Meetings

The Precambrian

The Third Penrose Conference of the Geological Society of America met at the University of Wyoming Science Camp in the Medicine Bow Mountains west of Laramie from 19 to 24 September 1970. Its purpose was "to ascertain the main facts and views about the early lithospheric evolution of North America" and to place them in global context.

Interest in Precambrian (or, better, pre-Paleozoic) history has grown with realization of its great length, its far-reaching implications for biologic, atmospheric, and planetary evolution, and its decipherability—stimulated by the insights of Joseph Barrell, Arthur Holmes, and others among the pioneering galaxy whose creative works set the stage for the emergence of better integrations of earth evolution. The nuclear physicists and geochemists gave the coup de grâce to the generalizations that, until recently, continued to impede Precambrian studies and made an anachronism of the very term "Precambrian," when they opened the farthest vistas of time and broadened the applications of geochronology by isotopic analyses of radioactive and radiogenic elements beginning in the 1940's. Geologists were quick to see and act upon the new possibilities, and they have been supplemented in increasing numbers by others, especially during the past decade. Paleontologists, sedimentologists, biologists, organic chemists, atmospheric scientists, planetary astronomers, and geophysicists have taken notice of and have contributed to the growing but still very tangled and incomplete body of knowledge about this first seven-eighths of earth history.

Despite the deficiencies inherent in so vast a system of disrupted and incompletely preserved information, this information is what we must work with. The purpose of this conference was to bring together some of the people working toward the development of new syntheses and unifying concepts in order to exchange and integrate information and ideas in an informal but structured framework.

It is not possible in brief space to do more than give the general flavor of the discussions, which ranged over the preserved record of earth history from 3.6 to 0.6 aeons (years $\times 10^9$) ago, over the entire globe and out to the moon, and which involved 38 North American geologists and five from other continents. Discussion, always lively, sometimes heated, swirled around many issues in and out of scheduled meetings, but it returned most frequently to certain focal points. These included: (i) the nature, age, distribution, origin, and younger analogs of the greenstone-granite belts that constitute a prominent fraction of the oldest recognized rocks in many shield areas; (ii) the thickness, lateral extent, and geographic arrangement of primitive continental crust and the question of the existence and nature of supracrustal rocks antecedent to about 3.6 aeons ago; (iii) the time of onset, the facies patterns, the lateral extent, and the correlation of the oldest clearly cratonal and ensialic sedimentary sequences; (iv) the younger pre-Paleozoic and its correlation, including the question of the base of the Paleozoic; (v) the utility in correlation of distinctive, possibly time-marking criteria and events such as glacial episodes, banded iron formation, and stromatolite zones; (vi) the problem of a pre-Paleozoic time scale and time-stratigraphic nomenclature with special reference to geologic cartography and map classification; and, of course, (vii) the implications of all these things for the evolution and differentiation of the earth.

The oldest rocks on all continents, between about 3.6 and 2.7 to 2.5 aeons, include, as a conspicuous component, rocks of the so-called greenstone-granite belts or terrains, as stressed elsewhere by C. R. Anhaeusser, R. Mason, the Viljoen brothers, and others. In addition to commonly enveloping granites and gneisses, these include ultramafic to felsic volcanics, graywackes, bedded cherts, and sometimes amphibolite schists and the oldest banded iron formation. Such greenstone piles, having thicknesses up to 20 km and often chaotic structure, average from 30 to 70 percent essentially unweathered sediments. The remainder, at places as much as 98 percent, is volcanic. Mature sediments like clean quartzites are rare, as are carbonate rocks. Such assemblages, generally older than 2.6 aeons and generally called Archean (*1*), were described in detail from Western Australia (by Rudolph Horwitz), from South Africa (by Hugh Allsopp and A. E. J. Engel), and from Minnesota (by Paul Sims, Gilbert Hanson, and S. S. Goldich). Canadian equivalents, described by John McGlyn and Roger Walker, contain remarkably well-preserved sediments. Greenstone-granite belts of similar age occur also in central Africa, Nigeria, the Ukraine, and the Kola Peninsula, as well as in a much younger sequence (1.82 to 1.72 aeons old) described by Charles Anderson and L. T. Silver from central Arizona. They find their nearest analogs in relatively recent calc-alkaline volcanic suites and associated sediments such as the circum-Pacific island arcs and the Fossa-Magna of southern Honshu. The fact that volcanic rocks of the greenstone suite are chemically like those of modern island arcs and mid-ocean ridges (including a similarly low content of K, U, Th, and Pb) leads to the conjecture that core-mantle differentiation was already essentially complete when they were erupted, and that they were erupted either at protocontinental margins or through a relatively thin protocontinental crust (perhaps 5 km thick). Associated intrusive granites and granite gneisses seem to have been emplaced as shallow intrusions that overlapped sedimentary-volcanic deposition broadly enough in time to (at least locally) become unroofed and shed granitic clasts into the still-accumulating intruded sediments. Despite some obvious similarities between such complexes and the Benioff or Subduction Zone complexes of the plate tectonics model, the old greenstone complexes contain only metamorphic assemblages typical of a high thermal gradient and lack blueschists. Hence these old greenstones were probably not exposed to deep burial with a low thermal gradient as in the blueschist environment (although some were buried deeply with high thermal gradients). They may not be plate margin complexes like the blueschists but may have been generated as a result of foundering of thin protocrust over hot spots in a then generally hotter mantle.

Engel proposed a crustal model calling for differentiation of a thin but still essentially basaltic and extensive continental crust over a single large force field (convection cell?). This crust was ensimatic and probably constituted a single continental mass (or surely no more than three). It became more ensialic with time as the continental K ratio (K_2O/Na_2O) increased above unity. In this model a later ensimatic episode began with continental breakup and outflow of ultrabasics from the mantle beginning only about 200 million years ago. Thus the sedimentary-volcanic record is seen as primarily extracratonic and ensimatic from 3.6 to roughly 2.6 aeons ago and during the last 0.2 aeon, separated by a long and fluctuating interval of mainly cratonic and ensialic sedimentation and volcanism between about 2.6 and 0.2 aeons ago. This model drew vigorous criticism from Silver and James Gilluly, reinforced by Henno Martin who sees the crust of South Africa as 32 to 35 km thick by no later than about 2.6 aeons ago. John Sutton, on the other hand, who visualizes episodes of crustal mobilization and craton building with durations of about an aeon each beginning 3.6 aeons ago, sees his shorter-term changes as not inconsistent with the very long-term underlying cycle of crustal evolution proposed by Engel. The question of the oldest supracrustal rocks was woven into this same set of discussions. The oldest rocks in North America, the 3.6-aeon-old Morton and Montevideo gneisses of the Minnesota River Valley (discussed by Goldich from his work with C. E. Hedge and T. W. Stern) may well represent the reconstitution of antecedent sediments, as may rocks of other old greenstone-granite belts. And the conglomerates of the Moodies System in South Africa contain clasts of sedimentary rocks unlike those known to underlie them, and possibly of pre-Swaziland age. Still the search for known pre-3.6-aeon rocks has everywhere run into a basal barrier of nonpreservation or metamorphism.

The oldest cratonal sequences in North America are those of the older Proterozoic (middle Precambrian), mainly in the Canadian Shield (including its extensions into the United States). These are in every way of cratonal chemistry and lithic aspect, although parts of most such sedimentary prisms were deposited in deeply subsiding linear depressions or basins, or grade laterally into shield-margin sediments. Such sedimentary complexes are not known before about 2.6 aeons but are repeated upward through geologic time. Examples from the lower Proterozoic (and associated tillites) were described in detail from the type Huronian of the north shore of Lake Huron (by Grant Young), from the circum-Ungava geosyncline (by Erich Dimroth), and from the northwestern Slave Province (by Paul Hoffman). These deposits and their associations with other rocks of cratonal geochemistry imply the existence by that time of a well-differentiated sialic crust of substantial thickness—the antecedent protocontinent or protocontinents on or adjacent to which most of the now-accessible sedimentary record was to accumulate. It was suggested (by Young) that tillites and aluminous quartzites may provide a time marker for rocks of older Proterozoic age over a large part of North America. Most of the distinctive chemical deposits known as banded iron formation (BIF) are also associated with such wedges, particularly in the range of 1.8 to 2.2 aeons ago.

The younger pre-Paleozoic (younger Proterozoic)—that is, younger than about 1.8 to 2.0 aeons ago—is characterized by the extensive formation of ferric-oxide–coated, continental clastic deposits ("red beds"). Some overlap in time of these with characteristically older facies now seems probable. The younger Proterozoic is most characteristically distinguished in its platform or shallow basin facies by an abundance of carbonate rocks, by red beds, by abundant algal structures (stromatolites), and at places by flood volcanics (Keeweenawan). But it also expresses itself in ensialic clastic complexes grading from platform to deep basin or trench. In North America this part of the pre-Paleozoic sequence seems to be the most varied and, in some respects, the most difficult to correlate. Such younger Proterozoic deposits were described from the Belt "basin" of the northern Rocky Mountains in the United States (by J. E. Harrison); the Mackenzie, Selwyn, and Rocky mountains of the Canadian Cordillera (by Hubert Gabrielse); the Wasatch and Uinta mountains (by Max Crittenden and Chester Wallace); southern Death Valley (by B. W. Troxel); central and northern Arizona (by D. E. Livingston); and the Appalachians (by P. B. King). Some correlations were suggested, but they suffer from a dearth of radiometric dates in critical places.

As for the base of the Paleozoic, A. R. Palmer, reflecting the current view of many Phanerozoic paleontologists, proposed that it be drawn at the first appearance of shelly fossils, down from the once generally preferred position below the oldest olenellids and, more recently, the oldest trilobites. Cloud prefers a still lower position, at the base of the range zone of Metazoa, below the trails and body imprints of the Ediacarian, Kuibis, and upper Vendian beds of central Australia, South West Africa, and the U.S.S.R. He supports the idea that a useful operational boundary might be drawn just above a pair of tillites that is found in uppermost pre-Paleozoic deposits at many places (Norway, Greenland, Russian Platform, Siberian Platform, South West Africa, South Australia, Western Australia, and perhaps elsewhere), and below which is the youngest so-far established occurrence of *Conophyton*, a seemingly distinctive Precambrian stromatolite.

Correlation of pre-Paleozoic times and events is, of course, hampered by the scarcity of definable biologic zones and the frequent absence of radiometric dates. It would be convenient if there had been widespread contemporaneous episodes in crustal evolution that left distinctive marker zones in the rock record. In a broad sense, but with much uncertainty and overlap, we see such aids to correlation in the broad trends of crustal evolution described above and in the equally broad clustering of ages of plutonism and volcanism. But something more is sought. It may be asserted that desperation causes Precambrian geologists to grasp at straws, but glacial episodes and the seemingly general (but not universal) termination of banded iron formation about 1.8 to 2 billion years ago offer some hope.

Tillites, varved clays, and water-laid glacial deposits make their first recorded appearance not long after the onset of a cratonal type of sedimentation, beginning with the deposition of Huronian sediments on the Canadian Shield about 2.6 to 2.5 aeons ago, and perhaps equivalent rocks in the Medicine Bow Mountains. Similar, but much younger, glacial deposits, often as a pair of tillites, seem to cluster in the uppermost pre-Paleozoic rocks of Norway, Greenland, the Russian and Siberian platforms, South West Africa, southern and western Australia, and perhaps at other places. If all present continents were at that time gathered in a single circumpolar sialic blob, one might visualize such a late pre-Paleozoic glacial episode as being truly "worldwide" as far as records are concerned. Since there is enough evidence to suggest both that this might be so and that it could provide a well-defined operational boundary between Paleozoic and pre-Paleozoic, the possibility deserves intensive, open-minded study. An interesting possibility to be considered here involves the idea that associated lowering of groundwater levels might be reflected by the deep leaching and oxidation of much older BIF protores commonly observed where glacial deposits of younger pre-Paleozoic age are missing.

If Cloud's model of early biospheric-atmospheric-lithospheric evolution is valid, then the onset of red-bed sedimentation should be expected to overlap only slightly in time with the last major episode of banded iron formation, denoting another phase of crustal evolution that seems to have time significance and generally to separate older from younger Proterozoic. Stromatolite zonation, if it can be shown to have consistent interregional applications, would apply on a scale of units hundreds of millions of years long, and primarily to the younger (middle and upper) Proterozoic. Soviet stromatolite students generally have supported this view, recently with the limited concurrence of Martin Glaessner and associates and of Cloud. But at this conference both Hans Hofmann and Paul Hoffman strongly questioned the utility of interbasinal stromatolite correlation on grounds of their experience with the Proterozoic rocks of Canada.

All this interplay made evident both a broad agreement about the main modalities of crustal evolution during pre-Paleozoic time in North America, and much disagreement about details, about the philosophy on which a stratigraphic nomenclature or symbolism should be based, and on how many major divisions should be recognized and what names or symbols should be applied to them. In general this is so the world over at the present time. In broad terms, informed geologists generally recognize (i) a basal granite-greenstone-graywacke-bedded chert-amphibolite facies older than about 2.4 to 2.7 aeons; (ii) an intermediate facies of mainly ensialic clastic prisms or wedges that includes the oldest clean quartzites and generally the youngest banded iron formation above the greenstone-granite facies and older than about 1.8 to 2.1 aeons; and (iii) a younger, more diversified set of rocks which characteristically include the oldest red beds, an abundance of commonly stromatolitic carbonate rocks, and, at many places tillite-containing sediments somewhat older than about 0.6 aeon. The words Archean, Eparchean, Katarchean, lower Proterozoic, and middle and upper Proterozoic are commonly applied to these divisions or parts of them; but, even though the same broad groupings of rocks are recognized, usage of terms is not consistent from one continent and country to another, and there seems to be little prospect of agreement on a uniform global nomenclature at this time.

The consensus at the Medicine Bow conference, insofar as there was one, was that it would be premature to seek nomenclatural agreement. In retrospect it seems not terribly important that we could not agree on names or precise boundaries in view of the fact that we did see the same broad trends and were able to discuss them without much terminological difficulty. This is attributable, above all, to the magnificent labors of the last two generations of geochronologists. But that does not mean that radiometric numbers should define rather than calibrate crustal evolution. The issue will be rejoined—there is no doubt of that. And if it is successfully resolved, the groundwork laid at this conference may take some of the credit.

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Notes

1. The terms Archean and Proterozoic here refer to major divisions of the pre-Paleozoic, older and younger, respectively, than about 2.5 to 2.6 aeons, following current practice in Canada where the great bulk of North American pre-Paleozoic rocks are found. Two of the respondents to a draft of this report objected to that usage as not properly reflecting the lack of agreement on nomenclature at the conference. Another felt "that almost everyone agreed that the Precambrian . . . should be divided by arbitrary absolute time boundaries." I did not detect such a consensus, and it is convenient for present purposes, and consistent with much accepted practice, to utilize the terms Archean and Proterozoic in their Canadian sense. The reader should realize, however, both that opinion and practice are unsettled and that there was no agreement among the conferees in favor of this or any other terminology.
2. My research on the primitive earth, my contribution to this conference, and the expenses of attendance and participation by H. L. Allsopp, R. L. McConnell, and myself were supported by NSF grant GB-7851 and NASA Exobiology grant NGR-05-010-035.

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