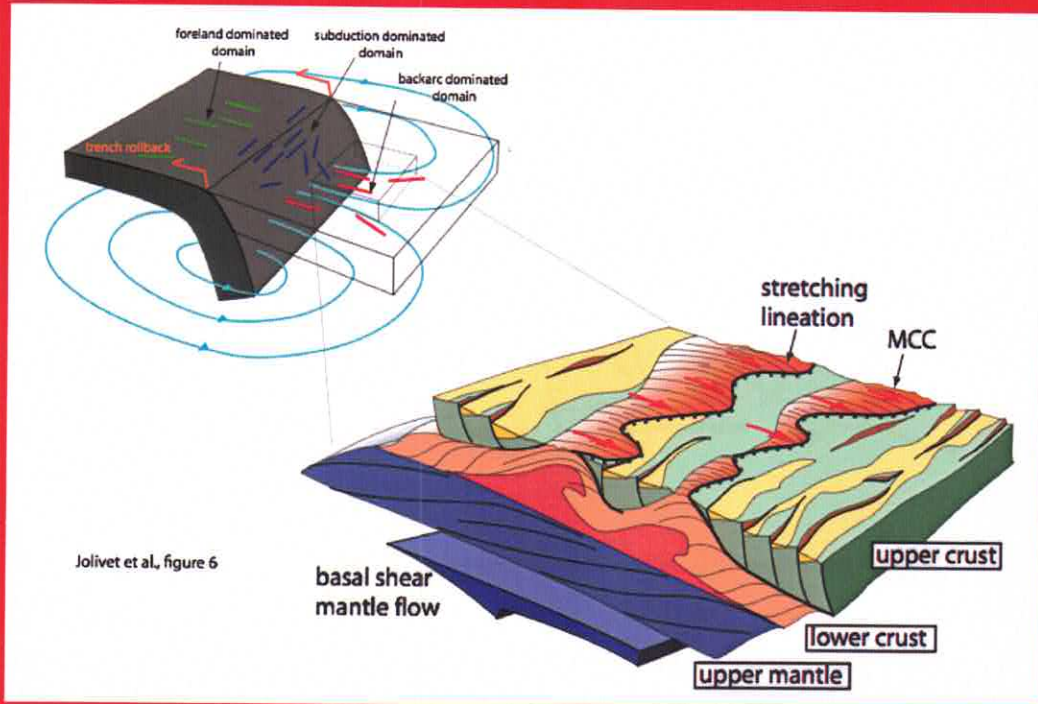


(Lecomte et al. sous presse)

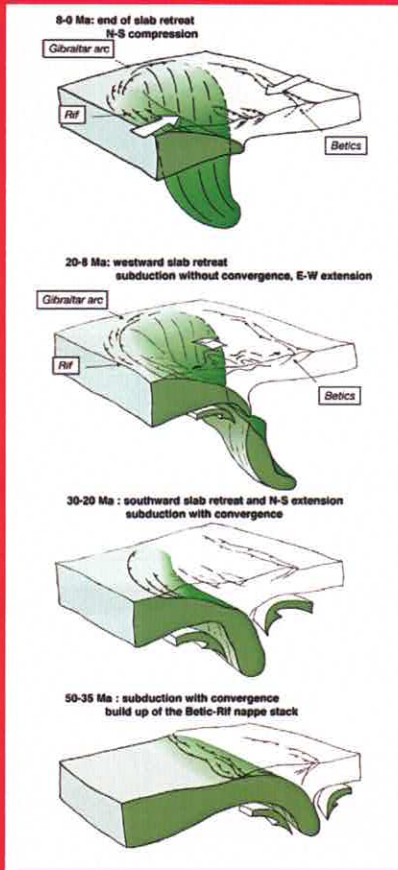


(Jolivet et Brun 2010)

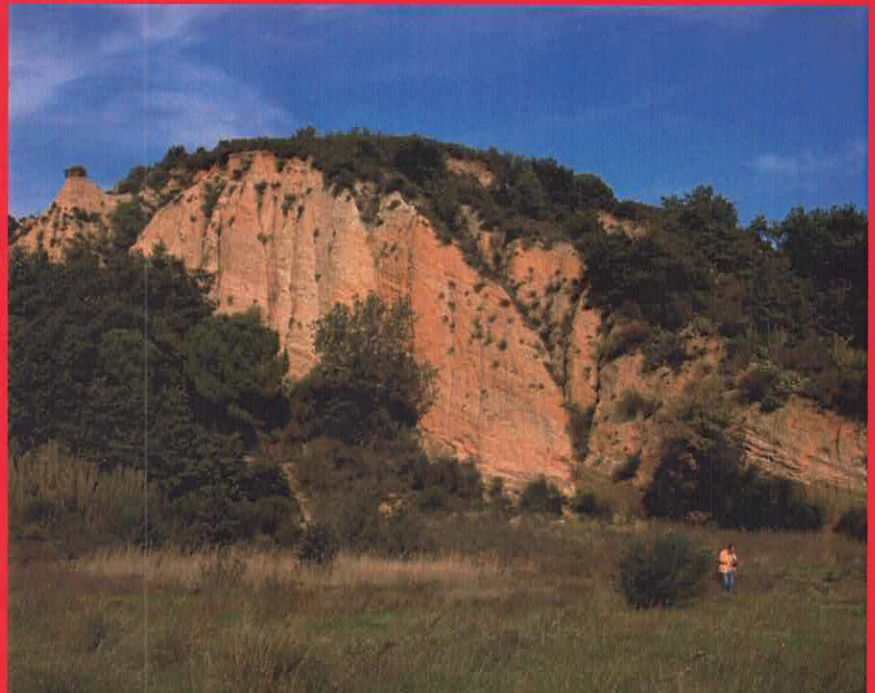




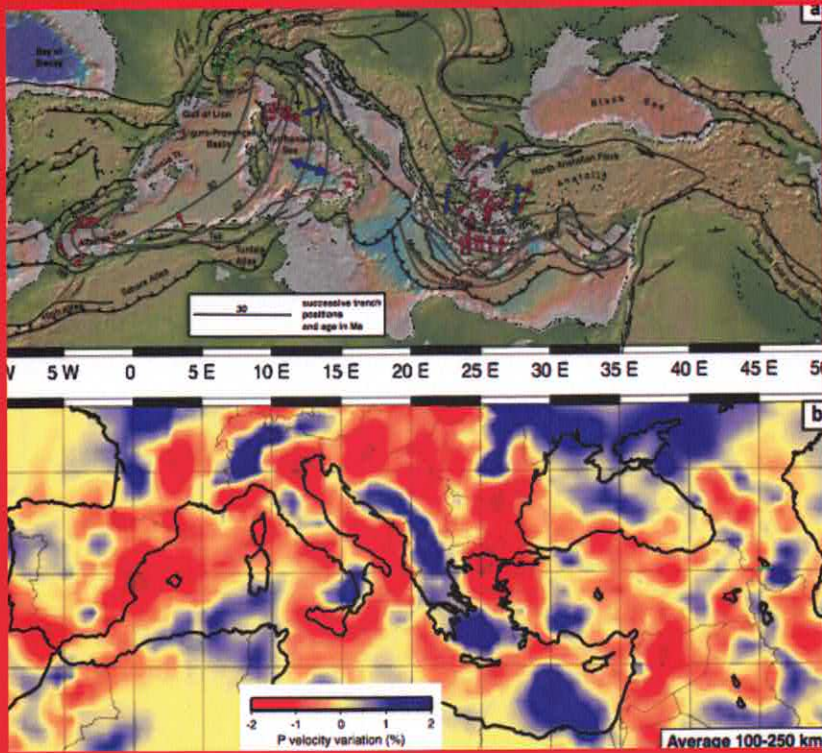
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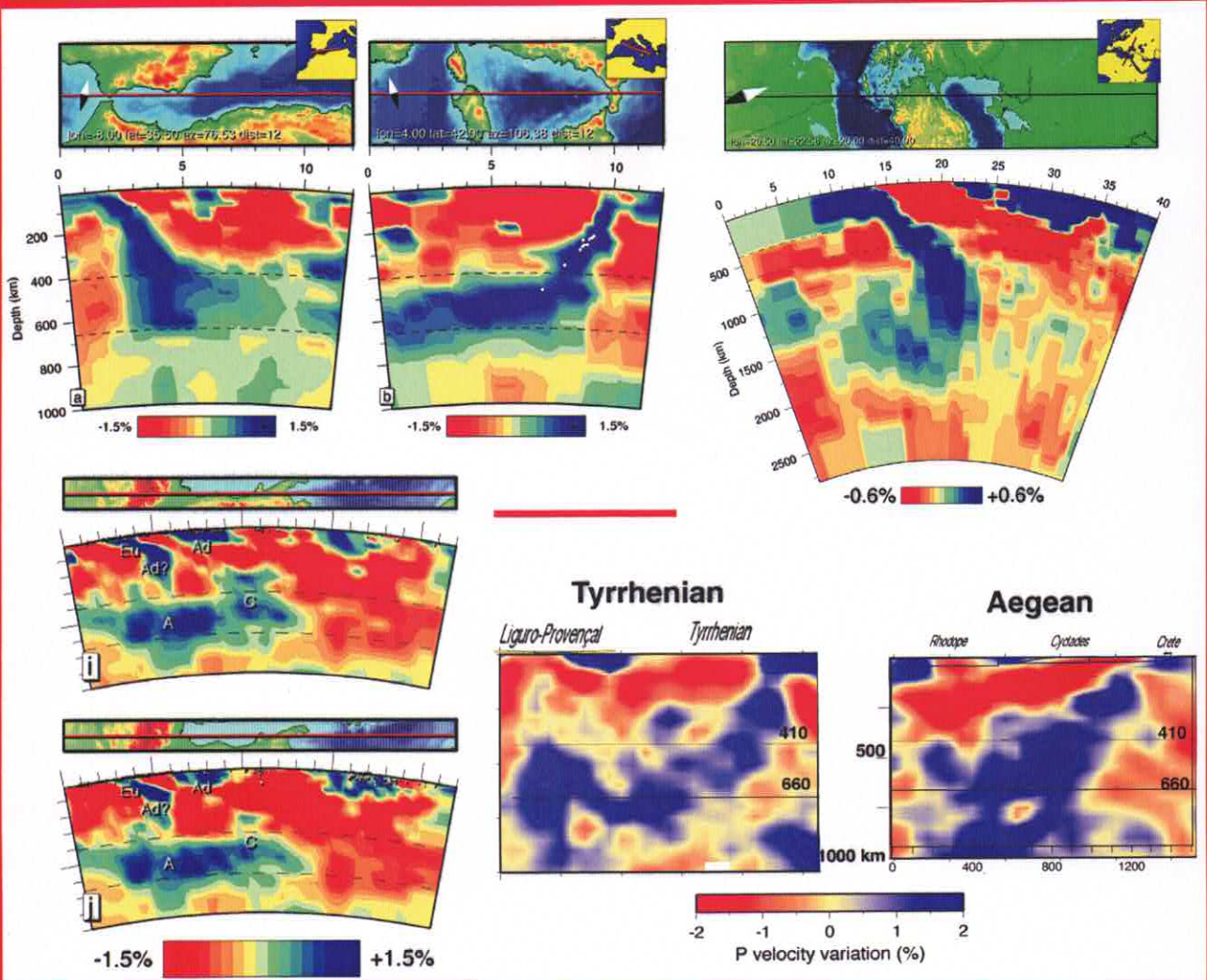
(Jolivet et al. 2008)



(Tet Valley, Jolivet)



(Jolivet et al.)



(Jolivet et al. 2009)

(Spackmann et Vortel 2004)



2. NATURAL HAZARDS and RISKS

2.1. Seismic risks and hazards

Seismic risk corresponds to the probability of earthquakes with a certain magnitude or greater striking at least once in a region during a specific period. Seismic hazard expresses the effects of an earthquake on property and human activity in a given area. Seismic hazard analysis requires a thorough knowledge of local geological structures and, more importantly, the local processes of deformation and stress genesis, which may be more or less correlated with seismic activity. In particular, this will involve a characterization of the active-fault network and the acquisition of paleoseismology and historical seismology data. The relationships between the rates of instantaneous, historical and longer term displacement around the faults will also need to be analysed. When considering seismic cycles over time, it is crucial to understand why these various rates may be different, but in some cases identical; this requires various supplementary approaches in studying the object (structural geology, morphotectonics, paleoseismology and geodesy). In theory, it also requires a thorough understanding of the laws governing fault activity, loading/unloading processes and the behaviour of faults in the surrounding medium. We also need to improve our knowledge of crustal deformation modes, both seismic and aseismic. The superficial crust (uppermost 2 to 3 km) is highly problematic: in many Mediterranean earthquakes, coseismic deformation is weak near the surface, implying that deformation occurs at another stage of the seismic cycle (whether systematically or not). It follows that ground deformation measurements during the seismic cycle should take into account this necessarily non-elastic rheology of the upper crust. The ground deformation measured during earthquakes also raises the issue of what we actually observe in trenches dug to investigate normal faults in the Mediterranean domain.

Because of the size of the ruptures involved, the greatest magnitudes (8 or more) are observed in subduction zones, whereas the magnitudes of major earthquakes involving strike-slip faults (North Anatolian Fault, Cephalonian Fault) tend to range from 7 to 8 and are located in extensional zones (Rift of Co-

rinth, Tyrrhenian side of the Apennines, Peloponnese), magnitudes range from 6 to 7. Do rupture processes remain the same, irrespective of the type of fault? The frequency spectrum of the seismic waves (essential information for seismic hazard analysis) differs according to whether the rupture is propagated at a rate slower than the Rayleigh wave or faster than the S-wave (i.e. sub-Rayleigh or super-shear velocity). Such S-wave velocities have recently been observed for the first time in certain parts of the North-Anatolian Fault, but the reasons for this high seismic velocity remains unknown. Similarly, in the Rift of Corinth, there is a marked contrast between seismic activity in the eastern part of the rift (three earthquakes of magnitude 6.2-6.7 in 2 weeks, on relatively steeply dipping faults with nodal planes dipping 40-45°) and in the Aigion area, located west of the rift, where activity is subcontinuous along a gently dipping zone (earthquakes with 30-35° dipping nodal planes). In this zone, crises take place every 18 months and deformation comprises a strong aseismic component. Despite these discrepancies, the amount of seismic energy released in the past 40 years in both areas is of a similar order of magnitude.

It is quite natural that the scientific community should pay more attention to high-hazard zones. However, recent moderate events such as the Newcastle earthquake on the eastern coast of Australia (12/27/1989, Mw=5.6 – 13 deaths and \$4 billion worth of damages), plead against ignoring the study of seismic hazards in areas of moderate seismic activity. From this point of view, the North-Ligurian margin and its Alpine foreland represent a particularly relevant target as historical seismology shows superficial earthquakes of a magnitude greater than 6 (Imperia earthquake on 2/23/1887, Mw~6.5, for instance). Moreover, given its high population density and coastal position, this zone is highly vulnerable. It is a scientific challenge to characterize seismic activity in areas with low rates of deformation since little is known about destructive earthquakes with very long return times or the faults that produce them.

In highly active domains, but also in high-risk zones

with a more moderate seismic activity, such as in the Maghreb or the Ligurian region, this means that in situ laboratories are required on each type of fault (normal, reverse or strike-slip) if one day we can expect to have accurate modelling tools and use appropriate earthquake engineering to reduce seismic risks. As pointed out in the geodynamics section, all three types of fault are found in the Mediterranean Basin, and we cannot concentrate on any one type at the expense of the others, even if this work entails coordination with other international actions undertaken outside the Mediterranean Basin.

Seismic hazard not only depends on the earthquake source, but also the seismic-wave velocity. This latter will differ with the degree of homogeneity of the overburden. Thus, any modelling of wave-velocity imperatively requires a thorough knowledge of the propagating medium. Wave amplification effects occur at local and regional scale (site-related effects). To date, it is unrealistic to attempt dense recording of seismic waves in all the urban zones of the Mediterranean region. However, one could reasonably start equipping the most critical Mediterranean high-risk zones (for example, the most exposed megalopolises such as Algiers, Beirut, Naples, Messina, Istanbul or Athens) so as to obtain accurate data on site-related effects that can then serve to determine earthquake-resistant building codes. Cities where seismic hazards are lower because major earthquakes occur less frequently should also be studied, particularly in France (Grenoble, Nice, etc.) and the Maghreb (Al Hoceima, etc...). The resistance of built structures during earthquakes has an impact on the city's vulnerability and resilience.

Seismic prediction demands that the definition of a probability law characterizing the precise timing of expected earthquakes should be added to the seismic hazard. However, no definitive way of achieving this

objective has yet emerged. On the other hand, this concept has recently progressed with the definition of so-called "early-warning procedures". These procedures use recordings, taken within a few seconds of the rupture onset, to assess the magnitude of the earthquake that will be generated by the rupture. Thus, for strike-slip earthquakes with a magnitude greater than 7 which involve rupture lengths of up to 100 km, the information can be available within a few dozens of seconds before the rupture arrives and, more importantly, nearly a whole minute before the most destructive surface waves. This allows the automatic triggering of preventive measures (shutdown of gas and electricity supplies, stopping of underground and high-speed trains, etc.). Such procedures are beginning to be implemented in Japan and could be applied the Mediterranean Basin, provided a satisfactory degree of coordination is achieved between the various observation systems of the countries concerned. In this respect, links should be encouraged with scientific programmes, as well as the participation of researchers in teaching programmes such as Sismos à l'école in France (<http://edusimo.org>). Implementing such procedures also requires excellent communication between monitoring stations and the various administrative structures and organizations involved in civil security as well as adequate training of the populations concerned. The SAFER project (Seismic Early Warning for Europe) runs along these lines: 14 EU nations have developed early-warning systems around 3 major cities located in high-risk areas (Naples, Istanbul and Bucharest).

It is also essential to complete compiling our databases on active faults. Indeed, it is crucial to list all these active faults, whether marine or continental, while also analysing their behaviour patterns (in terms of recurrence times, for instance). An extensive mapping of marine and continental active faults in the Mediterranean domain should also be undertaken.

ACTIONS 2.1

In situ laboratories for improved specification of fault behaviours, aseismic/seismic deformation relationships, fluid/fault interactions (Rift of Corinth, North-Anatolian Fault) and participation in other fault study programmes (Alto-Tiberina Fault, Levant Fault, etc.)
Submarine laboratories

Extensive mapping of active faults in the entire Mediterranean, both onshore and offshore, and study of associated risks.

Earthquake-related electromagnetic anomalies: we need to go beyond the statistical stage and establish unequivocal correlations between land-based signals (seismic, geochemical, electromagnetic, etc.) and data provided by the Demeter satellite. This type of complementary approach is essential to refine our understanding of the signals observed onboard Demeter and, if applicable, their propagation from source to ionosphere.

Slip-rates, seismic recurrence, paleoseismic study of the seismic faults found in southern and western Mediterranean areas; already mentioned in the section concerning crustal dynamics.

Detection and investigation of active faults in areas with low deformation rate, paying particular attention to the land-sea continuity of structures such as the Saorge-Taggia Fault (North-Ligurian margin) or the Thenia Fault (Algerian margin).

Upgrade certain GPS networks for high-frequency acquisition, particularly to complete seismological data in case of earthquakes.

Field studies, coupled with study of microseismic activity and GPS surveys, to locate land deformation along the African/European plate boundary and in peripheral active belts (Provence, Southern Alps, Apennines, etc.).

Study of site-related effects in the main cities on the shores of the Mediterranean.

Interface with European groups working on this theme at EuroGeoSurvey level.

Plan for permanent and semi-permanent marine observatories to monitor seismic activity. Consider using resilience studies as tools to manage risks and disasters.

2.2.

Volcanic risks and hazards

The Mediterranean Basin is not only associated with high seismic/tectonic activity, but is also one of the areas with the most intense volcanic activity worldwide. In this domain, there is a particularly acute need for understanding and forecasting eruptions, along with the prevention of associated risks. Indeed, several large cities (Naples and Catania in Italy, Kayseri in Cappadocia) and/or highly populated areas are directly threatened by volcanoes that are either in continuous eruption (Mount Etna, Stromboli), or dormant (Vesuvius, Campi Flegrei and Vulcano in Italy; Santorini in Greece, Erciyes in Cappadocia), some of which have produced recent or historic cataclysmic eruptions (Campi Flegrei: 36 ka & 12 ka BP; Mount Etna: 3.9 ka BP; Santorini: 1.66 ka BP; Vesuvius 79 AD, for instance). The eventual renewed activity of Vesuvius (dormant since 1944, after 3 centuries of almost continuous eruption) would require the evacuation of approximately one million persons, thus representing the largest civil-protection challenge in Europe.

Scientists have long been interested in Mediterranean volcanism, particularly in Italy because of its accessibility and the existence of a historical observational framework dating back to Antiquity. Italian volcanoes also display specific dynamics (Mount Etna is the largest source of volcanic gas emissions worldwide) and magmatology (nearly all types of magmatic series are represented, ranging from rift tholeiites, OIB-type alkaline basalts, calc-alkaline island arc basalts, to saturated or undersaturated ultrapotassic magmas). In fact, since the 1960-1970 period, several teams (i.e. INGV in Italy, CNRS, CEA, IPG and French universities) have initiated and developed highly innovative and productive research projects on Mediterranean volcanoes (in Italy, Greece and Turkey) covering the fields of petrology, geochemistry and geophysics (publication database available). These studies come in addition and even sometimes upstream of surveys conducted by local institutions. In particular, Mount Etna has been a crucial experimental volcano for European programmes since 1993, and numerous foreign volcanologists have been involved as partners, consultants or even

coordinators. This has promoted fruitful scientific interactions with local institutions which, in return, have achieved considerable progress in their research and in the monitoring of volcanoes (networking). In Italy, the INGV (National institute of geophysics and volcanology), has been coordinating research and monitoring activities since 2002 and is nowadays an internationally ranking partner for foreign researchers. The TerMex programme offers promising perspectives to European volcanologists who wish i) to develop new research programmes on Mediterranean volcanoes in close collaboration with local institutes, and (ii) share and reinforce their own skills in understanding volcanic processes, hazard forecasting and risk management. On the basis of past experience, current ongoing programmes (Italian, Greek, Turkish French and other European) and the discussions that served to develop this document, three key principles have been selected to define the actions to be implemented:

- Understanding the entire volcanic plumbing, from the magma source and chamber/chimney system, all the way to the surface. Know how to observe and interpret (from a quantitative point of view) the various precursor signs that herald an eruption. This implies developing multidisciplinary actions (field/satellite measurements, laboratory experimentation and modelling) and promoting a critical analysis of the methods used to detect precursor signs (signal/noise ratio, meaning of signals with respect to observed phenomena).
- As far as possible, these multidisciplinary actions should be focused on one or several target Mediterranean volcanoes so as to encourage cohesion in multinational teams as well as reinforce the scientific impact and international dimension of their studies and results.
- Envisage initiating long-term actions, beyond the scope of TerMex, which would guarantee a continuity in data observation and acquisition, compatible with the time constants of the studied volcanoes (e.g. dormant volcano likely to erupt in the medium term).

On this basis, three sites have been selected for coor-

dinated multi-disciplinary action:

■ Mount Etna, an ideal target given its eruptive activity and persistent gaseous emissions, its easy access and the existence of a remarkable monitoring network. This is the type of volcano where large series of data can be acquired and where new investigation tools can be developed and tested (land-, air- and satellite-based). All actions undertaken by Termex on this volcano would be specific and complementary to those undertaken by the INGV, to avoid reduplication.

■ Campi Flegrei is a vast caldera located nearby to Naples. This highly urbanised area has experienced several historical phases of activity, the most recent being in 1971-74 and 1982-84 (bradyseismic episodes). Various recently detected signals indicate a possible renewal of activity. With a magma chamber much larger than that of Vesuvius, this volcano represents a major threat for the densely populated western part of Naples and neighbouring cities.

■ Santorini, with its cataclysmic eruption followed by historical activity, deserves a more detailed investigation of its feeding system.

ACTIONS 2.2

Study of gaseous emissions (composition, gas and particle fluxes, heavy-metal isotope ratios) in order to identify precursor/?premonitory signs of eruption and quantify environmental impacts.

Study of the effects of magmatic degassing on a hydrothermal system (Campi Flegrei) and analysis of the physical processes involved in bradyseismic episodes (LGIT in collaboration with INGV Bologna and Naples).

Study of volatiles dissolved in the magma (glass inclusions), degassing processes according to pressure, redox conditions and magma-ascent dynamics and the texture of explosive products. Modelling of these processes by combining with data on gases and experimental petrology (LPS, IPGP+INGV-Pisa).

Study of radon daughter-isotopes in fumaroles and volcanic plumes (requires a high-speed analysing device for the short-lived radon daughters).

Elemental budget of trace-metal contents in the plumes and their isotopic fractionation (requires the use of MC-ICP-MS (Multi Collector-Inductively Coupled plasma Mass Spectrometry). Identifying volcanic signatures is essential for determining of the geodynamic cycle of these elements. Major fractionation occurs at the interfaces between magma/gases and surface/atmosphere, etc. [demonstrated for zinc (Zn), mercury (Hg) and thallium (Tl)], and initial results suggest a great sensitivity of Hg to various processes (superficial degassing, deep recharge, etc.).

Experimental petrology: determination of the solubility of volatile constituents (H-C-O-S-Cl-F system) in magmas (Mount Etna, Stromboli, Vesuvius, Pantelleria), from phase equilibria during the pre-eruptive stages; study of interactions between basaltic magma and carbonate host-rocks, thus allowing the digital simulation of degassing processes and ga-

seous phase composition (ISTO-Orléans + collaborations).

Development of modelling codes for magma ascent and eruptions, carefully taking into account the specific properties of host-rocks and magmas. Magma-ascent models used to assess magma rheology should take more account of observations on dissolved volatiles, exsolved gas ratios, crystallinity and decompression rates.

Stratigraphy, dating, phase equilibria and isotopes will all contribute to reconstructing the evolution of the Santorini magma chamber (LMV, ISTO, LPS, CEA, + Barcelona Univ.).

Petrology/ geochemistry of Cappadocian volcanic products in a post-collisional setting and associated hazards (LMV + Turkey Univ.).

Doppler radar investigation of eruption jet dynamics (LMV) and setting up of a permanent radar on the summit of Mount Etna (ongoing INGV project).

Acoustic measurement of eruption dynamics (IPGP).

Continuous or combined electric and electromagnetic measurements, magnetotelluric surveys and spontaneous-polarization mapping coupled with other seismic/thermal/ground-gas monitoring techniques (LMV-LMTG).

Satellite (InSar) and GPS imaging of Mount Etna ground deformation (ENS-Paris).

Seismic, thermal and electric imaging of the hydrothermal plume in Solfatara de Pouzzoles (Campi Flegrei), modelling of mass and heat flows and connection with plume activity (LGIT, in collaboration with INGV Bologna & Naples).

Coupling of earthquakes and eruptions on Mount Etna, particularly concerning superficial seismic activity, often highly destructive for villages on the flanks of the volcano.

Use of continuous gravimetry and other associated methods to study the behaviour of Mount Etna's hydrothermal system (BRGM).

Further study of Mount Etna's subsurface structure to obtain the best possible knowledge of geology, rheology and magma fractionation in the uppermost km of this volcano. This uppermost km plays a major part in the filtering of ultra-deep signals, as well as affecting the study of fluids and deformation.

Faults: modelling of fault behaviour; maximum expected eq.; stress redistribution

Off-shore volcanoes: bathymetry; acoustic transponders

Lava flows: calculation; lava channels

Ash: improvement of models; prediction (long-term); health; small pat.d.

Hydrothermal v/s magma contribution

2.3.

Gravity-driven ground failure risks and hazards

Both the offshore and onshore Mediterranean domains are strongly affected by hydrogravity-driven risks and hazards (i.e. slope failure), which express themselves in several ways: landslides, rock falls and collapses as well as mud flows. Similar mass remobilisation of sediment exists offshore, as shown by the Nice airport landslide. The morphology of such mass flows is similar to that observed in onland slope movements, but they usually extend much further (several thousands of square kilometres and hundreds of cubic kilometres) despite the gentle slopes (2-5°, on average) on which they occur.

These gravity-driven instabilities are dynamic phenomena with complex behaviours, both in time and space; they are controlled by inherited or present-day conditioning and triggering (climatic, seismic and anthropic) factors. While difficult to forecast, these processes have a disastrous impact in highly urbanized areas with steep slopes, as well as on coastal and marine infrastructures. The existence of these controlling factors indicates that hydrogravity-driven risks and hazards are at the interface between several disciplines: Earth Sciences, continental geomorphology, and Human Sciences.

Despite the considerable progress in identifying control variables and fundamental mechanisms as well as developing physically based models, it remains difficult to: (1) achieve a quantitative evaluation of the conditions leading to slope failure, reactivation or major acceleration of an incipient slide and, (2) simulate post-rupture behaviours (slow sliding, rapid mass flow) and assess sediment transport distances.

Research is concentrated along the following lines:

- Identifying, recognizing and performing three-dimensional studies of the morphological structure of slides, both onshore and offshore, by building a Digital Topographic Model (DTM) and using very-high-resolution geophysical/electric data; characterizing rheological, granulometric and sedimentometric variables as well as environmental parameters (hydrogeological, tectonic and climatic) that are specific to terrestrial and submarine sediment slides.
- Improved understanding of the physics involved in the phenomena (pre-rupture, rupture and post-rupture stages), particularly regarding the thermal, hydric and mechanical behaviour of materials.
- Improve our quantification of conditioning factors (spatial forecasting of source zones, rheology of materials involved in rupture phenomena, alteration of materials under the impact of fluid circulation and triggering factors (temporal prediction; precipitation threshold, seismic acceleration, fluid expulsion).
- Perform a quantitative analysis of the likelihood of gravity-driven failure risks and hazards as well as alert methods.
- Studying transfer processes on various spatial scales (ranging from valley slope to catchment area, around the entire Mediterranean Basin). The EU framework directive on soil protection reflects the crucial need to assess the “erosivity” of soils and their future evolution (changes in climate and land use).
- Volcano flank destabilization processes and their associated risks of tsunamis and eruptions (see also 3.2 & 3.4)
- Study of the vulnerability and resilience of Mediterranean urban systems faced with gravity-driven hazards.

ACTIONS 2.3

Develop equipment and methods for the monitoring of key variables (acceleration of soil flows, pore-pressure variation) and validate numerical codes for instrumented onshore/offshore sites in the Mediterranean area (INSU OMIV, ORE 'Draix' observatories, Ligurian sea-bed observatory)

In situ and laboratory measurements of rheological variables of materials; - Regular HR mapping (monthly, annual) to characterize possible changes in sensitive areas; associated core drilling

IODP drilling project in various slope-failure settings and consequences of these phenomena (South Sicily, Nile, Israel, Spain)

Implementation of initiatives aimed at reinforcing the resilience of Mediterranean cities.

EMSO - Ligurian Site: long term monitoring strategy

2.4. Coastal risks and hazards

The Mediterranean Basin and its associated civilizations have been deeply affected by tsunamis; such was the case in 365 AD, when Alexandria was destroyed by a tsunami following an earthquake in the Hellenic subduction zone, or, more recently, after the earthquakes of Noto (1693), Lisbon (1755), Imperia (1887) or Messina (1908). However, we should also bear in mind the minor tsunami in 1979 in Nice (local 2-m high wave), which resulted from the submarine landslide and turbidity current triggered by the airport extension works, not forgetting the various tsunamis triggered by the slumping of volcano flanks (notably Stromboli).

As for other natural risks, hazard characterization requires the identification of sources (type of seismic source, offshore landslides). Indeed, knowing the source type will allow us to characterize distant tsunamis generated in seismically active Mediterranean

areas and proximal tsunamis generated near the coast by submarine slides affecting the upper part of continental slopes.

Risk prevention requires an evaluation of both the period and amplitude of the generated waves; this strongly depends on the distance from the source and on local bathymetry. Recently, Italian studies have shown that a major earthquake in the Hellenic Trench generated waves with an amplitude greater than 5 m in southern Italy, whereas other less distant earthquakes, with a smaller magnitude consistent with the type of fault involved, only generated waves of less than 1.5 m amplitude. Small-volume (106-109 m³) submarine slides frequently generated at depths of 100-300 m are likely to generate surface waves with an amplitude of 2-5 m. Given these data, what can we say about the impact of megauruptures (several hundred km³) such as those observed in the Wes-

tern Mediterranean and on the Nile margin? Various scenarios need to be studied to determine which prevention methods should be considered.

Otherwise, as in the case of earthquakes, but much more effective given the slow propagation of waves in water (1.5 km/h), the early-warning system allows the prompt detection of any tsunami build-up, and the areas concerned can then be alerted as soon as the earthquake is detected. This prevention requires an efficient earthquake detection system as well as the setting up of a high-performance gauging network for the entire Mediterranean basin, or even a continuous satellite monitoring system. However, this method is not useful for tsunamis generated by submarine slides which so far remain undetected. Indeed, in such cases, given the proximity of the source, the resulting tsunami is bound to arrive only a few minutes after the beginning of the slide, which means that

specific detection systems need to be developed.

Tsunamis are much feared for their devastating effects, although their occurrence is rare compared to the two other hazards - coastal erosion and surges - which threaten Mediterranean shores. There is a common need to assess possible phenomena and population exposure by performing a fine-scale topobathymetry study of shallow waters (wave distortion due to seabed roughness may amplify tsunamis) and coastlands (roughness and extent of submersion due to tsunamis or surges). In these areas, we also need to acquire long time series of key observations (bathymetry, sedimentation rates, etc...). Projects already exist for developing gauging networks to prevent tsunami-related risks (see: Rapport Courteau. <http://www.senat.fr/noticerap/2007/r07-117-notice.html>). All that remains is to fund them. This could be done within the framework of TerMEx.

ACTIONS 2.4

Develop studies on source characterization

Develop rapid determination methods for the most discriminant source parameters regarding the potential generation of tsunamis: magnitude, depth, focal mechanism, rupture propagation length, for earthquakes located offshore or near the coast.

In situ measurements

Attempt to characterize the parameters, the respective contributions of earthquakes, eustatic variations, water contents, clay mineralogy, gaseous fluid contents and circulation, deposition slopes, etc.

IODP Project

Modelling of generated tsunamis by evaluating the mobilised volumes

Improved bathymetry; network of tide gauges; off-shore buoys
Need of GPS network merged with tide gauge networks) + on line data
Need of stations in Africa. (example of DART, off-shore buoys)

3. WATER and ENERGY RESOURCES

3.1.

Energy resources

In the Mediterranean area, oil and gas resources are very unequally distributed and prospected (2-4% of worldwide resources, 4% of known reserves). This extremely varied region includes contrasting geological settings such as the passive margins of Western Mediterranean and the foreland basins at the foot of the Apennines. The largest producers (Algerian and Libyan gas, Syrian and Egyptian oil) are well known, and these countries will undoubtedly remain the main local suppliers for a long time. However, other resources do exist in the Mediterranean area, although they are probably under-investigated. The frontiers of oil prospecting have been pushed outward to ultra-deep areas, with major discoveries being made near the ocean/continental transition on the Atlantic margins.

To optimise prospecting, we need an improved knowledge of hydrocarbon genesis as well as migration and trapping processes. Generally speaking, the flow of fluids, their interactions with rocks and their entrapment represent a major research field, whether for petroleum or mineral prospecting. The environmental impact of these fluid flows are also a fundamental issue.

For this purpose, we need to undertake fundamental studies on source rocks, tectonic settings, history of subsidence and thermicity in the entire Mediterranean area. In this subject area, the issues of petrology research converge with the interests of academics, although very few academic teams are involved full-time in this type of work. This type of research is usually undertaken in direct collaboration with national and international prospecting companies, or with national petroleum institutes, where widely-used methods have been developed. It might be a good idea to encourage academic laboratories to take fuller account of oil and gas issues and persuade oil companies to improve their integration of geodynamic processes. Both national and international companies are in possession of high-quality data, generally not available to academic laboratories. This means that the potential benefits of using such data for research on other scientific issues are seldom recognized.

Such research could, for instance, greatly contribute to geodynamic studies by providing accurate geometric data and precise dating. Long-term cooperation between the academic and industrial worlds, more formal and permanent than the ongoing projects (often headed up by a very small number of individuals), would promote an exchange of data and skills that would benefit both parties.

For instance, in the field of modelling, there is a very large discrepancy between the thermomechanical models used and developed by academics (who are mainly interested in crustal or even lithospheric processes), and the basin models developed by IFP and other applied institutes, which are used by oil companies to study accretionary prisms and passive margins; discrepancies are even greater when dealing with Dionisos-type stratigraphic modelling. These various approaches investigate different issues, but efficiency would be greatly improved if (1) these tools were interactive and took lithospheric processes more into account in terms of subsidence and thermicity, (2) researchers in geodynamics used the constraints provided by the history and geometry of sedimentary bodies as well as intra-basin fluid fluxes. Therefore, it might be judicious to try and couple geodynamic codes with stratigraphic codes. Similarly, by taking surface processes such as erosion and sedimentation into account, we could obtain observable parameters that could then be tested in geodynamic modelling. Regarding dynamic studies, an integrated 3D modelling project of the object "Mediterranean" could be initiated, covering all aspects, from surface to mantle, and over sufficiently long periods of time to include all the source rocks of the region. This would also involve a close collaboration between oil companies and academics and should last for at least ten years to really achieve these objectives. As a starting point, we could select a few major Mediterranean events, such as the Messinian salinity crisis, the Upper Oligocene, or other periods involving the deposition of sapropels and black shales on passive margins; a 3D model could be developed for the entire basin before, during and after these events, in order to predict potential sites of oil and gas genesis

and entrapment. In this context, and because they potentially represent both a cover (impervious strata) and/or a structural trap (over a fault or antiform), Messinian evaporites should also be viewed in the perspective of Plio-Quaternary salt tectonics. Recent research (Gulf of Lions, Nile and Algerian margins) has shown that, beyond its direct industrial application (location of traps), this type of approach, from a purely conceptual point of view, allows a distinction between strictly tectonic and halokinetic forcings in sedimentary basin deformation.

Regarding potential source rocks and reservoirs in the Mediterranean region, we need to ascertain the lithological nature, age and hydrocarbon potential of deep-basin pre-salt series; these differ between the western and eastern basins, hence deep drilling with riser core sampling in these basins would have major consequences on the assessment of oil and gas resources.

In addition, over the past few years, major fluid seepages, both thermogenic and biogenic (and, more locally, gas-hydrate) have been encountered in the Western Mediterranean Basin, or at least its passive margins and accretionary prisms. These seepages are all indications of the presence of deep oil and gas systems (under the Messinian salt and/or in early-Pliocene slope deposits). Studies are under way to characterise these fluids, their emplacement mechanisms, their impact on the deep environment (geology, biology, hydrology) and to understand their role in the destabilization of sedimentary cover series. We need to understand their “plumbing” system and assess the quantities emitted so as to take these losses into account in global mass balances, notably concerning methane. Over the course of geological time, potentially vast amounts of fluid could be emitted from the seabed which should be taken into account, along with their eventual impact on climate change.

ACTIONS 3.1

Characterize seabed fluid emissions using acoustic tools.

Measure, sample and analyse these fluids in situ

Install seabed observatories to measure emissions and assess the functioning of these systems.

3.2. Water resources

Fresh water is the other crucial resource that has governed the development of civilisations. Globally, our day-to-day management of water has long assumed this resource as being more or less infinite. This attitude is no longer possible for a number of (urban, recreational, agricultural and industrial) reasons, all leading to water resource degradation that is sometimes irreversible. Often expressed in public health terms, this degradation represents a vital threat for the populations concerned. Because of their connections with the marine environment, coastal aquifers are notably sensitive to salt-water intrusion phenomena in the event of over-exploitation. This is particularly true with islands, where aquifers are highly challenged (e.g. Majorca, Malta, etc.), but also on the continent (e.g. Spain, Algeria, Tunisia, Morocco, Italy, etc.).

Given the current limitations of fresh water supply and increased needs due to constant demographic pressure (and other associated constraints), Mediterranean areas are increasingly dependent on their subsurface water resources. One of the specificities of Mediterranean fresh water reserves is the wide extent of karstic zones, whether in the south of France, Spain, the Algerian coast, most of the East Adriatic coast or the eastern shores of the Mediterranean. Other porous-type reservoirs, less extensive but usually with better defined boundaries, have developed in the clastic sedimentary series of coastal areas. Independently of the type of reservoir considered, the management of subsurface water resources requires an understanding of the genesis, geometry and functioning of these reservoirs, as well as a detailed monitoring of their temporal dynamics.

Karsts landscapes are characterized by soluble calcareous rocks and dolomites. These rocks have specific aquifer properties that depend on the structural context, eustatic variations and climatic conditions. Thus, the genesis of karstic systems in the Mediterranean Basin has been strongly influenced by eustatic variations, notably by the Messinian crisis which

led to the development of very deep karstic networks (that sometimes give rise to abundant submarine fresh-water springs) which may prove interesting to study from a physicochemical point of view. [Flow rate determination, using hydraulic modelling, and sediment transport remain the main challenges, both for resource evaluation and for assessing the input of groundwaters to the Mediterranean water budget (see HyMEX)] A better knowledge of stable sea-level stands during the Messinian crisis could allow us to estimate the extent of deeper paleodrainage networks.

Karstic aquifers are characterized by a dual-flow behaviour with part of the flow occurring in a network of karstic channels and otherwise in the breccia matrix. Exchanges between both systems are controlled by the difference in hydraulic head, the range of hydraulic parameters and the reservoir geometry. Assessing water resources or the degree of saturation of karstic aquifers is not easy: indirect methods have been developed, both hydraulic and geophysical, that yield an evaluation of the quantities of water stored (tiltmeter or microgravimetric studies to detect mass distribution variations, for instance). In France, several underground laboratories are being instrumented in this way, including the Laboratoire Souterrain à Bas Bruit de Rustrel (Vaucluse department) which also hosts a particle physics study programme on neutrino and muon attenuation. A programme is currently being developed on this site to compare and integrate the various observation techniques. With this programme, we hope to obtain a better definition of mass distribution variations, and, as a result, ascertain the water reserves of the “Fontaine du Vaucluse”, a resurgence spring tapped since Roman times and famous for its discharge variations. Elsewhere in France, major geophysical instrumentation (gravimetry, tiltmetry, etc..) is being installed at the Larzac site.

Karstic aquifers are vulnerable to contamination: their structure and functioning mean that we need to improve our identification and characterization of the epikarst. This latter corresponds to a zone just under

the surface, with poorly defined extension and continuity, which acts as a buffer zone and delays infiltration. Moreover, karstic aquifers around the Mediterranean are subject to extreme rainfall which may lead to flooding. New management schemes need to be designed for this type of aquifer so as to mitigate floods and temporarily store surface waters that are otherwise likely to evaporate. Characterizing the structure of subsurface karstic aquifers using geophysical imaging techniques (i.e. airborne, electromagnetic) represents a challenge for karstic aquifer management, both in terms of quality and quantity.

We should mention here one of the main characteristics of the Mediterranean climate, related to the existence of extreme rainfall events (ranging from 200 to 300 mm per 24 hrs). This characteristic is problematic in karstic areas where conventional methods cannot be used to determine flood hazards. This is because the simple correlation between rainfall and discharge is disrupted by storage specificities inherent to the karstic nature of these terrains. They can neither absorb surface runoff considered in terms of losses, nor, on the contrary, contribute to temporary groundwater discharge phenomena of the resurgences.

Finally, while all coastal areas are concerned by the

issue of brackish water/fresh water interfaces due to the overexploitation of coastal aquifers, the incision of deep canyons during the Messinian crisis and their infilling by varied alluvial deposits during rising sea level, are specific to the Mediterranean. Due to their coarse-grained fraction, they make good aquifers that can currently be encountered under coastal plains. Usually at shallower depth (less than a few hundred metres) and easily accessible to drilling, these much exploited reservoirs are sensitive to over-extraction and are at risk of associated salt-water intrusion. Coastal reefal reservoirs are also at risk, and marked degradation of this resource has been noted over the past 30 years (e.g. Majorca). In order to design coastal aquifer management models and review conceptual salt-water intrusion models, we need to investigate the geometry and nature of sedimentary bodies as well as their extension into the offshore zone (Aunay, 2007). Our knowledge of coastal reservoirs could be improved by drawing up a paleogeographic reconstruction of the coast, defining the reservoir areas and improving our monitoring of fresh-water/salt-water interfaces. We should continue to develop methods to assess the dynamics of these systems, notably those based on subsurface instrumentation, so we can monitor certain strategic sites for forecasting or remediation purposes.

ACTIONS 3.2

Improve our knowledge of karstic aquifers beneath the sedimentary cover by means of geophysical methods, characterizing potentially karstic seismic objects and carrying out validation drilling all around the Mediterranean;

Improve our hydrogeological knowledge of already recognized karstic aquifers, using geophysical methods to characterize degree of saturation, in France and in other countries (Slovenia, Algeria, Libya and Morocco, for instance).

Consolidate our exploration of karstic aquifers with a view to improving management (protection - vulnerability audit, artificial recharge - underground storage), using geophysical methods and robots.

Airborne electromagnetic studies could allow a more global approach to determine recharge areas, discharge areas, as well as karstic objects (channels, sinkholes, collapse zones, etc.). Many European laboratories have achieved a high degree of expertise in this

field, for which they have the appropriate equipment. This research should also use other methods. Robots could be developed capable of penetrating karstic networks (via exsurgences or preferential infiltration points such as sinkholes), where we require a statistical analysis of the distribution and dimension of karstic voids. Existing robots could also be adapted to inspect boreholes or passages. All these methods would provide us with additional information on the geometry of the networks.

Improve models for karstic aquifer genesis by using various modelling approaches, integrating data concerning the development of karstic aquifers in the Mediterranean (Messinian crisis, etc...), structural data, karstic network geometry, at different scales for each key phase of karst deepening and stabilization.

Develop methods to extrapolate the hydrogeological properties of water-bearing sedimentary bodies at the level of Plio-Quaternary coastal aquifers, so we can then design a 3D hydrogeological model of water flow with a continuum from land to sea. Characterize low-permeability sedimentary formations, using geophysical methods or in situ tests to characterize seawater incursions into formations of varying permeability (hydraulic conductivity) and porosity (storage coefficient). This would serve to optimize groundwater quality monitoring systems and develop hydrogeological water-resource management models.

4. PALEO-ENVIRONMENTS, PALEOCLIMATES, ECOSYSTEMS and their FUTURE EVOLUTION

4.1. Mediterranean paleoenvironments, paleoclimates, ecosystems and their future evolution

During the past 25 million years, the Mediterranean area has experienced major upheavals and climate changes, both onshore (Alpine uplift) and offshore (opening of basins, interbasin connections/isolation, formation/disappearance of straits), in addition to the highly characteristic and catastrophic environmental episode of the Messinian salinity crisis. Given the extremely complex history of the Mediterranean environment, our priority consists of distinguishing, both in time and space, between changes that can be attributed to geodynamics and to the climate.

On land, there has been considerable progress with geographical reconstructions, particularly mapping, and the boundaries between aquatic and terrestrial environments are now well characterized. Certain points remain unclear, particularly concerning the estimation of elevation of relief, and a wide range of geomorphological and paleobiological approaches (palynology, plant macro-remains, mammals, etc.) should be used to investigate as many of these points as possible. Similarly, we now know that corridors/seaways allowed almost continuous communication (and therefore exchanges) since 14 Ma ago between the Mediterranean *stricto sensu.* and its eastern prolongation, the Paratethys. The successive locations of these corridors should be identified in this area, now occupied by major relief (Dinarides, Balkans and Rhodopes).

To date, pollen analysis has shown how Neogene Mediterranean environments have changed from a tropical/subtropical context to the present-day conditions, but certain questions remain unresolved. What were the climatic conditions during the Tortonian (around 10 Ma ago), a time that could be considered as a close analogue to the current global warming context? In what way did the onset of glacial-interglacial cycles occur between 3.6 and 2.6 Ma ago? The Mediterranean bioclimate currently represents one of the global hotspots of plant diversity: how did the transition take place from a richly diversified regional flora, predominantly tree-based, to a grass and

shrub-based flora? Pollen assemblages have also shown that the southernmost Mediterranean environments correspond to zones where open and arid landscapes appeared at a very early stage (at least since 24 Ma ago). How and when did these Mediterranean steppes become established (during the Oligocene?) and what is the correlation between this change and the emergence of the Sahara desert? Situated in middle latitudes (halfway between temperate and desert climate zones) and with a considerable longitudinal extent (which means that its eastern and western fringes are affected by monsoons, albeit moderate), the Mediterranean area is favourably located for pollen analysis and therefore also for paleoclimatic investigations. Indeed, due to the relief of the Mediterranean peninsulas, the boreal environments penetrated (at altitude) into subtropical to tropical environments (on the coast) during the Neogene period. As a result, the southern pollen flora of these peninsulas are representative of the European climate and vegetation history at similar longitudes, given the transposition of the vegetation from vertical stratification to horizontal zonation. With their high density in both time and space, Mediterranean pollen floras give rise to an extensive digital data base which, in association with other paleobiological investigations (mammals, etc...) and geochemistry, should be at the leading edge of environmental modelling, whether concerning past history or future projections.

Offshore geographic reconstructions benefit from the same advances and suffer the same shortcomings as on land. While one of our priorities is to improve understanding of the communication and exchange via seaways/corridors between various Mediterranean sub-basins as well as between the Mediterranean and Paratethys basins, we should focus on studying the organisms living in surface waters (planktonic foraminifera, calcareous coccoliths, dinoflagellates, diatoms, etc...) and carry out the appropriate geochemical studies. The idea is to use biological and geochemical markers to localise the straits and corridors in space and time. This should lead us to pose

new questions of a geodynamic nature and initiate multiple investigations combining tectonic and seismic approaches. For instance, the age of formation of the Sicilian-Tunisian Channel is an essential question in relation to the Messinian salinity crisis. Moreover, we need to explain why corridors assumed to exist between the Mediterranean and Paratethys are preferentially located in areas that are nowadays mountainous. And how did they come to be fully or partially obliterated? In the Eastern Mediterranean, rhythmic sapropel deposits mark the progressive anoxia of the Mediterranean Sea. Considerable progress has been achieved in understanding the cause of such deposits (the massive input of lower-salinity surface waters), and their chronology can be correlated with orbital parameters (precession and excentricity). However, when considering potentially petroliferous source rocks (whose accumulation can be projected back into the past), we need a more specific characterization of their respective signatures (geochemistry, paleobiology) to identify the source(s) of the fresh water masses involved (Nile floods and/or fresh water discharge resulting from the melting of ice on the European continent), and quantify the fluxes. A more rigorous reconstruction should also be performed of the complex effects of precession on the Mediterranean climate and environment, both offshore and onshore, using detailed multi-proxy studies.

Nearly completely closed and surrounded by land, the Mediterranean Sea has in the past been subject to major environmental changes associated with major variations in sea level. These sea-level variations had a large impact on sedimentation in the basin and margins. In particular, during the Messinian salinity crisis, the 1,500-m water-level drop was accompanied by the deposition on the basin floor of evaporite series over 1000 m thick, the incision of deep canyons on the edges of the basin (over a distance of more than 1,000 km in the case of the Nile), the deposition of large detrital accumulations (?debris fans) at the foot of the continental slopes, and a complete remodelling of the circum-Mediterranean karstic system. After the crisis, the sudden reflooding of the basin resulted in sedimentary infilling of the Messinian canyons, which then became deep rias at the site of Gilbert deltas during the Pliocene.

The Messinian salinity crisis was undoubtedly one of the most spectacular examples of the major changes that have affected the Mediterranean. Indeed, its consequences are still visible today, whether environmental (on living organisms) or morphological (reworking of the subsequent cover of the margins). However, there are other important periods to consider in the history of this region. As an example, we

are beginning to recognize the morphology of Early Miocene incisions in South-East France, but still do not know their geographical extent. It would be interesting to draw up a picture of the Mediterranean landscape during the Early Miocene, when sea levels were high. Indeed, it would be a great step forward to be able to reconstruct the landscapes of pivotal periods and correlate them with lithospheric evolution. Relief and sedimentary architecture are indeed linked to both deep Earth and climatic processes. In this region, it becomes realistic to distinguish the contribution of climate from tectonic effects.

Accurate dating of sedimentary successions and high-resolution correlations are essential to understand the sequence of events during the Salinity crisis or any other environmental upheaval. Since the Mediterranean is a nearly closed basin, with high sedimentation rates in the deltas, whatever the sea level, it is a good candidate for improving the calibration of chronostratigraphic scales using micropaleontology, geochemistry and cyclostratigraphy. All around the Mediterranean, sediments are currently used to test the accuracy of astronomical parameters, but it is difficult to go back any further than ~15 Ma due to the scarcity of adequate sediment outcrops. On the other hand, one or several deep drill holes would enable us to reach the Lower Miocene or Uppermost Oligocene. Such drill cores would provide us with detailed records of stable isotopes, seawater temperature and estimates of oceanic ventilation, the provenance of aeolian deposits (Sahara, monsoons, etc.), which could be analysed to reconstruct past climates in this area.

The influence of glaciation began from ~2.6 Ma onwards, as Late Pliocene and Quaternary sedimentation was largely controlled by glacio-eustatic changes on the northern boundaries of the basin, along with the establishment of monsoons on its south-western boundary. The upper parts of the drill cores will provide a very detailed chronostratigraphic framework for dating the onset of glacio-eustatic cycles and their timing; they will also help assess the impact of alpine glaciers on local sedimentation.

Once the main parameters controlling the climate are identified, it will then be possible to relate the geodynamic reconstructions mentioned above to the evolution of paleoenvironments and paleoclimates. Climate modelling will then be based on a multitude of accurate observations. Similarly, possible trends might be highlighted for the near to distant future.

4.2. The Messinian salinity crisis

A MAJOR ENVIRONMENTAL EVENT

The Messinian salinity crisis was an extraordinary event with many varied consequences (environmental, sedimentary, geodynamic, etc...), which explains why this event has attracted attention and justifies the specific study dedicated to it (see the ECLIPSE programme, 2001-2007). Recent work by European teams has resulted in a consensus regarding the unravelling of this crisis. This two-stage scenario, initially suggested by Clauzon et al. (1996), is now unanimously supported by all authors.

However, several points remain to be elucidated:

■ The age and content of the evaporites deposited in the deep basins before the total desiccation episode are not yet accurately known due to a lack of drilling data for this episode. All the scenarios developed so far are based on our knowledge of “marginal” basin evaporites deposited in initially shallow basins (with Sicily providing an intermediate example).

■ Connections between the western basin (west of the Sicilian-Tunisian Channel) and the eastern basin (east of this channel) are still not clear. The eastern basin was probably deeper during the crisis, similar to its present-day level. How could two shallow basins be separated by a strait during the sea-level drop? What was the supply to the eastern basin? The relevance of this question has recently been renewed by an oil and gas drilling campaign, offshore from the Nile delta.

■ The mammalian fauna indicates that exchanges between Europe and Africa apparently occurred just before the Messinian salinity crisis and during its paroxysmal phase. The timing of these exchanges needs to be refined, but obtaining more precise indications on the exchange routes (islands, land bridges) would represent a clear advance in paleogeographic reconstructions.

■ All the geological evidence points towards an extremely rapid rise of the sea. What was its cause? How did the Gibraltar strait open? Current models suggest that the opening might have been caused by the regressive erosion of rivers combined with the

sudden communication established between the Atlantic and the Mediterranean. Traces of this new cataclysm are partly visible in the strait itself, but lack precision. Traces should also be sought on land.

■ During the crisis, the only way to explain the volume of salt deposited would involve maintaining a constant water input from the Atlantic. Was Gibraltar really the only route for Atlantic waters feeding into the Mediterranean? Was this water flow regular, or not? Could the eastern basin, probably isolated from the western basin, be fed by another sea-water source? Does the halite buried under the central basins preserve any traces of pre-desiccation sea-water microbiology and chemistry?

■ During refilling, what was the role of Paratethys waters? Were there one or more Lago-Mare-type episodes (invasion of the Mediterranean by Paratethys waters, one way flow during certain episodes, bidirectional during others)?

■ Finally, we should bear in mind that this episode also had major consequences on the vertical behaviour of the crust of the basins and continental margins (if only due to the sudden drop of sea level and the rapid deposition of over 1,000 m of sediments) and on the subsequent morphostructural evolution of most circum-Mediterranean continental slopes (gravity-driven tectonics)

To answer these questions, we require improved knowledge of the geometry of Messinian and Pliocene sedimentary basins, both offshore and onshore, and 3D modelling of their substratum morphology. We also need more information on the nature of sediments now buried at deep levels and the history of their deposition.

THE GEODYNAMIC AND SEDIMENTARY IMPLICATIONS OF THE CRISIS

We need to know more about the unravelling of the Messinian crisis. Indeed, its consequences are not restricted to its immediate impact on sedimentation. Although its geodynamic implications and influence

over recent sedimentation are undeniable, these aspects remain poorly identified and quantified;

- The effects of the crisis should be modelled and integrated into the basin subsidence models.
- On the margins, the deep Messinian canyons often control the localisation of Quaternary canyons channelling the sediments towards the deep-sea basin. In the deep-sea basin, the massive amounts of salt deposited during the crisis are subject to ductile deformation, which leads to the deformation of overlying sediments. The Messinian imprint thus has a strong impact on the distribution of present-day sedimentary deposition, so it must be taken into account.
- The formation of karsts, which accompanied the fall of sea level over most of the Mediterranean area, could lead to the storage of significant water reserves that need to be listed and quantified so they can be available for use, notably on the south Mediterranean sea-board where water resources represent a major issue.
- Finally, due to its phenomenal amplitude, the Mes-

sinian crisis created a complete break in basin and margin sedimentation. While there are several important markers onshore, the markers are mainly preserved in offshore sediments: erosion surfaces on the upper part of margins, large debris fans at the foot of the slopes, evaporites in deep-sea basins. These markers characterize identifiable and dated levels on seismic profiles, thus enabling us to calibrate our interpretations. Similarly, the unusually high Pliocene sea-level also provides some essential markers. These are accurately dated and indicate specific paleogeographic conditions for each of the different parts of the basin as well as its margins. They also yield local paleo-water depths or land/sea limits, representing a powerful tool for calibrating geodynamic reconstructions and the vertical movements of the basin and its edges during basin evolution. Therefore, these markers should be identified extremely accurately and mapped on the basin scale so they can then be used in subsidence and geodynamic modelling of the entire basin.

ACTIONS 4

Ultra-deep wells (targeting the deep biosphere, assessment of resources and storage capacities below the Messinian salt, and nature of the basement in various Western and Eastern Mediterranean sub-basins), and regional trans-Mediterranean deep seismic profiles as discussed above.

More conventional wells aimed at documenting the sedimentary and climatic records in targeted areas such as the extensive deep sea fans of the Nile and Rhône deltas.

Coupled onshore-offshore geophysical experiments in key areas such as the Alboran and Aegean margins, the Ligurian coast and the borders of the Gulf of Lions.

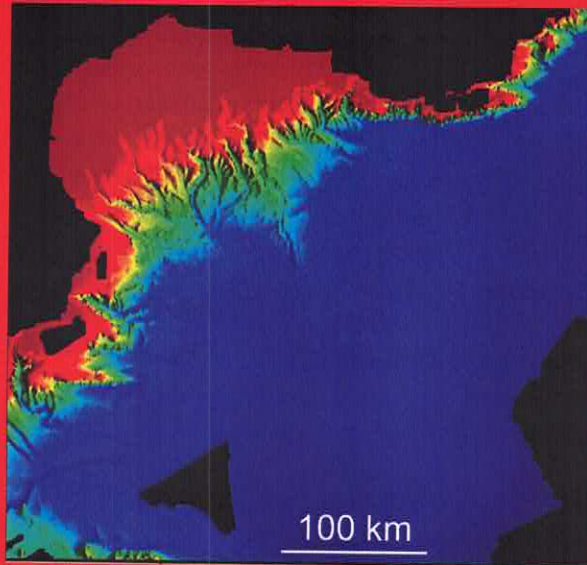
Seismic reprocessing and mapping of the Messinian erosional surface around the Mediterranean Basin.

Federating sedimentologists, along with European and circum-Mediterranean experts of the Messinian. Also, investigating the links with the Black Sea, as well as former marine connections with the Atlantic located both north and south of Gibraltar.

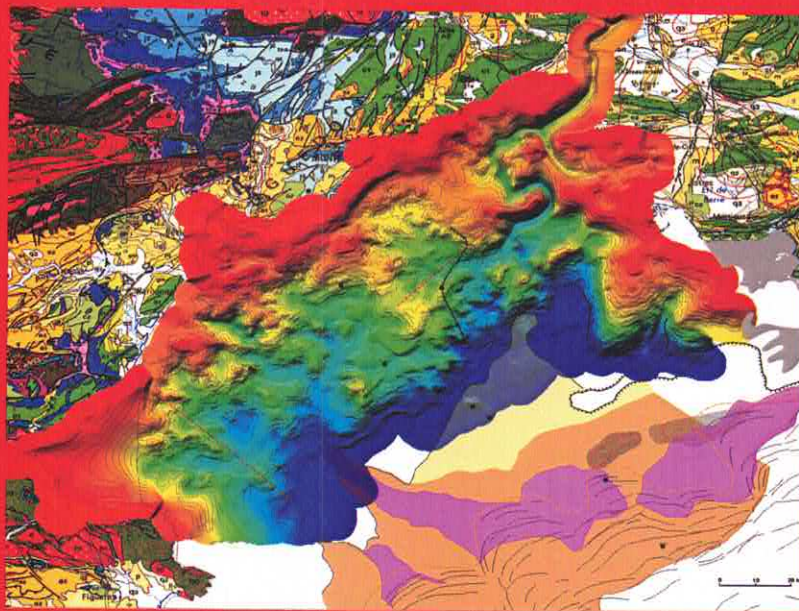
Major efforts must be focused on integrating the data bases, i.e. seismic profiles, as well as geological and geophysical studies, to identify and map the Messinian and Pliocene markers on all the Mediterranean margins, ensuring a link between onshore and offshore records, as well as in the deep basins.

Contribute to ICDP wells targeting circum-Mediterranean lakes in the Dinarides and Hellenides as well as in the Dead Sea and Tiberiade Lake (Sea of Galilee).

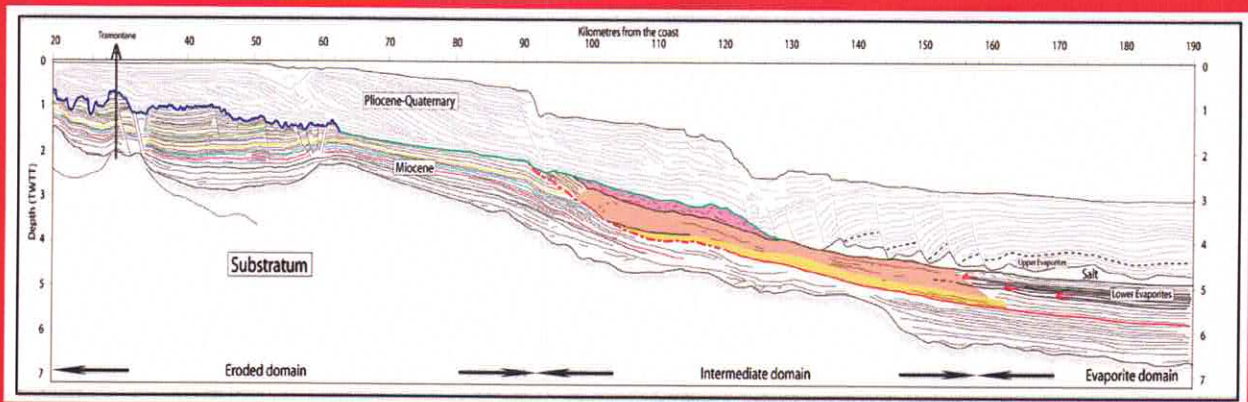
Reconstructing the paleoclimates and paleoenvironments, taking into account updated geodynamic scenarios.



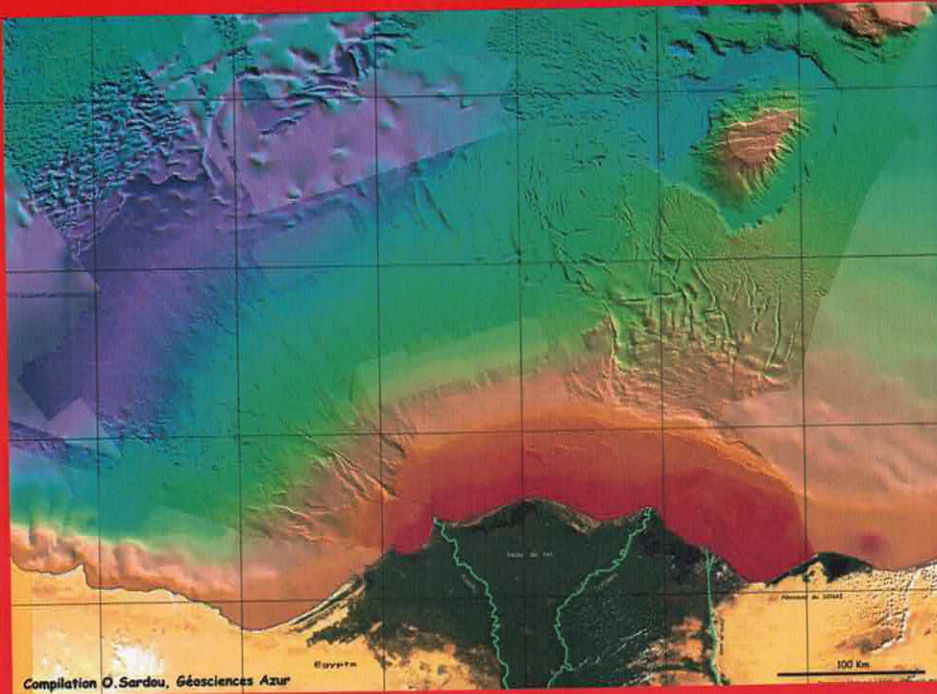
Morpho-bathymetry of the Mediterranean Sea; CIESM/Ifremer special publication, Atlases and Maps, two maps at 1/2 000 000. (MediMap Group, 2005.)



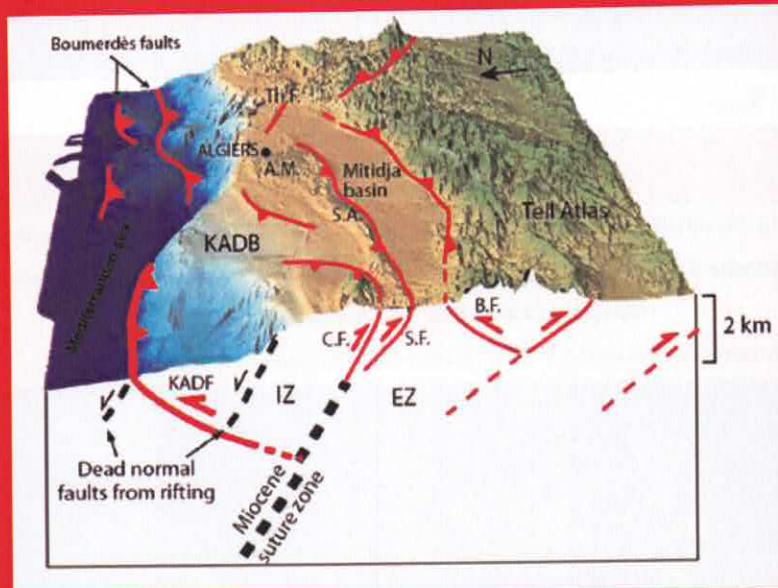
Map showing the sedimentary units and the erosion located just below the Pliocene. The drainage network (Margin Erosion Surface) dominates on the gulf of lion shelf (South France). (Gorini 2007 after Guennoc et al. 2000 , Lofi 2005, Bache 2008)



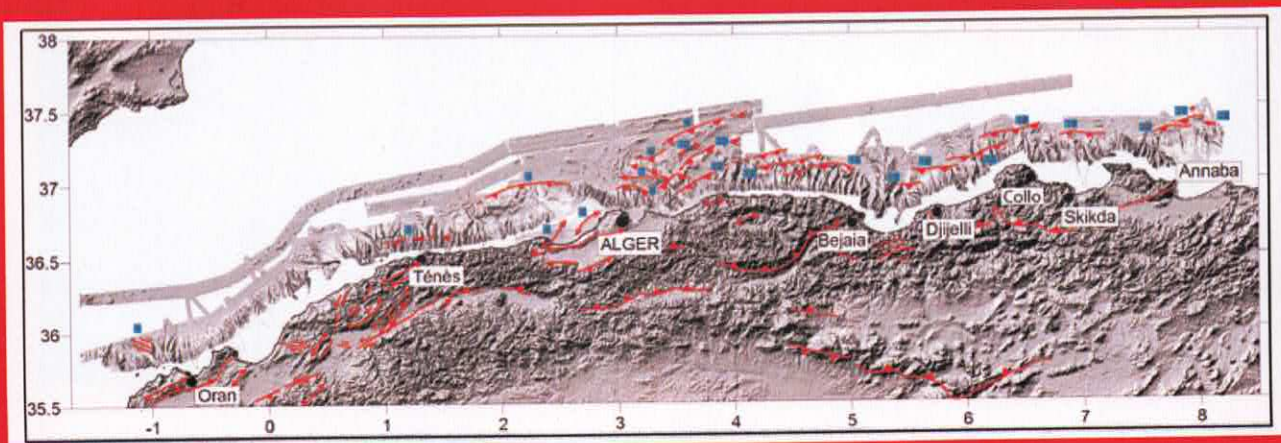
Dip Line drawing cross the gulf of lion showing the evidence of a pre-evaporite phase corresponding to a prominent erosional crisis responding to a major drawdown of the Mediterranean seawater. Assuming that this major drawdown corresponds to the major Messinian drawdown, the authors conclude that Mediterranean bathymetry significantly decreased before the precipitation of central basins evaporites. (Bache et al 2009)



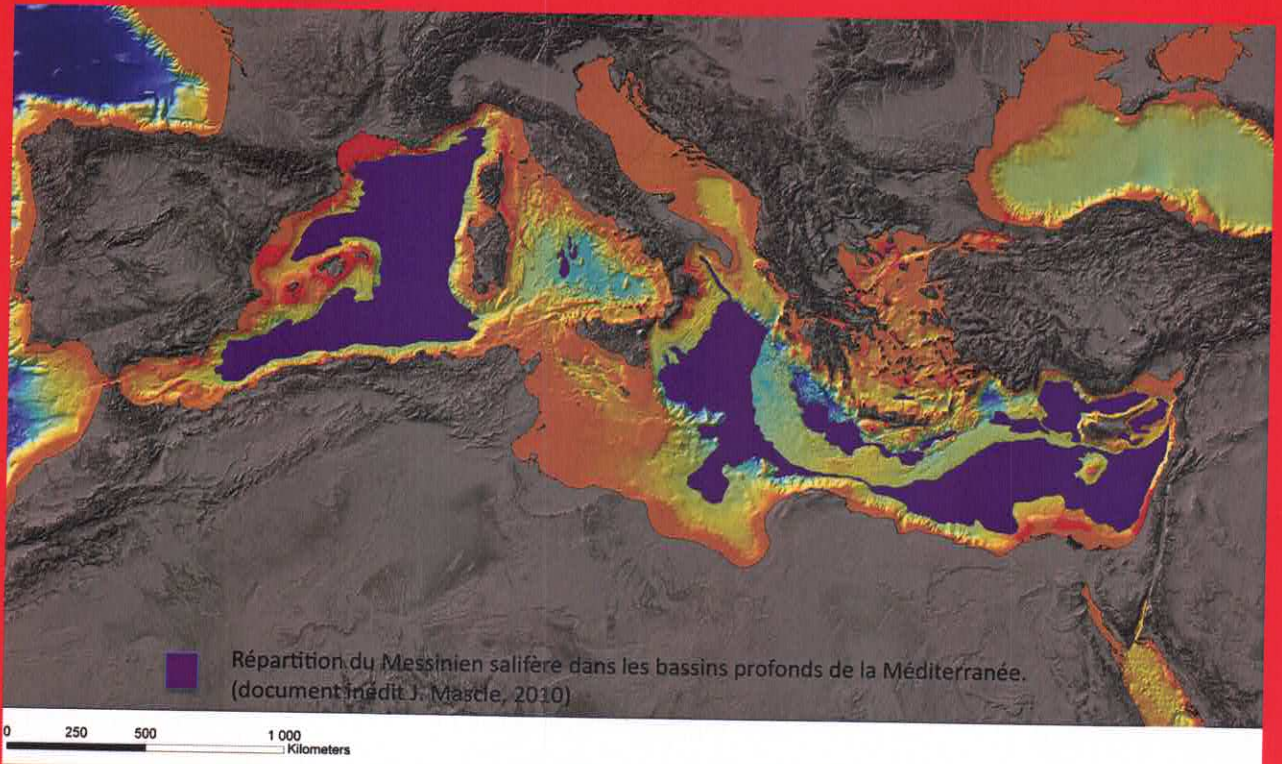
(Sardou et al.)



Tentative 3D view of the marine and terrestrial Digital Elevation Models showing our interpretation of the tectonic framework and fault geometry at depth in the offshore/onshore Algiers region. The black dashed line (suture zone, Miocene Tethyan slab) is assumed to be mostly inactive. KADB: Khayr al Din bank, KADF: Khayr al Din fault, Th.F.: Thenia fault, A.M.: Algiers Massif, S.A.: Sahel Anticline, S.F.: Sahel fault, G.M.: Chenoua Mount, C.F.: Chenoua fault, B.F.: Blida fault, IZ: Internal Zones, EZ: External Zones. - After Yelles et al., 2009



Bathymetry, topography and main active faults in northern Algeria, after Domzig (2006)



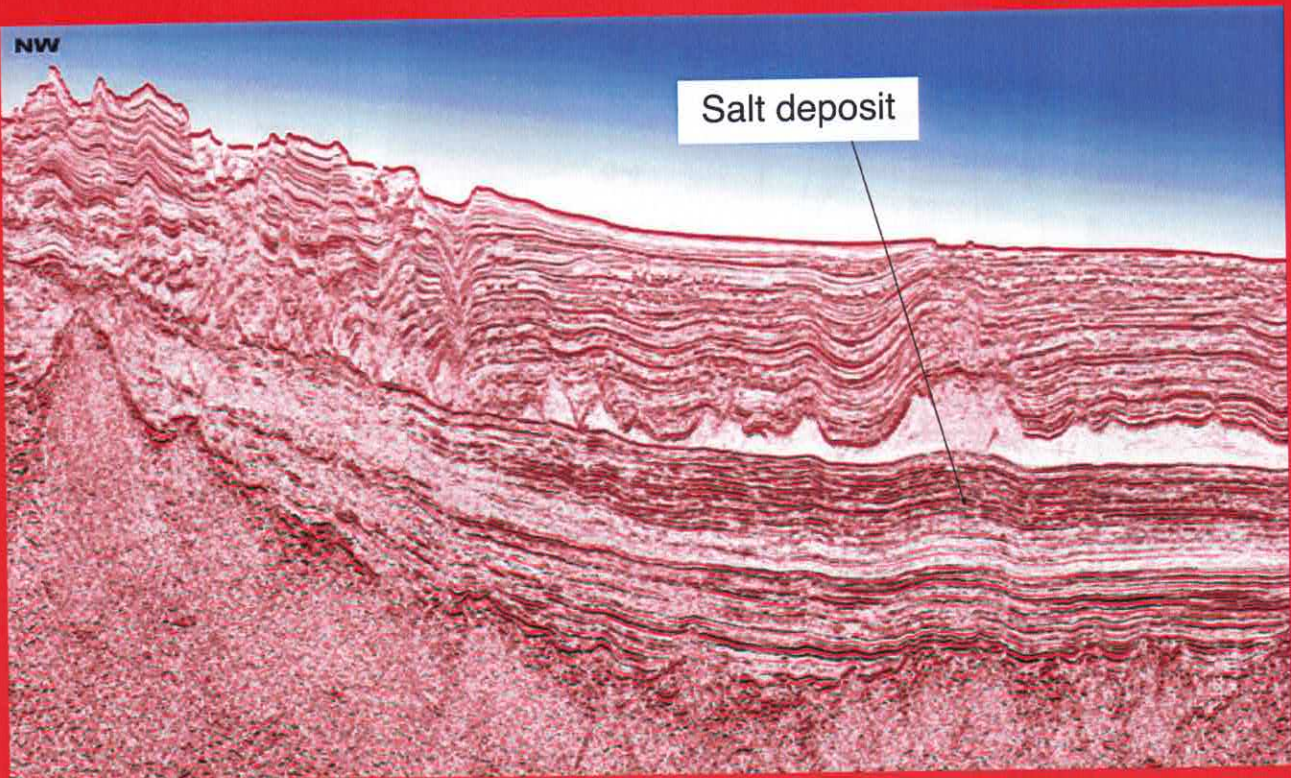
crue Building An IODP Complex Drilling Project In the Western Mediterranean Sea
Global Climate & Sea-level Changes, Extreme Events, Margin formation, Deep Biosphere
Using the Chikyu, MSP and Joides Resolution

IODP **JAMSTEC** **ECERD** **UPMC** **ifremer**

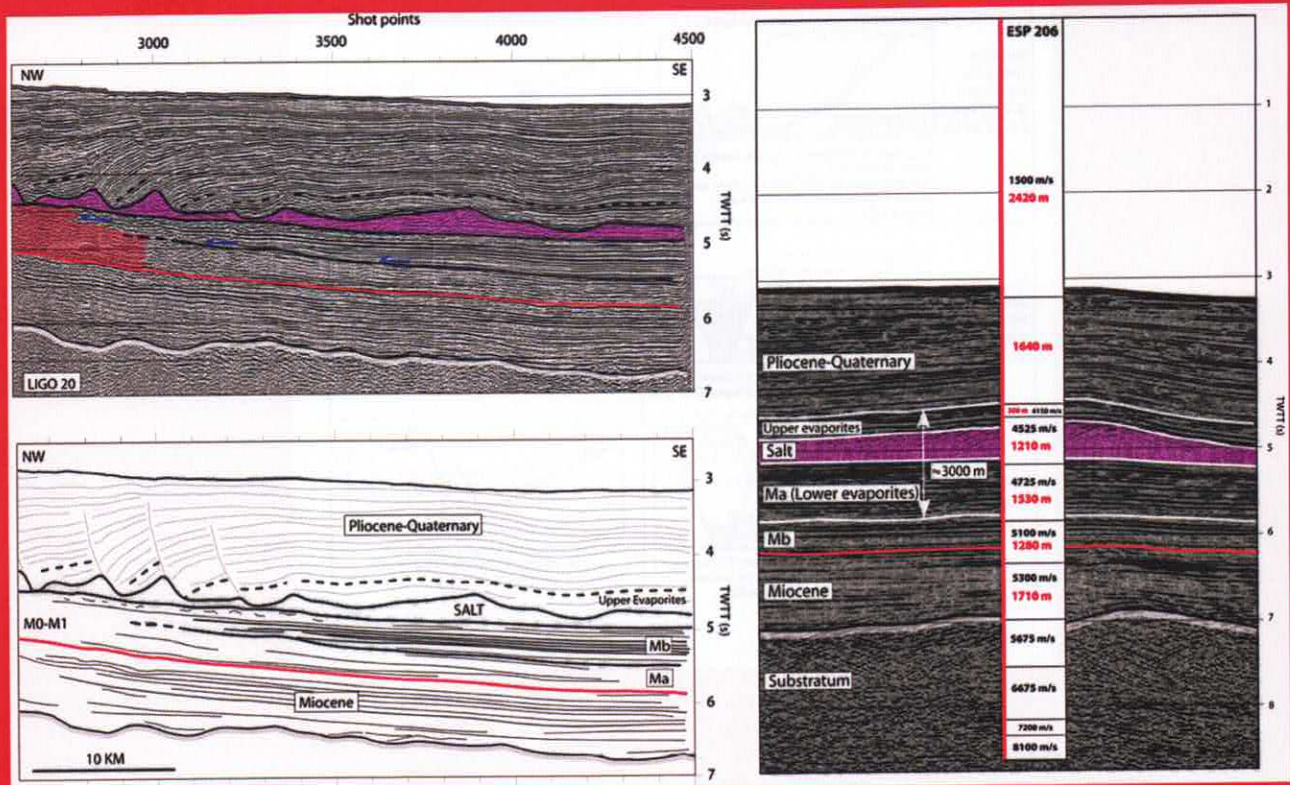
Proponents: Marina RABINEAU¹ & internationals (marina.rabineau@crue-breast.fr)

EGU meeting, Vienna, 2009 - 21st April 2009

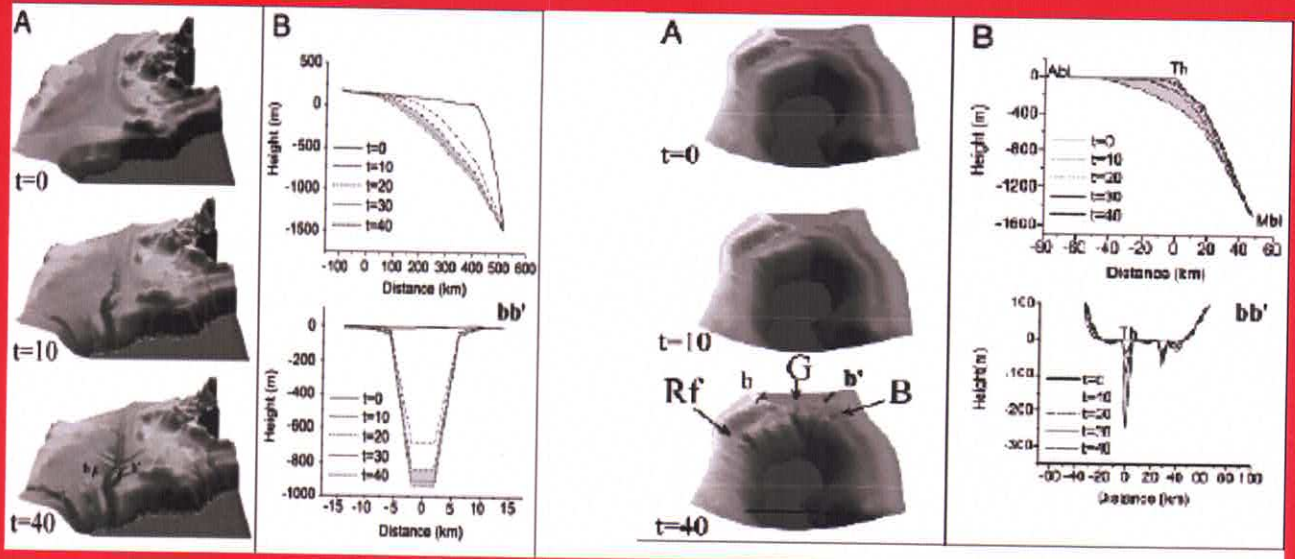
Gold project presentation in the Gulf of Lion



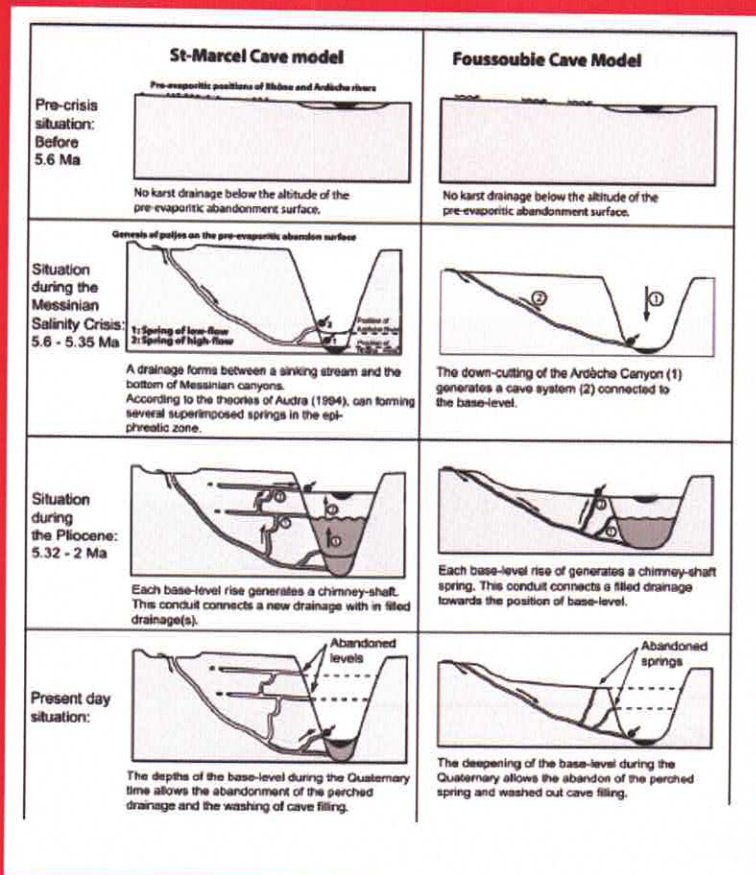
Source: TGS-NOPEC website (http://www.tgsnopec.no/datalibr/frame_w_mediterranean.htm)



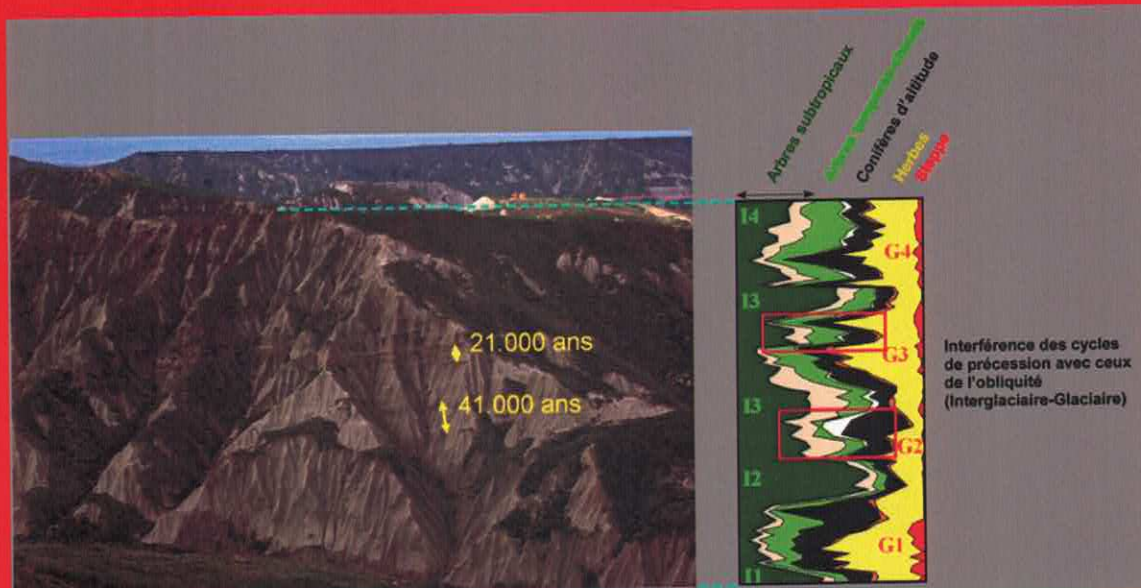
Provencal basin seismic units with expanding seismic profiles (ESP) (Pascal 1993) projected onto ECORS NW-SE deep seismic reflection profile. 4 Terms are interpreted as members of a thick Messinian sequence: Upper Unit, Mobile Unit (Halite), Lower Unit (4-5 Km). The DSDP cores only sampled the very top of the precipitates—only tens of metres of gypsum-anhydrite and literally only tens of centimetres of halite. (Bache 2008)



(Logez & Van den Driessche 2006)



(Moccochain et al. 2006)



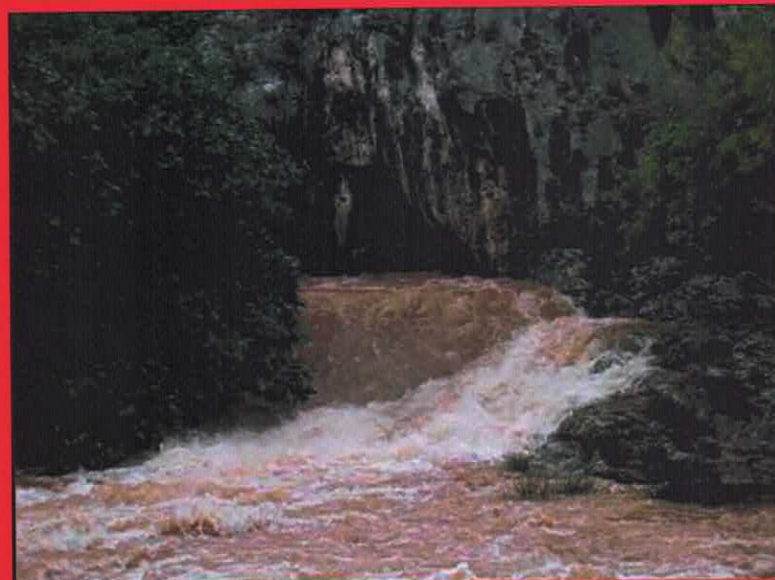
Spécificité des cyclicités climatiques au Pléistocène inférieur en Méditerranée centrale.

Partie inférieure de la série de Crotona (Calabre), référence globale pour l'enregistrement des premiers cycles glaciaire-interglaciaire de l'Hémisphère Nord (2.47-2.23Ma) (Suc et al., 2010). Les alternances colorimétriques soulignent ces cycles climatiques forcés par l'obliquité (41.000 ans) tandis que les sapropèles indiquent l'influence de la précession (21.000 ans). L'étude pollinique de cette coupe a révélé 4,5 cycles climatiques (interglaciaires I1 à I4 chauds et humides, glaciaires G1 à G4 frais et secs) (Combourieu-Nebout, 1993). Cependant, les deux cadres rouges montrent des intervalles à glaciaire ou interglaciaire "avorté" en raison de l'interférence des cycles de précession. Ces intervalles miment des variations moins intenses se réduisant à des fluctuations de la seule humidité (Suc et al., 2010).

Références.

Combourieu-Nebout N., 1993. Vegetation Response to Upper Pliocene Glacial/Interglacial Cyclicity in the Central Mediterranean. *Quaternary Research*, 40, 22-236.

Suc J.-P., Combourieu-Nebout N., Seret G., Popescu S.-M., Klotz S., Gautier F., Clauzon G., Westgate J., Sandhu A.S., 2010. The Crotona series: a synthesis and new data. *Quaternary International*, sous presse (doi: 10.1016/j.quaint.2010.01.008).



Célèbre résurgence du karst messinien de la Fontaine de Vaucluse.

Lorsqu'un système karstique messinien s'est creusé en dehors du réseau fluvial des résurgences à débit élevé ont pu s'être mises en place lors du paroxysme de la Crise de salinité puis continuer de fonctionner à des profondeurs parfois considérables sous le niveau actuel de la mer (Mocochain et al., 2006). La cartographie à terre et en mer des canyons fluviaux messiniens et, dans une plus large mesure, de la Surface d'érosion messinienne livrera les pistes à suivre pour identifier ces ressources potentielles en eau douce qui manquent cruellement sur les rives méridionales du bassin méditerranéen. Par exemple, le bassin de Marseille, entouré de massifs carbonatés, ne recèle pas de réseau fluvial messinien bien qu'étant aujourd'hui drainé par un fleuve, l'Huveaune. Les reconstitutions climatiques menées sur le pourtour méditerranéen à partir de la palynologie montrent l'évaporation intense et constante que connaissaient les bassins centraux quasi asséchés se traduisait par des précipitations accrues sur les reliefs septentrionaux et, par conséquent, par une augmentation significative du ruissellement, du débit des fleuves et de la mise en charge des réseaux karstiques (Fauquette et al., 2006). Des réseaux karstiques similaires à celui qui a dû caractériser le bassin de Marseille sont ainsi à rechercher puis à exploiter.

Référence.

Fauquette S., Suc J.-P., Bertini A., Popescu S.-M., Warny S., Bachiri Taoufiq N., Perez Villa M.-J., Chikhi H., Subailly D., Feddi N., Clauzon G., Ferrier J., 2006. How much did climate force the Messinian salinity crisis? Quantified climatic conditions from pollen records in the Mediterranean region. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 238, 1-4, 281-301.

Mocochain L., Clauzon G., Bigot J.-Y., Brunet P., 2006. Geodynamic evolution of the peri-Mediterranean karst during the Messinian and the Pliocene: evidence from the Ardèche and Rhône Valley systems canyons, Southern France. *Sedimentary Geology*, 188-189, 219-233.



5. FUTURE PERSPECTIVES

5 OUT-REACH

TerMEx will provide long-term support to European, national and regional agencies and urban communities to ensure better protection of society from natural hazards and to manage water and energy resources in the Mediterranean realm. It will also offer a wide range of information to a wider public, raising awareness of the respective roles of geology and climate in the evolution of the Mediterranean environment.

5.1- GEOLOGICAL PARKS

Numerous theme parks are currently planned to attract and inform the public on a variety of geological issues related to the TerMEx programme, i.e. parks dealing with the Messinian salinity crisis in Sicily and Southern Spain (Sorbas karst), with paleo-climate

(Crotone). TerMEx could promote the out-reach of geological studies towards the public, by publicizing existing parks aimed at preserving vulnerable geological sites (i.e. in Corsica and the Cyclades Islands), and by providing an international label of quality, scientific expertise and financial support to similar initiatives.

5.2- GEOLOGICAL ATLAS OF THE MEDITERRANEAN

The results of TerMEx will be contributed to public data bases, which must have secure links and interoperability. Ultimately, these data could be used to compile and publish new thematic and interactive maps at the scale of the Mediterranean, i.e. for various natural hazards, water resources and energy, paleogeography and future evolution.

The Commission of the World Geological Map should be contacted to coordinate the types of deliverables envisaged by the TerMEx programme.



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