obtained; each point on it represents the carbon and oxygen isotopic composition of a true North Sea shell at a specific temperature.

It is interesting to note that the intersection of the carbonate lines of the two estuaries falls on the equilibrium line for true marine conditions. The point of intersection corresponds to an average temperature of about 13.5°C, which is a reasonable average for the main growth period of mollusks (April to June) in this region (*7*); thus it seems evident that isotopic equilibrium exists between the shell carbonate and the surrounding water.

If one assumes equilibrium for ^{18}O and a temperature of 13.5°C (α^{18} = 1.00083), a fractionation factor for the $CaCO_3-HCO_3^-$ equilibrium can be derived from the samples from the Westerschelde; the value α^{13} = 1.00096 yielded is in good agreement with results from laboratory experiments: α^{13}, 1.00075 (13.5°C). The fact that mean deviation of an individual sample (± 0.36 ppt) is surprisingly small means that, for the shells we used, equilibrium is very likely not only for oxygen but also for carbon isotopes. For different regions, different $\delta^{18}O$ and (possibly) $\delta^{13}C$ values of the freshwater contaminant are to be expected, so that a straight carbonate line can only be expected in a restricted area.

Besides the mentioned effect of atmospheric exchange, quite large deviations from our figures on shell isotopic compositions can presumably result from local conditions. Local production of metabolic CO_2 or high photosynthetic activity by water flora could easily lower or increase the ^{13}C content, respectively, while the ^{18}O content can be changed, for instance, by local freshwater contamination or by evaporation in more or less closed basins. In a region of flowing water and under mild climatic conditions, such as we have considered, the correlation seems to hold remarkably well.

Thus one may draw the following conclusions:

1) In an estuary of fast-running brackish water there is a similar linear relation between the ^{13}C of the dissolved bicarbonate (ranging from −12 to +1 ppt) and chlorinity as there is known to be for the $\delta^{18}O$ of the water.

2) At least for the shells we investigated, there is a state of isotopic equilibrium between carbonate and solution, not only for the oxygen but also for the carbon isotopes.

3) An average growth temperature can be deduced for shells from an estuary by extrapolation of the $\delta^{13}C/\delta^{18}O$ plot to oceanic conditions.

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9. We thank D. Eisma, University of Groningen, for discussions. Most of the shells came from the Zoological Museum, Amsterdam, and the State Museum of Natural History, Leiden. Samples of water were collected by the Netherlands Institute of Sea Research, Den Helder.

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Palinspastic Restoration Suggesting Late Paleozoic North Atlantic Rifting

Abstract. *Palinspastic restoration of sinistral wrench faults in Britain and of dextral wrenches in Canada, starting with the palinspastic pre-continental-drift map, implies the possibility of as much as 424 kilometers of rifting between Newfoundland and Ireland. The wrench-faulting and postulated resultant rifting are of Devonian and Carboniferous age.*

The development of a rift between Newfoundland and Ireland during the Late Paleozoic is postulated on the basis of the occurrence of both sinistral and dextral slips in the once continuous Great Glen–Cabot Fault system; it may be termed the Labrador-Biscay Rift.

Recent recognition of continuing spreading of the ocean floor in the North Atlantic (*1*) is a compelling argument in favor of the continental-drift theory. Assuming continental drift, Wilson (*2*) has called attention to the striking predrift continuity of the Great Glen Fault (or fault system) and of what he terms the Cabot Fault—in fact a system of faults extending southwestward across Newfoundland, the Maritime Provinces, the Bay of Fundy, the Gulf of Maine, and southeastern New England; he suggested a history of Devonian-to-Early Carboniferous sinistral slip for the entire Great Glen–Cabot system. Two facts argue against the sinistral-slip history as proposed:

1) A probable age distinction exists between the British wrenches and the wrenches of the northern Appalachians. The former are Devonian where dated, as in the case of the Great Glen Fault (*3*), the Fintona Fault (*4*), and the Highland Boundary Fault (if a wrench, *5, 6*); more loosely dated otherwise on the Leannan (*7*) and the Minch (*8*) faults. By contrast, the Canadian wrenches cut Lower to Upper Carboniferous, where dated (*9, 10*); while the ages may overlap in part, as some of the British faults have had post-Devonian history (*11*) and the Canadian faults may have had pre-Carboniferous movements, the major displacements apparently were not synchronous.

2) Probably of greater significance is the apparent discrepancy in slip directions. Sinistral slip dominates the major faults trending from northeast to southwest in the British Isles (*3–5, 7, 8*), although the Highland Boundary Fault may be an exception (*6*). Late Carboniferous sinistral slip did occur along the Cabot Trend on one fault—the Harvey-Hopewell of eastern New Brunswick (*9*)—but otherwise the dominant sense of displacement is dextral on most of the Cabot Fault system (*9, 10, 12, 13*), possibly including an earlier phase on the Harvey-Hopewell Fault itself. Thus, aside from the question of age, the opposition of slip directions precludes a single shear history of the Great Glen–Cabot Fault system. However, palinspastic analysis does suggest at least two solutions to the problem that could be compatible with the continental-drift theory.

Figure 1 is taken from the palinspastic map of Bullard *et al.* (*14*), with prominent wrenches and other faults added. Further palinspastic reconstruction can then be made (Fig. 2) by restoration of the Late Paleozoic wrench displacements in one of several ways: First, one may see that the sinistral slips of the British Isles and the opposed dextral slips in Canada could have resulted in the driving together of the Hebrides-Greenland block and the Labrador-Laurentia block, closing out an ancestral Labrador Strait. Such a closure should have created an orogenic belt trending along the present Labrador Strait; lacking evidence of such a Late Paleozoic orogene, however, I propose the alternative of a single and stable Laurentia-to-Hebrides block and the development of a Late Paleozoic rift resulting from the wrench movements. Figure 1 shows the possible extent of the rift, located between Newfoundland and Ireland, now beneath the continental shelves. Presumably the rift was more or less filled with Late Paleozoic extrusives and sediments, but large-scale intrusives also may have been important. I suggest for it the name Labrador-Biscay Rift because the ancestral Labrador Strait and the Bay of Biscay [the Biscay Rift or Biscay Sphenochasm of Carey (*15*)] appear to be extensions of it.

Acceptance of the continental-drift theory and of the reality of the wrench faults leads to the construction of Fig. 2 from Fig. 1 by restoration of the wrench-fault displacements. Two hundred and twenty-four kilometers of sinistral displacement was taken to be the net effect of the Minch Fault, the Great Glen Fault, the Leannan Fault, the trend of the Fintona–Highland Boundary Fault, and other faults of lesser slip. This displacement probably is a minimum; it may easily be 270 km or more. An estimated 190 km of dextral slip across western Newfoundland is taken as the net effect of displacements on the Lubec Fault of Maine and its branches, the Belleisle, Peekaboo, and Clover Hill–Dorchester faults, the Harvey-Hopewell Fault of New Brunswick, and the Cobequid-Hollow Fault of Nova Scotia. All these seem to be represented in Newfoundland by the Hampden system and the Luke's Arm Fault. Again, the estimated total of 190 km may well be less than the true total. The many possible interpretations will be discussed more fully later.

The proposed rift would be terminated at both ends by Paleozoic wrench faults acting as transform faults (*16*). On the northwest the rift would make a T junction with the Great Glen–Cabot Fault system, the rifting having opened primarily northeastward during the Devonian, with accompanying Great Glen sinistral slip, then southwestward during or at the end of the Early Carboniferous (Mississippian), accompanying Cabot dextral slip. The rift should be terminated at the southeast end by another transform wrench fault or fault system, either entirely sinistral and trending southwestward from the end of the rift zone, with the combined total of 424 km or so of slips, or trending both southwestward and northeastward as a mirror image of the Cabot–Great Glen system. It might have been off the present Iberian coast; indeed later it may have become the site of the Mesozoic Atlantic Ocean rift there. However, all or part of the wrench system could have been inside the present coast and in fact

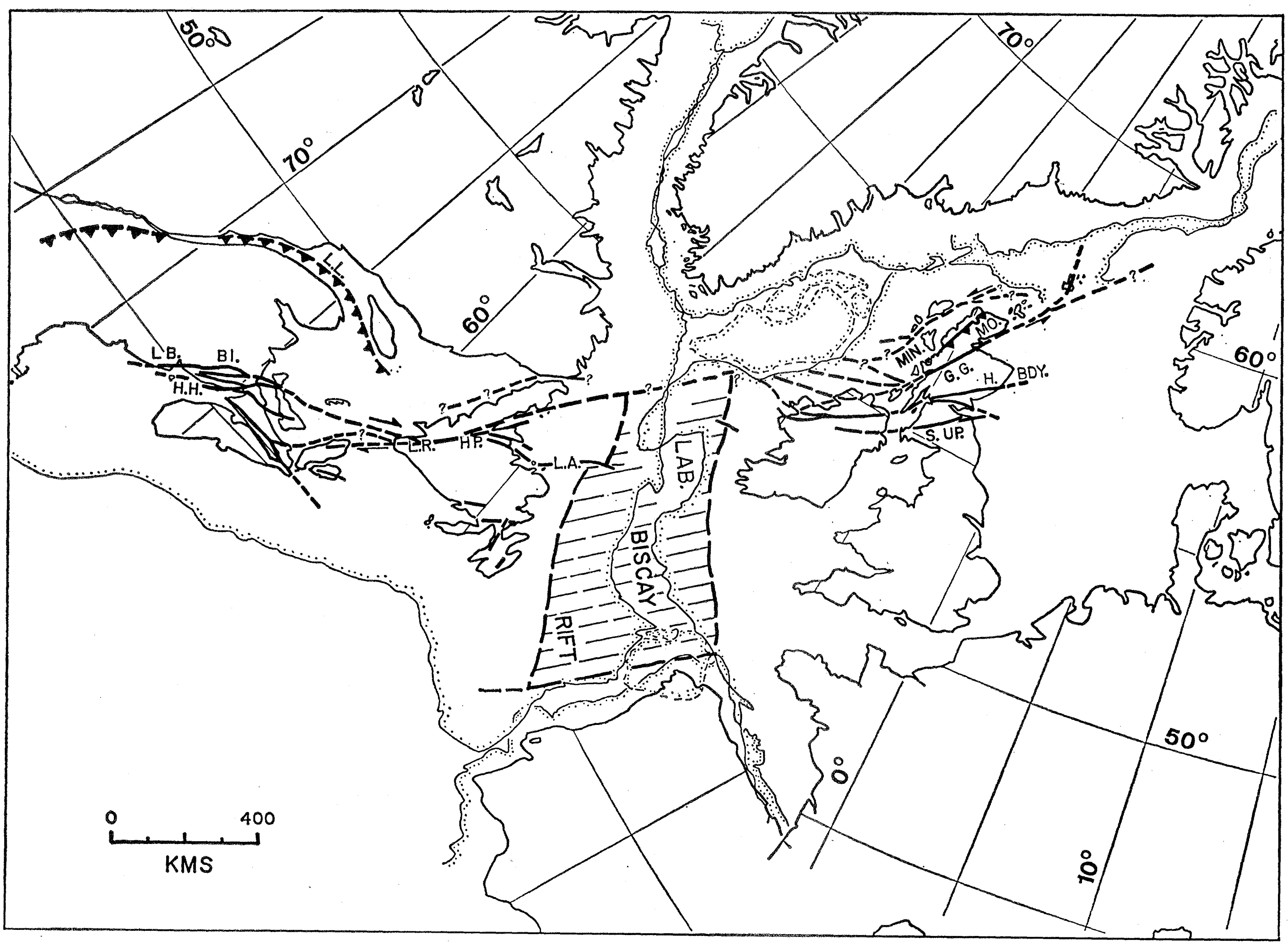

Fig. 1. Pre-continental-drift palinspastic base map from Bullard *et al.* (*14*), with important faults added. Great Glen system (Minch, Great Glen) may include sinistral wrench movement on Highland Boundary and Southern Upland faults. Cabot system may include dextral slip on Harvey-Hopewell Fault before the sinistral slip on the latter. Postulated extent of Labrador-Biscay Rift is obtained by expansion of the rift line shown in Fig. 2. Abbreviations: *LB.*, Lubec; *H.H.*, Harvey-Hopewell; *BI.*, Belleisle; *L.R.*, Long Range; *HP.*, Hampden; *L. A.*, Luke's Arm; *LAB.*, Labrador; *MIN.*, Minch; *MO.*, Moine; *G. G.*, Great Glen; *H. BDY.*, Highland Boundary; *S. UP.*, Southern Upland.

coincident with the Lisbon Scarp of Carey (*15*); in that case the wrench fracture, possibly already extended into the English Channel region, would have predetermined the location of the later flexure or downfaulting that produced the scarp.

The reconstruction (Fig. 2) involves a small amount of rifting between Ireland and England, with the remainder concentrated between Ireland and Newfoundland. However, fault displacement could be distributed differently, without alteration of the total displacement of England relative to Nova Scotia, by assumption of more rifting in the Irish Sea and a considerable amount in Cabot Strait; thus Ireland and Newfoundland would not have been quite as close together as I show them. Revision of the estimated net effect of the wrench-fault displacements would of course alter the required width of a rift zone as well; it might be considerably less, as would be the case if the entire Cabot–Great Glen system had moved sinistrally the 224 km estimated for Great Britain during the Devonian, with later dextral return of the Canadian portion synchronously with Carboniferous rifting totaling only about 190 km. This possibility is suggested by evidence of pre-Carboniferous faulting in northern Cape Breton Island (*13*) and perhaps elsewhere. On the other hand, the amount of rifting may have been made even greater than the suggested 424 km by closure of the Irish Sea, Cabot Strait, and the remainder of the space between Ireland and Newfoundland for another 230 km, or a maximum possible of about 664 km. Even this figure may be considered low if the relation between fault offset and fault length, observed by Menard, can be applied in this instance (*17*).

Another variation may be that the sinistral slip in the British Isles is due largely to crustal spreading in the Appalachians, caused by synchronous batholithic intrustions, because both the Great Glen slip and the Acadian intrusives are dated Middle Devonian. Just what effect that relation would have on the restoration is uncertain, as are the possibilities of a similar mechanism involving either the Caledonian intrusives in the British Isles or the dextral Carboniferous wrenches in eastern Canada. Not all the intrusives could have developed the differential widening effects necessary to cause such wrench-faulting, however, since they straddle the wrench faults in places—notably in New Brunswick–Nova Scotia and in Scotland (*18*). In view of the probability that the batholith-spreading mechanism was not the major causal factor in the wrench displacements I now prefer the rift-zone hypothesis.

The relation of the proposed reconstruction to Acadian and Hercynian orogeny remains difficult to assess. The Carboniferous Hercynian deformation seen in the southern British Isles presumably occurred after the British wrench displacements mapped here, and during or just after those in Canada; thus Fig. 1 is the more appropriate

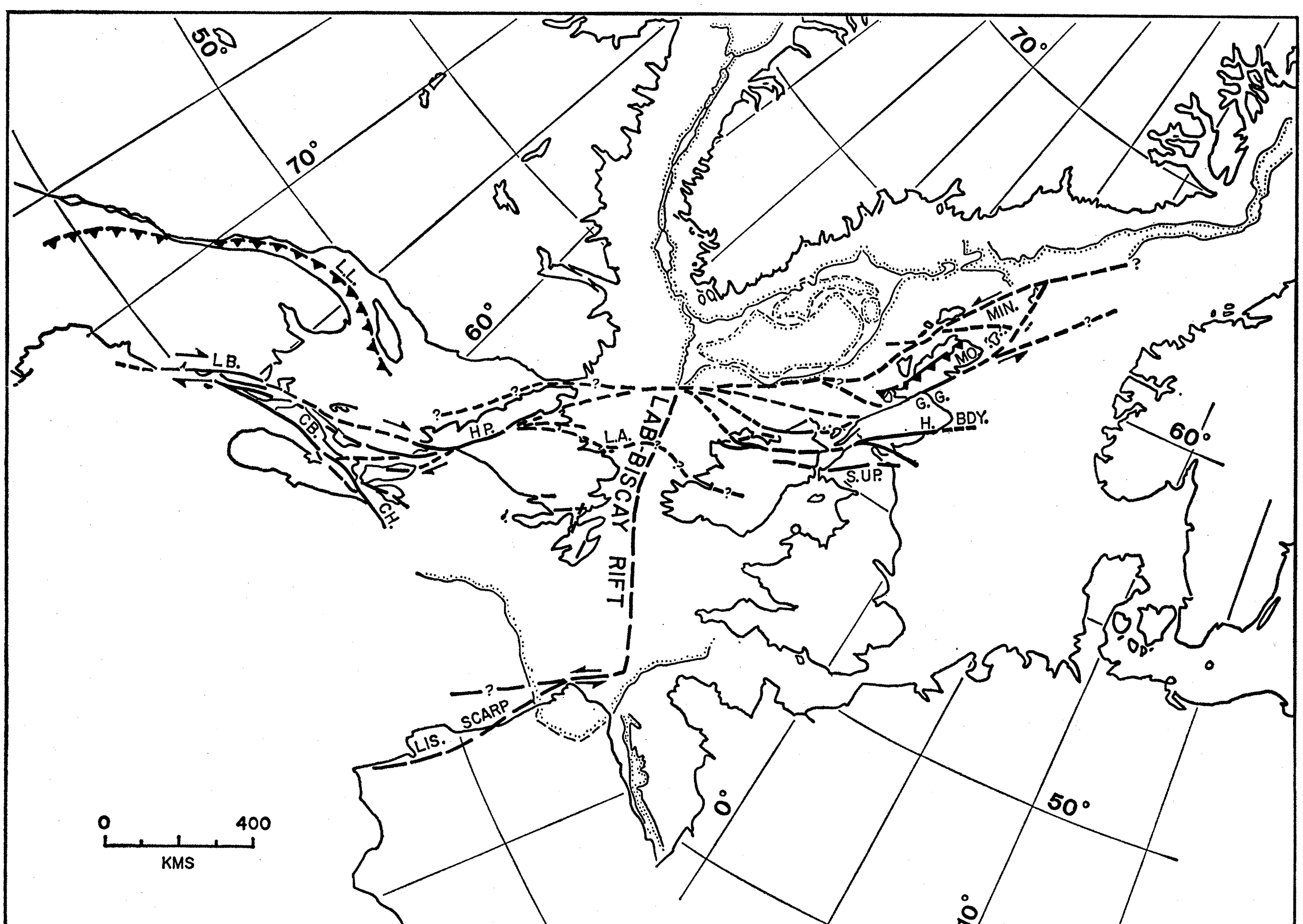

Fig. 2. Pre-wrench-fault palinspastic map derived from Fig. 1 by restoration of an estimated 224 km of sinistral slip on the Great Glen system and 190 km of dextral slip on the Cabot system. Postulated position of the then-incipient Labrador-Biscay Rift is indicated between Newfoundland and Ireland; it was used in turn to outline the rift as shown in Fig. 1. Abbreviations: *CB.*, Cobequid; *CH.*, Chedabucto; *LIS.*, Lisbon; others as for Fig. 1.

base from which to depart with restorations of Hercynian movements in Europe. Figure 2 was intended to depict essentially Late Caledonian and Late Acadian conditions in the vicinity of the wrench-faulted and rifted area, but it still represents post-Hercynian relations in southern Britain and the European mainland, as no attempt was made to include European Hercynian movements in the restoration. Thus the relation of the proposed rift to the Iberian Peninsula and other parts of the mainland of Europe is especially uncertain. Nor are the Appalachian and Caledonian portions of Fig. 2 entirely compatible; in the sense of age, the British wrench faults were already in motion while the Appalachian area was still in the throes of Acadian orogeny, which included widespread intrusions and metamorphism. Thus the Caledonian belt in Britain is mapped for pre-Middle Devonian, post-Silurian, while the Appalachian belt is mapped as pre-Middle Carboniferous, post-Middle Devonian. The internally somewhat anachronous restoration proposed in Fig. 2 should be considered only as a first and incomplete approximation in the process of unraveling the record of crustal movements in the North Atlantic region.

The proposed rift hypothesis would have certain other ramifications. Wilson (*19*) has emphasized that the Mesozoic rift, which initiated the present Atlantic Ocean, split off a portion of the Europe-Africa block and left it as the part of North America that extends southwestward along the present coast from eastern Newfoundland, the block originally having been part of the eastern side of the Appalachian belt, itself of oceanic origin. Newfoundland in particular demonstrates the presence of the eastern flank of the geosyncline (*20*). Likewise, the Mesozoic rifting detached the Lewisean basement of the Hebrides from the Greenland portion of the old Laurentia and left it as a part of Europe. Therefore the postulated Late Paleozoic rifting appears to have predetermined the part of the Mesozoic oceanic rift that cuts across the grain of the Appalachian-Caledonian geosynclinal belt, the oceanic split following one or perhaps both of the northeasterly trending transform boundary faults as well (see Figs. 1 and 2). Likewise, the two distal extensions have predetermined location of the present Labrador Strait and Bay of Biscay. All three segments seem to have functioned as true rifts, but presumably the center portion first opened in one or two stages during the Late Paleozoic; the remaining segments, during the Middle Mesozoic. The ultimate origin of the proposed line of weakness is of course obscure, but its great length and relatively straight trace may suggest an earlier wrench-fault history.

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Hydration Rind Dates Rhyolite Flows

Abstract. *Hydration of obsidian has been used to date rhyolite flows, containing obsidian or porphyritic glass, at Glass Mountain (Medicine Lake Highlands) and Mono Lake, California. The method is simple and rapid and can be used to date flows that erupted between 200 and approximately 200,000 years ago.*

In 1960 Friedman and Smith (*1*) described a technique for dating obsidian artifacts; it was based on the fact that the artifact maker, in chipping or flaking the artifact, exposed a fresh surface of the volcanic glass to the atmosphere; water vapor was adsorbed on the surface, and slowly diffused into the body of the artifact, producing a hydrated layer or rind. The hydrated glass has a higher refractive index than does unhydrated material, and the boundary between is sharp; one can observe this boundary optically on thin sections of the artifact cut normal to the water-diffusion front (Fig. 1). Rates of diffusion were derived by measuring hydration rinds on artifacts of known age, or on artifacts whose ages could be inferred by C^{14} dating of associated carbonaceous material. The rates were shown to be independent of relative humidity, but dependent on the temperature of hydration. The hydration rates varied from 0.36 μ^2/1000 years for the Arctic to 11 μ^2/1000 years for the tropics.

It occurred to Friedman and Smith that this method of dating might be used to date rhyolitic flows also. However, the problem of the large amount of hydration that may have occurred, as the flow cooled from its high original temperature, deferred a test of this method on flows.

Several samples of trees burned by the composite rhyolite-dacite flow at Glass Mountain, Medicine Lake, California, recently yielded C^{14} ages of 390, 380, 190, and 130 years, all $\pm$ 200 years (*2*). These ages are much younger than the 1360 $\pm$ 240 years obtained by Chesterman (*3*) on a tree buried by air-fall pumice that was erupted before the glass flow. Since Glass Mountain was erupted recently (less than 500 years ago) and since the date of eruption was known reasonably well from C^{14} measurements, this flow seemed suitable for checking the importance of hydration of the glass during cooling. Accordingly I set up a saw, lap, and microscope at Glass Mountain and examined the hydration layers on original surfaces from various parts of the flow.