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APAT

Agenzia per la Protezione dell'Ambiente e per i Servizi Tecnici

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DESCRITTIVE DELLA

CARTA GEOLOGICA D'ITALIA

VOLUME LXIV

FROM SEAFLOOR TO DEEP MANTLE: ARCHITECTURE OF THE TYRRHENIAN BACKARC BASIN

Dal fondale marino al mantello profondo:architettura del bacino Tirrenico

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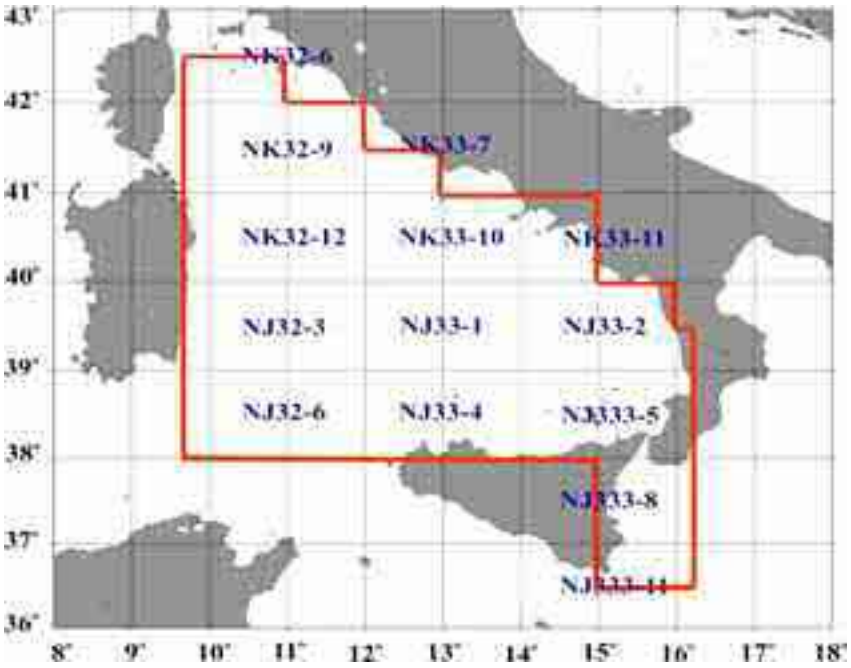

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A. FABBRI, F. INNOCENTI, P. MANETTI & R. SARTORI†

PRESENTATION

The official Italian geological mapping project (CARG), at scale 1:50000, promoted the importance of marine geology research in the knowledge of the complex geological structure of Italy.

The vast amount of data collected with the most modern technologies in the Tyrrhenian basin has been, in fact, very important to reconstruct the environmental and geodynamic evolution of the Italian peninsula. In particular the morpho-bathymetric, gravimetric and magnetometric data that resulted from the Tyrrhenian Project, provided the basis for a series of structural, volcanological and palaeo-climatologic studies.

Important achievements are, for example, the localization and the boundaries of the oceanic structures in the basin and in the surrounding areas, an accurate spotting of volcanic emission centres, a detailed map of the sediment entrainment toward the inner areas, the recognition of the gravitation instability zones.

All these data are important for the scientific community, but also for the Institutes, either public or not, surrounding the Tyrrhenian sea. This is why the Italian Geological Survey (now Land Resources and Soil Protection Department of the Italian Agency for the Protection of the Environment and Techinical Services, APAT) co-financed this project and is now publishing the results.

Il progetto di cartografia geologica di base (CARG) ha, fin dall'inizio, messo in luce quanto la conoscenza dettagliata della geologia dei mari italiani sia uno strumento fondamentale per la comprensione della complessa struttura geologica del Paese e, conseguentemente, per la valutazione del rischio geologico, vulcanico e sismico.

Per questo motivo, oltre a quanto previsto dal CARG, si è ritenuto importante acquisire con tecnologie moderne un complesso di dati di estremo dettaglio nel Bacino Tirrenico, strettamente legato all'evoluzione geodinamica della nostra penisola.

Il rilievo morfobatimetrico ad alta risoluzione, insieme ai dati gravimetrici e magnetometrici raccolti per il "Progetto Tirreno", ha dato il via ad una serie di studi di geologia strutturale, vulcanologia e paleoclimatologia che hanno visto convergere le conoscenze scientifiche della comunità internazionale.

La posizione e i limiti delle strutture oceaniche del bacino e delle zone circostanti, lo studio delle strutture tettoniche, la localizzazione dettagliata di centri di emissione lavica, la rappresentazione particolareggiata delle vie di trasporto sedimentarie verso le zone interne del bacino, il riconoscimento delle aree di instabilità gravitativa, sono informazioni di estrema importanza non solo per la comunità scientifica, ma anche per le altre Istituzioni, pubbliche o no, che con il Tirreno hanno a che fare.

Per tutti questi motivi il Servizio Geologico Nazionale (ora confluito nel Dipartimento Difesa del Suolo dell'APAT) ha co-finanziato il progetto e si è fatto carico della pubblicazione dei risultati.

Leonello SERVA

PREFACE
The Tyrrhenian Project

It gives me great pleasure to present this volume dedicated to the Tyrrhenian Sea, containing the results of years of scientific research on our small Mediterranean "ocean"; many of its secrets are finally revealed to us, starting with its morphology.

In 1996, Professor Enrico BONATTI, *director of the CNR Institute for Marine Geology (IGM), submitted a proposal to the CNR Committee for Geological and Mineral Resources for a study of the Tyrrhenian Sea; one of the objectives of this research proposal was the compilation of a morpho-bathymetric chart of the Tyrrhenian sea.*

I can remember his presentation of the project and his description of the results he expected to achieve by adopting a multi-beam. Even then, and things have not improved since, it was extremely difficult to obtain funds for such a complex and ambitious project. The Committee reported back to CNR recommending that the project should be included among the CNR "Strategic Projects", which meant that it would be allotted funds for a two-years period of research. This would suffice to cover part of the cost of chartering the ship fitted with the multi-beam, mission expenses, and the cost of analysing and processing the data. It was, however, a start, and allowed Bonatti to launch his project and begin the work.

Finding the financial resources to continue the project was just as difficult. Part of the money was taken from the yearly budget of the IGM, but a large injection of funds was to come from a research agreement between CNR and the National Technical Services – Geological Survey of Italy, thanks to the strong support given to the project by the Under-.Secretary for Civil Defence at that time, Professor Franco BARBERI, *who firmly believed that the "Tyrrhenian Project" would produce information of immense benefit to geological risk surveillance, especially as regards seismic and volcanic hazards. Additionally funding came from the Volcanology Group of Italy (GNV), whose activity includes the study of seismic and volcanic risks.*

As President of the Committee for Geological and Mineral Sciences, I signed the research agreement on behalf of CNR in 1998. I will spare you the details of the administrative and practical difficulties involved in implementing such an agreement, which included chartering a ship form the Russian Academy of Sciences. I would like to thank the director of the Geological Survey of Italy at that time, Andrea TODISCO, *his deputy-directors* Fernando PETRONE *and* Norman ACCARDI, *and the CARG project leader,* Fabrizio GALLUZZO, *whose support was instrumental in stipulating the agreement between CNR and the Geolgical Survey; but who also provided valuable assistance in solving problems that arose frequently during the research work. We are similarly indebted to* Pasquale SIDARI, Alessandro VOLPE *and* Maria Teresa LETTIERI, *for their help in overcoming the problems of a day-to-day nature, which were of no les importance to the success of the project. It is thanks to them what we were able to complete all the activities scheduled in the agreement.*

From the moment in which Enrico BONATTI *first illustrated his project, throughout the research activity and on to the final printing of this volume, many changes were to take place in our scientific community. The research institutions and universities have been repeatedly restructured and reorganised. The re-structuring of CNR that ensued from Act 19 to 30 January 1999 has been superseded by a new re-organisation dictated by legislation of 3 February 2003; similarly, the Geological Survey of Italy has now become an integral part of the Territorial Protection Department of the Agency for the Environmental and Technical Services (APAT).*

Despite such alarming and erratic background conditions, the researchers continued to work with the same dedication and enthusiasm, as demonstrated by the excellent results contained in this splendid edition of the Memorie descrittive della Carta Geologica d'Italia. This publication will become a major reference volume for scholar of the geology of Italy and the Mediterranean for many years to come.

Progetto Tirreno

Il Tirreno, questo piccolo "oceano" mediterraneo, ha finalmente un volume nel quale, dopo anni di ricerche, sono stati raccolti I dati scientifici che svelano molti dei suoi segreti a cominciare dalla sua morfologia.

Nel 1996 il Prof. Enrico BONATTI, direttore dell'Istituto di Geologia Marina (IGM) del CNR, sottopose al Comitato per le Scienze Geologiche e Minerarie del CNR un progetto riguardante lo studio del mar Tirreno che, tra gli altri obiettivi, proponeva l'elaborazione di una carta morfobatimetrica dei finali marini.

Ricordo la presentazione del progetto e l'illustrazione di quello che si poteva ottenere attraverso l'utilizzazione di un multibeam. Anche allora, come ora, i fondi necessari per il finanziamento di un progetto così complesso e ambizioso erano pochi. Il Comitato propose al CNR di inserire tale ricerca nei "Progetti Strategici" ottenendo così un finanziamento biennale che copriva solo in parte le spese di noleggio di una nave attrezzata con il multibeam, le spese di missione e quelle per l'analisi ed il trattamento dei dati raccolti. Era comunque una base finanziaria che permise il decollo del progetto e l'inizio dell'attività.

Trovare le risorse mancanti non fu certo cosa semplice e facile. Una parte fu reperita dalla dotazione ordinaria aell'IGM e una parte consistente arrivò attraverso un accordo di programma tra il CNR ed i Servizi Tecnici Nazionali – Servizio Geologico Nazionale e fortemente sostenuto dall'allora sottosegretario della Protezione Civile con delega per i Servizi Tecnici Nazionali, Pprof. Franco BARBERI che ritenne il "Progetto Tirreno" di grande interesse conoscitivo ai fini della prevenzione dei rischi geologici, soprattutto sismici e vulcanici. Inoltre il Gruppo Nazionale di Vulcanologia (GNV), la cui attività prevede lo studio di queste ultime tematiche, ha partecipato al progetto con un ulteriore contributo.

Il sottoscritto, quale Presidente del Comitato per le Scienze Geologiche e Minerarie, fu nominato dal CNR Funzionario Delegato per la stipula dell'Accordo di Programma che fu firmato nel 1998.

Enumerare le molte difficoltà di gestione di un accordo di programma che prevedeva il noleggio di una nave dell'Accademia delle Scienze russa il rispetto di tutte le procedure burocratiche e le molte scadenze amministrative sarebbe troppo lungo.

Devo ringraziare l'allora Direttore del Servizio Geologico d'Italia, Andrea TODISCO, i Vicari F. PETRONE e N. ACCARDI ed il responsabile del progetto CARG, Fabrizio GALLUZZO, che oltre a favorire l'attuazione dell'accordo tra il CNR ed il Servizio Geologico Nazionale hanno dato il loro prezioso aiuto anche per risolvere i problemi che si presentavano durante lo svolgimento delle attività di ricerca.

Per la risoluzione dei problemi "giornalieri", ma non per questo meno importanti, hanno ampiamente contribuito Pasquale SIDARI, Alessando VOLPE e Maria Teresa LETTIERI che hanno permesso di portare a termine tutte le attività previste nell'accordo di programma.

Dalla presentazione del "Progetto Tirreno", all'inizio delle ricerche ed infine alla stampa del volume, molte cose sono cambiate nel mondo della ricerca. Si sono susseguiti con ritmo notevole i cambiamenti nell'organizzazione e nelle finalità degli Enti Ricerca e delle Università. Con il decreto legislativo n. 19 del 30 gennaio 1999 è stato riordinato il CNR che attualmente sta per subire una nuova riorganizzazione in base al Decreto legislativo del 3 febbraio 2003 mentre il Servizio Geologico Nazionale è entrato a far parte del Dipartimento per la Difesa del Suolo dell'Agenzia per l'Ambiente ed i Servizi Tecnici (APAT).

Anche in presenza di queste continue riorganizzazioni il lavoro dei ricercatori è continuato con impegno e dedizione come dimostrano gli ottimi risultati scientifici presentati in questo bellissimo volume delle Memorie Descrittive della Carta Geologica d'Italia che rimarranno a lungo come punto di riferimento per gli studiosi che si occupano della Geologia dell'Italia e del Mediterraneo.

Piero MANETTI

PREFACE

The Tyrrhenian: a Project of the Institute of Marine Geology (now ISMAR) of the CNR

The Tyrrhenian is a sea shrouded in myth, legend and history since the rime of the Homeric poems. For a modern Earth Scientist, the Tyrrhenian Sea is a beautiful example of a young marginal basin within a structurally very complex region of our Planet. The study of the geology of the Tyrrhenian has been as intellectual challenge taken up first, almost half a century ago, by people such as Aldo Segre and then Raimondo Selli and coworkers.

It became increasingly clear that knowledge of the geology of the Tyrrhenian Sea floor is essential to understand the evolution of the entire circumtyrrhenian region, including the Italian territory. This knowledge is important also to understand the distribution of seismicity and volcanism in our region, and to assess risks due do subaerial and submarine processes, such as landslides, tsunamis, etc.

Development of new technologies, such as multibeam acoustic bathymetry, made clear a few years ago that our knowledge of the Tyrrhenian sea floor could achieve a quantum-jump if these technologies could be applied. The Institute of ;Marine Geology (IGM) of the Italian National Research Council (Istituto di Geologia Marina del CNR) took the lead in pushing forward a project for multibeam swath-mapping of the entire Tyrrhenian sea floor. A major problem was that Italy, although notoriously a country not only of poets and saints, but also of navigators, lacked a modern research ship equipped with multibeam technologies. We bypassed this problem obtaining at very low costs the use of two Russian research vessels, i.e. the R.V. Gelendzhik and the R.V. Akademic Strakhov, both equipped with modern, ocean-depth multibeam. We had already a good deal of experience with these vessels and with working together with scientists of the Russian Academy of Science, since we had carried out with them a number of expeditions in the central and southern Atlantic, part of a CNR-sponsored project on Mid Ocean Ridges.

Funds for this project were obtained mostly from the CNR, but also from the Italian Geological Survey and from GNV (National Group on Vulcanology). Scientists of IGM, now part of a larger Institute of Marine Sciences (ISMAR) of the CNR, have been active in various themes, from coastal geology and biogeochemistry to ocean geology.

Two expeditions were carried out planned, organized and led by researchers of IGM, with the collaboration of a number of other Institutions. In addition to 100% multibeam coverage, continuous seismic reflection, gravimetric and magnetometric data were acquired mostly with instrumentation of IGM. The large set of data that were acquired are being processed and interpreted at IGM: the entire scientific community will then be able to share there results. The maps presented in this volume are part of the first harvest produced by this project. The Tyrrhenian is less mysterious, but not less fascinating.

Enrico BONATTI
Mariangela RAVAIOLI

INTRODUCTION

From seafloor to deep mantle: architecture of the Tyrrhenian backarc basin

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The western Mediterranean can be viewed as a single subduction zone, stretching from southern Spain to the northern Apennines, running parallel to the north African margin. During the last –30 Ma, slam retreat produced discreet intervals of back arc extension in the region, generally migrating from in time west to east, to the present Tyrrhenian back arc basin facing the narrow oceanic slab underlying the compact Calabrian arc.

Pioneering studies in the Tyrrhenian Sea carried out in the 1960's, first by A.Segre then by R.Selli, triggered the development of modern marine geology in Italy. Knowledge of the Tyrrhenian general structure, sedimentary depositional styles and submarine volcanism became well established in the following years, leading to the first ideas concerning the formation of the basin. Subsequent drilling surveys, first through the Deep Sea Drilling Project (DSDP) in 1975 and then through the Ocean Drilling Program (ODP) in 1986 gave new impetus to the understanding of the processes that played a part in the evolution of the Tyrrhenian sea.

Since then, however, innovative marine geology techniques were developed. In particular, the employment of swath bathymetric mapping as a remote sensing tool, augmented by steadily increasing ground truthing as a result of sampling and direct observations. Caused a forward thrust in our knowledge of seafloor geology.

As a consequence, a new research effort was undertaken in the with the objective of obtaining the detailed multibeam mapping of the Tyrrhenian seafloor. The "Tyrrhenian Project", (full title "The Tyrrhenian sea: High Resolution Morphology and Structure of a Back-arc Basin") initiated as a project of the Consiglio Nazionale delle Ricerche (CNR) and was completed with support also from the Gruppo Nazionale di Vulcanologia (GNV) and from the Servizi Tecnici dello Stato – Servizio Geologico Nazionale. In addition, the Istituto Idrografico della Marina provided shallow water data for several areas.

A full-ocean depth multibeam instrument was utilised to map the challenging topography of the Tyrrhenian basin. Continuous multibeam bathymetry was acquired from the deepest seafloor to an average of 350m below sea level. Four months of seagoing surveys, covering more than 60,000km, and many more months of processing the vast amount of collected data have resulted in the maps appended to this volume. Although of complete multibeam coverage was the priority of the surveys, contemporaneous collection of seismic reflection, magnetic and gravimetric data was also accomplished. The new maps have provided, moreover, base-line data for the planning of subsequent accurately targeted sampling and high resolution seismic reflection surveys.

In order to frame the new information within a wider scientific perspective, an effort was made to place our results within a wider geological and geophysical context. To meet this end. Invitations were issued to leading scientists of the field to summarise up to date results of studies pursued in the Tyrrhenian region. The response received from the invited authors has resulted in this volume. It is an opportunity to assemble together the diverse scientific disciplines that have been applied to improve our understanding of the Tyrrhenian region. Each of the papers collected in the volume offer the latest models and hypotheses aimed at understanding the subduction-backarc system of the Tyrrhenian region as a whole.

Papers in the volume have been ordered according to thematic groupings. The first two papers deal with the deep structure of the Tyrrhenian region.

Utilising a new three-dimensional P-wave velocity model obtained with a novel nonlinear inversion of high quality teleseismic data, CIMINI *highlights the complexity of the mantle structure beneath the Tyrrhenian-Apennnine area. Three basic types of lithosphere sinking are interpreted from the tomography data within the general geodynamic context of oceanic-continental subduction.* PANZA *et alii outline the mosaic of lateral variations in the upper mantle structure of the region trùhrough the integration of surface wave tomography maps with petrological and geochemical data from the Italian volcanic provinces.*

The Authors show how large-scale inhomogeneities in the lithosphere-asthenosphere structure are mirrored by large variation in the composition of magma types. In particular, the backarc volcanism the Southern Tyrrhenian Sea, is shown to be associated with a very shallow crust-mantle transition above a soft mantle that is related to 10% of partial melting.

The subsequent three papers focus on the geophysical and geological properties of the nature of the lithosphere in the region, namely seismicity, heat flow and petrology of submarine volcanism. A review of the seismicity-prone sectors of the Tyrrhenian region is offered by FAVALLI *et alii before discussing. with recent examples, the challenges and opportunities of extending the Italian seismological network offshore. The Authors present results of experiments involving marine seismological observations, emphasizing the significant improvements in the detection and accurate localisation of offshore events. Essential for unravelling the present-day geodynamics of the region.* MONGELLI *et alii suggest the necessity of migrating astenospheric intrusions to explain the high heat flow of the eastern Tyrrhenian region. They image the present heat flow as a transient wave migrating eastward in time.* TRUA *et alii present new geochemical and isotope analyses of recent seafloor samples and a useful summary of available submarine sampling data, to discuss the coexistence of Island Arc and Ocean Island Basalts in the southern Tyrrhenian region in order to map mantle structure and define the geodynamics of mantle flow in the region.*

The following three papers examine the geology of the Tyrrhenian Sea based on the new bathymetric data, specifically structure and tectonics, sedimentology and submarine volcanic landforms. MARANI *and* GAMBERI *describe the geodynamic provinces of the Tyrrhenian basin, providing focused maps to outline the structural trends that define the different sectors of the basin.* GAMBERI *and* MARANI *describe the present-day sedimentary processes and depositional system of the diverse portions of the Tyrrhenian Sea. The authors present examples of the reflection profiles acquired during the swath mapping surveys and their preliminary interpretations .Lastly,* MARANI *and* GAMBERI *present examples of the morphology of submarine volcanic landforms, highlighting the differences between the submerged arc volcanoes and the edifices constructed in the back-arc.*

Three final papers put forward models of the development of the Tyrrhenian region. Combining structural data and magmatism, DOGLIONI *et alii discuss the geodynamics of the Tyrrhenian region including unique explanations for uplift in different sectors of the region. The authors attribute the diversity of Quaternary volcanism in the southern Tyrrhenian to the interaction of an eastwards moving mantle wedge with a predominant contaminating component linked to altered oceanic crust in the Aeolian magmas or to sediments in the Campania province magmatism. The paper by* FACCENNA *et alii is based on a multidisciplinary approach combining surface geological data, mantle tomography images and tectonic reconstructions. The results of the integrated dataset, tested by laboratory experiments, suggest that the intermittent extension producing the opening of the Liguro-Provençal and of the Tyrrhenian basins can be explained by the interaction between the subducting slab and the 660-km discontinuity. The final paper by* MARANI *proposes the Marsili volcano in the Southern Tyrrhenian as a super inflated spreading ridge resulting from the up-rise of deep buoyant asthenosphere across lateral tears that develop at the sides of the subducting lithosphere. The author considers vertical accretion as the dominant mechanism acting within a restricted spreading environment.*

Michael P. Marani

Fabiano Gamberi

Enrico Bonatti