PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY A
MATHEMATICAL, PHYSICAL & ENGINEERING SCIENCES

Introduction

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Introduction

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The topic for this Discussion Meeting arose from the apparent paradox that extensional tectonics are commonly associated with 'compressional' plate boundaries. Elsasser (1970) first showed how extension could be associated with convergent plate boundaries, and subsequently (1971) he added a 'suction force' caused by the sinker effect of the cold subducting slab (see also Forsyth & Uyeda 1975). At about the same time, Karig (1970, 1971) suggested that several 'marginal' basins in the western Pacific had originated by back-arc spreading, an interpretation foreshadowed by Wegener (1924, p. 123). Karig (1972) also postulated that the isolated ridges within these back-arc basins were 'remnant arcs' inherited from earlier stages in their development. Subsequent drilling and detailed geophysical surveys have fully vindicated the back-arc spreading – remnant arc model.

Despite these initial advances, the origin of extensional features associated with convergent plate boundaries is still poorly understood, and their distribution in space and time is not well known. This Discussion Meeting was therefore organized at the suggestion of one of us (A.G.S.) and under the auspices of the British National Committee for Geodynamics to air some of these problems. The objective was not to produce a global synthesis of all extensional features associated with convergent zones, but to review basic observations from areas that illustrate the many different facets of a phenomenon for which there is almost certainly no single explanation.

Extensional tectonics associated with convergent plate boundaries are expressed in a variety of ways, ranging from back-arc spreading with recognizable magnetic lineations, as in the western Pacific, through extensional basins in the western Mediterranean with poorly defined magnetic lineations, to extensional basins in continental crust associated with active convergent margins, as in the Aegean, or with recently active margins, as in the Basin and Range province of the western United States.

The first four papers in this volume review the geophysical and geochemical characteristics of the crust formed by back-arc spreading in the Scotia Sea and western Pacific, both areas with well defined magnetic anomalies. In all four papers the authors have emphasized the variation of back-arc spreading in space and time, and have evaluated the extent to which back-arc ocean floor resembles that of the main ocean basins. In general one is struck by the remarkable similarities between the two spreading processes and their products, rather than by the few differences. Back-arc ocean crust does, however, appear to be systematically deeper than that of the same age formed at a major ridge crest, and in addition the crustal structure is often more complex and the basalts may be transitional geochemically to island-arc types, especially during the early stages of back-arc spreading. The relatively short time spans of back-arc spreading cycles are emphasized, and Sharaskin maintains that in the Marianas area, back-arc magmatism alternated with island-arc magmatism with only minor overlap in time.

These papers are complemented in a fascinating way by the following two papers on ophiolite complexes in Oman and the southern Andes, which are thought to have originated as Mesozoic back-arc ocean basins. Subsequent tectonic emplacement, uplift and erosion presents well exposed back-arc crust. The crust that formed in the early stages of opening during the splitting of a pre-existing continent, as in the Andes, or a pre-existing ocean, as in Oman, has been studied structurally and geochemically in detail. Present-day examples cannot be studied in this way because they are as yet inaccessible to the drill.

In a discussion of two continental back-arc areas, the Aegean and central Andes, Mercier shows that, even within a period as short as 10 Ma, extensional faulting can alternate with high-angle thrust faulting. It is thought that these phases may reflect varying angles of dip of the subducting slab. Staying in the Alpine-Mediterranean area, the next two papers present elegant models of crustal attenuation and the history of subsidence in the Aegean Sea and Pannonian Basin areas; a third paper reviews various models for back-arc basin formation with particular reference to the Aegean, Pannonian, Tyrrhenian and Alboran basins. All these Alpine–Mediterranean models invoke crustal stretching or subcrustal erosion over updomed asthenosphere, followed by crustal subsidence resulting from isostatic readjustment and cooling of the lithosphere.

An interesting contrast is then provided by Molnar's review of the very different modes of extensional deformation associated with the collision of India with Eurasia. East–west extension of the Tibetan plateau appears to be due to lateral spreading of the crust as a result of its height relative to surrounding areas.

Finally, two papers discuss the geology of the Basin and Range province of western North America, where the bulk of the extension, associated with igneous activity, took place in the final stages of the subduction of the Farallon plate along the Pacific margin. Though subduction has ceased, except in the northwest, the Basin and Range province is still actively extending. Effimoff & Pinezich present previously unpublished seismic reflexion profiles across four of the basins, showing evidence of listric faulting bounding typical Basin and Range structures. Zoback reviews the evolution of the province as a whole, emphasizing that extensional faulting was in part contemporaneous with active subduction, but that much of the Basin and Range structure itself may be younger.

Plate tectonic interpretations of back-arc or subduction-related extension typically invoke a triggering in some way of asthenospheric upwelling. The nature of the trigger remains elusive in that extension is typically episodic and erratically distributed. To explain such temporal and spatial variations, contributors have appealed to variations in the rate and direction of convergence, the age and angle of dip of the subducting lithosphere, and the nature of the overriding crust or of the crust being subducted. Although one might expect some or all of these parameters to be relevant, some of the most convincing and successful models for back-arc extension rely solely on geometric and kinematic arguments. Thus Le Pichon & Angelier consider that the behaviour of the Aegean region results from the fact that a subduction zone has been pinned to the east and the west by continental collision, and has continued to consume a trapped remnant of oceanic lithosphere. This model would appear to apply equally well to the western Mediterranean 'back-arc basins', where the oceanic lithosphere was originally pinned by the collision of Italy with Europe and of north Africa with southern Spain. Its sinking into the mantle could have caused the detachment of the Balearic Islands and of Corsica and Sardinia from Europe, and the separation of small continental slivers now found in the Atlas mountains and northern Sicily.

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This type of model might also fit the fruitful suggestion of Chase (1978), that large-scale back-arc extension develops when the absolute motion of a back-arc plate has a component of motion normal to the plate boundary that is directed towards this plate. In other words, the position of a trench-line or subducting slab cannot retreat with respect to an absolute motion frame, but only remain stationary or advance over the plate that is being subducted. This concept fits well with currently favoured models for absolute plate motions (Minster & Jordan 1978) and active sites of back-arc spreading at the present day (figure 1).

These introductory remarks implicitly assume that all the extensional features mentioned so far have a plate tectonic explanation. Further work may show that plate tectonics does

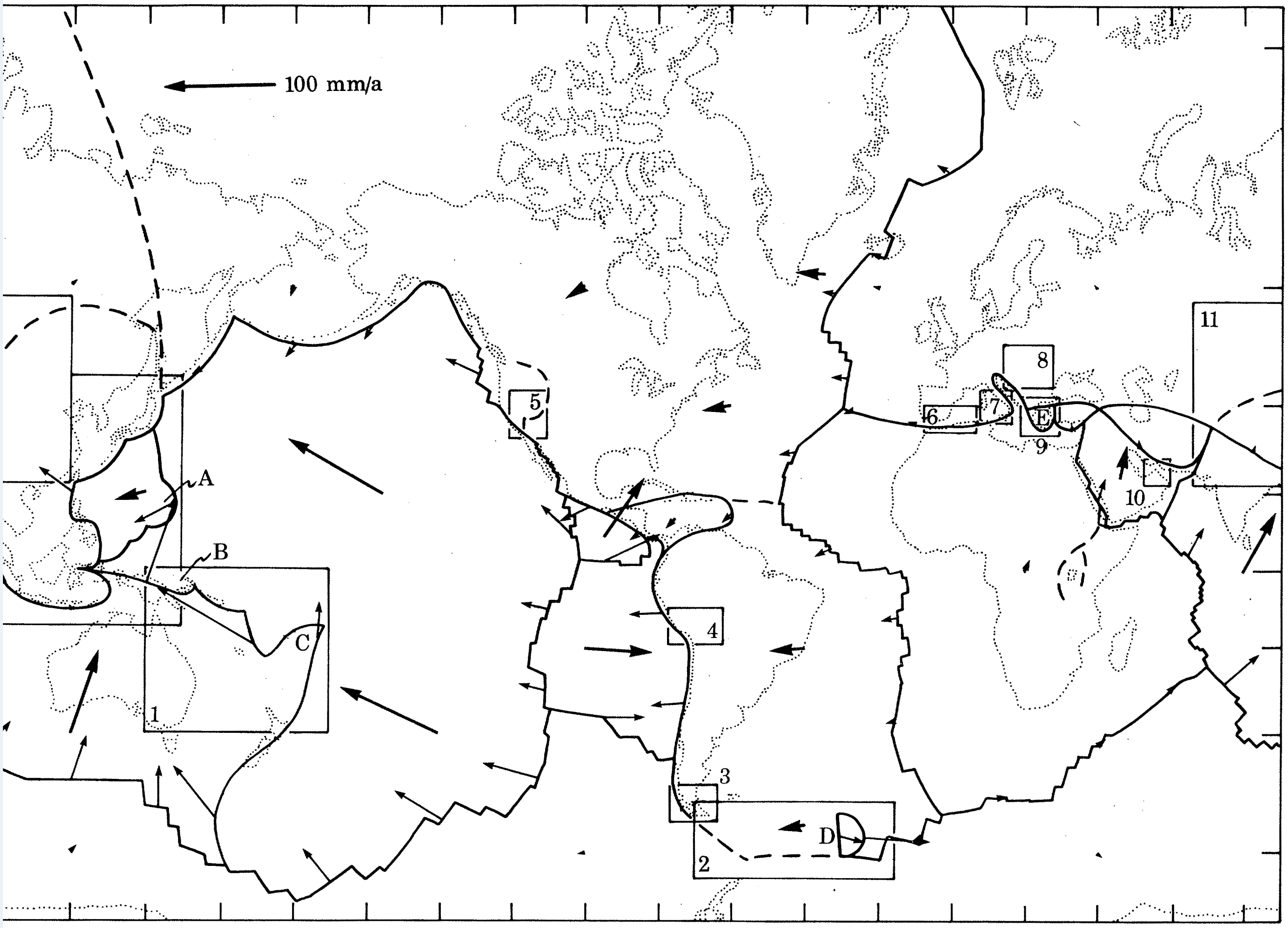

FIGURE 1. Vectors illustrating the present-day motions of plates and plate boundaries according to the 'hot-spot' model (AM1-2) of Minster & Jordan (1978). Areas of well documented active back-arc spreading or extension are indicated with letters as follows: A, Mariana trough; B, Bismarck basin; C, Lau basin; D, East Scotia Sea; E, Aegean Sea. Note that with the exception of the East Scotia Sea the bark-arc extension has been omitted from the analysis and that the back-arc plate, and hence the arc and trench system which are attached to it, 'retreats' in front of the advancing oceanic plate. If the back-arc extension is included, however, as in the East Scotia Sea, these trenches then 'advance' over the subducting oceanic lithosphere as is generally so elsewhere (see Chase 1978).

The rectangular boxes indicate the specific areas discussed in this volume and are numbered as follows: 1, western Pacific marginal basins; 2, Scotia Sea; 3, southern Andes; 4, central Andes; 5, Basin and Range province of western North America; 6, Alboran Sea; 7, Tyrrhenian Sea; 8, Pannonian and other intra-Carpathian basins; 9, Aegean Sea; 10, Oman mountains; 11, southeast Asia.

not provide the correct conceptual framework in which to analyse these features, and that the various environments have fundamental differences. However, it was not envisaged that this meeting would solve the many problems surrounding the origin of extensional features associated with convergent plate boundaries, but rather that it would provide a useful and thought-provoking state-of-the-art review, drawing on examples from very different parts of the globe. This was certainly the reaction of participants at the meeting and, we hope, will be the experience of those who read this volume.

We thank all contributors for their ready willingness to take part, for the uniformly high standard of their papers and for their prompt submission.

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