Suggested Extension of the Grenville Orogenic Belt and the Grenville Front

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IN recent years much evidence has tended to show that the area of the Canadian Shield designated as the Grenville subprovince by M. E. Wilson (*1*) and as the Grenville province by J. E. Gill (*2*) was mountain-built in later pre-Cambrian time. Both Gill and J. Tuzo Wilson (*3*) have discussed its relationship to other major features of the Shield. Determinations of ages of radioactive minerals in the Grenville province fall within the range 1100 to 800 million years (*4–7*). However, there are many unanswered questions concerning the relations of the uraniferous pegmatites to the orogeny or orogenies that have affected the region.

The province is approximately bounded on the southeast by the St. Lawrence River, but with the Adirondack Mountains as a southeastern outlier (Fig. 1). The northwestern border of the province lies about 250 mi northwest of the St. Lawrence. This boundary is known as the Grenville front (*8*).

The extent of the Grenville orogenic belt is not yet fully established. J. Tuzo Wilson (*9*) suggested that it is truncated at the northeast (outside the limits of Fig. 1) by the Labrador orogenic belt, but later he seems to have regarded the relationship an open question (*3*). The linears shown on his earlier map may allow the interpretation of the two belts as contemporaneous. Their junction is rather similar to that of the eastern Himalayas with the north-south Burma ranges. Alternatively, the Labrador belt may be older than, and truncated by, the Grenville. This latter interpretation is supported by a few age measurements of about 1500 million years in the Labrador belt and has been adopted by Collins, Farquhar, and Russell (*10*) in a recent revision of Wilson's map that shows the Grenville fault zone passing into the Atlantic on the Labrador coast north of Hamilton Inlet.

To the southwest, the Grenville belt passes out of sight under early Paleozoic sediments north of Lake Ontario, with no indication of diminished intensity of folding, if we may judge from the intricate structure in the Hastings district (*11*). It could be expected to continue for some hundreds of miles. Directly along its strike lie three anticlinal structures in the Paleozoic rocks. In order, from northeast to southwest, these are (i) the Findlay arch, (ii) the Cincinnati dome, and (iii) the Nashville dome (Fig. 1). It is suggested that these broad, gentle upwarps are the present surface expression of the Grenville mountain range.

After the Grenville orogeny and the intrusion of the Killarney granite, the mountains were eroded and perhaps peneplaned. According to current tectonic concepts, such an orogenic belt typically develops a deep "root" of sialic material and is persistently buoyed up by the underlying sima, while being reduced by erosion. The Cincinnati and Nashville domes throughout Paleozoic time were alternately shallowly submerged and slightly exposed above the sea, while adjacent areas to east and west sank more consistently and received thicker deposits of sediments (*12*). The Grenville orogeny may be the reason for the existence of these anticlines, which continued to rise isostatically or, at least, to sink much less rapidly than neighboring areas. That the belt now appears as a group of domes may be conjecturally attributed to variable depth or intensity of deformation at different places.

Probably the most striking feature of the structure in the southern United States is the great offset of the Ouachita Mountains folded belt relative to the Appalachians. Details of the displacement are concealed beneath Cretaceous and Tertiary sediments of the Mississippi embayment. It is noteworthy that the relationship of the Ozark uplift to the Ouachitas is practically identical with that of the Nashville dome to the Appalachians (*13*). It is as if the Grenville belt were offset in the same direction and about the same amount as the belt affected by the late Paleozoic orogeny.

It is therefore suggested that the Grenville mountain range originally curved smoothly from a southwesterly to a westerly trend near the present Mississippi River and that a great fault of later (but still pre-Cambrian) date cut across it at the bend and dislocated the western side (the Ozark uplift) horizontally northward 200 mi or more. It is further suggested that this fault and the known Grenville front in Canada *may be one and the same*. The resulting trace is fairly straight. The Grenville front disappears under Lake Huron at Killarney, Ontario. The proposed extension would pass, beneath Paleozoic rocks, through the "thumb" of Michigan, the extreme northwestern corner of Ohio, southwestern Indiana, and approximately along the Mississippi River between Arkansas and Tennessee (Fig. 1).

If such a displacement of the Grenville belt did occur, there seems to be no possibility that it took place later than the end of pre-Cambrian time, for none of the Paleozoic rocks along its suggested course show large disturbance. If this hypothesis is correct, the equal dislocation of the Appalachian-Ouachita belt must be due to the circumstance that the uplift

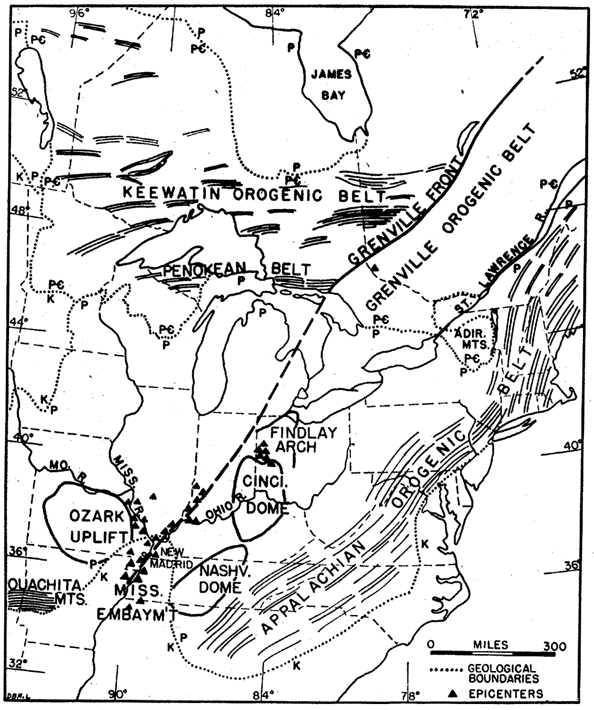

Fig. 1. Sketch map showing relationships of major structural features of eastern United States and Canada, including the Grenville front and proposed extension (heavy dashed line). Earthquake epicenters distant from the extension are not shown. *PC*, pre-Cambrian; *P*, Paleozoic; *K*, Cretaceous and Tertiary.

of the old Grenville belt determined the northwestern and northern limits of the Paleozoic geosyncline.

That the exposed part of the Grenville front in the Canadian Shield is a great fault zone now appears very probable. Areas along the boundary have been studied in detail by Quirke and Collins (*14*), Cooke (*15*), Fairbairn (*16*), Norman (*17, 18*), and Tiphane and Dawson (*19*). In particular, Norman, Tiphane, and Dawson (*20*) have called attention to the Grenville front as "a fault zone of continental proportions." In all the reports just mentioned, the rocks near the contact are described as intensely crushed and sheared (in some places for a width of more than a mile). All agree that the gneisses of the Grenville province have been thrust northwestward on the Huronian, Keewatin, Timiskaming, and intrusive rocks of the adjoining Superior province to the west.

Along the greater part of the Grenville front, it has been found impossible to identify formations across that boundary. The east-trending folded belts of Keewatin and Timiskaming volcanics and sediments of northern Ontario and Quebec represent the oldest known orogenic belt in the Canadian Shield, for which radioactive determinations yield ages around 2200 to 2500 million years (*6, 21*). These folded rocks are cut off abruptly at the Grenville front, and no recognizable equivalents have been identified farther east along the continuation of their strike. Farther south, near the north shore of Lake Huron and through northern Michigan and Wisconsin, the Penokean folds involve the Bruce and Cobalt series and the iron formations and associated sediments, all of Huronian age. Although recent work in Ontario (*22*) has reopened the question of equivalence of the Bruce series and the Timiskaming, the radioactive age measurements give figures clustering about 1300 million years for this belt (*6*), making the Penokean orogeny distinctly younger than that which affected the Keewatin-Timiskaming belts farther north. The Penokean folds are likewise truncated by the Grenville front. However, Quirke and Collins (*14*) identified some large remnants or "inclusions" of metamorphosed Huronian rocks in the Grenville gneisses near Killarney, and Quirke (*23*) found some as far as 20 mi east of the Grenville front. Nevertheless, the transition from Huronian sediments to gneisses at the front was abrupt.

The faulting along the Grenville front was post-Mistassini (*18*), post-Cobalt, and post-Penokean, but it was pre-Killarneyan, for Cooke (*24*) found Killarney granite invading and obliterating the fault zone southeast of Sudbury. Quirke (*25*) found similar relationships near Killarney. The most significant observations, for our present purpose, are those of Cooke. He found evidence of two faulting movements. The first apparently determined the major displacement, and all the evidence indicated that *the southeastern block moved not only upward, but southwestward as well, relatively to the northwestern block.* This is consistent with my suggestion that the Ozark uplift was displaced northward along a continuation of the Grenville fault zone. The later movement apparently coincided with the intrusion of the Killarney granite; it was also upward on the south, but in the opposite horizontal direction. Unless I have misinterpreted Cooke's statements, this later movement was not evident except in those localities where granite was intruded along the fault. The displacement was probably of much smaller magnitude than the earlier movement. This evidence appears favorable to the suggested large motion along the fault in a direction required to make the Ozark uplift a former extension of the Grenville orogenic belt.

The apparent impossibility of recognizing formations across the Grenville fault zone may then be due, not only to metamorphism, but to the existence of an offset of 200 mi or more. This is comparable with the recently suggested cumulative displacement along the San Andreas fault (*26*).

The intrusion of the Killarney granite may be supposed to have welded the old fault at many places. Certainly no extensive movement occurred during the Paleozoic and later periods. However, it seems possible that the old fault is not entirely dead, more especially near the southern end of its hypothetical continuation. A large number of earthquake shocks have been felt near the confluence of the Ohio and Mississippi rivers. The New Madrid earthquake of 1811 was one of the most violent known. A recent map (*27*) shows a strong concentration of epicenters (Fig. 1) trending northeastward from the vicinity of New Madrid into southwestern Indiana, where it suddenly terminates. These do not seem to be related to the Rough Creek fault zone (*28*), for they trend across it, rather than along it. Their trend is parallel to the hypothetical trace of the Grenville fault zone and to a number of small faults in the Paleozoic rocks, which may be the surface expression of vertical movements on the buried Grenville fault. Another compact group of epicenters in western Ohio is some 50 mi east of the suggested trace of the fault. These would not be inconsistent with an eastward-dipping fault zone. Finally, a strong shock originated near Timiskaming, Quebec, 1 November, 1935. This locality is about 25 mi east of the Grenville front. The epicenter seems to have been well determined, but the depth of focus, tentatively indicated as 200 km (*29*), later proved to be indeterminate (*30*). It is probably an open question whether this earthquake was associated with the Grenville front or with the Timiskaming lineament (*31*).

Since the preceding paragraphs were written, my attention has been called to a group of reports (*32–34*) on areas near the supposed course of the Grenville front in Quebec, about latitude 49°30′, longitude 74°30′. In three adjacent 15-min quadrangles, the Keewatin-type lavas and associated meta-sediments were found increasingly metamorphosed toward the east and also showed increased complexity of folding in the same direction. Judging from the prevalence of hornblende and biotite paragneisses, the Grenville belt seemed to have been entered, but no major fault was located, although the eastern area lies athwart the front, as is shown on the Tectonic Map of Canada. Either the front passes farther east, or it is locally obscured by intrusives, or it is discontinuous. This last alternative, if conclusively demonstrated, would of course be a most serious difficulty for the hypothesis here proposed. Evidently much additional work will be required before the major structure can be considered fully established.

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With the consent of the author, we quote these remarks made by two of our advisors: "This paper involves a high degree of speculation, but is sufficiently intriguing and stimulating as an example of what W. M. Davis called 'outrageous hypotheses' [Science 63, 463 (1926)] to be a 'must' for publication." "It is thought provoking, stimulating, and challenging—inviting confirmatory observations on the one hand and exposing the author to sharpshooting critics on the other."