Late Precambrian evolution of North America: Plate tectonics implication

John H. Stewart
U.S. Geological Survey
Menlo Park, California 94025

ABSTRACT

Approximately 850 m.y. ago, the tectonics of North America changed from a pattern of scattered, locally deep epicratonic troughs to a pattern of encircling marginal miogeoclines. This change can be interpreted as indicating the start of rifting that extended almost continuously around the North American craton. This concept seems to require that North America was once an interior piece of a much larger continent and that the pieces of this fragmented continent drifted away to form new continents. A test of this hypothesis requires an analysis of the world-wide distribution of late Precambrian continents, a subject of current controversy and speculation.

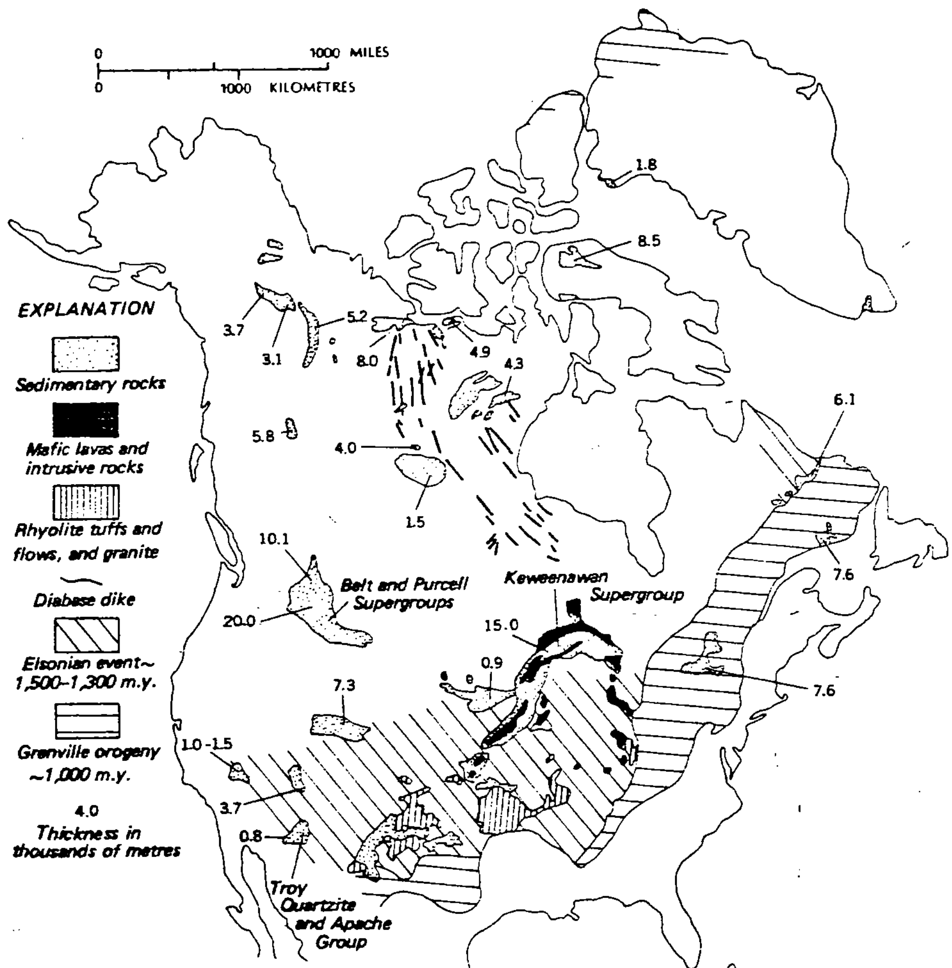

Figure 1. North American Precambrian rocks ranging in age from about 1,700 to 850 m.y. Compiled from many sources, including, in particular, Bayley and Muehlberger (1968), Fraser and others (1970), Gabrielse (1972), Goldich and others (1966, Fig. 6), Wynn-Edwards (1972), Donaldson and others (1973), Irving and others (1974), and Armstrong (1975). Elsonian event and Grenville orogeny include igneous activity and metamorphic overprinting of older crustal rocks. A few scattered intrusive complexes ranging in age from 1,000 to 1,200 m.y., such as Pikes Peak batholith (Hutchinson, 1972) in Colorado, Muskox layered basic intrusive (McGlynn, 1970) in northern Canada, and alkaline intrusives in eastern Canada (Gittins and others, 1967; Doig, 1970) are not shown. Included in figure are some uncertainly dated sedimentary rocks that may be younger than 850 m.y. (King and Beikman, 1974). These rocks include Chuar Group (Ford and Breed, 1973) of Grand Canyon region in Arizona and Bayfield Group of Keweenawan Supergroup and Jacobsville and Hinckley Sandstones (Halls, 1966; Lochman-Balk, 1971) of Lake Superior region of United States.

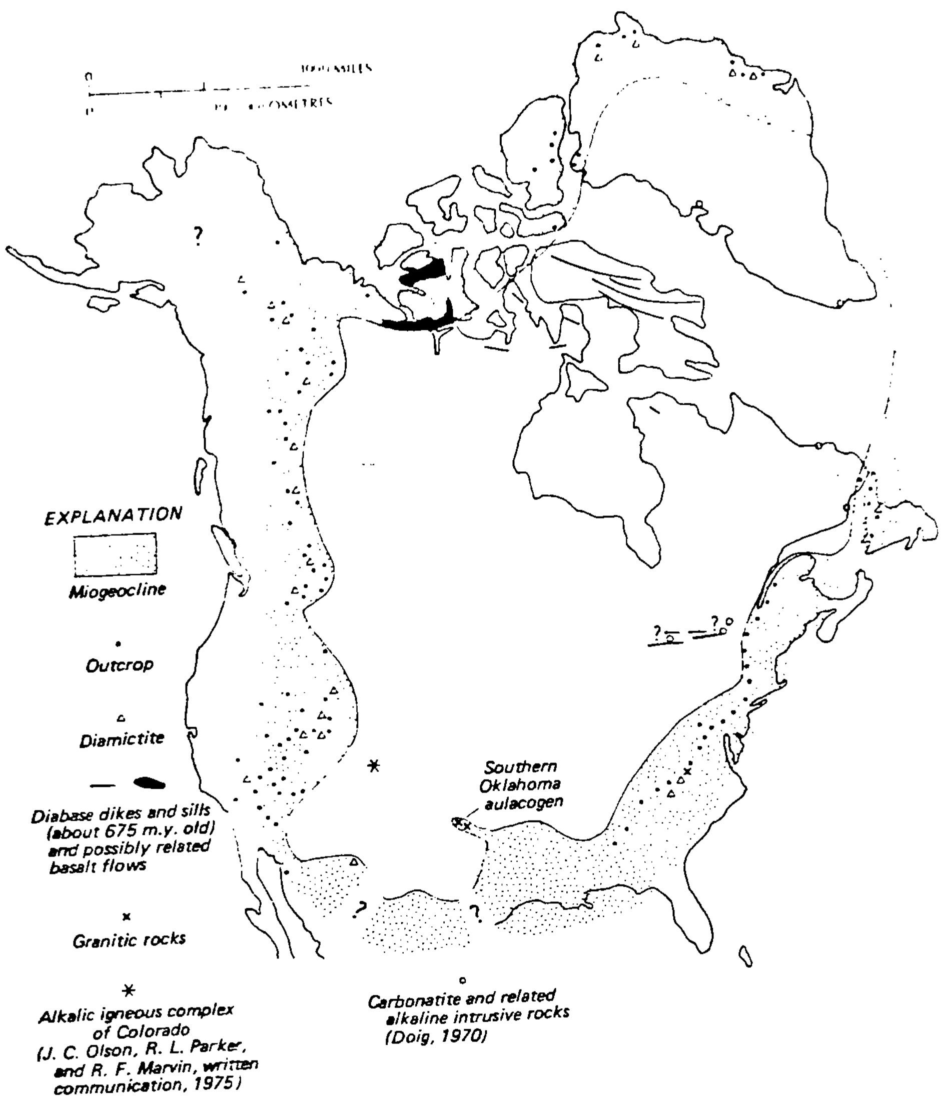

Figure 2. Precambrian and Lower Cambrian rocks ranging in age from 850 to 540 m.y. Compiled from many sources, including, in particular, Cowie (1971), Palmer (1971), Lochman-Balk (1971), Ham and others (1964), and Stewart (1972). Granitic and sedimentary rocks involved in Avalonian orogeny in southeastern Canada and Virgilina deformation in eastern United States are not shown.

INTRODUCTION

Great uncertainty exists about the distribution of continents in late Precambrian time. This uncertainty is due to the fragmentary record of these old rocks, to incomplete information, and to major interpretive differences. Geologic opinion is most diverse concerning the Precambrian and Paleozoic development of Africa (Piper and others, 1973; Hurley, 1972; Burke and Dewey, 1973b). One view is that major belts in Africa are zones of lithospheric plate convergence where continents that were once widely separated were brought together. The other view is that the orogenic belts are largely ensialic and were developed between continuous blocks of continental crust. Equally great uncertainty exists as to the Precambrian and Paleozoic development of China and some other parts of Asia, which appear to be composed of numerous microcontinents (Hamilton, 1970; Burrett, 1974; Terman, 1974).

This article presents data that may suggest major continental fragmentation of North America about 850 m.y. ago. If this concept is valid, then a major world-wide reassembly of continental fragments in late Precambrian or early Paleozoic time seems likely.

I compare here the geology of rocks of two age ranges: 1,700 to 850 m.y. and 850 to 540 m.y. The older age limit (1,700 m.y.) is approximately the age of recognizable events following the Hudsonian orogeny. This orogeny has a mean K-Ar date of approximately 1,735 m.y. ago (Stockwell, 1970) but is considered much older (ending approximately 1,800 m.y. ago) on the basis of U-Pb and Rb-Sr whole-rock isochron dates (Stockwell, 1972). The 850-m.y. date is approximately that of inferred rifting, although the dating of this event is not precise nor was rifting necessarily synchronous around North America. The later limit (540 m.y. ago) is the end of Early Cambrian time (Geological Society of London, 1964).

PRECAMBRIAN ROCKS 1,700 TO 850 M.Y. OLD

Rocks ranging in age from 1,700 to 850 m.y. in North America consist of metamorphic and intrusive rocks involved in the Elsonian event and Grenville orogeny, as well as relatively unmetamorphosed supracrustal sedimentary, volcanic, and intrusive rocks (Fig. 1). The supracrustal rocks rest on older crystalline basement or are the final deposits in epicratonic basins formed prior to 1,700 m.y. ago. The Elsonian event and Grenville orogeny involved plutonic activity and metamorphic overprinting of older crust. The Grenville orogeny has been interpreted in terms of plate tectonics theory to have been produced by continental collision (Dewey and Burke, 1973), and perhaps the Elsonian event is related to an older continental collision or to orogenic activity along an Andean-type continental margin.

Supracrustal rocks deposited in the interval from 1,700 to 850 m.y. ago are scattered throughout the North American craton (Fig. 1). Some occur in troughs that are inferred to have been fault bounded, at least on one side (McMannis, 1963; Crittenden and Wallace, 1973). Two of these troughs (the Belt-Purcell and the Keweenawan Supergroups) contain more than 15,000 m of sedimentary and volcanic rocks. Other supracrustal rocks occur in shallow troughs or basins, and some strata (Troy Quartzite and Apache Group) appear to have been deposited in a platform or shelf environment. Mafic intrusive and extrusive igneous rocks are commonly associated with the supracrustal sedimentary rocks and also occur, in Canada, as dikes cutting older metamorphic rocks.

The fault-bounded troughs and the abundance of mafic intrusive and extrusive igneous rocks suggest widespread extensional events in the interval from 1,700 to 850 m.y. ago, but in contrast to younger rocks, this extension cannot be shown to be confined to the margins of the craton. Instead, extension appears to have taken place sporadically across the entire craton, producing rift features and leading to emplacement of mafic intrusive and extrusive rocks.

Burke and Dewey (1973a) have presented a contrary view. They suggested that the major epicratonic rift features are related to a time of continental fragmentation that shaped the North American continent about 1,200 m.y. ago. They considered that most of the major sedimentary troughs are related to failed arms of radial rift systems and were connected to oceans that surrounded North America. This concept is based in part on the idea (Price, 1964; Fraser and others, 1970; Gabrielse, 1972; Monger and others, 1972; Seyfert and Sirkin, 1973; Harrison and others, 1974) that an ocean margin existed along the west edge of North America during deposition of the Belt and Purcell Supergroups and related rocks and that this ocean margin was in approximately the same position as later Cordilleran miogeoclinal deposits, such as those shown in Figure 2. In support of this view, Gabrielse (1972), on the basis of data from Price (1964), has suggested that the Purcell in southwestern Canada is a miogeoclinal deposit with deeper water sediments on the west. In addition, Fraser and others (1970) have indicated a westward decrease in grain size in rocks correlative with the Purcell in northwestern Canada and have suggested that the western, finer grained rocks are part of a miogeoclinal assemblage. Nonetheless, evidence concerning the location of an ocean related to deposition of the Belt and Purcell Supergroups is vague, and there is no firm evidence in the Great Basin in the southwestern United States of the location or even of the existence of such an ocean (Stewart and Poole, 1974). The interpretation suggested here is that most, if not all, of units such as the Belt and Purcell were deposited in epicratonic troughs. Some of these troughs may have extended into ocean basins to the west, but the location of such basins and of the continental margin at this time is not considered here to be definitely known.

The Purcell Supergroup and related rocks were mildly deformed and possibly metamorphosed in Canada before deposition of the next younger group of rocks, the Windermere Group. This deformation is referred to as the East Kootenay orogeny in southwestern Canada and as the Racklan orogeny in northwestern Canada. These orogenies have been tentatively attributed by Monger and others (1972) to the development of a subduction zone along western North America. If so, the continental margin must have been in nearly the same position as in latest Precambrian and Early Cambrian time (Fig. 2), although such an interpretation does not preclude the possibility of minor reshaping of the margin by rifting before deposition of the Windermere Group. Another possibility is that the East Kootenay and Racklan orogenies resulted from a continental collision, although this possibility seems unlikely, judging from the relatively minor deformation observed. Another interpretation is that these deformational events are related to compression and metamorphism within the epicratonic troughs, some of which are deep and probably represent sites of near rupture of continental crust. In this respect, the epicratonic basins are similar to aulacogens within which tectonic compression and extensive volcanic and plutonic activity have been described (Ham and others, 1964; Hoffman and others, 1974). The Racklan orogeny, in addition, includes extensional block faulting (Aitken and others, 1973) that could be related to the late Precambrian rifting event described here.

PRECAMBRIAN AND LOWER CAMBRIAN ROCKS 850 TO 540 M.Y. OLD

Rocks that range in age from 850 to 540 m.y. (Fig. 2) consist dominantly of quartzite and siltstone and generally minor amounts of conglomerate, limestone, and dolomite. The detrital sequence is remarkably similar everywhere in North America and grades from thin sandstone units on the craton to thick miogeoclinal sequences away from the continent. The miogeocline is developed mainly on older metamorphic and igneous basement rocks and only rarely on older relatively unmetamorphosed sedimentary rocks. Diamictites (a nonsorted sedimentary rock consisting of sand and [or] larger particles in a muddy matrix), which are commonly considered to be glacial in origin, occur near or at the base of the miogeoclinal wedge in western North America, in eastern Greenland, in western Newfoundland, and in the eastern United States (Schermerhorn, 1974). Volcanic rocks, generally mafic lavas including tholeiitic basalt, occur mainly in the lower part of the sequence in western North America, in western Newfoundland, and in the eastern United States. Whole-rock K-Ar dates from greenstone in the lower part of the miogeoclinal sequence in the northwestern United States range from 827 to 918 m.y. (Miller and others, 1973), and Pb-U dates on zircon from felsic rocks in the lower part of the sequence in the eastern United States (Rankin and others, 1969) suggest an original age of 820 m.y.

Mafic igneous rocks are also widespread (Fig. 2) in the Canadian Arctic (Fahrig and others, 1971; Robertson and Baragar, 1972; Fahrig and Schwarz, 1973). These rocks consist of voluminous diabase sills and dikes and apparently related basalt flows, and they have an average K-Ar age of about 675 m.y. (Franklinian age of Fahrig and others, 1971; Donaldson and others, 1973; Irving and others, 1974). Diabase dikes (Fig. 2) of possibly the same age occur in southeastern Canada (Murthy, 1971).

Rocks involved in the Avalonian orogeny in southeastern Canada (Poole and others, 1970) and the Virgilina deformation (Glover and Sinha, 1973) in the eastern United States are not considered here. In the Bird and Dewey (1970) and Rodgers (1972) models of eastern North America, these rocks formed far from the North American continent and were emplaced on North America after the closing of the proto-Atlantic Ocean in mid-Paleozoic time. The view that these rocks formed far from North America is accepted here, although Hatcher (1972) and Glover and Sinha (1973) have presented alternative models in which these rocks formed close to North America.

The late Precambrian and Early Cambrian detrital rocks (850–540 m.y. old) are considered to have formed along a newly formed Atlantic-type continental margin resulting from late Precambrian (approximately 850 m.y.) rifting. This concept has been developed independently for eastern North America (Bird and Dewey, 1970; Rankin, 1972; Rankin and others, 1973) and western North America (Stewart, 1972). Mafic volcanic rocks in both regions, as well as felsic and granitic rocks in eastern North America, have been interpreted to be related to the thinning and rifting of the crust during the continental separation. In addition, the southern Oklahoma aulacogen (Fig. 2), which contains radiometrically dated Early and Middle Cambrian volcanic and granitic rocks and older undated sedimentary and volcanic rocks (Ham and others, 1964), is considered to have developed as the failed arm of a three-armed radial rift system (Hoffman and others, 1974), the other two arms presumably forming part of the late Precambrian rift system considered here to have largely encircled North America.

The concept of an 850-m.y.-old rifting event is particularly speculative in western North America. As mentioned above, many geologists (Fraser and others, 1970; Gabrielse, 1972; Monger and others, 1972; Seyfert and Sirkin, 1973; Harrison and others, 1974) have suggested that an ocean margin existed in western North America during deposition of the Belt and Purcell Supergroups. Hoffman (1973), in addition, has described an even older ocean margin in northwest Canada that could be a precursor of the Belt and Purcell ocean. Burchfiel and Davis (1975) have tried, in part, to reconcile these different views by suggesting two times of rifting in western North America, one before deposition of the Belt and Purcell and one after deposition of these units (the 850-m.y.-ago event described here). If their suggestion is followed, then the 850-m.y.-ago event may have involved only relatively minor reshaping of the western margin of North America as a result of rifting and westward drift of microcontinental blocks away from the continent. Precambrian crystalline basement rocks that crop out in areas west of the main Cordilleran geosynclinal belt, such as in the northern Cascade Mountains (Mattinson, 1972), could be the remnants of these microcontinental blocks. Such Precambrian rocks have been considered to be either the basement of late Precambrian and early Paleozoic island arcs lying along western North America (Churkin, 1974), an interpretation consistent with the concept of an 850-m.y.-ago rifting event, or island-arc assemblages once far removed from North America and transported there by lithospheric plate convergence in Mesozoic time (Monger and others, 1972).

The 675-m.y. age of the mafic igneous rocks in the Canadian Arctic is younger than the general date of rifting (850 m.y. ago) suggested here, although both the 850-m.y. and the 675-m.y. dates are approximate. If the dating is correct and if the mafic rocks in the Arctic indicate a time of continental rifting, then the development of the continental margin in the Arctic was considerably younger than elsewhere in North America. Alternatively, the mafic rocks may indicate a secondary event unrelated to the shaping of the continent. Some of the dikes in the Canadian Arctic trend at a relatively high angle to the presumed Precambrian margin of the continent, indicating either that the dikes have nothing to do with the shaping of the continent or that they represent rifting extending into the continent along abandoned arms of radial rift systems.

The late Precambrian and Early Cambrian detrital sequence (850 to 540 m.y. old) comprises the oldest deposits in North America that clearly have a depositional pattern similar to overlying early Paleozoic strata. The pattern shown in Figure 2 is, for example, nearly identical to that of Middle Cambrian, Late Cambrian, and Early and Late Ordovician sequences (Palmer, 1971, Fig. 5; Seyfert and Sirkin, 1973, Fig. 10.5 *A*, *B*, and *C*) in North America. The late Precambrian and Early Cambrian detrital sequence can be considered the initial deposits in the Cordilleran and Appalchian geosynclines, although this view is controversial in regard to the former (compare, for example, the interpretations of Stewart, 1972, with those of Fraser and others, 1970; Gabrielse, 1972; Monger and others, 1972; Seyfert and Sirkin, 1973; Harrison and others, 1974).

DISCUSSION AND CONCLUSIONS

The main suggestion of this paper is that a marked change occurred in the tectonic setting of North America approximately 850 m.y. ago. Prior to that time, deposition was primarily in scattered, locally deep epicratonic troughs; after that time, deposition was in marginal miogeoclines that extended almost continuously around North America. In terms of plate tectonics theory, such a change may be due to rifting that extended around the continent.

The rifting concept is difficult to analyze without data concerning the worldwide distribution of continents in late Precambrian time, data that are sparse and difficult to interpret. If, for example, the cratonic masses of Africa were brought together by plate convergence during the Pan-African orogeny (Burke and Dewey, 1973b) in late Precambrian and early Paleozoic time, then some of these African cratonic masses could be pieces of continental crust rifted from North America during the late Precambrian. On the other hand, Piper and others (1973) have suggested on the basis of paleomagnetic data that the cratonic areas of Africa were approximately in their present relative position and orientations as early as 2,200 m.y. ago and that much of Gondwanaland may have been a single continent in Precambrian time. If this is the case, then perhaps part of the large Gondwanaland continent itself may have been in contact with part of North America. Such a hypothesis has been proposed by Piper and others (1973). Other cratonic areas that might have once encircled North America include the Precambrian shield areas of Europe and Asia, including the numerous microcontinents of China. Spall (1973), on the other hand, although he emphasized the difficulties in interpreting present paleomagnetic data, suggested that Europe, North America, and parts of Africa drifted independently of one another, and thus were not joined, during Precambrian time after about 2,000 m.y. ago. Along western North America, as previously described, another possibility is that the rifted pieces were relatively small and now form the Precambrian basement of areas west of the main Cordilleran geosynclinal belt.

Regardless of the validity of the rifting concept, the tectonic change described appears to be part of an evolution of lithospheric structural systems as described by Burke and Dewey (1973b). This development started more than 2,700 m.y. ago with a permobile phase, when the Earth was so mobile that no plate tectonics system operated and continued through a transitional phase to the plate tectonics regime that started about 2,000 m.y. ago. The 1,700 to 850–m.y. period described here is, in the early part of Burke and Dewey's plate tectonics regime, characterized by extensive cratonic instability, development of cratonic basins and troughs, and emplacement of extensive basaltic dike swarms. The 850 to 540–m.y. sequence represents part of a time of cratonic stability that has continued to the present.

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ACKNOWLEDGMENTS

This report has benefited from views and comments by M. E. Bic Burke, P. J. Coney, M. D. Critter W. R. Dickinson, H. Gabrielse, F J. E. Harrison, Henry Spall, anc R. F. Marvin supplied an unpu

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