

The Geological Evolution of the Eastern Mediterranean

Geological Society Special Publications
Series Editor A. J. FLEET

GEOLOGICAL SOCIETY SPECIAL PUBLICATION NO. 17

The Geological Evolution of the Eastern Mediterranean

EDITED BY

J. E. DIXON AND A. H. F. ROBERTSON
Dept of Geology & Geophysics
University of Edinburgh
UK

Published by
The Geological Society
London

THE GEOLOGICAL SOCIETY

The Society was founded in 1807 as The Geological Society of London and is the oldest geological society in the world. It received its Royal Charter in 1825 for the purpose of 'investigating the mineral structure of the Earth'. The Society is Britain's national society for geology with a membership of around 8000. It has countrywide coverage and approximately 1000 members reside overseas. The Society is responsible for all aspects of the geological sciences including professional matters. The Society has its own publishing house, which produces the Society's international journals, books and maps, and which acts as the European distributor for publications of the American Association of Petroleum Geologists, SEPM and the Geological Society of America.

Fellowship is open to those holding a recognized honours degree in geology or cognate subject and who have at least two years' relevant postgraduate experience, or who have not less than six years' relevant experience in geology or a cognate subject. A Fellow who has not less than five years' relevant postgraduate experience in the practice of geology may apply for validation and, subject to approval, may be able to use the designatory letters C Geol (Chartered Geologist).

Further information about the Society is available from the Membership Manager, The Geological Society, Burlington House, Piccadilly, London W1V 0JU, UK. The Society is a Registered Charity, No. 210161.

Published by The Geological Society from:

The Geological Society Publishing House
Unit 7, Brassmill Enterprise Centre
Brassmill Lane
Bath BA1 3JN
UK

(Orders: Tel. 01225 445046

Fax 01225 442836)

First published 1984

Reprinted with additional material 1996

The publishers make no representation, express or implied, with regard to the accuracy of the information contained in this book and cannot accept any legal responsibility for any errors or omissions that may be made.

© The Geological Society 1984. All rights reserved. No reproduction, copy or transmission of this publication may be made without written permission. No paragraph of this publication may be reproduced, copied or transmitted save with the provisions of the Copyright Licensing Agency, 90 Tottenham Court Road, London W1P 9HE. Users registered with the Copyright Clearance Center, 27 Congress Street, Salem, MA 01970, USA: the item-fee code for this publication is 0305-8719/96/\$7.00.

British Library Cataloguing in Publication Data

A catalogue record for this book is available from the British Library.

ISBN 1-897799-66-7

ISSN 0305-8719

Printed in Great Britain by Aldens, Oxford, Didcot and Northampton

Distributors

USA

AAPG Bookstore
PO Box 979
Tulsa
OK 74101-0979

USA

(Orders: Tel. (918) 584-2555

Fax (918) 560-2652)

Australia

Australian Mineral Foundation
63 Conyngham Street
Glenside
South Australia 5065
Australia

(Orders: Tel. (08) 379-0444

Fax (08) 379-4634)

India

Affiliated East-West Press PVT Ltd
G-1/16 Ansari Road
New Delhi 110 002
India

(Orders: Tel. (11) 327-9113

Fax (11) 326-0538)

Japan

Kanda Book Trading Co.
Tanikawa Building
3-2 Kanda Surugadai
Chiyoda-Ku
Tokyo 101
Japan

(Orders: Tel. (03) 3255-3497

Fax (03) 3255-3495)

Preface

In the years since the 1977 Aegean conferences in Athens and Izmir there has been an explosion of new information on the Eastern Mediterranean, particularly on the Turkish area. Some three years ago we sensed that the time might be ripe for a meeting to consider all aspects of geology relevant to the tectonic evolution of the Eastern Mediterranean. We sounded out opinion in most of the European laboratories involved and received enthusiastic support for the idea. The boundaries of the area to be discussed were fixed early on: the Apennines to the west, the Carpathians and Caucasus to the north, the Zagros to the east and North Africa to the south. The meeting concentrated on the Late Palaeozoic to Recent evolution, as few coherent tracts of older rocks exist in the area.

The conference was held in Edinburgh from the 28 to 30 September 1982 and was attended by 220 scientists from 13 countries, 88 papers were read and 22 given in poster form. Sixty one contributions are published in this volume.

One of the key starting points of Eastern Mediterranean geology is deceptively easy to state. Several global reconstructions of the continents for Permian time indicate that a substantial tract of ocean, the 'Tethys', existed between Africa, and a Eurasian landmass to the north. Since little or none of this oceanic crust remains, the history of the Tethys from the Late Palaeozoic onwards must involve destruction of this ocean area. Perhaps surprisingly, however, the geology of the Eastern Mediterranean land areas is not dominated by this process but by the products of Mesozoic rifting and the formation and destruction of new oceanic basins. From this it is evident that closure of the Palaeozoic Tethyan ocean can not simply have involved continuing subduction culminating in continental collision in the Neogene. Tectonic events must have involved comprehensive re-organizations of plate boundaries so that the distribution of continent and ocean is almost bound to have been complicated and frequently changing.

The book is organized by age of events discussed and by area within this framework, and it is in five sections. Following the editors' introductory chapter the first is concerned with early Mesozoic events linked to ocean closure and so by implication deals with the fate of the Palaeozoic Tethys or *Palaeotethys*. Later sections deal with events following the birth and growth of wholly Mesozoic ocean basins of the

Neotethys. This division follows the interpretation of the contributors and is not inherently clear-cut. We use the term *Palaeotethys* to imply an ocean basin already in existence at the end of the Palaeozoic, but one that may have continued in existence in the Mesozoic and Tertiary. We argue, for example, in our own introductory chapter that the destruction of *Palaeotethys* in this sense was a long-drawn-out process lasting until Tertiary times, and even that early Mesozoic compressional events in the area, though related to *Palaeotethyan* subduction, could also have involved the formation of short-lived *Neotethyan* ocean basins. While questions of this kind dominate the book as a whole, much of the research documented here is also concerned with fundamental questions of continent-ocean dynamics. How do continental margins evolve from the early rift stage? Where are ophiolites formed and how are they emplaced? How do blueschist belts come to be created and exhumed? What is the relationship between consumption of oceanic crust and the construction of volcanic arcs? With its great geological diversity and relative accessibility the Eastern Mediterranean is an exceptionally valuable field laboratory, producing results complementary, for example, to those of the Deep Sea Drilling Project or marine geophysical exploration.

The reader will find disparity in the depth of knowledge and the coverage of different areas and processes. He may be disappointed that the jig-saw puzzle is not yet fully solved, but he may in return come to appreciate how many of the pieces are turning out to have the same pattern on them, and he may catch occasional glimpses of parts of the picture. He will also find amid the tentative models and the many expressions of uncertainty, flat contradictions and diametrically opposed interpretations. Perhaps these simply reflect the state of earth science a decade and a half after the plate-tectonic revolution. They are, none-the-less, a stimulus for us to question the validity of the ground rules. Do palaeomagnetic inclinations faithfully record palaeo-latitudes? Are ophiolites really remnants of oceanic crust, from marginal or any other kind of basin? Does calc-alkaline magmatism mean active subduction? Must blueschists and melanges also be linked to subduction? Whatever one's doubts, the philosophy behind a book like this is clear enough. Directing the contributors to the wider implications of their work should help progress towards greater

overall understanding which must come from the dynamic interaction of large-scale thinking and small-scale research.

ACKNOWLEDGEMENTS:

Esso Exploration Inc. provided generous financial support for which we are particularly grateful. Financial support was also received from BP.

We would like to thank Professor G. Y. Craig of the University of Edinburgh, Depart-

ment of Geology, for making available to us the full range of departmental facilities both in initially organizing the conference, then editing this book. Our sincere thanks go to our secretaries Mrs M. Wright and Mrs H. Hooker for their unfailing help, particularly with retyping edited manuscripts. Mrs D. Baty assisted with photography and, together with Mrs F. Tullis, with drafting also.

Finally we wish to record our thanks to Mr N. Palmer of Blackwell Scientific Publications for his friendly advice and assistance at all stages.

Introduction to the reprint

Since its publication in 1984, *The Geological Evolution of the Eastern Mediterranean* has proved to be an invaluable aid to research in this important region. Many of the papers are classics that report basic data and tectonic interpretations that still remain valid today. The individual papers summarize a large amount of international research that was carried out in the Eastern Mediterranean region during the previous decade and this was the first attempt at

overall synthesis. Those who have tried to obtain this book in the last few years have been disappointed, hence the decision to reprint. The editors have added an outline of the main research developments since 1984 and key references to the more recent literature. In addition, many of the figures in the chapter 'Introduction: aspects of the geological evolution of the Eastern Mediterranean' have been redrawn.

Recent research developments

The early 1980s saw the publication of several companion volumes on the Eastern Mediterranean region, both on land and beneath the sea. Aspects of the marine geology of the Mediterranean Basin were reported in 'Geological Evolution of the Mediterranean Basin' edited by Stanley and Wezel in 1985. In 1986, Dercourt *et al.* published an atlas of palaeogeographic maps of the Tethyan area which were accompanied by text, and incorporated data from the Eastern Mediterranean region. By the mid-1980s it was clear that different regional tectonic interpretations were mutually contradictory. Problematic aspects included the history of Africa-Eurasia plate motion, the nature of the crust beneath the Mediterranean Sea, and the origin of the ophiolites. This, in turn, stimulated an expansion of field-based research. The southern margin of Eurasia, represented by complex,

often metamorphic terrains (e.g. the Pontides of N Turkey) emerged as a key study area. Attempts were renewed to resolve outstanding problems concerning the origin of Mesozoic ophiolites, particularly in the Greek and Turkish areas. Integrated field-based studies led to an improved understanding of the pattern of microplates that were rifted from Gondwana in the Early Mesozoic. The Eastern Mediterranean became established as one of the best areas in the world for study of processes of tectonic collision that include 'tectonic escape' and 'orogenic collapse'. In addition, much effort has recently gone into study of active and recently active tectonics, including seismicity and measurements of absolute plate motions. Finally, interest in the marine geology has received a boost from the return of the R.V. *Joides Resolution* to the Mediterranean Sea.

Selected references

Some of the main literature sources published since 1984 are indicated below.

- CHANNELL, J. E. T., WINTERER, E. L. & JANSA, L. F. 1991 Paleogeography and paleoceanography of Tethys. *Palaeogeography, Palaeoclimatology, Palaeoecology*, **87**, 289-344 (papers dealing mainly with palaeoenvironmental aspects of Tethys).
- DERCOURT, J., RICOU, L. E. & VRIELYNCK, B. (eds) 1993. *Atlas Tethys Palaeoenvironmental Maps*, Beicip-Franlab, 1992 (coloured palaeogeographical maps of Tethys as a whole and accompanying explanation).
- ZONENSHAIN, L.P., RICOU, L. E., KAZMIN, V. G., LE PICHON, X., KNIPPER, A. L., GRANDJACQUET, C., SBORTSHIKOV, I. M., GEYSSANT, J., LEVRIER, C., PERCHERSKY, D. H., BOULIN, J., SIBUET, J.-C., SAVOSTIN, L. A., SOROKHTIN, O., WESTPHAL, M., BAZHRNOV, M. L., LAUER, J.-P. & BIJU-DUVAL, B. 1986. Geological evolution of the Tethys belt from the Atlantic to the Pamirs since the Lias. *Tectonophysics*, **123**, 241-315 (synthesis of Tethyan geology and tectonics).
- EMEIS, K., ROBERTSON, A. H. F. & RICHTER, C. 1996. *Initial Results of ODP Leg 160*, College Station, Texas (recent results from deep sea drilling in the Eastern Mediterranean Sea).
- JACOBSHAGEN, V. 1986. *Geologie von Griechenland*, Gebrüder Börtraeger, Berlin, Stuttgart (a comprehensive summary of information on Greek geology, in German).
- MALPAS, J., MOORES, E. M., PANAYIOTOU, A. & XENOPHONTOS, C. (eds) 1987. *Ophiolites Oceanic Crustal Analogues*, Proceedings of Symposium 'Troodos 1987', Cyprus Geological Survey Department (includes a set of papers on Cyprus and other Mediterranean ophiolites).
- MORRIS, A. & TARLING, D. H. (eds) 1996. *Palaeomagnetism and Tectonics of the Mediterranean Region* Geological Society, London, Special Publication, **105** (new palaeomagnetic data for the Mediterranean region).
- OKAY, A. 1989 Alpine-Himalayan blueschists. *Annual Reviews of Earth and Planetary Sciences*, **17**, 55-87 (survey of Tethyan blueschists).
- PRICHARD, H. M., ALABASTER, T., HARRIS, N. B. W. & NEARY, C. R. (eds) 1993. *Magmatic Processes and Plate Tectonics*. Geological Society, London, Special Publication, **76** (includes review papers on Hellenic-Dinaric, and Troodos ophiolites).
- ROBERTSON, A. H. F. 1994. Tectonic Facies Concept and its application to Tethys in the Eastern Mediterranean region. *Earth and Planetary Science Reviews*, in press (tectonic settings and modern counterparts).
- DIXON, J. E., BROWN, S., COLLINS, A., MORRIS, A., PICKETT, E., SHARP, I. & USTAOMER, T. 1996 Alternative tectonic models for the Late Palaeozoic-Early Tertiary development of Tethys in the Eastern Mediterranean region. In: MORRIS, A. & TARLING, D. H. (eds). *Palaeomagnetism and Tectonics of the Mediterranean Region*. Geological Society, London, Special Publication, **105**, 239-264 (discussion of the current alternative models pointing out the pros and cons of each).

- GRASSO, M. 1995 Special issue-Later Tertiary-Quaternary Mediterranean tectonics and palaeoenvironments. *Terra Nova*, 7, 112-293 (set of papers dealing with later tectonic history, including overview paper).
- TEKELI, O. & GÖNÇÜOĞLU, M. C. (eds) 1984. Geology of the Taurus Belt, International Symposium, 26-29th September 1983 Ankara-Turkey. (regional geological data)
- ŞENGÖR, A. M. C. 1987 Tectonics of the Tethysides: orogenic collage development in a collisional setting. *Annual Reviews of Earth and Planetary Sciences*, 15, 213-244 (Eastern Mediterranean tectonics in a wider context).
- 1990 Plate-tectonics and orogenic research after 25 years—a Tethyan perspective. *Earth Science Reviews*, 27, 1-20 (Overview).
- GÖRÜR, N. & ŞAROĞLU, F. 1985. *Strike-slip Faulting and Related Basin Formation in Zones of Tectonic Escape*. Society of Economic Mineralogists and Paleontologists, Special Publication, 37, 227-264 (collisional and post-collisional history of mainly Anatolia).
- STANLEY, D. J. & WEZEL, F.-C. 1985. *Geological Evolution of the Mediterranean Basin*. Springer, New York (papers on marine geology).
- YILMAZ, Y. 1991. Allochthonous terranes in the Tethyan Middle East: Anatolia and surrounding regions. In: DEWEY, J. F., GASS, I. G., CURRY, G. B., HARRIS, N. B. W. & ŞENGÖR, A. M. C. (eds) *Allochthonous terranes*. Cambridge University Press, 155-167 (summary of data from allochthonous terranes in several areas of Turkey).
- ZIEGLER, P. A. 1990. *Geological Atlas of Western and Central Europe*. Shell International Petroleum Company (relationship of Eastern Mediterranean to Western Mediterranean geology).

Contents

Preface	vii
Introduction to the reprint	ix
Recent research developments	xi
ROBERTSON, A. H. F. & DIXON, J. E. Introduction: aspects of the geological evolution of the Eastern Mediterranean	1
1. Palaeotethys	
<i>Editor's introduction</i>	75
ŞENGÖR, A. M. C., YILMAZ, Y. & SUNGURLU, O. Tectonics of the Mediterranean Cimmerides: nature and evolution of the western termination of Palaeo-Tethys	77
MONOD, O. & AKAY, E. Evidence for a Late Triassic-Early Jurassic orogenic event in the Taurides	113
KEREY, I. E. Facies and tectonic setting of the Upper Carboniferous rocks of northwestern Turkey	123
DEMIRTASLI, E. Stratigraphic evidence of Variscan and early Alpine tectonics in southern Turkey	129
2. Neotethys: Levant and North African offshore	
<i>Editor's introduction</i>	147
DELAUNE-MAYERE, M. Evolution of a Mesozoic passive continental margin: Baër-Bassit (NW Syria)	151
SESTINI, G. Tectonic and sedimentary history of the NE African margin (Egypt-Libya)	161
GVIRTZMAN, G. & WEISSBROD, T. The Hercynian geanticline of Helez and the Late Palaeozoic history of the Levant	177
GARFUNKEL, Z. & DERIN, B. Permian-early Mesozoic tectonism and continental margin formation in Israel and its implications for the history of the Eastern Mediterranean	187
DRUCKMAN, Y. Evidence for Early-Middle Triassic faulting and possible rifting from the Helez Deep Borehole in the coastal plain of Israel	203
ABED, A. M. Emergence of Wadi Mujib (Central Jordan) during Lower Cenomanian time and its regional tectonic implications	213
HIRSCH, F. The Arabian sub-plate during the Mesozoic	217
DELALOYE, M. & WAGNER, J.-J. Ophiolites and volcanic activity near the western edge of the Arabian plate	225
3. Neotethys: Turkey	
<i>Editor's introduction</i>	235
POISSON, A. The extension of the Ionian trough into southwestern Turkey	241
ROBERTSON, A. H. F. & WOODCOCK, N. H. The SW segment of the Antalya complex, Turkey as a Mesozoic-Tertiary Tethyan continental margin	251
WALDRON, J. W. F. Structural history of the Antalya Complex in the 'Isparta angle', Southwest Turkey	273
HAYWARD, A. B. Miocene clastic sedimentation related to the emplacement of the Lycian Nappes and the Antalya Complex, SW Turkey	287

WHITECHURCH, H., JUTEAU, T. & MONTIGNY, R. Role of the Eastern Mediterranean ophiolites (Turkey, Syria, Cyprus) in the history of the Neo-Tethys	301
REUBER, I. Mylonitic ductile shear zones within tectonites and cumulates as evidence for an oceanic transform fault in the Antalya ophiolite, SW Turkey	319
YILMAZ, P. O. Fossil and K-Ar data for the age of the Antalya Complex, SW Turkey	335
RICOU, L. E., MARCOUX, J. & WHITECHURCH, H. The Mesozoic organization of the Taurides: one or several ocean basins?	349
MICHARD, A., WHITECHURCH, H., RICOU, L. E., MONTIGNY, R. & YAZGAN, E. Tauric subduction (Malatya-Elazig provinces) and its bearing on tectonics of the Tethyan realm in Turkey	361
AKTAS, G. & ROBERTSON, A. H. F. The Maden Complex, SE Turkey: evolution of a Neotethyan active margin	375
HELVACI, C. & GRIFFIN, W. L. Rb-Sr geochronology of the Bitlis Massif, Avnik (Bingöl) area, SE Turkey	403
AKINCI, Ö. T. The Eastern Pontide volcano-sedimentary belt and associated massive sulphide deposits	415
OKAY, A. I. & ÖZGÜL, N. HP/LT metamorphism and the structure of the Alanya Massif, Southern Turkey: an allochthonous composite tectonic sheet	429
NORMAN, T. N. The role of the Ankara Melange in the development of Anatolia (Turkey)	441
TANKUT, A. Basic and ultrabasic rocks from the Ankara Melange, Turkey	449
OKAY, A. I. Distribution and characteristics of the north-west Turkish blueschists	455
GÖRÜR, N., OKTAY, F. Y., SEYMEN, I. & SENGÖR, A. M. C. Palaeo-tectonic evolution of the Tuzgözü basin complex, Central Turkey: sedimentary record of a Neo-Tethyan closure	467
LAUER, J. P. Geodynamic evolution of Turkey and Cyprus based on palaeomagnetic data	483
4. Neotethys: Greece and the Balkans	
<i>Editor's introduction</i>	493
HALL, R., AUDLEY-CHARLES, M. G. & CARTER, D. J. The significance of Crete for the evolution of the Eastern Mediterranean	499
BONNEAU, M. Correlation of the Hellenides nappes in the south-east Aegean and their tectonic reconstruction	517
OKRUSCH, M., RICHTER, P. & KATSIKATSOS, G. High-pressure rocks of Samos, Greece	529
KATAGAS, C. G. High pressure metamorphism in Ghiaros Island, Cyclades, Greece	537
RIDLEY, J. The significance of deformation associated with blueschist facies metamorphism on the Aegean island of Syros	545
PAPANIKOLAOU, D. J. The three metamorphic belts of the Hellenides: a review and a kinematic interpretation	551
PE-PIPER, G. & PIPER, D. J. W. Tectonic setting of the Mesozoic Pindos Basin of the Peloponnese, Greece	563
KEMP, A. E. S. & MCCAIG, A. M. Origins and significance of rocks in an imbricate thrust zone beneath the Pindos ophiolite, northwestern Greece	569

MOUNTRAKIS, D. Structural evolution of the Pelagonian zone in northwestern Macedonia, Greece	581
JACOBSHAGEN, V. & WALLBRECHER, E. Pre-Neogene nappe structure and metamorphism of the North Sporades and the southern Pelion peninsula	591
DIXON, J. E. & DIMITRIADIS, S. Metamorphosed ophiolitic rocks from the Serbo-Macedonian Massif, near Lake Volvi, north-east Greece	603
SPRAY, J. G., BÉBIEN, J., REX, D. C. & RODDICK, J. C. Age constraints on the igneous and metamorphic evolution of the Hellenic-Dinaric ophiolites	619
SMITH, A. G. & SPRAY, J. G. A half-ridge transform model for the Hellenic-Dinaric ophiolites	629
MÁRTON, E. Tectonic implications of palaeomagnetic results for the Carpatho-Balkan and adjacent areas	645
5. Neogene	
<i>Editor's introduction</i>	655
STEININGER, F. F. & RÖGL, F. Paleogeography and palinspastic reconstructions of the Neogene of the Mediterranean and Paratethys	659
KISSEL, C., JAMET, M. & LAJ, C. Palaeomagnetic evidence of Miocene and Pliocene rotational deformations of the Aegean Area	669
KONDOUPOULOU, D. & LAUER, J. P. Palaeomagnetic data from Tertiary units of the north Aegean zone	681
FYTIKAS, M., INNOCENTI, F., MANETTI, P., MAZZUOLI, R., PECCERILLO, A. & VILLARI, L. Tertiary to Quaternary evolution of volcanism in the Aegean region	687
MYRIANTHIS, M. L. Graben formation and associated seismicity in the Gulf of Corinth (Central Greece)	701
LYBERIS, N. Tectonic evolution of the North Aegean trough	709
LE PICHON, X., LYBERIS, N. & ALVAREZ, F. Subsidence history of the North Aegean Trough	727
JACKSON, J. & MCKENZIE, D. Rotational mechanisms of active deformation in Greece and Iran	743
RIDLEY, J. Listric normal faulting and the reconstruction of the synmetamorphic structural pile of the Cyclades	755
BARKA, A. A. & HANCOCK, P. L. Neotectonic deformation patterns in the convex-northwards arc of the North Anatolian fault zone	763
QUENNEL, A. M. The Western Arabia rift system	775
JASKO, S. On the Neogene development of the Eastern Mediterranean basins	789
CHORIANOPOULOU, P., GALEOS, A. & IOAKIM, C. H. Pliocene lacustrine sediments in the volcanic succession of Almopias, Macedonia, Greece	795
CRAMP, A., COLLINS, M. B., WAKEFIELD, S. J. & BANNER, F. T. Sapropelic layers in the NW Aegean Sea	807
CHIOTIS, E. D. A middle Miocene thermal event in northern Greece confirmed by coalification measurements	815
FABRICIUS, F. H. Neogene to Quaternary geodynamics of the area of the Ionian Sea and surrounding land masses	819
Index	825