METEOR-Berichte 03-1

Ostatlantik-Mittelmeer-Schwarzes Meer

Part 1

Cruise No. M51, Leg 1

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1.2 Research Program

The main aim of the project is to address the causes for the existence of a volcanic belt extending ca 1,700 km between 23°N and 38°N in the eastern north Atlantic as well as the reasons for the volcanism in the Alborán Sea (western Mediterranean) which are a subject of ongoing debate. Proposed geodynamical models include 1) a plume swarm, 2) a single mega-plume, 3) subduction, 4) delamination / detachment of lithosphere, and 5) rifting. Recent geochemical studies and age dating indicate at least two independent active hot spot systems (mantle plumes) in the eastern north Atlantic, which can be retraced to ca 70 million years (Ma) before present. Supplementary to previous onshore field work studies, the age and geochemical composition of offshore Madeira archipelago volcanic structures will provide information about the temporal evolution of the Desertas ridge as compared to Madeira and the youngest submarine manifestations of the Madeira hot spot track.

In contrast, the volcanism in the Alborán region is probably associated with Miocene subduction of oceanic lithosphere or delamination/detachment of subcrustal lithosphere. The aim of the research project is to test these models based on a temporal and spatial reconstruction of the volcanism in the working areas by using major and trace element as well as Sr-Nd-Pb-O isotope and laser $^{40}Ar/^{39}Ar$-age data. This study will also serve as a contribution to the understanding of the causes of the desiccation of the Mediterranean Sea ca 5-6 million years ago (Messinian Salinity Crisis). The long-term objective is the reconstruction of the Cenozoic mantle dynamics in the eastern north Atlantic and in the western Mediterranean.

The main part of the research program was sampling of volcanic seamounts and ridges by dredging in the following four working areas: I) Madeira-Tore Rise including seamounts to the east of it; II) rift systems of the Madeira Archipelago; III) seamounts northeast of the Canary Islands; and IV) the Alborán Sea / western Mediterranean (Fig. 1.1). Using chain sack dredges, the volcanic edifices were sampled at various water depths ranging from 250 to 4,600 m including their summits, slopes and bases. The exact locations for sampling were specified by using the METEOR's PARASOUND sediment echosounder and HYDROSWEEP swath mapping sonar system in order to find suitable sites with steep slopes and little sedimentary cover. These systems were also used for detailed mapping of selected areas along the flanks of the Madeira and Desertas islands' rift systems, for discovering new volcanic cones, and for logging possible flank collapse deposits. Furthermore, the HYDROSWEEP and PARASOUND systems served for hydroacoustic mapping of sedimentary deformation patterns associated with major faults in the Alborán Sea and the eastern North Atlantic such as the Azores-Gibraltar fracture zone. All rocks recovered from the seafloor were immediately examined petrographically and prepared for subsequent analysis on board.

Other material recovered in the dredges such as manganese crusts, sediments, corals and zoological material, was also sampled for geochemical, palaeontological and biological studies, which may allow for the reconstruction of past oceanic circulation and climatic changes and may help dating some of the dredged rocks.

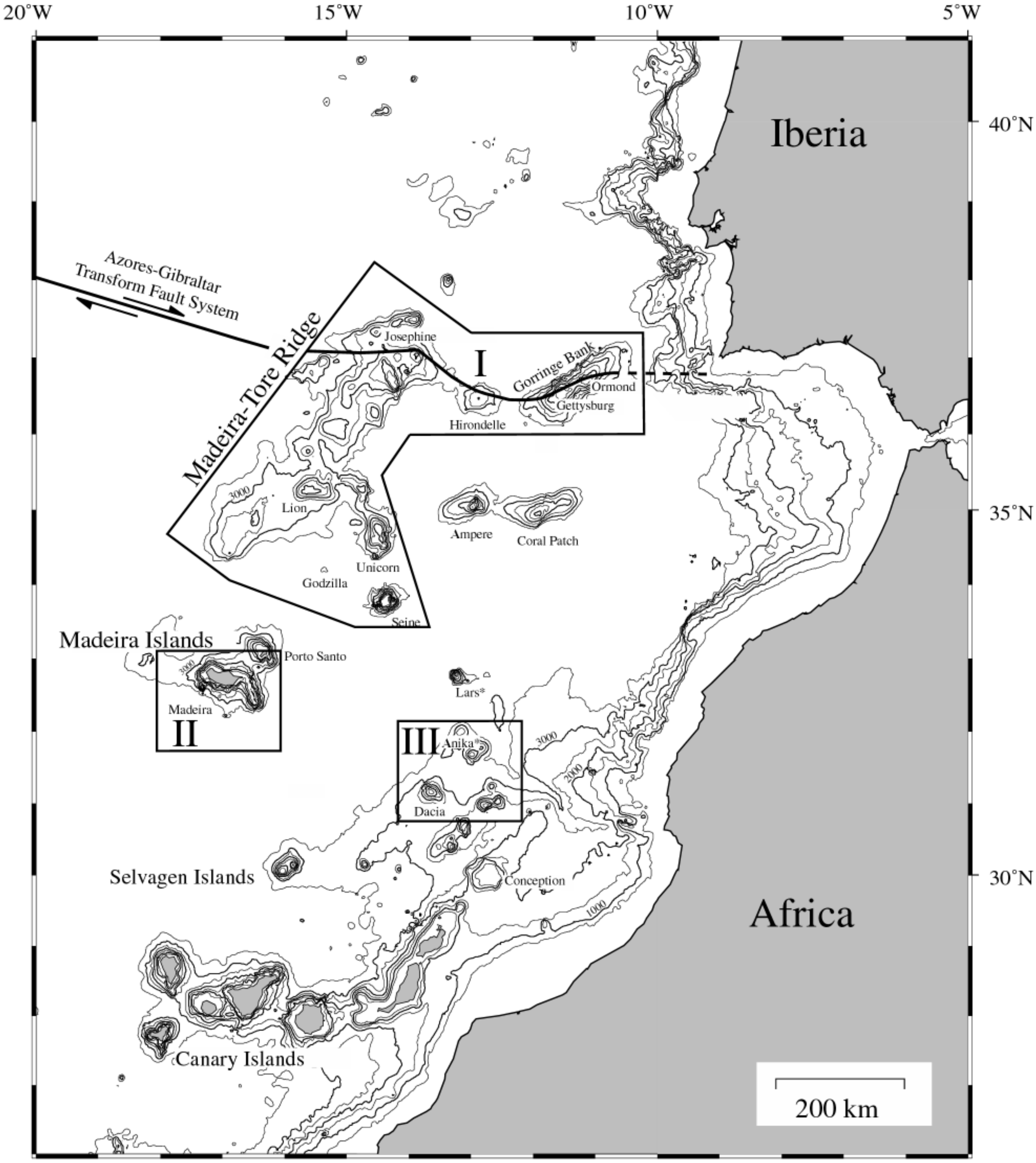

Fig.1.1: Bathymetrical map of the northeast Atlantic showing working areas I-III (I: eastern Azores-Gibraltar Transform Fault System and Madeira-Tore Ridge; II: Madeira Archipelago; III: Seamounts north of the Canary Islands). Names with asterisk (*) denote working names of hitherto unknown and unnamed seamounts. Bathymetrical data source: TOPEX, Smith and Sandwell, 1997.

1.3 Narrative of the Cruise

The final preparations for cruise M51/1 were carried out on the Research Vessel METEOR in the harbor of Rostock-Warnemünde (Germany) on September 11 after the delivery of two containers from GEOMAR Research Center in Kiel. All 23 scientists including the Moroccan and Portuguese observers boarded the ship and began preparing the laboratories for the expedition. A reception and ship's tour were held for e.g. diplomatic corps from countries to be visited during the M51 expedition and for German officials.

METEOR left Rostock-Warnemünde on the morning of September 12. On board were 25 guests of the Rostocker Institut für Ostseeforschung, who disembarked during the half-hour stay in the locks in Kiel on the same afternoon. A journalist from the Northern German Radio Station briefly interviewed ship's officers and scientists. Many visitors including family members and friends of cruise participants watched as the METEOR passed through the locks.

After passing through the Kiel Canal during the night, the METEOR entered the German Bight the next morning and began her transit through the North Sea, English Channel and Bay of Biscay to the first working area west of Portugal. The scientists used the five day transit to introduce themselves to the ship's hydroacustic systems (HYDROSWEEP and PARASOUND), to prepare the dredges and laboratories for sampling and to determine the detailed sampling plan. In addition, the scientists held a daily seminar with 20 individual presentations over the diverse research objectives of the cruise. The chief scientist held a special presentation to summarize the major scientific objectives of the cruise to the ship's crew.

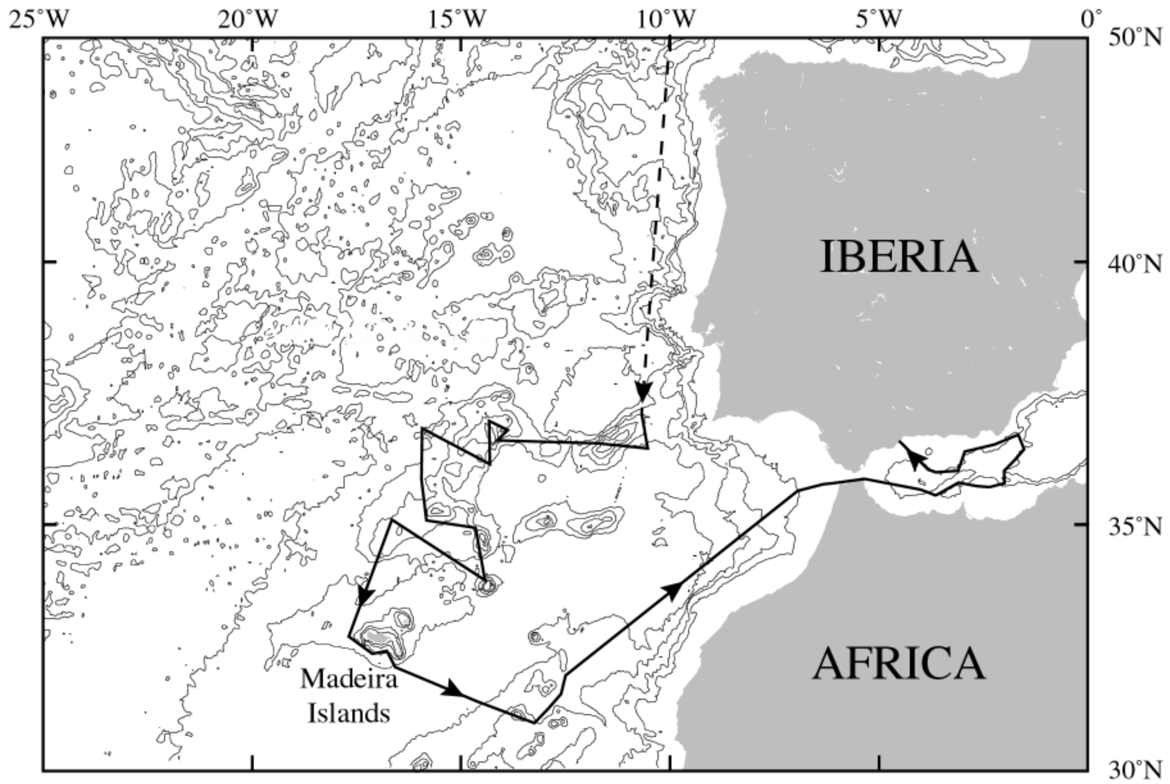

Fig.1.2: Ship track of the METEOR 51/1 Cruise. Bathymetrical data source: TOPEX, Smith and Sandwell, 1997.

Because of favorable weather conditions, the first site in area I was reached one day earlier than scheduled. The hydroacustic observations and mapping of the seafloor began on the evening of September 17 as the ship approached the Azores-Gibraltar fracture zone – the boundary between the European and African plates. Sampling of volcanic rocks from the sea floor along the fracture zone, as well as mapping and structural interpretation of this plate boundary, was an important aim of this part of the cruise. The first dredging station, Ormonde Seamount located on the Gorringe Bank west of Gibraltar, was reached on the morning of September 18 and was successfully sampled. A total of seven dredge hauls were completed on Ormonde, Gettysburg (both belonging to Gorringe Bank) and Hirondel Seamounts. They contained volcanic and serpentinite rocks, as well as clastic continental sedimentary material.

On the September 20th, the METEOR reached Josephine Seamount, located on the Madeira-Tore Rise. While on station, the crew performed a drill maneuver with the scientists using the ship's Zodiac rubber raft. During the following four days, 18 dredge hauls were carried out in the northern part and flanks of the Madeira-Tore Rise, including Josephine North, Teresa, Julia, Josephine and Erik Seamounts and Toblerone Ridge (working names). Mafic volcanic rocks were obtained from each of these volcanic structures. Sandstones were also obtained from Josephine North and Teresa Seamounts, which lie on the Azores-Gibraltar Fracture Zone. Vesicular olivine basalt samples were dredged at 4600 m on the northwest edge of the Madeira-Torre Rise. The cruise continued further south along the Madeira-Tore Rise to Lion Seamount. Volcanic and carbonate rocks were sampled during 7 dredge hauls. Between September 25 and 27, volcanic rocks (5 dredge hauls) were recovered from Unicorn and Seine Seamounts. These seamounts are located east of the Madeira-Torre Rise and form isolated volcanoes, belonging the Madeira hotspot track. The METEOR then returned to the Madeira-Torre Rise. On the way, a new seamount was discovered and successfully sampled. The last stations of Area I were Dragon Seamount and an unnamed seamount in the southwestern end of Madeira-Tore Rise where five dredge hauls were carried out. Area I was left on the evening of September 28.

On September 29, the METEOR reached the first dredge station of Area II – a small ridge located west of Madeira Island. On the same day, a submarine volcanic ridge south of Funchal was discovered. Eight dredges were recovered from volcanic cones along the length of this ridge structure. On the morning of October 1, the weekly safety drill was held south of São Lourenço Peninsula. The drill included the rescue of two volunteers in survival suits and a maneuver with the ship's lifeboats. Five dredge hauls were carried out on the Desertas rift arm south of the São Lourenço Peninsula. A warden from the Parque Natural do Madeira, stationed on the Deserta Grande, approached the ship by rubber raft contacting some of the scientists whom he had previously assisted during field studies on the Desertas Islands.

Area III was reached on the afternoon of October 2 after half a day transit to the southeast. The first locality was Dacia Seamount, the southernmost station of the cruise. Eight dredge hauls were carried out yielding a variety of volcanic rocks. The METEOR continued to Annika Seamount (working name) further northeast where five dredge hauls were taken. On the evening of October 4, the METEOR began her transit towards the northeast, reaching the Straits of Gibraltar on the morning of October 6.

After entering Area IV in the western Mediterranean (Alboran Sea), the METEOR headed eastward. Four dredge hauls were taken at each of the following localities: Ibn Batouta Seamounts, Eastern Djibouti Bank and Alboran Ridge. On October 8, five scientists disembarked on Alboran Island (volcanic in origin) using the ship's zodiak. These scientists spent the day carrying out field studies and sampling the different volcanic units on the island, which consisted of ignimbrites and lava flows as well as conglomerates containing volcanic clasts. While the scientists carried out field studies, the METEOR dredged the northwestern flank of the Alboran Ridge. The ship continued to Cabliers Bank where four dredge hauls were carried out. An official Algerian observer came on board at sea on October 9 around noon and remained on board until the end of the cruise. Five dredge hauls were subsequently carried out on Yusuf

Ridge and Al Mansour Seamount respectively, both are volcanic structures. Dredging had to be stopped on the evening of October 10 as a result of storm conditions. Over the course of the next day, the METEOR carried out hydroacustic mapping on the Maimonides Ridge and Macizo de Chella and then continued eastward towards Cresta de los Genoveses. Despite the bad weather, the Carboneras Fault system in the Gulf of Almeria and the Palomares fault system southeast of Cabo de Gata were successfully mapped using PARASOUND, providing evidence that both fault systems have recently been active. Dredging resumed late on the evening of October 11 at Cresta de los Genoveses and subsequently in the Polacra area to the north with 8 dredge hauls being carried out.

On October 13 the METEOR returned to the Cabo de Gata shelf area where six sediment cores were taken by coring along two transect lines. She then continued to the Gulf of Almeria for further hydroacustic mapping of recent off-shore fault systems and proceeded to Mazico de Chella, where the last of the 106 dredge hauls of the cruise were conducted. The METEOR called at the port of Malaga on the morning of October 15, having successfully completed cruise M51/1.

1.4 Preliminary Results

1.4.1 Volcanology and Petrology

(K. Hoernle, S. Duggen, A. Klügel, J. Geldmacher)

1.4.1.1 Working area I (Azores-Gibraltar Transform Fault System, Madeira-Tore Rise)

Working area I includes the 900 km long Madeira-Tore Rise and a chain of large, isolated seamounts (Seine, Unicorn, Ampère, Coral Patch, Hirondel, Gorringe Bank) to the east (Fig. 1.1). The northern boundary of the working area is marked by the Azores-Gibraltar Transform Fault System (“Gloria Fault”) which represents the African-Eurasian plate boundary. The exact location of the fault in this part of the Atlantic Ocean, however, is not clear. Based on morphology, the fault zone seems to cut the northern part of the Madeira-Tore Rise and to continue along the Hirondel Seamount and Gorringe Bank and from these to the Iberian continental rise.

The 250 km long Gorringe Bank forms two summits, Gettysburg Seamount in the west and Ormonde Seamount in the east. Except for the Ormonde summit, which is formed by 65-67 Ma old alkaline rocks (Féraud et al., 1982, 1986; Cornen, 1982), it appears that Gorringe Bank consists largely of serpentinized peridotite and tholeiitic basalt. Ryan et al. (1973) and Féraud et al. (1986) proposed that Gorringe Bank represents a fragment of early Cretaceous lithosphere (upper mantle and oceanic crust) that has been uplifted along the Azores-Gibraltar fracture zone (Auzende et al., 1978). In contrast, Ampère and Coral Patch seamounts further south contain alkaline basaltic rocks with ocean island basalt (OIB) signature (Matveyenkov et al., 1994; Geldmacher and Hoernle, 2001). Based on age and geochemical data, Geldmacher and Hoernle (2000) propose a Madeira hotspot track composed of the Madeira Islands and the eastern seamounts of working area I (Seine, Unicorn, Ampère, Coral Patch) including the alkaline summit of Ormonde.

The nature of Madeira-Tore Rise in the western part of working area I remains unknown. Based on gravimetric studies of Josephine Seamount located in the northern part of the rise, Peirce and Barton (1991) suggest that the entire Madeira-Tore Rise was formed at the Mid-

Atlantic Ridge. Geochemical studies and age dating of rocks from the summit of Josephine Seamount, however, show alkali basaltic compositions (Eckardt et al, 1975; Matveyenkov et al., 1994,) and Miocene ages (Wendt et al., 1976).

The dredge hauls from Ormonde and Gettysburg Seamounts (Gorringe Bank) and Hirondel Seamount recovered primarily serpentinite rocks, some containing fresh clinopyroxene and/or orthopyroxene, which indicates former peridotites as major component at all dredge localities. The abundance of serpentinites at the northern flanks of Hirondel Seamount and Gorringe Bank points to an origin from former peridotitic mantle consistent with a model of uplifted oceanic lithosphere. Alternatively, the peridotites could represent former continental mantle as found in the ultramafic massifs in southern Spain and northern Morocco (e.g. Ronda and Beni Boussera), or ultramafic magma chamber cumulates from the lower oceanic crust or from volcanic seamounts now exposed. Geochemical studies of immobile elements, particularly the Rare Earth Elements (REE) and Nd- and Hf-isotopes, will provide important tools to distinguish between these three models and possibly to determine the composition of the upper oceanic or continental mantle.

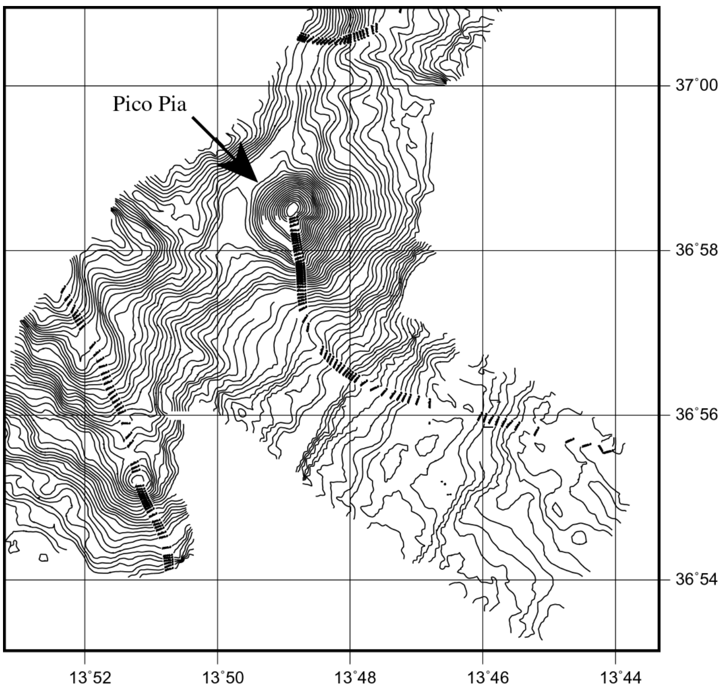

Fig. 1.3: HYDROSWEEP map of parts of Josephine North Seamount on the northeastern Madeira-Tore Rise displaying the newly discovered ca 600 m high scoria cone ´Pico Pia´ with its summit at ca 1.160 m water depth. Dredge haul 399DR recovered young, fresh basaltic rocks from the slope of Pico Pia. A second ca 400 m high volcanic cone (top at depth of ca 1.815 m) can also be discerned on the southeastern slope of Josephine Seamount (lower left corner).

The samples from seamounts near the Azores-Gibraltar Transform Fault System (Gettysburg, Hirondel, Josephine North and Teresa) contain fine-grained, often calcite-cemented quartz-sandstones. The similar lithology to sandstones located onshore in Spain and Portugal, suggest that the seamounts along the transform fault system could contain fragments of continental lithosphere. If the sandstones are not of continental origin but formed in situ, transport distances of more than 500 km have to be considered. These sandstones, however, appear to be too coarse to be distal deposits of turbidites and therefore have most likely been transported tectonically.

In addition to the sandstones mentioned above, dredge hauls from Jospehine and the nearby smaller seamounts at the northern end of the Madeira-Tore Rise recovered volcanic rocks of mainly basaltic but also more evolved compositions. Samples from newly discovered volcanic structures such as Pico Pia, Pico Julia and Toblerone Ridge (working names) (Fig. 1.3) appear relatively young, possibly <1Ma for Toblerone Ridge (based on lack of vesicle fill, fresh matrix and olivine phenocrysts, and lack of manganese crusts) and are interpreted to be associated with the Azores-Gibraltar transform fault system. In particular, Toblerone Ridge runs sub-parallel to the local transform fault system. They represent local volcanic structures possibly underlain by non-volcanic (continental?) basement or uplifted seafloor.

These three young volcanic structures associated with the Azores-Gibraltar transform fault system indicate subaerial and/or shallow water eruptions as deduced from rounded beach cobbles, shallow water fossils (Pico Pia), and the presence of volcanic bombs and welded spatter and tuff at Pico Pia. This implies rapid subsidence to the present sampling depths of 1200-1900 m. The subsidence rates can be determined when the samples have been age dated by $^{40}Ar/^{39}Ar$-age dating. In addition, eruption depths can be determined by electron microprobe analysis. If this interpretation is supported by further volcanological investigations on these samples, large subsidences along the Azores-Gibraltar fracture zone can be postulated.

Besides the area near Josephine and Erik Seamounts in the north, several seamounts along the entire Madeira-Tore Rise including Lion and Dragon (Fig. 1.1) and the deep slopes of the platform itself have been dredged. At the western edge of the Madeira-Tore Rise the deepest dredge haul of the cruise (414DR, about 4600 m) recovered vesicular basalt. This implies that either the magma was extremely CO_2-rich (and therefore alkaline OIB rather than tholeiitic MORB), or that the basalt was erupted at more shallow depths and that the entire northern Madeira-Tore Rise had subsided. The large majority of samples from the entire rise is composed of olivine-basalt with subordinate amphibole in all states of alteration. Some dredge hauls (e.g. at the southern flank of Lion Seamount) contain olivine-clinopyroxene basalt, possibly ankaramite. The petrology of the volcanic rock samples appears to be characteristic of hotspot- rather than of mid-ocean ridge origin. Carbonates from Lion Seamount of presumably Campanian age based on microfossils have been dredged together with the basalts. If the Campanian age can be confirmed through age dating of the volcanic rocks of the same dredge, then this suggests that the Madeira-Tore Rise (at least southern end) is Cretaceous in age. Except for the locations near the Azores-Transform Fault System, no more sandstones or other material of possibly continental origin have been found strongly suggesting that Madeira-Tore Rise does not represent an isolated block of continental crust within the Atlantic Ocean but a volcanic structure. $^{40}Ar/^{39}Ar$-dating and geochemical analyses including isotope ratios will show whether the rise represents an old feature (Early Cretaceous) originating at the Mid-Atlantic ridge or a younger (Late Cretaceous or younger) possibly hotspot related oceanic plateau.

Finally, three additional seamounts along the postulated Madeira hotspot track have been sampled in working area I, namely Seine and Unicorn and a newly discovered small seamount, Godzilla Seamount (working name), within the abyssal plain between Seine Seamount and Madeira-Tore Rise (Fig. 1.1). The samples contain fresh and also altered olivine-basalt, basaltic breccias and clinopyroxene-bearing basalt. All samples seem to be submarine in origin with most rocks representing fragments of pillow lavas. The majority of samples are well suited for geochemical analyses and age dating.

1.4.1.2 Working area II (Madeira Archipelago)

The Madeira Archipelago consists of five islands that are interpreted to have formed through movement of the African Plate above a hotspot (e.g. Geldmacher et al. 2000) (Fig. 1.4). Subaerial volcanic activity on Madeira Island, rising almost 6.000 m from the seafloor, began >4.6 Ma ago when a shield volcano with a dominant E-W trending rift system formed during the early rift phase until ca 3.9 Ma. The three Desertas Islands are the surface expression of an over 60 km long submarine ridge extending from the easternmost tip of Madeira, the São Lourenço peninsula, towards the southeast (Fig. 1.5a). The ridge represents an abandoned rift arm of Madeira that was active between 3.6 and 3.2 Ma when volcanic activity on Madeira ceased. At about 3 Ma, volcanic activity shifted from the Desertas rift arm back to the main E-W trending rift zone on Madeira continuing until 0.7 Ma (late rift stage). Thereafter post-erosional volcanism continued until at least 6,000 years before present (Geldmacher et al. 2000).

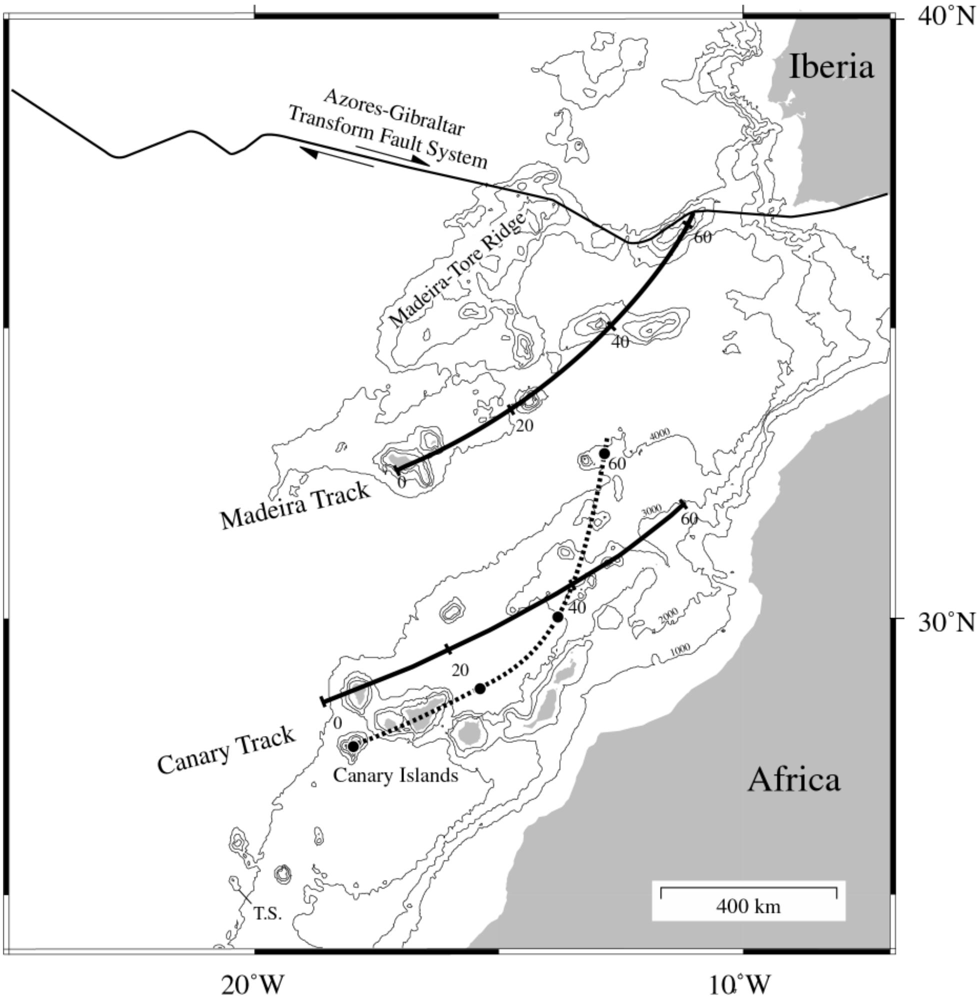

Fig. 1.4: Positions of the postulated Madeira and Canary hot spot track (modified after Geldmacher et al. 2001). Dashed line: Canary hot spot track proposed by Holik und Rabinowitz (1991). Tick marks with ages counting million years.

Some of the main questions addressed during cruise M51/1 included 1) the type of volcanic connection between Madeira and the Desertas Islands, 2) the reconstruction of the magma plumbing system between the islands, and 3) the locus of recent volcanic activity within the

Madeira Archipelago. Thus, the major objectives in working area II were to locate submarine volcanic cones that could be the youngest manifestation of the inferred Madeira hotspot track, and to examine and sample the submarine flanks of the Desertas Islands and the vicinity of São Lourenço peninsula in order to better understand the temporal and spatial evolution of the Madeira-Desertas rift system.

Artifact seamount. One important result of the M51/1 cruise is that a prominent seamount southwest of Madeira (Fig. 1.5a), as is visible on bathymetric maps based on gravity-based satellite altimetry (Smith and Sandwell 1997) but which is not shown in nautical charts, is a very small topographic feature. This was expected by the scientists and could be confirmed by hydroacoustic mapping. The artifact structure indicates that this small hill is associated with a strong positive gravity anomaly which likely is related to dense magmatic intrusions as a result of young volcanic activity. Thus, the hypothesis of Geldmacher et al. (2000) may hold that this structure reflects the present location of the Madeira hotspot track, although it cannot be tested since the small hill could not be dredged. Some 20 km further southeast, however, a number of apparently young volcanic cones have been found and sampled.

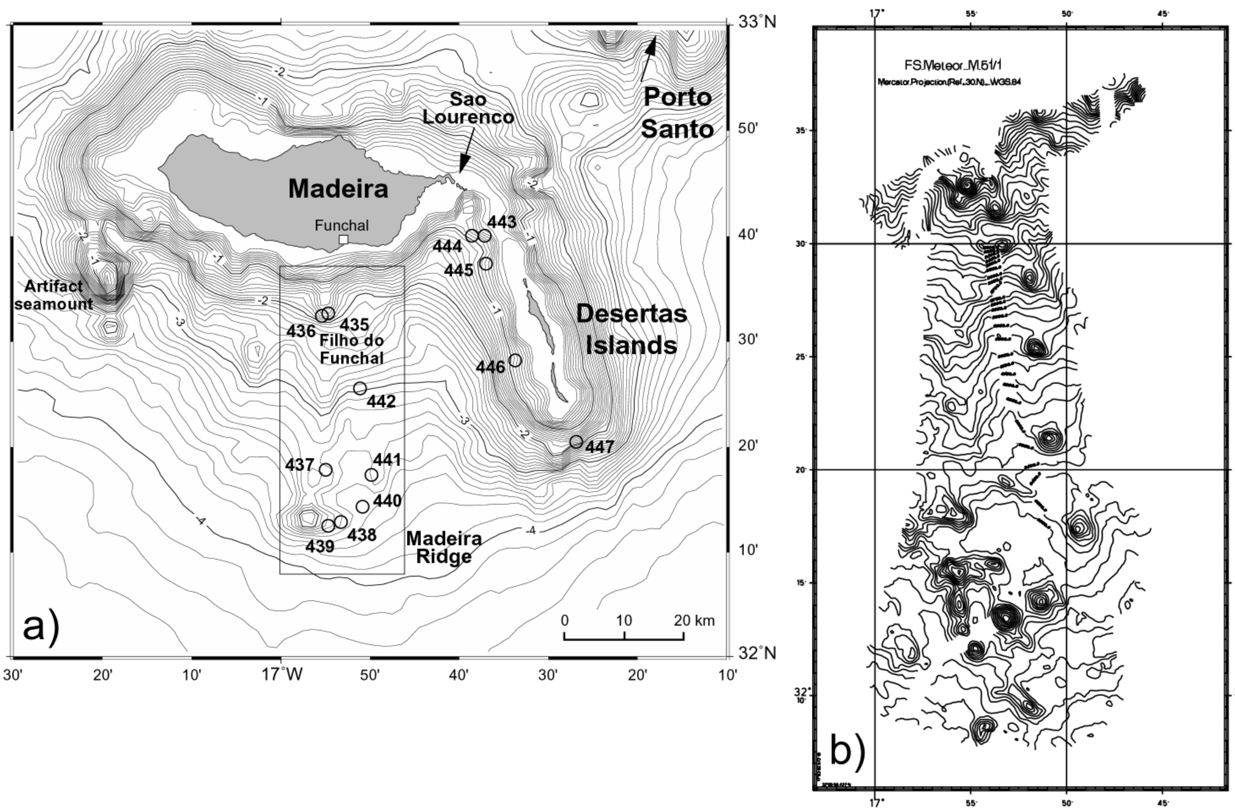

Fig. 1.5a: Map of the Madeira and Desertas-Islands as well as the newly discovered north-south trending rift zone (Funchal Ridge). Circles: Dredge stations of the M51/1 Cruise. Bathymetry after TOPEX, Smith und Sandwell, 1997.

Fig. 1.5b: HYDROSWEEP map of Funchal Ridge showing clusters of volcanic cones along the rift zone.

New rift zone. One of the most exciting results is the discovery of an apparently young north-south trending ridge due south of the island capital Funchal. At least 20 volcanic cones have been identified by hydroacoustic mapping and dredging (Fig. 1.5a,b). Funchal ridge (working name) is about 50 km long and represents by definition a volcanic rift zone almost similar in size to that building the Desertas Islands. The northern end or subaerial continuation of this rift zone is indicated by a number of relatively young volcanic cones around Funchal. The southern end of the rift zone comprises a volcanic field where more than half of the newly discovered cones are concentrated. The basalts dredged here represent the freshest rocks found so far on the Archipelago. They are remarkably vesicular with some samples resembling volcanic bombs indicative of gas-driven magma fragmentation. Such a high vesicularity despite sampling depths of >3.100 m indicates that the lava was extraordinarily rich in fluids, probably CO_2 which is readily degassing upon decompression. Alternatively, the lava could have erupted at much shallower depths, although this would imply extreme subsidence of the volcanic field which is hardly conceivable. To resolve this question, the fresh glasses on some samples can be analyzed by electron microprobe for their sulfur content in order to estimate the eruption depth as based on sulfur degassing (e.g. Moore and Clague, 1987, 1992).

The implications of the newly discovered Funchal rift zone are two-fold. First, the exceptional degree of freshness of the samples suggests that southernmost Funchal ridge is the locus of the most recent volcanic activity of the Madeira Archipelago and of the present location of the hotspot close to the locality predicted by Geldmacher et al. (2000). Second, because Funchal ridge is apparently younger than the Desertas ridge, a rift jump must have occurred after volcanic activity had ceased along the Desertas rift zone. It is unclear, however, whether the new Funchal rift arm developed during the late Madeira rift phase or during the post-erosional stage. Geochemical analyses and dating of the dredged rocks are essential tools in order to resolve these questions.

Desertas Ridge. A number of volcanic cones have been dicovered and successfully dredged on the shallow Desertas ridge between the Desertas Islands and São Lourenço peninsula (Fig. 1.5a). This discovery is an important result supporting the notion that Madeira and the Desertas Islands may once have been connected and that there was a continuous chain of volcanoes between these islands allowing for faunal exchange. The existence of endemic tarantula on the Desertas islands but not Madeira island indicates that a separation occurred at least several hundred thousand years in the past. The dredged basaltic and ankaramitic rocks represent the northernmost samples of the Desertas ridge so far. Geochemical analyses and $^{40}Ar/^{39}Ar$-dating of these rocks in combination with geobarometric studies which allow the identification of depths of magma storage will be carried out improving our understanding of the connection between Madeira and the Desertas rift zone. Another successful dredge haul south of Bugio Island (most southerly of the Desertas Islands) at >1800 m depth recovered surprisingly fresh submarine basalts representing the southernmost samples from the Desertas ridge (Fig. 1.5a). These rocks are well suited for geochemical analyses and dating. It is possible that some of these rocks are younger than previously dated samples from the Desertas Islands which give ages of >1.9 Ma (Geldmacher et al. 2000; Bogaard, unpubl. data).

1.4.1.3 Working area III (Seamounts northeast of Canary Islands)

The seamounts in this area form a chain of scattered volcanoes located between 90 and 420 km northeast of the Canary Islands (Fig. 1.1). Nothing was known about the age and geochemical composition of these volcanoes, until in a recent study Geldmacher et al. (2001) presented geochemical evidence for an origin of these seamounts as part of an old Canary hotspot track. The few available $^{40}Ar/^{39}Ar$ age data, however, show a rather irregular age-distance correlation not in accordance with the classic hotspot model. This irregularity can be explained by long periods of volcanic hiatuses between the shield stage and subsequent rejuvenated volcanism which could be a characteristic feature for most of these seamounts. As seen on Selvagem Grande (Geldmacher et al., 2001) and the Canary Islands (e.g. Hoernle and Tilton, 1991; Hoernle et al., 1991), Pb isotope ratios can be used to distinguish between the shield stage and the post-erosional or rejuvenated stage of the volcanoes. Considering large temporal gaps, a crude but overall increase in age for the shield stage can be seen from El Hierro, the youngest Canary Islands in the southwest (1.2 Ma), towards Lars Seamount in the northeast having the oldest age (68 Ma).

During POSEIDON cruise 235, one single sample from the top of Dacia Seamount, located more than 600 km away from Hierro, was recovered which yielded a surprisingly young age of 9.2 Ma. Considering plate motions and the Canary hotspot model, an age of ca 50-60 million years is expected for the shield stage of Dacia Seamount. Since the Pb isotope composition shows that the single dated sample belongs to the late post-erosional stage of the volcano, an overall span of activity of ca 40-50 Ma for this single volcano is indicated, which is unique in a marine plate tectonic setting. Further age determinations and geochemical data of seamounts in working area III are therefore needed to support the postulated models.

The dredge hauls on Dacia Seamount during M51/1 were primarily performed on the deep flanks of the volcano in order to recover material from the old shield stage suitable for dating. All sampled lavas are slightly to highly altered basalts with olivine, clinopyroxene and rare amphibole phenocrysts. Dredge hauls from Anika Seamount, located to the northeast of Dacia (Fig. 1.1), recovered relatively fresh and more evolved volcanic rocks (presumably trachybasalt) as well as lapilli tuff and breccias with altered clinopyroxene- and olivine-bearing lava fragments. Some basalt clasts from the top contain strongly altered peridotite and intermediate volcanic rock xenoliths. It is noteworthy that carbonates with microfossils recovered from Anika Seamount indicate a preliminary Palaeocene age (64-55 Ma) consistent with the hotspot models of Geldmacher et al. (2001) and Holik and Rabinowitz (1991). During the cruise sufficient material was dredged from the base of both seamounts in working area III that is suitable for geochemical analyses and $^{40}Ar/^{39}Ar$-dating, so that the Canary hotspot track model can be tested.

1.4.1.4 Working area IV (Alborán Sea)

A long-standing plate tectonic paradox has been the formation of the western Mediterranean through extension, rifting and seafloor spreading contemporaneously (Eocene to Miocene) with the collision of the African and Iberian plates (Dewey et al., 1989). The formation of the Alborán Basin and Sea (Fig. 1.6), which is surrounded by a mountain belt extending from the Betic Cordillera in southern Spain through the Gibraltar Arc to the Rif in northern Morocco, represents this paradox in miniature and serves as one of the best areas to study the origin of ‚Mediterranean-style Back-arc Basins‘.

Different, partially contradictory, models have been proposed to explain the origin and the magmatic and geodynamic evolution of the Alborán Basin in the Miocene (~5-24 million years ago). The models can be divided into three groups: 1) mantle diapirism (e.g. Loomis 1975; Weijermars, 1985), 2) delamination/detachment of subcrustal lithosphere (Platt and Vissers, 1989; Docherty and Banda, 1995; Seber et al., 1996; Calvert et al., 2000) and 3) subduction and detachment of oceanic lithosphere (Blanco and Spakman, 1993; Zeck et al., 1998; Hoernle et al, 1999; Lonergan and White, 1997).

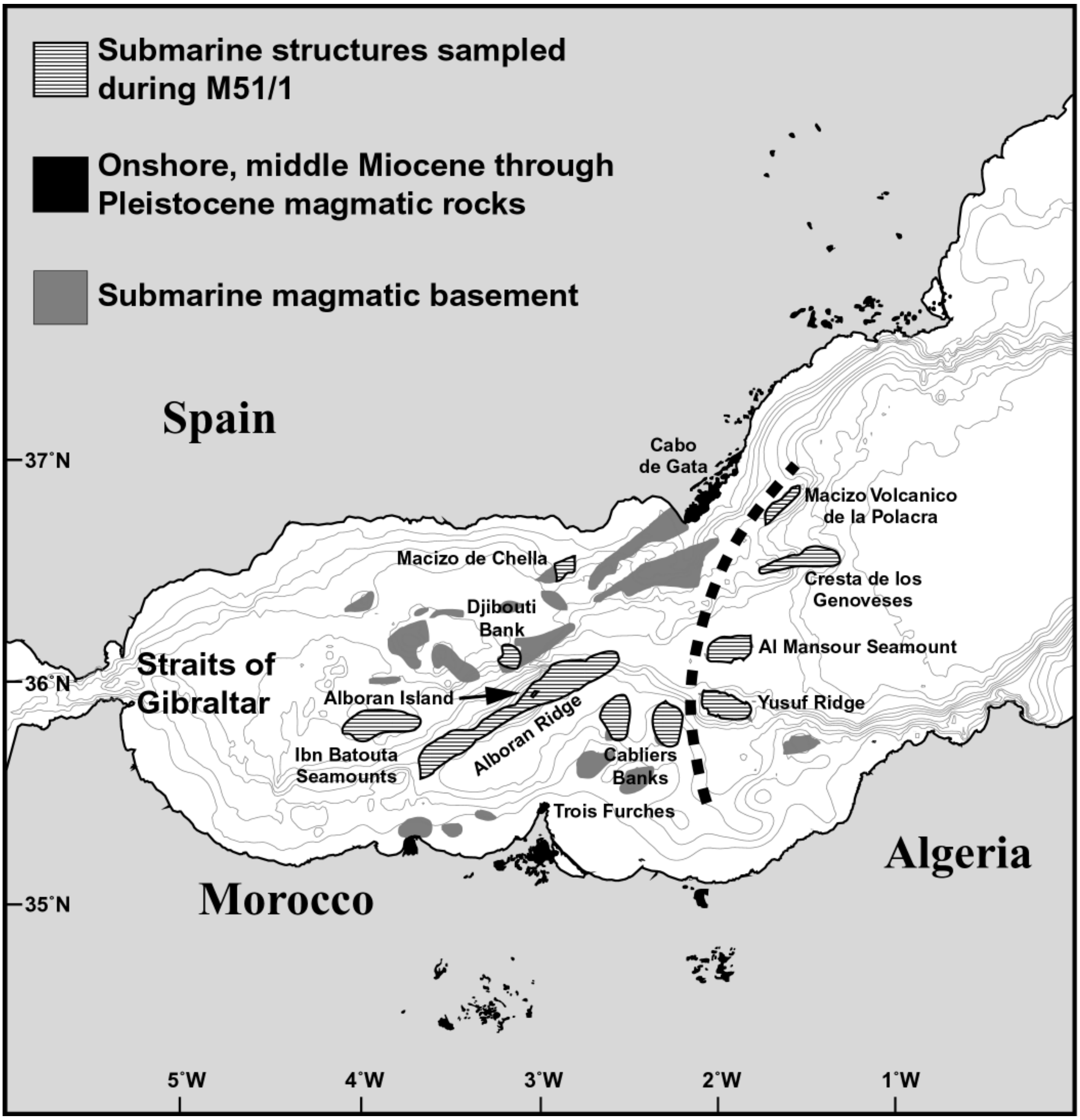

Fig.1.6: Map of the Alborán See showing the onshore and offshore Miocene through Pliocene volcanic structures. Bathymetrical data source: TOPEX, Smith and Sandwell, 1997. The dashed line divides the proposed tholeiitic zone in the east from the calc-alkaline zone in the west. Outcropping and covered magmatic basement after Comas et al., 1999.

All of the aforementioned models are associated with volcanic activity, which have distinct chemical characteristics. In addition, the temporal and spatial evolution of volcanism is different for each model. Therefore, detailed petrological and geochemical studies, combined with radiometric age-dating, will allow us to distinguish between these models. Integration of these studies with the results of geophysical, sedimentological, structural and tectonic studies carried out by other groups will provide strong constraints on the geodynamic evolution of the region.

A better understanding of the geodynamic evolution of the Alborán Region may also hold the key to understanding the origin of the Messinian Salinity Crisis, which occurred approximately 5-6 million years ago. At this time, closure of the marine gateways between the Mediterranean Sea and the Atlantic Ocean in southern Spain and northern Morocco resulted in the drying up of the Mediterranean and the formation of vast salt deposits and brine lakes on its floor. Due to the reopening of the Straits of Gibraltar at ca 5 million years ago the Mediterranean Sea was reflooded with Atlantic seawater in a sudden, catastrophic event.

The following structures were sampled (Fig. 1.6):

Ibn Batouta Seamount. This seamount rises in the west to a height of 780 m b.s.l. A dredge haul contained a metasediment and a gabbroic rock, probably an amphibole gabbro that is well suited for gechemical analyses and age dating, but no volcanic rock. These lithologies clearly indicate that Ibn Batouta West Seamount represents metamorphic and/or igneous basement rather than a volcanic cone.

Djibouti Bank. In contrast to Ibn Batouta Seamount, several dredge hauls from the Eastern Djibouti Bank further east contained volcanic rocks. Surprisingly, one extremely large block about 2x1 m in size and 1 ton in weight was recovered, hanging on the cable. This block consists largely of a clinopyroxene, alkali feldspar, and biotite-rich rock, probably granodiorite, covered by sediments and a highly diverse reef-like body on its surface. Other dredge hauls from the Eastern Djibouti Bank contained volcanic rocks ranging from andesitic/dacitic to trachytic composition and one olivine basalt. Most of the rocks are relatively fresh and are well suited for geochemistry and dating.

Alborán Ridge. Only a small pebble of presumably basaltic composition (469 DR) was recovered.

Alborán Island. One day of field work on Alborán Island provided ca 50-100 kg of volcanic rocks ranging from basaltic andesite to dacite. The island consists primarily of pyroclastic volcanic material, such as ash flow tuffs and block and ash flow deposits overlain by a layer of beach cobbles. The volcanic rock deposits are very similar to those outcropping onshore in the stratovolcanic complexes in Cabo de Gata, Spain, and Ras Tarf, Morocco, forming a northeast to southwest belt of calc-alkaline volcanic rocks. Alborán Island volcanic rocks contain pyroxenes (clinopyroxene and orthopyroxene), feldspar, biotite, amphibole and rare cumulus clinopyroxene xenoliths. The mineralogy is typical for volcanic rocks found in subduction zones. Geochemical analyses and age dating are necessary to confirm a relationship to volcanic rocks on land.

Cabliers Banks. Dredge hauls from the Cabliers Banks recovered a number of volcanic rocks and volcanic breccias petrologically similar to those found on Alborán Island.

Yusuf Ridge and Al Mansour Seamount. Volcanic rocks recovered from the Yusuf Ridge and Al Mansour Seamount contain olivine, clinopyroxene and plagioclase and range from possible tholeiitic to andesitic composition.

Cresta de los Genoveses. During HYDROSWEEP mapping of the eastern summit area of eastern Cresta de los Genoveses a number of cones were discovered which have the typical form of volcanic cones. A volcanic rock cobble of about 5 kg was recovered from the cone. The volcanic rock is a vesicular (probably tholeitiic) basalt with fresh clinopyroxene and many small feldspar laths and is very similar to those occuring at Yusuf Ridge and Mansour Seamount.

Macizo Volcanico de la Polacra (Abubacer Horst). Dredging at Macizo Volcanico de la Polacra provided plutonic fragments of biotite-bearing gabbroic to dioritic rocks which are mildly to moderately altered and one fragment of a mildly metamorphosed plutonic rock (probably gabbro). These plutonic rocks could represent continental basement or an intrusive unit of a volcanic edifice.

In summary, Ibn Batuota East, Djibouti Bank, Alborán Ridge, Cabliers Bank, Yusuf Ridge, Al Mansour Seamount, at least one cone of Cresta de Los Genoveses and probably Macizo de la Polacra consist of magmatic rocks. Ibn Batuota West Seamount is made up of crustal rocks. An additional preliminary result from the Alborán Sea is a chemical zonation in the volcanic rocks: The seamounts in the east, Yusuf Ridge, Mansour Seamount and the area east of the Cresta de la Los Genoveses appear to have tholeiitic composition, whereas the western volcanic regions appear to be calc-alkaline in composition (Fig. 1.6). Zonation of the volcanism with respect to geochemistry and age may hold the key for understanding the Alborán geodynamic evolution.

1.4.2 Neotectonics / Structural Geology

(K. Reicherter with the help of A. Rechlin, T. Buchmann, A. Kaiser, W. Steinborn, C. Wohlgemuth-Ueberwasser, S. Kischkies)

1.4.2.1 Rationale

The on-board hydro-acoustic systems HYDROSWEEP and PARASOUND were used to observe and store bathymetric data and information of the geological composition of the seafloor. Penetration of the seafloor is strongly dependent on geophysical properties, i.e. in recent sediments we reached sub-surface information up to 80 m depth, whereas in volcanic basement penetration is almost 0 m. PARASOUND is strongly limited by the seafloor topography, with slopes inclined by more than 2° not revealing information due to reflection signal loss.

A main focus of this project is to characterize the relationship between morphology of the seafloor and tectonic structures. The hydro-acoustic/sedimentary data will be analyzed with respect to structural elements which have been active during the last 10-50 ka. Typical tectonic structures are indicated by folded, warpped or displaced reflectors. Furthermore, sedimentary patterns with pinching-out of strata, stratal onlaps, and foresets can be observed.

1.4.2.2 Tectonic and neotectonic evolution of the East Atlantic and the Western Mediterranean

In a number of cases, preservation but also exhumation of Neogene and Quaternary sediments as well as volcanic rocks in the western Mediterranean and in the East Atlantic are intimately linked to the structural framework. In working area I, the Gorringe Bank and Madeira-Tore Rise, the dextral Gloria Fault forms the plate boundary between the Eurasian and African plates. Along the plate boundary deformation takes place at least since the Aquitanian (Maldonado et al., 1999), due to westward progression of the deformation front out of the western Mediterranean region into the East Atlantic (Fig. 1.7). Recent earthquake data, as well as the record of the past 1000 a, show that moderate to strong earthquakes occur frequently within the Afro-European Convergence Zone. Foci of instrumentally measured earthquakes are aligned along faults and structures associated with the African-European plate boundary. The epicenter of the catastrophic earthquake of Lisbon (M>8) of the 1th of November 1755 is assumed to be in the Eastern Atlantic, also that of the last important major earthquake of 1969. Related tsunamis have been described from Morocco, Madeira, Portugal, Spain, and the British Channel, varying between 20 and 2 m in wave height. Possible candidates for fault activity during earthquakes are (1) the Gorringe Bank region, a push-up structure of deeper oceanic crust or upper mantle along the major plate boundary in the north (Fig. 1.7) or (2) the Coral Patch and Ampère Seamounts to the south, from where large-scale folded basement and sediments have been reported (Banks, unpubl. Darwin-cruise report).

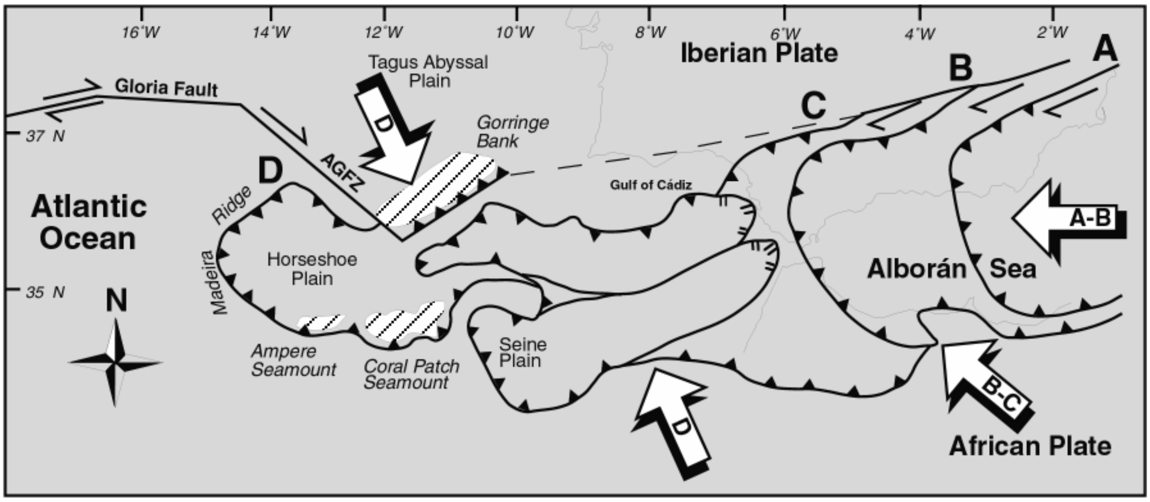

Fig. 1.7: Westward progression of the deformation zone along the plate boundary in the study area (modified after Maldonado et al., 1999). A: ?Oligocene-Aquitanian; B: early to middle Miocene; C: Late Tortonian; D: Pliocene to Recent.

To the East, the plate boundary can not be precisely located in the Alborán Sea, the Betic Cordilleras or the Rifian Chain. The interplay of complex tectonic and sedimentary history of the Alborán Sea in combination with the Neogene subduction-related volcanism in its eastern part, as well as the transition from attenuated continental crust to oceanic crust in the South Alborán Basin, are rather difficult to decipher. Geophysical data and rare geological data from commercial and ODP wells indicate that the Alborán Basin was formed due to extensional tectonics in an overall convergent plate-tectonic setting, with Neogene sediments up to 8 km in thickness. Roughly 200 km of N-S convergence occurred during the middle Oligocene to late Miocene, an important rotation towards NW-SE compression took place approx. 10 Ma ago. The maximum horizontal compression direction is stable to Recent times (Fig. 1.7). Coeval compression with thrusting and shortening within the Betic Cordilleras and the Rif Mountain Chain, and extension in the Alborán Region is observed. As such, the sedimentary patterns depicted by PARASOUND are analyzed with respect to the structural elements, i.e. faults and major lineaments, to prove activity of those during the latest Pleistocene to Recent.

Two active left-lateral strike-slip faults, the NE-SW striking Carboneras Fault and the N-S trending Palomares Fault, control the depositional conditions of the carbonate prism of Cabo de Gata region (working area IV). The Carboneras Fault Zone (CFZ) represents a major sinistral strike-slip fault in the Betic Cordilleras of southeastern Spain accompanied with pressure ridges and pull-apart basins (Fig. 1.8). The onshore segment of the "Trans-Alboran shear zone" of Montenat & Ott D´Estevou (1995) is striking approx. NE-SW and anastomosing in E-W striking minor faults of about 50 km length. Neogene slip along the fault may be distributed during approx. 10 Ma of NW-SE and subsequent N-S shortening, with important influence on the tectono-stratigraphic evolution of the Betics (Sanz de Galdeano, 1990; Montenat & Ott D´Estevou, 1995; Martin & Braga, 1995). Since the Tortonian, about 30 km horizontal slip occurred along the individual faults, placing Neogene volcanics of the Sierra de Gata against the metamorphic basement of the Betics and syn-tectonic sediments. The northeastern termination branches into the sinistral NNE-SSW trending Palomares Fault, which on the other hand is connected with and related to the Ramonete Fault Zone (Fig. 1.8). The southwestern continuation of the CFZ prolongs offshore into the Gulf of Almería. The CFZ displaces the Cabo de Gata Block (Neogene volcanics) against Neogene basinal sediments and the metamorphic basement of the Alpujárride Complex and the Nevado-Filábride Complex along individual northern fault strands (Fig. 1.9).

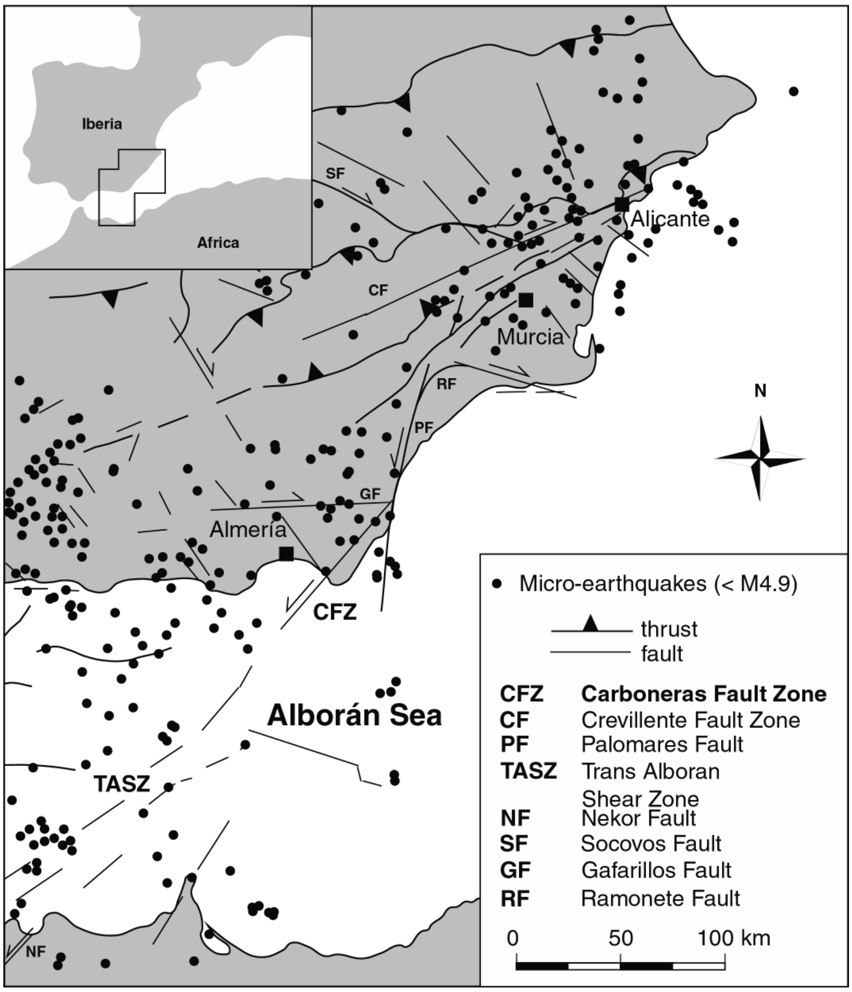

Fig. 1.8: Map of southeastern Spain displaying the main structural features. Dots mark instrumental earthquake foci (M< 4,9 between 1990-2000, data selection from www.ign.es; www.ugr.es/iag; www.ua.es/ursua), note apparent accumulation along the Crevillente Fault Zone west of Alicante and around the Granada Basin (west of Almería), and offshore along the Carboneras Fault Zone and the Palomares Fault (from Reicherter & Reiss, in press).

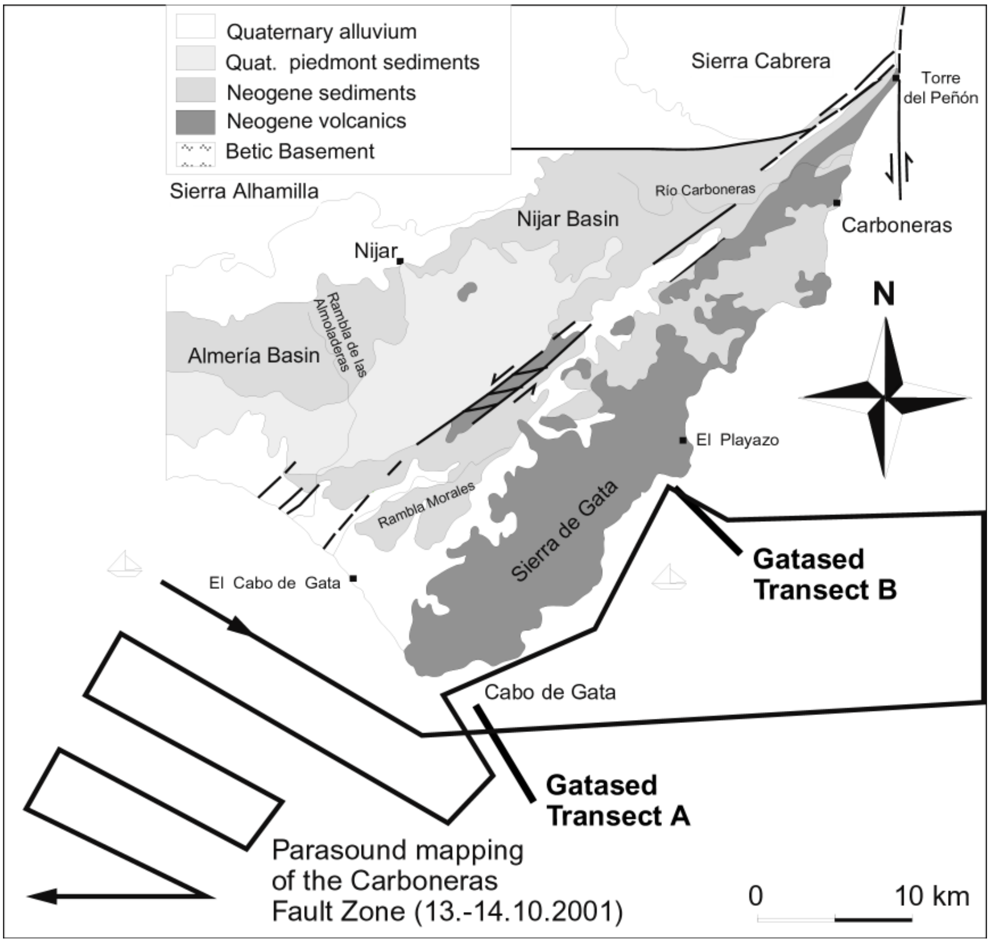

Fig. 1.9: Simplified geological overview of the Carboneras Fault Zone and the Cabo de Gata region. Small Neogene basins within the Cabo de Gata Block have been left (modified from Reicherter & Reiss, in press). Indicated are the mapping track of METEOR during Leg 51/1 in the Gulf of Almería and the localities of transects A and B offshore the Cabo de Gata, where gravity coring was carried out.

1.4.2.3 Preliminary results

Neotectonic investigations and observations on cruise M51/1 were very successful, especially in the Alborán Sea. During the M51/1 leg we crossed six times the Carboneras Fault Zone in the Gulf of Almería, in order to map the prolongation of the offshore system (Fig. 1.9). Last major earthquake with a magnitude > 6.2 occurred on 15. September 1522, destroying Almería and much of the surrounding villages, including the Moorish water systems. Paleoseismologic evidence with a typical surface rupture has not been found, also the epicenter is unknown. In our PARASOUND investigations, we have found several fault strands in the Gulf of Almería, some of which are associated with faults, folds and onlap-patterns. The missing recent sedimentary cover of the faulted sediments in an area of relatively high sedimentation rates, lead us to the conclusion that faulting must be very recent (Fig. 1.10).

Along the southern flank of the Yusuf-Ridge in the Southern Alborán Sea, a pull-apart basin formed (Fig. 1.11). The basin is sediment-filled. The northern margin of the small-scale basin is characterized by an onlap of sediments, pointing to fault activity, whereas the southern margin is apparently inactive, no fault could be detected (asymmetric pull-apart basin?).

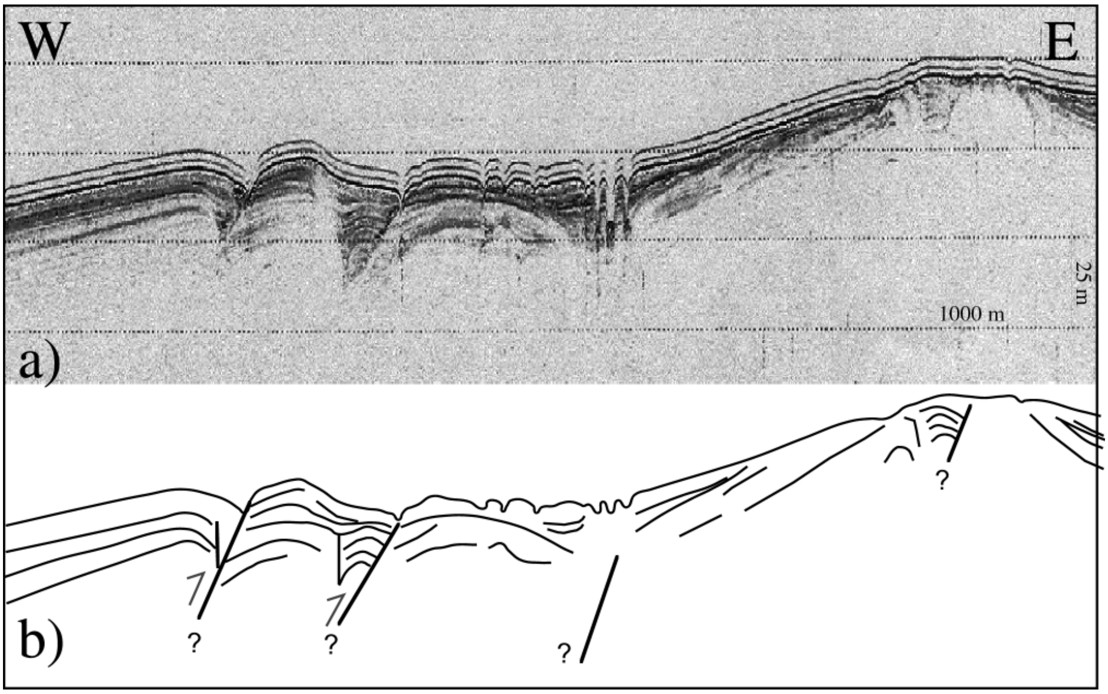

Fig. 1.10a: PARASOUND-profile along the Carboneras-Fault Zone in the Gulf of Almería. The deformed recent sediments proof present-day activity of the fault.

Fig. 1.10b: Interpretation of the PARASOUND data.

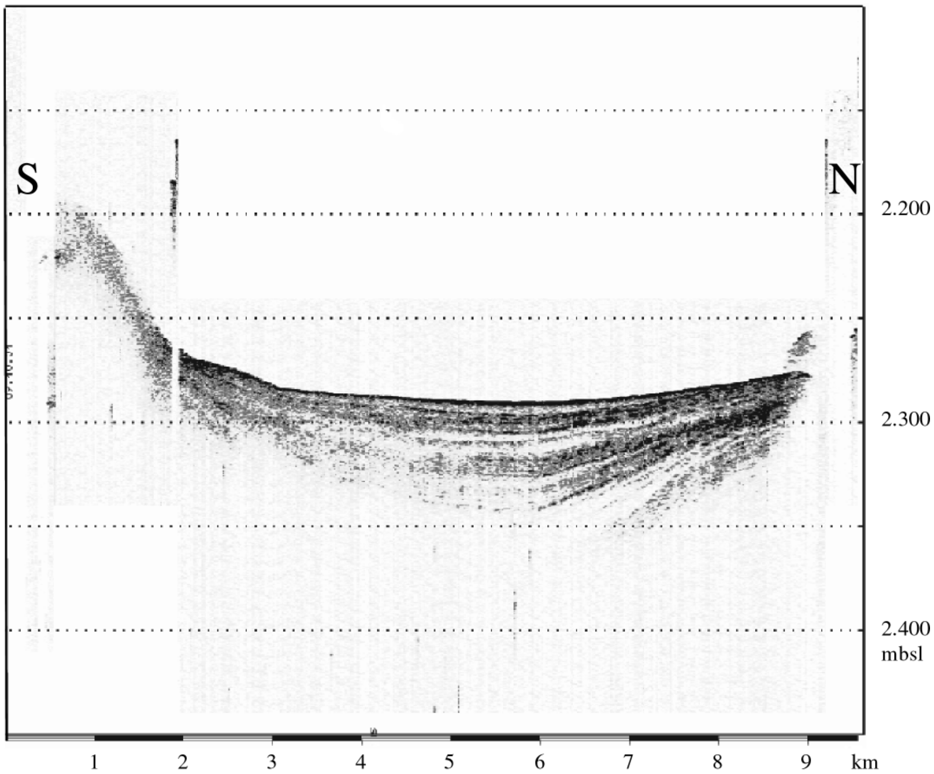

Fig. 1.11: PARASOUND-profile of the on-lapping discontinuities of Pliocene-Quaternary sediments in the Yusuf-Basin (southern Alborán basin), penetration depth approx. 70 m.

In contrast, the Gorringe Bank area did not show any tectonically disturbed sediments at the rise. A clear onlap geometry is visible in PARASOUND profiles. Some rare profiles show folding of sediments, however, along N-S striking structural features. Further evidence has to be checked on processed PARASOUND profiles.

1.4.2.4 Open questions

Alborán region

- Can we distinguish several deformation pattern along the Carboneras Fault Zone, in order to characterize the active segment? Is the off-shore evidence for an earthquake-related seafloor rupture? Can we obtain, with the help of the grid, a map showing the active zones of the CFZ?
- Does the Palomares Fault east of Cabo de Gata exhibit comparable deformation patterns in recent sediments, and hence is the fault active?
- Is the Yusuf pull-apart basin still active, and since when? Is it a “classic” pull-apart basin?
- Abrasion platform question: what are the different levels of those platforms? Are these platforms suitable to delineate and calculate uplift/drowning rates during the last 200 ka?

East Atlantic

- Are there any indicators for active tectonics along the Gloria Fault Zone?
- Abrasion platform question: what are the different levels of those platforms? Are these platforms suitable to delineate and calculate uplift/drowning rates during the last 200 ka?
- In which relation are the tectonic history, the sedimentation history and the volcanic history of the Madeira-Tore Rise?

1.4.3 Sedimentology

(K. Reicherter, B. Berning; shore-based: C. Betzler, University of Hamburg)

1.4.3.1 Rationale

The Mediterranean Sea is a world-class natural laboratory which allows to analyze aspects related to sedimentary depositional systems, tectonic control on basin evolution, or the temporal paleoceanographic changes in a semi-enclosed sea. The scientific project “Sedimentary evolution of a non-tropical Quaternary carbonate prism (Cabo de Gata, Alborán Sea): sealevel, climate, neotectonics” aims to analyze deposits which were, until now, not accessible using conventional drilling and sampling techniques: the near-shore, neritic sediments in the Cabo de Gata region (working area IV). We applied gravity coring on two transects offshore in water depths between 400 and 30 m and hydro-acoustic mapping (HYDROSWEEP and PARASOUND). Within this broad area it is intended to focus especially on (1) the benthic carbonate associations and its distribution, i.e. the non-tropical carbonate factories; (2) the spatial and temporal sedimentary and paleoecological dynamics of these ecosystems as a response to past sea level and climate fluctuations; and (3) the tectonic and neotectonic control of the depositional system. Depending on penetration depth, internal sedimentary structures (stacking patterns, on- and off-lap geometries) and tectonic features (faults and folds) can be visualized by PARASOUND.

Besides, rich limestone findings and sediment samples taken with sedimentary tubes within the dredges obtained from seamounts in the Alborán Sea and the East Atlantic (working areas I to III) complement the data collection of the project, also with hydro-acoustic investigations.

1.4.3.2 Preliminary results

a) Gravity coring

Gravity coring along two transects in the Cabo de Gata region was successful (Fig. 1.9). On Transect A, several m-sized cores were obtained under relatively bad coring conditions. The carbonate-siliciclastic facies turn out to be very coarse-grained (coarse sand to micro-conglomerate with cm-sized shell debris), so gravity coring is not an adequate method to obtain long complete cores. Our longest cores (2.65 m) were obtained in deeper water up to 250-400 m depth, where facies was generally finer-grained. Transect B yielded also the desired bryomol facies but cores measured, due to same coring problems, only 35 cm. The entire length of all cores is about 8-9 m. The sample material was stored directly in the container without further description for temporal reasons (last working day of the cruise). Further work on the core material will be done at GEOMAR research center (scanning, cutting, description, sample preparation etc.).

b) Dredge samples

The (semi-)lithified carbonate sediments of the dredges and attached sediment tubes were screened on fossil/biogenic contents and sedimentary structures by hand-lens and microscope/stereoscope. About 100 rock samples were cut, described, classified and stored. Smear-slides were prepared and analyzed from approx. 30 recent and fossil carbonate sands and oozes. Split samples were taken from all sedimentary tubes for later on-shore analysis.

- **Working area I**

Gorringe Bank, Ormonde Seamount (1750-1050 m depth): Three dregdes at Ormonde Seamount contained bioclast-rich foraminiferal pack-/wackestones partially covered by Mn-crusts. The abundant occurrence and preservation of *Orbulina* and *Globigerina* planktic foraminifer tests allow a preliminary Neogene age assessment of the carbonates. Bioturbation is frequently observed, the bioclasts are made up of shell debris, echinoid spines, pteropods and crinoid fragments.

Gorringe Bank, Gettysburg Seamount (3660-1300 m depth): No carbonates have been encountered, but rich serpentinite findings. A fine to medium grained sandstone, probably of turbiditic origin, yielded some biogenic and volcanic components, it may be suitable for dating and provenance analysis.

Madeira-Tore Rise, Hirondel Seamount (2200 m depth): Different calcareous sediments were dredged at Hirondel Seamount. A foraminiferal wacke-/mudstone resembles the sample of Ormonde, however, it contains only a small amount shell debris. Surprisingly, well lithified lime- and sandstone samples of supposed Mesozoic age could be identified. Exhumation along the Gloria Fault and/or redeposition from the Spanish/Portuguese hinterland, where these rocks are outcropping today, seems likely.

Madeira-Tore Rise, Josephine Seamount (1400-1200 m depth): Calcareous sediments have only been dredged at Pico Pia (working name), a small volcanic cone. These sediments resemble the "young" foraminiferal packstones obtained from the above mentioned seamounts. Again, lithified sandstones were obtained.

Lion Seamount (2500-700 m depth): Limestones of Lion Seamount are yellowish-grayish foraminiferal wacke-/packstones with abundant bioclasts (coral debris, bivalves, gastropods, brachiopods, echinoids, sponge spicules) and bioturbation. Frequently, Mn-impregnation forming halos and dendritic structures as well as Mn-crusts have largely modified primary composition and sediment chemistry. The planktic foraminifers *Orbulina* and *Globigerina* are significant for a preliminary Neogene age of the rocks. The samples of a dredge also contained some grayish-pinkish limestone. By hand-lens, rare keeled and small planktic foraminifers were discovered. This particular fauna could point to an Late Cretaceous-early Paleogene age. Moreover, these rocks exhibited a more complex diagenetic overprint, at least 3 generations of carbonate cement including dog tooth spar in voids were distinguished. Other samples indicate redeposition, most probably slide or slump deposits. A bioclast-rich packstone contains carbonate extraclasts up to 3 cm in diameter. Forams have partly aragonitic shell preservation. Bioclasts are from shallower bathyal/neritic environments around the seamount, transported downslope.

Seine Seamount (3200-700 m depth): Yellowish-gray foraminiferal packstones found at Seine Seamount are identical to the supposed Neogene carbonate sediments of the other seamounts. The presence and preservation of *Orbulina* and *Globigerina* planktic foraminifer tests allow a preliminary Neogene age assessment of the carbonates. Again, Mn-crusts and halos, as well as Mn-filled micro-cracks have been observed.

Dragon Seamount (2700-1300 m depth): Besides the abundant foraminiferal wackestones, limestones from shallower environments have been found, as documented by rich bioclast input. The formation of these shallow-water carbonate facies points at least to near-by shallow water conditions. An important input for reconstruction of the drowning history of the volcanic Dragon Seamount may be expected from the analysis of the carbonates.

- **Working area II**

Madeira Ridge (3200-700 m depth): Pelagic foraminiferal pack-/wackestones, partly with relatively large bioclasts were dredged (coral fragments, bivalves, gastropods, pteropods, crinoids). Due to contamination by volcanic debris, limestones are brownish and have abundant vesicular volcanic fragments. The samples are probably Neogene in age.

- **Working area III**

Dacia Seamount (2700-1500 m depth): Limestones dredged at Dacia Seamount resemble foraminiferal wackestones with *Globigerina* and other planktic forams of suspected Neogene age, perhaps some slightly older sediments were found. In contrast to the above described limestone, these are partly very indurated and have pinkish-reddish colors. Mn-crusts, Mn-filled micro-cracks and Mn-halos are abundant, it seems likely that diagenetically rhodochrosite cementation took place. Some of the limestones are poor in bioclasts but are intensely bioturbated. Volcanic fragments up to cm-size occur. Surface borings are frequently observed.

Anika Seamount (2.700-1.300 m depth): In general, Anika Seamount carbonates do not significantly vary from those of Dacia Seamount. One sample yielded large benthic foraminifers which are shallow-water indicators. The age of the foraminifera of a diverse assemblage containing Nummulitids, Amphisteginids and Discocylinids, is presumably Paleogene. The sample may be suited for the reconstruction of the drowning history of Anika Seamount.

- **Working area IV**

Alborán Sea: Frequently carbonates, vermitid reefs and coral debris were dredged. Samples will be described at University of Hamburg.

1.4.3.3 Open questions

- Bryomol facies of the Cabo de Gata region: does the material obtained from gravity coring yield sufficient information to the topics delineated above? Is the fault activity of the Carboneras and Palomares Fault Zone expressed in the carbonate sediments?
- Provenance of fine-grained sandstones and Mesozoic shallow carbonates around Gorringe Bank and Madeira-Tore Rise (Flysch Zone? Betics?)
- Paleobathymetry of different Neogene-Quaternary carbonate sediments around seamounts? Redeposition from shallower bathyal/neritic environments? Drowning history or subsidence history of volcanic seamounts, uplift history of tectonically elevated blocks.

1.4.4 Manganese Crusts

(S. Muiños)

Manganese and ferromanganese oxides constitute various types of deposits in the oceans occuring as nodules, crusts and massive deposits. According to their occurrence, structural form, chemical composition and mineralogy, they can be classified in hydrogenetic, hydrothermal and diagenetic deposits (Usui et al., 1997).

Cruise M51/1 was very successful for studies of ferromanganese crusts since a large number of samples was recovered from most of the dredge stations in the NE Atlantic area and from two stations of the Mediterranean area (485DR, 493DR). The crusts occur isolated or as external covers of a variety of substrates including volcanic rocks (basalts, lapilli tuffs, volcanic breccias), carbonates and sandstones. On volcanic substrates, the crusts reach thicknesses from about 1 mm to 3 cm, and in some samples a replacement of former rock vesicles by manganese oxides could be recognized (e.g. 414DR-1). The growth occurs usually in parallel layers reflecting the morphology of the substrate surface. When carbonate serves as a substrate, the crusts are also a few mm to cm thick. In the thickest crusts, a gradation from a massive crust to a halo can locally be observed. Ferromanganese oxides also occur as disseminations in the limestone, as fillings of microfractures and as thin films on reef organisms such as corals and worm tubes. Respecting the outside aspect, there were samples with rough botryoidal surfaces and others with smooth flat surfaces.

One important aspect that should be stressed is the sampling of massive crusts of up to 15 cm thickness. They consist of massive Fe-Mn oxides with some of them showing growth layers and microfractures filled with carbonate material, some of which are parallel to the growth direction. There are also massive samples without internal structure which can also show fractures filled with carbonate material.

According to earlier studies at Lion and Tropic Seamounts (Koschinsky, 1996; Halbach, 1993; Gaspar, 2001), we expect that most of the crusts dredged during M51/1 should have an hydrogenetic origin. This type of crust is formed in regions with high bioproductivity in the surface waters. In these regions, the concentration of dissolved oxygen in the surface water is very low due to decomposition of organic matter, resulting in reducing conditions where manganese appears in the form of Mn^{2+}. The oxydation of Mn^{2+} and the precipitation of $Mn^{IV}O_2$ occurs in deeper water layers, where morphologic barriers such as seamounts cause the mixture between Mn-rich, oxygen-depleted waters with cold, oxygen-rich waters from bottom currents. Manganese and other hydroxide-forming elements such as Fe, Al, Si and Ti form colloidal phases which can scavenge heavy metals and finally precipitate as hydrated oxides and oxyhydroxide phases with mixture of MnO_2, amorphous FeOOH and Fe-aluminosilicates (Koschinsky et al., 1995). According to this genetic model, the existence of an Oxygen Minimum Zone (OMZ) is an important precondition for the formation of hydrogenetic crusts.

Because of the slow formation of hydrogenetic crusts (1-15 mm/Ma), their layers have the potential to record and preserve information of the chemical and isotopic evolution of the seawater. The ferromanganese crusts are therefore useful for paleoceanographic studies. Their thickness is not only controlled by the duration of their growth but also by the rate of accumulation of ferromanganese oxides, which in turn depends on geochemical and oceanographic conditions at the site of formation (Cronan, 1992). For the growth of thick crusts, geologic stability is required as slumping and erosion at seamounts can destroy or abrade the crusts reducing their thickness. According to Manheim (1986), it seems that significant covers of crusts essentially occur on seamounts after 60-80 Ma or more.

A suitable explanation for the thickness of some crusts recovered could be a well developed OMZ, possibly affected by the degree of bioproductivity in the overlying waters. The presence of a regional OMZ, however, may not be necessary if horizontal advection occurs or if there is local obstructional upwelling around the seamounts and ridges, causing an increase of bioproductivity in the surficial water and localized OMZ in the layers below (Cronan, 1992). Another possible explanation for the occurrence of thick ferromanganese encrustations could be two or more periods of growth (Cronan, 1992).

On the other hand, the crusts of many samples dredged are too thin to have been continuously accumulated since the formation of their substrates. This apparent discrepancy may reflect processes such as reworking, abrasion, burial and local volcanic activity. The first two possibilities are consistent with the occurrence of volcaniclastic breccias and rounded fragments in the dredge hauls. Further investigations including mineralogical and geochemical analyses and traverses across the layers of representative ferromanganese samples will be carried out in order to reconstruct the environmental and geochemical conditions and growth rates during formation of these crusts.

1.4.5 Biology

(S. Löffler, L. Hoffmann, B. Berning, P. Imholz)

An important aim for the participation on this cruise was the selective collection of azooxanthellate deep-water corals to reconstruct the palaeooceanographic ventilation of the deep Atlantic. Alone from this point of view, cruise M51/1 was very successful since abundant deep-water corals could be sampled, apart from other organisms including sponges, bryozoans, bivalves, serpulides and gastropods, from over 70 dredge stations.

The impetus for the global mixture of water masses is the formation of deep water in the North Atlantic and the surface water currents in the oceans. The intrusion of oxygen-enriched, young, deep water in the deep basins of the Atlantic and Pacific is called ventilation. Climatic changes are generally accompanied by a change of these circulations in the North Atlantic. Detailed information about the ventilation during the glacial and interglacial periods as well as changes in ventilation during sudden climatic changes are of great importance for the understanding of these global events and especially for their modelling with the aim of prediction. The study of the Cd/Ca ratio and the $\delta^{13}C$ values of benthic foraminifera in sediment cores of different water depths in the North Atlantic shows a dependance on the circulation of water masses (Bertram et al., 1995; Venz et al., 1999). Venz et al. (1999) describe three different scenarios for the circulation of deep water in the North Atlantic: during the glacials, at their termination and today.

In particular, poor ventilation is assumed during the termination of a glacial period between 1000 m and 2000 m water depth. Because of the increased influx of melted snow and ice, the production of Glacial North Atlantic Intermediate Water (GNAIW) decreases and older Southern Source Water (SSW) intruded into the upper Intermediate Water. In comparison the North Atlantic has a better ventilation today and had during the glacial period. A central parameter for reconstructing the ventilation is the so-called "age of ventilation" (age of the deep water). A measure for the age of ventilation is the difference of the $^{14}C/^{12}C$ ratio between the surface water, which is represented in the carbonate of planctonic foraminifera, and the deep water as represented in the carbonate of benthic foraminifera (Shackleton et al., 1988; Duplessy et al., 1988, 1989; Broecker et al., 1990; Adkins & Boyle, 1997). Up to now, only a few ages of ventilation from foraminifera of the North Atlantic have been published (Broecker et al., 1990). Only deep water cores with high sedimentation rates can be used for the reconstruction of the ages of ventilation to achieve an exact stratigraphic classification and to minimize the disturbing influence of bioturbation. Broecker et al. (1999) were able to show that bioturbation and temporal modifications of the influence of different foraminifera species lead to mistakes in determining the ages of ventilation. In contrast, azooxanthellate colonial or solitary deep-water corals are unique archives in view of the concentration of ^{14}C and nutrients of deep water in the past. The age of deep-water corals can be exactly determined using the $^{230Th}/^{234}U$ dating method. Comparison of the ^{14}C-age of the corals, influenced directly by the exchange of carbon between atmosphere and ocean, with the $^{230Th}/^{234}U$-age, representing the exact age of the coral, gives the age of ventilation of the deep water (Mangini et al., 1998; Adkins et al., 1998). Unlike the zooxanthellate hermatypic corals living in the euphotic zone, the biotope of deep-water corals is the cold and aphotic bottom of the deep sea. Some solitary species of Scleractinia occur in the Mediterranean Sea in depths of up to 2500 m and in the North Atlantic down to 4800 m where they are especially abundant around Iceland, the Azores and the Cape-Verde Islands (Zibrowius, 1980; Cairns & Stanley, 1981). Colonial species like *Lophelia pertusa* partly build large reef complexes. A compilation of the distribution of *Lophelia pertusa* gives evidence of the existence of an open coral belt reaching from the Iberian Peninsula as far north as the Scandinavian Shelf (Freiwald, 1998).

Deep-water corals were considered to be impossible to date for a long time because most samples were covered by a layer of Fe- and Mn-oxides/hydroxides several 100 µm thick. However, a newly developed procedure using the thermion mass spectrometry (TIMS) the $^{230Th}/^{234}U$ dating method has been applied to deep-water corals for the first time (Lomitschka & Mangini, 1999). During the Pleistocene / Holocene transition between 25 to 8 ka before present several periods with higher ages of ventilation can be observed, which point to a more intense input of southern (old) deep water. The determination of the ages of ventilation using deep-water corals is recommended by Boyle (2000) and Stocker (2000) as a very useful proxy for the decoding of global ocean circulations during climatic transitions.

On the basis of this background, the participating biologists and palaeontologists on cruise M51/1 collected all fossil and Recent organisms with the focus on the scleractinian reef-forming deep-water corals of the eastern North Atlantic (working area I-III) and western Mediterranean Sea (working area IV) from different submarine seamounts of water depths between 4600 m and 260 m. Of particular interest was the occurrence of the colonial corals *Lophelia* and *Madrepora* as well as the solitary corals *Desmophyllum* and *Deltocyathus*. Notable is the frequent occurrence of the deep-water coral *Lophelia* in working area I in water depths of about 1100 m and 2500 m, while in the working areas II and III *Lophelia* is found more seldom, although the occurrence of *Lophelia* in these areas has been reported from some earlier cruises (e.g. POSEIDON 235). One possible reason for this phenomenon could be the great water depths of more than 3000 m of many dredge stations in working areas II and III.

As already known in literature the Mediterranean Sea can be called a “fossil hot spot” of *Lophelia* coral thickets. Through the Strait of Gibraltar, *Lophelia* invaded the Mediterranean deep sea after the Messinian Event in the Pliocene and is concentrated in regions of intense tectonic uplift (for detail see e.g. Freiwald, 1998). In working area IV the occurrence of *Lophelia* and some other deep-water corals (like e.g. *Madrepora* and *Desmophyllum*) could be recognized very often in bathyal marls in close vicinity to palaeo-escarpments as well as from some deep sea hardgrounds. The coral pieces are often covered by Fe/Mn-crusts and sometimes filled by biomicrite.

Looking at the dredged corals there are some diagnostic features to recognize. The main framework constructing, azooxanthellate coral reefs are formed by only one or two different species (e.g. *Lophelia* and *Madrepora*). Furthermore, the bioerosional impact on deep-water coral reefs seems to be relatively high. The corals are infested by heterotrophs such as bryozoans and sponges. Also conspicuous is the frequent presence of encalcified, long, sinuous and anastomosing networks of tubes of the polychaete *Eunice*. It is interpreted that the existence of this worm stimulates the thickening of the coral reef and strengthens the architectural framework (Freiwald, 1998; Rogers, 1999).

The living organisms within the dredges were mainly represented by different species of epifaunal Porifera, Octocorallia, Hydrozoa, Mollusca, Polychaeta, Bryozoa, Brachiopoda and Ophiuroidea, seldom by Crustacea. The organic content of the sediment within the sediment tubes is mainly composed of Foraminifera and Pteropoda, secondary of Gastropoda, Bivalvia, Ostracoda, fish-otoliths and fragments of Balanomorpha and Echinodermata. All living specimens were preserved in 70% ethanol. The sediment and the dead corals were dried for later studies.

The sampled material of this cruise will be investigated in detail and compared with other known deeper water coral ecosystems along the European Atlantic Margin (e.g. the Galicia Bank, Porcupine Slope, Rockall Trough and Sula Ridge) to cover the variation of environmental factors. Important aims will be to get further informations about possible changes of the biogeographic diversity of azooxanthellate coral reefs in the eastern North Atlantic and the western Mediterranean Sea and to use the aragonitic coral skeleton to obtain new data of oceanographic proxies.

1.5 Ship's Meteorological Station

(G. Kahl, W.-T. Ochsenhirt)

When the METEOR left Warnemuende in the morning of September 12th, 2001, a low of 1006 hPa had just passed that part of the German Baltic coast and was moving off eastward. The migrating high following it was short lived, and so the northwesterlies developing behind the low were up to 6 Bft only during the passage of Fehmarn Belt. When the METEOR was in the Kiel Canal in the evening, a frontal trough extending from a gale center 980 hPa just west of the Faroeer Isles passed it. The ship was in German Bight early on September 13th.

The gale center moved southeast quickly, filling thereby, the ship experiencing westerly, then almost northerly winds of 6 Bft during the passage of the Southwestern North Sea.

Winds abated somewhat while the ship passed Dover – Calais and the eastern part of the English Channel, but then the next gale center of 990 hPa had reached a position just northwest of the Shetlands, and a frontal trough extending from it passed the region. So the METEOR experienced northwesterlies 6 Bft again on September 15th when nearing the western entrance of the English Channel.

Out in the Atlantic, the gale center was opposed by a high of 1027 hPa centered at 50 North 20 West. Further west, two hurricanes were travelling east: "Erin" just east of St. John's, Newfoundland, and "Felix" at about 36 North 42 West. Of these, "Erin" converted into a mid-latitude storm center of 975 hPa over southern Greenland by September 16th and then moved northeast to Denmark Strait, filling on its way, while "Felix" remained stationary for some time, retaining its intensity. The high strengthened to over 1030 hPa and moved to the area just southwest of Ireland, a wedge extending south east of the Acores. In its influental region, the METEOR enjoyed light northeasterly winds during passage of the Bay of Biscay going up to 6 Bft when in the vicinity of Cape Finisterre in the evening of September 16th. Northerly winds slowly abated to 4 Bft when the ship moved south along the Portuguese coast to begin working on September 18th.

Meanwhile, hurricane "Felix" had converted into a mid-latitude gale center of 998 hPa still southwest of the Acores while another tropical twister, hurricane "Gabrielle" had appeared on the synoptic chart northeast of Bermuda. "Ex-Felix" retained its position and filled slowly to 1004 hPa by September 19th. The METEOR reported light to moderate northerly winds during these days. She was influenced by a low on the Portuguese coast that had slowly intensified to a central pressure of 1010 hPa near Cabo Sao Vicente. This low filled, and winds were light and variable. Hurricane "Gabrielle" had converted into a mid-latitude storm center of 980 hPa and had moved to a position south of Greenland on September 20th. It is worthwile mentioning that every hurricane mentioned up to now managed to convert into a mid-latitude gale or stormcenter because this fact cannot be taken for granted.

"Ex-Felix" had filled to a central pressure of about 1010 hPa, but id had induced a new low at 38 North 18 West that seemed to have a central pressure of 1010 hPa, too. However, when that low moved to a position north of that of the METEOR on September 21th, it proved to be a gale center with a minimum central pressure of 1000 hPa. There were gales of 8 Bft for several hours with a solitary peak of 9 Bft. Strong northwesterlies of 6 to 7 Bft lasted until the next day before subsiding to 3 to 4 Bft on September 24th. The gale center had moved away northeastward. At the same time, a tropical low northeast of the Bahamas was developing into hurricane

"Humberto". More near to the METEOR's probing area, a low of about 1717 hPa developed west of the Canary Islands, moving east before filling. At the ship's position north of Madeira light northerly winds veered east. The low received a new lease of life on September 27th when colder air masses arrived in the area, originating from a complex gale center of 985 hPa at about 53 North 25 West. A frontal trough arrived in the Madeira region, and we observed westerlies of 6 Bft on September 28th. The system's central pressure was down to 975 hPa by now while hurricane "Humberto" had converted into a weak mid-latitude low northwest of the Acores before vanishing from the synoptic map. The low eventually moved on towards Lisboa on September 29th while the gale center had apparently found acces to air masses from the Greenland inland ice sheet whereupon central pressure plunged further to under 955 hPa. The METEOR was unmolested, light and variable winds blowing just south of Madeira and in the Desertas archipelago where the ship was cencentrating her efforts on October 1st, benefitting from the influence of a high of 1022 hPa that extended from there to the region southwest of the Acores.

When the ship moved on to the east and finally turned northeast winds were light to moderate westerlies and finally southwesterlies on October 5th. Meanwhile further north a gale center having originated east of Cape Hatteras and another one coming all the way from east of the Canadian Rocky Mountains and passing Labrador had merged into one gale center of 965 hPa west of Ireland. Its cold front extended from the North Sea past western France and the Iberian Pensinsula's western part to south of Madeira. Before it could swing east towards Gibraltar on October 6th, the METEOR passed that strait on her way into the Mediterrenean, bright sunshine accompanying our ship.

The cold front followed suit, and after its passage on October 7th, there were westerly winds of 6 Bft for some hours. They only subsided to 4 to 5 Bft until October 9th when there were light northwesterlies in the evening. These veered to northeasterlies during the night and force went up peaking 6 to 7 Bft on October 10th. At nightfall on that day there were thunder and lightning, too. When the thunderstorm was gone winds were down to 5 to 6 Bft. The reason for all this was threefold:

A subtropical high of 1030 hPa centered over the Acores was extending a wedge of 1028 hPa to France and to the northern rim of the Alps. This wedge strengthened to a high of its own, central pressure being 1034 hPa, some deceisive hPa more than had been forecast.

2) During the last few days, there had been a transportation of cold air masses following the passage of cold fronts in high elevations to northwestern Africa This led to the development of a low in the upper athmosphere southwest of Gibraltar, a sea level low of 1009 hPa central pressure being added only now. Consequently, there had been high clouds at first, low clouds being added, the thunderstorm cloud mentioned earlier being a combination of both. The low, too, was thus more intense than had been forecast. From these developments northeasterly gales up to 9 Bft followed on October 11th, lasting all day up to the evening when they abated to 7 Bft. So this was the most bad weather during the cruise.

3) On October 11th, a wave originated along the trough described under 2), and this moved but slowly eastward to lie southwest of the Balearic Islands by October 13th. Consequently, the METEOR had to report diminishing northeasterly winds until shortly before the end of her voyage.

During the last days of the voyage, the low southwest of Gibraltar moved but slowly, filling thereby. After all, a cold air mass in the middle troposphere in such a low latitude may roam there for quite a few days. So the northeasterly winds were slow to abate further.

The METEOR called at the port of Malaga on October 15th.

1.6 Station List M51/1

The complete station list of M51/1 with geographic descriptions and a detailed sample list are presented in the online-version of the cruise report.

Abbreviations:

DR: Chain-bag dredge; SL: Gravity coring; Smt: Seamount; MTR: Madeira-Tore Rise; N: North(ern); E: East(ern); S: South(ern); W: West(ern).

Date 2001	Station	Locality	on bottom: Latitude	Longitude	Depth (m)	off bottom: Latitude	Longitude	Depth (m)
18.09.	391 DR	Ormonde Smt	36°44,67N	11°15,82W	1250	36°44,72N	11°15,48W	1202
	392 DR	Ormonde Smt	36°43,54N	11°15,66W	1145	36°43,80N	11°15,19W	1054
	393 DR	Ormonde Smt	36°36,16N	11°09,96W	1748	36°36,66N	11°09,76W	1598
	394 DR	Gettysburg Smt	36°41,23N	11°42,56W	3662	36°41,24N	11°41,81W	3496
19.09.	395 DR	Gettysburg Smt	36°37,66N	11°37,89W	1653	36°37,66N	11°37,43W	1300
	396 DR	Hirondel Smt	36°36,77N	12°46,24W	3127	36°35,15N	12°46,64W	2980
	397 DR	Hirondel Smt	36°29,45N	12°54,75W	2230	36°29,25N	12°54,52W	2058
20.09.	398 DR	Josephine N Smt	36°57,54N	13°51,80W	1343	36°57,58N	13°51,87W	1317
	399 DR	Pico Pia	36°58,90N	13°48,80W	1464	36°58,33N	13°48,82W	1231
	400 DR	NE flank MTR	37°12,56N	13°37,90W	3658	37°12,35N	13°12,19W	3432
	401 DR	NE flank MTR	37°14,30N	13°36,99W	3846	37°13,86N	13°37,17W	3708
21.09.	402 DR	Teresa Smt	37°35,44N	13°45,21W	4443	37°35,40N	13°46,01W	4200
	403 DR	Teresa Smt	37°33,80N	13°49,50W	3200	37°33,95N	13°50,62W	2846
	404 DR	Teresa Smt	37°32,50N	13°52,20W	1900	37°32,50N	13°52,50W	1700
	405 DR	Teresa Smt	37°24,93N	14°07,88W	2450	37°25,30N	14°08,57W	1903
22.09.	406 DR	Toblerone Ridge	36°55,31N	14°02,83W	1930	36°55,40N	14°03,38W	1592
	407 DR	Pico Julia	36°41,70N	14°01,42W	2200	36°50,59N	14°01,65W	1960
	408 DR	E flank MTR	36°30,54N	14°10,21W	3600	36°30,91N	14°10,48W	3053
	409 DR	E flank MTR	36°35,03N	14°16,17W	1303	36°34,95N	14°16,26W	1200
	410 DR	Josephine Smt	36°30,46N	14°12,48W	2436	36°30,72N	14°13,04W	2161
23.09.	411 DR	Erik Smt	36°04,99N	14°25,52W	3684	36°05,35N	14°26,50W	3428
	412 DR	Erik Smt	36°10,23N	14°29,59W	2198	36°10,47N	14°29,95W	1839
	413 DR	NW edge MTR	36°57,41N	15°26,28W	2737	36°57,41N	15°25,64W	2375
24.09.	414 DR	NW edge MTR	36°58,19N	15°44,90W	4586	36°58,23N	15°44,80W	4603
	415 DR	W edge MTR	36°43,95N	15°44,05W	3250	36°44,02N	15°44,49W	3109
	416 DR	Smt N Lion Smt	36°03,26N	15°44,02W	3253	36°03,58N	15°44,46W	3116

Station List M51/1 (continued)

Date 2001	Station	Locality	*on bottom:* Latitude	Longitude	Depth (m)	*off bottom:* Latitude	Longitude	Depth (m)
25.09.	417 DR	Lion Smt	35°12,68N	15°42,03W	938	35°13,05N	15°42,36W	688
	418 DR	Lion Smt	35°07,98N	15°41,41W	2409	35°08,04N	15°42,13W	2021
	419 DR	Lion Smt	35°08,61N	15°42,08W	1951	35°08,71N	15°42,47W	1767
	420 DR	Lion Smt	35°09,01N	15°37,14W	2453	35°09,21N	15°36,74W	2274
	421 DR	Lion Smt	35°10,10N	15°29,28W	2100	35°10,56N	15°29,30W	1809
	422 DR	Lion Smt	35°06,61N	15°10,08W	3054	35°06,83N	15°10,85W	2825
26.09.	423 DR	NW Unicorn Smt	34°47,41N	14°35,28W	1352	34°47,26N	14°34,72W	1100
	424 DR	Unicorn Smt	34°27,19N	14°24,12W	3164	34°27,36N	14°24,42W	3018
	425 DR	Seine Smt	33°54,31N	14°25,09W	2950	33°53,83N	14°25,58W	2419
	426 DR	Seine Smt	33°52,07N	14°22,14W	1365	33°52,08N	14°22,02W	1360
27.09.	427 DR	Seine Smt	33°44,34N	14°33,08W	3181	33°44,74N	14°32,59W	2860
	428 DR	Godzilla Smt	34°27,64N	15°32,13W	3160	37°27,21N	15°32,51W	2733
	429 DR	Dragon Smt	35°04,59N	16°21,37W	2456	35°04,28N	16°22,13W	2173
28.09.	430 DR	Dragon Smt	35°01,15N	16°22,00W	2084	35°01,28N	16°22,68W	1896
	431 DR	Dragon Smt	34°54,12N	16°28,26W	1675	34°54,08N	16°28,89W	1286
	432 DR	Dragon Smt	34°40,61N	16°25,93W	2737	34°40,82N	16°26,37W	2401
	433 DR	SW edge MTR	34°22,02N	16°50,80W	3167	34°22,61N	16°51,06W	2938
29.09.	434 DR	Ridge W Madeira	32°57,65N	17°50,62W	3300	32°57,96N	17°51,15W	2966
	435 DR	Ridge S Funchal	32°32,67N	16°54,68W	1773	32°32,54N	16°55,26W	1387
	436 DR	Ridge S Funchal	32°32,30N	16°55,26W	1602	32°32,28N	16°55,24W	1616
30.09.	437 DR	Ridge S Funchal	32°17,89N	16°54,83W	3541	32°17,98N	16°55,42W	3206
	438 DR	Ridge S Funchal	32°12,91N	16°53,21W	3501	32°13,47N	16°53,21W	3022
	439 DR	Ridge S Funchal	32°12,38N	16°54,72W	3648	32°11,97N	16°54,69W	3414
	440 DR	Ridge S Funchal	32°14,19N	16°50,93W	3462	32°14,18N	16°51,56W	3104
	441 DR	Ridge S Funchal	32°17,36N	16°49,86W	3302	32°17,36N	16°49,42W	3116
01.10.	442 DR	Ridge S Funchal	32°25,54N	16°51,22W	2991	32°25,34N	16°51,80W	2675
	443 DR	N ridge Desertas	32°40,14N	16°37,12W	723	32°40,20N	16°37,23W	540
	444 DR	N ridge Desertas	32°40,01N	16°38,48W	717	32°40,03N	16°38,45W	617
	445 DR	N ridge Desertas	32°37,52N	16°37,02W	1000	32°37,75N	16°36,98W	815
	446 DR	W flank Desertas	32°28,27N	16°33,77W	774	32°28,50N	16°33,61W	606
	447 DR	S ridge Desertas	32°20,41N	16°26,98W	1900	32°20,27N	16°26,89W	1810
02.10.	448 DR	Dacia Smt	31°19,46N	13°47,79W	3147	31°19,15N	13°48,32W	2939
	449 DR	Dacia Smt	31°17,30N	13°44,62W	2690	31°17,22N	13°44,85W	2553
	450 DR	Dacia Smt	31°13,62N	13°45,05W	1977	31°13,40N	13°44,83W	1795
03.10.	451 DR	Dacia Smt	31°12,28N	13°43,92W	1962	31°12,36N	13°46,07W	1728
	452 DR	Dacia Smt	31°04,78N	13°45,40W	2006	31°05,14N	13°45,53W	1699
	453 DR	Dacia Smt	31°03,57N	13°42,37W	1692	31°03,57N	13°42,28W	1515
	454 DR	Dacia Smt	31°17,04N	13°34,45W	2177	31°17,08N	13°34,52W	2053
	455 DR	Dacia Smt	31°15,75N	13°34,15W	1867	31°15,77N	13°34,50W	1693

Station List M51/1 (continued)

Date 2001	Station	Locality	on bottom: Latitude	Longitude	Depth (m)	off bottom: Latitude	Longitude	Depth (m)
04.10.	456 DR	Anika Smt	31°34,45N	12°59,06W	2705	31°34,28N	12°59,08W	2568
	457 DR	Anika Smt	31°37,43N	12°56,78W	1781	31°37,83N	12°55,80W	1423
	458 DR	Anika Smt	31°42,45N	12°48,63W	2422	31°42,62N	12°49,24W	1834
	459 DR	Anika Smt	31°44,49N	12°50,90W	1550	31°44,61N	12°51,18W	1280
	460 DR	Anika Smt	31°47,79N	12°55,79W	2671	31°47,77N	12°55,78W	2646
06.10.	461 DR	I. Batouta W Smt	35°51,58N	04°12,52W	1254	35°51,39N	04°12,89W	1077
	462 DR	I. Batouta W Smt	35°50,62N	04°12,80W	1312	35°50,76N	04°12,70W	1130
	463 DR	Ib.Batouta E Smt	35°50,09N	04°02,35W	1136	35°50,09N	04°01,85W	879
07.10.	464 DR	I. Batouta E Smt	35°46,91N	03°55,66W	1082	35°47,22N	03°55,80W	889
	465 DR	E Djibouti Bank	36°04,98N	03°32,45W	786	36°05,26N	03°32,77W	503
	466 DR	E Djibouti Bank	36°05,80N	03°34,24W	414	36°05,70N	03°34,37W	546
	467 DR	E Djibouti Bank	35°59,59N	03°27,07W	1351	35°59,65N	03°27,12W	1314
	468 DR	E Djibouti Bank	35°59,45N	03°27,29W	1402	35°59,66N	03°27,37W	1231
	469 DR	SW Alboran Ridge	35°46,62N	03°17,90W	442	35°47,04N	03°18,00W	259
08.10.	470 DR	SW Alboran Ridge	35°54,60N	03°16,09W	996	35°54,19N	03°16,38W	808
	471 DR	E Alboran Ridge	36°02,69N	02°58,88W	1164	36°02,47N	02°59,01W	1069
	472 DR	E Alboran Ridge	36°00,80N	03°02,36W	870	36°00,45N	03°02,65W	763
	473 DR	NW Cabliers Bank	35°54,33N	02°35,93W	1155	35°53,99N	02°35,65W	867
	474 DR	NW Cabliers Bank	35°53,66N	02°33,97W	744	35°53,45N	02°34,51W	501
	475 DR	NE Cabliers Bank	35°51,73N	02°17,10W	881	35°51,57N	02°16,88W	685
09.10.	476 DR	NE Cabliers Bank	35°50,19N	02°09,57W	954	35°50,10N	02°09,97W	790
	477 DR	Yusuf Ridge	35°55,28N	01°56,39W	1802	35°55,68N	01°56,44W	1540
	478 DR	Yusuf Ridge	35°54,45N	01°54,28W	1777	35°54,47N	01°54,31W	1578
	479 DR	Yusuf Ridge	35°54,55N	01°53,88W	1690	35°54,79N	01°53,94W	1363
10.10.	480 DR	Yusuf Ridge	35°56,87N	02°00,52W	1606	35°57,15N	02°00,51W	1482
	481 DR	Yusuf Ridge	35°55,50N	01°51,97W	1732	35°53,70N	01°52,22W	1559
	482 DR	Al Mansour Smt	36°07,38N	01°55,70W	1630	36°07,54N	01°56,01W	1478
	483 DR	Al Mansour Smt	36°08,09N	01°55,12W	1344	36°08,35N	01°55,46W	1235
	484 DR	Al Mansour Smt	36°08,59N	01°56,30W	1189	36°08,67N	01°56,04W	1042
	485 DR	Al Mansour Smt	36°08,93N	01°59,69W	1404	36°08,71N	01°59,44W	1125
	486 DR	Al Mansour Smt	36°07,82N	01°59,84W	1215	36°08,06N	01°59,94W	1263
11.10.	487 DR	Cresta Genoveses	36°34,53N	01°28,84W	1581	36°34,75N	01°28,36W	1367
12.10.	488 DR	Cresta Genoveses	36°31,41N	01°28,05W	1850	36°31,74N	01°72,64W	1554
	489 DR	Cresta Genoveses	36°33,44N	01°21,53W	1944	36°33,62N	01°21,01W	1795
	490 DR	Cresta Genoveses	36°32,09N	01°20,55W	1860	36°32,39N	01°20,30W	1621
	491 DR	Cresta Genoveses	36°31,54N	01°35,80W	1343	36°31,74N	01°35,80W	1150
	492 DR	Macizo Polacra	36°44,84N	01°40,57W	1190	36°44,85N	01°40,58W	1012

Station List M51/1 (continued)

Date 2001	Station	Locality	on bottom: Latitude	Longitude	Depth (m)	off bottom: Latitude	Longitude	Depth (m)
13.10.	493 DR	Macizo Polacra	36°43,20N	01°42,15W	1041	36°43,23N	01°42,20W	881
	494 DR	Macizo Polacra	36°45,22N	01°40,47W	961	36°45,32N	01°40,33W	1090
	495 SL	Transect B	36°48.07N	01°57.15W	120			
	496 SL	Transect B	36°48.40N	01°57.73W	70			
	497 SL	Transect A	36°39.01N	02°06.74W	298			
	498 SL	Transect A	36°39.56N	02°07.32W	251			
	499 SL	Transect A	36°40.11N	02°07.93W	158			
	500 SL	Transect A	36°40.63N	02°08.95W	108			
	501 SL	Transect A	36°41.20N	02°09.25W	86			
	502 SL	Transect A	36°41.24N	02°10.67W	21			
	503 SL	Transect A	36°42.11N	02°10.72W	48			
	504 SL	Transect A	36°41.75N	02°09.74W	73			
	505 SL	Transect A	36°37.14N	02°08.16W	181			
14.10.	506 SL	Transect A	36°37.14N	02°08.16W	396			
	507 DR	Macizo Chella	36°30,68N	02°48,32W	432	36°31,01N	02°48,20W	382
	508 DR	Macizo Chella	36°29,49N	02°53,92W	493	36°29,64N	02°53,78W	329
	509 DR	Macizo Chella	36°29,60N	02°52,85W	466	36°29,73N	02°53,01W	394

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