measuring system sufficiently "tight" or leak free, and the uncertainty introduced by prolonged drilling-induced disturbances.

The special nature of flow and its characterization in low-diffusivity formations is well illustrated by recent field studies in the Cretaceous Pierre Shale. Quartz pressure transducers were permanently cemented into boreholes terminated at three levels in the 250 m thick shale. This technique gave a high probability of successfully sealing the boreholes, but required highly reliable instrumentation because retrieval is not feasible. Pressure measurements from the three transducers have shown that drilling induced disturbance is still dissipating more than a year after sealing the boreholes. However, these long-lived disturbances, which are apparently caused by near-field inelastic dilatation, were relatively minor. In this rock, at least, the measured pressures showed no significant changes after the boreholes had been sealed for several days.

The measured pressures, which after more than a year apparently closely approximate the natural conditions, indicate an interesting pattern in the vertical dimension; all are significantly below hydrostatic and the lowest hydraulic head is at mid-level in the shale. In a system with dominantly vertical flow such as this one, the resulting flow must be toward the shale interior from the upper and lower formation boundaries. This unusual regime can be explained as a response to erosional unburdening over the last several Ma. The rate of rebound dilatation is sufficient to increase pore volume more rapidly than fluid flow can occur to accommodate it. According to this interpretation, the same flow regime will persist for a significant period in the future, even if erosion were to cease. Thus the site studied may represent a rare instance in which it is possible to predict groundwater flow over the next 10^5 years with some degree of confidence.

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Geologic Evolution of South America During Late Proterozoic

The welding and final consolidation of the Gondwana Super-continent was achieved during late Proterozoic times, by activation and agglutination of several mobile bets that form a continuous tectonic network around older cratonic areas. On that occasion, the geologic evolution of South America cannot be dissociated from that of Africa, both continents being affected by the essentially synchronous Brasiliano and Pan-American orogenic cycles.

The central-eastern part of the Brazilian Shield was strongly involved in the late Proterozoic orogeny, which produced the most visible geologic structures, not only with the Brasiliano mobile belts, but also over their cratonic areas (São Francisco, São Luiz, Rio de La Plata), affected in different ways by tectonism during the latest Precambrian and early Phanerozoic. In contrast, the northwestern part of the shield (Amazonian Craton) was almost unaffected by the Brasiliano orogeny, its structures being older, formed principally in early and mid-Proterozoic times.

Different types of late Proterozoic mobile belts can be described in South America according to their tectonic significance and development:

1. The Periamazonian Folded System (Paraguay–Araguaia–Tocantins and associated belts), as marginal units at the eastern and southern borders of the Amazonian craton.
2. The Mid-Coreau fold belt, correlative of the Pharusian belt in Africa, as marginal units at the eastern border of the São Luiz -west African craton.
3. The Oiapoc belt, correlative of the Rockelide belt in West Africa, ensialic and intracratonic, in view of the probable link of the Amazonian and West African cratons in late Proterozoic times.
4. The Brasilia, Rio Preto, Sergipe, and related folded belts, as marginal units at the western and northern borders of the S¸ao Francisco craton.
5. The Araçuai fold belt, correlative of the West Congolian belt, with intracratonic development, considering the obvious connection of the São Francisco and the Congo–Kasai cratons in late Proterozic times.
6. The Ribeira fold belt, marginal to a cratonic unit that is supposed to be present beneath the sediments of the Paraná basin.
7. The Don Feliciano belt, marginal to the Rio de La Plata craton at its southeastern border.

In addition, two large areas with crustal shortening, basement reactivation, and intense tectonism along megasutures can be characterized:

1. The Borborema structural province, correlative of the Eastern Nigerian province in Africa, in which a complex interaction of microplates and microcontinents occurred during the Brasioliano–Pan-African orogeny.
2. The Central–Coiás collisional terranes, a mosaic of tectonic blocks bounded by large thrusts and transcurrent faults, generally associated with the Transbrasiliano lineament.

Finally, fragments of late Proterozoic belts can be identified within the domains of the Andrean cordillera, overprinted by Phanerozoic tectonomagmatic events. Their paleogeographic position and tectonic significance cannot be envisaged with the reduced data presently available.

The marginal belts exhibit the well-known twofold distribution: a peli- carbonatic component over and along the cratonic border, with skin tectonics and reduced magmatism typical of passive margin evolution; and a flysch-type volcanosedimentary component, including important amounts of bimodal volcanics and calcalkaline plutonic rocks characteristic of magmatic arcs and associated tectonic environments.

The geometry of the late Proterozoic mobile belts in South America is strongly influenced by structures originated in previous mid-Proterozoic tectonic events that occurred between 1800 and 1000 Ma. These include crustal fracturing and development of rift-type environments, as well as the evolution of ancient passive margins. For example, an extensive metamorphic belt of mid-Proterozoic age extends semicontinuously below the supercrustals of the Brasilia and Rio Preto folded belts, across the Borborema province, the probably onto the Eastern Nigeria belt in Africa. One other example is the Araçuai–West Congolian belt, which occupies an area previously affected by strong tectonism and development of aulacogenic basins in mid-Proterozoic (Espinhaço–Kibaran times.

At continental scale, the structural trends of the Brasiliano–Pan-African belts indicate the existence of practically synchronous multilateral stresses within the lithospheric plates, partially following previous zones of crustal weakness. This can be produced by complementary deformational adjustments of the continental plates as response to major events, analogous to the modern India–Asia collision. In this scenario, two large tectonic zones are the best candidates for such major collisions: the Hijaz–Mozambique megasuture, which is the probable site of connection of East and West Gondwana; and the Transbrasiliano lineament, which cut across South America and extends in North Africa along the Pharusian and Dahomeyian megasutures.

Considering pervasive calcalkline granitoids as indicators of subduction-related juvenile material, the Transbrasiliano lineament may have been the site of consumption of a previous oceanic basin, and subsequent collision of two large continental masses, one including the Amazonian and the West African craton, the other including the São Francisco, Congo–Kasai, and Kalahari cratons. A smaller wedge-shaped oceanic basin, opening towards the south (the Adamastor Ocean), can also be envisaged to account for the observed features within the Don Feliciano and Gariep belts, formed in connection with its closure in late Proterozoic times.

The deformations connected with lithosphere cooling at the end of the Brasiliano orogenic cycle produced widespread fracturing with graben formation and associated volcanism, with ages around 520–580 Ma, in all of the mobile belts but especially along the weakness zones of the Ribeira and Don Feliciano belts and along the Transbrasiliano lineament in Ceará and Goiás.

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Contribution to Geochronological Subdivision of Precambrian of South America

The Geochronological Research Center of the University of São Paulo is celebrating 25 years of existence, with about 16,000 determinations already done. These data associated with other available data from different laboratories proved a considerable amount to be worked out in terms of the geochronologica evolution of South American Precambrian.

The absolute majority of the data were achieved through Rb-Sr (60%) and K-Ar (40%) methods. This is indeed a modest geochronological background, if it is taken into consideration the geographic distribution and the dimensions onf the shield areas are around 5,000,000 km^2.

The major stratigraphic marks proposed by Almedia (1971), with quite few number of data for the most important tectonomagmatic cycles are now being confirmed, with improvement expected. It is also observed that the recent proposition made by the Submission on Precambrian Stratigraphy (SPS), signed by Plumb and James (1986), may be useful for the Precambrian of South America, if some adjustments will be done.

Age values in the range of the Archean I Era (>3.5 Ga) are practically unknown up to now, this being understood only as a result of the present stage of knowledge.

Age values in the range of the Archean II Era (3.5–2.9 Ga) have been obtained, but most of them still need further improvement in terms of new analytical methodologies. Generally, they have been detected with a character of relict among many other values of younger ages of the end of the Archean, in the basement of old cratonic blocks and of Early Proterozoic mobile belts. This situation tends to be changed with the introduction of new methodologies of analyses, but for the moment we should state the impossibility of speaking about a complete cycle prior to the end of the Archean.

The geochronological representation of the Archean III (2.9–2.5 Ga) is very good all over the shield areas, usually in some scattered portions of the basement of old cratonic blocks (Santa Izabel, Jequié, Lençóis, Xingu,

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Central Goiás, Rio Piranhas, and so on) and of the basement of the Early Proterozoic mobile belts (Western Bahia, Salvador–Juazeiro, Maroni-Itacaiunas), etc. Mostly these Archean data reflect the climax of metamorphic activities, both of low-grade and high-grade terranes. These tectonomagmatic events are enclosed in the Jequi–e cycle. Many of the continental masses accreted during the Jequié cycle exhibit today a very irregular geographic–geologic distribution as product of Proterozoic events of rifting, drifting, and collisions. A paleogeographic reconstitution of the original framework of the Archean terranes is impossible to figure out.

The Early Proterozoic in the South American continent has its limits proposed between 2.5–2.4 and 1.8 Ga., different from that proposed by the SPS (2.5–1.6 Ga). Particularly a period of this era, 2.1–1.8 Ga, is of special importance due to diversified phenomena of folding, metamorphism, and igneous activities, recognized as the Trans-Amazonian cycle. Accreting processes and crustal reworking processes of several intensities emphasize that this cycle is responsible for extensive agglutination of continental masses that characterize the history of the following mid-Proterozoic.

Prior periods or events of tectonic quiescence and sedimentation during the Early Proterozoic (Au-U bearing conglomerates, BIFs, etc.) do not have direct geochronological data yet, but they are estimated around 2.7/2.5–2.2 Ga. The transition periods of the last stages of cratonization, given by K-Ar method, vary from 1.9 up to 1.7 Ga, with the value of 1.8 Ga the most usual.

The evolution of the South American continent during mid-Proterozoic times includes a diversity of events of orogeny, reactivation, quiescence tectonic, platformal sedimentation, and continental rifting, with diachronism from place to place. For these reasons it is not possible to propose a rigid scheme of time markers or even a scheme of subdivision like that one proposed by the SPS.

The most important events of the orogeny took place in restricted areas along some special fold belts such as Rio Negro–Juruena. 1.7–1.5 Ga. They were identified mostly through the climax of the magmatic or tectonometamorphic activities.

The major cycles of formation of sedimentary and volcanic sedimentary cratonic covers of the mid-Proterozoic supercontinents may be outlined only in an informal way. It is possible to figure out four major events, one more (older) than those of the local orogenies: 1.89–1.7 Ga ("Uatumã" and "Rio dos Remédios cycle"); 1.7–1.5 Ga ("Beneficente"); 1.4–1.2 Ga ("Caiabis"); and 1.0–0.95 Ga ("Guajará Mirim"), according to different sites of cover occurrences and to a still unsatisfactory group of geochronological data. There are a mutual recovery in age between the orogenic processes and the platformal sequences, and indeed they should be somehow (orogeny and lithosphere activation processes) connected at that time.

So far, even recognizing the further possibility of subdivision of the mid-Proterozoic in four different time intervals (as was done by the SPS) in the South American continent, this is not proposed with the present data. The above mentioned marks should be accounted as informal, as preliminary results from a stage at the reconaissance scale.

In the range of the Proterozoic III Era (0.9–0.57 Ga) is situated the Brasiliano cycle, by all means the most important and extensive of all in the final structuration of Western Gondwanaland. In this sense, "cycle" should be understood to include magmatism preceding orogenesis and intense deformation, metamorphism, and plutonism (main stages of orogenesis). Because there is some geochronological evidence, including some paleontological data, that the episodes of rifting and formation of the volcanosedimentary and sedimentary basins accounted for the Brasiliano fold belts took place in the preceding mid-Proterozoic, along different phases of evolution, from one belt to another (since 1.8 Ga). Only a few sequences may be attributed to the span of time proposed for the Proterozoic III itself.

Moreover, the late and posttectonic events of the Brasiliano cycle, along the main fold belts and reactivated forelands, may be observed since the late Proterozoic (0.58 Ga) up to the beginnings of the Ordovician period (0.46 Ga).

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The Ideas of A. G. Werner and J. Hutton in America

1800 to 1820 can be looked on as a crucial time period in the history of geology in the United States. While far removed from the intellectual centers of London, Edinburgh, and the Continent, a group of highly individual scientists made the transition from purely descriptive geology to a predictive, sometimes experimentally tested science.

During its development in the last decades of the eighteenth century in Europe the science that we recognize as, and that was now called, geology had emerged as a field of study apart form generalized natural philosophy. American geologists first studied and echoed the theories from Europe. As the century progressed, they added their field evidence and laboratory experience to come to independent judgment on theories of rock origin and mineral characterization.

The best known late eighteenth century theorists for rock origin were James Hutton (1726–1797) of Edinburgh and Abraham Gottlob Werner (1750–1817) of Freiberg, Germany. Werner was well known for his descriptive mineralogy as well. Hutton's theory included not just igneous origin for virtually all rocks, but also the assumption of vast time periods for the processes we observe to form the world as we see it. Werner's theory, informed by field observation in his native Saxony, was that rocks were formed by successive precipitation and deposition from water. This theory served as an explanation for rock stratigraphy as well as a predictive tool for further discovery. Werner was at least as well known as the author of a method for mineral classification that used his "external characteristics" in a systematic way.

There were a number of enthusiastic, sometimes thoughtful and well educated, American men of science who went beyond the descriptive reports of travelers to conjecture about the science. For this short paper the contributions of six of these men will be discussed. Some were and are well-known, and were associated with institutions that continue to the present. Others are not so familiar, but they were influential in, and representative of, the geology of their time. There were others who should be included in any complete account, but the length of this paper does not allow it. The six are: Thomas Cooper (1759–1839), who was born in London but came to the U.S. in 1795; William Maclure (1763–1840), who first came to the U.S. in 1782, and who traveled widely; Samual Latham Mitchill (1764–1831); Archibald Bruce (1777–1818); Benjamin Silliman (1779–1864); and Parker Cleaveland (1780–1858).

Thomas Cooper always remained more outside the establishment than did some of his colleagues, and followed a sometimes astonishing variety of callings. Although his impact may have been greatest as an educator, he was active as a chemist as well as a geologist, lectured, published, and edited a journal. Although active in the laboratory in analyzing minerals, he thought that minerals should not be studied out of their geological context. He criticized Cleaveland for his favorable view of an aqueous origin for basalt. In 1813 Cooper gave a very even-handed discussion of Werner's Neptunism and Hutton's Plutonism.

William Maclure is best known for his geological map of the U.S., published in 1809. Geologists of today can easily recognize the rocks of the east coast from his description, although many interpretations are different. His 1818 paper on rock origin is not quite so well known. Maclure used Wernerian nomenclature, as did many geologists on both continents, because it was descriptive and serviceable. However, after noting that a fluid origin was necessary for both the systems in question, he found that where "positive analogy finishes, and probable conjecture begins, will be the natural line which will divide the rocks into *two classes*;" (Maclure, 1818, p. 266). One of those classes was igneous, the other aqueous. In 1819 he published an article particularly addressing Wernerian classification.

Samuel Latham Mitchill, born on Long Island, studied at Edinburgh. Although grounded in European geology and theory, his interpretation of American phenomena was original and based on his own careful field observations.

Archibald Bruce was known as a mineralogist and as the editor of the four parts of the first volume of the *American Mineralogical Journal*, published from 1810 until 1814. His analysis of a red oxide of zinc (Bruce, 1811) revealed his familiarity with the methods of Werner, Kirwan, and other European "hands on" mineralogists.

Benjamin Silliman is known for his work at Yale and as the editor of *The American Journal of Science*. Although he had studied law, he was offered a position as professor of chemistry and natural history at Yale. To learn the subjects he studied at Philadelphia and at Edinburgh. He eventually committed himself to a theory of granite origin by a combination of heat and water.

Well known in his time, Parker Cleaveland was the author of *An Elementary Treatise on Mineralogy and Geology*. He displayed his thorough familiarity with European mineralogy, much of his information having come from Kirwan, Jameson, Werner, and Brongniart. In the geology section he postulated not the two rather standard possibilities for basalt origin, but also added a third.

All of these men used European ideas to clarify and explain American geology. Many of them extended those ideas by their own observations and creativity.

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