PLATE TECTONICS

Ancient Plate Motions

from our Structural Geology Correspondent

ONE of the problems facing the structural geologist is that of determining the net displacement related to crustal shortening across an orogenic fold belt; indeed, it is often difficult to determine even the orientation of displacement vectors giving the direction in which the opposing edges of the belt have moved. Most orogenic zones have their constituent fold and thrust structures developed parallel to the gross linear trend of the belt and it is this conformity that has led most structural geologists to assume that the fold belts have been developed as the result of direct orthogonal closing of the margins, rather in the fashion of the closing jaws of a vice.

The theory of plate motion makes this situation the exception rather than the rule, for only in extreme conditions will the relative motion of colliding plates have occurred perpendicular to the plate margins. W. B. Harland (*Geol. Mag.*, **108**, 27 ; 1971) has formulated a range of deformation situations which can be developed as a result of varying relationships between the direction of plate motion and the attitude of the plate edge. In this analysis the traditional regimes of extension, transcurrence and compression occur only as the result of special orthogonal relationships between moving plates.

For the general motion of plates Harland recognizes two novel regimes: transtensile regimes operating in zones of oblique extension, and transpressive regimes in zones of oblique compression. The former is typified by the opening of the Atlantic Ocean where the spreading ridge is repeatedly offset by transform faults, whilst it is the latter that is particularly pertinent to the present discussion.

During the early stages of deformation, fold and thrust structures will tend to develop perpendicular to the motion of the colliding plates and hence oblique to the plate margins. If the structures were to be frozen at this stage there would be no difficulty in recognizing both the transpressive nature of the deformation and the direction of motion of the associated plates. As the two plates continue to move, however, one plate sinks beneath the other and so these early structures are increasingly transpressed, the fold axes and thrusts being gradually rotated into alignment with the plate margins. The effects of transpression can, therefore, be divided into two distinct stages: first, a component of compression with shortening parallel to the plate motion and, second, a component of transcurrence with extension parallel to the plate margins.

The various manifestations of the extension component outlined by Harland are not by any means always easy to recognize and this factor has largely contributed to the false impression that most fold belts have been developed by orthogonal compression. Some measure of the direction of plate motion can be reached by virtue of the fact that the smaller the angle between the plate margin and the direction of plate motion the greater the component of transcurrence. But it is unlikely that even detailed strain analysis of a fold belt would lead to any precise assessment of the displacement vector, as normally the strain will be heterogeneous throughout the belt.

A. G. Smith (*Bull. Geol. Soc. Amer.*, **82**, 2039 ; 1971) has suggested a far more compelling model to determine ancient plate motion. Smith's reasoning is based first on the fact that, in recent oceans, plate motion is parallel to transform faults and perpendicular to spreading ridges and, second, on the contention that it is possible to reconstruct ancient plate margins—and hence plate motions—by restoring the past positions of fold belts, transforms and spreading axes. Clearly, the reliability of the restoration of the plate margin will decrease with age, but Smith has been able to reconstruct the relative positions of the continental areas surrounding the Mediterranean by means of a computer match of the continental margins which he showed to be consistent with a three stage model for the opening of the Atlantic.

The model demonstrated the existence by Lower Jurassic time of an extensive Tethys Ocean, entirely east of and separate from the present Mediterranean, which was gradually and completely closed during the three distinct movement phases associated with the opening Atlantic. Smith postulates that the Great and Little Caucasus Mountains represent transpressive fold belts developed by the closing of the Tethys ; the former along the northern margin with Laurasia and the latter along the southern margin with Gondwanaland. The west to east plate motions involved can be determined from the N–

Palaeozoic Movement in the Iberian Peninsula

THE geological structure of central and southern Europe is dominated by features formed during two collisions between continents. The first of these occurred before the Atlantic was formed when a land mass extending from present-day North America into northern Europe impinged on north-west Africa and an extensive mountain system formed in central and southern Europe. These movements ended about 225 million years ago and were followed about 200 million years later by a collision between Africa and southern Europe which occurred as the Atlantic opened and the Tethys Sea, which lay along the southern flank of Europe, finally closed.

Understanding the structures formed in the earlier of these collisions is particularly difficult because the Hercynian fold belts formed at that time were disrupted by the more recent movements and over much of Europe have been buried by younger deposits. In the past few years it has become clear that the most recent approach of Africa and Europe was accompanied by several subsidiary displacements as smaller blocks of crust were rotated or squeezed between the colliding continents. The rotation of Spain and Portugal, first postulated by Carey, is one instance in point. The reality of this rotation has been substantiated by palaeomagnetic measurements within the Iberian Peninsula and by evidence obtained on the floor of the Bay of Biscay which indicates that the bay developed as France and Spain separated. But it is still far from clear how the various smaller blocks, displaced during the Alpine movements, were originally situated. Analysis of contemporary earthquakes indicates the sense of movement of the smaller plates of crust at present, but earlier movements have to be inferred by other means.

An article by Ries and Shackleton in next Monday's *Nature Physical Science* bears in two ways on this problem. The article presents a new synthesis of Palaeozoic structures preserved in north-west Spain and northern Portugal. It thus provides direct evidence of the possible nature of Hercynian movements in this part of the Palaeozoic fold belt. But the structures recognized by Ries and Shackleton are so large that it seems possible that they once continued outside Spain and Portugal and so may, in the future, be used to reconstruct the relationships as they existed before later movements opened the Bay of Biscay. The structures are complex; the critical new point is the recognition by Ries and Shackleton that several isolated masses of Precambrian rock now found above younger strata once formed part of a thrust mass of crystalline rock. They suggest that this formed a plate of continental crust driven from a westerly source, presumably as a result of a Palaeozoic collision of continents. If their tentative synthesis is supported and can be extended into other parts of the Hercynian cnain, the results of Ries and Shackleton may also throw light on the nature of the much younger movements which disrupted south-west Europe in Tertiary times.