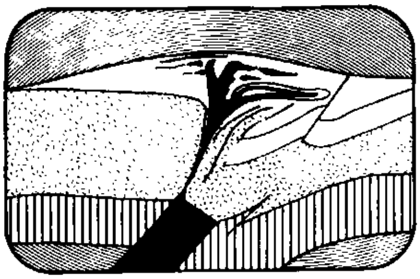

An Ensimatic Island Arc and Ocean Closure in the Grenville Province of Southeastern Ontario, Canada

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Summary
Within the Grenville Province of Southeastern Ontario geological data may be interpreted in the light of plate tectonic theory. An early cycle involving subduction of oceanic lithosphere, generation of an island arc complex together with partial melting of the down-going slab to produce calc-alkalic volcanism and granodioritic intrusions, was followed by a second cycle during which the island arc was uplifted, eroded and covered by miogeoclinal sediments. Subsequently the miogeocline was deformed presumably during continental collision. The evolution from early island arc phase to ocean closure and consolidation took approximately 250 m.y.

Introduction
A generally acceptable tectonic model for the evolution of the Grenville structural Province has yet to be proposed; the diversity of opinion has been recently outlined in this journal by Baer *et al.* (1974).

Much of the province is pparently underlain by reactivated older sialic basement (Wynne-Edwards, 1972), and lack of evidence of belts of ensimatic rock has favoured interpretations which would place a suture southeast of the exposed Grenville terrain (Wynne-Edwards, 1972; Dewey and Burke, 1973). On the other hand paleomagnetic results suggest a possible suture lying well within the exposed part of the Grenville Province (e.g., Irving *et al.*, 1974; Ueno *et al.*, 1975).

It is the purpose of this communication to call attention to published information and new data which in our opinion point to the former existence of ocean floor and island arc volcanism in part of the Grenville Province in southeastern Ontario (Fig. 1), and to present a tectonic model compatible with these results.

The model rests on four main points of evidence: a) relict oceanic lithosphere is preserved in the terrain northeast of Madoc, Ontario (Fig. 1, 2); b) granitic to dioritic batholiths were intruded into the oceanic crustal material; c) platformal sediments were deposited unconformably over intruded oceanic crust; d) the basement and cover then became involved in intense regional deformation and metamorphism.

a) Evidence of Relict Oceanic Lithosphere.
The petrology of the metavolcanic rocks has been described by Sethuraman and Moore (1973), and their geochemistry has recently been considered by Condie (1975). An apparent thickness of 7 km is exposed in the vicinity of Bishop Corners (Fig. 2) and top determinations from pillow lavas indicate an essentially unrepeated, easterly facing stratigraphic succession. The lower part of the succession (A - B, Fig. 2) comprises mainly pillowed and massive tholeiite flows; the eastern upper part (C - D) includes the top of the basalts and ranges upwards from andesite flows and pyroclastic rocks to rhyodacite pyroclastics with intercalated carbonates at the top. All the basalts contain less than 0.6 percent K_2O; half contain 0.1 percent or less. Sethuraman and Moore (1973) pointed out that the low potassium content of the basalts implies that they were extruded on oceanic crust, and that the succeeding calc-alkalic activity is consistent with development of the entire assemblage at a consuming plate margin. Figure 3 summarizes some of the chemical data of the volcanic rocks (see also Sethuraman and Moore, 1973).

New evidence for the existence of ocean floor material has recently been found by one of us (J.F.C.). Near Flinton, the lower lavas are in contact with mafic and untramafic metaplutonic rocks, which are also enclosed as fragments in the basalt flows (locality 1, Fig. 2). In addition, pods of ultramafic material up to 1 m in diameter are incorporated in metagabbro (locality 2, Fig. 2). Several lenses of ultramafic rock have been tectonically emplaced in the volcanics, granitic rocks and overlying metasediments, but the evidence indicates that at least some of the ultramafics are the oldest rocks in the area, and are followed closely by mafic plutonic rocks which predate the early basalts.

Lead isotope ages of 1310 ± 15 m.y. have been reported by Silver and Lumbers (1966) for zircons from metarhyolite which is probably correlative with the upper part of the volcanic succession in the region.

b) Origin of Granodiorite Batholiths.
The intrusive nature of granitic rocks in the region was first pointed out by Miller and Knight in 1914. Although in much of the region contact relationships between salic rocks and pillow lavas have been obscured by later deformation, several excellent exposures have been located which unequivocally demonstrate that the granodioritic and granitic rocks of the Elzevir and Weslemkoon batholiths respectively are intrusive into the metavolcanic rocks (localities 3, 4, 5, Fig. 2). Xenoliths of mafic metavolcanics are common within the granodiorite; dykes similar in composition to the Elzevir batholith cut the mafic volcanics and associated mafic intrusive rocks.

Zircons from granodioritic intrusions in the area yield lead isotope ages of 1250 ± 25 m.y. (Silver and Lumbers, 1965). The tholeiitic volcanic rocks and associated mafic/ultramafic rocks thus comprise the oldest known rocks in the region.

c) Deposition of Platformal Sediments.
Evidence for the deposition of clastic and carbonate sediments (Flinton Group) unconformably over the intruded volcanic sequence has previously been documented (Sethuraman and Moore, 1973; Moore and Thompson, 1972; Thompson, 1972). Stratigraphic

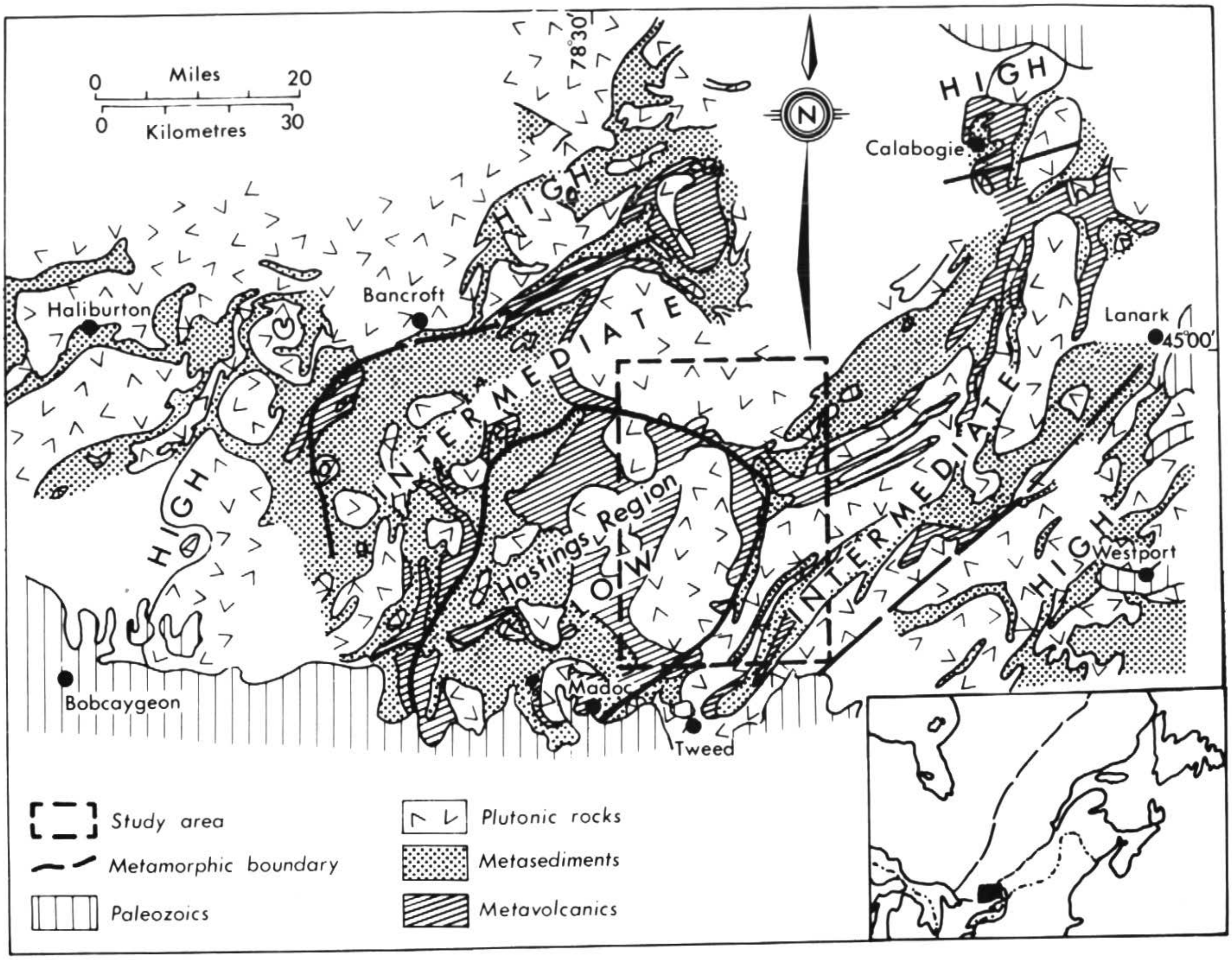

Figure 1
Geological sketch of part of the Grenville Province in southeastern Ontario (after Lumbers, 1964). The area of Fig. 2 is enclosed by the rectangle.

boundaries in the volcanic-marble succession are truncated by the base of the Flinton Group (locality 6, Fig. 2); contacts between volcanic and plutonic rocks are also transected. Conglomerates of the Flinton Group consist mainly of quartzite clasts, but locally contain clasts of the underlying salic plutonic rocks. There is no evidence of large mafic or granitic intrusions postdating the Flinton Group in the area.

d) Deformation
With the exception of a weak fabric seen in the volcanic rocks at several localities (Thompson, 1972), folds and penetrative fabrics recognized in the intruded oceanic crustal material and unconformably overlying platformal sediments were formed after deep burial of the platformal rocks. Large scale isoclinal folds developed at this time in an intermediate-pressure regional metamorphic environment (Moore and Thompson, 1972). The isoclines now exhibit steeply dipping axial surfaces and non-cylindrical hinge lines. In detail, the geometry is complex due to the rotation of planar and linear elements during progressive deformation, and superposition of two phases of refolding (Thompson, 1972).

Although a low-angle discordance at the base of the Flinton Group is regional in extent, high-angle unconformity is present only around Bishop Corners and Flinton (Fig. 2). Lack of evidence of important penetrative deformation predating deposition of Flinton Group rocks, and the spatial association of the high-angle unconformity with the Elzevir suggest to us that pre-Flinton deformation was probably restricted to local arching and perhaps faulting related to diapiric emplacement of the salic plutonic rocks.

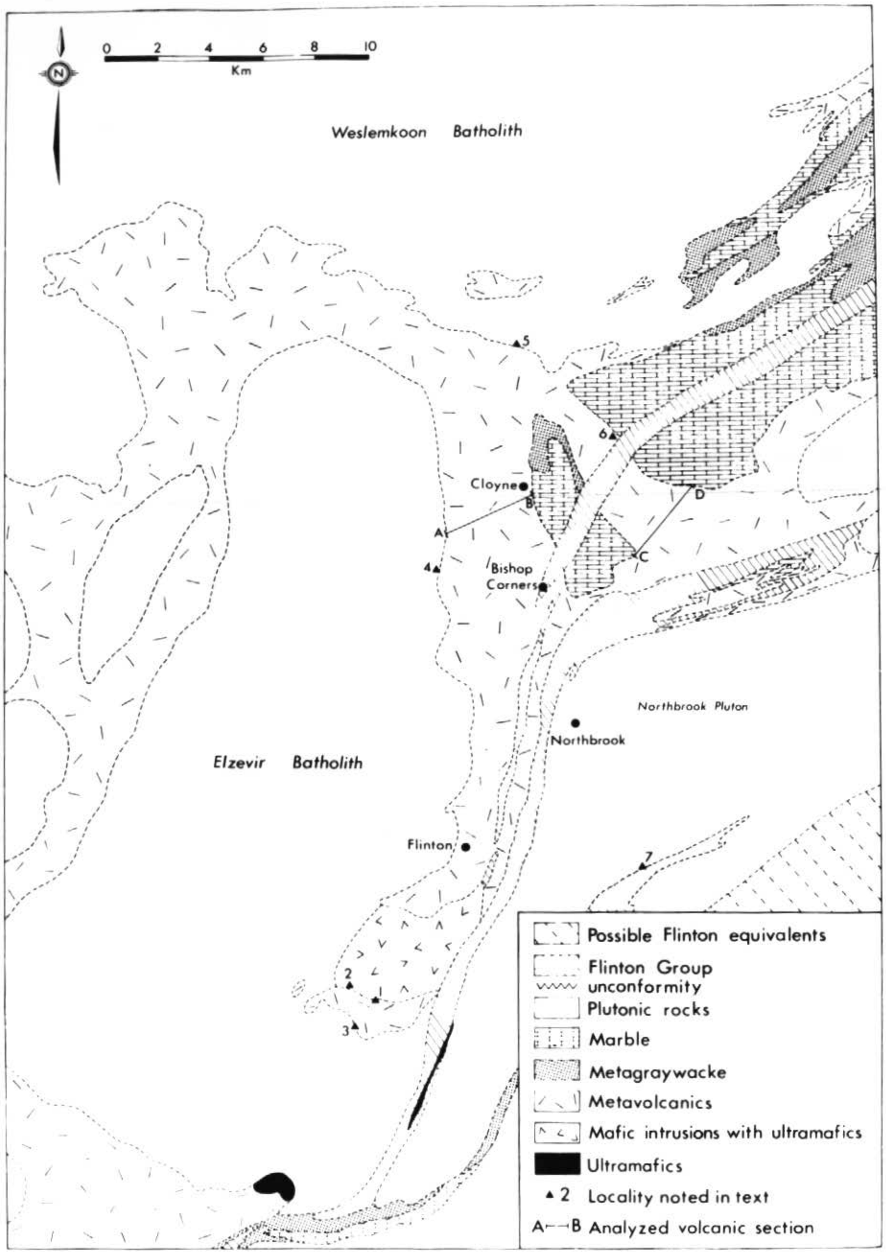

Figure 2
Geology around the eastern margin of the Elzevir Batholith. (after Hewitt, 1964; Sethuraman and Moore, 1973; Moore and Thompson, 1972; Thompson 1972).

Discussion

The similar ages of the oceanic volcanic rocks and intruded salic plutons together with the marked transition from tholeiitic to calc-alkalic volcanism suggest a related cause. The chemistry of the volcanic rocks and the observation that they are underlain by mafic and ultramafic rocks, and pass upwards into pyroclastics and carbonate sediments, lead us to propose an ensimatic island arc environment. If subduction of oceanic lithosphere is accepted as the cause of oceanic island arcs it is most likely that the associated granodioritic intrusives were generated at depth by partial melting of the subducted slab.

The earliest evidence of sediments possibly derived from a continent appears in the Bishop Corners Formation, at the base of the unconformably overlying metasedimentary rocks of the Flinton Group (Moore and Thompson, 1972). Some of the clastic material is clearly of local derivation, but a large proportion of the Formation consists of hematitic quartzites and quartzite pebble metaconglomerates. As there is however no other evidence of an adjacent pre-volcanic sialic terrain, these clastics may imply local uplift and erosion of sedimentary rocks derived from the unroofed plutons in the area. The paucity of local pre-Flinton rocks in the conglomerates, and the oxidized character of the base of the Flinton Group, suggest deep weathering and intermontane deposition.

Locally derived clasts of underlying plutonic material are extremely coarse in places, and are indicative of a rejuvenated terrain induced perhaps by block faulting. This was followed by subsidence and the accumulation of a thick miogeoclinal clastic-carbonate shallow marine sequence.

We appear to be dealing with a two-phase orogenic cycle. The regional strain and metamorphism occurred late in the tectonic history of the region and cannot have resulted from early subduction of oceanic lithosphere, but rather must be related to the final closing of the ocean. This closure was followed by consolidation and uplift (about 1050 m.y. Silver and Lumbers, 1966; Krogh and Hurley, 1968).

The region of Figure 1 is interpreted to be underlain by a collision zone. The continental margins to the relict "Grenville ocean" are likely to be northeast-trending lines lying just northwest of Bancroft and somewhere southeast of Westport respectively (Fig. 1).

Summary of Conclusions.

A model of tectonic evolution for part of the Grenville Province in Eastern Ontario comprises: 1) Generation of pillow lavas in an island arc environment involving subduction at converging oceanic lithosphere plate margins (about 1300 m.y.). 2) Calc-alkalic volcanism coincident with the generation of granodioritic magma derived at depth by partial melting of the subducted slab of oceanic lithosphere. 3) Diapiric intrusion of the granodioritic plutons, locally deforming the overlying oceanic crust and arc (about 1250 m.y.).

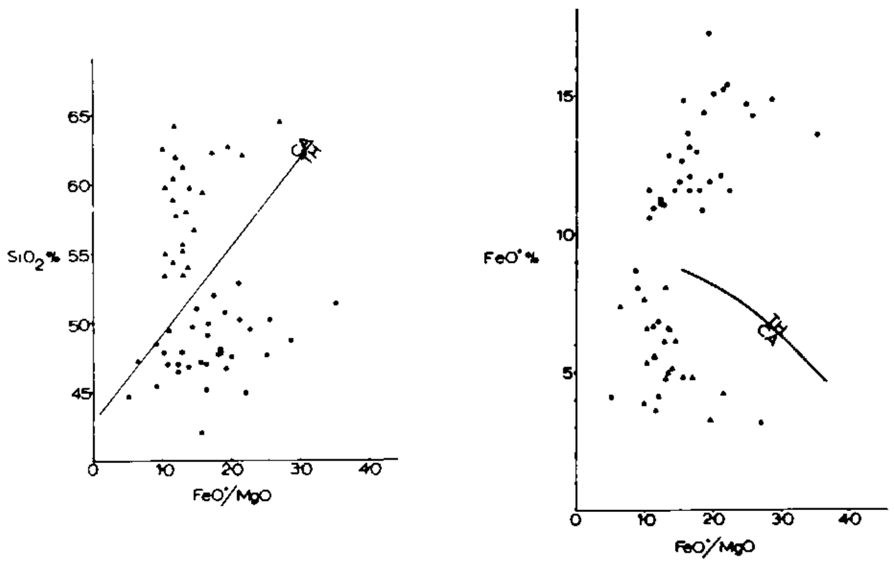

Figure 3
Correlation of SiO_2 and FeO (total iron as ferrous) with MgO/FeO* ratio in the Tudor metavolcanic rocks (plot after Miyashiro, 1974). Triangles are rocks classified as calc-alkalic by 3a, entirely confined to section C - D (Fig. 2). Circles are tholeiites from section A - B and the lower part of C - D. Data from Sethuraman and Moore (1973).*

4) Erosion of uplifted basement terrain together with influx of externally derived mature clastics to provide material for the unconformable deposition of a clastic-carbonate succession (Flinton Group). 5) Continental collision to produce isoclinal folding and refolding, together with regional metamorphism of the basement and cover yielding the present complex (about 1050 m.y.).

Acknowledgements
We gratefully acknowledge support by the National Research Council of Canada in the form of an N.R.C. Scholarship to Chappell, and operating Grants A 2693 and A 1506 to Brown and Moore respectively.

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MS received April 28, 1975.