I - EXECUTIVE SUMMARY
1. **INTRODUCTION**

The workshop was held on the island of Djerba, Tunisia, from 22 to 25 November 2000. A total of 15 scientists (see list at end of volume) originating from nine countries attended the seminar at the invitation of CIESM. In opening the meeting, Dr Frederic Briand, Director General of CIESM, and Dr Jean Mascle, Workshop chairman and President of CIESM Marine Geoscience Committee, expressed their great pleasure to see eminent researchers from both shores gathered here – and in many cases meeting each other for the first time – to tackle in an original and intensive fashion a complex and challenging issue: the African continental margins of the Mediterranean Sea.

Although practical considerations did prevent, in the end, the attendance of a few invited specialists from further countries, the organizers felt gratified to see scientists from Algeria, Morocco and Tunisia, representing both academic research and national petroleum organizations, able to exchange their knowledge, hypotheses, and perspectives with specialists from Europe (France, United Kingdom, Germany, Belgium and Russia), and among themselves as well. As pointed out by several participants, the workshop permitted an intensive scientific dialogue, not only across the north-south divide of the Mediterranean Sea, but also, and for the first time, among top geoscientists from north Africa.

1.1. Background and objectives

The north African and Levant continental margins are quite contrasted, representing either segments of an old Mesozoic passive margin, or more recent and tectonically active continental borders. In spite of their scale and importance, they remain surprisingly poorly known, at least from an academic point of view, and poorly understood. These continental margins have never been studied by academic drilling and no real synthesis exists concerning their morphology, history, structure and sedimentation. Marine surveys remain sparse, and information from hydrocarbon exploration remains selective (e.g., Nile delta).

In brief, from the Levantine region to central Tunisia, the continental margin is considered to be an old passive-type margin that has resulted from a long Mesozoic rifting history. It was later subjected to important sedimentary accumulations (such as the Nile deep sea fan construction) and might be locally starting to collide with the southern border of Europe (particularly south of Cyprus and south of Crete). From western Tunisia to Gibraltar, the north African margins result from complex interactions between the much more recent opening of the Western Mediterranean and Alboran basins, and from active tectonic evolution related to the surrounding Alpine collisional setting which has created the north African mountain ranges. As a consequence this sector can be considered as a tectonically active area, still subjected to damaging earthquakes and shaped by fairly active sedimentary processes.

Currently many questions are a matter of debate. For instance what is the timing and process of continental break-up and spreading of the Tethys ocean? Is the north African margin of volcanic- or non-volcanic-rifted type, or both? When did ocean spreading begin? Is the Levant margin segment of transform, or orthogonally rifted type? To what extents are parts of the margin now affected by collisional tectonics?
During the course of their four-day meeting, the participants extensively covered such ground, reviewing current knowledge of the structural and geodynamic evolution of the region. Based on the various discussions and presentations, Dr Alastair Robertson summarizes below the geodynamic evolution of the north African and Levant margin segments, integrating the many threads provided by the participants.

In addition, two workshop sessions were set apart to evaluate the best ways (and the best tools) to further our understanding of the structural and sedimentary processes at work in this zone, and to identify promising paths for future research projects at regional and/or thematic scales. These are presented in sections 3 and 4 below.

2. OUTLINE OF GEODYNAMIC EVOLUTION (summary by A. Robertson)

2.1. Pre-Late Permian

During the Paleozoic the present north African/Levant passive margin formed part of Gondwana bordering the Paleotethys ocean to the north (see references in Robertson, this volume). A major question is whether the south-Gondwana margin was also affected by the Hercynian orogeny (e.g. Sengör et al., 1984). Recent work has tentatively correlated the Betics (S Spain) with Gondwanian crust, which would favour such an hypothesis (Michard et al., 1997; Chalouan and Michard, this volume).

2.2. Late Permian-Mesozoic rifting

Hercynian deformation was followed by extension during Late Permian-early Mesozoic time (Guiraud and Bosworth, 1999). For example, in Tunisia, a deformed Paleozoic succession is unconformably overlain by Late Permian rift-related sediments (Dridi, this volume). Rifting was there active until Early Cretaceous time and facies belts are oriented E-W, while sub-surface successions thicken northwards (see references in Bedir, this volume). The Tunisian margin is dissected by N-S faults which can be interpreted as reactivated Pan-African basement structures, and the southward continuation of the Malta Escarpment is seen as one of the major N-S transverse structures.

Local Late Triassic fault blocks in Tunisia, associated with rift magmatism, are sealed by Lower Jurassic sediments (Bedir, in press; Bedir, this volume), and the Late Jurassic was marked by a regression and clastic sedimentation that could correspond to flexural uplift of the margin, coeval with opening of an oceanic connection between the Central Atlantic and the Western Mediterranean. In general, individual fault blocks in Tunisia exhibit contrasting movement histories controlled by regional extension, wrench movements and salt tectonics (Bedir, in press). A comparable rift history is seen Morocco, Libya and Egypt (Guiraud and Bosworth, 1999).

2.3. Two-phase continental break-up

It is generally agreed that the north African/Levant passive margin owes its origins to two fundamentally different spreading episodes (Sengör et al., 1984; Robertson and Dixon, 1984; Dercourt et al., 1986, 1992; Ziegler, 1990; Ziegler et al., in press). The first is the opening of the eastern Neotethys, westwards from Oman, along the Arabian margin into the Eastern Mediterranean. Evidence from the Levant margin (Ben-Avraham, this volume), from Cyprus, and from southern Turkey (e.g. Antalya) is consistent with initial spreading in Late Triassic-Early Jurassic time, but this early oceanic basin probably remained narrow (<500 km) (Robertson, 1998a).

The second spreading event relates to the opening of the North Atlantic in the Late Jurassic. This is well documented by the existence of ophiolites (e.g. Liguria, E Alps) and deep-sea sediments in the Atlantic and Western Mediterranean region (Bernoulli and Jenkyns, 1974; Ogg et al., 1980). The oceanic crust extended thus through the Betics/Rif area of S Spain/N African into the western Neotethyan ocean, and this, in turn, extended through the Eastern Alps into the Pannonian Basin.

An important question is the nature of this oceanic connection. The linkage is marked by fragmentary ophiolitic rocks of the Betic and Rif regions (Puga et al., 1989, 1999). Recent work indicates that the ophiolite-related volcanics are of MORB type, supporting an oceanic connection,
rather than a rift basin. In recent models the southern Betics are seen as a rifted microcontinent that was separated from the Iberian plate to the north, both by a westward extension of the late Mesozoic-early Tertiary “Pennine” ocean in the north, and by another oceanic strand to the south.

How the eastern (Triassic-Early Jurassic) and western (Late Jurassic-Early Cretaceous) spreading systems interacted remains controversial. In one view the two stopped short of each other, leaving an Apulian promontory as a small N-S barrier. Alternatively, the two ocean stands converged (or overlapped), opening an E-W oceanic basin along the entire length of the north African margin by Late Jurassic time. It is likely that by Early Cretaceous time the north Africa/Levant margin existed as a continuous rifted continental margin, separated from a number of rifted continental fragments by Neotethyan oceanic crust. It is not surprising, therefore, that the Late Permian/Early Mesozoic rift history of north Africa was multi-pulsed and locally variable, as this region was affected by continental break-up of both the eastern and western Neotethys.

2.4. Passive margin history

After formation of a single north-facing passive margin, by Late Jurassic time the north African/Levant margin underwent passive margin subsidence during Cretaceous-Early Tertiary time. The history of the Mediterranean deep southern margin and adjacent basin during this time remains poorly known. As an exception, the structure and stratigraphy of the passive margin is relatively well documented in the Levant, based on seismic and well data (Garfunkel, 1998). Locally, the Early Cretaceous and younger history of a rifted continental fragment, the Eratosthenes Seamount, in the Eastern Mediterranean was recorded by drilling during ODP Leg 160 (Robertson, 1998b; Mart and Robertson, 1998). Additional information on the mid-Cretaceous (Aptian-Albian) and younger sedimentary history is provided by sedimentary rock clasts recovered from mud volcanoes in a number of areas of the Mediterranean, notably south of Crete (see references in Akhmanov et al., this volume).

During its “passive margin phase” the north African/Arabian margin was also influenced by far-field tectonic events, including pulses of compression, strike-slip and extension in specific areas (Guiraud and Bosworth, 1999). Most notably, in the Arabia-Egypt region the margin was affected by stratigraphic inversion along the Syrian arc (Garfunkel, 1998), probably related to ophiolite emplacement along the northern margin of Arabia (Robertson, 1998).

2.5. Neogene collisional deformation in the west

During the Tertiary, especially in Eocene time, many parts of the north African margin experienced deformation and thrusting related to the convergence of the African and Eurasian plates (Dewey et al., 1989; Robertson and Grasso, 1995).

Along the southern Mediterranean margins, collisional deformation was manifested first in the west (west of the Malta Escarpment), as documented by Early Miocene thrusting onto north Africa. As a result, former passive margins units (platform/slope) were detached and thrust southwards as a stack of thin-skinned thrust sheets. Thrusting was accompanied by widespread genesis of Burdigalian olistostromes and related foreland basin flysch sediments, as in Sicily, the Maghrebides and Kabilides) (Saad and Caby, 1994; Braik, this volume). Recent marine studies of the Sardinia channel area now allow detailed correlations between Tunisia, Sardinia and Sicily (Bouillin, this volume; Torelli et al., this volume).

The favoured explanation of the Miocene collisional deformation is that oceanic crust of the western Neotethys was subducted generally northwards beneath the Iberian margin. With time, the subducting slab migrated southwards (i.e. “rolled back”) until it collided with the north African continental margin. This margin was, however, irregular in shape, such that collision in Sicily and Tunisia and Algeria occurred in Early Miocene time, whereas the eastern Neotethys further east remained largely unaffected. Collision with the northwest African margin was thus diachronous, becoming younger westwards towards the Rift/Betics region (Chalouan and Michard, this volume).

2.6. Orogenic collapse

The Neogene compressional deformation was accompanied by pervasive extension of hinterland areas, dating from latest Oligocene/Early Miocene (Aquitanian-Burdigalian) time. Rifting took
place extensively, as documented in the Alboran Sea (Watts et al., 1993). Extension also gave rise to core complexes in some areas (e.g. Grande Kabylie in Algeria; Saad and Caby, 1996). In addition, Neogene extensional basins are well developed in some onshore areas of north Africa (e.g. in Algeria) and include records of Miocene extensional volcanism (Kheidri et al., this volume).

Rifting proceeded to oceanic spreading in some hinterland areas, including the North Balearic (Provencal) Basin, the north Algerian Basin and the Tyrrenhian Sea. Extension was coupled with the detachment of Corsica and Sardinia from southern Europe (see papers in Robertson and Comas, 1998).

Rifting of the present-day north African continental margin was accompanied by left-lateral strike-slip, as documented by onshore and offshore studies (Comas et al., 1992; Braïk, this volume). Some margin areas remained tectonically active into Pleistocene-Holocene time (Kheidri et al., this volume; El Moumni et al., this volume). In Tunisia, for example, Plio-Quaternary tectonics included fault inversion, mud diapirism and rapidly subsiding basins in a strike slip dominated setting (Bedir, this volume).

One apparent problem is that the northern (European) Neotethyan northern margin collided with north Africa during the Early Miocene, yet further NE the Tyrrenhian Sea did not open until Late Miocene onwards (Kastens et al., 1990). To accommodate this, Gueguen et al. (1998) postulate a major NW-SE trending dextral strike-slip zone between the Algerian and Provencal basins, which thereby allowed the Ionian Sea oceanic plate to continue to “roll-back” southwards, accommodating further back-arc extension in the Tyrrenhian Sea.

2.7. Incipient collision in the Eastern Mediterranean

East of the Malta Escarpment, the Cyrenaica region of Libya is interpreted as a large promontory of the north African continental margin during its rift/passive margin development; this promontory would be the first area to collide with the Mediterranean Ridge accretionary wedge as it migrated southwards in Neogene-Recent time (Camerlenghi et al., 1995). The timing of initial collision remains controversial, but was arguably since Late Miocene (Chaumillon and Mascle, 1995; Mascle et al., this volume), but more probably since Late Pliocene time. An intriguing aspect is that processing and interpretations of seismic refraction data suggest that an undeformed continent-ocean transition zone may still exist between Cyrenaica and Crete (Brönner and Makris, this volume). By contrast, interpretations based on shallow seismic reflection data favour a collision-related setting, implying that the pre-existing margin should be partly disrupted in this region (Mascle et al., this volume).

Further east again the Egypt and Arabian margin segments remain in a “passive margin” state. However, these areas were affected by Eocene-Oligocene collision of the regional Arabian promontory with Eurasia, as documented by the thrust belts in southern Turkey and Iran (Fourcade et al., 1991; Yilmaz, 1993; Robertson, 1998a) and this, in turn reactivated the Syrian Arc in the Levant and northern Egypt. More recently, during the Plio-Quaternary, the Eratosthenes Seamount, interpreted as a rifted north African/Arabian continental fragment (Woodside, 1977; Ben-Avraham et al., 1986; Kempler and Ben-Avraham, 1987; Robertson et al., 1995; Mart and Robertson, 1998) began to collide with the Cyprus active margin to the north. However, the Nile cone area to the south has so far remained largely unaffected by these collisional effects (Bellaiche et al., 1999). Instead, salt tectonics has played a critical role in subsurface structuration and sediment dispersal (Gaultier et al., 2000; Loncke, this volume). In addition, the Late Oligocene and subsequent rifting of the Red Sea/Gulf of Suez/Gulf of Aqaba systems might have also affected the eastern Nile Cone area (Mascle et al., 2000).

2.8. Summary

In summary, the north African-Arabian margin was affected by the evolution of the Tethys ocean to the north from early Paleozoic times onwards. The eastern Mediterranean basin experienced Late Permian rifting, followed by early Mesozoic oceanic spreading and has survived relatively unscathed until present time. On the other hand, the Western Mediterranean basin also experienced Late Permian-early Mesozoic rifting, but Tethyan oceanic spreading was delayed until Late Jurassic time. Collisions in orogenic areas to the north reflect the amalgamation of continental
fragments, mainly in Late Cretaceous-Paleogene time. Owing to the narrowness of the western Neotethys, relative to further east, and the Africa-Eurasia convergence history, this western region adjacent to north Africa experienced collisional deformation first (Early Miocene), creating the Maghrebides-Kabilides-Rif chain and counterparts in the Betics. By contrast, the north African margin in the Eastern Mediterranean has experienced only incipient collision in some areas. Back-arc marginal basins in the Eastern Mediterranean basin were restricted to rifts (e.g. N Aegean), but widened into small ocean basins in the Western Mediterranean (e.g. Tyrrhenian Sea).

The probable ultimate fate of the Mediterranean region is a thrust belt similar to the Zagros Mountains of Iran.

3. RESEARCH NEEDED ON STRUCTURAL FRAMEWORK AND GEODYNAMIC EVOLUTION (session summarized by Alastair Robertson)

With regard to fundamental scientific objectives, available techniques and potential achievements, the group identified two main topics: 1) Neogene-Recent tectonic evolution of the Western Mediterranean basins and margins; 2) Rifting/passive margin history of the Mesozoic Tethys ocean.

Potential study on the Neogene-Recent tectonic evolution of the Western Mediterranean basin (from Tunisia to Morocco) requires both new data and synthesis of existing data. The main techniques to use should be swath bathymetry, coring and other marine studies of the offshore areas, coupled with onshore studies, mainly of neotectonic processes (e.g. field mapping, kinematic analysis of faults, tectonic geomorphology). The end product would be an improved understanding of the geodynamic evolution of Neogene deep-sea basins and margins in the Western Mediterranean region.

Research on the Rifting/passive margin history of the Mesozoic Tethys ocean (Libya, Egypt, Levant, Syria) should be mainly based on existing, largely industrial data, that could be used for collaborative studies with academia, supplemented, where possible, by acquisition of new data. Aspects could include improved interpretation of deep geophysical data and land-based studies. The end-product would be a better understanding of the Mesozoic history of rifting and sea-floor spreading in the central and eastern Mediterranean regions.

Both topics appear to have important social relevance. For example topic 1 (Western Mediterranean basins/margins evolution) relates to seismic hazard (earthquakes and tsunamis), and topic 2 (Mesozoic rifting/spreading) clearly relates to hydrocarbons, especially exploration of deep-water and ultra deep water continental margins.

3.1. Fundamental scientific objectives

The following topics were assessed for possible future research.

3.1.1. Mesozoic rifting of Tethys

This concerns the opening of the Mesozoic Tethys ocean (Neotethys), as documented in north Africa/Arabia. Aspects that require future investigation include:
- timing of rifting and spreading;
- location and nature of the continent-ocean transition zones;
- role of extension, or strike-slip in basin evolution;
- role of magmatism in continental break-up;
- sedimentary facies and depositional processes related to rifting.

3.1.2. Tethyan passive margin history

Aspects that require future investigation include:
- onshore passive margin subsidence history;
- tectonically emplaced passive margin units (i.e. N Syria and parts of the NW African flysch nappes);
- deep-sea drilling (ODP);
- sampling of clasts from mud volcanoes.
3.1.3. Collision and emplacement history
Future investigations should include:
• late Cretaceous emplacement of margin/oceanic units onto the Arabian margin (N Syria);
• oligocene-Miocene emplacement of margin/oceanic units onto the NW African margin
  (Tunisia, Algeria, Morocco);
• Miocene?-Recent collision of the Mediterranean accretionary wedge with the Cyrenaica
  Peninsula (Libya).

3.1.4. Neotectonic rift/spreading processes
This concerns the opening of the Neogene-Recent deep water/oceanic basins of the Western
Mediterranean Sea. Expected investigations include:
• timing of rifting and spreading;
• location and nature of the continent-ocean boundary in different basins;
• sedimentary facies and depositional processes related to rifting;
• role of extension, or strike-slip in basin evolution.

3.1.5. North Mediterranean margins
It was stressed that the conjugate margins of the rifted Mesozoic Tethyan margins (e.g. in Greece,
Cyprus, Turkey) and also of the Western Mediterranean Neogene basins (S Spain, S France, Italy)
must be taken into account in any synthesis.

3.2. Research techniques
Participants discussed the techniques that could be applied to the studies listed in the above sec-
tion, as follows:

3.2.1. Standard marine geophysical surveys
This includes classical marine survey techniques, including magnetic and gravity surveys. Most
of the necessary data already exist, but may merit re-interpretation e.g. to examine the possible
role of magmatism in rifting.

3.2.2. Deep refraction seismic investigations
Data now exist (e.g. Libya-Crete), but could be re-analysed in terms of E-W, in addition to N-S
trends. There is also a need for refraction surveys of the N Levant margin (Syria) and some other
areas.

3.2.3. High-resolution swath bathymetry
This is an efficient and very effective technique that recently has shed much light on the topog-
raphy and recent deformational sedimentary processes of the Mediterranean basins (e.g.
Mediterranean Ridge). A future aim is to complete the coverage of the Mediterranean Sea.
Surveys should include inshore areas as far as possible. For the Western Mediterranean there is
a need to collate data from surveys by different countries to achieve an overview.

3.2.4. Deep-sea drilling (ODP)
This is an effective, but very expensive, approach that yields invaluable evidence of the sub-
surface stratigraphy of the Mediterranean basins (e.g. recent drilling in the Alboran Sea and on
the Eratosthenes Seamount). However, no future drilling is likely in the Mediterranean within
the foreseeable future (next 3-5 years) despite good and relatively mature proposals (e.g. Rhone
fan and Mediterranean Ridge.

3.2.5. Sampling of clasts from mud volcanoes
This is a relatively cheap and effective way of shedding light on the facies and age of rock types
beneath the Mediterranean seafloor. It is, however, limited by the localised development of mud
volcanoes and does not allow the surface stratigraphy to be reliably reconstructed.

3.2.6. Onshore fieldwork
This approach is of limited value in determining the Neotethyan rift/passive margin history, as
coastal areas are widely buried by younger sediments. Exposures further inland (e.g. Sirte Basin,
Libya) commonly reflect north African intraplate deformation as a whole and not simply
Mediterranean basinal tectonics. However, onshore fieldwork is invaluable where Tethyan mar-
gin/basin units have been tectonically emplaced. Principally this is seen in north Syria (Baer-Bassit), where Triassic-Late Cretaceous margin units were tectonically emplaced in latest Cretaceous time. Tethyan units in NW Africa were emplaced in Oligo-Miocene time (e.g. Maghrebides, Cabilides, Rif) as basal levels of “flysch nappes”. However, these do not document the pre-Cretaceous history. In addition, onshore fieldwork can shed much light on the Miocene-Recent history of the Western Mediterranean Neogene basins, as coeval sedimentary succession, are exposed in Tunisia, Algeria and Morocco.

3.2.7. Industry well and seismic data analysis

Extensive industry seismic reflection and well data sets exist for the Mesozoic north African basins, including the Suez Rift and Sirte Basin. However, the deep-water continental margin areas have, to date, been largely ignored, with the exception of the Nile Cone. For some areas (e.g. Sirte Basin) industry data sets are already partly in the public domain. Opportunities may exist for industry/academic collaboration to utilise existing seismic and well data sets. The north African deep-water margins are one of the world’s major frontier areas that are likely to be explored further in coming years.

3.3. Regional aspects

Bearing in mind the scientific objectives and the potentially available techniques, the following specific research targets were identified for individual continental margin segments. Working clockwise around the southern Mediterranean these are as follows:

3.3.1. North Levant margin

This is the least well known segment of north African/Arabian Tethyan margin, requiring all types of data to progress with regional understanding.

3.3.2. South Levant Margin

This is currently the best documented area, but much industry data are still not in the public domain.

3.3.3. Nile Cone

Areas in the south (Gulf of Suez rift) are well documented, but the data are mainly not in the public domain. Recent swath bathymetry has shed much light on the northward prolongation of the Gulf of Suez structures beneath the Nile Cone (distributed extension zone, or microplate boundary). The deep structure and stratigraphy of the deep-water basins beneath the inner and outer Nile Cone are under industry study, including reflection seismics and planned drilling. However, little of these data are likely to be available for academic study in the near future. The surface morphology of the Nile Cone is revealed most effectively by high-resolution swath bathymetry and a more complete coverage is expected to be obtained during future cruises. In addition, ultra-long piston cores will be acquired from the Nile Cone within several years.

3.3.4. Cyrenaica Peninsula

A recent deep-seismic refraction survey from offshore Libya to Crete has revealed the deep structure of the central north African margin. This apparently includes a transition from subsided continental crust to oceanic crust. Two along-strike survey lines reveal apparently different continental margin structure and further processing of data is needed to determine if this is a real effect (e.g. caused by segmentation of the continental margin), or an artefact of processing. Shallow seismic reflection and swath bathymetric surveys extend from the Mediterranean ridge as far south as the Cyrenaica Promontory. Interpretation suggests that the accreted sediments of the Mediterranean Ridge are in the process of being thrust southwards over the Cyrenaica margin segment, which is interpreted as a promontory of the north African margin. However, the deep structure of this inferred collision zone remains largely unknown and the timing of any initial collision is unclear.

The inference from seismic refraction data of a still extant continent-ocean transition zone located basinwards of the Cyrenaica Promontory appears to conflict with the interpretation of this region as a continental collision zone, as hypothesised from shallow seismic data. Processing of seismic reflection and refraction data to evaluate E-W, in addition to N-S structural trends may help resolve the problem. Onshore fieldwork may contribute, as the coastal Cyrenaica hills (sev-
eral hundred metres high) may reflect collisional processes. Their timing of uplift might be determinable, e.g. by fission track dating. Also, analysis of onshore industry seismic data may reveal tilting or other structuration referable to continental collision.

### 3.3.5. Tunisian margin

This is a critical segment of the north African margin as it illustrates the combined effects of 1) E-W extension; 2) N-S extension/strike slip; 3) mid-Tertiary collision in the north (Maghrebides); 4) Plio-Quaternary localised extension/strike slip. To the east, the Tunisia margin segment is bounded by the southward extension of the Malta Escarpment, a N-S lineament that was probable active in segmenting the north Africa margin during Mesozoic rifting of Neotethys. Additional evidence of N-S tectonics is revealed by the N-S Axis, further west. This extends northwards from the Saharan basement, through surface outcrops, then beneath basinal units, as revealed by industry seismic reflection data. The Tunisian margin segment underwent overall oblique extension during Late Permian to Jurassic rifting. Basement structures were reactivated to create a mosaic of rift blocks, with variable extensional and trans-tensional effects between. Salt tectonics have played an important role during rifting and subsequently. Recent studies link the tectonics of Tunisia across the Sardinia Channel to Sardinia. Correlations have also been established with Sicily.

Although quite well known from combined industry and academic studies, several aspects of the Tunisian margin segment are worthy of further study, as follows:

- role of Pan-African basement fault lineaments in Neotethyan rifting;
- relationship of the N-S Axis to rift processes and later Mesozoic-Tertiary history;
- nature and geometry of rift-related blocks;
- effect of Oligo-Miocene collision on margin structure;
- nature of Plio-Quaternary tectonics including exceptionally rapid local basin subsidence;
- role of salt tectonics.

### 3.3.6. Algerian margin

Data exist from industry, but only few are available from academia for onshore areas. However, there is a need for some updating and improved correlation with adjoining regions (Tunisia and Morocco). Some relevant aspects are as follows:

- the Maghrebides/Kabilides formed by Oligo-Miocene collision; this requires additional study to link sub-surface structure with outcrop geology in detail;
- Neogene history of post-collisional extensional tectonics and related (dextral?) strike slip in the north (coastal areas); fission track studies could elucidate the timing of exhumation (as determined for Sicily and elsewhere);
- study of onshore Plio-Quaternary sedimentary basins could shed more light on the rift/extensional history;
- neotectonic studies (i.e. of fault planes) are needed to determine kinematic history and the role of strike-slip versus extension;
- the structure of the continent-ocean transition zone in deep water off Algeria remains poorly understood.

### 3.3.7. Moroccan margin

Much data from industry and academia for onshore areas have already been published, and synthesis is well advanced. Few major problems appear to remain. A more extensive collisional orogenic history is present in the Betics of southern Spain and detailed comparisons between the two areas will be useful. Aspects for potential studies include:

- comparison of the Hercynian orogenesis of the Atlas, the Moroccan margin area and the Betics;
- comparison of the processes and timing of Neotethyan rifting within adjacent areas (e.g. Tunisia, Libya, N Egypt);
- comparison of the timing and processes of Neogene collision, particularly to test models suggesting diachronicity of collision from east to west;
- more detailed geochemical studies of magmatic units, including the Rif peridotites and extrusive igneous rocks.
• neotectonic and sedimentary studies of the northern coastal areas to compare with marine studies of the rifting/subsidence history of the Alboran Sea;
• detailed comparative studies of the Betics to decide whether the Rif nappes record a Tethyan rift, narrow (transform dominated?) oceanic connection between Tethys and the Atlantic, or a wider ocean basin;
• finally, the alternative models for the origin of the Alboran Sea (i.e. delamination of the dense lower crustal root or slab “roll-back” need to be tested by all possible means (e.g. seismic tomography).

4. SEDIMENTARY PROCESSES ON THE NORTH AFRICAN MARGIN (session summarized by N. Kenyon)

4.1. Mapping
The mapping of bathymetry and reflectivity (backscattering) using the latest swath mapping techniques is proving to be of considerable value as a basis for many marine scientific and commercial activities. This will be increasingly so over the next decades with the growth, for instance, of deep sea hydrocarbon exploitation, the submarine cable industry and deep sea fishing. Such data exist for most of the deeper waters of the northern Mediterranean and for the eastern north African margins. Mapping should be extended to the remainder of the north African margins and will provide part of the infrastructure for the development of the submarine margins of north Africa. The shelf and coastal zones should clearly be included: although their mapping will be more costly in ship time, they are of great importance to the health and wealth of the coastal population.

Such mapping should include acquisition of high quality, high resolution seismic profiles. Added value from such mapping would be to place the many existing bottom samples in context and to better evaluate the recent tectonic activity. Data banks currently being developed in the EU countries for cores, seismic profiles and sidescan sonar, etc., necessarily include all of the Mediterranean Sea. They should be supported by both the provision of data and by the use of such data for research and commercial purposes.

The meeting participants considered of particular value to develop studies on slope instability and sedimentary processes, as well as on mud volcanoes which are relatively common features in the deep basins of the Mediterranean sea

4.2. Slope instability and sedimentary processes
The failure of sediments is particularly significant along the north African margins and was noted early, e.g. in the study of the turbidity current following the Orleansville-El Asnam earthquake of 1954 (Heezen and Ewing, 1955).

The types of slope failure need to be identified and their ages determined. The north African margin appears as a particularly good place for studies aimed at understanding failure triggered by tectonic or rapid sedimentation. The effects of tsunamis, caused by some combination of earthquake displacement of the sea bed, major sediment failure or volcanic eruption, need to be checked by studies of characteristic tsunami deposits on low lying coasts of north Africa.

The very thick and extensive turbidites found in Mediterranean abyssal plains are also believed to be associated with major tsunamis, such as the one inferred to be associated with the eruption of Thera, or with sediment failures, such as a slide identified on the Libyan margin. The origins and age of these deposits need to be established and this approach, together with modelling studies, should lead to improved hazard prediction.

Extreme end members of the types of turbidite system are present on the north African margin. The Nile Cone is an example of a very large system, fed by a major river input and having many sinuous channel-levee systems that lead down to the abyssal plain. The detailed history of channel migration and switching has yet to be determined for any such system. For this, very detailed high resolution seismic profiles and dated samples on a portion of a single sinuous channel are required.
Steep, tributary canyon fed systems are common along most of the north African margin, west of the Nile cone, particularly off Algeria. Such systems are poorly studied. The frequency of flows needs to be determined at times of both high and low sea level, as does the role played by debris flow processes as compared to turbidity current processes. The fate of fine grained materials, both sediment, organic matter and pollutants that are fed into the sea, mainly during peak river flow should be studied. Canyons are expected to play a major role in this on the north African margin from western Tunisia to Morocco, where many of the shelves are particularly narrow.

Strong near surface currents are known on the north African margin, for instance the gyres in the Alboran Sea and the eastward flowing Algerian current. Erosion and deposition from such currents will be significant but are as yet unstudied. The discovery of long term currents, both at great depths and on the shelf, can be readily discovered by geophysical and sedimentological techniques, to the mutual benefit of interdisciplinary studies. Once the main current patterns are established, their high frequency variability can be investigated by measuring the effect of, for instance, benthic storms.

4.3. Mud volcanism

A major addition to the knowledge of deep stratigraphy in the deep Mediterranean marine basins, at a relatively low cost compared with drilling, can derive from the analysis of rock clasts brought to the surface by deep seated mud volcanoes.

Further work is required, particularly along the western arm of the Mediterranean Ridge and in the Alboran Sea. Improved provenance for clasts should come from detailed comparisons with rocks recovered from boreholes and outcrops.

Data bases for Mediterranean-wide rocks should contain improved descriptions, without which provenance studies are less reliable. A study of the veining in clasts will lead to a better understanding of fluid flow mechanisms as should more measurements of heat flow. The study of specific life colonies, associated with such environments, is in its infancy. Careful biological sampling in relation to more detailed geological mapping is strongly recommended.