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Stratigraphy and Sedimentology

Stratigraphie et Sédimentologie

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PREFACE

The conveners of Section 6 had a difficult time in that they had to strike a balance between the very large and important fields of stratigraphy and sedimentology in one section. It was plainly impossible to choose themes that could in any way cover the entire field in both disciplines, and so it was decided to plan for symposia on certain defined, but limited, topics.

The first of these, on the stratigraphic evidence for or against the relative movements of continental blocks, elicited a somewhat disappointing response, although several papers of considerable interest and importance are presented. The symposia on economic aspects of the genesis and diagenesis of carbonate rocks and the comparative stratigraphy and sedimentology of flysch basins, on the other hand, generated a satisfactory response in terms of numbers of papers and interest.

General papers, both in stratigraphy and sedimentation, covered a wide range. Some papers which were of interest to one or another of the symposia, but which, owing to shortage of time, had to be presented in the general sessions, are now grouped under the relevant symposia. The remainder are classified according to interest under stratigraphy or sedimentation.

The conveners would like to thank first all those who have submitted papers to the section, thereby contributing to the Congress program and to this volume. Papers in the first group have been reviewed and edited by J. D. Aitken, H. G. Bassett and R. deWit; those in the second group, by Jean Lajoie and R. G. Walker; those in the third group, by F. W. Beales, J. W. Keith, A. E. Oldershaw and G. P. Lozej; those in stratigraphy, by R. W. Macqueen, and in sedimentation, by R. G. Walker and J. Lajoie. All of the above are gratefully acknowledged.

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PRÉFACE

Les organisateurs de la Section 6 ont eu un moment difficile lorsqu'ils ont dû essayer de trouver un équilibre entre des chanps de connaissance aussi vaste et aussi importants que la stratigraphie et la sédimentologie, dans une seule section. Il fut tout simplement impossible de choisir des thèmes qui auraient pu dans tous les cas couvrir entièrement le champ de connaissance des deux disciplines, et c'est pourquoi il fut décidé d'établir pour les colloques certains sujets définis, mais limités.

Le premier de ceux-ci, les données stratigraphiques pour ou contre les mouvements relatifs des aires continentales, a suscité une réponse plutôt décevante, bien que diverses communications d'un tntérêt et d'une importance considérables aient été présentées. Le colloque sur les aspects économiques de la genèse et de la diagenèse des roches carbonatées ainsi que celui sur les études comparatives de la stratigraphie et de la sédimentologies des bassins de flysch, de leur côté, ont suscité une réponse satisfaisante tant au point de vue du nombre qu'à celui de l'intérêt.

Les communications d'intérêt général dans le domaine le la stratigraphie et de la sédimentologie couvrent un champ très vaste. Certaines communications qui auraient normalement dû se rattacher à l'un ou l'autre colloque mais qui, faute de temps, devaient être présentées à l'assemblée générale, sont maintenant regroupés dans les colloques adéquats. Celles qui restent sont classifiées selon leur intérêt en stratigraphie ou en sédimentologie.

Les organisateurs désirent remercier d'abord tous ceux qui ont présenté des communications à cette section, collaborant ainsi au programme du Congrès ainsi qu'à ce volume. Les communications du premier groupe ont été revisées et éditées par J. D. Aitken, H. G. Bassett et R. deWit; celles du deuxième groupe, par Jean Lajoie et R. G. Walker; celles du troisième groupe par F. W. Beales, J. W. Keith, A. E. Oldershaw et G. P. Lozej; celles de la stratigraphie, par R. W. Macqueen et de la sédimentologie, par R. G. Walker et J. Lajoie. Que toutes ces personnes soient chaleureusement remerciées.

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Sédimentation

The Stratigraphic Evidence for or Against the Relative Movements of Continental Blocks

Données stratigraphiques pour ou contre les mouvements relatifs des aires continentales

The Amazon Coast Geology

WALDIR MARTINS de REZENDE,
Brazil

ABSTRACT

The integration of geophysical and geological data from the Marajó basin and the Amazon continental shelf and slope led to the construction of a regional geologic model comprising a sequential deposition of seaward prograded geoclines. The net progradation is so extensive that the bulk sedimentation is both ensialic and ensimatic. While the geoclines are depositionally confined, the supposedly underlying extension of the Amazon and Maranhão Paleozoic layers is structurally interrupted in consequence of the South American-African rifting.

Lithostratigraphic information from the area under consideration permitted a global facies interpretation of the geoclinal sediments which comprise subaereal clastics, inner shelf clastics plus carbonates, outer shelf carbonates and slope clastics. Paleontologic evidence indicates that sedimentation has been active from Lower Cretaceous up to Recent. Lithologic data and reworked Paleozoic palynomorphs established the Maranhão basin as the main source area up to the Oligocene; since then up to the present, the Amazon basin shared with the Maranhão basin as source areas.

The tectonics of the marginal and intracratonic taphogeosynclines in Brazil, especially those in the area under consideration, can no longer be explained without the support of the rifting and drifting of South America and Africa. Although the original continental drift theory was established mainly on the geomorphologic fitting of the continental margins, a geological approach was necessary to complement the previous information. The principal contribution of this paper consists in showing that the post-Jurassic geotectonic pattern in South America resulted from the rifting and the subsequent readjustment contemporaneous to the drifting, and that the continent did not drift as a rigid entity, but is fragmented into mega-mosaic shield blocks readjusted mainly by vertical compensation and by differential rotation relative to each other.

Authors' addresses are given at the back of this book.

Silurian Paleogeographic Development of the Proto-Atlantic Ocean

W. S. McKERROW,
Great Britain
A. M. ZIEGLER,
U.S.A.

ABSTRACT

The evolution of the British Isles and the northern Appalachians during Silurian times is examined in the light of plate tectonic theory. Silurian paleogeography is consistent with a Proto-Atlantic Ocean extending from the Southern Uplands of Scotland, through the central part of Newfoundland, to the Fredericton Trough of New Brunswick. Evidence suggesting that this ocean was contracting during the Silurian is:

(1) The loss of Cambrian and Ordovician faunal provinces on opposite sides of this ocean in late Ordovician time. Silurian faunal elements on opposite sides of the Proto-Atlantic appear to be identical.

(2) The fact that trench deposits on the northwest side of the Proto-Atlantic were progressively deformed after deposition, suggesting a line of ocean plate subduction. During the late Ordovician and Silurian, this trench was continually displaced to the southeast as folding of trench sediments and production of coastal mountains occurred along its northwest margin.

(3) The accumulation of thick piles of andesitic lava, particularly along the northwest side of the Proto-Atlantic. These are especially well seen in the Gaspé Peninsula of Quebec and in northern Maine.

(4) The gradual restriction of the seas and the onset of non-marine conditions during the late Silurian suggests the approach of the period of continental collision which terminated in the Middle Devonian.

An Andean type continental margin (Mitchell and Reading, 1969, p. 644) is envisaged for the edge of the Canadian Shield and its extension into northwest Scotland. The southeast margin appears to have been more passive, but in some areas, such as coastal Maine and adjacent New Brunswick, andesitic volcanism occurred.

INTRODUCTION

THE EVIDENCE for an early Paleozoic ocean lying along the line of the Caledonian/Appalachian orogen is very strong (Dewey, 1969; Bird and Dewey, 1970; Mitchell and Reading, 1971; Ziegler, 1970; McKerrow and Ziegler, 1971), and may be summarized as follows.

(a) Only oceanic sediments of Ordovician and Silurian age are present along the site of the former ocean: a strip of country now only about 50 miles wide which passes through the Southern Uplands of Scotland, central Ireland, central Newfoundland and the Fredericton Trough of New Brunswick.

Authors' addresses are given at the back of this book.

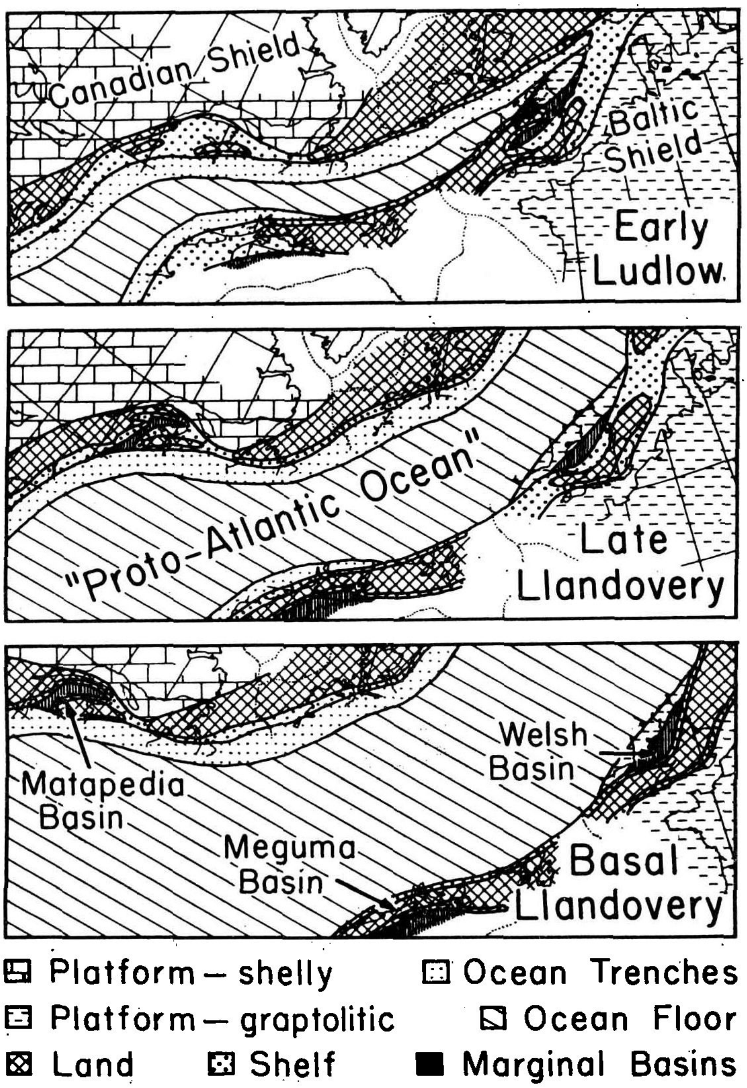

FIGURE 1 — Three stages in the Silurian development of the Proto-Atlantic Ocean (after Zeigler, 1970; and McKerrow and Ziegler, 1971).

(b) The Precambrian and Lower Paleozoic structural history has been very different on either side of this strip of oceanic sediments (Rodgers, 1968; 1970; Dewey, 1969; McKerrow and Ziegler, 1971).

(c) The Cambrian and Ordovician faunal provinces (Palmer, 1969; Williams, 1969) suggest that, until Ashgill time, the ocean was wide enough to prevent much mixing of the shallow marine animals on either side. It was the distinctness of these faunal provinces which first gave rise to Wilson's (1966) hypothesis of a wide Proto-Atlantic ocean in the Lower Paleozoic.

The paleomagnetic evidence for the relative positions of the Canadian and Baltic Shields is still far from satisfactory, but the few pole positions that have been determined for late Ordovician and early Silurian rocks from these two areas coincide in the western Pacific (Irving, 1964; Fig. 6.13). Thus, paleomagnetic evidence suggests that these two shield areas were in the same position relative to each other that they are today (Deutsch, 1969, p. 950). Other geologic evidence indicates that by Middle Devonian times, closure was complete and nonmarine conditions existed on the site of the former ocean basin (Friend, 1969, p. 706).

We have prepared paleogeographic maps for three stages in the Silurian (Fig. 1), using the North Atlantic reconstruction of Bullard *et al.* (1965, Fig. 7). This base map was simply cut along the site of the Proto-Atlantic, and the relative positions of the two halves was interpolated between the situations in the Late Ordovician and the Middle Devonian mentioned above. Such reconstructions are consistent with known rates of crustal convergence. They are also consistent with the fact that closure occurred earlier in Great Britain (early Devonian) than in the Northern Appalachians (middle Devonian), because the paleomagnetic evidence indicates that the crustal plates would have been closer to the northeast than to the southwest. In fact, the axis of rotation would seem to have been about the site of the present magnetic pole. The paleogeographic details plotted on Figure 1 have been taken from Ziegler (1970) and McKerrow and Ziegler (1971).

MARGINAL BASINS

Apart from the Proto-Atlantic Ocean, deep-water sediments (turbidites and graptolitic shales) were deposited in several marginal basins; these include the Welsh Basin and the Meguma Basin of Nova Scotia on the southeast side of the Proto-Atlantic, and the Matapedia Basin on the northwest side (Fig. 1). Unlike the ocean, there is no evidence that plate consumption took place on the continental margins of these basins. As the sediments in these basins are not strongly folded, the basins were probably never very much wider during the Early Palaeozoic than they are now. These basins can be distinguished from the ocean in several ways.

(a) These marginal basins at no time affected faunal distribution.

(b) Similar Precambrian rocks occur on both sides of the Welsh Basin and between the Meguma Basin and the Proto-Atlantic; they yield 580 to 600 million year dates in Anglesey, Cape Breton Island and southern New Brunswick (Dewey, 1969). These dates suggest that the Precambrian rocks lying on the ocean side of the Welsh and Meguma Basins were subjected to the same 580- to 600-m.y. event as the Malvern Hills of England, the Channel Islands, Brittany and eastern Newfoundland, which are all areas forming part of the continent to the southeast of the Proto-Atlantic Ocean.

(c) The sediments in these marginal basins are frequently seen to rest unconformably on older rocks. This contrasts with the Proto-Atlantic where we know of no major unconformities within the deep-water Proto-Atlantic sedimentary sequences, nor for that matter do we know of rocks older than Lower Ordovician.

(d) The turbidites of the Meguma and Matapedia Basins grade conformably upward in the Silurian into shallow-water deposits (McKerrow and Ziegler, 1971). This cover appears (as far as present outcrops permit) to extend over the whole width of the basin, suggesting, again, that there has been no very great expansion or contraction of these basins since the Silurian.

Bird and Dewey (1970, p. 1033) considered the Matapedia Basin to be the site of the ocean trench during the Early Paleozoic. In Silurian times, at least, this does not seem to have been the case. The history of this basin has been reviewed by McKerrow and Ziegler (1971). During the Cambrian and early Ordovician (until mid-Caradoc time) coarse clastic turbidites were being deposited in this area, perhaps on ocean floor which may have extended far to the northwest of its Silurian position. These turbidites were then folded and uplifted in mid-Caradoc times. This Taconic uplift was followed by the deposition of a thick succession of mid-Caradoc to mid-Llandovery calcareous flysch, though shallow conditions surrounded the basin on all sides except near Houlton, Maine, where the basin appears to have opened into the Proto-Atlantic. In places these Llandovery shelf deposits are seen to lie unconformably on the folded Cambrian and pre-mid-Caradoc turbidites. Toward the end of the Upper Llandovery, the shelf environments spread across the Matapedia Basin, the calcareous flysch succeeded by Upper Silurian and Lower Devonian shallow water sediments. This interpretation therefore suggests that in the Silurian, the northwest margin of the Proto-Atlantic lay about 150 miles to the southeast of its pre-Caradoc position.

THE CLOSURE OF THE PROTO-ATLANTIC OCEAN

Four types of evidence point independently to the closure of the Proto-Atlantic.

(a) The faunal provinces present in the Cambrian and early Ordovician become indistinguishable in the late Ordovician.

(b) The andesitic volcanic piles on both margins of the ocean suggest that, at different times and places, subduction zones lay below areas now exposed along the orogen. Plate consumption was thus taking place on both sides of the ocean.

(c) The deposition of oceanic turbidites and other sediments ceased in many areas before the end of the Silurian Period. Old Red Sandstone conditions appear in Scotland and western Ireland as early as the Wenlock, and gradually spread, allowing non-marine fish to cross the site of the former ocean by early Devonian time.

(d) Orogeny ranging in age from late Silurian in Great Britain to mid-Devonian in the Northern Appalachians probably resulted from continental collision.

Discussing faunal provinces, Williams (1969, p. 254) has shown how the coefficients of association between Ordovician Trilobite and brachiopod faunas of the Anglo-Welsh and Scottish - West Irish areas increase in the late Caradoc and Ashgill. During the Silurian, the faunas are virtually identical throughout the North Atlantic region. The width of ocean necessary to separate two provinces depends on the distribution of ocean currents and oceanic islands. Williams (1969, p. 259) has made an inference of what the currents might have been like, and concluded that they flowed sub-parallel to the ocean margins. Assuming this to be true, a relatively narrow ocean basin would have been sufficient to prevent migration. All that can really be inferred is that this ocean basin ceased to be a barrier toward the end of the Ordovician.

The closure of the Proto-Atlantic may also be inferred from the type of volcanicity along its margins. Calc-alkaline to alkaline lavas, commonly andesites, occur on the northern margin of the Proto-Atlantic in Scotland (Devonian); White Bay, Newfoundland (Silurian ?); northern New Brunswick and Gaspé Peninsula (Ordovician, Silurian and Lower Devonian); and on the southern margin of the ocean in England and Wales (Ordovician and Lower Silurian); Nova Scotia (Ordovician and late Silurian); southern New Brunswick and southern

Maine (Ordovician, Silurian and Lower Devonian). It has been suggested (Dewey, 1969; Mitchell and Reading, 1969; 1971; Fitton and Hughes, 1970) that all these areas lay above subduction zones, which, at different times, descended below the continental margins on both sides of the Proto-Atlantic. Some of these areas may have been island arcs (e.g., the Ordovician Borrowdale Volcanics of the English Lake District), others may have been Andean-type margins (e.g. the northern margin of the Scottish Southern Uplands). There is no doubt that both margins of the Proto-Atlantic contracted by plate consumption at intervals throughout the Ordovician, Silurian and Lower Devonian.

Sedimentation in the Proto-Atlantic Ocean frequently appears to have stopped earlier than in adjacent marginal basins. In the Southern Uplands no beds younger than Wenlock are known (Cocks *et al.*, 1971), although Ludlow turbidites continue in the Lake District and in North Wales. In Ireland, the uppermost fossiliferous Silurian is everywhere of Wenlock age, except in two areas: Dingle (where a shelly Ludlow succession occurs on the northwest margin of the Proto-Atlantic) and parts of Counties Tipperary and Waterford (where Ludlow beds occur above Wenlock turbidites near the southwestern margin of the old ocean) (Cocks *et al.*, 1971).

No fossils younger than Late Llandovery (C_6) are known in the areas of central Newfoundland covered by the Silurian Proto-Atlantic, although Ludlow beds may be present in the Bay of Exploits and at Sops Arm. In the Fredericton Trough, the latest graptolitic sediments which undoubtedly belong to the Proto-Atlantic area are of Wenlock age, though these appear to grade southward into the Waweig Formation of Ludlow-Pridoli age (Ruitenberg, 1967). It is thus possible that in New Brunswick some of these younger beds also occur in the area of the Proto-Atlantic ocean, but in the British Isles and Newfoundland, the deposition of sediments on oceanic crust appears to have ceased during the Wenlock.

Non-marine (Old Red Sandstone) environments appear earlier in the northeast of the area under consideration (Friend, 1969). On the northwest side of the Proto-Atlantic, non-marine conditions are present in the Wenlock of the Midland Valley of Scotland, while in the Matapedia Basin the Lower Devonian is marine. On the southeast side of the ocean the evidence is not so clear, but the transition from marine to non-marine sedimentation occurs at the base of the Lower Downtonian in Shropshire and at the base of the Upper Downtonian in the Arisaig area of Nova Scotia (Boucot *et al.*, in press).

Turner (1970) points out that there are two separate shallow marine thelodont faunas in the Silurian: one fauna occurs in Scotland and near Oslo; the other is present in Gotland, Germany, England and New Brunswick. This shows that by Ludlow time there was some shallow-water connection across the site of the Proto-Atlantic between Scotland and Oslo, but there must have been a marine area to the south of Scotland and Norway too wide for these fish to cross—probably there was an eastward extension of the Ludlow turbidites present in the Lake District.

In the Downtonian, fish shifted to more brackish environments. Turner also states that in the late Downtonian some new agnathan fish (traquairaspids and *Turinia pagei)* appeared in freshwater environments; this latter fauna occurs in Scotland, England, Germany, the Baltic, Russia and Vestspitsbergen. There is thus no doubt that by the end of the Downtonian, the two sides of the Proto-Atlantic were in close contact in the area of the British Isles, and probably the northward extension of this ocean between Norway and Greenland had also closed.