Paleogeography of Ancient Worlds

Goals

1. examine the evidence on which reconstruction of depositional environments for sedimentary rocks is based
2. illustrate how Cambrian sedimentary rocks can be used to reconstruct the Cambrian depositional environments of North America
3. demonstrate that the succession of similar depositional environments that existed at different times during the Cambrian indicate a transgressive sequence and changing Cambrian landscapes across North America
4. introduce the concept of polar wandering, and how this idea caused geologists to consider the reality of plate motion
5. examine the utility of paleomagnetic data to determine the positions of continents throughout geologic time
6. discuss the mechanisms of plate tectonics, and how movement of continents throughout geologic time could be identified
7. review the paleogeographic reconstructions of ancient worlds for selected intervals of geologic time

Introduction

Sediments accumulate on the Earth's surface in localized low or flat areas called **depositional environments**, because of the downward force of gravity. These regions are characterized by particular transporting media (gravity, ice, running water, wind, or water waves); climatic, sedimentary textures; grain mineralogies; and commonly unique plant and animal life.

A comparison of the preserved remains of these features found in ancient rocks with those observed under similar conditions in modern depositional environments can be used to infer conditions that may have existed in ancient worlds, and thereby to suggest the existence of landscapes in ancient worlds similar to those of today.

Sea level change causes shifts in the positions of sedimentary environments. Shorelines move landward (**transgression**) during periods of rising sea level because of increased rates of **sea-floor spreading**, **melting of glacial icecaps**, or **localized shoreline subsidence**. Shorelines move seaward (**regression**) during periods of falling sea levels because of decreased rates of **sea-floor spreading**, **building of glacial icecaps**, or **localized outbuilding of shorelines**.

Increased continental deposition results from widespread transgression, and increased continental erosion results from widespread regression. Biological productivity seems to benefit from transgressive events, and species commonly suffer mass extinction during regressive events.

Whereas sedimentary rocks provide evidence of the nature of ancient landscapes, **paleomagnetic data** locked inside abundant extrusive **igneous rocks** provide valuable evidence about the geographic location of these ancient landscapes. Tiny mineral crystals of **magnetite** (black iron oxide) found in basalt rocks record the **ancient magnetic field alignment** present at the rocks' **time of cooling**. Such information has been found to include both **direction to true north** and the **orientation of the earth's magnetic field lines of force**.

The orientation of the long axes of magnetite crystals found inside the basalt rock faithfully preserve these data from the time of the rock's cooling from lava. Although the direction to true north as indicated by magnetite crystal orientation in ancient surface basalts varies widely between the different continents of today's world, it was impractical to assume that more than a single north magnetic pole could ever exist. The realization that plates of the earth's crust move helped resolve this **polar wandering** problem.

When the widely separated continents of today are placed together in their ancient alignments, the multiple pole directions as indicated by studies of ancient surface basalts from different continents resolve themselves into a single direction to true north. Despite the fact that these basalts have been subsequently carried to different, faraway regions by later plate movement, unless the rocks have been heated to their melting point, the original alignment remains intact inside.

Although the causes of plate movement remain under intensive study and debate, the effects of plate movement are readily identified and provide important information about the landscapes of ancient worlds. The relative motion observed between the adjoining edges of two adjacent plates, or **plate boundaries**, describes the type of plate movement.

When the edges of adjacent plates move toward each other, the boundary is termed **convergent**; the processes associated with the colliding plates include earthquakes, volcanism, and mountain building. When the edges move away from each other, the boundary is termed **divergent**; the processes associated with spreading plates include earthquakes and volcanism. When the edges move past each other, the boundary is termed **transform**; the main process associated with this boundary type is the occurrence of earthquakes.

Convergence of crustal plates has the effect of building continents, divergence of crustal plates rifts them apart, and the transform motion of crustal plates can produce either larger or smaller continents. Overall, the **tectonic** history of a continent can be reconstructed by a study of the landforms present, and their relative ages.

The **geologic age** of each basalt sample studied from different locations on a single continent, or from locations on different continents, can be determined by numerical dating. Thus, both the **paleogeographic position** and the geologic age of thousands of basalt samples throughout the world have been determined. The synthesis of these two studies provides vital information that allows us to reconstruct the **paleogeography** (continent and ocean configuration) of ancient worlds, and to open a window onto the landscapes on which the evolution of life as we know it has occurred throughout geologic time.

Exercises

Sedimentary Depositional Environments

A major surface process of the **rock cycle** is the **transport** of eroded sediments from a **bedrock** source to a **depositional site** where the sediment is no longer moved, either because of its size or because of the inability of the transporting medium to transport it further. These **depositional environments** include both **clastic** environments, where sediments composed of preexisting rock and mineral fragments are transported in from another region, and **chemical** environments, where dissolved ions precipitate to form crystal aggregates of a single mineral species in restricted environments characterized by unique water chemistries.

Terrestrial sedimentary environments such as **rivers** and **alluvial fans**, for example, can be combined to produce a **clastic wedge** of sediments shed from an eroding **mountain range**.

Marine sedimentary environments such as **beaches**, **clastic shelves**, and **carbonate shelves** indicate the existence of a stable, **passive tectonic plate margin**. Carbonate shelves indicate warm, shallow-water conditions where huge volumes of **limestone** may form. Undersea landslides characterize the **shelf edge** depositional environment, which commonly indicates the proximity to a deep-sea trench and the existence of an unstable **active tectonic plate margin** characterized by earthquake and volcanic events.

Throughout the Cambrian Period, a stable, passive tectonic margin existed along the entire edge of the North American continent. Shoreline position was indicated by the presence of a basal sandstone, the nearshore shelf region by an overlying shale, and the offshore carbonate shelf area by limestone strata. As the seas **transgressed** across North America from the southwest, south, and southeast, these lateral sedimentary environments of **beach**, **nearshore shelf**, and **offshore shelf** became stacked as vertical sequences of shoreline **sandstone**, nearshore shelf **shale**, and offshore shelf **limestone** sedimentary rock formations (see Figure 1).

1. Northern Inyo County, California (after Palmer, 1971)
3. Calls Fort, Utah (after Palmer, 1971)
12. Mt. Martin, Arizona (after Hayes and McCone, 1975)

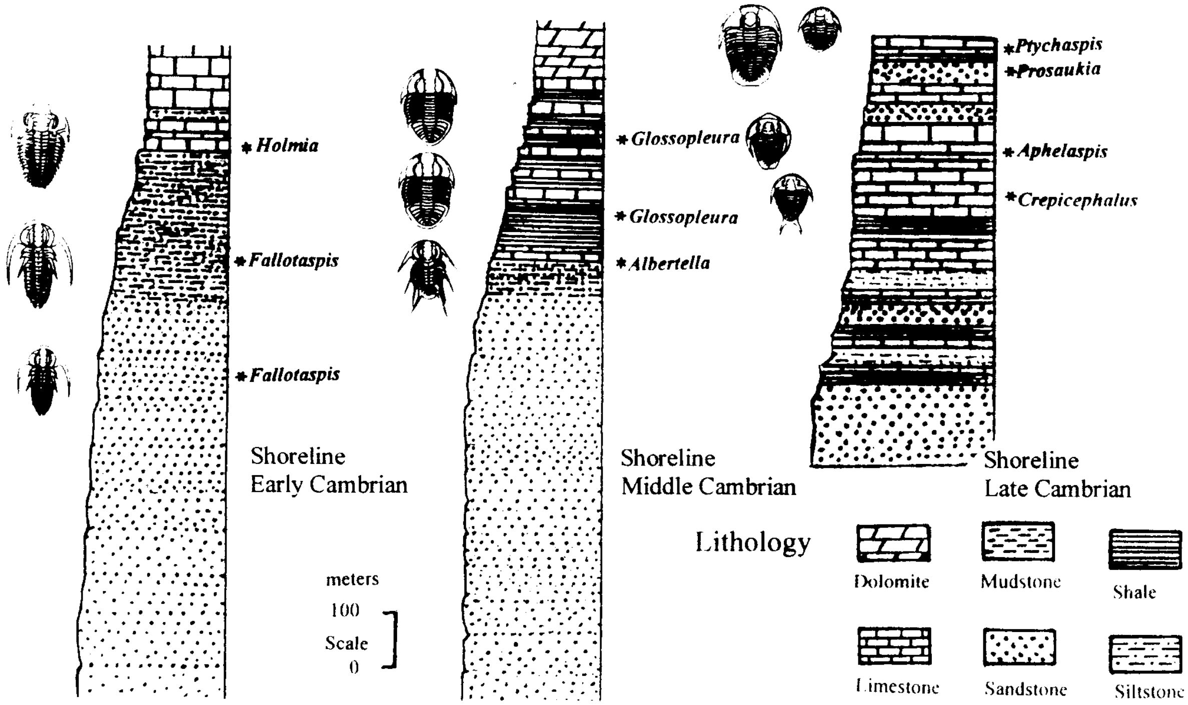


Figure 1. Cambrian transgressive sedimentary sequences of the western United States

As life on land developed, terrestrial sedimentary environments became easier to identify as invertebrate fossils (Silurian Period), vertebrate fossils (Devonian Period), plant fossils (Devonian Period), and trace fossils provided additional clues about the nature of the landscapes. **Alluvial** and **coastal plain** sedimentary environments were most favorable to life forms living on land. These sedimentary environments also favored the preservation of fossils because the rapid deposition of fine-grained sediments quickly buried animal remains and also denied access of oxygen to the corpses that were buried there.

Tectonic landscapes are commonly indicated by wedges of coarse, angular, mineralogically diverse sediments (farther away) or by erosion surfaces (closer). **Desert landscapes** are indicated by sedimentary structures characteristic of sand dunes, seasonal precipitation (flash-flooding and intense drying), and deposition of evaporite minerals such as gypsum. Thus, the combination of sedimentary rock types, bedding and sedimentary structures, fossils and trace fossils, and overall stratigraphic and structural relationships of sedimentary rock formations in a region all provide clues as to the identity of the ancient depositional environment(s) present and the nature of the ancient landscapes that once existed there.

Information Provided by Paleomagnetic Data

The extrusive igneous rock **basalt** is the most common and widespread igneous rock found on the Earth's surface. During cooling, its magnetite minerals crystallize with their long axes parallel to the force lines of the Earth's magnetic field. The north-seeking end of the magnetite crystal's long axis points in the direction of the **magnetic north** pole, just as the north-seeking pointer on a compass points to what the layperson interprets is **geographic north**. Magnetite crystals inside the basalt are thus oriented to the **paleomagnetic north pole** direction that was present at the time of cooling.

When paleomagnetism was first being studied, this measurement led to considerable confusion, because different magnetic north values were being indicated for rocks of different ages from the same location (see Figure 2). It was assumed at this time that continents were fixed in their positions, and so somehow the pole had to move. This concept was described as "polar wandering."

The idea sounded reasonable enough for one continent, but when the magnetic north values for rocks of the same age from different continents were compared, the data indicated different locations for the same pole (see Figure 3). Clearly, there could not be multiple poles!

When the fixed continents were moved together into their ancient orientations however, the multiple pole directions resolved themselves into a single direction (Figure 4). The poles were not moving—it was the continents that moved. We now know that ancient magnetic north directional data are different and independent of the present-day direction to north as provided by a compass, because the modern orientation of a particular continent differs greatly from its ancient positions.

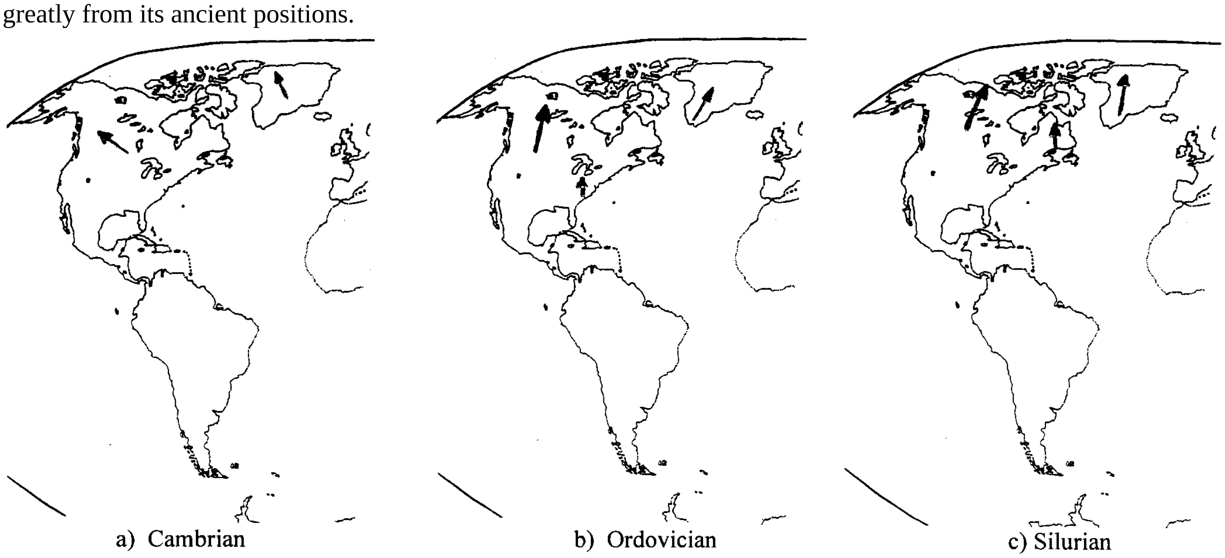
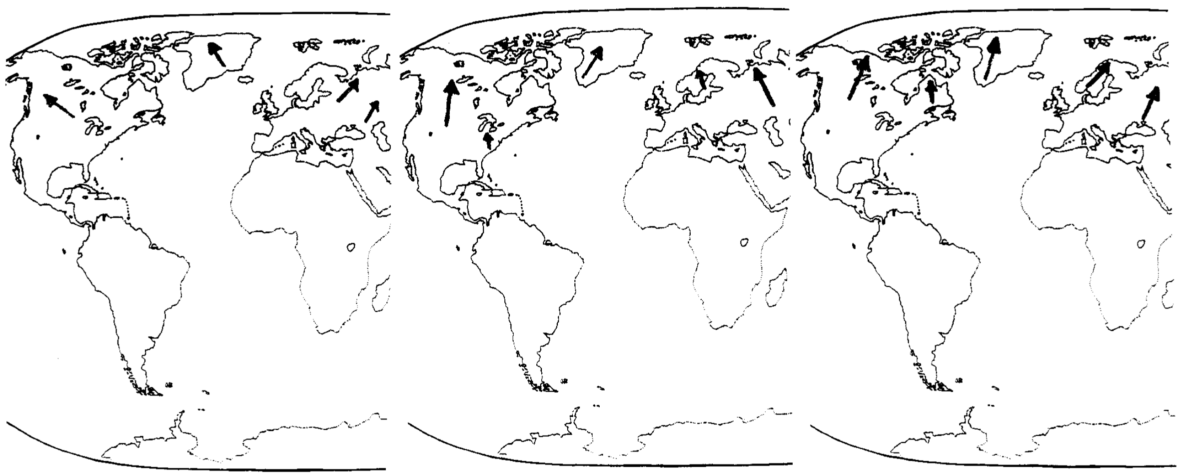
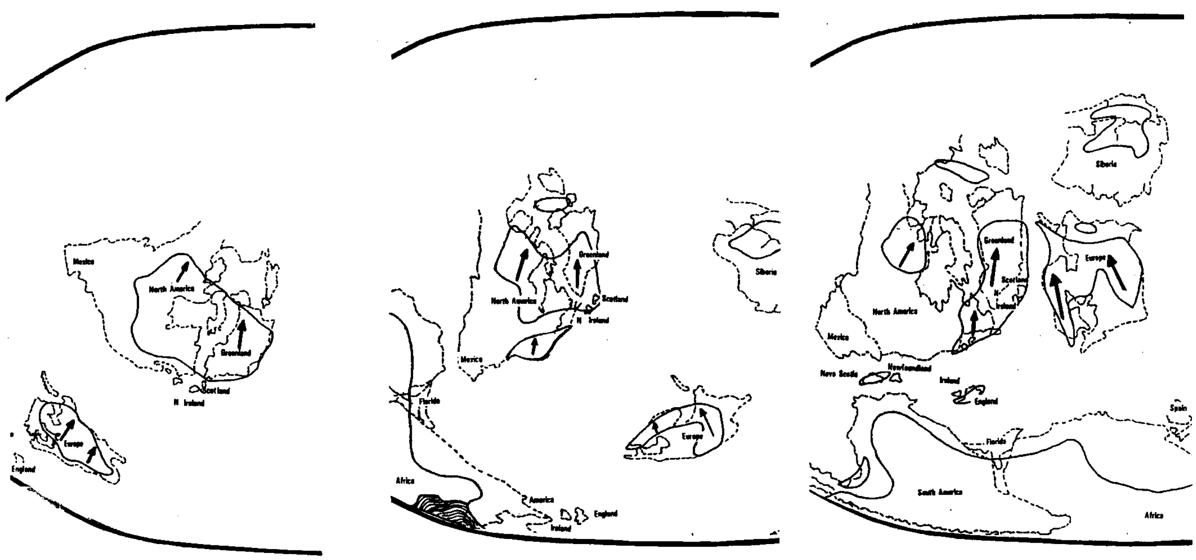


Figure 2. Early Paleozoic magnetic north directional data for a fixed North American continent



a) Cambrian b) Ordovician c) Silurian

Figure 3. Early Paleozoic magnetic north directional data for the fixed North American and European continents



a) Cambrian b) Ordovician c) Silurian

Figure 4. Early Paleozoic magnetic north directional data for the drifting North American and European continents

The long axes of the magnetite crystals are also consistently aligned with respect to the **horizontal Earth's surface**, again paralleling the orientation of the ancient magnetic field lines of force, and being unaffected by the current lines of force from the modern north magnetic pole. In the Northern Hemisphere, this alignment varies from the north-seeking ends of the axes being oriented **perpendicularly down into** the Earth's surface at the **North Magnetic Pole**, to the long axes being oriented **parallel** to the Earth's surface at the **equator**. In the **Southern Hemisphere**, the alignment of the long axes of the magnetite crystals varies from being **perpendicular**, with the north-seeking ends of the axes **directed up and away** from the Earth's surface at the **South Magnetic Pole**, to the long axes being oriented **parallel** to the Earth's surface at the **equator** as before (see Table 1 and Figure 5).

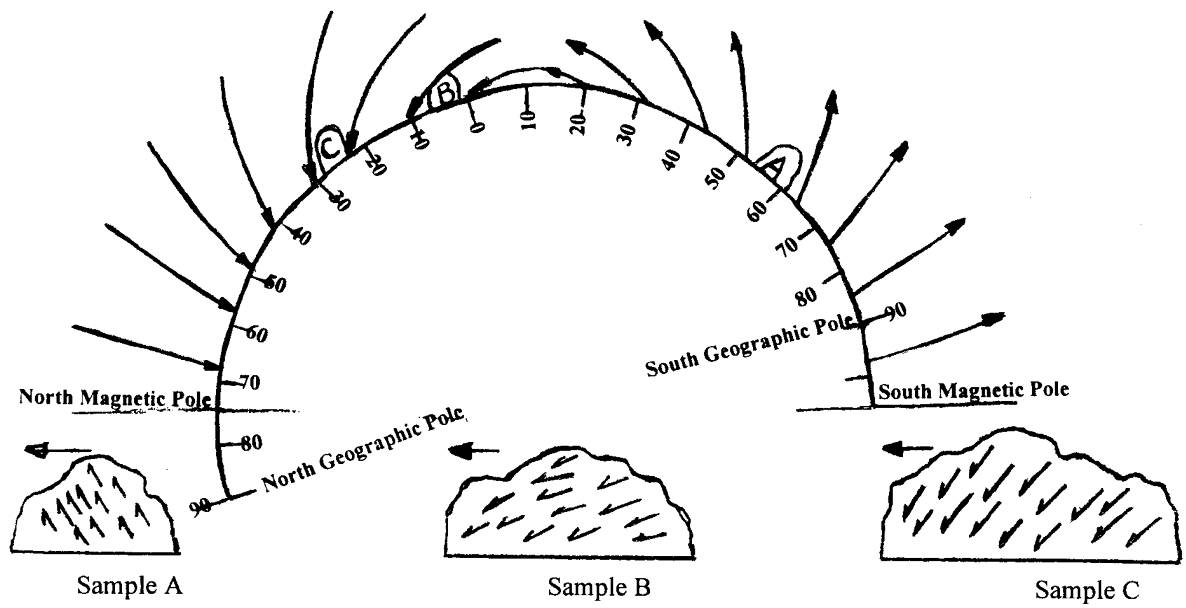


Figure 5. Information supplied by paleomagnetic measurements from selected basalt samples
A) Southern Hemisphere B) Equator C) Northern Hemisphere
(after Birkeland and Larson 1989)

Table 1. Paleomagnetic data as a function of determining paleolatitudes of ancient worlds

Paleomagnetic Orientation Angle	Angle Above or Below Horizontal	Paleogeographic Latitude
90 degrees into the ground	Directly below	75 degrees north presently
75 degrees into the ground	Below	66 degrees
70 degrees into the ground	Below	56 degrees
65 degrees into the ground	Below	47 degrees
58 degrees into the ground	Below	38 degrees
43 degrees into the ground	Below	26 degrees
34 degrees into the ground	Below	20 degrees
30 degrees into the ground	Below	8 degrees
19 degrees into the ground	Below	0 degrees
0 degrees (parallels the ground)	Parallel	14 degrees south presently
20 degrees into the air	Above	27 degrees
27 degrees into the air	Above	34 degrees
34 degrees into the air	Above	48 degrees
49 degrees into the air	Above	55 degrees
55 degrees into the air	Above	68 degrees
64 degrees into the air	Above	77 degrees
75 degrees into the air	Above	84 degrees
81 degrees into the air	Above	85 degrees on opposite side
90 degrees into the air	Directly Above	77 degrees on opposite side

Paleomagnetic data for each basalt sample supply its paleogeographic direction to the **paleomagnetic north pole** at the time of cooling and also the **inclination angle of** the **paleomagnetic field lines** in that location. The latter feature can be interpreted as being equivalent to the paleogeographic latitude or approximate distance from the north magnetic pole. With both the direction to and the distance from the paleomagnetic north pole, the approximate position of the continent can be plotted for each geological age once numerical age determinations have been made.

Despite the fact that the approximate east-west location or **longitude** of the continents is not supplied by these data, the overall placement of the continents in the successive ancient worlds has been achieved with great success (Scotese 1986). Currently, these paleogeographic maps have been constructed with confidence as far back as the Early Cambrian, and even some Precambrian reconstructions have been made. As more stratigraphic and paleomagnetic measurements are added, the east-west relationships of the continents through time will become better understood.

Plate Tectonics

The processes associated with different types of plate motion produce recognizable and characteristic landforms, particularly in close proximity to the boundaries of the plates. How can these boundaries be located? Figure 6 shows the world distribution of volcanoes with known eruption dates. The majority of these occur at or near plate boundaries. Figure 7 exhibits the distribution of recent earthquakes of different depths. Earthquakes also occur most frequently at or near plate boundaries, associated with the movement along faults at these locations. Figure 8 shows the modern tectonic plates, which can be inferred from the volcano and earthquake distribution maps shown in Figures 6 and 7.

Convergent boundaries that involve **ocean-ocean** plate boundaries are typified by volcanic island arc systems with deep intrusive igneous rock bodies. **Deep focus earthquakes** commonly occur at these locations. **Ocean-continent** plate boundaries are indicated by highly deformed sediments that are folded, faulted, metamorphosed, and intruded by plutons. **Deep** to **intermediate focus earthquakes** occur here. **Continent-continent** plate boundaries are characterized by folded mountain ranges, which are also faulted, metamorphosed, and commonly intruded by magma bodies. **Intermediate-depth focus earthquakes** commonly occur at these locations. **Divergent boundaries** involve either ocean-ocean, or continent-continent plate boundaries. Ocean-ocean boundaries form the extensive **mid-ocean ridges** and are characterized by basaltic extrusive rocks, gravity faults, and **shallow focus earthquakes**. Continent-continent boundaries form **rift valleys** on land and feature down-dropped valleys, extensive volcanic activity, and shallow-focus earthquakes. These rift valleys commonly fill with great thicknesses of clastic sediments. **Transform boundaries** can involve either ocean-ocean or continent-continent plate boundaries. Both are characterized primarily by shallow focus earthquakes, and thus their recognition from surface volcanic or subsurface structural landforms is much more difficult. **Assembly** of continents involves continent-continent convergent boundaries. **Breakup** or **rifting** of continents involves continent-continent divergent boundaries. **Drifting** of continents involves ocean-ocean divergent boundaries. An understanding of the processes and products of modern plate tectonic motion can help to determine the existence of ancient tectonic processes and their resultant landscape products.

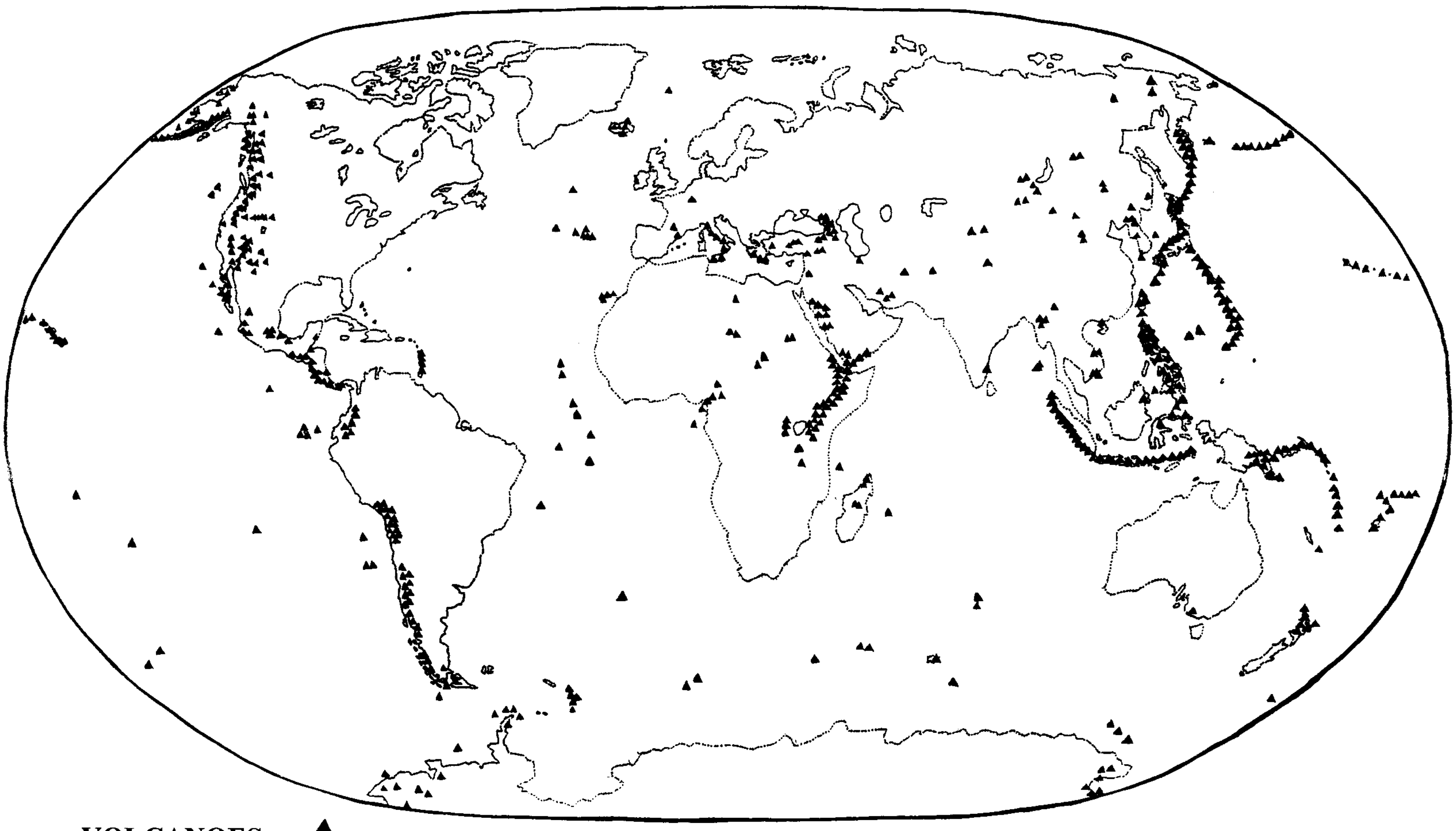


Figure 6. Distribution of the world's volcanoes with known eruption history (after Sawyer 2000)

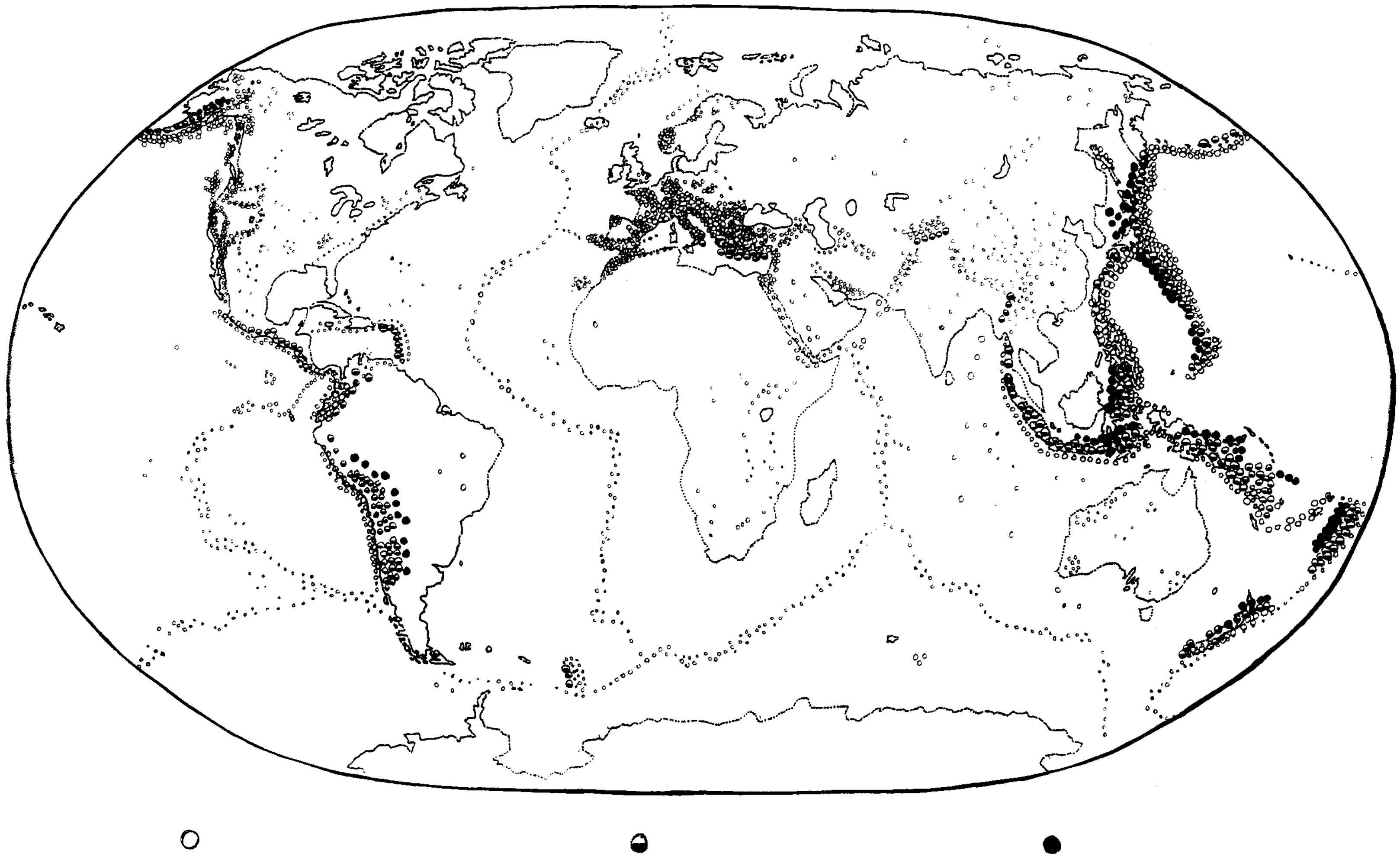


Figure 7. Distribution of the world's earthquakes (1990–1996) (after Sawyer 2000)

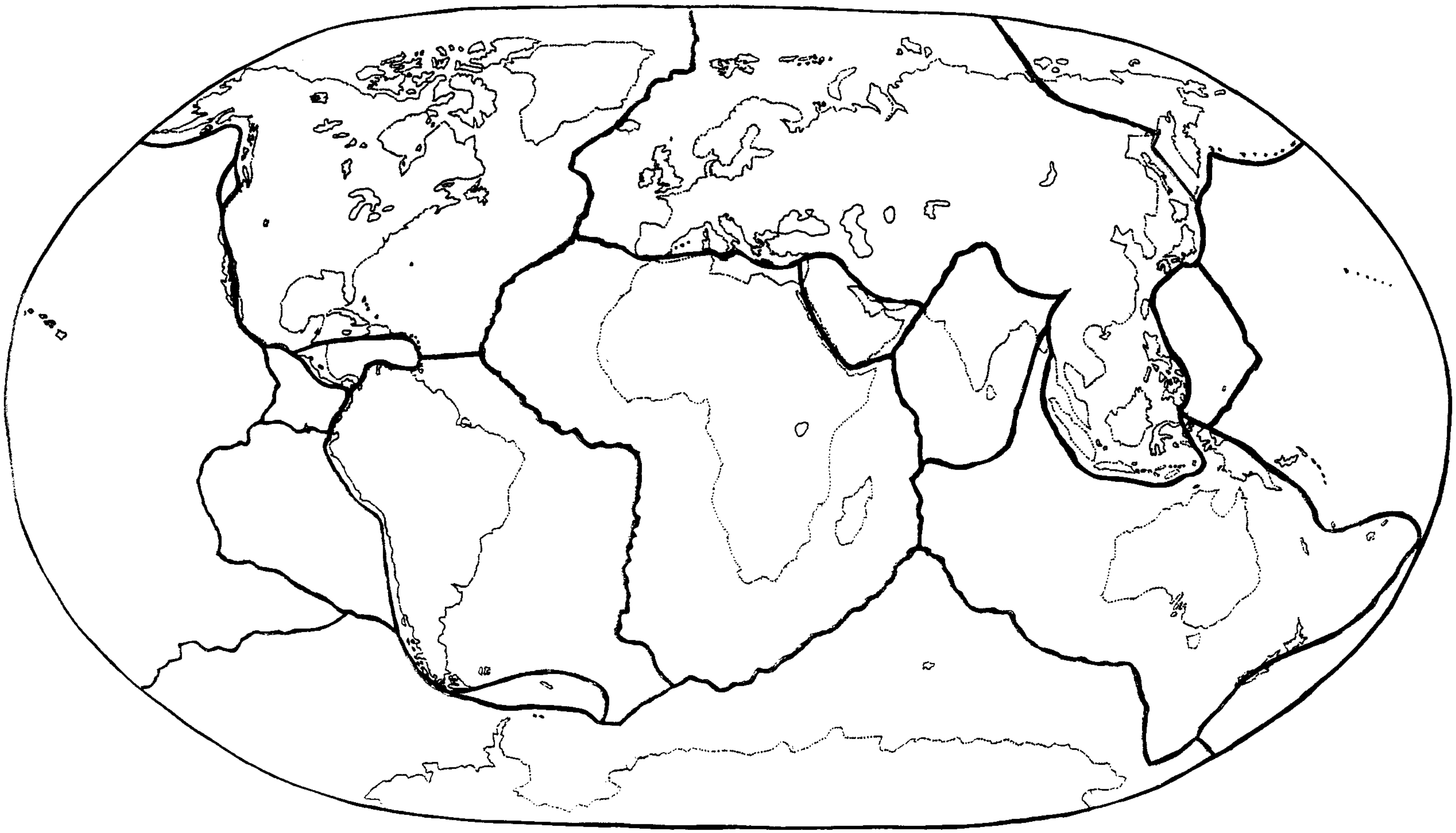


Figure 8. The tectonic plates of the world (after Sawyer 2000)

Important Features of Ancient World Reconstructions

Terrestrial features of ancient world reconstructions include **icecaps**, **mountain ranges**, **highlands**, **deserts**, **and alluvial/coastal plains**. Icecaps indicate periods of global sea level change, mountain ranges originate with tectonic activity; and highlands are the result of erosion of mountain ranges. Deserts may result either from continental drifting into subtropical regions favorable for desert formation or from downwind proximity to a major mountain range. Alluvial/coastal plains represent clastic wedges derived from the erosion of mountain ranges through time and are the most favorable and productive environments for biological activity.

Marine features of ancient world reconstructions include **organic reefs**, **shallow seas**, **oceans**, and **volcanic island arcs**. Organic reefs form on the **passive tectonic margins**, as do shallow seas characteristic of the broad, continental shelves of continents; both indicate periods of tectonic inactivity**.** Oceans are formed when continents are rifted apart, and volcanic island arcs are formed by convergent ocean-ocean or convergent continental-ocean plate collisions. Mountain ranges will ultimately be produced from these tectonic interactions, only to be worn down by erosion into highlands, deposited by streams into alluvial/coastal plains and continental shelves, and to then be thrust up into mountains again as tectonic activity resumes.

On a larger scale, **supercontinents** have been **assembled**, **rifted apart**, **drifted away**, and **assembled** again several times throughout the geologic record.

Worksheet: Paleogeography of Ancient Worlds

Name: ________________________ Lab Section: _______ Date: __________

Activity 1: Using Sedimentary Rock Distributions to Map Ancient Sedimentary Environments

1. Figure 9 illustrates the distribution of several types of sedimentary rock formations of Medial Cambrian *Glossopleura* Zone age in the western United States. Answer the following questions.

   a. Color the areas on the map in Figure 9 according to the following scheme: (fine)**Ls**—blue; **Sh**—light green; **Ss**—yellow; **Er**—brown.

   b. What depositional environment is indicated by each of the symbols in (a)?

   Ls _______________________________________; Ss _____________________________________;

   Sh _______________________________________; Er ____________________________

   c. What clues to each of these depositional environments is contained in each of these rock types?

   Ls _______________________________________; Ss _____________________________________;

   Sh _______________________________________; beyond Ss ____________________________

   d. What evidence indicates that dry land (Er) existed during the Cambrian *Glossopeura* Zone age?

   ____

2. Figure 10 (page after Figure 9) illustrates the distribution of several types of sedimentary rock formations of Late Cambrian *Prosaukia* Zone age in the western United States. Answer the following questions.

   a. Color the areas on the map in Figure 10 according to the following scheme: **Ls**—blue; **Sh**—light green; **Ss**—yellow; **areas to the right of Ss**—brown.

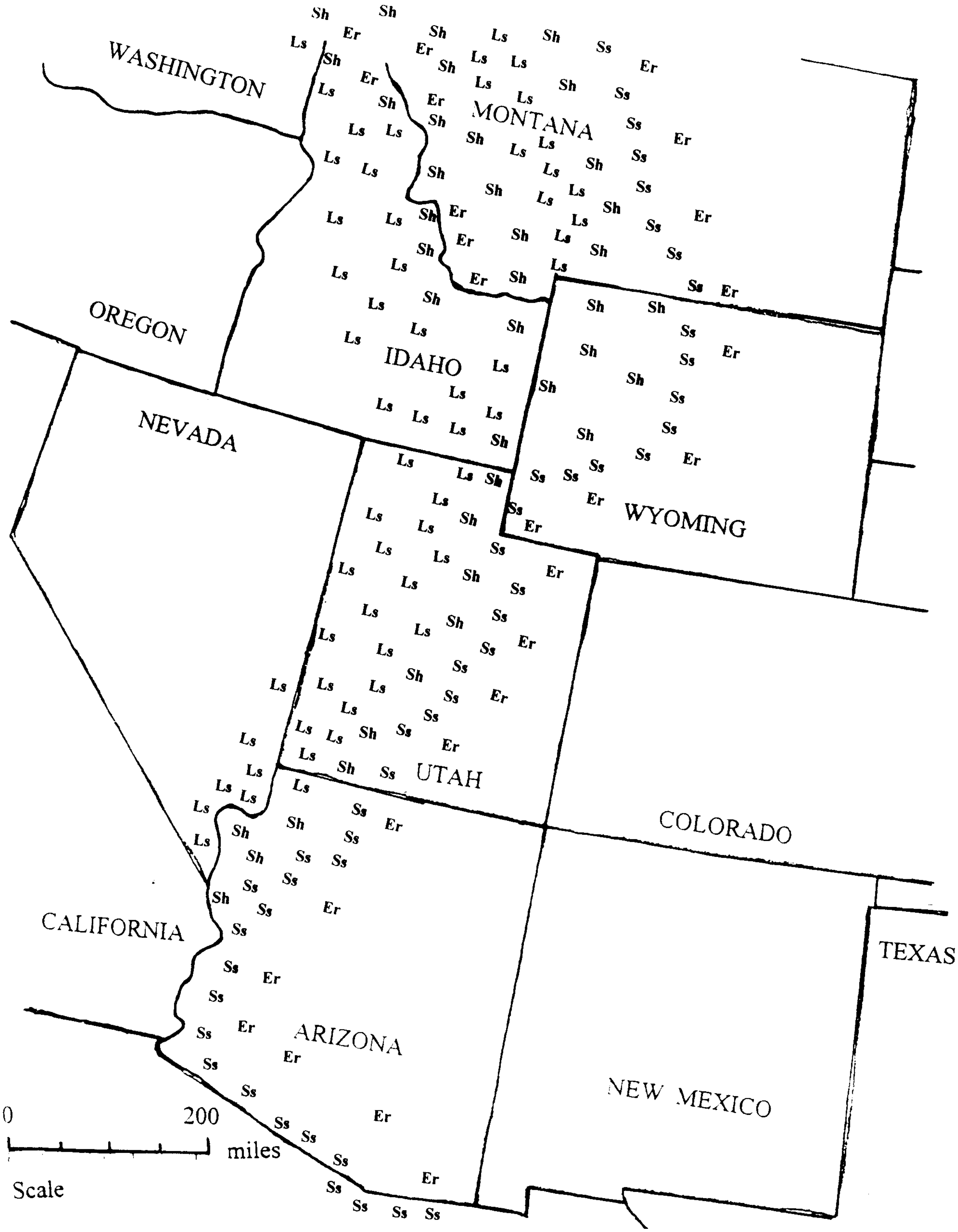
   b. What environments are indicated by each of the symbols in (a)?
   Ls _________________; Ss ___________________; Sh _________________; beyond Ss ___________

   c. What overall changes have occurred to the Cambrian landscape during the *Prosaukia* Zone time?
   ____

   d. What processes could have caused such changes to occur?

   ____

   ____



Ls = Limestone Ss = Sandstone Sh = Shale Er = Eroded

Figure 9. Distribution of Middle Cambrian sedimentary rocks of the *Glossopleura* Zone (after Lochman-Balk 1971, p. 96, Fig. 10)

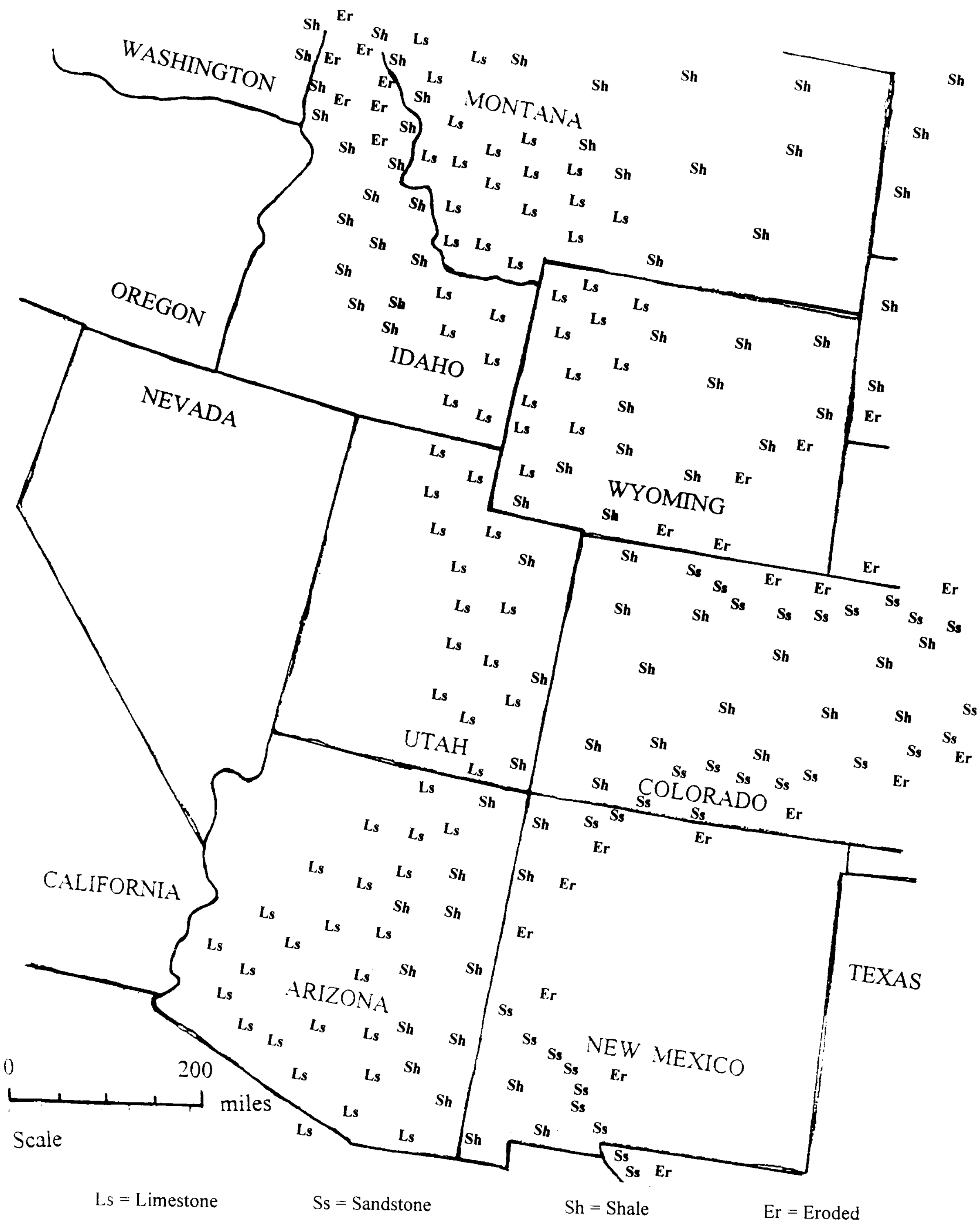


Figure 10. Distribution of Upper Cambrian sedimentary rocks of the *Prosaukia* Zone (after Lochman-Balk 1971, p. 102, Fig. 21)

Activity 2: Paleomagnetic Data for Britain Over the Last 500 Million Years

1. Table 1 illustrates paleomagnetic data for determining paleoaltitudes for ancient worlds. Table 2 lists paleomagnetic angles for Britain for selected geologic time periods. Refer to Tables 1 and 2 and the world map in Figure 11 to answer the following questions.

Table 2. Paleomagnetic data of Britain for selected geologic time periods

Geologic Period	Paleomagnetic Angle	Angle Orientation	Paleolatitude
Tertiary	67 degrees into ground	Above horizontal	
Jurassic	58 degrees into ground	Above horizontal	
Permian	34 degrees into ground	Above horizontal	
Devonian	19 degrees into ground	Above horizontal	
Silurian	24 degrees into air	Below horizontal	
Ordovician	62 degrees into air	Below horizontal	

a. Complete the Paleolatitude column of Table 2 by referring to the data in Table 1. For some readings, interpolation will be required.

b. Use a large **B** to plot the position for Britain for each of the time periods in Table 2 on the world map in Figure 11. What process has caused this northward migration over the last 400 million years of Earth history?

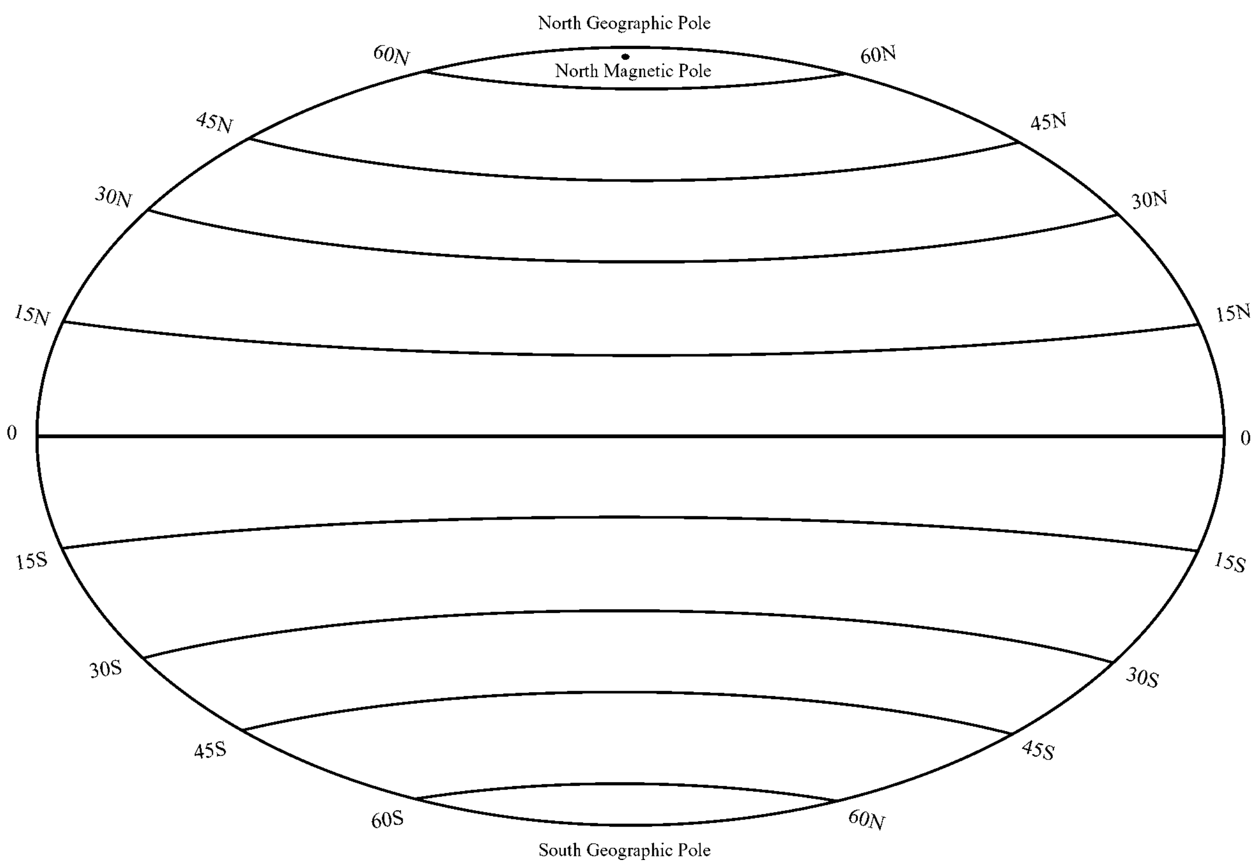


Figure 11. Movement of Britain through time

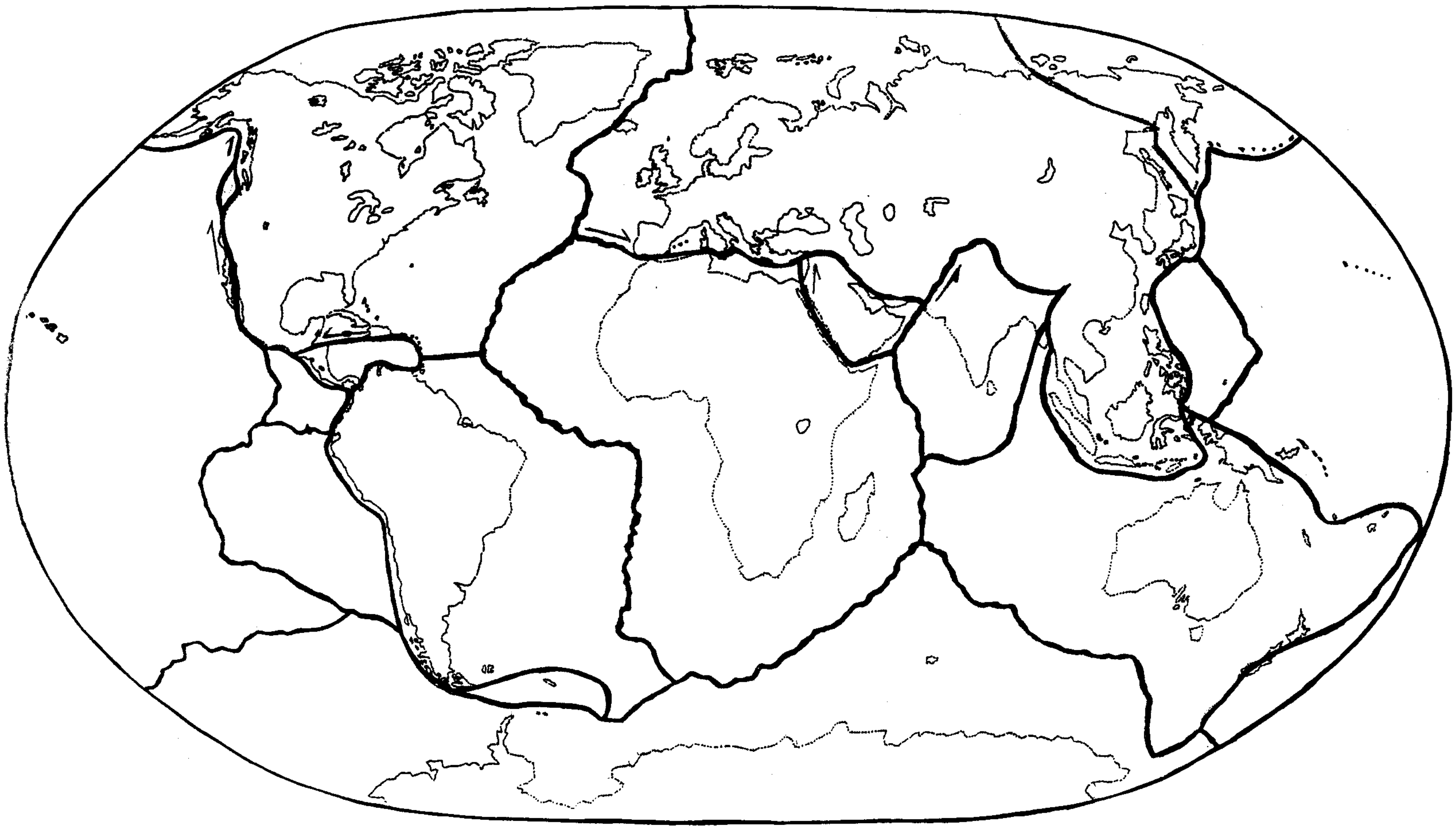


Figure 12. The tectonic plates of the world today (after Sawyer 2000)

Activity 3: The Modern Plate Tectonics World

a. Figure 12 shows the modern tectonic plates of the world today. Use this map to complete the following questions.

Label and color each of the tectonic plates on Figure 12 as follows:

North America — RED
South America — GREEN
Australia — YELLOW
India — PINK
Arabia — GOLD
Nazca — TURQUOISE
Caribbean — LIGHT GREEN
Juan de Fuca — RED ORANGE
Eurasia — BROWN
Africa — ORANGE
Pacific — BLUE
Antarctic — PURPLE
Phillipine — SILVER
Scotia — LIGHT BLUE
Cocos — LIGHT BROWN

b. Study Figure 7, which shows the distribution of the world's earthquakes. From this map and the discussion, you know that deep and intermediate focus earthquakes occur along convergent margins, and that shallow focus earthquakes are characteristic of divergent plate margins. Label the convergent and divergent plate boundaries on Figure 12 according to the following scheme:

Convergent Boundaries 

Divergent Boundaries

c. Now that you have determined the type of plate boundaries, place arrows along the plate boundaries in Figure 12, noting the direction in which each plate edge is moving. The transform boundary is already supplied for you.

d. Study carefully Figures 13A through 25A. Can you locate examples of convergent and divergent plate boundaries? Be sure to examine several maps in succession to determine first the relative plate motion from map to map.

Activity 4: The Paleogeography of Ancient Worlds

Figures 13 through 25 show the Paleogeographic reconstructions of ancient worlds for the Cambrian through Quaternary Periods. The (a) part of each figure illustrates the world view; the (b) part of each figures focuses specifically on North America. You will be asked to color regions on each map of North America to represent its reconstruction for each geologic time period.
Use the following color scheme to fill in the paleogeographic (regions) as designated on each North America map:

Icecaps — WHITE BOX	(M) Mountains — ORANGE
(H) Highlands — BROWN	(AC) Alluvial/coastal plains — PINK
(D) Deserts — YELLOW	(L) Lowlands — GREEN
(S) Shallow Seas — LIGHT BLUE	(O) Oceans — DARK BLUE

Continental shelf edge indicated by Heavy dashed line on each map
Shoreline-indicated by Heavy solid line on each map

List of Maps and Selected Features:

Figure 13a	Cambrian World Iapetus Ocean Sauk Sea	13b	Cambrian North America Appalachian, Cordilleran Seaways
Figure 14a	Ordovician World Iapetus Ocean Gondwana Sahara glaciers	14b	Ordovician North America Taconic Mountains Queenston Alluvial Plain Tippecanoe Sea
Figure 15a	Silurian World Caledonian Mountains Ural	15b	Silurian North America Taconic Highlands Patch Reefs of Michigan Basin
Figure 16a	Devonian World Caledonian Highlands Laurasia Old Red Sandstone Alluvial Plain	16b	Devonian North America Acadian Mountains, Antler Mountains Catskill Alluvial Plain (Delta) Kaskaskia Sea
Figure 17a	Mississippian World Gondwana glaciers Ural Sea Tethys Ocean	17b	Mississippian North America Acadian Highlands, Pocono Alluvial Plain Franklin Mountains Kaskaskia Sea
Figure 18a	Pennsylvanian World Hercynian Mountains Gondwana	18b	Pennsylvanian North America Ouachita Mountains Ouachita Alluvial Plain Absaroka Sea
Figure 19a	Permian World Ural Mountains Zechstein Salt Sea Pangaea Supercontinent	19b	Permian North America Appalachian Mountains Guadalupe Reef Tract Phosphoria Sea
Figure 20a	Triassic World Karoo Basin Incipient Gulf of Mexico Pacific	20b	Triassic North America Appalachian Fault Basins Sonoma Mountains Redbeds

Figure 21a	Jurassic World North Atlantic Linear Sea Tethys Ocean India	21b	Jurassic North America Zuni (Sundance) Sea Morrison Alluvial Plain Sierra Magmatic Arc
Figure 22a	Cretaceous World South Atlantic Ocean Indian Ocean	22b	Cretaceous North America Montana Sea Sevier Mountains
Figure 23a	Tertiary World Alps Mountains North European Alluvial Plain Himalayan Mountains	23b	Tertiary North America Rocky Mountains Great Plains Alluvial Plain San Andreas Rift Zone
Figure 24a	Quaternary (Ice Age) World Alaska-Siberia Land Bridge Baltic Ice Sheet Siberian ice Sheet	24b	Quaternary (Ice Age) North America Laurentide Ice Sheet Cordilleran Ice Sheet Lake Bonneville (Pluvial Lakes)
Figure 25a	Quaternary (Interglacial) World Baltic Embayment Ganges Embayment Amazonian Embayment	25b	Quaternary (Interglacial) North America Mississippi Embayment St. Lawrence Embayment Great Valley Embayment

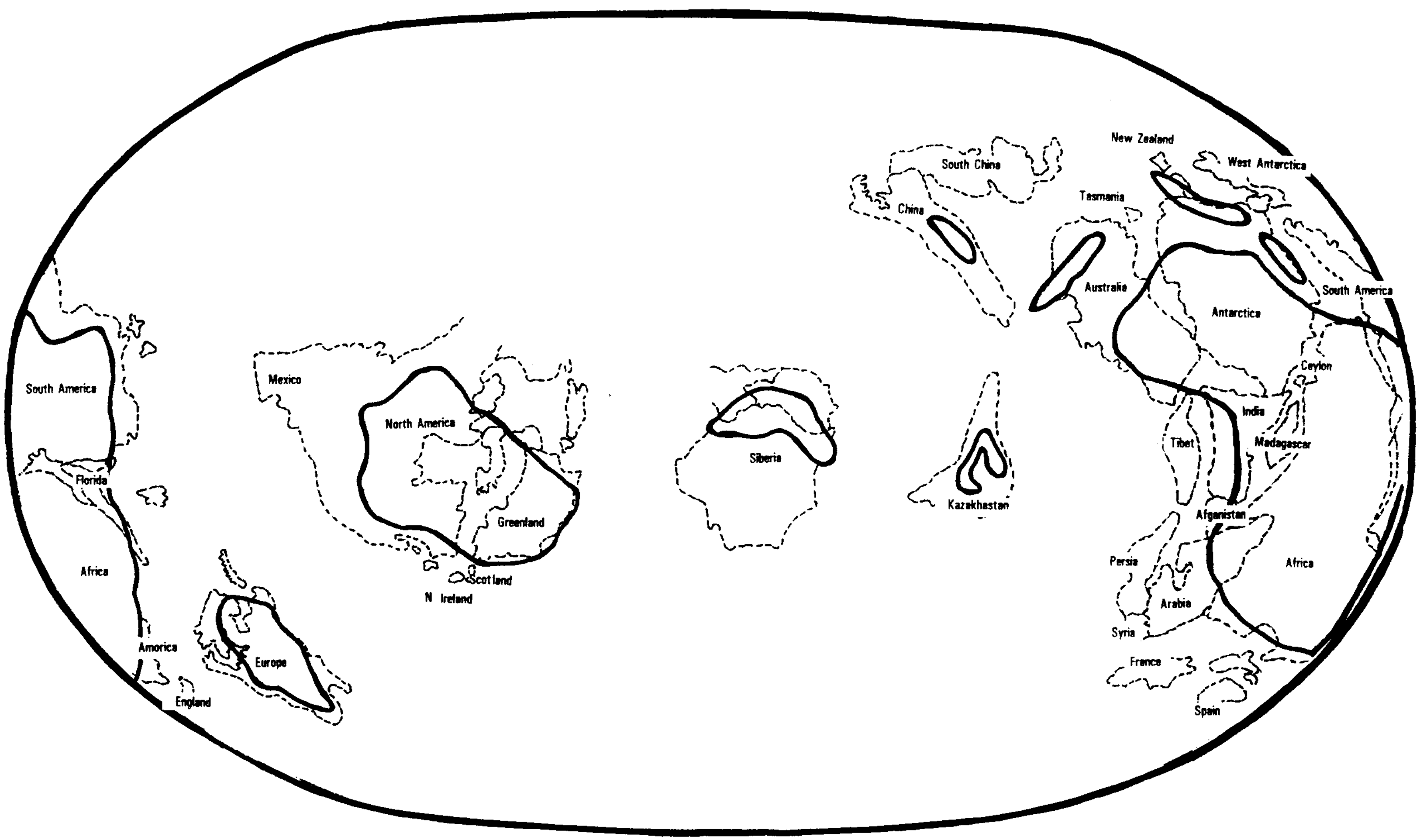


Figure 13a. The Cambrian paleogeography of the world (after Scotese 1986)

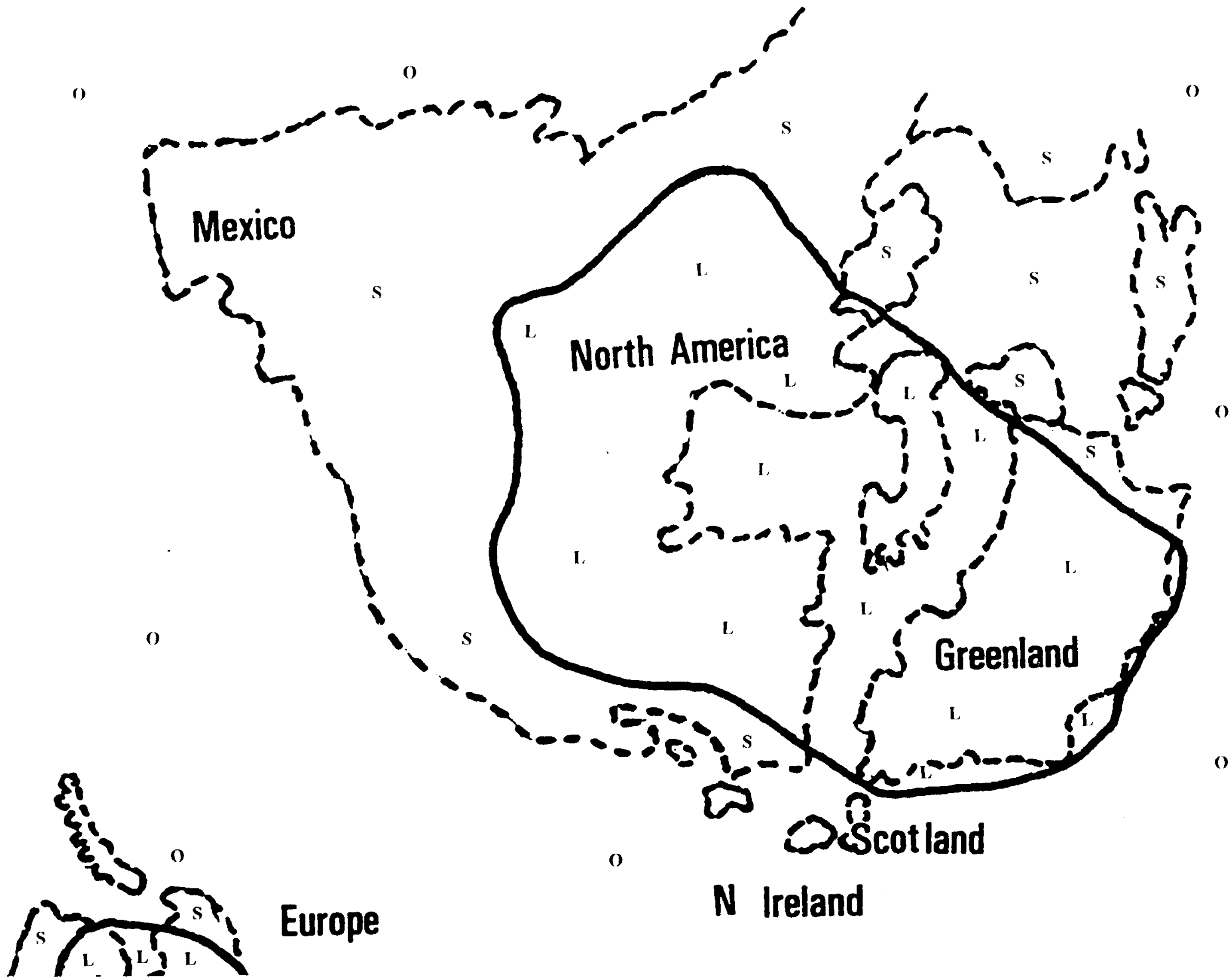


Figure 13b. The Cambrian paleogeography of the North America (after Scotese et al. 1979)

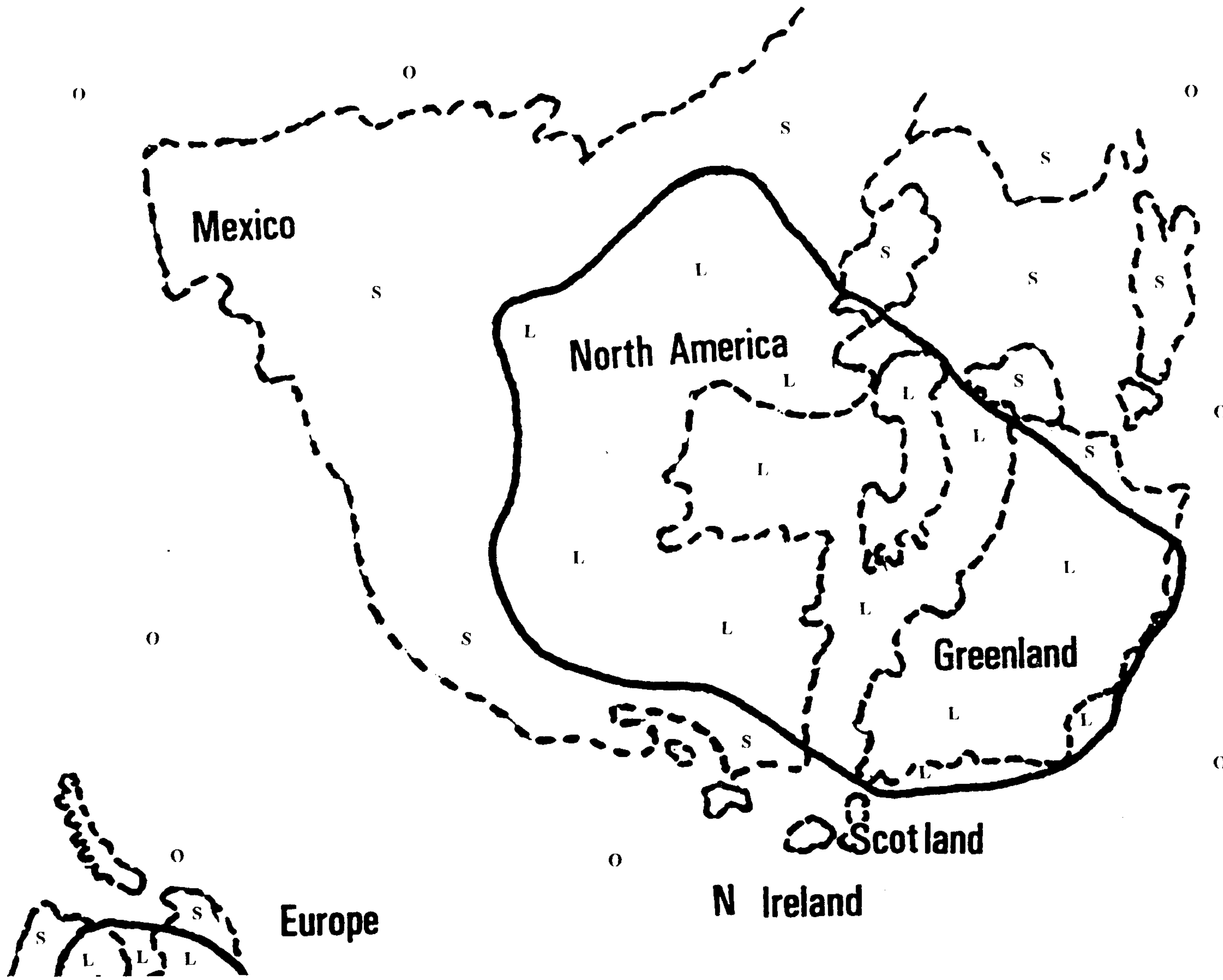


Figure 14a. The Ordovician paleogeography of the world (after Scotese 1986)

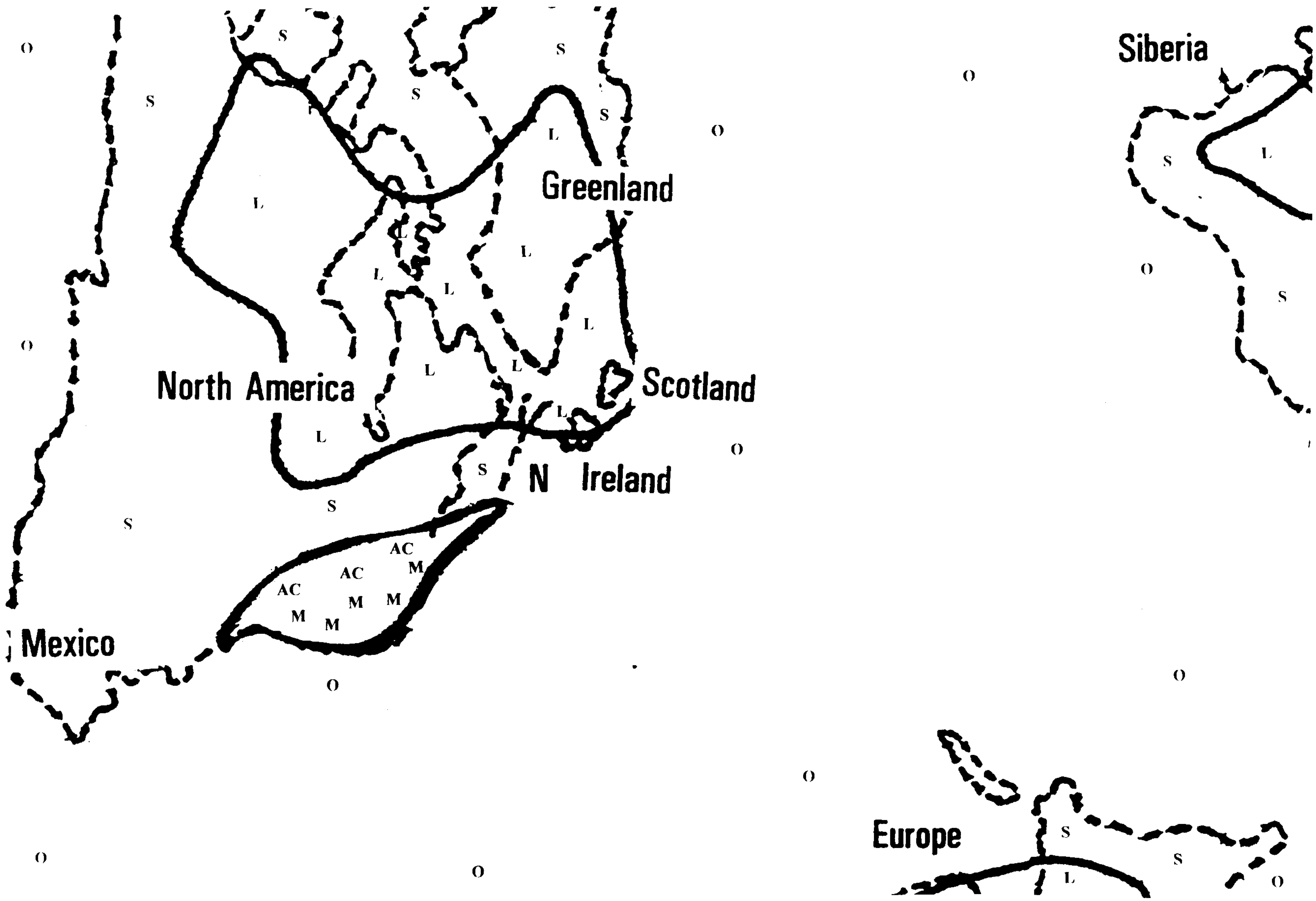


Figure 14b. The Ordovician paleogeography of North America (after Scotese et al. 1979)

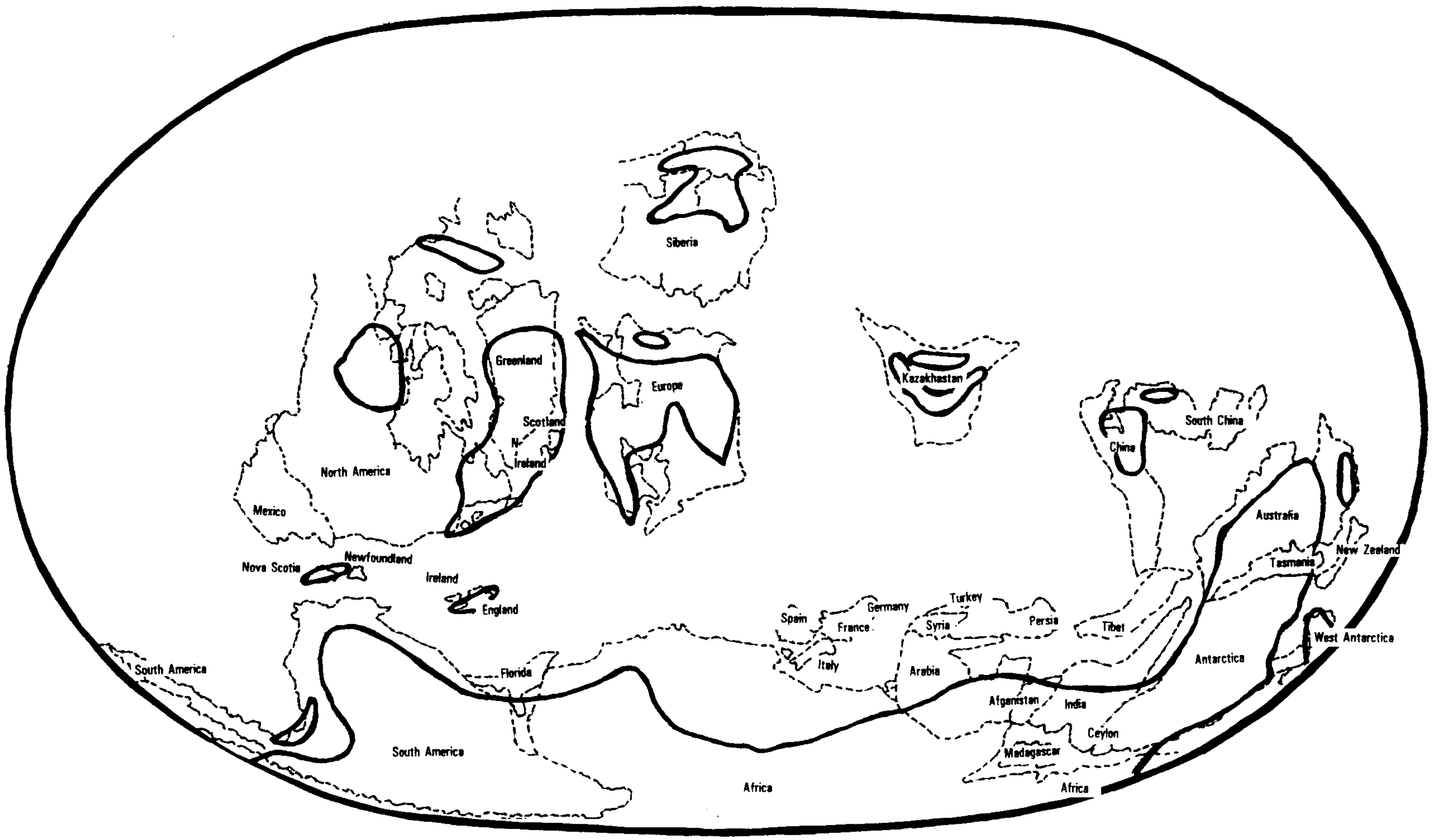


Figure 15a. The Silurian paleogeography of the world (after Scotese 1986)

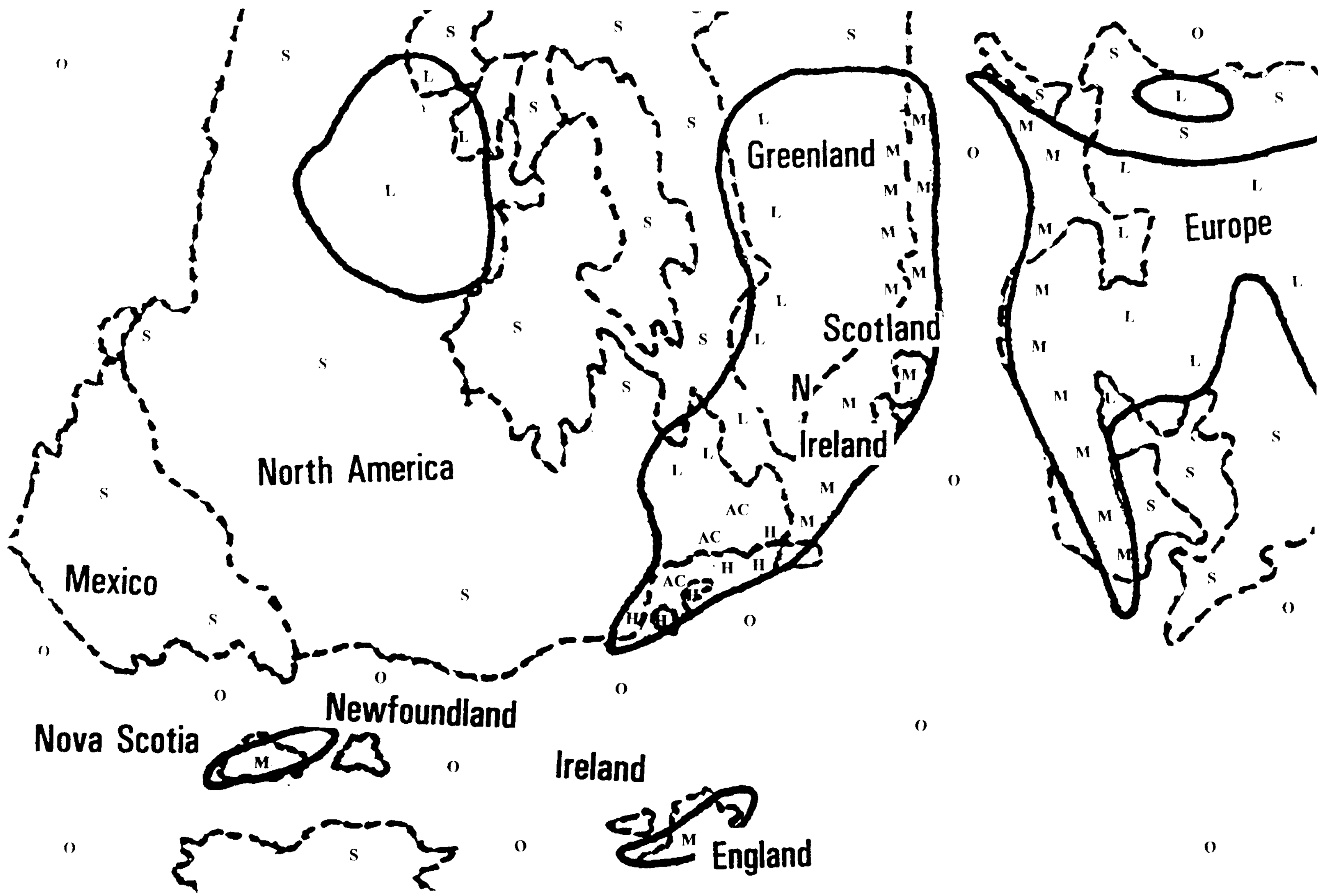


Figure 15b. The Silurian paleogeography of North America (after Scotese et al. 1979)

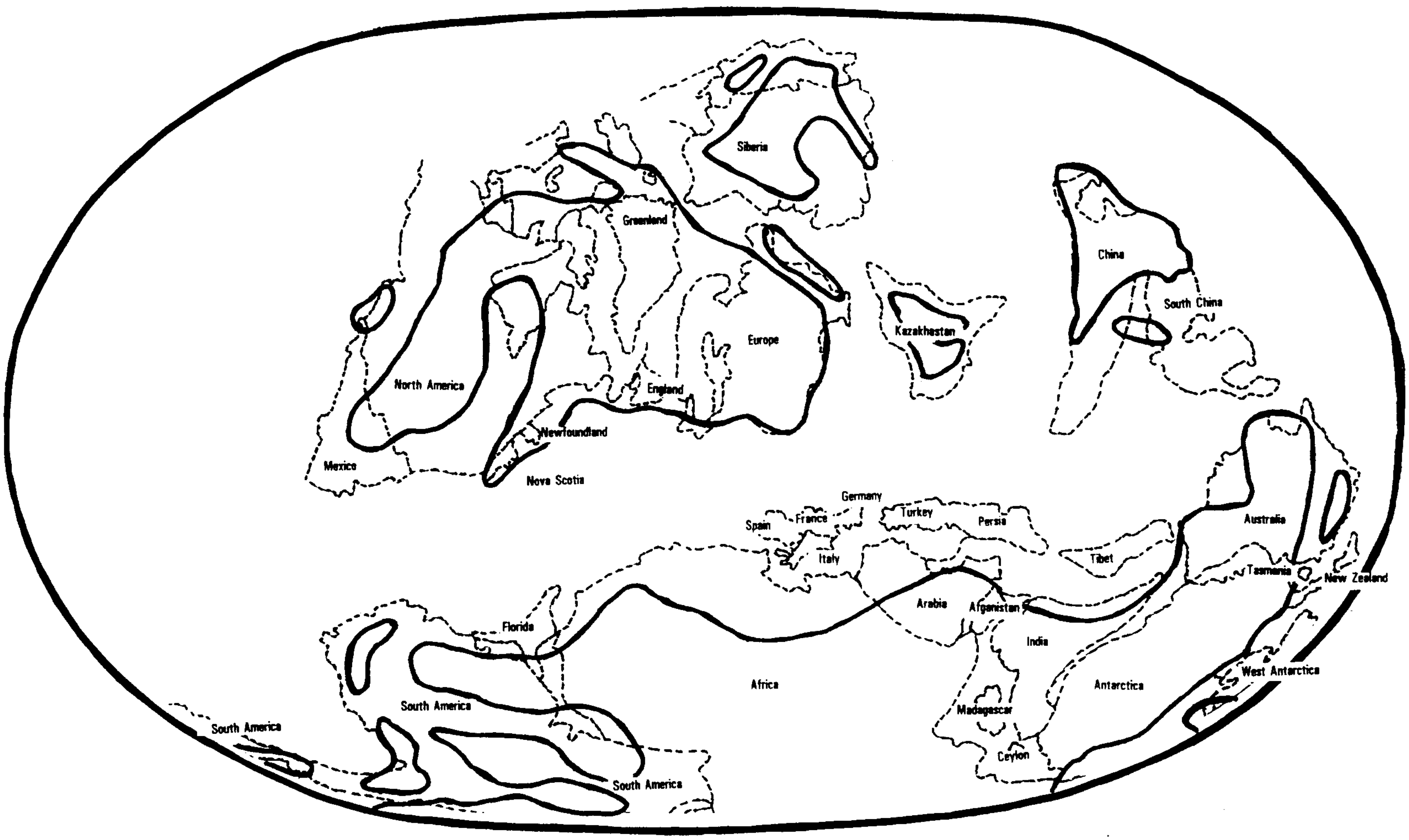


Figure 16a. The Devonian paleogeography of the world (after Scotese 1986)

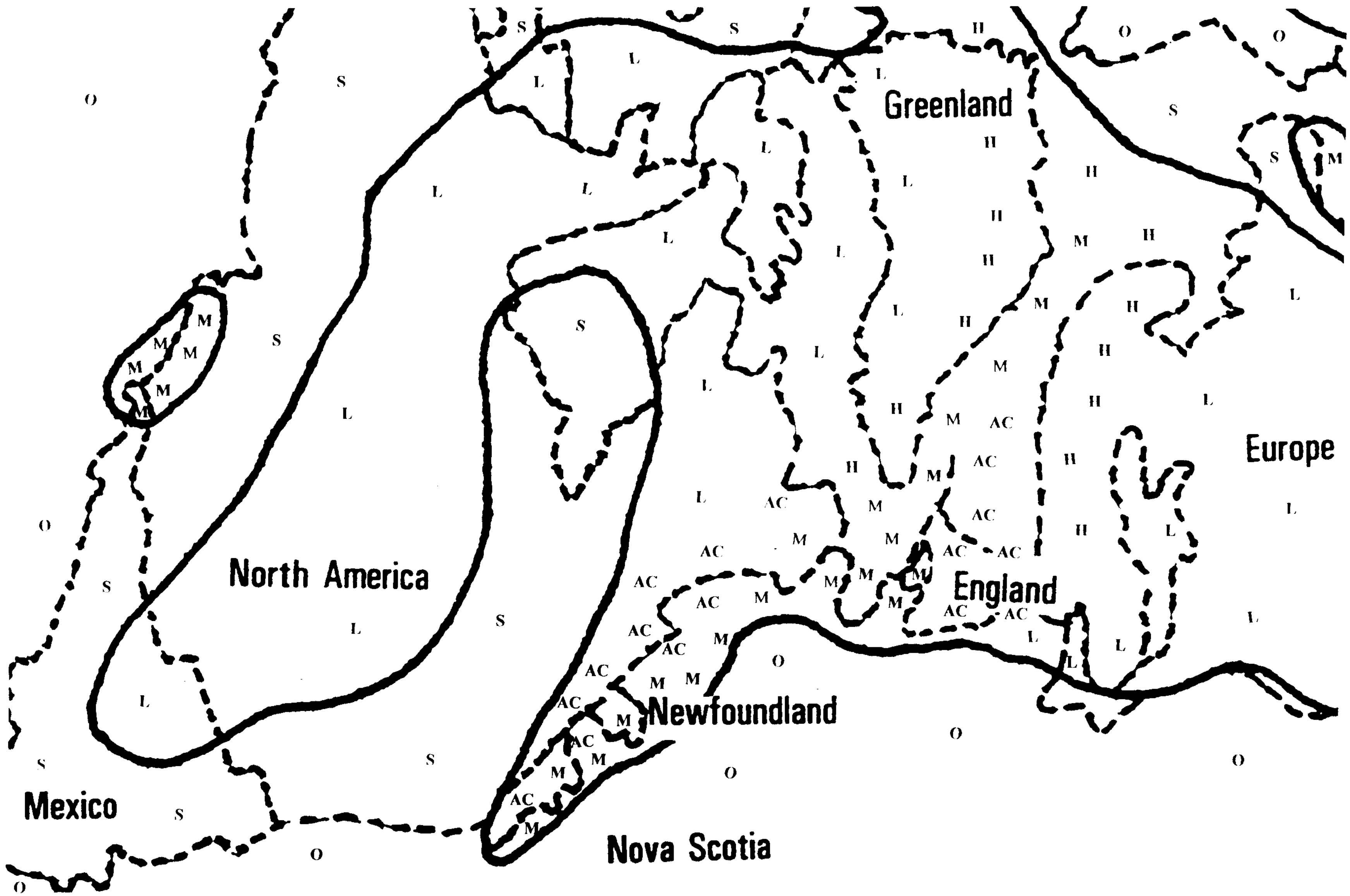


Figure 16b. The Devonian paleogeography of North America (after Scotese et al. 1979)

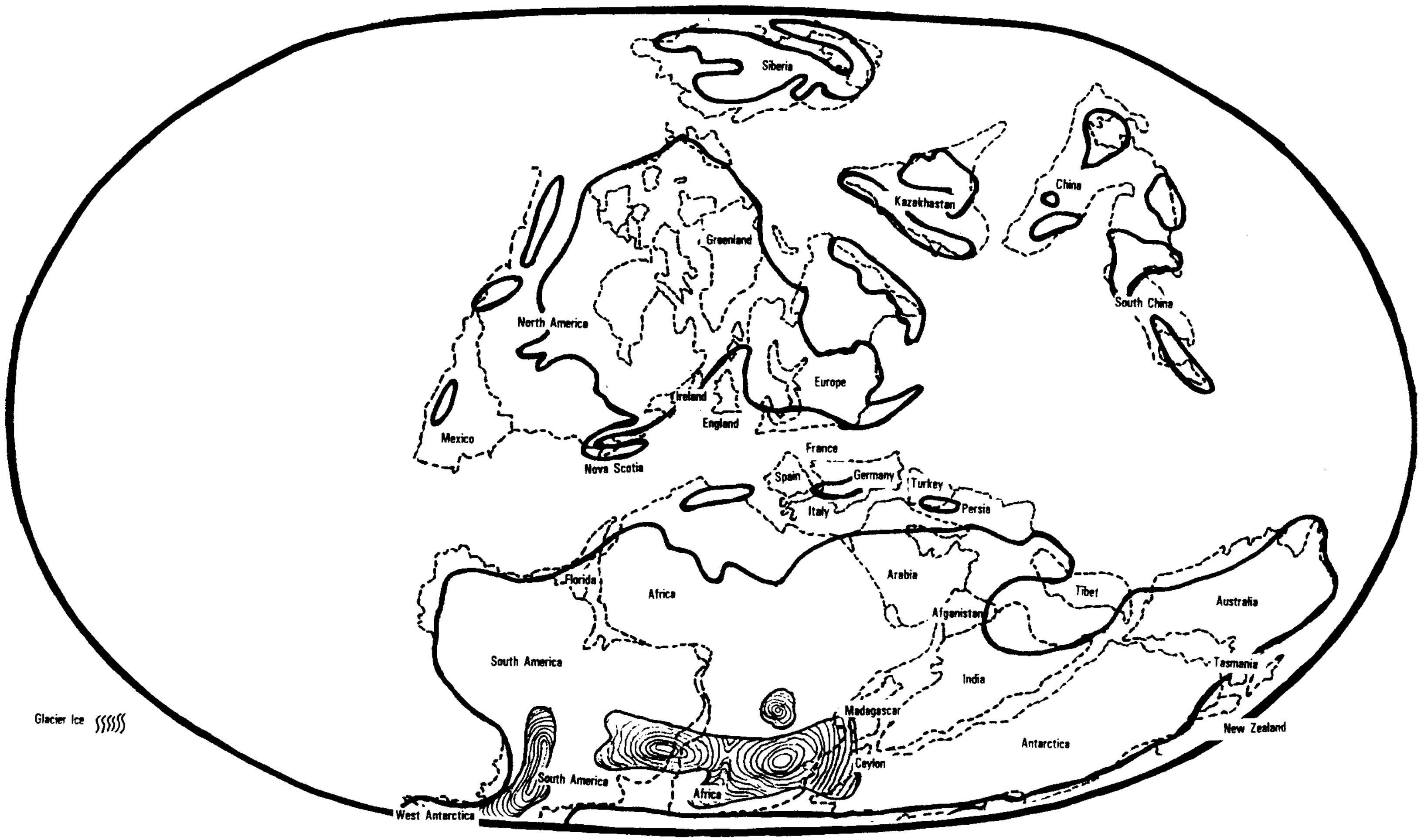


Figure 17a. The Mississippian paleogeography of the world (after Scotese 1986)

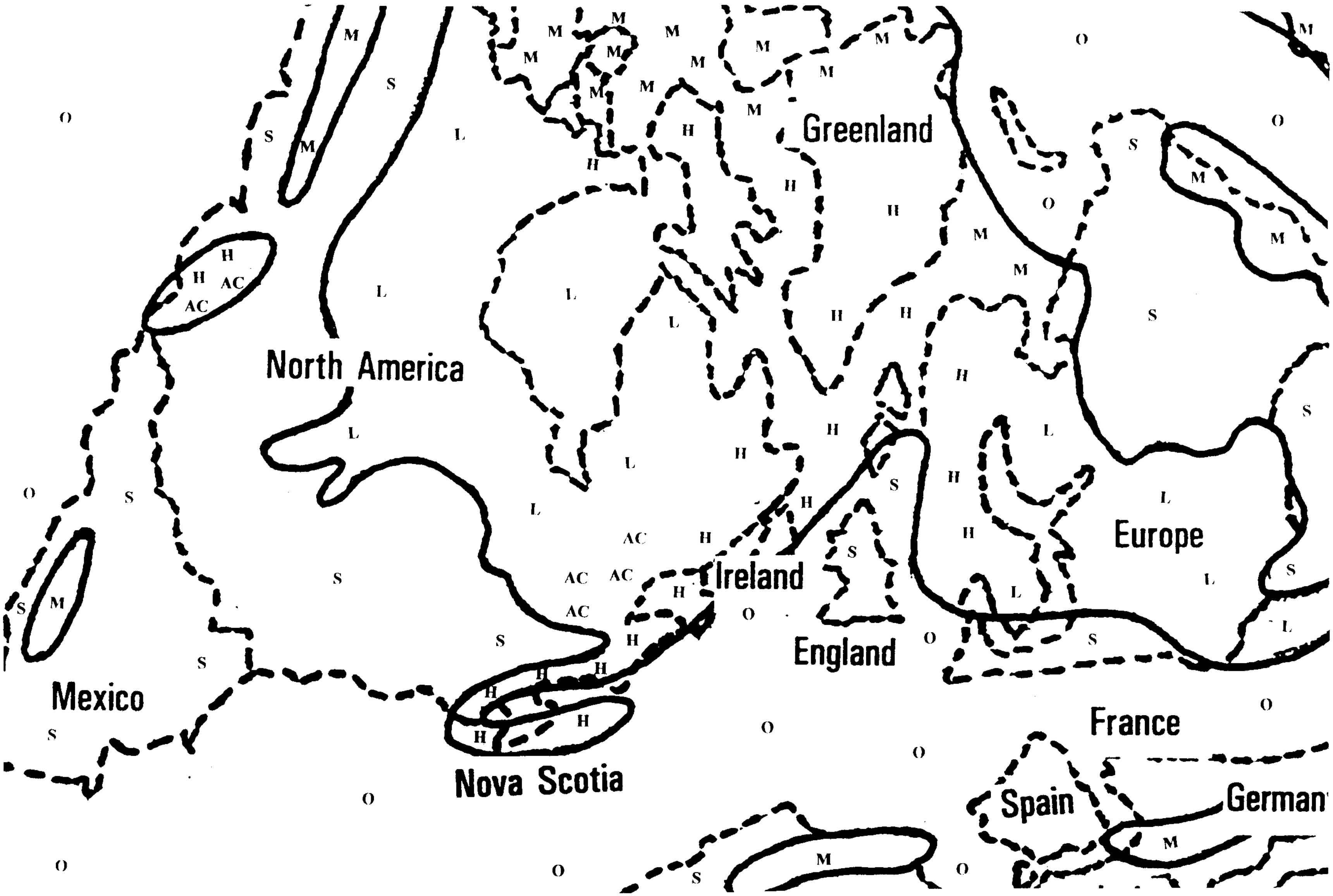


Figure 17b. The Mississippian paleogeography of North America (after Scotese et al. 1979)

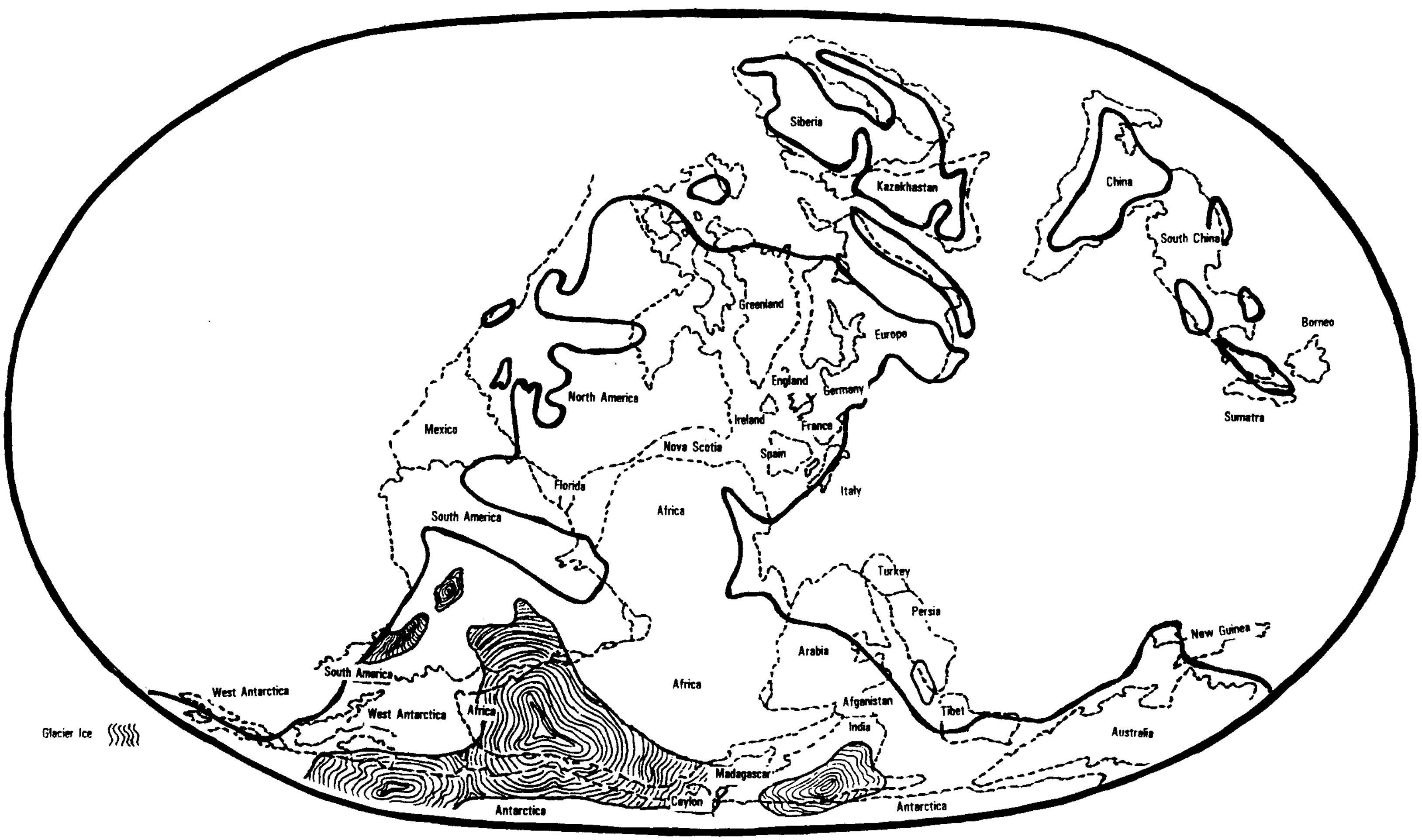


Figure 18a. The Pennsylvanian paleogeography of the world (after Scotese 1986)

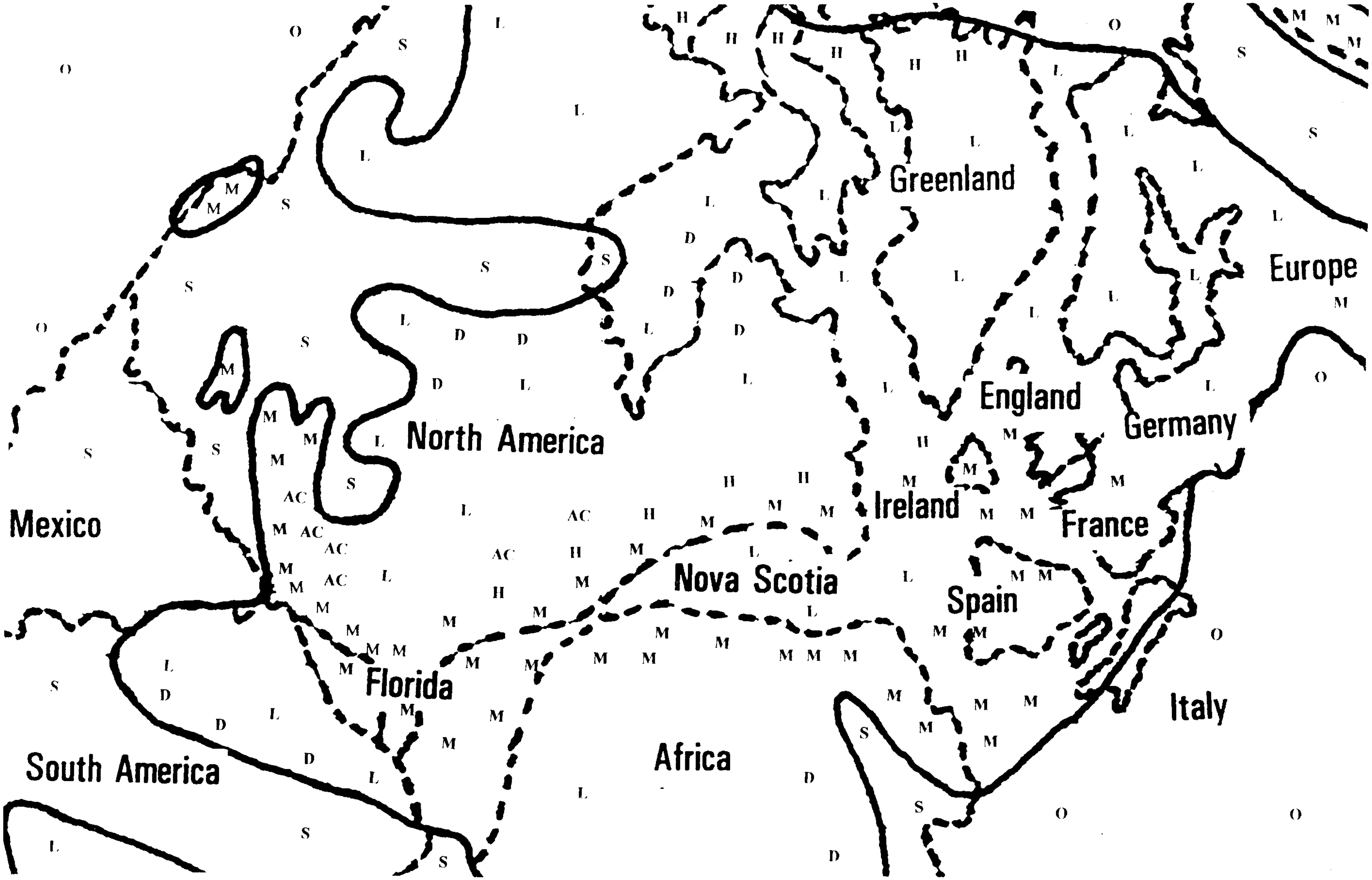


Figure 18b. The Pennsylvanian paleogeography of North America (after Scotese et al. 1979)

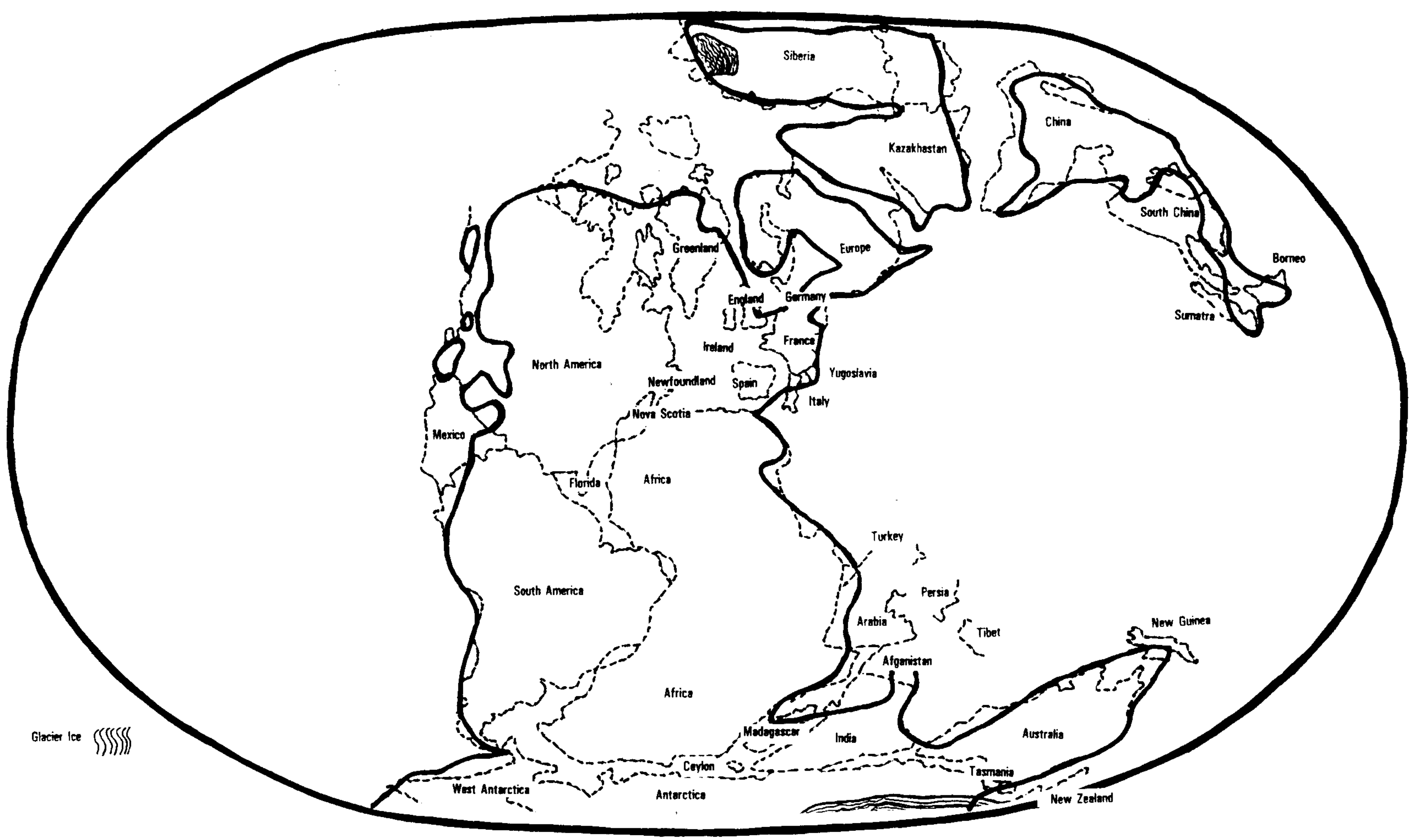


Figure 19a. The Permian paleogeography of the world (after Scotese 1986)

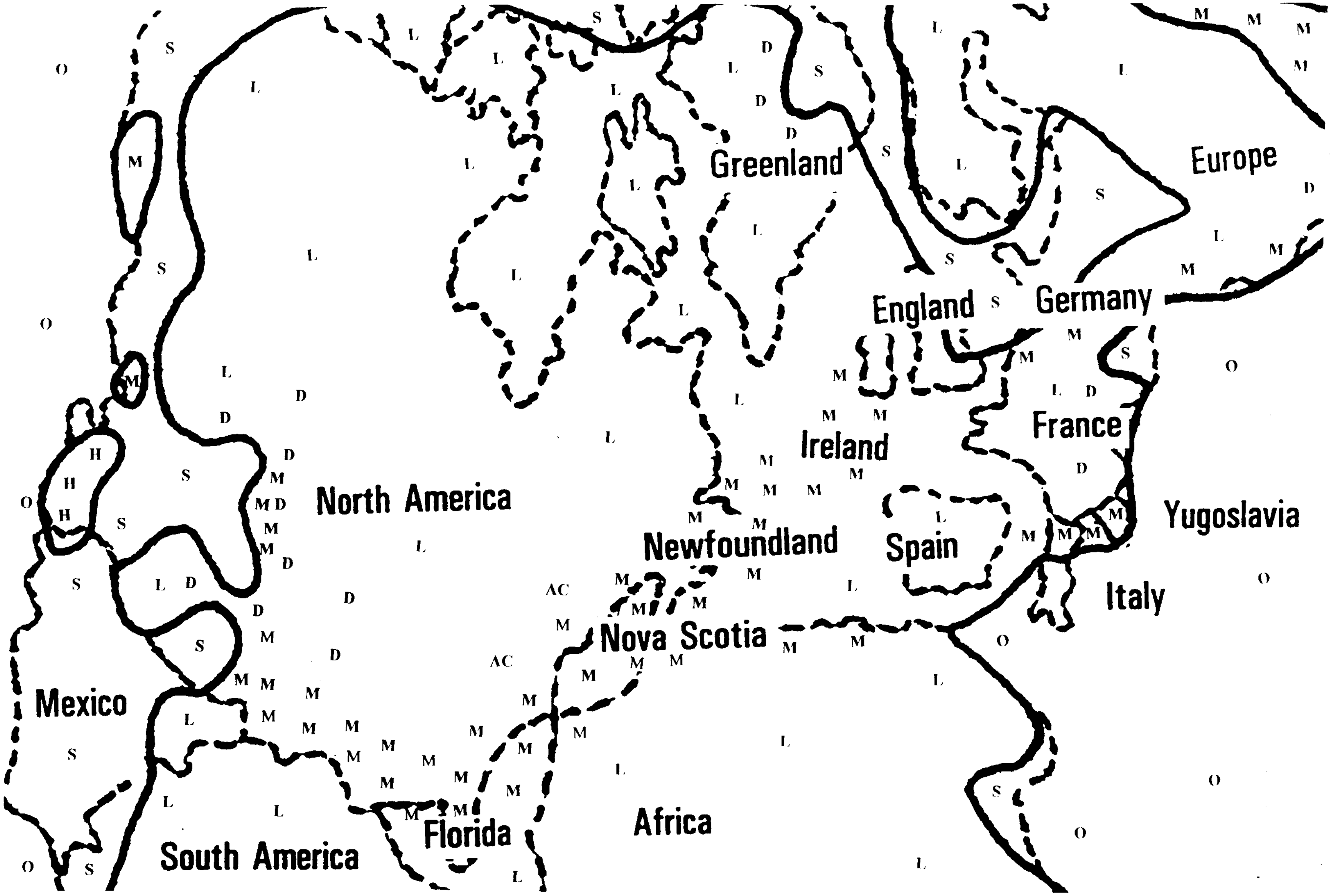


Figure 19b. The Permian paleogeography of North America (after Scotese et al. 1979)

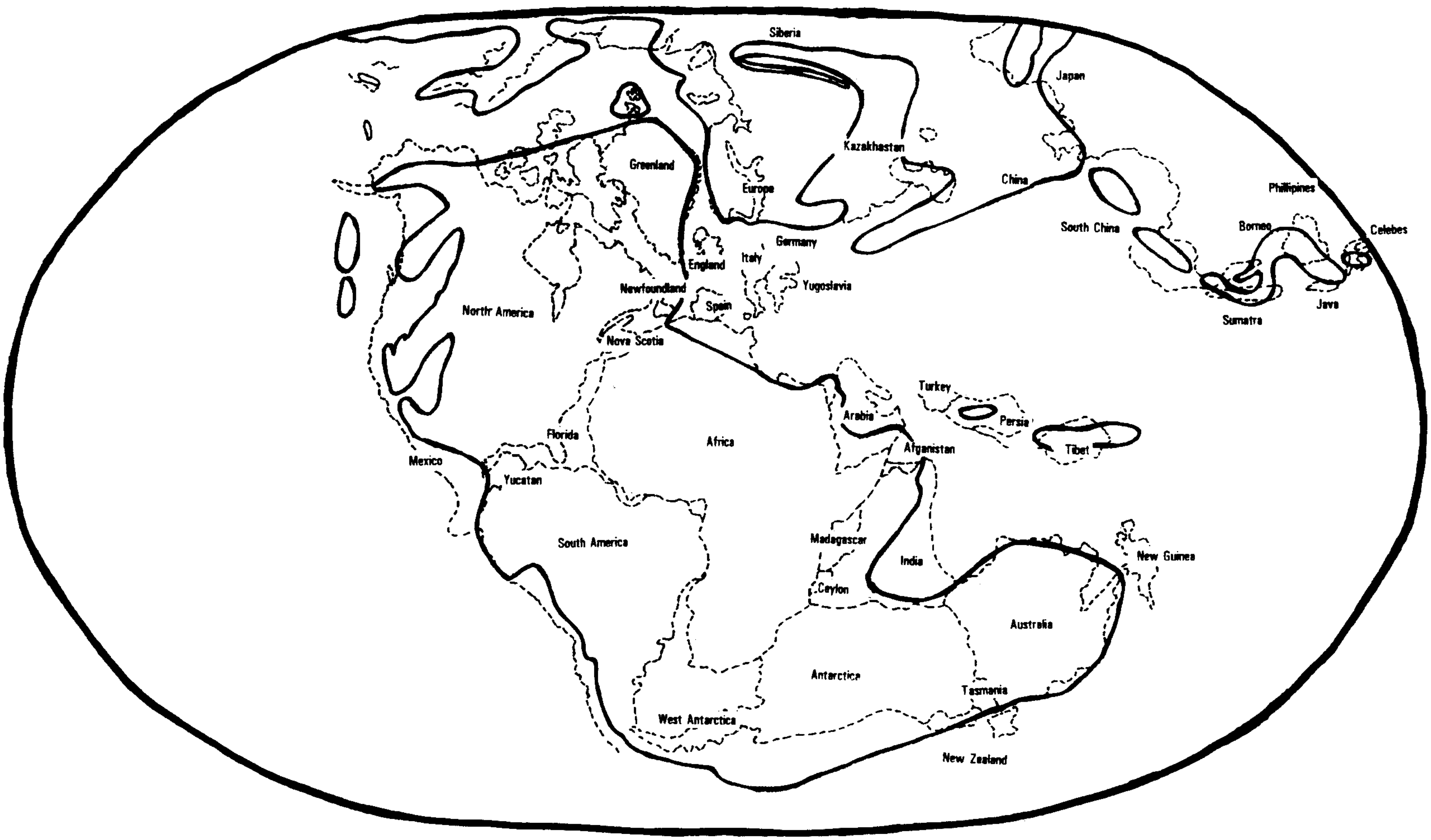


Figure 20a. The Triassic paleogeography of the world (after Scotese and Golanka 1992)

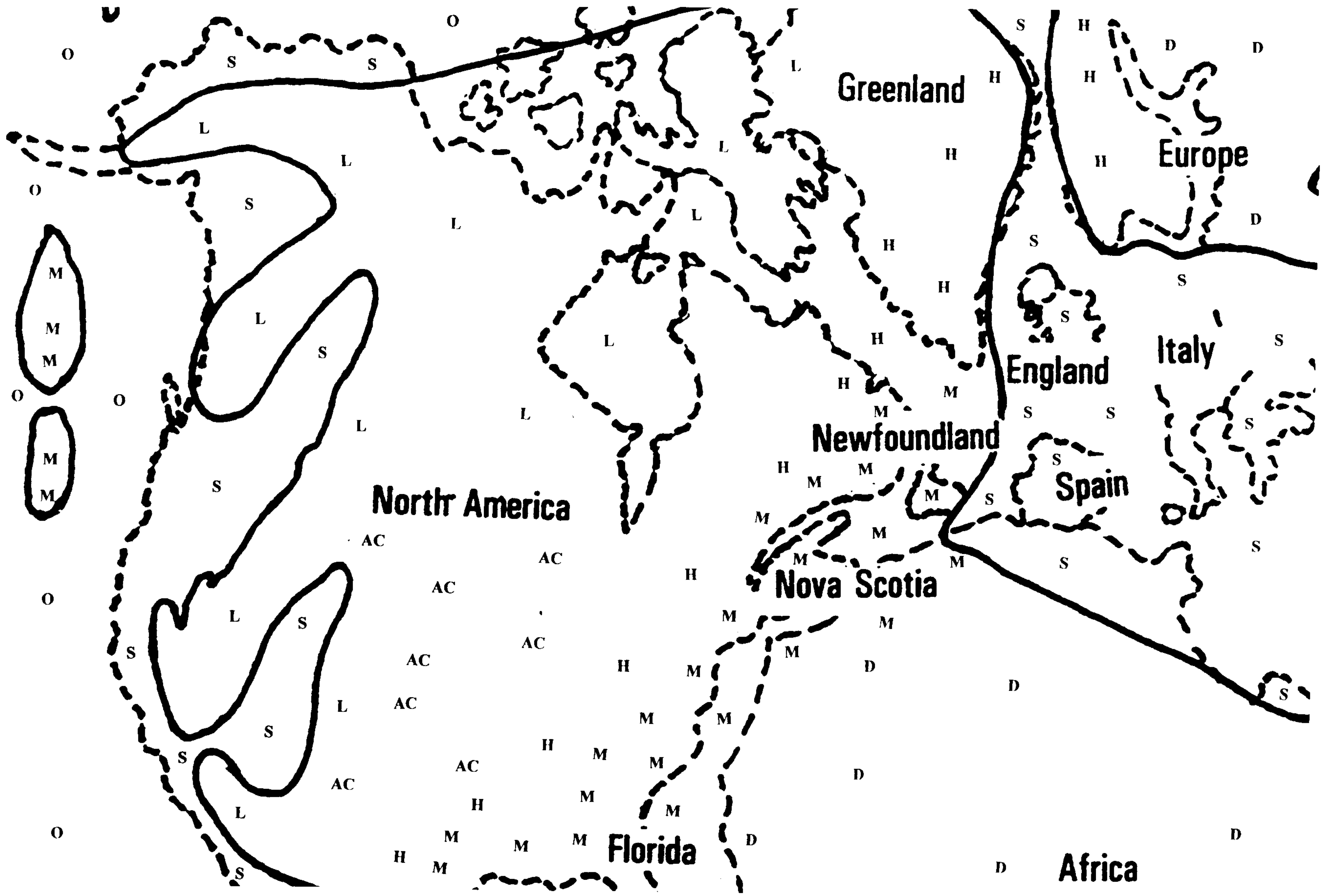


Figure 20b. The Triassic paleogeography of North America (after Scotese and Golonka 1992)

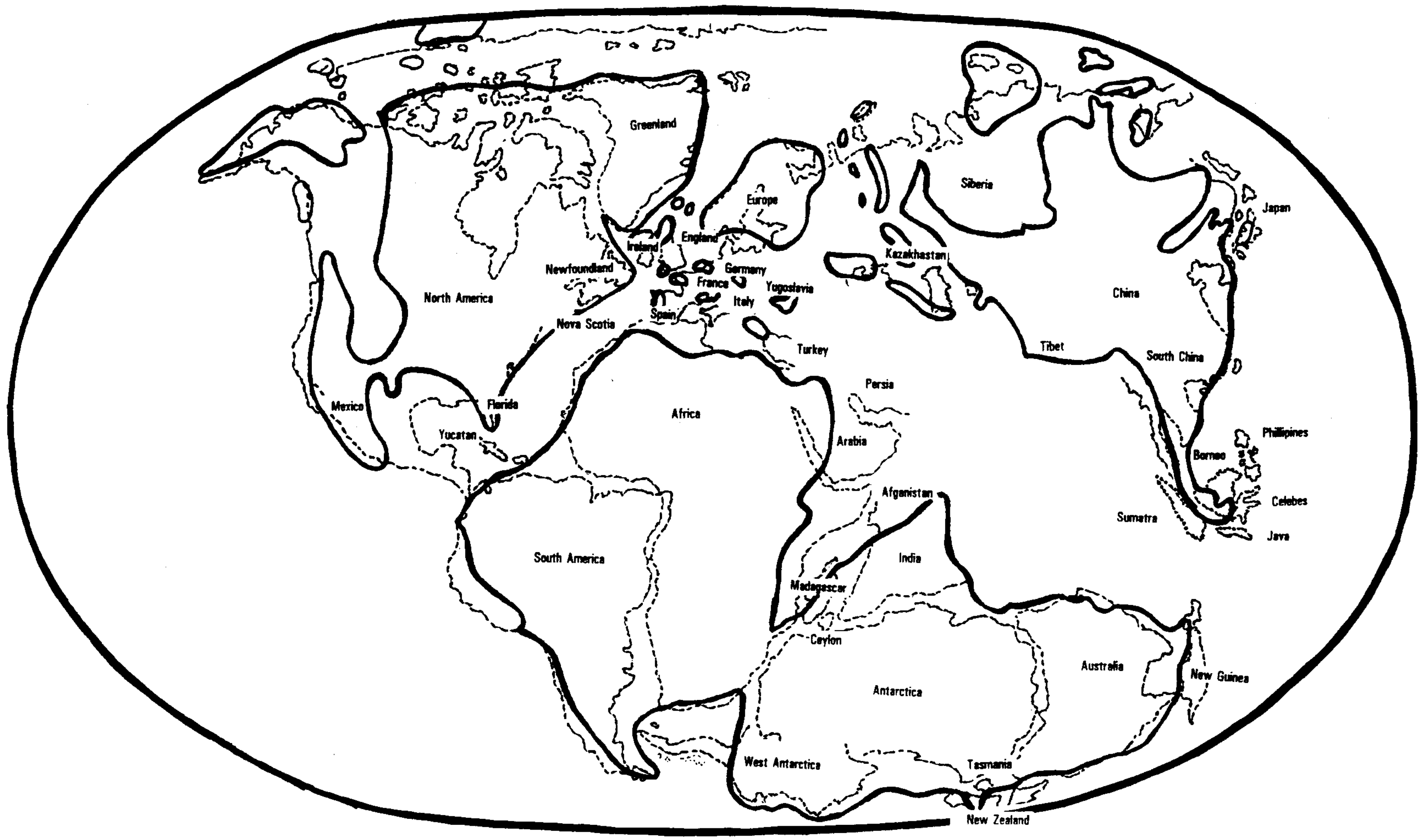


Figure 21a. The Jurassic paleogeography of the world (after Dixon 1988 and Norman 1988)

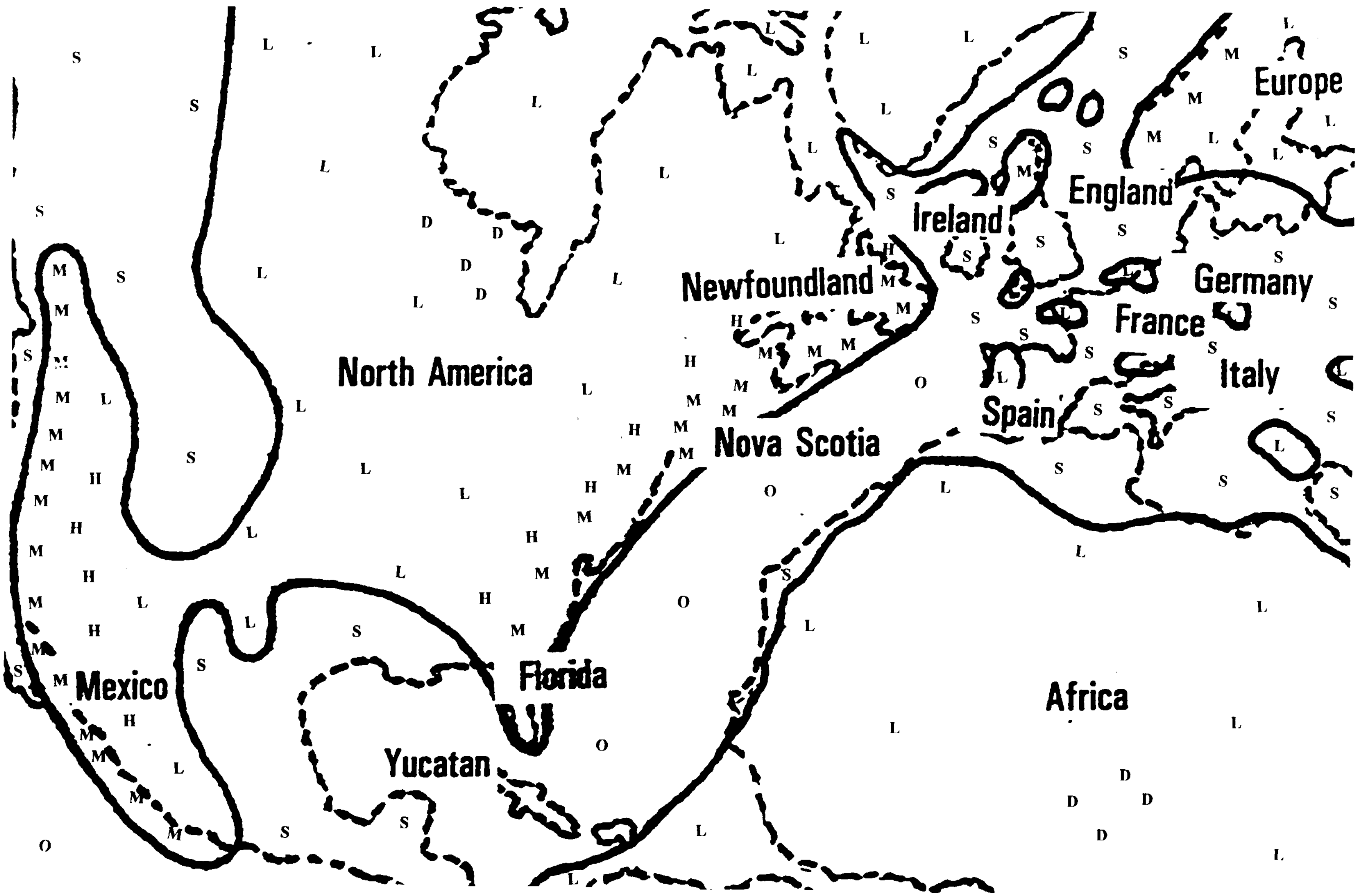


Figure 21b. The Jurassic paleogeography of North America (after Dixon 1988 and Norman 1988)

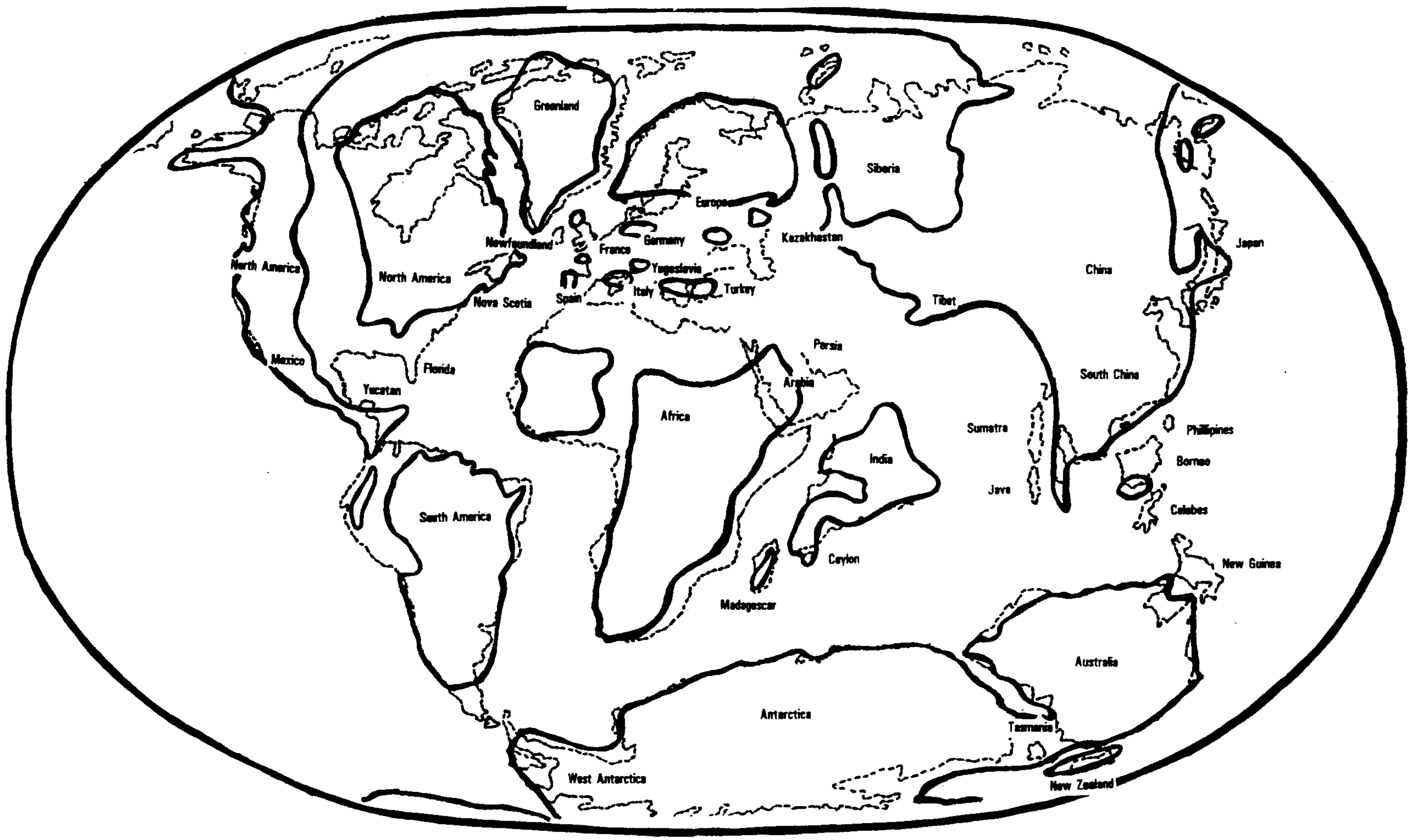


Figure 22a. The Cretaceous paleogeography of the world (after Dixon 1988 and Norman 1988)

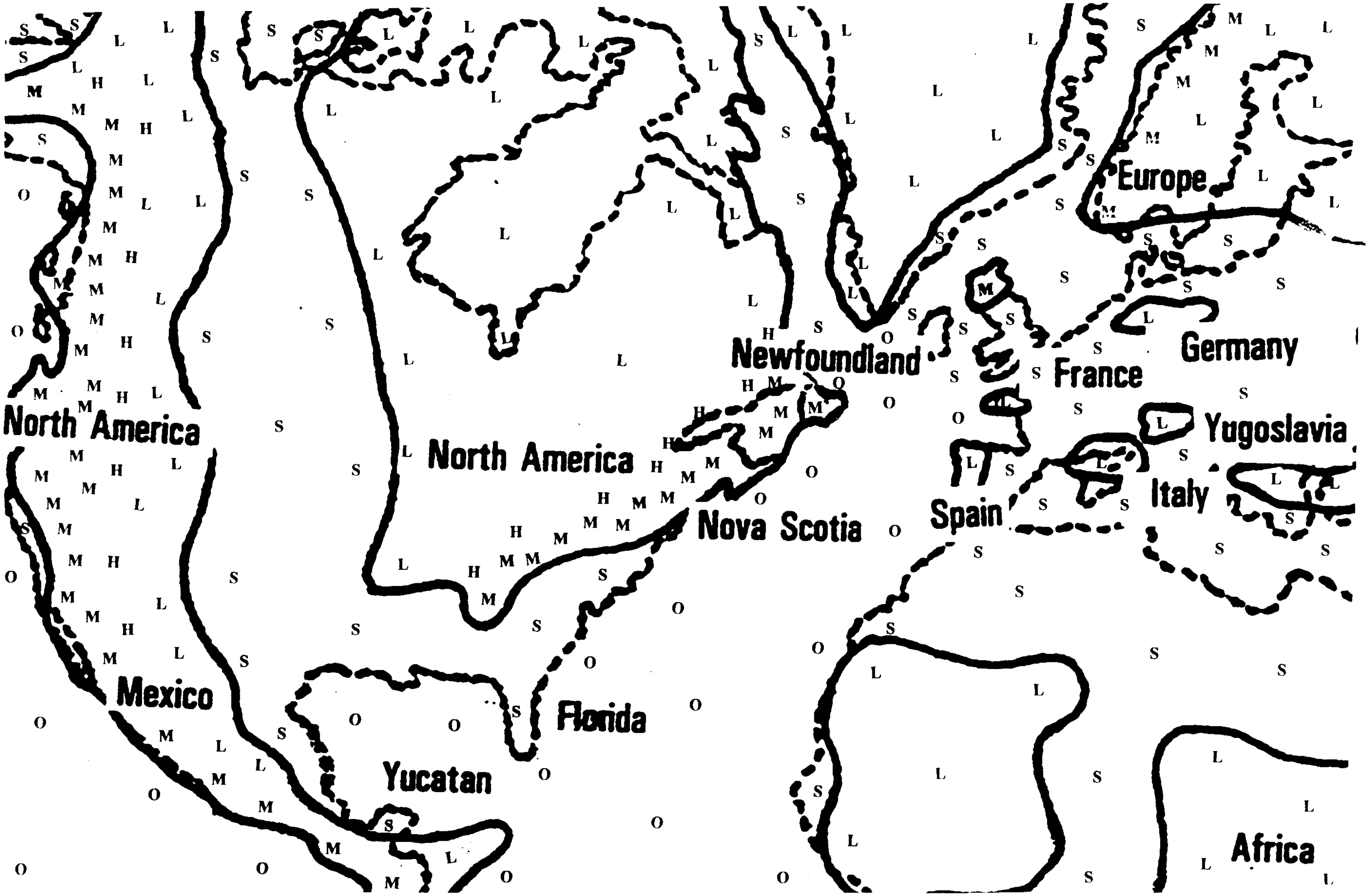


Figure 22b. The Cretaceous paleogeography of North America (after Dixon 1988 and Norman 1988)

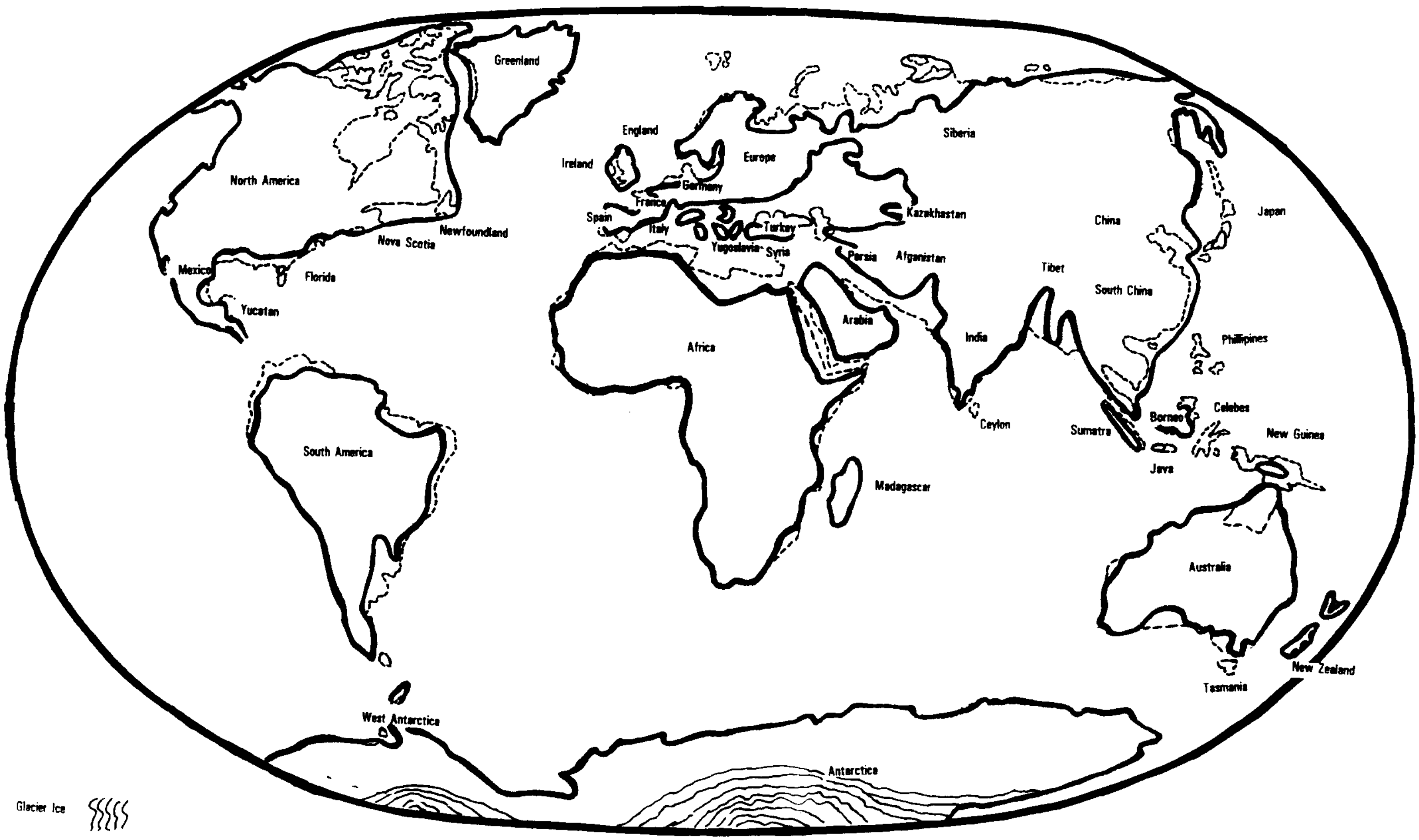


Figure 23a. The Tertiary paleogeography of the world (after Wicander and Monroe 1989)

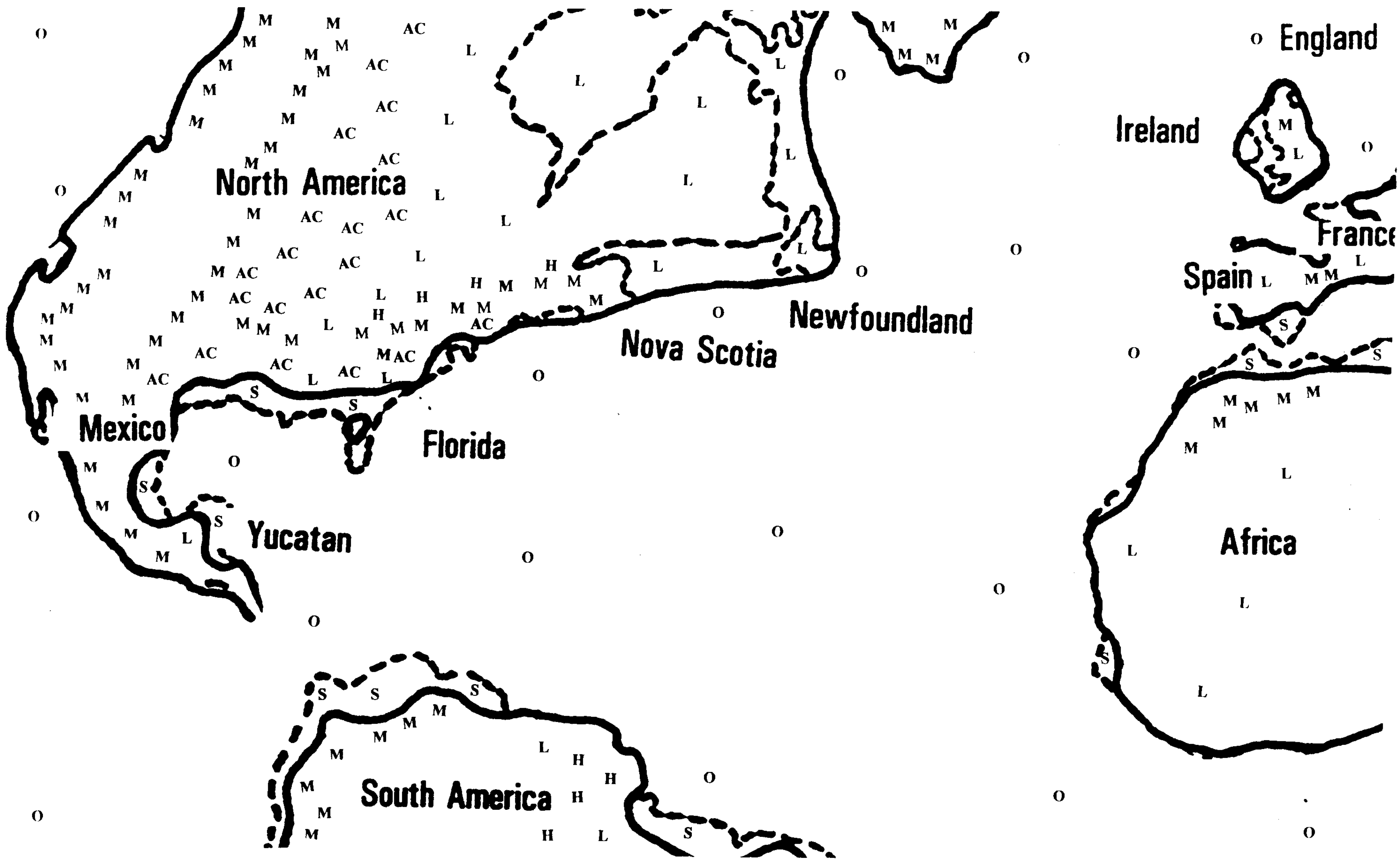


Figure 23b. The Tertiary paleogeography of North America (after Wicander and Monroe 1989)

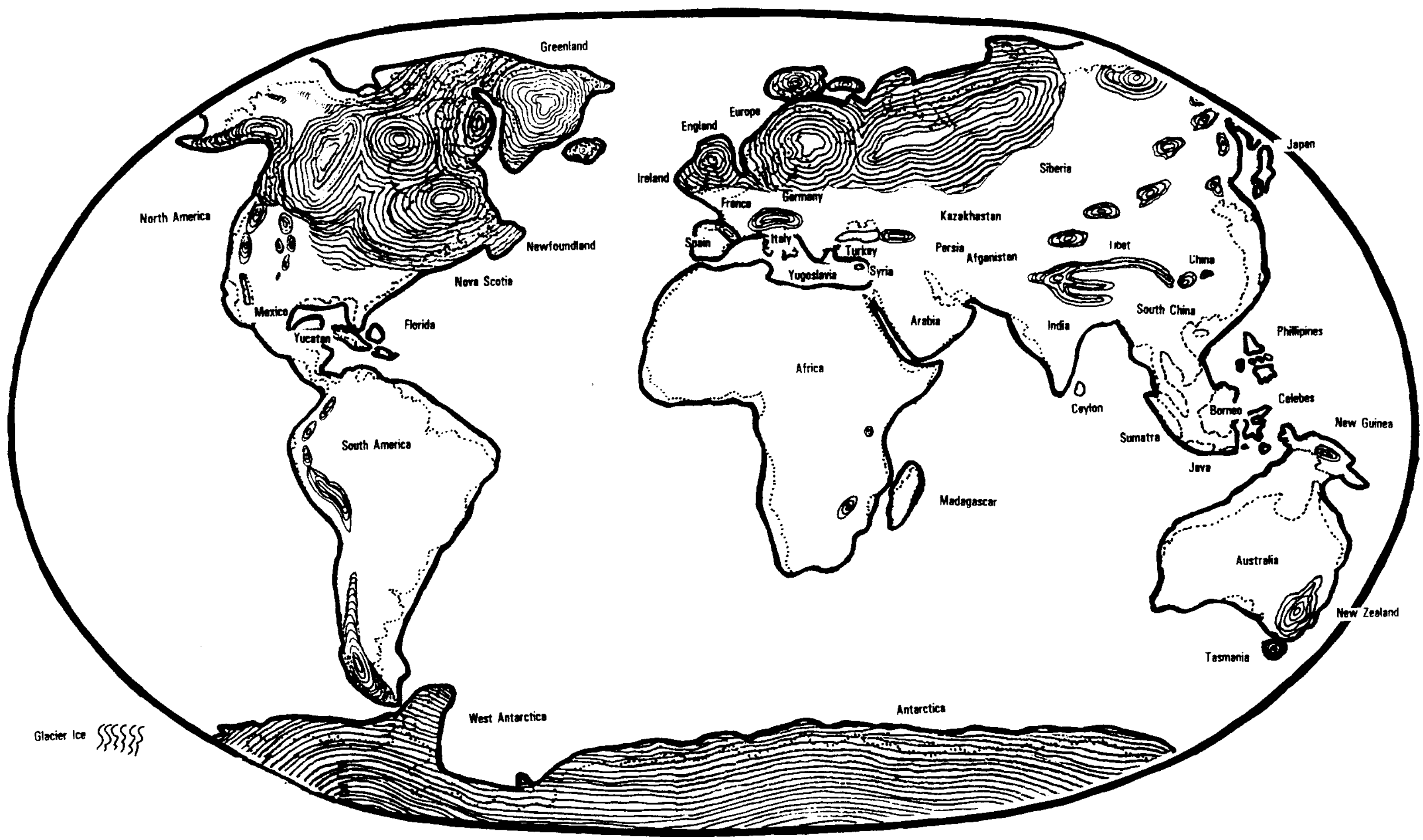


Figure 24a. The Quaternary (Ice Age) paleogeography of the world (after Wicander and Monroe 1989)

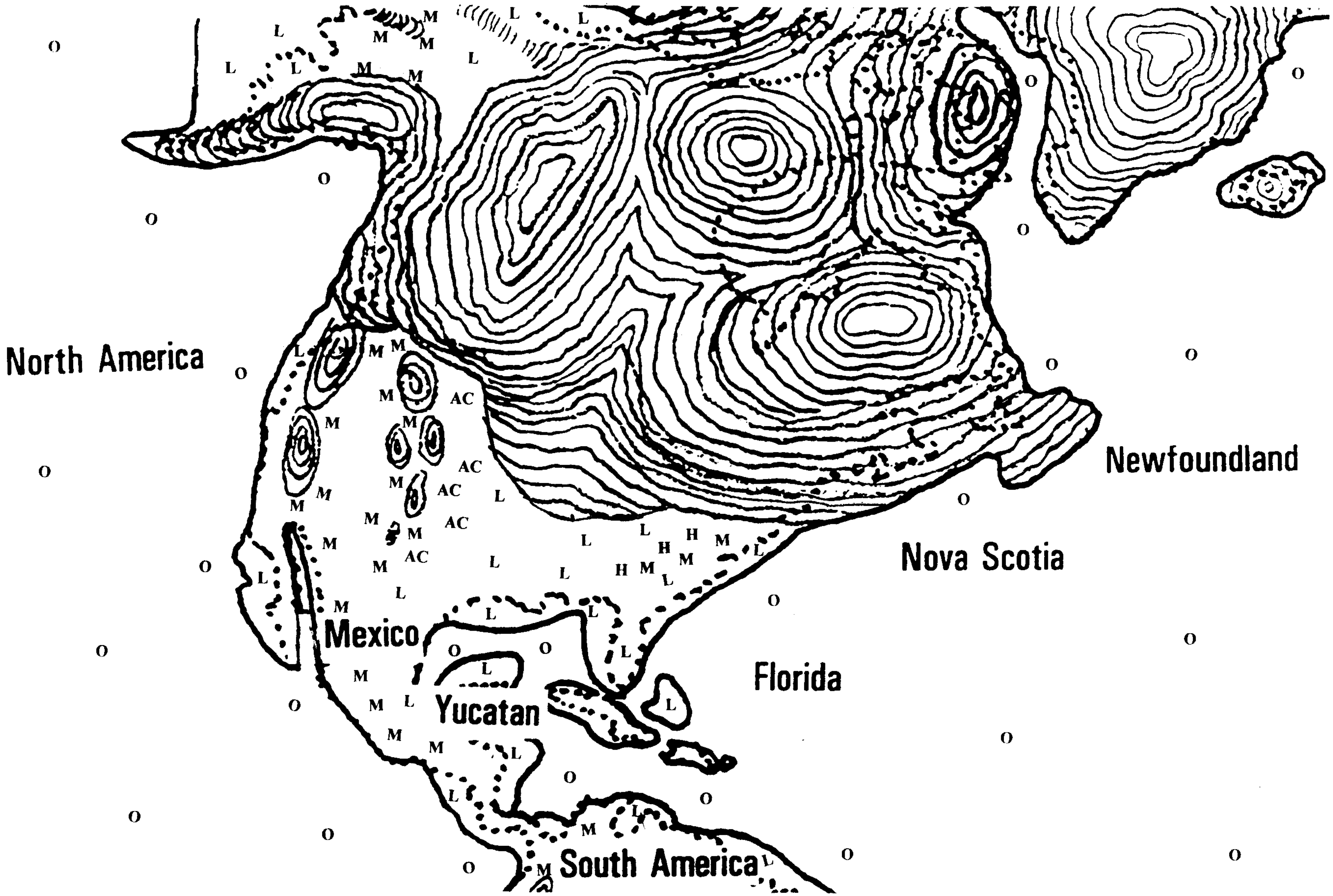


Figure 24b. The Quaternary (Ice Age) paleogeography of North America (after Wicander and Monroe 1989)

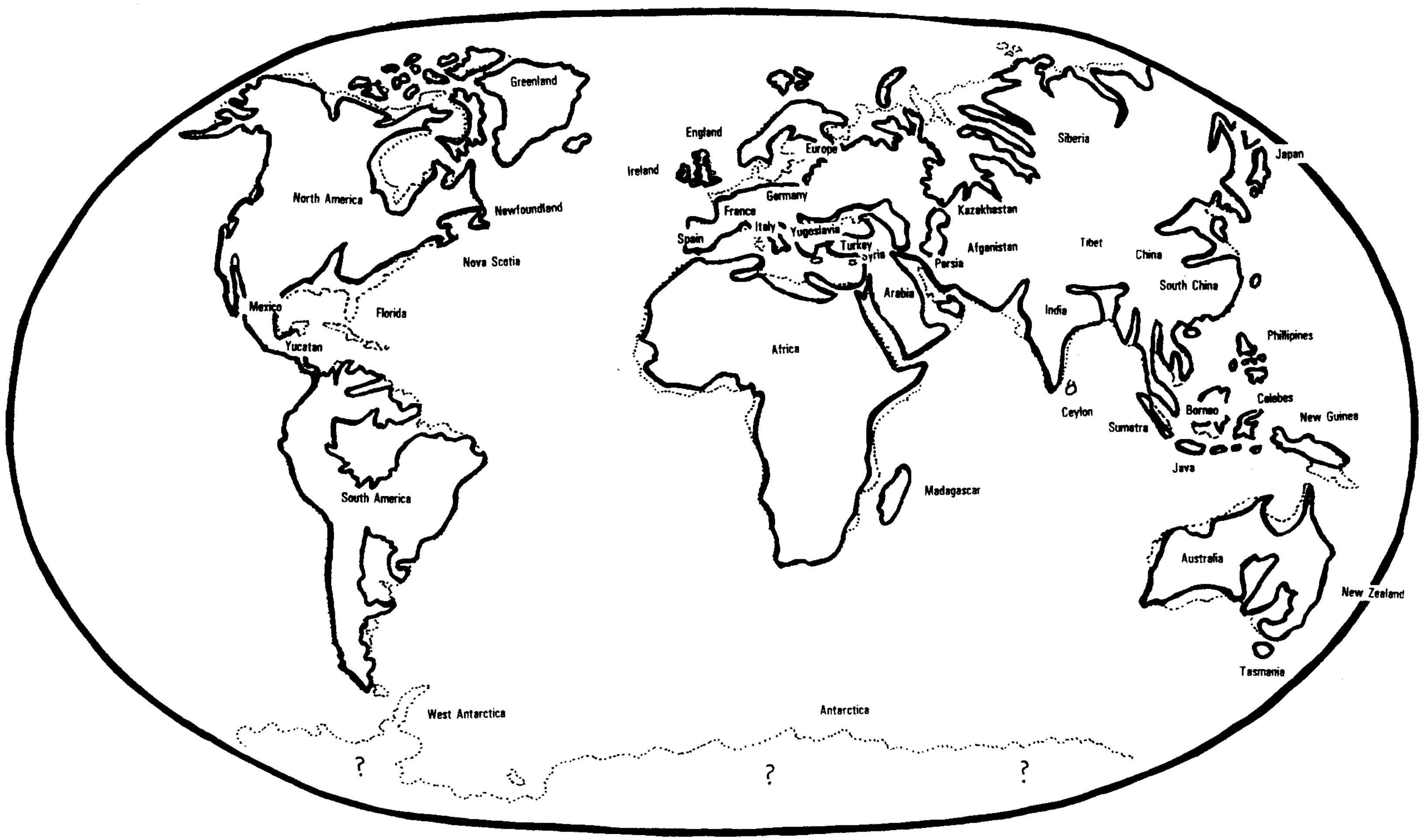


Figure 25a. The Quaternary (interglacial) paleogeography of the world (after Wicander and Monroe 1989)

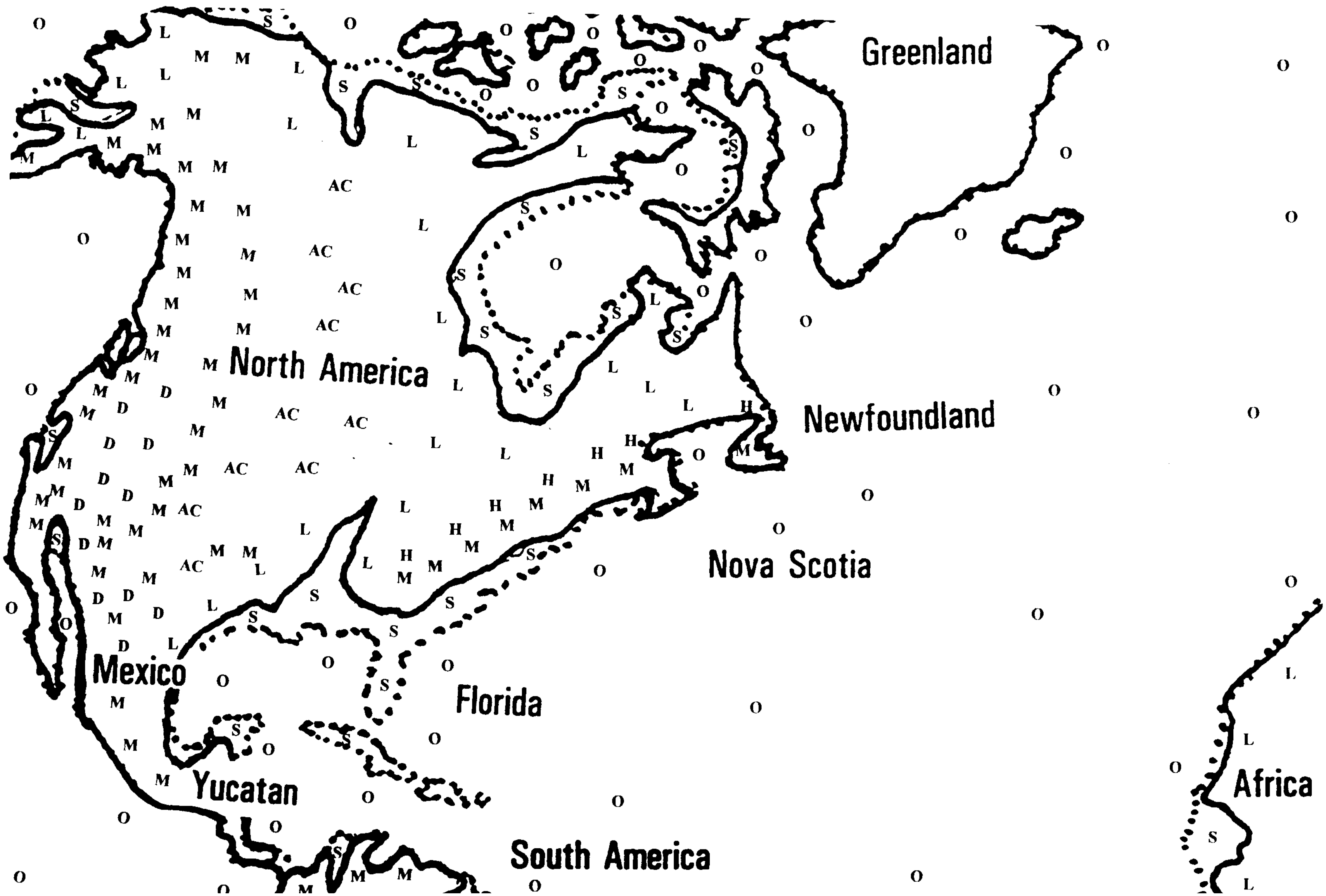


Figure 25b. The Quaternary (interglacial) paleogeography of North America (after Wicander and Monroe 1989)

REFERENCES

Birkeland, Peter W., and Edwin E. Larson. 1989. *Putnam's Geology*. 5th ed. New York: Oxford University Press.

Dixon, Dougal. 1988. *The Illustrated Dinosaur Encyclopedia.* New York: Gallery Books.

Hayes, Phillip T., and George C. Cone. 1975. *Cambrian and Ordovician Rocks of Southern Arizona and New Mexico and Westernmost Texas.* United States Geological Survey Professional Paper 873.

Levin, Harold H. 1999. *The Earth Through Time.* 6th ed. Orlando, Fla.: Saunders College Publishing.

Lochman-Balk, Christina. 1971. "The Cambrian of the Craton of the United States." In *Cambrian of the New World,* ed. C. H. Holland, pp. 79–167. New York: Wiley-Interscience.

Norman, David. 1988. *The Prehistoric World of the Dinosaur.* New York: Gallery Books.

Palmer, Allison R. 1971. *The Cambrian of the Great Basin and Adjacent Areas, Western United States.* In *Cambrian of the New World,* ed. C. H. Holland, pp. 1–78. New York: Wiley-Interscience.

Sawyer, Dale S. 2000. "Discovering Plate Boundaries"; http://terra.rice.edu/plateboundary/

Scotese, Christopher R. 1986. *Phanerozoic Reconstructions: A New Look at the Assembly of Asia.* Texas Institute for Geophysics Technical Report 66, Paleogeographic Mapping Project Report No. 19-1286.

Scotese, Christopher R., and Jan Golonka. 1992. *PALEOMAP Paleogeographic Atlas.* Department of Geology, University of Texas at Arlington.

Scotese, Christopher R., et al. 1979. "Paleozoic Base Maps." *Journal of Geology* 87 (3): 217–277.

Wicander, Reed, and James S. Monroe. 1993. *Historical Geology: Evolution of the Earth and Life Through Time.* 2nd ed. San Francisco: West Publishing.