

Geological Evolution of the Mediterranean Basin

Geological Evolution of the Mediterranean Basin

Raimondo Selli Commemorative Volume

Edited by
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With 287 Figures



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Preface

The Mediterranean Sea, nestled between Africa, southern Europe, and the Middle East, may be envisioned as a complex picture-puzzle comprising numerous intricate pieces, many of which are already in place. A general image, in terms of science, has emerged, although at this time large gaps are noted and some areas of the picture remain fuzzy and indistinct. In recent years this fascinating, mind-teasing puzzle image has become clearer with individual pieces more easily recognized and rapidly emplaced, largely by means of multidisciplinary and multinational team efforts. In this respect, the Special Program Panel on Marine Sciences of the NATO Scientific Affairs Division considered the merits of initiating four conferences bearing on the Mediterranean ecosystem. It was suggested that the first, emphasizing geology, should dovetail with subsequent seminars on physical oceanography, marine biology, and ecology and man's influence on the natural Mediterranean regime.

At a conference held in Banyuls-sur-Mer, France, in August 1979, Professor Raimondo Selli was urged by some panel members to initiate an Advanced Research Institute (ARI) that would focus primarily on the geologically recent evolution of the Mediterranean Sea and serve as a logical base for future NATO conferences on the Mediterranean. Further encouragement to prepare such a function was given by the NATO Scientific Affairs Division, and in late Fall of that year, Professors Selli and Daniel Jean Stanley were selected as Co-Directors of the ARI. They, in turn, selected an *ad hoc* Advisory Group consisting of A. Azzaroli, B. Battaglia, L. Montadert, and C. Morelli and met with these specialists in late April 1980 at the Geological Institute of the University of Bologna. It was here that the principal objectives of the future conference were determined, i.e., a series of multidisciplinary debates to be presented in seminar fashion on the evolution of the Mediterranean, with most attention paid to Neogene to Recent geological and geophysical aspects of this complex region. Each invited contribution was to be a synoptic review and state-of-the-art analysis of specific marine geological problems.

It was agreed in Bologna, and at a subsequent meeting of the Co-Directors and Advisory Group at the 27th C.I.E.S.M. Congress in Cagliari, Sardinia, that the program should include a region-by-region survey of the submarine realm with a tie, where possible, to the adjoining land area. A final preconference meeting was held at the Smithsonian Institution in Washington, D.C., on 5–8 April 1981 where Selli and Stanley prepared the definitive

conference program. Sicily was selected as the conference site in view of its ideal geological location in the central Mediterranean and its pertinence to the ARI theme. The Co-Directors deemed it important that, in addition to a four-day round-table seminar, the program should include a three-day field excursion in western and central Sicily enabling the participants to discuss at the outcrop some critical aspects of recent Mediterranean geology—including neotectonics and evaporite deposition. The most unfortunate stroke that disabled Professor Selli in late January 1982 resulted in a delay of the ARI until 19–27 November 1982. A colleague of Selli's, F.-C. Wezel, was asked by D.J. Stanley to assist in the preparation and logistics of the conference and excursion in Sicily. His designation as Co-Director was officially announced at the conference held in the "Ettore Majorana" Center for Scientific Culture at Erice-Trapani.

It is fitting that this volume be dedicated to Raimondo Selli, who not only helped set the wheels in motion for the Erice conference, but who for so many years had played a leading role in interpreting deposits in the Alps and Apennines, and realized the possibility of correlating these with offshore, presently submerged, sections, primarily in the Tyrrhenian. His absence was deeply felt at Erice, and we most sincerely regret his death on 3 October 1983. The editors and authors, together, have prepared this published effort, which summarizes most of the topics and ensuing discussions presented at Erice, as a token of our esteem and as a remembrance in his honor.

Centuries from now, historians of science will surely record the near-sudden burst of interest on the geology of the Mediterranean from the mid-1960s to the mid-1980s that accompanied the naval ASW surveys, two Deep Sea Drilling Project legs, and accelerated petroleum exploration using considerably improved deep-penetration and high-resolution seismic systems. We have progressed to a point that would have pleased Jacques Bourcart who, 30 years ago, lamented "Malheureusement, cette mer est encore très mal connue. Il faut que demain nous lui consacrons l'essentiel de nos forces" (1954, *Le Fond des Océans*). Subsequent to the impetus of geophysical exploration of the 1960s and of the first Deep Sea Drilling Project Leg 13 in 1970, a number of international symposia have been held and a series of books published that focus on different geological aspects, both on the Mediterranean proper and adjacent emerged regions. In spite of the seemingly firm views on Mediterranean evolution promoted and strongly defended by some workers, it is our feeling that at present there are more hypotheses than convincing or definitive answers. With this in mind, it was our intent that the ARI serve as an international platform for an open exchange of information and presentation of concepts, and the 30 invited participants from ten countries were asked to provide a broad-front multidisciplinary approach to better assess recent geological events and the interrelation between terrestrial and contiguous marine settings.

This volume, an outgrowth of the conference, examines the effects of tectonic, climatic, and oceanographic changes with time by use of distinct, yet complementary, methods in view of updating—and in some cases, reinterpreting—the paleogeographic, paleoclimatic, and paleoecologic evolution of the Mediterranean. These methods, which help refine knowledge of the crust and its sedimentary cover, include geophysics, structural geology, volcanology, bio- and isotope stratigraphy, and sedimentology. The name *Mediterranean Basin* is applied here to the two closely genetically related entities: the submerged realm and circum-Mediterranean terrains. The time-

frame emphasized, Neogene to Recent time, encompasses a period of dramatic change for the post-Tethys Ocean, one which most workers recognize as having been very active and still evolving at present. The Mediterranean Sea is indeed an appropriate setting to examine the interplay of deep crustal and more surficial structural, morphological, paleoceanographic, and paleoclimatic changes, the results of which are well recorded by the nature and configuration of the basement and overlying stratigraphic sections. It is not surprising that this rapid evolution would be indicated by fauna, flora, and sediments in view of how easily changes, even minor, would likely affect physical and chemical systems in a quasi-closed setting. Modifications of tectonic style and intensity of activity, including extensive movement—vertical and lateral—of land masses relative to the sea, the nonrandom spatial and temporal distribution of volcanic emanations, and marked changes in climatic factors inducing paleoceanographic oscillations and that of evaporation to precipitation regimes are of special note. These would necessarily have affected the nature and distribution of sediment types (terigenous, biogenic, evaporites) and associated biota forming marine deposits presently exposed on land and mapped on the seafloor and in the subbottom.

The book comprises four parts, taking into account the diverse methodologies used as well as distinct attributes of this rapidly evolving region. The chapters take into account many of the major questions raised during the seminar and discussion sessions at Erice. Part I emphasizes the physiography and geotectonic framework of the Mediterranean. How closely, for example, do the Mediterranean geomorphic provinces correlate with the underlying structural framework and, in particular, stable margins, convergent regions, and rifted sectors (Vanney and Genesseeaux)? Does satellite imagery reveal structures on the circum-Mediterranean landmass that sustain hypotheses favoring crustal foundering or extensive horizontal motion, or both, in the Paleogene and Neogene (Foose)? Can seismicity and focal mechanism of earthquakes define the boundary between the African and Eurasian plates, and to what extent are tectonic features indicative of presently active compression versus horizontal tension (Udíás)? What is the nature of the crust underlying the different parts of the Mediterranean, and can geophysical data reveal the nature of the basement (including oceanic) as one extends from land to deep basins (Morelli)? In fact, how important is vertical motion, and can aeromagnetic, heat-flow, and deep-seismic profile systems provide information on the crust-to-mantle transition (Morelli)? Is it possible to calculate the amount of relative motion of stable Africa relative to stable Europe, and vice versa, through time, and what changes of oceanic area have occurred in the Mediterranean region since the Atlantic began to open (Livermore and Smith)?

Part II constitutes a region-by-region synthesis of the Mediterranean as presently constituted, proceeding from west to east. When, for example, did oceanic accretion occur in the Western Basin, and can the main spreading of axes in this region be defined by using paleomagnetic data, recognition of subbottom structure, and heat-flow measurements (Rehault, Boillot, and Mauffret)? To what extent is the Tyrrhenian related to collision between the Western Mediterranean and Adria microplates in the Central Mediterranean, and can a process of oceanization by mantle diapirism and isostatic foundering be recognized in this area (Selli)? What, then, is the areal distribution of the oceanic basement in the Tyrrhenian Basin, how important is vertical motion, and can the latter be activated by localized flowage in the

plastic mantle (Wezel)? Some seafloor sectors of the Mediterranean are significantly influenced by eustatism and sediment accretion. What information can be obtained in this respect from deep cores and high-resolution seismic systems? For example, can the sediment sources from the Apennines, Yugoslavian reliefs, and Po be identified in the Adriatic Sea, and to what extent have sea-level oscillations modified the Plio-Quaternary progradational trends (Dondi, Rizzini, and Rossi)? On what basis can the extensional tectonic phases be recognized in the Pelagian and Ionian seas, and how is paleoceanic crust recognized in this part of the Mediterranean (Finetti)? With respect to the Aegean and Hellenide areas, has its evolution been controlled mainly by relative movement between Europe and Africa, or is the present-day tectonic configuration largely a result of vertical movement (Makris)? In the case of the latter, is it reasonable to invoke lithothermal systems that rise from the upper mantle? In the eastern Levantine Basin and the Levant region, what are the underlying mechanisms for the development of physiography and structure, and is there evidence in this region for a relict Tethys Ocean (Neev, Greenfield, and Hall)? Genetically, what relation exists between the now-separated Eastern and Western Mediterranean basins?

More specific aspects pertaining to volcanism, tectonics, and sedimentation of Messinian to Recent age are treated in Part III of the volume. How has the configuration of the Mediterranean changed since the Miocene? Can, for example, geochemical and isotopic analyses of Neogene and Quaternary volcanic sequences in areas such as the Tyrrhenian shed light on the relationship between convergent plate tectonics and mantle degassing and vertical motion (Locardi)? What evidence is there in the Ionian area for vertical neotectonics, and is it rational to invoke large-scale foundering of basins and elevation of terraces on land in the Pliocene and Quaternary (Fabricius, Braune, and others)? How important and of what style were such tectonic events in the Miocene and earlier time in areas such as the Aegean and Ionian (Meulenkamp)? Returning to the persistent and perplexing problem of the upper Miocene evaporites and "salinity crisis," which of the models previously exposed really best explains the genesis of the Messinian salt sequences (Sonnenfeld)? Need we be restricted to the presently popular basin-wide desiccation model or are there other, more viable, explanations (Selli)? What about the possibility of a steady inflow/outflow regime across a severely restricted strait and precipitation induced by climatic fluctuations (Sonnenfeld and Finetti)? In those Mediterranean areas dominated by fluvial input—such as seaward of the Rhône, Ebro, Po, and Nile deltas—can we identify the interplay between transport process and eustatic oscillation as recorded by the deposits forming the shelves and upper slopes (Got, Aloisi, and Monaco)? In deeper environments such as lower slopes, fans, and basin plains, what is the origin of mud that is the main sediment type forming Plio-Quaternary sequences? In the case of silt and clay deposits, are we able to distinguish between the roles of gravity transport and hemipelagic settling from suspension (Stanley)?

Analysis of tectonics and sedimentation is not sufficient to interpret Mediterranean history. A focus on paleoclimatology and paleoceanography, the theme of Part IV, is needed if we are to understand its recent evolution. A most valuable tool in this respect is isotope analysis of the sediment and fossil record. Can this technique elucidate the nature of ocean evolution from the time of closure of the Tethys to the development of the present

Mediterranean (Vergnaud-Grazzini)? How reliable is this technique for use in regional stratigraphic correlation of the Cenozoic record? Does diversification of foraminiferal assemblages with time record changes in the configuration of the basins as well as of temperature, salinity, water-mass movement, and nutrient and oxygen supply (Bizon)? Do the nannoplankton evolve, in terms of time, in parallel fashion with the foraminifera, and are they as (or more) sensitive in defining paleoecological differences between the Eastern and Western Mediterranean (Müller)? What information can the radiolaria provide as to temperature trends, depth considerations, and productivity changes with time (Riedel, Westberg-Smith, and Budai)? Does the paleoclimatologic evolution as recorded by pollen on land correspond with and supplement the faunal and floral record offshore (Bertolani-Marchetti)? Why was the Miocene to Pliocene transition so sharply recorded by both micro- and macro-fauna? Where would one find—if at all—in the present Mediterranean ecological niches with conditions comparable to those that sustained Messinian species (Por and Dimentman)? Is the possibility of land-bridge connections in the Miocene sustained by study of the land mammal distribution and, in that respect, what do such faunas show that would bear on Messinian paleogeographic reconstructions (Steininger, Rabeder, and Rögl)?

In the Appendix a final chapter summarizes the highlights of the geological excursion in central and western Sicily led by Professor G. Ruggieri with the collaboration of F.-C. Wezel. Particular attention was paid to piercement structures, extensive strike-slip faulting, and nappes, all recording marked changes in the Neogene to the Quaternary. Visits were also made to critical outcrop localities that provide clues to understanding the Messinian “salinity crisis” and the role of eustatic and neotectonic oscillations affecting this critical sector in the Central Mediterranean. The excursion enabled the ARI participants to debate topics that bear directly on the recent geological evolution of the Mediterranean and that warrant careful correlation with offshore sectors.

Our thanks are expressed to the many persons and organizations who helped us with the ARI conference and subsequent preparation of the book. Foremost, the NATO Scientific Affairs Division is thanked for the grant enabling us to conduct the Advanced Research Institute at Erice and the associate excursion in Sicily. Funding for a large part of the costs relative to editing were provided by the Smithsonian Institution in the form of Scholarly Studies grants 1233S-405 and -502 awarded to one of us (DJS) through the Mediterranean Basin (MEDIBA) Project. The Director and staff of the “Ettore Majorana” Centre for Scientific Culture at Erice are acknowledged for insuring excellent and efficient logistical support during the conference. The effective help there of Drs. Elvio Moretti and Riccardo Vannucci of the University of Urbino is noted. Mr. Myles Weber and Ms. Maureen Cannell in Washington, and Drs. Elvio Moretti and Mario Tramontana in Urbino assisted actively with many of the tedious editorial duties. Editors and authors thank the many outside reviewers for their constructive critique and suggestions that improved the 26 chapters. We also acknowledge the cooperation of our publisher, Springer-Verlag New York, for efficient coordination through all stages of processing the book. And finally, very special thanks are expressed to Dr. Peter Sonnenfeld who, in addition to writing two chapters, generously gave of his time to prepare the index that should enhance the use of this volume as a reference text. We add that the untimely

death in 1984 of Etienne Winnock, one of the invited participants who played such an active role in Erice, saddens us. His input on the geology of the Pelagian Sea and Sicilian–Tunisian sector and his active participation in the discussions were most enlightening.

The book is by no means a final statement on the geology of the Mediterranean Basin, and it would be pretentious indeed to suggest that it is but one more step in the highlighting of problems relative to an extremely complex region. In a number of areas this work elucidates concepts that are counter to some presently more “popular” theories. An astute reader may surmise from a reading of the text that there are sufficiently numerous controversial interpretations and unresolved aspects of Mediterranean geology and geophysics to attract the energies of many earth scientists for years to come. If our joint effort prompts further, more careful work at sea and on land with regard to the evolution of this remarkable and fascinating region, we then will have been successful in achieving one of our major original goals.

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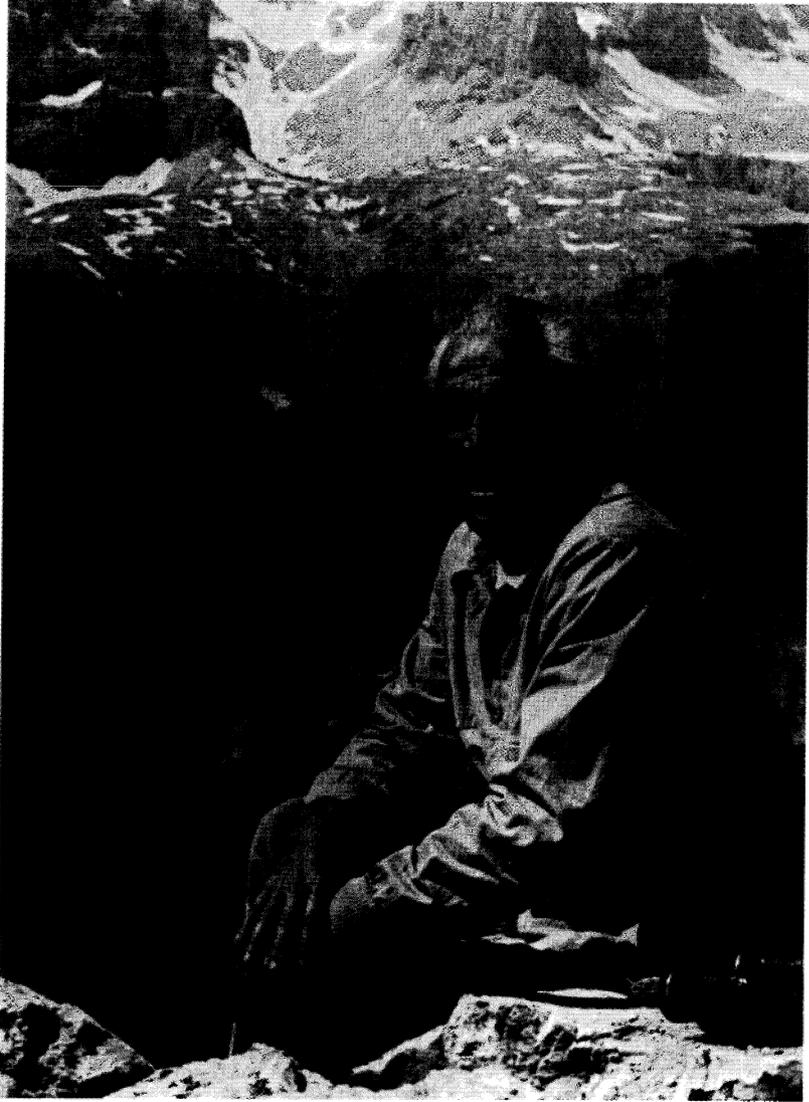
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Raimondo Selli—A Life for Geology

Bologna, Italy 30 September 1916–3 October 1983

Raimondo Selli, distinguished Professor of Geology at the University of Bologna and of international renown, was released from a cruelly unmerited suffering as a result of a stroke on 3 October 1983 at the age of 67. Except for one year at the University of Palermo he occupied the Chair of Geology at Bologna for 29 years, from 1954 until his untimely death. For many years he was the Director and tireless cornerstone of both the scientific and administrative spheres at the Institute of Geology in Bologna, contributing significantly to its growth and international stature, the result of his natural capacity for solid research and sheer hard work.

In 1968 he succeeded in organizing in Italy the first team capable of developing research in marine geology. Thus, the C.N.R. Laboratory of Marine Geology, which Professor Selli directed from 1968 until 1976, blossomed at Bologna. Later, he succeeded in launching the first C.N.R. Italian Project of Oceanography, which he directed during its initial phase.

In addition to editing the journals *Giornale di Geologia* and *Grotte d'Italia*, he was the author of nearly 145 scientific papers and maps, many of them significant, which focus on various fields of the Earth Sciences. The breadth is remarkable: the geology and tectonics of the Alpine and Apennine chains; the geology and tectonics of the Italian seas; Neogene and Quaternary stratigraphy, including evaporite deposition; the geology of mineral resources; seismic hazards; and problems of subsidence and vertical tectonics. Science was more than simply a career for him—it was a total and consuming passion. In more than 40 dedicated years of inspired research, the consistent high level of his output is truly astonishing, and even more so when we consider the multiplicity of themes, always handled with thoroughness, equilibrium, and clarity insofar as predicting future developments. It is to be regretted that many highly relevant, scientific contributions were written in Italian and thus lost the international acclaim they deserved. Even so, this work established Raimondo Selli among the leaders of the European masters of his generation. His thorough, modern syntheses of southern Alpine, southern Apennine, and Tyrrhenian Sea geology are indeed milestones and essential points of reference for much future research.

Raimondo Selli received many honors and distinctions. He was Corresponding Member of the Accademia Nazionale dei Lincei and of other academies (Bologna, Turin, and Bordeaux), and the University of Bordeaux conferred on him an honorary doctorate in Natural Sciences. He was President of the Italian Geological Society (1962–1963), President of the Interna-

tional sub-Commission on the Neogene and of the Committee on Mediterranean Neogene, and Vice-President of the C.I.E.S.M. He was also a member of numerous other international committees and Italy's representative at the United Nations on the Commission for the peaceful use of the seafloor. In addition to all of the above he found time to serve as visiting Professor and guest lecturer at European and North American universities, including Bordeaux, Aarhus, Miami, San Diego, Berkeley, Princeton, and Halifax.

To keep the image and work of this man well before us and in our memory the words of another master come to mind. "If you seek my monument, look around you." For those of us fortunate enough to have known him personally we can remember clearly the moral values of his teaching of life, his thirst for knowledge, his energy and capacity, and a true human dignity.

With warm affection and appreciation of his remarkable service to geology on land and at sea, we the editors and contributors—friends and colleagues—dedicate this volume to Raimondo Selli.

Forese-Carlo Wezel

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