Does the Grenville Front Tectonic Zone Lie West of its Previously Inferred Location in West-Central Ohio?

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ABSTRACT

The Grenville front tectonic zone (GFTZ), or Grenville deformation front, marks the western limit of Grenville-age deformation in Canada, where exposures have been mapped and studied in detail. At the outcrop near Georgian Bay, Ontario, this tectonic lineament separates higher-grade Grenville metamorphic rocks on the southeast from older, non-metamorphosed and low-grade metamorphic rocks of the Southern Province to the northwest. Starting in the early 1960s, geoscientists have used linear, north-south anomalies on regional aeromagnetic maps to infer a subsurface extension of the GFTZ beneath Phanerozoic cover into Michigan, Ohio, Kentucky, and Tennessee. However in the late 1990s and 2000s, using reprocessed Ohio Consortium for Continental Reflection Profiling (COCORP) OH-1 seismic reflection and sparse deep-well control data, geologists questioned the location of the GFTZ in Ohio as the westernmost limit of Grenville deformation. The term 'Grenville front magnetic lineament' was suggested as a substitute for 'Grenville front' in Ohio until ambiguous well and seismic interpretations could be resolved.

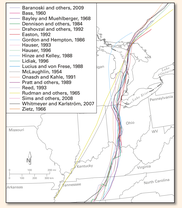
In our study digital, composite aeromagnetic maps of the central United States and southern Canada are used to improve the delineation of upper crustal features. Magnetic anomalies delineate the GFTZ in southern Canada, as corroborated by surface geology, and show its southward continuation beneath Phanerozoic cover into Ohio and beyond. In Ohio the revised GFTZ is a crustal-scale feature, characterized by high-amplitude magnetic anomalies on the eastern margin of the granite-rhyolite province. Thus we reinterpret the position of the GFTZ on aeromagnetic maps to lie in westernmost Ohio and eastern Indiana. The new location is west of the traditionally accepted position of the Grenville front magnetic lineament in west-central Ohio, which instead may represent additional complexity within the Grenville orogenic belt. We assess the pros and cons of this new aeromagnetic interpretation by comparing deep-well data, seismic reflection data, earthquake history, and Mesoproterozoic/Phanerozoic sedimentary basin architecture. We also consider the implications for basement influence on potential Paleozoic saline reservoirs and cap rocks for industrial-waste and brine disposal, gas storage, CO_2 sequestration, and hydrocarbon exploration.

STOP 1

Grenville "front" extension from the Canadian outcrop

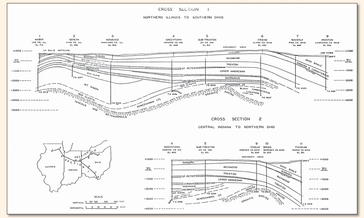
McLaughlin (1954) shows a Grenville "front" extension from the Canadian outcrop SW through Michigan, Ohio, and Indiana, using New Madrid earthquakes to define the trend. Modified from McLaughlin (1954).

Grenville "front" and "magnetic front" (GMF) extension from the Canadian outcrop



Numerous authors following McLaughlin (1954) show a Grenville "front" extension from the Canadian outcrop SW through Ohio; most use aeromagnetic maps to define the trend following Bass' (1960) lithology and radiogenic isotope work.

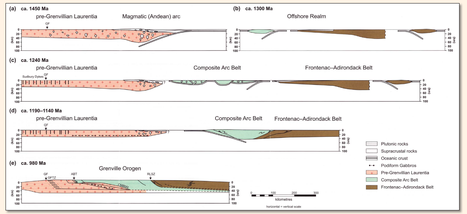
Early deep wells show vertical tectonics and interesting deep stratigraphy



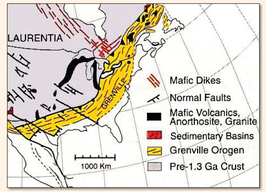
Note the Cincinnati Arch, Keweenawan, and enigmatic Friend well deposits. Modified from Wasson (1932).

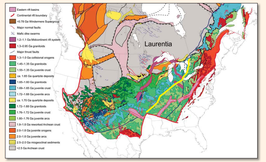
STOP 2

Recent models of Laurentia do not show foreland/rift deposits



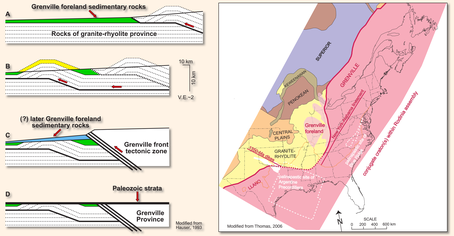
Diagrammatic cross section showing evolution of Grenville Orogen southern Ontario to New York, modified from Carr and others (2000). Model shows detail based on many years of work on the outcrop and using geophysical data. Note the absence of foreland/rift sedimentary basins in the model.





Diagrammatic maps showing Grenville Orogen, modified from Karlström and others (2001, top) and Whitmeyer and Karlström (2007, bottom). Note the absence of Grenville foreland/rift sedimentary basins in the model. Great Lakes region.

Grenville foreland models



Gordon and Hempton (1986) interpreted Keweenawan rifting and strike-slip faulting and pull apart basins in a Grenville foreland during continent-continent collision; their maps suggest possible Grenville overthrusting above gravity lows in Ohio.

Culotta and others (1990) discounted Grenville foreland basin deposits as eroded and interpreted horizontal reflectors in western Ohio as possible Huronian sediments (flgs show thrusting of both EGR and Huronian? seismic layers west of GMF). Their model implicitly assumed regional peneplation and similar Proterozoic terrane in the Ohio subsurface as found exposed in Canada.

Drahovzal and others (1992) discounted a Grenville foreland because of the presence of mafic volcanic and clastic sediment (possibly Keweenawan rift related) and paucity of metamorphic sediments (abundant rhyolite clasts).

Lidiak and Hinze (1993) correlate Grenville subprovinces into Ohio based largely on geopotential maps. They point out complexity on either side of GMF in SE Michigan, where wells were drilled into granite gneiss and amphibolite-grade schists of unknown age.

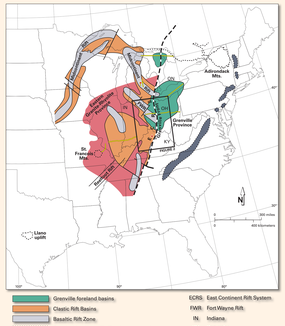
Hauser (1993) (see A–D above) is the first to develop a scenario for thrusted Grenville foreland basin and Eastern Granite-Rhyolite west GMF.

Hauser (1996) modified his 1993 interpretation more in line with a Keweenawan rifting model similar to Gordon and Hempton (1986). He discussed the midcontinent rifting preceding Grenville orogeny and in part based on the lack of Grenville material in the "rift sediments." This is contrary to his 1993 model showing thrusted EGR, which would be shed off the eroded orogen and deposited westward (into Middle Rub basins).

Thomas (2005) used the Drahovzal and others map (1992) and interpreted the Middle Run as Grenville foreland.

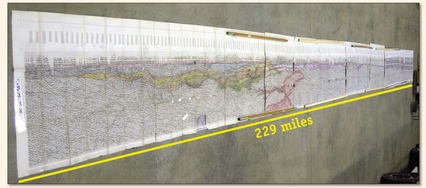
Rainbird and others (2011) modified the Whitmeyer and Karlström (2007) map and added Middle Run as foreland basin.

Geological map of Precambrian North America (simplified from Whitmeyer and Karlström, 2007), to show the location of Proterozoic sedimentary basins and orogenic belts in the southeastern part of the continent. The orogenic zones contributed sedimentary detritus to huge river systems that crossed the continent, spreading northwesterly and forming the thick sandstone successions preserved in the Thelon, Athabasca, and other basins. The Grenvillian orogenic belt is interpreted as the roots of a deeply eroded mountain chain, resulting from multistage continental accretion that formed from about 1.3 to 1.0 billion years ago. Sediments from this orogen have been recognized by westward-directed paleocurrents (black arrows). The blue dashed arrows show the suggested transport direction of the Paleoproterozoic sediments; the dashed red arrows illustrate transport directions proposed for Neoproterozoic sediments deposited in the Grenvillian hinterland Basins. In North America, the proximal part of the Grenvillian depositional system is represented by deposits located in the Middle Run Basin (subsurface) and Midcontinent Rift (MCR). The Grenville front is the approximate position of the thrust-fault marking the inboard edge of Grenvillian deformation. Modified from Rainbird and others (2011).

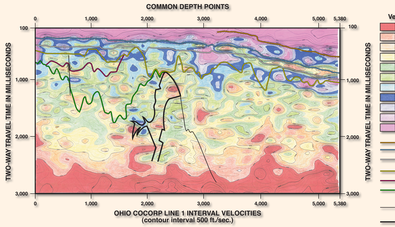


Regional base map of eastern North America showing major Precambrian tectonic elements, outcrops, and seismic lines. Modified from Baranoski and others (2009).

STOP 3



Several abstracts (Dean and others, 1998, 1999, 2000) and two papers (Dean and Baranoski, 2002, and Baranoski and others, 2009) put forth an expanded scenario of Hauser's (1993) Grenville foreland basin model using the first detailed interpretation of industry-reprocessed COCORP OH 1&2 unconformity-bounded seismic-reflection sequences and sparse deep-well control. They speculated that shallow, subhorizontal seismic reflectors on the GLIMPSE marine seismic line in Dean and others (1999) proposed significant Grenville horizontal shortening along the COCORP OH 1&2 across Ohio, ranging from 10 to 16% to as low as 2% into eastern Indiana. Dean and others (2000) used seismic impedence contrasts, abnormally low interval velocities, and second derivative magnetic intensity mapping to define Grenville foreland/rift basins.



Contoured interval velocities and major correlated reflectors along COCORP OH-1 profile. Modified from Dean and Baranoski (2002).

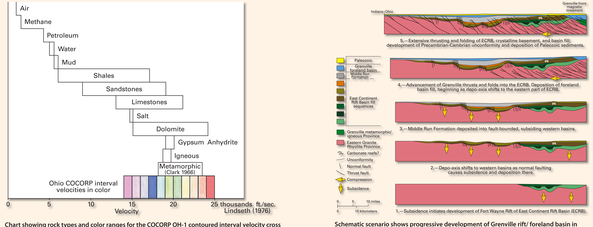
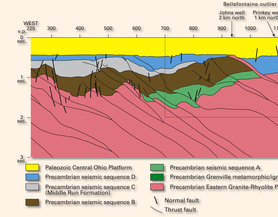
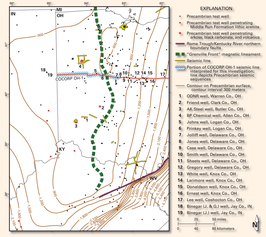


Chart showing rock types and color ranges for the COCORP OH-1 contoured interval velocity cross section (left).

Schematic scenario shows progressive development of Grenville rift/ foreland basin in western Ohio based on the COCORP OH-1 (Baranoski and others, 2009).



Simplified geology and unconformity-bounded stratigraphic sequences along western Ohio, based on the COCORP OH-1. Modified from Baranoski and others (2009).



Map of the Ohio-Indiana-Kentucky area showing wells penetrating the Precambrian (including the Middle Run Formation), structure contours on the Precambrian unconformity surface, and the locations of seismic lines. Modified from Baranoski and others (2009).

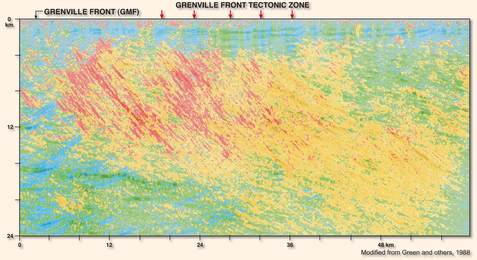
WELLS IN OHIO LISTED AT LEFT DRILLED TO THE PRECAMBRIAN (NUMBERS 5 TO 17 ARE WITHIN 3.2 KILOMETERS (2 MILES) OF CO-COMP OH-1 SEISMIC LINE 1

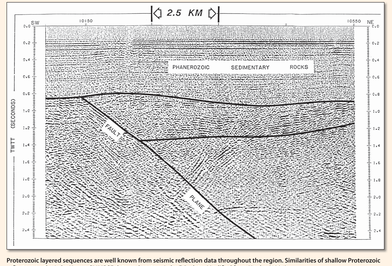
Map number	American Petroleum Institute number	County, State	Lessee	Company	Total depth (ft)	Reference elevation (ft above sea level)	Depth to Precambrian (ft)	Precambrian lithology	Sample type
1	34-165-00005	Warren, OH	Ohio Division of Geological Survey	American Aggregates Corp.	1396	1025	1025	Lithic arenite[2]	Drain mounts and core from outcrop
2	34-023-00004	Clark, OH	T. D. Friend	Mallinson	1413	331	1029	"Knoxa, black metavolcanic, felsic, volcaniclastic"[2]	Sample cuttings
3	34-017-00005	Butler, OH	Armco Steel Corp.	Armco Steel Corp.	988	204	865	Lithic arenite[2]	Sample cuttings
4	34-003-21000	Allen, OH	BP Chemicals	Sohio Chemicals	1002	297	860	"Rhyolite, porphyritic, volcanic"[2]	Drain mounts
5	34-001-00118	Logan, OH	"V. Johns, et al. Unit"	Ohio Oil Co.	1002	992	860	"Rhyolite, porphyritic, felsic flows"[2]	Drain mounts, sections
6	34-091-00096	Logan, OH	R. Pinkey Unit	Ashlea Exp. Co. Inc.	991	942	955	"Felsic granite, gneiss, altered syntes, volcanics"[2]	Drain mounts
7	34-041-00002	Delaware, OH	JoRff	Funk Exploration Inc.	1028	284	1010	Granite[2]	Samples not available
8	34-041-00002	Delaware, OH	F. Jones	Southern Triangle Co.	1042	951	1040	Arkose[3]	Sample cuttings
9	34-041-00026	Delaware, OH	Case	Funk Exploration Inc.	1085	279	1061	Arkose[3]	Sample cuttings
10	34-041-00027	Delaware, OH	L. H. Smith	Funk Exploration Inc.	1100	910	1080	"Felsic, amphibolite"[2]	Drain mounts
11	34-041-00046	Delaware, OH	L. A. Sheets	NGO Development Corp.	1320	900	1058	NA	Samples not available
12	34-041-00070	Delaware, OH	C. Gregory	Consumers-Ohio Oil Co.	1425	966	1425	Altered gneiss[1]	Drain mounts
13	34-083-00004	Knox, OH	D. White	Cities Oil and Gas Corp.	1537	389	1517	NA	Samples not available
14	34-083-0148	Knox, OH	D. Larrimore	Ohio Fuel Gas Co.	1635	966	1631	Altered syenite[1]	Drain mounts
15	34-083-00615	Knox, OH	J. Donaldson	Cities Drilling & Production	1628	1028	1590	NA	Samples not available
16	34-083-4064	Knox, OH	E. Ernest	Pioneer Oil Co.	1592	307	1571	NA	Samples not available
17	34-031-00003	Coshocton, OH	E. Lee	Bob Tatum	2120	318	2113	Altered granite[1]	Sample cuttings
18	1417701	Jay, IN	J. A.G. Binegar	Farm Bureau Co-Op.	1034	299	1016	Carbonates[4]	Sample cuttings
19	1417711	Jay, IN	J. Binegar	Petroleum Dev. Corp.	1398	299	1001	Carbonates[4]	Sample cuttings

TOTAL	REFERENCE	DEPTH TO
DEPTH	ELEVATION	PRECAMBRIAN
1396	1025	1026.0080
1413	331	1029.0000
988	204	865.0000
1002	297	860.0000
1002	992	860.0000
991	942	955.0000
1028	284	1010.0000
1042	951	1040.0000
1085	279	1061.0000
1100	910	1080.0000
1320	900	1058.0000
1425	966	1425.0000
1537	389	1517.0000
1635	966	1631.0000
1628	1028	1590.0000
1592	307	1571.0000
2120	318	2113.0000
1034	299	1016.0000
1398	299	1001.0000

1026.0080	1013.0320	311.0920	1021.0176	1021.0176	1021.0176	1021.0176	1021.0176	1021.0176
1029.0000	1013.0320	302.0000	1029.0000	1029.0000	1029.0000	1029.0000	1029.0000	1029.0000
865.0000	204.0011	204.0011	865.0000	865.0000	865.0000	865.0000	865.0000	865.0000
860.0000	297.0000	297.0000	860.0000	860.0000	860.0000	860.0000	860.0000	860.0000
860.0000	992.0000	951.0000	860.0000	860.0000	860.0000	860.0000	860.0000	860.0000
955.0000	942.0000	942.0000	955.0000	955.0000	955.0000	955.0000	955.0000	955.0000
1010.0000	284.0000	284.0000	1010.0000	1010.0000	1010.0000	1010.0000	1010.0000	1010.0000
1040.0000	951.0000	951.0000	1040.0000	1040.0000	1040.0000	1040.0000	1040.0000	1040.0000
1061.0000	279.0000	279.0000	1061.0000	1061.0000	1061.0000	1061.0000	1061.0000	1061.0000
1080.0000	910.0000	910.0000	1080.0000	1080.0000	1080.0000	1080.0000	1080.0000	1080.0000
1058.0000	900.0000	900.0000	1058.0000	1058.0000	1058.0000	1058.0000	1058.0000	1058.0000
1425.0000	966.0000	966.0000	1425.0000	1425.0000	1425.0000	1425.0000	1425.0000	1425.0000
1517.0000	389.0000	389.0000	1517.0000	1517.0000	1517.0000	1517.0000	1517.0000	1517.0000
1631.0000	966.0000	966.0000	1631.0000	1631.0000	1631.0000	1631.0000	1631.0000	1631.0000
1590.0000	1028.0000	1028.0000	1590.0000	1590.0000	1590.0000	1590.0000	1590.0000	1590.0000
1571.0000	307.0000	307.0000	1571.0000	1571.0000	1571.0000	1571.0000	1571.0000	1571.0000
2113.0000	318.0000	318.0000	2113.0000	2113.0000	2113.0000	2113.0000	2113.0000	2113.0000
1016.0000	299.0000	299.0000	1016.0000	1016.0000	1016.0000	1016.0000	1016.0000	1016.0000
1001.0000	299.0000	299.0000	1001.0000	1001.0000	1001.0000	1001.0000	1001.0000	1001.0000

Table showing index of key wells drilled to the Precambrian for the adjoining map. Modified from Baranoski and others (2009).





Proterozoic layered sequences are well known from seismic reflection data throughout the region. Similarities of shallow Proterozoic reflectors on the Lake Huron GLIMPSE data and eastern Lake Erie data. Modified from Hoehn (1991).

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