If this is put on smaller sphere, everything fits — is earth expanding?

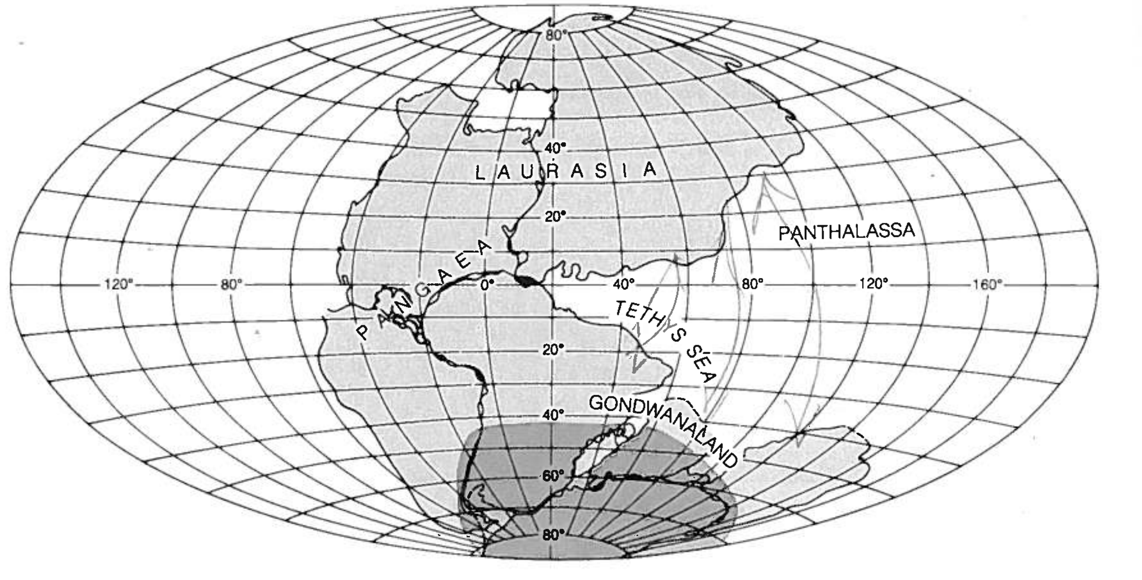

Figure 19-1
The ancient landmass Pangaea, meaning "all lands," may have looked like this some 200 million years ago. Panthalassa ("all seas") evolved into the present Pacific Ocean, and the present Mediterranean Sea is a remnant of the Tethys. Permian glacial deposits are found in widely separated areas, such as South America, Africa, India, and Australia. This distribution is simply explained by postulating a single continental glacier flowing over the south polar regions of Gondwanaland in Permian time, before the breakup of the continents. Probable extent of glacier shown by shading.

Although the theory received serious attention for about a decade, aside from a few vocal geologists in Europe and South Africa, "continental drift" never caught on. The proponents could not come up with a plausible driving force. More important, drift advocates buttressed their speculation with special pleading, selecting evidence patently favorable to their views, evidence that was far from incontrovertible. Aside from the geometrical matching of continents, their main arguments were based on fossil and climatological data. The evolution of vertebrates and land plants showed similarities in development on different continents up to the supposed breakup time, after which they showed divergent evolutionary paths. The distribution of Permian glacial deposits in South America, Africa, India, and Australia was difficult to explain in terms of separate glaciers, some close to the equator. Note, however, that if the southern continents are reassembled into Gondwanaland in the south polar region, a single continental glacier could account for the glacial deposits (Fig. 19-1). "It has always happened that after several distinguished palaeontologists have presented evidence favourable to continental drift, some other equally distinguished ones have proceeded to point out other facts that are made more difficult to explain"—so argued Sir Harold Jeffreys in his influential book *The Earth.* Independent, diverse, corroborative evidence would be needed before the scientific establishment would abandon prevailing ideas and elevate an unorthodox speculation to the level of a generally accepted theory.

In 1928, Arthur Holmes, a widely respected British geologist, wrote an article invoking the mechanism of thermal convection in the mantle as the driving force. Holmes proposed that subcrustal convection currents "dragged the two halves of the original continent apart, with consequent mountain building in the front where the currents are descending, and ocean floor development on the site of the gap, where the currents are ascending." Holmes came close to expressing the modern notions of plates, divergence, and subduction when he speculated that a subcrustal basaltic layer serves as a conveyor belt that carries a continent along to the place where the belt turns downward into the mantle, leaving the continent resting on top. Figure 19-2, which depicts his concept, contains many

Conveyor [illegible]

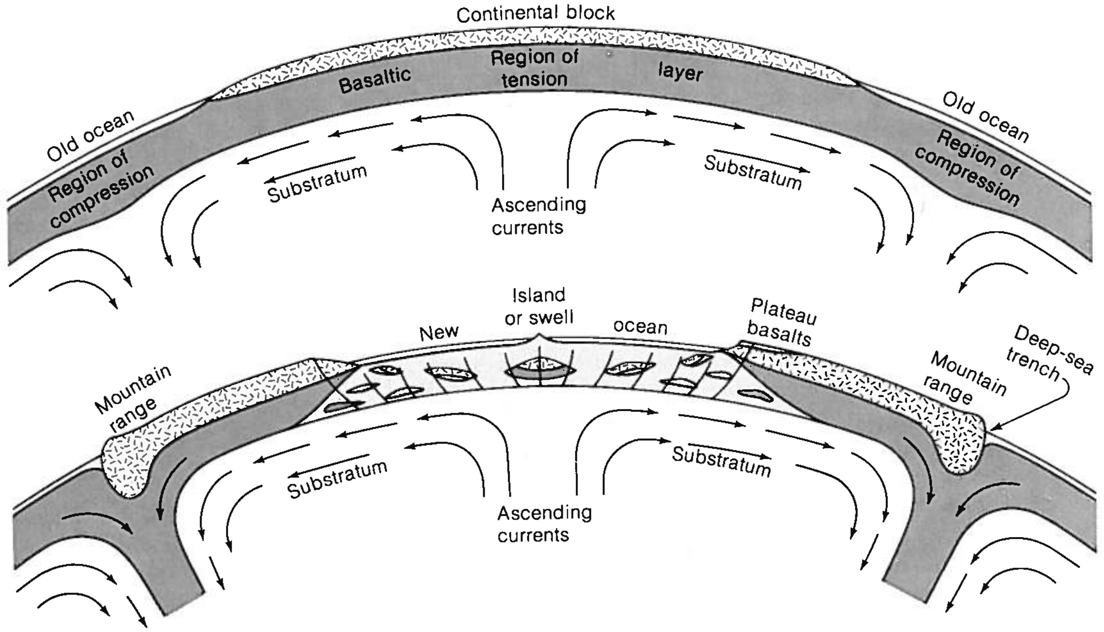

Figure 19-2
This early convection model, which remained unknown to many geologists for 30 years, was proposed by Arthur Holmes around 1930. It shows a continent being pulled apart by rising mantle currents, with new ocean developing from the growing rift. In the vicinity of a descending current, a mountain range and bordering deep-sea trench develop. Holmes's theory, which has been called "sea-floor stretching," is a forerunner of the modern theory of "sea-floor spreading." The figure is modified from an illustration published by Holmes in 1929 in the *Transactions of the Glasgow Geological Society.*

of the ingredients of the theory of sea-floor spreading as we know it today. Nevertheless, Holmes called attention to the tenuous nature of his views when he wrote that "purely speculative ideas of this kind, specially invented to match the requirements, can have no scientific value until they acquire support from independent evidence."

Convincing evidence began to emerge as a result of extensive exploration of the sea floor during the years following World War II. In particular, the mapping of the mid-Atlantic ridge and the discovery of the deep, crack-like valley or rift running down its center line sparked much speculation. In the early 1960's Harry Hess of Princeton University suggested that sea floors separate along the rifts in mid-ocean ridges, and that new sea floor forms by upwelling of mantle materials in these cracks, followed by lateral spreading (see Fig. 15-38). The work of Vine and Mathews, mentioned in the previous chapter, showed how the oceanic magnetic patterns could be explained by Hess's concept. Thus was born the theory of sea-floor spreading. Within a few years abundant confirmation would be available from the study of such diverse evidence as that provided by worldwide magnetic-anomaly surveys, the observation of earthquake mechanisms, the measurement of heat flow, and the determination of the thickness and age of the sedimentary layers of the sea floor.

It remained for a younger generation of geophysicists to broaden the concepts of continental drift and sea-floor spreading into the more general theory of plate tectonics. Beginning about 1967, they extended the idea of Hess and Canadian geophysicist J. T. Wilson about the mobility of the lithosphere by identifying the separate lithospheric plates and discussing the geometry of their relative motions and the phenomena that occur at their boundaries. By the end of the 1960's the evidence became so persuasive that most Earth scientists, except for a few prominent holdouts, embraced these concepts. Textbooks were revised, and specialists began to think of the implications that the new discoveries held for their own fields.

Let us return to the question raised earlier about why these new concepts became generally accepted so late in the history of geology. There are different styles among scientists. Some sci-