Benchmark Papers in Geology / 44

A BENCHMARK ® Books Series

MINERAL DEPOSITS, CONTINENTAL DRIFT AND PLATE TECTONICS

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SERIES EDITOR'S FOREWORD

The philosophy behind the "Benchmark Papers in Geology" is one of collection, sifting, and rediffusion. Scientific literature today is so vast, so dispersed, and, in the case of old papers, so inaccessible for readers not in the immediate neighborhood of major libraries that much valuable information has been ignored by default. It has become just so difficult, or so time consuming, to search out the key papers in any basic area of research that one can hardly blame a busy man for skimping on some of his "homework."

This series of volumes has been devised, therefore, to make a practical contribution to this critical problem. The geologist, perhaps even more than any other scientist, often suffers from twin difficulties—isolation from central library resources and immensely diffused sources of material. New colleges and industrial libraries simply cannot afford to purchase complete runs of all the world's earth science literature. Specialists simply cannot locate reprints or copies of all their principal reference materials. So it is that we are now making a concerted effort to gather into single volumes the critical material needed to reconstruct the background of any and every major topic of our discipline.

We are interpreting "geology" in its broadest sense: the fundamental science of the planet Earth, its materials, its history, and its dynamics. Because of training and experience in "earthy" materials, we also take in astrogeology, the corresponding aspect of the planetary sciences. Besides the classical core disciplines such as mineralogy, petrology, structure, geomorphology, paleontology, and stratigraphy, we embrace the newer fields of geophysics and geochemistry, applied also to oceanography, geochronology, and paleoecology. We recognize the work of the mining geologists, the petroleum goelogists, the hydrologists, the engineering and environmental geologists. Each specialist needs his working library. We are endeavoring to make his task a little easier.

Each volume in the series contains an Introduction prepared by a specialist (the volume editor)—a "state of the art" opening or a summary of the object and content of the volume. The articles, usually some twenty to fifty reproduced either in their entirety or in significant extracts, are selected in an attempt to cover the field, from the key papers of the last century to fairly recent work. Where the original works are in foreign languages, we have endeavored to locate or commission translations. Geologists, because of their global subject, are often acutely aware of the oneness of our world. The selections cannot, therefore, be restricted to any one country, and whenever possible an attempt is made to scan the world literature.

To each article, or group of kindred articles, some sort of "highlight commentary" is usually supplied by the volume editor. This commentary should serve to bring that article into historical perspective and to emphasize its particular role in the growth of the field. References, or citations, wherever possible, will be reproduced in their entirety—for by this means the observant reader can assess the background material available to that particular author, or, if he wishes, he, too, can double check the earlier sources.

A "benchmark," in surveyor's terminology, is an established point on the ground, recorded on our maps. It is usually anything that is a vantage point, from a modest hill to a mountain peak. From the historical viewpoint, these benchmarks are the bricks of our scientific edifice.

RHODES W. FAIRBRIDGE

PREFACE

The literature for this volume has been grouped into two somewhat unequal parts. Part I attempts to provide an historical perspective, with articles summarizing earlier ideas on continental drift and its relation to mineral deposits. When mentioned together continental drift and the formation of mineral deposits were treated essentially as two independent processes: continental drift merely broke up pre-existing mineral provinces, and in this context only the Mesozoic disruption of supercontinents and subsequent movement of the fragments were considered. Part I also includes a brief examination of ideas on the development of metallogenic provinces and the source of ore metals.

Part II contains a selection of the necessarily recent literature that emphasizes the causal links between plate tectonics and formation of mineral deposits, metallic as well as nonmetallic, both in a general way and with reference to specific plate tectonic or geographic settings. The influence of plate tectonic concepts on ideas about the source of ore metals is also examined.

Plate tectonic concepts are not accepted by all earth scientists and dissenting views are also given a place in this compilation.

The nouns *metallogeny* and *metallogenesis* and the adjectives *metallogenic* and *metallogenetic* seem to be used interchangeably in the literature and the commentaries on the articles in this volume are no exception. These words are close enough in appearance and meaning for such usage to present no problem, except to the dedicated purist.

Some authors receive considerable coverage in terms of numbers of articles. This is inevitable where the field is still new, and the number of authors relatively small. In fifty years time, an Earth Sciences Citation Index might tell us which of these papers, if any, represented true milestones (benchmarks). As it is, while many papers appear to handle the same subject matter, closer inspection shows that there are contrasted points of detail or emphasis that are worth recording at this early stage.

There still remains a large number of papers that have not been included, and the References on pages 381–387 list them. Therefore this volume should also serve as a fairly comprehensive bibliography for the literature on the relationship between mineral deposits and plate tectonics (see also Kasbeer, 1973).

ACKNOWLEDGMENT

I would like to thank Eileen Thompson for her help in typing and keeping track of successive drafts of this publication.

J. B. WRIGHT

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Part I

HISTORICAL PERSPECTIVE

HISTORICAL BACKGROUND TO CONTINENTAL DRIFT AND PLATE TECTONICS

The idea that continents can move relative to one another has been with us since at least the mid-nineteenth century and possibly since the seventeenth, although this remains a matter of debate (Carozzi, 1970; Rupke, 1970). Antonio Snider (1858) can probably be credited with the first published illustration of continental drift (Figure 1).

In the twentieth century Taylor (1910), Wegener (1929), and du

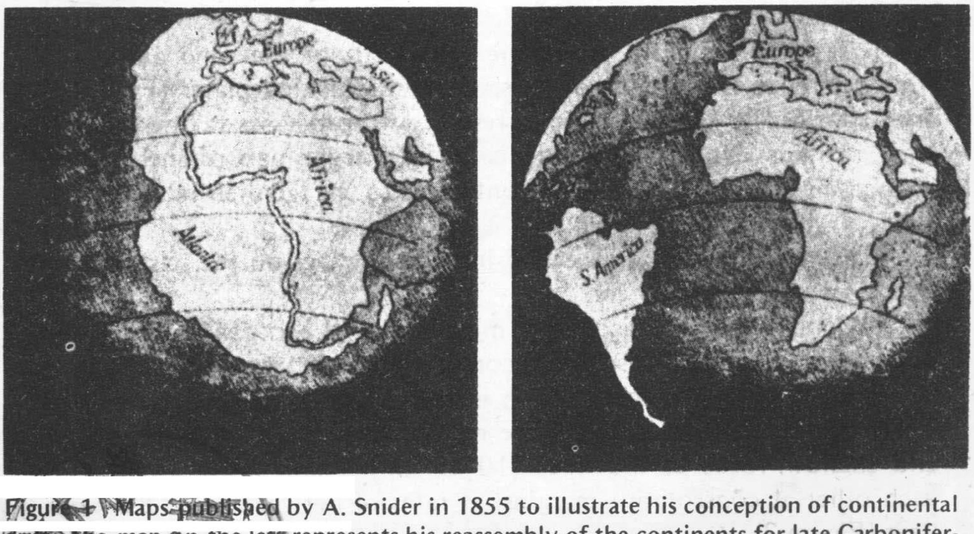

Figure 1 Maps published by A. Snider in 1855 to illustrate his conception of continental drift. The map on the left represents his reassembly of the continents for late Carboniferous times. Source: Holmes, 1965, Fig. 860.

Toit (1937) were chiefly responsible for collating the evidence and formulating the hypothesis of continental drift in scientific terms. However, even the wealth of supporting data presented first by Wegener and then by du Toit failed to gain general acceptance for the theory until well into the 1950s. It had the support of some distinguished advocates, nonetheless, such as King (1953), Vening Meinesz (1964) and Holmes (1931, 1944, Fig. 262), whose descriptions of mantle convection currents as a driving mechanism are remarkably similar to current ideas. But even Holmes (1953) was not always a totally convinced supporter.

The failure of the continental drift theory to achieve respectability was due partly to the incomplete nature of the evidence (e.g. Longwell, 1944), but principally to the contemporary state of knowledge about the structure and properties of the earth's outer layers. Geophysicists could not reconcile their data, either with Wegener's picture of sialic continents "ploughing" through a simatic "sea" and pushing up mountain ranges in front of them, or with mantle convection currents. So continental drift remained "impossible" dismissed by the more forthright as little more than a fairy tale (Willis, 1944).

In the decades following the mid-1950s, the situation reversed quite suddenly. Paleomagnetic evidence in favor of relative continental movements was accumulating rapidly. New information about the crust and upper mantle meant that convection currents were no longer "impossible." The resulting "revolution in the earth sciences" is chronicled in many books and articles (e.g. Blackett et al., 1965; Kanamori et al., 1967; Gass et al., 1972; Hallam, 1973; Cox, 1973). Earth scientists have become equipped with a unifying global theory of sea-floor spreading and plate tectonics, within which most geological processes can be accommodated.

The present picture shows the outer part of the solid earth—the lithosphere—as a carapace or mosaic of interlocking plates (Figure 2) that continually change shape in response to processes taking place at their margins. Since the continents are an integral part of such plates, changes in plate shape cause the continents to change their relative positions.

Plate margins can be classified into three types on the basis of the processes taking place there.

1. Constructive or accreting margins are the ocean ridge crests, where new oceanic lithosphere is continually generated by rise of material from the upper mantle, which is hotter and of lower density than elsewhere, so that ocean ridges are regions of relatively high heat flow and shallow focus earthquakes (10–20 km). Plates move away from each other at constructive margins, at rates of between 1 and 8 cm per year (Figure 2).

2. Destructive or consuming or convergent margins are recognized

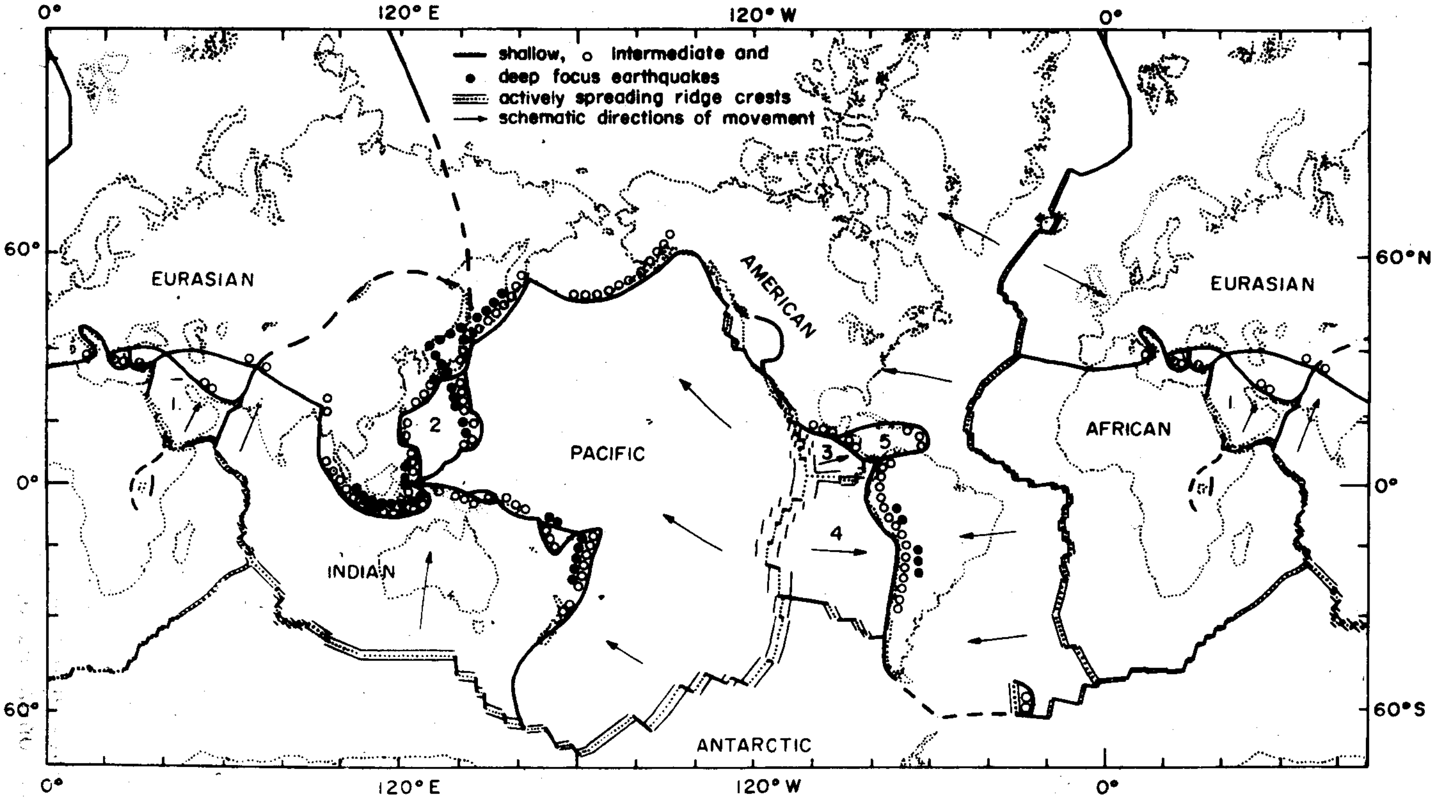

Figure 2 Summary of the seismicity of the earth, and distribution of lithospheric plates. The six major lithospheric plates bounded by active ridge crests, transform faults, trench systems and zones of compression are named. The following minor plates are numbered: (1) Arabian; (2) Phillipine; (3) Cocos; (4) Nasca; (5) Caribbean. Spreading rates at ridge crests are indicated schematically and vary from 1 cm per year per ridge flank in the vicinity of Iceland to 8 cm per year per ridge flank in the equatorial Pacific Ocean. Source: Professor F. J. Vine.

at ocean trenches near island arcs and orogenic continental margins (e.g. South America), where lithosphere is underthrust or *subducted* and resorbed into the mantle along an inclined plane identified by a zone of earthquake foci deepening to a maximum of 700 km—the Benioff Zone. Plates move toward each other at destructive margins and if two continental masses meet (collide) at such a margin they become sutured together, with a mountain range between them—continental crust is not dense enough to be taken down into the mantle. Such sutures may be marked by ophiolite complexes, which are interpreted as slices of oceanic lithosphere overthrust or obducted onto the crust.

3. Passive or transform margins are giant fault planes along which the plates move past each other, involving lateral movements measurable in hundreds of kilometers.

Transform faults also occur as cross-fractures at both constructive and destructive plate margins and probably represent accommodation to distortional stresses resulting from changes in the direction or rate of sea floor spreading or subduction (Wilson, 1965). They are typically a feature of oceanic lithosphere, but many transcurrent faults of continental regions are now recognized as landward extensions of major transform fractures. Two well-known examples, which in this case happen also to be plate boundaries (Figure 1), are the San Andreas system of western North America, and the New Zealand Alpine fault.

The lithosphere is 100–150 km thick, and consists largely of upper mantle peridotite, overlain by a thin (c. 5 km) skin of gabbroic and basaltic crust (sima) beneath the oceans and a much thicker (c. 35 km) granitic crust (sial) in continental areas.

Lithospheric plates can move at rates of a few cm per year because the underlying asthenosphere or low velocity layer (so-called because earthquake waves are slowed down and attenuated as they pass through it), which is 100–200 km thick, is believed to be a zone of partial melting and hence of lower shear strength. Recognition of the asthenosphere as a zone of relatively low friction upon which the lithosphere can move, eliminated one of the major obstacles that prevented acceptance of Wegener's ideas. The driving force for plate movements is less satisfactorily established, but some form of convective circulation is the most generally accepted.

The validity of the new global tectonics is now accepted by the great majority of earth scientists, despite a spirited rearguard action by some well-known names (e.g. Beloussov, 1970; Jeffreys, 1970a, p. 450–459 and 1970b; Meyerhoff et al., 1972a, b). Even among the majority who accept the principle, however, dissenting voices may be heard. As some of the papers in this volume will show, not everyone is agreed that continental drift and plate tectonics have anything at all to do with the formation of mineral deposits.

Editor's Comments on Papers 1, 2, and 3

1 HALL
Excerpts from *The Coal of Gondwanaland*

2 HUENE
A Possible Method for the Proof or Disproof of the Wegener Theory

3 DAUVILLIER and HENRY
A Decisive Argument Against the Theory of Continental Drift

MINERAL DEPOSITS AS EVIDENCE FOR CONTINENTAL DRIFT

As long as continental drift remained merely a hypothesis, rejected by most earth scientists because it was impossible according to contemporary geophysical knowledge, the main concern of its adherents was naturally to accumulate further evidence in its favor. Little attempt was made to establish causal relationships with geological processes such as magmatism, regional metamorphism, development of major sedimentary basins, or accumulation of mineral deposits—even the connection with mountain building was treated in a rather superficial way. For example:

> Thus the East Indies went to the north and are still moving north, causing the damming or urging up of the great mass we call the Himalayan Range; just as the earlier drift of South America is puckering up the great American backbone (Haddock, 1936, p. 68).

So it is hardly surprising that the only references to mineral deposits in the early continental drift literature occur almost incidentally, when distribution patterns were used merely as evidence to test the hypothesis.

Paper 1 by Hall is an example of how the distribution of Carboniferous coals could be used to support continental drift theory. It is a review article, based on more up-to-date information than was available to Wegener and du Toit.

Climate obviously exerts an important control over the formation