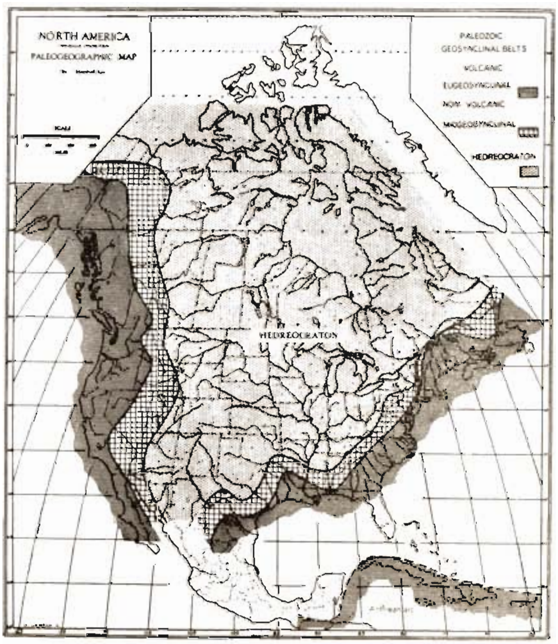
MODERN AND ANCIENT ISLAND ARCS

MARSHALL KAY
Professor of Geology, Columbia University, New York City

THE nature and history of modern island arcs has become better known in the past twenty years through the studies of geophysicists and geologists (MEINESZ, KUENEN & UMBGROVE, 1934; HESS, 1939; 1948; UMBGROVE, 1947, pp. 144-216). Within this same period, stratigraphic studies have brought recognition that similar tectonic and volcanic patterns existed in regions that subsequently were so severely deformed as to obscure their earlier island arc character. The analogies lead to the judgement that modern arcs represent but an intermediate stage in a long development, and that the belts of arcs have retained distinctive properties since early stages in earth history. Such conclusions affect interpretations of the permanence of continents. The writer's knowledge and experience has been principally with North America and north-western Europe, but the conclusions bear on regions such as south-eastern Asia. The belts of great subsidence, of sediment classes, of extrusive volcanism, of orogenic deformation, and of intrusion of plutonic rocks whether quartz-rich plutons or ultrabasic, have systematic positions and successions; and these can be related to geophysical observations on modern island arcs.

The accompanying map of North America shows the present position of several belts of early Palaeozoic rock types; their original geographic relations differed because the rocks have been deformed and moved through later folding and thrusting; arrangements might better be expressed on base maps having geography restored to relative original positions, on palinspastic maps (KAY, 1945). The theory of marginal volcanic troughs and island arcs (KAY, 1942; 1944) postulates that the margin of the continent had geography similar to modern arcs through part of their histories. The prevailing hypothesis in the latter nineteenth century when knowledge was principally of the eastern half of the continent was that the crystalline rocks, schists, gneisses and granites were Protozoic (that is, pre-Palaeozoic), and that Palaeozoic seas lapped against islands of these ancient "Archaean" rocks; thus the hypothesis of Archaean protaxes of Dana. By the close of the century, many of the intrusions and much of the metamorphic rock along the continental margins had been found to be Palaeozoic and Mesozoic. But some of the marginal sediments seemed to have come from lands in the regions of the present shores; thus the hypothesis of borderlands of Schuchert, postulating great lands of pre-Palaeozoic gneisses and granites that persisted through most of the Palaeozoic era, an hypothesis still presented in current American text-books of historical geology. But the theory of marginal island arcs seems a more satisfactory explanation of present information.

It long has been known that the central part of North America, the hedreocraton, was relatively stable, subsiding little as compared to geosynclinal belts, along its margins, which came to be severely deformed during times of orogeny. A geosyncline is a surface



MAP

deformed downward during the deposition of its contained sediments; classification of geosynclines has been summarized (KAY, 1947) and a comprehensive treatise is soon to be published. The geosynclines that margined the North American continent during the Palaeozoic were of several kinds, having distinctive relations in space and time. In early Palaeozoic, the hedreocraton was separated by flexures from more deeply subsiding linear (orthogeosynclinal) belts. Non-volcanic subsiding zones along the hedreocraton gained sediments considerably derived by erosion from the area of the hedreocraton. Beyond these zones, sediments have thick associated sequences of lavas and volcanic detritus, as well as coarse debris that must have been derived from rapidly rising linear welts. The former, the non-volcanic linear geosynclines, have been designated miogeosynclines, and the latter, volcanic-bearing, eugeosynclines (STILLE, 1941). The eugeosynclinal belts from their stratigraphic record must have been deeply subsiding belts having raised welts within that supplied much of their sediment, and volcanic islands that were the sites of their volcanism. From time to time, plutonic rocks invaded the welts, and new lands were raised by the folding of preceding geosyncline-filling sequences. The interpretation of the stratigraphy alone strongly suggests modern island arcs, but it has been found that ultrabasic intrusions are limited to the eugeosynclinal belts, just as they are now distributed through island arcs (HESS, 1939), and as can be seen on the map, the Pacific eugeosynclinal belt extends north-westward toward the modern Aleutian arc, and the eastern belt curves westward around the Gulf of Mexico to recurve into the Antillean arc around the Caribbean Sea into the eastern Andes of South America. Similarly, the island festoons of Indonesia pass north-westward into Burma-Himalayan mountain systems (STILLE, 1943).

The belts that subsided deeply with accompanying volcanism, the eugeosynclinal belts, were also quite mobile, the sites of principal orogenies, with accompanying folding, thrusting and plutonic intrusion. In the earlier stages, welts raised by the orogenies were eroded to yield detritus to the subsiding non-volcanic, miogeosynclinal belts separating them from the craton. And as these stopped subsiding or were deformed, the sediment spread into lenticular or trough-shaped geosynclines along the border of the previously relatively stable hedreocraton; these geosynclines (exogeosynclines) peripheral within the craton received detritus from rising welts in the linear (orthogeosynclinal) belts. In North America, the eastern eugeosynclinal belt had become so deformed and intruded by mid-Palaeozoic time that it ceased being dominantly subsiding; the detritus eroded from its welts first formed exogeosynclines within the hedreocraton in the late Ordovician. Extensive folding and thrusting with plutonic intrusion affected parts in the late Ordovician, and orogenies and accompanying intrusions continued in late Devonian and late Carboniferous. In the west, the belt remained one like modern island arcs until the late Mesozoic, welts yielding detritus to the miogeosynclines in the late Palaeozoic, and orogenies and intrusions being particularly intense in late Jurassic and latest Cretaceous ; the first exogeosyncline was that of the later Cretaceous. Though plutons were predominantly in the earlier volcanic geosynclinal (eugeosynclinal) belts, some extended into the non-volcanic miogeosynclinal belts.

With the consolidation of the belt of volcanic-bearing geosynclines and tectonic islands, deeply subsiding, discontinuous, relatively non-volcanic geosynclines (epieugeosynclines) developed such as those of the late Palaeozoic of the eastern coast, and the Cretaceous and Tertiary of California. Along the Atlantic, there followed great rift-bounded troughs (taphrogeosynclines) that received several miles of non-marine sediments in the late Triassic, with accompanying basic lava flows and intrusions. With their conclusion, the Atlantic and Gulf Coasts of the Jurassic and Cretaceous became generally stable, affected by broader warping movements in which long non-volcanic troughs (paraliageosynclines) formed during late Mesozoic and Tertiary with flexures within, and axes near or beyond the present shores ; these contain the principal petroleum-bearing sediments and the salt-domes along the Gulf Coast. Their form is much like that of the miogeosynclines of the early Palaeozoic, but they lie beyond them on the deformed, intruded and stabilized rocks of the ancient island arcs, and their seaward border is in the relatively stable, non-volcanic shields or low cratons of the western North Atlantic and the Gulf of Mexico. The latter also border the active modern Antillean arc, with its deep submarine trough and belt of low gravity anomalies (HESS, 1938) which is considered to be the recurved continuant of the ancient island arc belt of the Palaeozoic through eastern Mexico. The belt continues into the eastern Andes, where the region to the east is the high craton of the Brazilian Shield. In north-western North America, the hedreocraton, the high craton of the early Palaeozoic seems to continue into the low craton of the northern Alaskan coast and the Arctic Ocean (PAYNE, 1948).

Although the pattern of North American arcs was established in the early Palaeozoic along the borders of the present continent, the interior had not been stable through Protozoic (pre-Palaeozoic) eras. The earlier Protozoic rocks of the Canadian Shield evidence deeply subsiding, sediment and volcanic filled geosynclines (PETTIJOHN, 1943) that were subsequently deformed and intruded in a manner analogous to the eugeosynclines of the later history of the continental borders. Thus, one can theorize that the region of the present continent had at an early stage several belts of island arcs, with volcanic islands and tectonic welts, and that with successive destruction of each in successive orogenies with associated intrusion, the continent has become progressively, though interruptedly, larger at the expense of the low oceanic basins.

The theories of continental drift have direct influence on the interpretation of the histories of the American continents, just as they have in south-east Asia. The protagonists and antagonists have presented their arguments with results that seem not to have been so conclusive as to dissipate the camps of belief and derision (WEGENER, 1929; A.A.P.G., 1928; DU TOIT, 1937). Just as suggestive similarities that would seem to require original close juxtaposition may be given alternate interpretations, so mechanical objections to hypotheses may require revision of parts rather than rejection of the whole. Relatively few North American geologists have become advocates of continental drift; nor do the theories have as great impact on their problems as in some other continents. Some of the stratigraphic conclusions of the past two decades in North America change the picture held at the time that Wegener prepared his hypothesis. The evidence indicates that island arcs are but a part of history that has been restricted to narrow belts through a very long span of geologic time, perhaps from the earliest records. There is rather conclusive evidence that the eastern and western margins of the continent have gone through essentially similar history since at least the beginning of Palaeozoic time, though in different stages through this time. Island arcs are not peculiar to the western margin of the Pacific, but the western margin is but less mature in its development than the western coasts of the Americas. The writer conceives of western North America in the Palaeozoic and early Mesozoic as having had geography and structure similar to that lying between the island arcs of the western Pacific and the shore of the Asiatic continent; similar interpretation has been presented by Eardley (1947), though he restricted the belt to a more coastal area. Thus, if the western Pacific arcs are taken as evidence that Asia drifted relatively westward from the Pacific, America must be interpreted as having drifted relatively eastward at an earlier time. If the ancient arcs of the Atlantic Coast be given similar interpretation, the theory that they continued through the Antilles into the eastern Andes introduces grave problems, for they come to lie west of the Brazilian Shield. The sceptic is lead to question that drift can have had any part in forming the arcs. The stratigraphic record of North America gives significant evidence that is contradictory to some aspects of the theories as they have been presented.

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