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# EARLY ARCHEAN BASEMENT IN THE CANADIAN SHIELD: A REVIEW OF THE EVIDENCE

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# EARLY ARCHEAN BASEMENT IN THE CANADIAN SHIELD: A REVIEW OF THE EVIDENCE

## Abstract

*The nature of the basement to Archean volcanic-sedimentary (greenstone) belts was obscured by the Kenoran Orogeny 2600 m.y. ago and it is now controversial as to whether it was simatic or sialic. Types of evidence observed in the Canadian Shield that support a sialic nature for the early crust are: 1. Unconformities; in six widely-separated localities unconformities between the volcanic-sedimentary assemblages and underlying granitoid rocks are evident in outcrop or interpretable from the geology. 2. Source of sedimentary materials; sedimentary components of many, or most, greenstone belts have, in part, a granitic provenance marked by the presence of granite-bearing conglomerates and quartz-rich greywackes. While both are in much greater abundance in the upper parts of the successions they may, nevertheless, be present at almost any level. 3. Radiometric ages. Ages determined on granitoid rocks in five separate localities of the Superior and Slave Provinces exceed 2900 m.y.; ages markedly older than any yet obtained from the greenstone belts. The early sialic crust thus indicated was evidently a soda-rich granitoid rock; a tonalite, trondhjemite, or sodic granodiorite.*

*A model proposed for development of the greenstone belts envisions a thin, continuous, sialic crust upon which a volcanic pile accumulates. Initially, both are below sea level and erosion is minimal. Withdrawal of material as magma from below the crust plus the density inversion of basalt over sial causes downwarp and outward spreading of the crust. At the base of the downwarp crustal melting begins and feeds plutons which supsequently rise through the crust and eventually into the volcanic pile. Crustal swelling and upflexing adjacent to the volcanic trough, marking the lateral transfer of material in crust and mantle, becomes a source of granitic sediment as it rises to sea level. Ultimately, as volcanism wanes, it becomes the major contributor to the "greenstone" succession.*

## Résumé

*La nature du socle sur lequel reposent les zones volcaniques-sédimentaires de l'Archéen (roches vertes) a été obscurcie par la phase tectonique kénoréenne qui date de 2600 millions d'années, et son origine simique ou sialique suscite maintenant des controverses. Les faits observés dans le Bouclier canadien qui tendent à étayer la nature sialique de la première croûte sont: 1. Les discordances. Dans six régions très éloignées les unes des autres, on observe, sous forme d'affleurements, des discordances entre les assemblages volcaniques-sédimentaires et les roches granitoides sous-jacentes, ou bien on peut les interpréter d'après la géologie. 2. La source des matériaux sédimentaires. Les composants sédimentaires d'une grande partie ou de la plupart des zones de roches vertes ont, en partie, une origine granitique identifiée par la présence de conglomérats graniteux et de grauwackes riches en quartz. Bien que ces deux minéraux abondent le plus dans les parties supérieures des successions, il se peut qu'il y en ait à presque tous les paliers. 3. Ages déterminés par radiométrie. Les âges obtenus par radiométrie des roches granitoïdes de cinq régions distinctes, dans les provinces du lac Supérieur et des Esclaves, dépassent 2900 millions d'années; ces âges sont de beaucoup antérieurs à ceux des zones de roches vertes. La première croûte d'origine sialique ainsi révélée était, de toute évidence, constituée par une roche granitoïde riche en sodium: tonalite, trondjhémite ou granodiorite sodique.*

*Selon un modèle qui a été proposé pour expliquer l'apparition des zones de roches vertes, représentons-nous un croûte sialique, mince et continue, sur laquelle se sont accumulées des roches volcaniques. Au début, les deux se trouvent sous le niveau de la mer et l'érosion est minimale. Le retrait des matériaux tels que le magma du dessous de la croûte combiné à l'inversion de densité du basalte au-dessus du sial provoque un affaissement et une expansion de la croûte vers l'extérieur. A la base de l'affaissement, la croûte commence à fondre, nourrissant les roches plutoniques qui montent à travers la croûte et, par la suite, dans l'accumulation des roches volcaniques. La croûte qui se gonfle et se redresse, de chaque côté de la dépression volcanique, marquant le transfert latéral des matériaux dans la croûte et le manteau, devient une source de sédiments granitiques à mesure qu'elle se rapproche du niveau de la mer. Enfin, à mesure que le volcanisme s'affaiblit, cette croûte devient le principal tributaire de la succession des "roches vertes".*

# EARLY ARCHEAN BASEMENT IN THE CANADIAN SHIELD: A REVIEW OF THE EVIDENCE

## INTRODUCTION

Archean volcanic-sedimentary belts of the Canadian Shield appear to have developed during a rather narrow time interval (± 200 m.y.) just prior to the widespread Kenoran Orogeny at about 2600 m.y. ago. Granitic intrusions emplaced during this orogeny almost totally envelop these belts and the original foundation upon which they were deposited is now obscure. The nature of that foundation is one of the most intriguing problems of the Canadian Shield. Two views are generally held: 1) the Archean volcanic-sedimentary assemblages were deposited directly on, and may include parts of, an oceanic crust and 2) they were emplaced on a pre-existing sialic crust. Support for the first view is founded on the chemical similarity of Archean volcanic assemblages to those of modern ocean floors and island arcs. The second view depends upon a fragmentary record of early Archean sialic crust imperfectly preserved at a few places in the Canadian Shield and in addition the evidence for its previous existence contained in the sediments of the volcanic-sedimentary sequences. Unfortunately the evidence is rarely so clear as to be compelling; some measure of interpretation is generally necessary. The purpose of the present paper is to assemble the evidence for an early Archean sialic crust so that it may be judged as a whole.

Three types of evidence will be presented: 1) that which is suggestive of an unconformity at the base of the Archean volcanic-sedimentary successions; 2) that which is indicative of the presence of sialic crust during the accumulation of the volcanic sedimentary successions; and 3) that which is obtained from radiometric dating. First, a general description of the geology of the Canadian Shield may be desirable to provide a geological setting for this review.

## GENERAL GEOLOGY OF THE ARCHEAN IN THE CANADIAN SHIELD

Archean rocks occur in six of the seven structural provinces of the Canadian Shield (Fig. 1). In the Bear Province there is evidence of deformed and remobilized Archean gneisses in domes in Aphebian metasediments near the old Archean craton of the Slave Province (Frith *et al.*, 1973). In the Grenville Province many workers have identified deformed Archean supracrustal rocks and granitic gneisses in a number of areas along the margins of the Superior Province. The extent of Archean rocks in the Churchill Province is not well

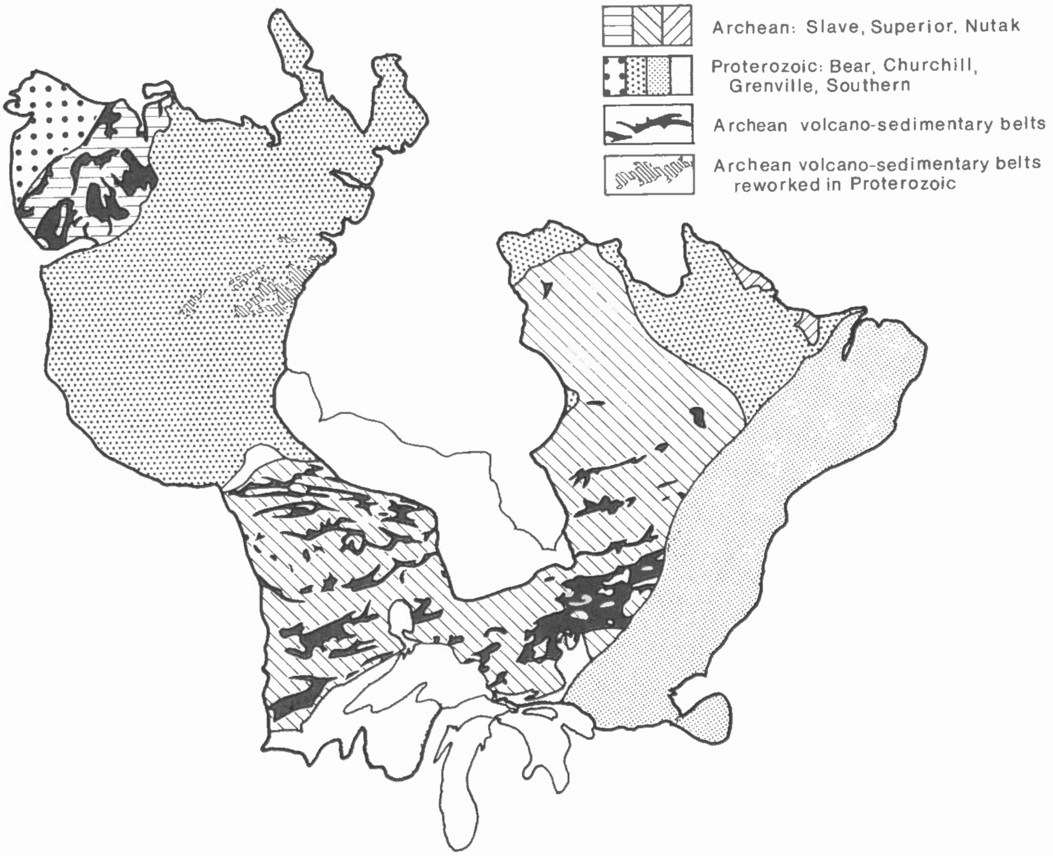


Figure 1. The major structural provinces of the Canadian Shield adapted from Douglas (1973) showing Archean "greenstone" belts.

defined, but, typical Archean supracrustal sequences with associated Archean granitic rocks have been outlined in the Kaminak area (Fig. 1) where they are overlain unconformably by Aphebian sediments (Eade, 1975). Radiometric ages from the granitic rocks that cut the supracrustal sequence are Archean (Wanless and Eade, 1975). Rocks of probable Archean age also occur in Melville Peninsula (at the Prince Alberta Group) and on Baffin Island.

Large areas of the remaining part of the Churchill Province are probably composed of Archean granitic gneisses and highly metamorphosed supracrustal rocks but at the current scale of mapping and with present techniques, their precise definition is not yet possible.

Most of the material in this paper relates to Archean rocks in the Slave and Superior structural Provinces where the supracrustal rocks, for the most part, have been little deformed and metamorphosed since Archean time.

In the Slave Province Archean volcanic and sedimentary rocks, and their metamorphosed and granitized equivalents underlie about two-thirds of the 70 000 square mile area of the province (Fig. 2) (McGlynn and Henderson, 1970, 1972). The supracrustal sequence is part of the Yellowknife Supergroup (Henderson, 1970) which is divisible into groups or formations in areas where detailed work has been completed.

The Yellowknife strata occur in three broad, poorly-defined zones that are separated by granitic intrusions. About 15 to 20 per cent of the Yellowknife Supergroup is volcanic in origin and the remainder is composed of sedimentary rocks. The volcanic rocks are in 18 or 19 belts, mostly along the margins of sedimentary terranes, and typically at the base of the supracrustal sequence. Thickness of individual belts varies from 300 to 12 000 m but the average thickness of the thickest parts of most belts measured is about 3000 m. In most belts the sequence thins along strike, so that in longitudinal section a pinch and swell effect is evident, with belts wedging out from centres of volcanism. It is thought that the volcanic sequences also wedge out under the sediments. The bulk of the acidic lava probably occurs in the thickest parts of the volcanic sequence.

The volcanic strata comprise massive mafic lavas, commonly basalts, pillowed and variolitic basic lavas and fragmental rocks, and intermediate to acidic lavas and tuffaceous rocks that include dacities, latites and quartz latites. Most of the lava sequence appears to be subaqueous. The more acidic strata commonly are near the middle or at the top of the sequence and in most belts studied, form about 15 per cent of the total sequence.

The Archean sedimentary rocks and their metamorphosed equivalents underlie about 60 per cent of the Slave Province and comprise about 80 to 85 per cent of the supracrustal rocks. They consist of a monotonous sequence of immature greywackes and mudstones with minor amounts of conglomerates, more mature sandstones, and carbonates. Typically, the greywacke-mudstone sequence overlies the volcanic rocks conformably. The transition is in places, gradational with interbedded flows, tuffaceous beds, and greywacke beds occurring between the volcanic and typical greywacke-mudstone sequences. Conglomerates, mature sandstones, and carbonate-rich exhalative deposits are restricted to this transition zone. The transition rocks occur not only above the volcanic rocks, but probably extend outwards from the volcanic piles as they interfinger with time equivalent sediments. Because of structural complexity and lack of marker horizons in the sediments, thicknesses are difficult to define, but estimates range from 300 to 4500 m.

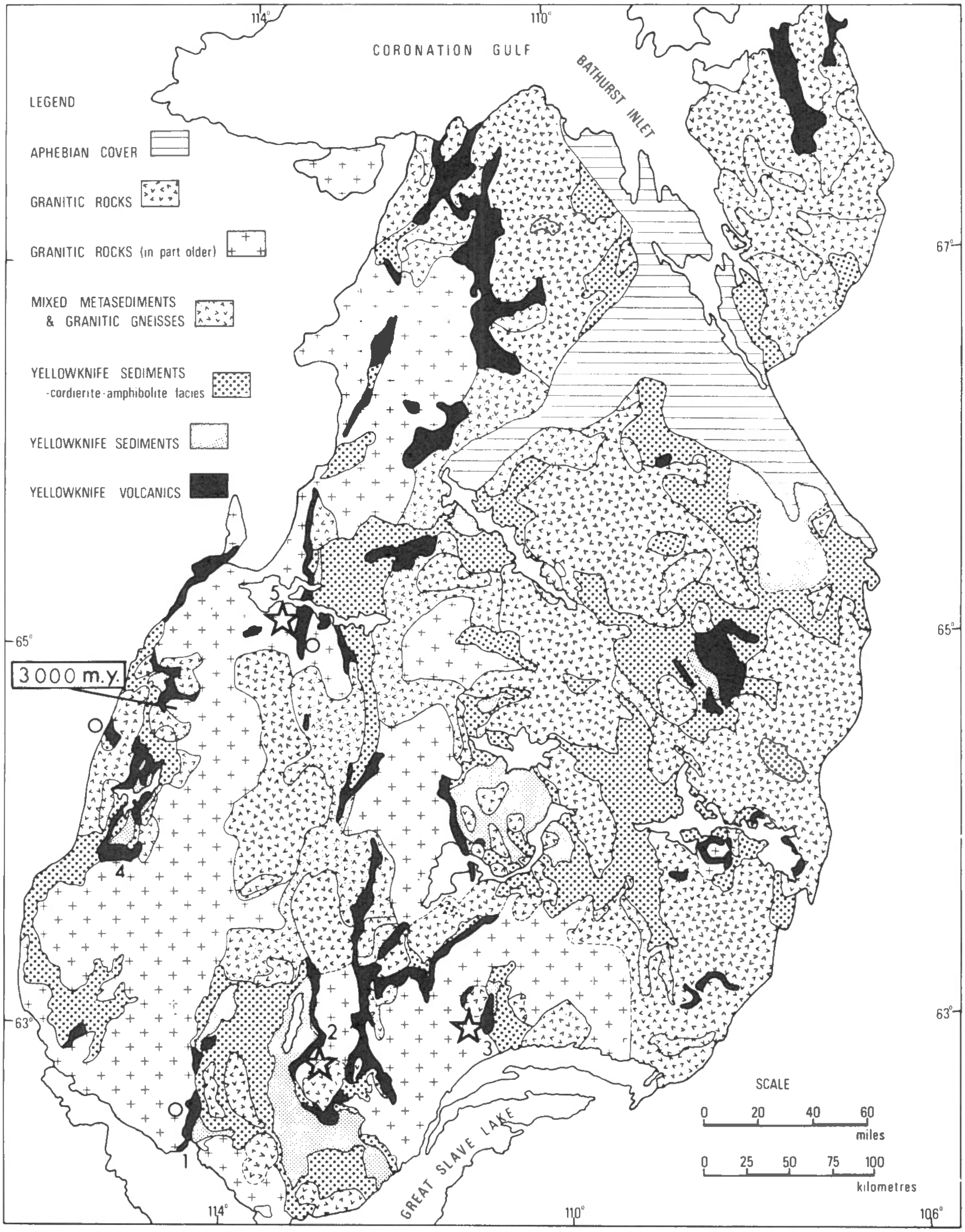
The greywacke-mudstone facies consists of typical turbidites (Henderson, 1970, 1975) of which the greywackes are composed of angular feldspars, rock fragments and quartz in a matrix of chlorite, muscovite, and fine grained quartz and feldspar.

In the transition zone between volcanic and sedimentary rocks are relatively thin sedimentary units of limited regional extent that include wedges of conglomerates, shallow water volcanogenic lithic wackes, quartzites, calcareous sediments, thought to be exhalite deposits for the most part, and locally, iron formations. The conglomerates are elongate lenses up to 450 m thick that can be traced as far as ten miles. They tend to wedge out along strike and to occur about thick parts of the volcanic pile. Boulders are dominantly of volcanic rocks of local derivation with some cobbles of greywacke, shale, quartz and chert. Well rounded boulders of granitic rock occur locally and in places are major components of the conglomerates.

Thus, the Archean succession in the Slave Province comprises firstly, rather thick sequences of essentially basic volcanics that generally are found along margins of sedimentary basins, and secondly, overlying, and in part time equivalent, greywacke-mudstone turbidites. The sedimentary rocks are folded into variably trending folds that are often isoclinal and plunge gently. These folds are usually refolded about upright axes, nearly at right angles to the first fold axes, yielding steeply plunging folds. The volcanic rocks are normally in steeply-dipping monoclinal successions or in broad open folds. The Yellowknife sequence is intruded by granitic rocks that range from quartz diorite to granite in composition. Very few ultramafic intrusions are in the sequence. The range of metamorphism is from greenschist to cordierite amphibolite facies. Deformation, intrusion, and metamorphism overlap in time.

In the Superior Province Archean supracrustal rocks are found in a number of easterly-trending belts (Fig. 3); most are predominantly volcanic rocks but some are dominantly sedimentary rocks or their metamorphosed equivalents. Although the stratigraphy of the supracrustal rocks is known in many areas, it is difficult to establish a stratigraphy for any single belt or for the province as a whole because of structural complexity and rapid facies changes.

Within the volcanic-rich belts the principal elements are flows and pyroclastics of the basalt-andesite-dacite-rhyolite association that commonly occur in mafic to felsic cycles. These volcanic strata are intercalated, especially in upper parts of sequences, with greywacke-mudstones, tuffs, conglomerate, and iron formation. Massive and pillowed basalts are dominant in the lower



○ – approximate locations of granite-bearing conglomerates within the Yellowknife Supergroup.

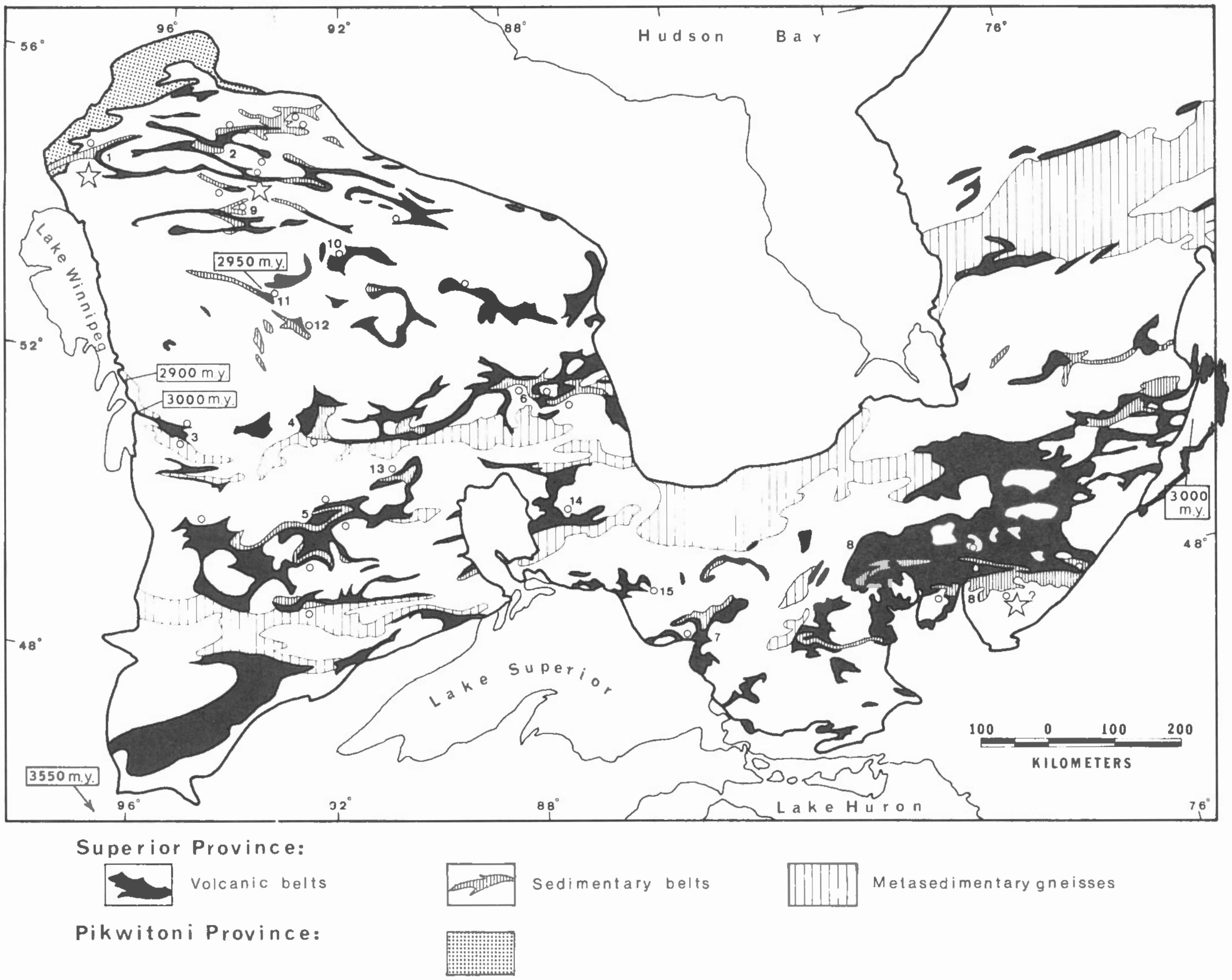
☆ – approximate locations of unconformities beneath the Yellowknife Supergroup.

3000 m.y. – age of pre-Kenoran granitoid rocks.

Numbers are volcanic-sedimentary belts as follows:

1) Yellowknife belt,
2) Cameron River belt, Ross Lake area,
3) Benjamin Lake belt,
4) Indin Lake belt,
5) Point Lake belt.

Figure 2. Geology of the Slave Province.



○ – approximate locations of granite-bearing conglomerates.

☆ – approximate locations of unconformities reported at the base of volcanic-sedimentary sequences.

2900 m.y. – ages of pre-Kenoran granitic rocks.

Numbers are volcanic-sedimentary belts as follows (the principal sources are included in the list of references):

1) Cross Lake,
2) Oxford Lake-Gods Lake,
3) Rice Lake,
4) Uchi Lake-Birch Lake,
5) Sioux Lookout,
6) Fort Hope,
7) Wawa,
8) Rouyn-Noranda,
9) Island Lake,
10) Muskrat Dam Lake,
11) Favourable Lake,
12) North Spirit Lake,
13) Savant Lake,
14) Sturgeon Lake,
15) Black River.

Figure 3. Simplified geological map of part of the Superior Province and the proposed Pikwitonei Province (Bell 1971a) showing "greenstone" belts and metasedimentary schists and gneisses. The granitoid mileau is unpatterned.

parts of most sequences and andesite flows and pyroclastics increase proportionately upwards. Felsic rocks, commonly pyroclastics, are present mainly in the upper parts of the sequences and in concentrations along the belt where the thickness is greatest, presumably at centres of eruption.

According to Goodwin *et al.*, 1972, a typical Archean sequence in the Superior Province may consist of 3000 to 6000 m of mafic flows and associated intrusions, 1500 to 3000 m of mafic to felsic flows and fragmentals, 600 to 3000 m of mostly felsic pyroclastics and flows, and finally, 600 to 2000 m of sedimentary rocks with minor interbedded volcanic rocks, giving a total thickness of about 10 000 to 15 000 m.

Extending from some of the volcanic-rich belts of the Superior Province are broad zones of metasedimentary rocks that grade outward into paragneiss, migmatites, and mixed gneisses. Their relationship to the better preserved sequences within the belts are often obscured by faulting along the belt margins, but in some areas they are stratigraphically below the volcanic rocks, and in others they are considered to be lateral, temporal equivalents of strata within the volcanic-sedimentary belts.

The most abundant sedimentary facies are greywacke-mudstone turbidite sequences. The sand portions comprise variable proportions of quartz, plagioclase and rock fragments in a fine, often abundant, matrix. Potash feldspar is rare. Conglomerates form a small proportion of the sequence, but may be locally thick; i.e. up to 1000 m or more. Iron formations are widespread in the Archean sequences, but they are usually thin and form a relatively small proportion of any one sequence. They are concentrated in the transition zones between volcanism and sedimentation and may occur as oxide, carbonate, or sulphide facies.

The supracrustal rocks are in long belts probably representing the original depositional troughs. Relative ages of these basins are not well known, but Krogh and Davis (1971) postulate that they range over a period of about 200 m.y.

Numerous ultramafic and gabbroic bodies occur in the Superior Province, commonly in the supracrustal rocks. They are typically pre-orogenic and have been deformed along with the enclosing stratified rocks. Alpine-type intrusions or ophiolite complexes have not been identified.

The supracrustal rocks have been deformed, but the style of deformation varies and this variation probably reflects the nature of the strata (Goodwin *et al.*, 1972). Massive, thick volcanic sequences are usually less complexly folded than the more heterogeneous sedimentary strata. In general, however, the belts are synformal and early folds have been refolded by one or two sets of later folds.

The supracrustal rocks have been metamorphosed and intruded by granitic rocks. The metamorphic grade ranges from prehnite-pumpellyite to amphibolite, and rarely, to granulite facies. The higher grades can be found along the margins of the belts near the boundary with granitic rocks and about granitic plutons within the belts. Granulite facies metamorphism is extensive in the northeastern and northwestern part of the province, but usually the original rock type is uncertain. The emplacement of granitic rocks, the metamorphism and the deformation, collectively known as the Kenoran Orogeny, occurred between 2500 to 2700 m.y. ago.

From this summary of Archean geology of the Superior and Slave provinces in the Canadian Shield, it is evident that they have much in common. The supracrustal sequences are grossly similar in that they comprise great thickness of essentially mafic submarine volcanic rocks that contain increasing proportions of intermediate to felsic rocks in the upper parts of the sequence which give way vertically and laterally to greywacke-mudstone turbidites. In the transition zone between the volcanic and turbidite facies are conglomerates, iron formation, shallow water quartzites, carbonates and tuffaceous rocks, some of which may be subaerial. The belts of supracrustal rocks are separated by granitic batholithic complexes and belts of granitic gneisses. The belts are not classical geosynclines in that related miogeosynclinal-eugeosynclinal belts, foreland overthrust zones, and high and low pressure metamorphic zones, are absent. In Archean terranes the basins of supracrustal accumulation do not appear to be draped about large stable cratons, but occur in an area of largely younger complexes of granitoid batholiths.

## UNCONFORMITIES

In each of the examples that follows an unconformity is interpreted as being present at the base of an Archean volcanic-sedimentary succession and the underlying material is granitoid. Their locations are shown in Figures 2 and 3.

### Ross Lake, Northwest Territories (Slave Province)

Near Ross Lake, about 45 miles east of Yellowknife, Northwest Territories the Yellowknife Supergroup of volcanic and sedimentary rocks is in contact with a complex assemblage of massive and gneissic granitic rocks (Fig. 4). The Yellowknife Supergroup is typically composed of a lower succession of mafic to felsic volcanic rocks and an upper sequence of greywacke and shale. At Ross Lake the volcanic sequence is about 3000 m thick but it diminishes southward to a strip of felsic volcanic rocks barely 100 m thick that separates greywackes and granitic gneiss. At this point a thin conglomerate member, composed mainly of volcanic clasts in carbonate cement, adjoins the contact and interfingers northward into volcanic rocks (Fortier, 1947). The volcanic formation is overturned and dips steeply towards the granitic complex. The contact between them is difficult to interpret even when well exposed; it is neither obviously intrusive nor obviously unconformable. In places it is obscured by shearing and may be a fault. Layering in the volcanic rocks invariably parallels the contact.

The granitic complex was mapped recently by Davidson (1972) and part of his map is incorporated in Figure 4. It contains at least two distinct generations of granitic rocks. The older generation includes the Ross Lake granodiorite to the south and a mixed group of dioritic, tonalitic, and granodioritic gneisses to the north (Davidson, 1972). Foliation is marked in both sets of granitoid rocks; in the Ross Lake granodiorite it roughly parallels the contact with the volcanic rocks but in the mixed gneisses it strikes into, and is truncated by, the volcanic belt. Two plutons invade the older granitic gneisses; an adamellite and the Redout Lake granite. Both of these are massive and potash-rich and the Redout Lake granite emits a swarm of rare-earth pegmatites (Hutchinson, 1955). The plutons tend to be separated from the older rocks by a migmatite zone except between the Redout Lake granite and the Ross Lake granodiorite where they are gradational.

A swarm of mafic dykes was emplaced during the interval separating the two generations of granitic rocks. It overlaps the contact between the volcanic succession and the Ross Lake granodiorite with dykes about equally abundant in each. No dykes are found in the sedimentary rocks overlying the volcanic sequence. Individual dykes range from 1 to 2 m to more than 30 m thick and are locally so closely spaced that only wedges and thin screens of country rock are found between them. The swarm is roughly parallel with the granodiorite-volcanic contact and dips steeply. A foliation is imposed upon both the granodiorite and the dykes. Southward the dyke swarm is transected by the Redout Lake granite but a few of the dykes actually extend short distances into the massive granite before terminating in strings of amphibolitic inclusions (Hutchinson, 1955).

The presence of an unconformity between the Yellowknife Supergroup and the older generation of granitic rocks would be entirely consistent with the geological relationships displayed (Baragar, 1966; Davidson, 1972). Structural trends in the older granitic gneisses are clearly truncated by those of the Yellowknife Supergroup and therefore, might, be attributed to an earlier period of deformation. The numerous mafic dykes which invade the older gneisses and volcanic rocks but not the directly overlying sediments are probably best interpreted as being contemporaneous with the volcanic rocks. Comparison of chemical analyses from three of the dykes with that of the average basalt of the Yellowknife Supergroup (Table 1) suggests that this is a feasible interpretation. If this is true, then the Ross Lake granodiorite together with the granitoid gneisses farther north are relicts of a pre-Yellowknife Supergroup basement. The later granitic plutons, the Redout Lake granite and adamellite can be interpreted as differentiates of the basement regenerated during the Kenoran Orogeny. Radiogenic

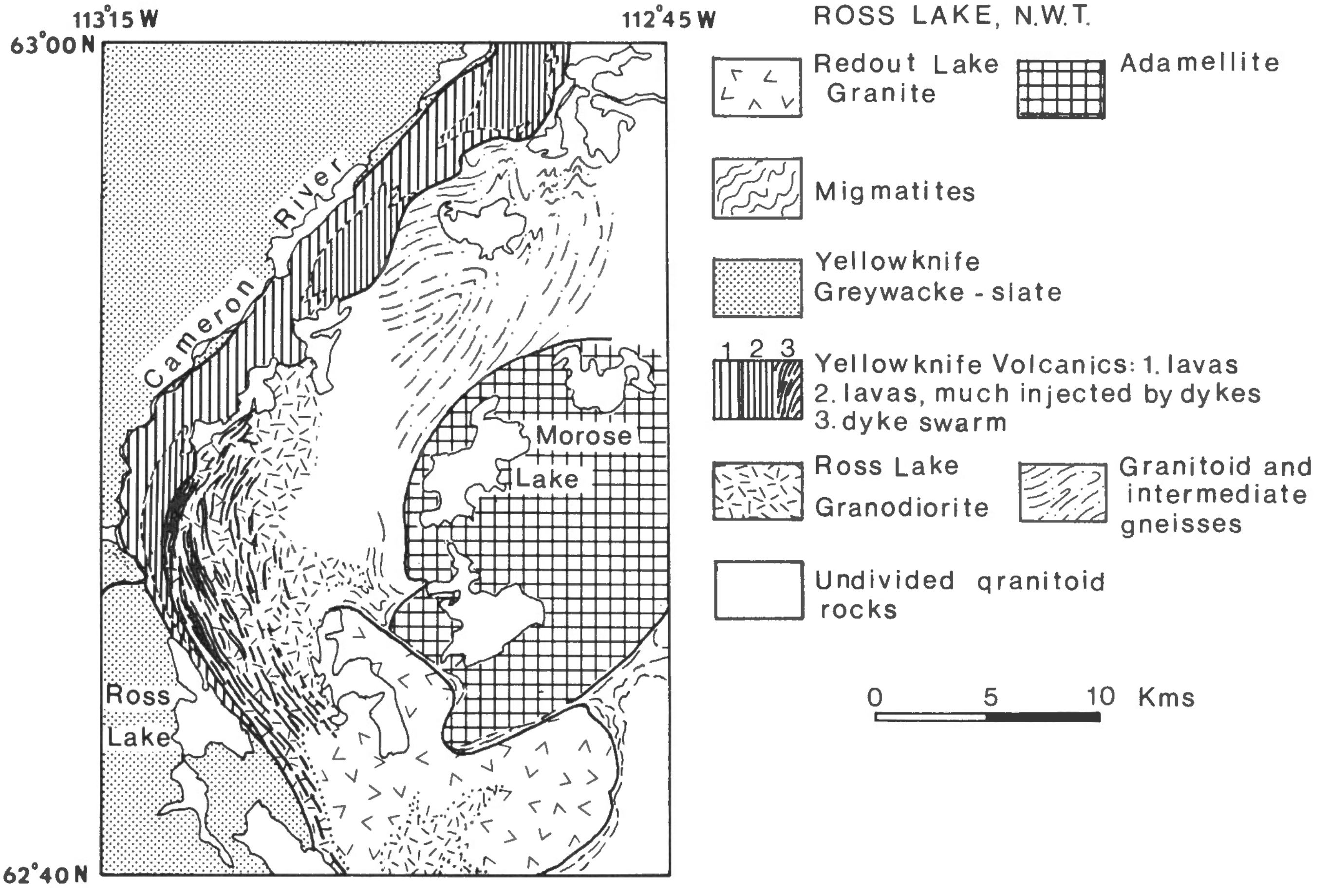


Figure 4. Geology of the Ross Lake area, Northwest Territories. Compiled from Henderson (1941), Fortier (1947), Baragar (1966), and Davidson (1972).

Table 1

Comparison of the composition of mafic dykes and average Yellowknife basalt, Ross Lake area

| $SiO_2$ | $Al_2O_3$ | $Fe_2O_3$ | FeO | MgO | CaO | $Na_2O$ | $K_2O$ | $TiO_2$ | MnO | |
|---|---|---|---|---|---|---|---|---|---|---|
| 49.1 | 15.2 | 1.6 | 10.0 | 6.6 | 9.4 | 2.4 | 0.3 | .88 | .16 | Mafic dykes[1] |
| 48.6 | 15.0 | 3.8 | 10.0 | 7.0 | 9.4 | 2.4 | 0.2 | .89 | .17 | |
| 52.7 | 13.4 | 2.8 | 10.9 | 4.5 | 7.5 | 2.3 | 0.1 | 1.20 | .17 | |
| 50.1 | 15.0 | 2.8 | 9.2 | 6.6 | 9.7 | 2.1 | 0.35 | 1.50 | .18 | Average basalt[2] |

[1] Analyses of rapid methods laboratory, Geological Survey of Canada

[2] Baragar, 1966

ages obtained from the Ross Lake granodiorite (Rb Sr 2512 ± 61 m.y.) and the Redout Lake granite (K Ar 2550 m.y.) (Green *et al.*, 1968; Green and Baadsgaard, 1971) are very close to one another and to the age (Rb Sr 2627 ± 104 m.y.) of the Yellowknife Supergroup volcanic rocks. These data are interpreted by Green *et al.* (1968) and Green and Baadsgaard (1971) as supporting the hypothesis of island arc origin advanced for the Yellowknife Supergroup by Folinsbee *et al.* (1968). However, if that were the case the various events, from the initial eruption of lavas to their final pervasion by granites, would have to have been extraordinarily compressed in time. Moreover, the initial $^{87}Sr/^{86}Sr$ ratio (0.707) is high for an Archean pluton supposedly derived from the mantle. A more likely explanation is that the Kenoran Orogeny has given the Ross Lake granodiorite an apparent younger age.

## Benjamin Lake, Northwest Territories (Slave Province)

In the Benjamin Lake area in the southeast part of the Slave Province, Heywood and Davidson (1969) have mapped a small mass of meta-tonalite bounded by mafic Archean volcanic rocks that they postulate may be basement to the Archean supracrustal rocks in the area (Fig. 5). The rock is composed of quartz, biotite and plagioclase, and is weakly to strongly foliated. It has been sheared, causing granulation of primary minerals, and recrystallized. Biotite occurs in oriented streaks in the foliated phase. Quartz commonly forms round polycrystalline eyes or grains bounded by a fine grained quartz mosaic.

Foliation at the margins of the tonalite are parallel to the contact which in turn is conformable with bedding or layering in enclosing rocks. No cross-cutting relations and no aureole of contact metamorphism were observed in the enclosing volcanic strata.

The tonalite is cut by a number of vertical amphibolite dykes (Fig. 5); some can be traced for as much as a mile, but most are discontinuous lenses formed from original dykes disrupted and broken during deformation of the tonalite. The dyke rocks are composed of equant hornblende grains with plagioclase in the interstices, along with minor magnetite and sulphide. Similar dykes are found in the lower mafic lavas of the bordering Yellowknife Supergroup, but not in the upper units of the sequence. They are interpreted as possible feeder dykes to the Yellowknife lavas.

Thus, on the basis of its deformation, metamorphism, lack of cross-cutting relationships and metamorphic effects on bordering Yellowknife strata, and its intrusion by mafic dykes that may be feeders to Yellowknife lavas, the tonalite is considered to be older than, and therefore basement to, the Archean Yellowknife Supergroup. A Rb/Sr age of 2720 ± 90 m.y.[1] for the tonalite is approximately the age of metamorphism of the Yellowknife strata, and if the interpretation of field evidence is correct, must represent not the absolute age of intrusion of the tonalite, but a redistribution of critical rubidium and strontium isotopes during metamorphism and deformation that affected it as well as the Yellowknife rocks.

## Point Lake, Northwest Territories (Slave Province)

Possibly the best documented case for basement rocks to Archean supracrustal rocks in the Slave Province is at Point Lake (Stockwell, 1933; Henderson, 1975) in the north central part of the province. According to Stockwell, highly altered and deformed chloritized granite that is intruded by younger granitoid bodies that also cut Yellowknife strata, is overlain by a conglomerate in the Yellowknife sequence that dips away from the chloritized granite and contains cobbles of rock identical to it. No metamorphic aureole around the granite is evident and cobbles in the conglomerate decrease in size away from the chloritized granite. Again basic dykes which may be feeders to the Yellowknife lavas cut the older granite but not the younger granitic rocks. Recent work by Henderson (1975) has confirmed these observations and defined

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[1] All Rb/Sr ages in this report are based on a decay constant $\lambda = 1.39 \times 10^{-11} yr^{-1}$.

an unconformity between the deformed, altered granite and conglomerate. Figure 6 illustrates the nature of the unconformity where fractures in the underlying granite are filled with conglomerate. The conglomerate conformably overlies mafic volcanic rocks of the Yellowknife Supergroup and laps onto the chloritized granite, so that it can be interpreted that the whole Archean sequence is younger than the granite. As well as pebbles of the altered granite, the conglomerate contains clasts of mafic and felsic volcanic rocks and is associated with lithic sandstones containing grains of felsic volcanic rock and quartz. Therefore, the source of sediment is mixed, including both Yellowknife volcanic rocks and older deformed granite.

### Cross Lake, Manitoba (Superior Province)

The Cross Lake region of Manitoba was one of the first places in the Canadian Shield to yield evidence of an early Archean granitoid basement. Its geology has been described by Horwood (1935), Bell (1962), and Rousell (1965).

Horwood (1935) observed a conglomerate at the base of a volcanic sequence now known as part of the

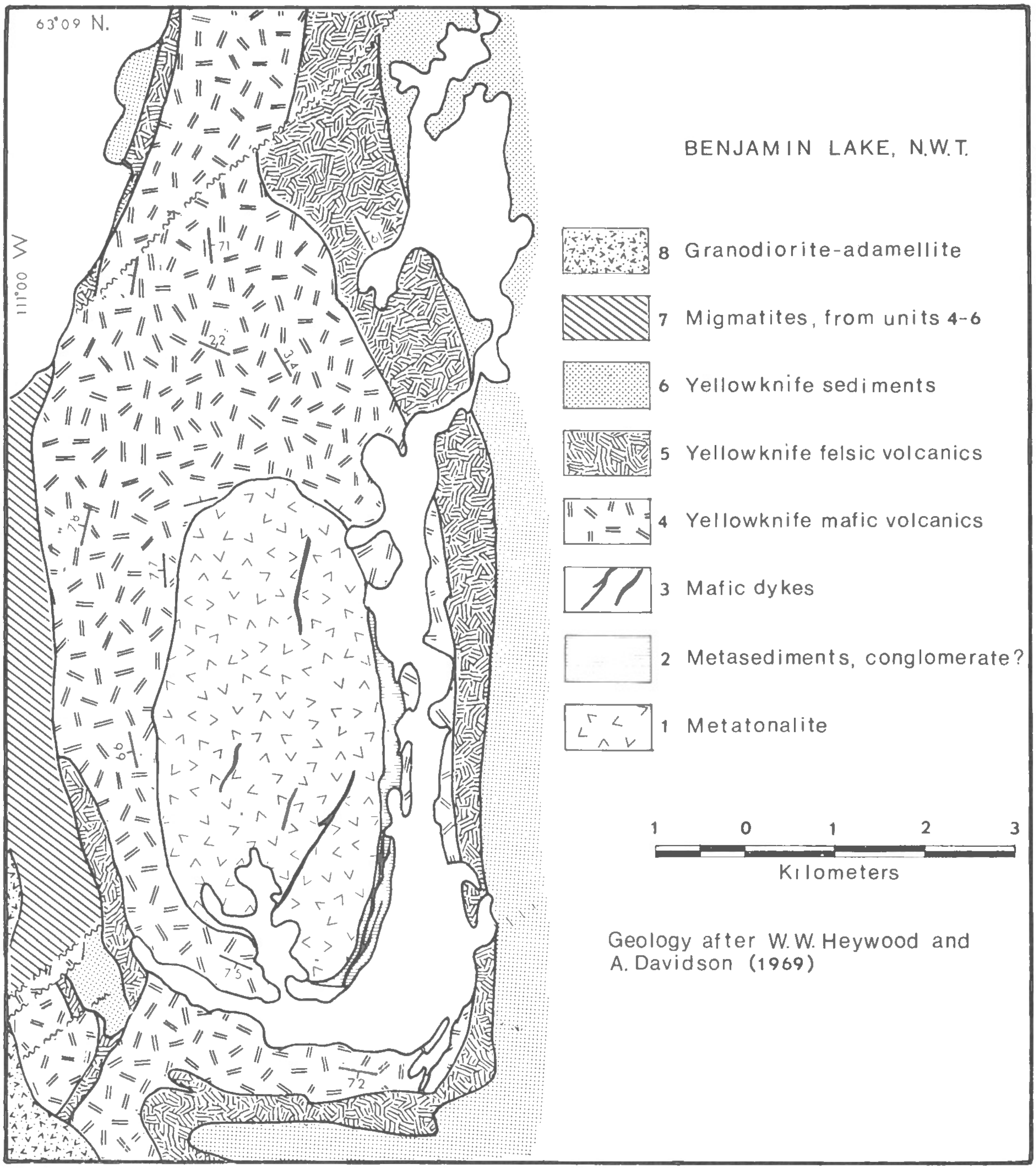

Figure 5. Geology of the Benjamin Lake area, Northwest Territories.

Cross Lake Group and established that the tonalite boulders it contained were almost identical to gneisses in the adjoining terrane to the north. The contact was not exposed but he concluded, quite reasonably, that the gneisses were basement to the volcanic succession. In more recent years at a locality about 90 km west of that reported by Horwood, Rousell (1965) found a similar conglomerate in direct contact with underlying granodiorite. Again granodiorite boulders in the conglomerate appeared identical to the underlying granodiorite gneisses.

Part of the western end of the Cross Lake volcanic sedimentary belt is shown in Figure 7. The map is adapted from Rousell and shows the location of the unconformity which he described. The Cross Lake belt which continues for several hundred kilometres eastward (Fig. 3) comprises a lower formation of predominantly pillowed basalts and an upper formation of conglomerates, arkoses, greywackes, and siltstones. The two formations interfinger and rare sedimentary beds may be found at all levels within the volcanic sequence (Bell, 1962). Upward in the succession the sedimentary formation becomes increasingly finer grained. In addition to granodiorite and tonalite the conglomerate contains clasts of quartzite, quartz, basalt, and argillaceous rocks, and the finer grained sediments are commonly arkosic (Bell, 1962); thus most materials are attributable to a granitic source.

The Cross Lake belt is enclosed by granitoid gneisses of chiefly tonalite or granodiorite composition. Gneissosity generally parallels the structures within the volcanic-sedimentary belt and only rarely do apophyses of granodiorite project into it. Migmatite zones observed at a number of places along the boundaries of the belt and relicts of metavolcanic and metasedimentary rocks found well within the gneisses appear to justify the conclusions of Bell (1962) and Rousell (1965) that the majority of the enveloping gneisses were mobile during the Kenoran Orogeny. Remnants of the earlier granodiorite basement are rare. In the locality shown in Figure 7 basement gneisses occur on the flanks of an anticline wherein the core appears to have been mobile. Compositional differences between the earlier and later gneisses do not seem to be great. According to analyses by Rousell both would be classed as tonalites or low-potash granodiorites.

The unconformity at the base of the Cross Lake Group was given regional significance by Bell (1971a, b). Prior to this time the boundary between the Superior and Churchill provinces had been defined differently by various authors but was generally placed along a line of gravity anomalies which roughly coincided with a structural break marking the northwestern limit of east-trending Superior Province structures. A broad zone of granulite gneisses parallel with the boundary was included in the Superior Province or the Churchill Province depending upon which interpretation of the boundary was accepted. Bell (1966) defined the boundaries of the gneissic zone more precisely and designated it the Pikwitonei subprovince and later (1971a), the Pikwitonei Province. The southern part of the Pikwitonei Province was interpreted by Bell as passing unconformably beneath the western arm of the Cross Lake belt (Fig. 3) and the granodiorite basement discovered by Rousell (1965) at Cross Lake was interpreted as a retrograded inlier of the same province. Another inlier was thought to occur about 40 km to the southeast where unconformable relations were again indicated between the Cross Lake succession and adjoining gneisses. Hence, Bell proposed that the Pikwitonei Province is part of an early Archean basement that outcrops in the northwest and because of a regional southward tilt passes beneath the Superior Province to underlie much of its western part (Bell, 1971a).

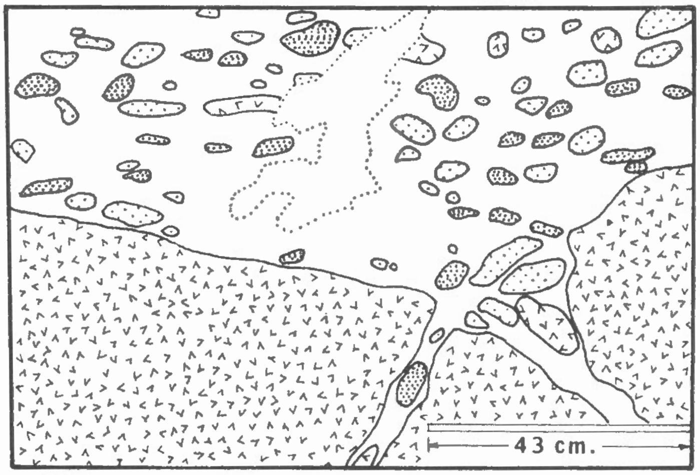

Figure 6. Sketch of a photograph by J. B. Henderson (1975) at Point Lake, N. W. T. showing an unconformable contact between granitoid basement and overlying conglomerates of the Yellowknife Supergroup.

mafic volcanic rocks – heavy stipple;

felsic volcanic rocks – light stipple;

granitoid rocks – V symbols;

unpatterned – lithic sandstone (and within dotted enclosure overburden). Note volcanic pebbles in fractures of the granite basement.

## Oxford Lake – Gods Lake Region, Manitoba (Superior Province)

Supracrustal rocks of the Oxford Lake-Gods Lake region form a complexly branching belt that is east of, and may in part be continuous with, the Cross Lake belt (Fig. 3). A simple three-part stratigraphic division appears to be applicable to the succession in most parts of the belt (Campbell *et al.*, 1972). In the lower part the predominantly mafic volcanic unit is the Gods Lake Subgroup. It is overlain conformably by the Knee Lake Subgroup composed mainly of felsic and mafic volcanic fragmental rocks with subordinate sediments. Conglomerate with some granite[1] clasts is a minor member of the subgroup. The two subgroups form the Hayes River Group (Table 2). Overlying the latter unconformably is the Oxford Group (Elbers, 1973) made up of a thick (±500 m) basal conglomerate, and sandstones of chiefly greywacke-type. The conglomerate clasts are composed of mafic and felsic volcanic rocks, sedimentary rocks of various types, granitoid rocks, and quartz.

Granitic intrusions invaded the supracrustal succession in two distinct pulses; 1) immediately before, and 2) following, deposition of the Oxford Group. The earlier intrusions are mainly tonalites and the later ones range chiefly from granodiorites to granites (Hubregtse, 1973). Undoubtedly much of the granitic material in the basal conglomerates of the Oxford Group can be attributed to the pre-Oxford Group intrusions. However, from granitic clasts in the conglomerates of the Knee Lake Subgroup noted above a plutonic source of still earlier age can be inferred. Evidence for such a source was recently uncovered

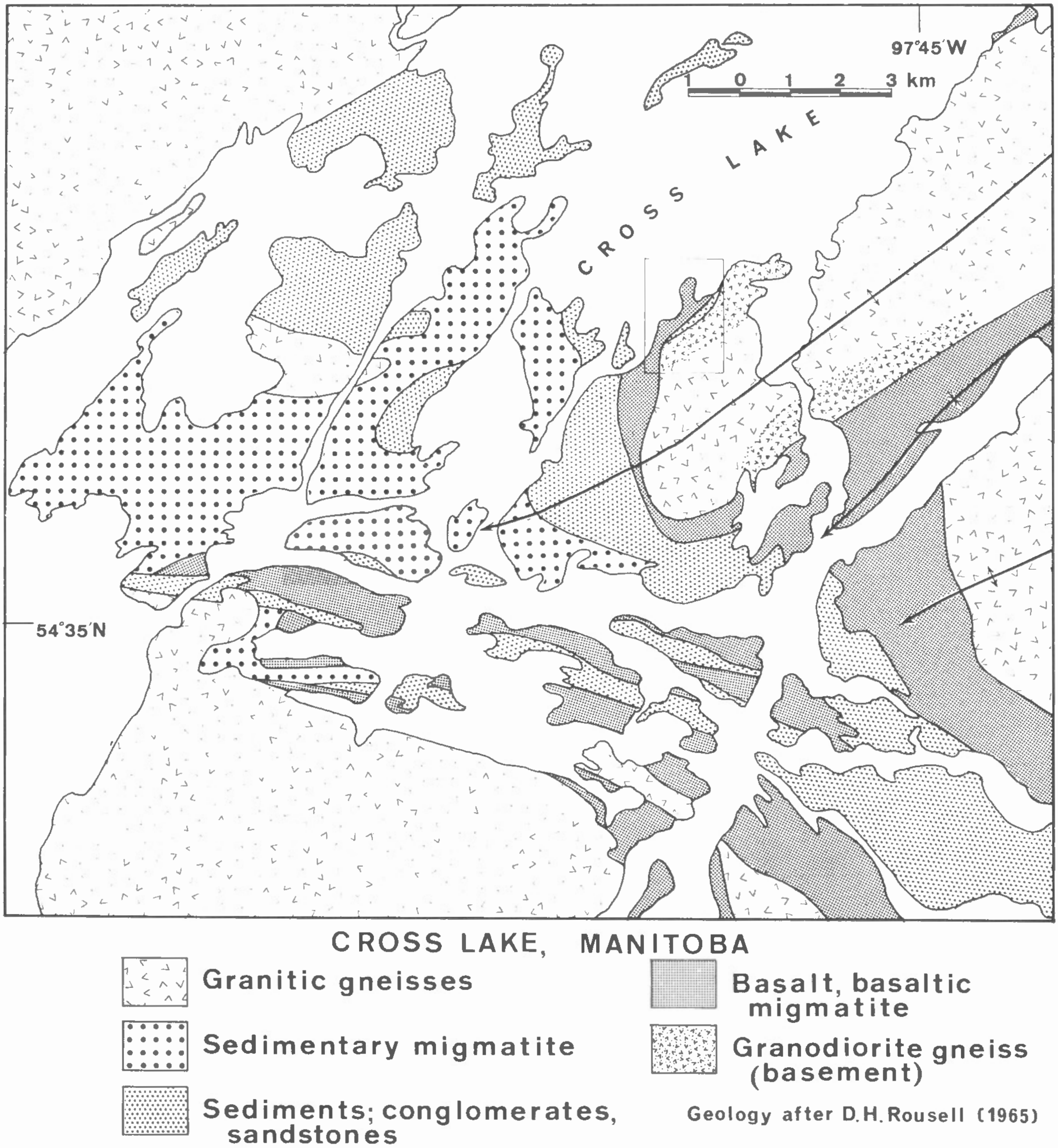

Figure 7. Geology of Cross Lake area, Manitoba. Location of the unconformity is contained within the rectangle.

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[1] Granite clasts, granite-bearing conglomerates, granitic rocks and granitoid rocks are all used in general sense in this paper to indicate leucocratic phaneritic rocks.

## Table 2

Stratigraphic sequences for eight volcanic-sedimentary belts of the Superior Province. Locations are shown in Figure 5. Boxed conglomerates are those containing granite clasts.

| CROSS LAKE, MAN.[1] | |
|---|---|
| | Leucogranite, leucongranodiorite<br>Granodiorite-tonalite gneisses |
| | intrusive |
| Cross Lake Group | Feldspathic greywackes and siltstones<br>$\boxed{\text{Conglomerate}}$ |
| | conformable |
| | Mafic pillow lavas, local felsic tuffs and flows<br>$\boxed{\text{Conglomerate}}$ |
| | unconformable |

Granodiorite gneiss basement (Pikwitoni gneisses)

| OXFORD LAKE-GODS LAKE, MAN.[2] | |
|---|---|
| | Granites, granodiorites |
| | intrusive |
| Oxford Lake Group | Greywacke, feldspathic greywacke, $\boxed{\text{conglomerate}}$, arkose, quartzite |
| | unconformable |
| | Tonalite, granodiorite, Quartz-feldspar porphyry |
| | intrusive |
| Hayes River Group | Knee Lake Subgroup<br>Mafic to felsic volcaniclastic rocks; greywacke shale, $\boxed{\text{conglomerate}}$ |
| | conformable |
| | Gods Lake Subgroup<br>Rhyolite, dacite breccia and tuff<br>Mafic lavas and tuff |
| | conformable |
| Pre-Hayes River Group | Quartz and feldspathic wacke; protoquartzite, and arkose<br>Arkosic $\boxed{\text{conglomerate}}$ |
| | unconformable? |

Granodiorite basement

| RICE LAKE, MAN.[3] | |
|---|---|
| | Quartz monzonite, granodiorite |
| | intrusive |
| San Antonio Formation | Arkose, quartzite<br>$\boxed{\text{Conglomerate}}$ |
| | unconformity |
| | Porphyries, quartz diorite |
| | intrusive |
| Rice Lake Group | Edmunds Lake Formation<br>Greywacke, shale<br>$\boxed{\text{Conglomerate}}$<br>Argillite |
| | unconformable? |
| | Gem Lake Subgroup<br>Rathall Lake Formation; subgreywacke, arkose, feldspathic greywacke, volcanic conglomerate<br>Banksian Lake Formation; rhyolitic pyroclastics and flows, dacitic pyroclastics, and pillow basalts |
| | unconformable? |
| | Bidou Lake Supergroup<br>Narrows Formation; dacitic pyroclastics<br>Stormy Lake Formation; feldspachic greywacke, iron formation, $\boxed{\text{conglomerate}}$<br>Gunnar Formation; pillow basalts<br>Dove Lake Formation; volcanic agglomerate, siltstone, greywacke<br>Tinney Lake Formation; pillow basalts<br>Stovel Lake Formation; greywackes, volcanic fragmentals<br>Basalt Formation |

Basement unknown

| UCHI LAKE-BIRCH LAKE, ONT.[4] | |
|---|---|
| | Granodiorite, granite<br>Syenite |
| | intrusive |
| Uchi Group | Rhyodacite-rhyolite, breccias, flows, tuffs<br>Massive and pillow basalt flows<br>Sediments' quartzite, shale greywacke, $\boxed{\text{conglomerate}}$<br>Andesite and dacite flows and pyroclastics<br>Massive and pillowed flows |
| | onformable to unconformable |
| Slate Lake Group | Impure quartzites, arkose, greywacke, shale, $\boxed{\text{conglomerate}}$ |

Basement unknown

| SIOUX LOOKOUT, ONT.[5] | |
|---|---|
| | Granite and granodiorite<br>Syenite<br>Granodiorite and granitic gneiss |
| | intrusive |
| Minnitaki Group | Slate, greywacke, arkose $\boxed{\text{conglomerate}}$ |
| | conformable |
| Central Volcanic Rocks | Massive and pillowed basalts |
| | faulted |
| Abram Group | Little Vermillion Formation; greywacke, shale<br>Daredevil Formation; mafic and felsic tuffs, greywackes<br>Ament Bay Formation; arkoses and $\boxed{\text{conglomerates}}$ |
| | unconformable |
| | Quartz porphyry, (granodiorite)? |
| | intrusive |
| Northern Volcanic Rocks | Massive and pillowed mafic flows, mafic fragmentals<br>Petara Formation; volcanogenic sediments<br>Massive and pillowed mafic flows |

Basement unknown

| FORT HOPE, ONT.[6] | |
|---|---|
| | Albite granite to quartz diorite<br>Quartz and feldspar porphyries, granite |
| | intrusive |
| | Mixed sediments and felsic volcanics; dacite and rhyolite flows and pyroclastics, $\boxed{\text{conglomerates}}$, quartzite, argillite |
| | contact uncertain |
| | Mafic flows and fragmentals including rare $\boxed{\text{granitic}}$ boulders<br>Felsic pyroclastics, rare sediments and $\boxed{\text{conglomerate}}$ |
| | contact uncertain |
| Miminiska Group | Impure quartzite, siliceous greywackes, argillites, $\boxed{\text{conglomerate}}$, arkose |

Basement unknown

| | WAWA, ONT.[7] |
|---|---|
| | Granite, granodiorite, syenite |
| | intrusive |
| Michipicoten Group | Upper Volcanic Rocks' mafic massive and pillowed flows<br>Dore Sediments; $\boxed{\text{conglomerate}}$, greywacke, shale<br>Middle Volcanic Rocks; mafic to intermediate flows<br>Helen Iron Formation<br>Lower Volcanic Rocks; felsic pyroclastics, mafic to intermediate pillowed and massive flows |

Basement unknown

| ROUYN - NORANDA, QUE.[8] | |
|---|---|
| | Granite<br>Hornblende granite, syenite, granodiorite |
| | intrusive |
| | Cadillac Group<br>Greywacke<br>$\boxed{\text{Conglomerate}}$ |
| | unconformable |
| Abitibi Supergroup | Blake River Group<br>Felsic flows and pyroclastics<br>Mafic pillowed and massive flows |
| | conformable |
| | Kewagama-Pontiac Group<br>Greywacke, argillite, $\boxed{\text{conglomerate}}$ |
| | unconformable |
| | Malartic Group<br>Mafic to intermediate pillowed and massive flows |
| | conformable |
| | Bellecombe Group<br>Greywacke, argillite, minor $\boxed{\text{conglomerate}}$, arkose |
| | unconformable ? |

Granodiorite basement?

[1] Rousell, 1965; Bell, 1962, 1971

[2] Campbell et al, 1972; Elbers and Gilbert, 1973 and Elbers, in preparation

[3] Stockwell, 1938; Campbell, 1971; Weber, 1971; McRitchie, Weber, and Scoates, 1971

[4] Bateman, 1940; Goodwin, 1967

[5] Turner and Walker, 1973; Walker and Pettijohn, 1971; Skinner, 1969

[6] Prest, 1939, 1944

[7] Goodwin, 1962

[8] Gunning and Ambrose, 1940; Ambrose, 1941; Wilson, 1962; Holubec, 1972

by Elbers (pers. comm., 1974) at Goose and Beaver Hill lakes in the southern-most part of the Oxford Lake-Gods Lake region. In that area, pillowed basalts, presumed to be equivalent to the Gods Lake Subgroup are underlain conformably by a succession of quartz-rich sediments and conglomerates. The base of the succession is not exposed; the nearest outcrops on the lower side of the sequence are of gneissic granodiorite of unknown relationship to the supracrustal rocks.

The sediments are composed of quartz with lesser plagioclase and subordinate microcline and biotite. Both the coarseness of grain size (1-3 mm) and the presence of perthitic grains in the sediments are suggestive of a plutonic source; a view that is corroborated by the high proportion of granitic clasts (as much as 90 per cent) contained in the accompanying conglomerates. These clasts range in composition from granodiorite to granite. They are well rounded but in places they are as much as 1 m in diameter, from which it might be inferred that their source was at no great distance. Crossbedding, with bedding at least 10 cm thick is ubiquitous and is interpreted by Elbers as denoting a shallow water deltaic environment.

Elbers suggests that these early sediments were deposited in a shelf environment between a craton and geosyncline. Of prime interest in the present enquiry is the evidence they afford of an unconformity between the base of the "greenstone" sequence and an underlying granitic basement. This is supported by preliminary Rb Sr data from the conglomerate boulders. Although scattered, the data indicate a minimum age of 2800 m.y. and a best-fit isochron of 3100 m.y. (Clark, pers. comm., 1974, Univ. Manitoba).

### Abitibi Belt, Quebec (Superior Province)

A problematic unconformity was described by Holubec (1972) at what may be the base of part of the Abitibi succession. The stratigraphy of the southern part of the Abitibi belt in the region of Rouyn-Noranda is given in Table 2, column 8. It results from several classical studies conducted a number of years ago by Gunning and Ambrose (1940), Ambrose (1941), and Wilson (1962) and modified recently by Holubec (1972).

The predominantly volcanic part of the belt, composed of the Malartic and Blake River volcanic groups and intervening Kewagama sediments, forms an east-west trough in parts of which the succession is at least 12 km thick (Baragar, 1968). Southward the volcanic trough is adjoined by a predominantly metasedimentary succession which is believed to be its stratigraphic equivalent in part. It consists of the Pontiac Group, long held to be the correlative of the Kewagama Group (Gunning and Ambrose, 1940), and the recently separated Bellecombe Group (Holubec, 1972) forming the lower part of the succession. A thin discontinuous volcanic unit lying between the two groups is correlated with the Malartic Group to the north. The metasedimentary succession, measured in one section, is about 2500 m thick and, according to Holubec, the structural style within the whole metasedimentary domain is suggestive of deformation of thin sediments as on a stable platform.

It is in this context that the unconformity described by Holubec in the lowest part of the Bellecombe Group is of special interest. Only one of the two outcrops he described need be noted here.

On the south side of Kinojevis Lake, 8 or 9 km south of the boundary of the predominantly volcanic trough, a granitic mass occurs in the core of a north-trending anticline involving the lower part of the Bellecombe Group. On its east side the granite intruded and metamorphosed the adjoining metasediments. On its west side an older phase of the granitic mass is brecciated near the contact with the metasediments. No contact metamorphism is evident. Fractures within the granite do not penetrate the overlying metasediments and some cracks in the granite seem to be filled with the overlying metasedimentary material. At a stratigraphic level about 420 m above the granite contact, pebbles and at least one large block of a very similar granite are present in the metasediments. Holubec interpreted the older of the two granites as being the original basement upon which the Bellecombe sediments were deposited. Remobilization of the basement during the Kenoran Orogeny produced the younger granite.

## SOURCE ROCKS OF ARCHEAN SEDIMENTS

### Slave Province

Of all the sedimentary sequences in the Slave Province only those near Yellowknife have been studied in enough detail to yield reliable data about the source areas of the sedimentary fill (Henderson, 1972). The turbidite sequences exposed in this area, however, appear to be a reasonably representative sample of the sediments of the Slave Province and in Henderson's conclusions probably have regional significance.

The major components of the greywackes are quartz, mostly from an indeterminate origin, rock fragments which include clasts of intermediate and felsic volcanic rocks, mudstones and granitic rocks, in that order of abundance, and plagioclase. These grains are dispersed in a fine matrix that forms about 30 per cent of the rock. Clasts in the conglomerates in the sequence comprise volcanic rocks, largely of intermediate or mafic composition, and granitic rocks in a greywacke matrix. The greywackes are mineralogically, chemically, and texturally immature in that chemically and mechanically unstable rock fragments and feldspar are abundant, the ratio of alumina to soda is low, and the sand-sized grains are very angular. Chemically, the greywackes at Yellowknife have compositions very similar to granodiorite. These characteristics suggest a mixed provenance for the Yellowknife sediments that include both volcanic and granitic terranes. The source area must have had a gross composition of about granodiorite. When the volume of sediments relative to volcanic rocks is considered, it seems clear that the Yellowknife volcanic rocks in the proportions presently exposed could not have provided all the sediment, and that another extensive source area is required (Henderson, 1972). A pre-existing crust composed of granitic and volcanic rocks, in other words, is required to supply the fill for the Archean sedimentary basins.

## Superior Province

### General Statement

Volcanic-sedimentary belts of the Superior Province shown in Figure 3, are long, narrow strips of relatively unaltered rocks commonly called "greenstone" belts. Fringing these "greenstone" belts in places are poorly defined zones of gneisses and schists, mainly of sedimentary origin, that merge outward into the granitic medium composing the bulk of the shield. The metasediments are generally considered to be part of the same stratigraphic successions as those of the "greenstone belts" but their position in the stratigraphic sequence is rarely clear. In Figure 3 the four components are shown separately.

### Conglomerates

Conglomerates are a common, although volumetrically negligible, constituent of the volcanic-sedimentary belts of the Superior Province. Their clasts comprise a variety of rock types ranging widely in their proportions from place to place. Generally, volcanic rocks are dominant but granitic clasts are a significant part of many of the conglomerates throughout the Superior Province.

The locations of a number of the granitic-bearing conglomerates are shown in Figure 3. These were obtained from a sampling rather than an exhaustive search of the literature and no doubt numerous occurrences have been missed. Nevertheless the distribution shown is sufficient to conclude that such conglomerates are a characteristic constituent of greenstone belts of the Superior Province.

The stratigraphic position of granite-bearing conglomerates within each sequence is not as rigidly fixed as was once believed. In the classical stratigraphy of the Superior Province the Archean supracrustal rocks were divided into a lower volcanic sequence and an unconformably overlying sedimentary sequence, commonly with a conglomerate at the base of the latter. These were the Keewatin volcanics and Timiskaming sediments respectively and this subdivision was applied widely and perhaps indiscriminately to many volcanic-sedimentary belts of the southern shield. Accordingly, it is now difficult to assess the reliability of some of the stratigraphic information contained in the older literature. However, sufficient new work has been done which, in combination with the older work, enables us to draw the following conclusions: 1) Granite-bearing conglomerates appear to be abundant only at relatively high levels in the stratigraphic sequence, following at least one volcanic episode and commonly after much of the volcanic activity; 2) Such conglomerates are as frequently concordant with the underlying volcanic rocks as they are discordant; marked unconformities are not the rule; 3) In places, granite-bearing conglomerates of lesser importance are interbedded with the lower volcanic sequence and rarely are found at the base of the section.

Examples of the stratigraphy in eight volcanic-sedimentary belts distributed widely across the Superior Province are given in Table 2. Granite-bearing conglomerates in the table are distinguished by a box around the word "conglomerate". The thicknesses of units are not represented but in general the volcanic units compose the major part of the sections. Typical total thicknesses of stratigraphic sections range from about 8000 to 15 000 m. The table demonstrates what was noted above, the granite-bearing conglomerates may occur at all levels in the stratigraphic sequence. Only in the Cross Lake and Oxford Lake-Gods Lake sections do they overlie granitic "basement" directly but in the Uchi Lake-Birch Lake, Hope Lake, and Rouyn-Noranda sections are they in the lowest recognizable stratigraphic unit and may be assumed to be close to the base of their respective sections.

The proportion and types of clasts in the granite-bearing conglomerates are more commonly recorded in qualitative than in quantitative terms. Donaldson and Jackson (1965), however, established by point count that leucophanerites (their field term for granitoid) comprise less than 10 per cent of the clasts in conglomerates of the North Spirit Lake area of Ontario whereas volcanic rocks make up about 50 per cent of the clasts and the remainder is a mixture of sedimentary rocks and quartz. Pettijohn (1970) reports that point counts on some outcrops of the Abram Group conglometates in the Sioux Lookout belt showed the content of granitic material to exceed 50 per cent. Elsewhere, estimates and pebble-counts of granitic clasts in conglomerates range from very rare in the Uchi Group (Goodwin, 1967) to as much as 75 per cent in parts of the Cross Lake Group (Rousell, 1965). In most places, however, granitic clasts appear to be greatly subordinate to clasts of volcanic rocks with felsic varieties predominating among the latter.

The rock types making up the granitic clasts are most often reported as tonalites, trondhjemites and granodiorites. The sodic nature of the granitic rocks has been stressed by a number of authors (Donaldson and Jackson, 1965; Rousell, 1965; Bass, 1961; Pettijohn, 1970). Gneissic fragments are rare but have been noted by Donaldson and Jackson and in North Spirit Lake area, by Bass (1961) in the Abitibi belt, and by Ermanovics (pers. comm., 1974.) in the Island Lake belt.

If the granitic clasts in the conglomerates represent true plutonic rocks it would be difficult to avoid the conclusion that a sialic crust was widespread prior to the formation of the greenstone belts. Bass (1961), noting that the majority of clasts in conglomerates in the Abitibi belt were volcanic in origin postulated that the few granitic clasts present were from shallow intrusives contemporaneous with volcanism and no granitic basement was thereby indicated. The scarcity or absence among the clasts of gneisses of high metamorphic grade and the sodic character of the granitic rocks similar to that of associated felsic volcanics were evidence of their essentially volcanic nature. Bass reasoned that a granitic basement which had undergone a previous orogenic cycle should contain a series of granitic intrusions ranging from soda- to potash-rich types. The paucity of potassic granites among the conglomerate clasts, therefore, would weaken the case for a pre-existing granitic basement. Goodwin expressed similar views on the origin of granitic clasts in the conglomerates of the Wawa (1962) and Birch-Uchi Lakes belts (1967). Turner and Walker (1973) believed that the sources of granitic boulders in the Ament Bay Formation of the Sioux Lookout belt were granodiorite intrusions which invaded the underlying volcanics and were exposed by erosion just prior to its deposition. The Ament Bay Formation was shown to overlie an intrusion of quartz porphyry unconformably but not of granodiorite. The principal evidence of attributing the granitic clasts to granodiorite intrusions in the underlying volcanics is the presence of "greenstone" inclusions in a few of the clasts.

Donaldson and Jackson (1965) argued that scarcity of gneissic materials among the granitic clasts of the conglomerates does not preclude their derivation from a pre-existing sialic basement. In a region of about 140 000 km$^2$ in western Ontario with which they were familiar only about 10 per cent of the granitic rocks were sufficiently foliated as to be recognizably gneissic on the scale of conglomeratic clasts. Their scarcity, therefore, might be more apparent than real. Within the same area the majority of the granitic rocks are quartz diorites, granodiorites, and quartz monzonites; potash-rich granites are rare. Subsequent work by Eade and Fahrig (1971) showed that the average composition of the Archean surface over a large part of the shield is that of a granodiorite. Thus the granitic clasts of the conglomerates are little different from those which would be produced from the present Archean terrane.

### Sandstones

Sandstones form the major part of the sedimentary component of the volcanic-sedimentary belts. They are predominantly greywackes in which quartz in a principal constituent. Donaldson and Jackson (1965) report that quartz grains make up between 23 to 71 per cent of greywackes in the North Spirit Lake area with plagioclase the next most abundant of the framework grains. Potash feldspar is generally negligible. Ayres (1974) records a very similar proportion of constituents in the Trout Lakes area where quartz-rich greywackes (36 to 68 per cent quartz) form 60 to 70 per cent of the greywackes present. Potash feldspar is essentially absent. Pettijohn (1970) finds 25 to 41 per cent quartz in greywackes of part of the Sioux Lookout belt. Elsewhere in the Superior Province the other authors mentioned above have also noted the quartz-rich aspect of many of the greywackes.

The quantity of quartz in the sediments increases upward in some sequences; for example, in the Rice Lake belt in Manitoba (Campbell, 1971) and in the Abrams Group in the Sioux Lookout belt (Walker and Pettijohn, 1971). In both these cases the authors attribute the increase to widening provenance from locally derived volcanic sources to distant plutonic terranes.

The quartz content of sediments at North Spirit Lake and at Sioux Lookout, according to Donaldson and Jackson (1965) and Walker and Pettijohn (1971) respectively, is much greater than could be expected from associated felsic volcanic rocks. In addition, many of the quartz grains exceed a millimetre in diameter and are polycrystalline, both properties more typical of the plutonic clasts of the interbedded conglomerates than of the felsic volcanic rocks in the sequence. Accordingly, these authors have looked to a plutonic source for the supply of much of the materials contained in the sediments. Ayres (1969a), on the other hand, has demonstrated that felsic volcanic materials are the principal constituents of Archean sediments in the Lake Superior park area of the Wawa belt. Unquestionably volcanism supplied a major part of the materials for sedimentary rocks of the greenstone belts but variable contributions from a plutonic source may be inferred by the constitution of a great many of these sediments.

## RADIOMETRIC AGES INDICATIVE OF AN EARLY ARCHEAN CRUST

### General Statement

Ages determined on granitic rocks that predate any yet obtained from the Archean volcanic-sedimentary belts must be interpreted as evidence of an early Archean sialic crust. Only a few exist at present (Figs. 2 and 3) and so they provide little information of the possible extent and continuity of such a crust. They do demonstrate however, that the history of the shield did not begin with the volcanism of the greenstone belts.

The Archean gneiss complex of Greenland (which forms the eastern extension of the Nutak Province of Labrador) yields considerable geological and isotopic evidence of the presence of major areas of sialic crust in that region earlier than 2800 m. y. old (*see* summary by Bridgewater *et al.*, in manuscript), i. e. older than the major greenstone belts that are farther west in the Canadian Shield. The Greenland gneiss complex has a long history extending at least as far back as 3750 m. y. and is regarded as having finally consolidated as a cratonic crust around 2700-3000 m. y. ago. Because of the voluminous literature already available on radiometric dating in west Greenland no attempt is made to include these data in this review; rather the reader is referred to the summary report noted above for further information.

### Minnesota River Valley, Minnesota, U.S.A.

The oldest rocks yet found in the Canadian Shield form part of an Archean inlier in Mesozoic terrane about 150 km south of the map-area of Figure 3. The arrow points towards the locality. These are the Morton and Montevideo trondhjemitic and granitic gneisses of the Minnesota River valley dated as 3550 m.y. old by Goldich *et al.* (1970). During the Kenoran Orogeny (2650 m.y.) the gneisses were intensely metamorphosed and widely intruded by granites; 1850 m.y. ago they underwent a further metamorphism of much milder intensity. All three events are preserved in the radiogenic ages obtained from this area but only the U Pb zircon and Rb Sr whole rock ages record the oldest of them. The superposition of three tectonic disturbances, two of which are synchronous with known major orogenies of the Canadian Shield, are indicative of the complexity to be expected in the history of the sialic crust.

### Trout Lakes Area, Ontario

In the Trout Lakes area of western Ontario the North Trout Lake batholith which intrudes the adjoining greenstone belt comprises twenty successive intrusive phases (Ayres, 1974). One of the oldest of these, a trondhjemite, which persists as a shredded remnant in the interior of the batholith, was dated by Krogh and Davis (1971) as 2950 m.y. old. Ayres suggested that it represents part of the basement upon which the volcanic-sedimentary sequence was emplaced.

### Lake Winnipeg, Manitoba

In the vicinity of the Rice Lake volcanic-sedimentary belt of Manitoba, Ermanovics (1971, 1973) found evidence for two superimposed orogenies. The earlier of the two is marked by northwesterly trends recognizable in the gneissic terrane to the north of the Rice Lake belt. The later orogeny of east-west trends involves the Rice Lake belt and is readily identified as the Kenoran Orogeny. The latter clearly truncates the former. Ermanovics suggested that the earlier orogeny predated the deposition of the Rice Lake volcanic-sedimentary succession. Gneisses forming the northwesterly trends are quartz diorites penetrated extensively by granodiorites and quartz monzonites related to the later Kenoran Orogeny.

Uranium lead zircon dating by Krogh *et al.* (in press) corroborates the sequence of events postulated by Ermanovics. Quartz diorite gneisses of the northwesterly-trending domain yielded ages of 2900 m.y. and 3000 m.y. whereas plutons attributed to the Kenoran Orogeny range in age from 2690 m.y. to 2760 m.y. Elsewhere in the Superior Province the volcanic-sedimentary belts have been shown to predate the accompanying intrusions by about 70 m.y. (Krogh and Davis, 1971). Hence, it seems likely that sialic crust existed prior to the emplacement of the Rice Lake succession; whether as a block of limited extent adjoining the Rice Lake belt to the north as postulated by Ermanovics (1973) and Krogh *et al.* (in press), or as a sialic basement beneath the Rice Lake belt, cannot be determined from the evidence at hand.

### Chibougamau Region, Quebec

The Superior Province is truncated on its eastern side by the Grenville Province (Fig. 1). For the most part changes in lithology across the boundary (the Grenville Front) are abrupt, with rocks of low metamorphic grade on the Superior side and high-grade gneisses on the Grenville side. In a few places rocks of the Superior Province can be traced several kilometres into the Grenville Province. One such place is in the Chibougamau region at the eastern end of the Abitibi belt where volcanic-sedimentary rocks of Abitibi-type appear on the Grenville side of the boundary in progressively reduced proportions as the distance from the boundary increases (Frith and Doig, 1975). This is in keeping with the view that the Grenville Province was uplifted relative to the Superior Province. Grey tonalitic gneisses accompanying the volcanic-sedimentary rocks on the Grenville side of the boundary were dated by Frith and Doig using the Rb/Sr whole-rock method. Specimens collected within 50 km of the boundary yielded an age of 3000 m.y. Farther from the boundary where the tonalitic gneisses become increasingly metasomatized the age obtained was 1112 m.y., the age of the Grenvillian Orogeny. Accordingly, Frith and Doig postulated that the grey gneisses represent the basement of the Abitibi volcanic-sedimentary succession and that they were increasingly exposed by the Grenville uplift. Southward they became rejuvenated by the Grenvillian Orogeny and assumed the appropriate Rb/Sr ages.

### Indin Lake Area, Northwest Territories

Grey tonalitic gneisses very similar in appearance to the old gneisses of the Chibougamau region were recognized by Frith *et al.* (1973) in the Indin Lake area of the Northwest Territories (Fig. 2). They adjoin volcanic rocks that make up the lower part of the Yellowknife Supergroup and are folded with it. A preliminary Rb/Sr whole rock isochron yielded an age of 3000 m.y. for the gneisses and Frith *et al.* suggested that they represent the basement of the Yellowknife Supergroup. Dating of other rocks in the area (Frith, 1974) gave evidence of repeated periods of intrusion and deformation in this part of the Shield. Recorded in the various ages obtained are the Kenoran Orogeny (2500-2600 m.y.), a post-Kenoran period of deformation (2200-2300 m.y.) and the Hudsonian Orogeny (1800-1900 m.y.).

## SUMMARY

The major points of this review are :

1) In six widely scattered localities of the Canadian Shield unconformities between Archean volcanic-sedimentary belts and underlying granitoid rocks have

been described or interpreted from the local geology.

2) The sedimentary components in many, if not most, of these belts have in part a granitic provenance as evidenced by the presence of granite-bearing conglomerates and quartz-rich sediments. Both the sedimentary rocks and their granite-derived constituents are found at all stratigraphic levels within the volcanic-sedimentary assemblages but as a rule become increasingly abundant upward in the sequence, commonly culminating in a predominantly sedimentary succession near its top. The latter may or may not be separated from the underlying, predominantly volcanic succession by an unconformity.

3) Radiometric ages derived from granitic rocks in five widely separated localities of the Canadian Shield range from 2900 to 3550 m.y. These predate any yet determined from the Archean volcanic-sedimentary belts of the Shield. This clearly indicates that granitic rocks existed prior to the formation of the greenstone belts.

Supplementary to the above is the observation that in the majority of cases where there is evidence for a granitoid basement its composition is notably poor in potash. Tonalite or quartzdiorite, trondhjemite, and soda-rich granodiorites are generally the basement rocks described.

## DISCUSSION

An early view of the origin of the granitic clasts in conglomerates of the greenstone belts was that they were derived from granitic rocks intrusive into the lower parts of the same assemblages. Deformation associated with the intrusion and subsequent erosion exposed the granites at the surface and provided a source of granitic material for later sediments (cf. Lawson, 1913). These were called the Laurentian granites and they formed the basis for the earlier subdivision of the Archean volcanic-sedimentary belts into Keewatin and Timiskaming divisions. Similar views have been expressed by a number of writers in recent years (e.g. Green and Baadsgaard, 1971); Turner and Walker, 1973; and Elbers and Gilbert, 1972). Following from this hypothesis is the corollary that granite-bearing conglomerates must succeed an unconformity in the Archean sequence. That this is not always so is evident from the stratigraphic tables presented in Table 2. Granite-bearing conglomerates are interbedded with, or lie below, the predominantly volcanic lower part of the succession in the Cross Lake, Oxford Lake-Gods Lake, Rice Lake, Uchi Lake-Birch Lake, Fort Hope, and Rouyn-Noranda regions.

An alternate explanation already discussed is that the granitic clasts are of subvolcanic origin, derived from the volcanic assemblage itself by shallow erosion (Bass, 1961; Goodwin, 1962). This does not accord with the observations by Donaldson and Jackson (1965) and Pettijohn (1970) who find that both the granitic clasts and materials of some of the sediments have characteristics of true plutonic rocks.

Obviously, then, granitic rocks must have been exposed throughout much, or all, of the time that the volcanic-sedimentary sequences were accumulating. This is supported by the radiometric ages which demonstrate the existence in places of pre-volcanic granitoid rocks and by the presence in others of an unconformity between the volcanic-sedimentary sequence and an underlying granite.

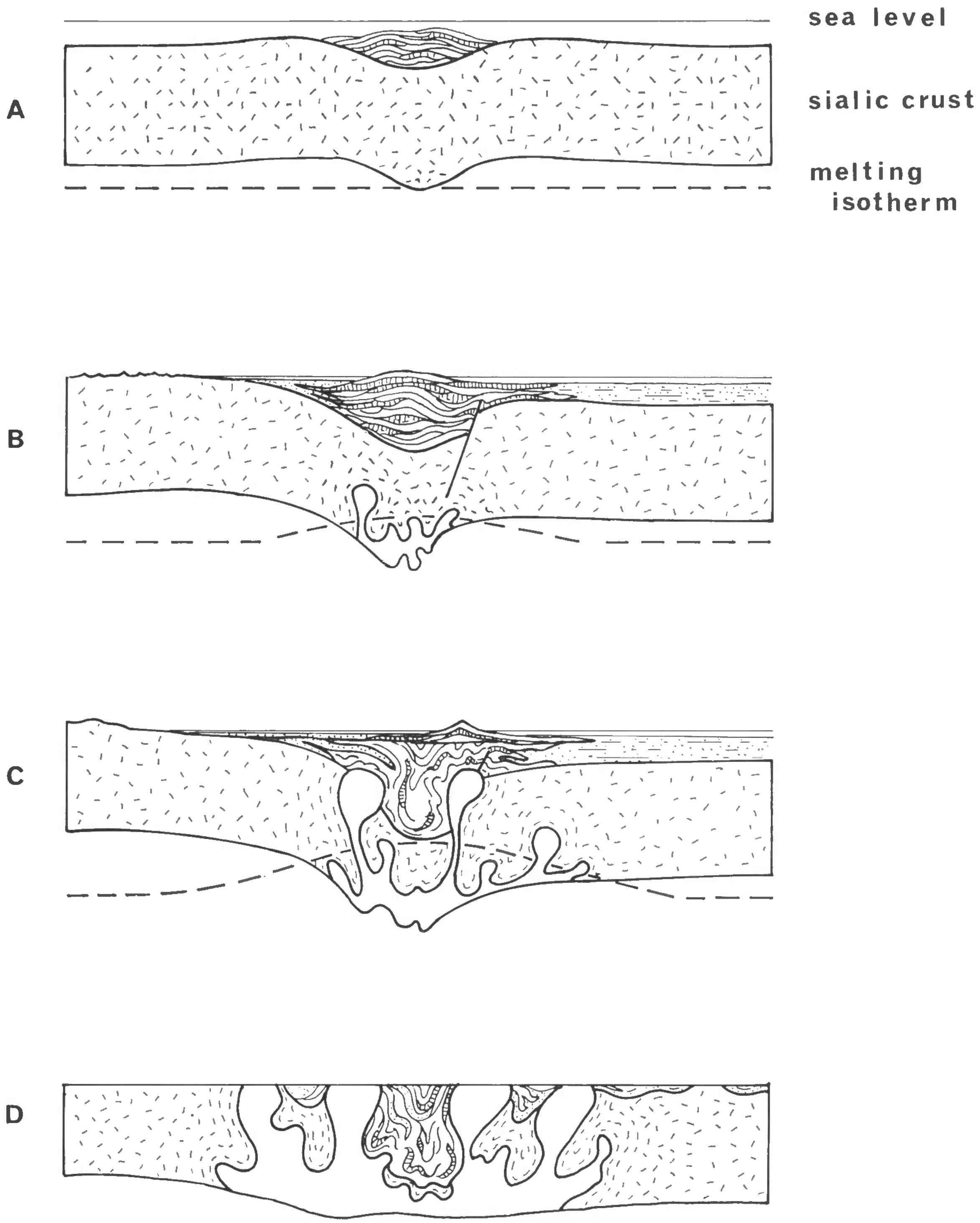
Thus, the sum of evidence favours the view that the volcanic-sedimentary belts succeeded the formation of a granitic crust. It cannot be proved that such a crust was continuous beneath the greenstone belts but the widespread distribution of the evidence for an early crust in the Superior and Slave provinces (Figs. 2 and 3) makes this an attractive hypothesis.

Assuming the existence of a continuous early sialic crust, a model for the development of a typical greenstone belt is illustrated in Figure 8. The crust is presumed to be universal (i.e. worldwide) and, accordingly, much thinner than at present; probably about 15 or 20 km thick. Much of it would be below sea level and hence immune to subaerial erosion. The geothermal gradient, because of the higher level of radioactivity prevailing at this early stage of earth history, would be greater than at present and the temperature at which granitic rocks begin to melt would be reached at much shallower depths (cf. Jacobs *et al.*, 1959). This model is not wholly new but incorporates features expressed in models previously proposed by Anhaeusser *et al.*, 1969, McGlynn and Henderson, 1970, and Pearce (pers. comm., 1974) among others.

In the first illustration (Fig. 8A) a volcanic pile begins to accumulate upon the sialic crust. Because of withdrawal of magma from below and the instability created by denser over lighter material, the crust buckles into the substratum and to some degree spreads laterally. On both sides of the volcanic pile the crust swells into upward bulges. The melting isotherm, the temperature at which sialic material begins to melt, is placed a short distance below the crust.

In the next diagram (Fig. 8B) the volcanic pile has grown to above sea level while the base of the sinking crust has descended into the region of melting. The rise of plutons from the deepest part of the downwarp raises the temperature in the overlying crust and causes an upwarp in the melting isotherm. Sinking of the crust beneath the growing volcanic pile can be accommodated by either flexure in the crust, faulting, or both. In this diagram both are shown. The crust is hinged on one side of the volcanic pile and descends along a fault on the other. The hinged side of the downwarp can continue to swell and flex upward by lateral transfer of material in both crust and mantle whereas the opposite side may be effectively isolated from these movements by the faulting. Thus, sediments from both the emergent crust and volcanic assemblage accumulate in the intervening wedge whereas on the opposite side of the volcanic pile they are mainly of volcanic derivation.

Figure 8C shows a more advanced stage in the development of a greenstone belt. The volcanic-sedimentary assemblage has been deformed by rising



A. Volcanic loading of the sialic crust initiates a downwarp into the mantle.

B. Meltings begins in the downwarp and plutons rise into the crust. Adjoining the volcanic pile on one side the crust emerges above sea level and is eroded; on the other side sinking of the volcanic pile is accompanied by faulting and no upward flexing of the crust takes place.

C. Rising plutons deform the volcanic-sedimentary sequence and it is subsequently overlain by sediments from the emergent crust and new volcanic rocks.

D. The profile of a "greenstone" belt as it might be seen today.

Figure 8. Model proposed for the development of a typical "greenstone" belt.

plutons from the melting zone and subsequently overlain unconformably by an increased volume of sediments from the emergent crust mixed with a reduced contribution from declining volcanic sources.

The last illustration (Fig. 8D) shows a stabilized crust possessing those features which are recognized in the present Canadian Shield: 1) rare unconformities between volcanic-sedimentary successions and earlier granitoid rocks; 2) plutonic intrusives enveloping the greenstone belts; 3) unconformities within the volcanic-sedimentary assemblage; and 4) increasing quantities of sedimentary materials of granitic derivation upward in the stratigraphic sequence.

It must be emphasized that this model is greatly simplified. The effects of tangential movements, such as might be expected from a primitive form of plate tectonics action, have been ignored. Crustal thickening which would be necessary to complete the model has not been shown and only one intrusive phase is represented. In reality the intrusives comprise a succession of phases ranging from potash-poor to potash-rich, possibly the result of successive melting of the early-formed sialic magma.

Finally, a major objection to this type of model – the problem of low initial $^{87}$Sr/$^{86}$Sr ratios common to many Archean plutons – must be considered. Two factors may be of importance in this regard. First, the primitive crust would probably be fractionated to some degree. Potassium and rubidium would be more concentrated in the upper than in the lower levels of the crust. Hence, the augmentation of radiogenic strontium with time in the lower crust would be minimal. Secondly, in the high-temperature environment assumed to prevail at the base of the crust, equilibration of $^{87}$Sr/$^{86}$Sr ratios might be expected to take place across the crust-upper mantle boundary in the manner postulated for a descending oceanic slab by Armstrong (1968). If these postulates are correct plutons derived from melting the base of the crust would be sodic and have a $^{86}$Sr/$^{86}$Sr ratio similar to that of the upper mantle of the time.

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## REFERENCES

Anhaeusser, C.R., Mason, R., Viljoen, M.J., and Viljoen, R.P.
1969: A reappraisal of some aspects of Precambrian Shield geology; Geol. Soc. Am. Bull., v. 80, p. 2175-2200.

Ambrose, J.W.
1941: Cléricy and La Pause map-areas, Quebec; Geol. Surv. Can., Mem. 233.

Armstrong, R.L.
1968: A model for the evolution of strontium and lead isotopes in a dynamic earth; Rev. Geophys. v. 6, p. 175-199.

Ayres, L.D.
1969a: Early Precambrian metasandstone from Lake Superior Park, Ontario, Canada, and implications for the origin of the Superior Province (Abstract); Geol. Soc. Am., Abstr., p. 5.

1969b: Geology of the Muskrat Dam Lake area; Ont. Dep. Mines, Geol. Rep. 74.

1974: Geology of the Trout Lakes area; Ont. Dep. Mines, Geol. Rep. 113.

Baragar, W.R.A.
1966: Geochemistry of the Yellowknife volcanic rocks; Can. J. Earth Sci., v. 3, p. 9-30.

1968: Major-element geochemistry of the Noranda volcanic belt, Quebec-Ontario; Can. J. Earth Sci., v. 5, p. 773-790.

Barry, G.S.
1959: Geology of the Oxford House-Knee Lake area; Manit. Mines Br., Pub. 58-3.

Bass, M.N.
1961: Regional tectonics of part of the Canadian Shield; J. Geol., v. 69, p. 668-702.

Bateman, J.D.
1939: Geology of the North Spirit Lake area; Ont. Dep. Mines, Ann. Rep., v. 47, pt. 7.

1940: Geology and gold deposits of the Uchi-Slate Lakes area; Ont. Dep. Mines, Ann. Rep., v. 48, Pt. 8, p. 1-43.

Bell, C.K.
1962: Cross Lake map-area, Manitoba; Geol. Surv. Can., Paper 61-22.

1966: Churchill-Superior province boundary in northeastern Manitoba; *in* Report of Activities; Geol. Surv. Can., Paper 66-1, p. 133-136.

1971a: Boundary geology, upper Nelson River area, Manitoba and northwestern Ontario; Geol. Assoc. Can., Spec. Paper 9, p. 11-39.

1971b: History of the Superior-Churchill boundary in Manitoba; Geol. Assoc. Can., Spec. Paper 9, p. 5-10.

Bridgwater, D., Keto, L., McGregor, V.R., and Myers, J.S.
The Archean gneiss complex of Greenland; *in* Geology of Greenland, A. Escher and W.S. Watt, (eds.) (in prep.)

Bruce, E.L.
1937: The eastern part of the Sturgeon River area; Ont. Dep. Mines, Ann. Rep., v. 45, Pt. 2, p. 1-59.

Campbell, F.H.A.
1971: Stratigraphy and sedimentation of part of the Rice Lake Group, Manitoba; *in* Geology and Geophysics of the Rice Lake region, Southeastern Manitoba, Manit. Mines Br., Pub. 71-1, p. 135-183.

Campbell, F.H.A., Elbers, F.J., and Gilbert, H.P.
1972: The stratigraphy of the Hayes River Group in Manitoba; Manit. Mines Br., Geol. Paper 2/72.

Davidson, A.
1972: Granite studies in the Slave Province; *in* Report of Activities, Part A, Geol. Surv. Can., Paper 72-1A, p. 109-115.

Donaldson, J.A. and Jackson, G.D.
1965: Archean sedimentary rocks of North Spirit Lake area, Northwestern Ontario; Can. J. Earth Sci., v. 2, p. 622-647.

Douglas, R.J.W.
1973: Geological Provinces of Canada; Dep. Energy, Mines, Resources, National Atlas of Canada.

Eade, K.E.
1975: Geology of the Kognak River map-area, District of Keewatin; Geol. Surv. Can., Mem. 377.

Eade, K.W. and Fahrig, W.F.
1971: Geochemical evolutionary trends of continental plates – a preliminary study of the Canadian Shield; Geol. Surv. Can., Bull. 179.

Elbers, F.J.
1973: Greenstones project; *in* Summary of Field Work, 1973; Manit. Mines Br., Geol. Rep. 2/73, p. 12.

Elbers, F.J. and Gilbert, H.P.
1972: Munro Lake area; *in* Summary of Field Work, 1972; Manit. Mines Br., Geol. Rep. 3/72, p. 39-40.

Ermanovics, I.
1971: 'Granites', 'granite gneiss' and tectonic variations of the Superior Province in southeastern Manitoba; Geol. Assoc. Can., Spec. Paper 9, p. 77-81.

Ermanovics, I. (cont.)
1973: Evidence for early Precambrian Mg-rich crust and 'Pre-Kenoran' sialic crust in northwestern Superior Province of the Canadian Shield; *in* Volcanism and Volcanic Rocks; Geol. Surv. Can., Open File 164, p. 163-176.

Folinsbee, R.E., Baadsgaard, H., Cumming, G.L., and Green, D.C.
1968: A very ancient island arc; Am. Geophys. Union, Geophys. Monogr. 12, p. 441-448.

Fortier, Y.O.
1947: Ross Lake, Northwest Territories; Geol. Surv. Can., Paper 47-16.

Frith, Rosaline
1974: Rb-Sr Geochronological study of rocks of the Bear and Slave Provinces; Northwest Territories MSc. Thesis, McGill University.

Frith, R.A. and Doig, R.
1975: Pre-Kenoran tonalitic gneisses in the Grenville Province; Can. J. Earth Sci., v. 12, no. 5, p. 844-849.

Frith, R.A., Frith, Rosaline, Helmstaedt, H., Hill, J., and Leatherbarrow, R.
1973: Geology of the Indin Lake area (86 B), District of Mackenzie; *in* Report of Activities, Part A, Geol. Surv. Can., Paper 74-1A, p. 165-171.

Goldich, S.S., Hedge, C.E., and Stern, T.W.
1970: Age of the Morton and Montevideo Gneisses and related rocks, southwestern Minnesota; Geol. Soc. Am., Bull., v. 81, p. 3671-3696.

Goodwin, A.M.
1962: Structure, stratigraphy, and origin of iron formation, Michipicoten area, Algoma District, Ontario, Canada; Geol. Soc. Am., Bull., v. 73, p. 561-586.

1967: Volcanic studies in the Birch-Uchi Lakes area of Ontario; Ont. Dep. Mines, Misc. Paper 6.

Goodwin, A.M., Ambrose, J.W., Ayres, L.D., Clifford, P.M., Currie, K.L., Ermanovics, I.F., Fahrig, W.F., Gibb, R.A., Hall, D.H., Innes, M.J., Irvine, T.N., MacLaren, A.S., Norris, A.W., Pettijohn, F.J., and Ridler, R.H.
1972: The Superior Province; *in* Variations in Tectonic Styles in Canada; R.A. Price and R.J.W. Douglas, (eds.), Geol. Assoc. Can., Spec. Paper 11, p. 528-623.

Green, D.C., Baadsgaard, H., and Cumming, G.L.
1968: Geochronology of the Yellowknife area, Northwest Territories, Canada; Can. J. Earth Sci., v. 5, p. 725-735.

Green, D.C. and Baadsgaard, H.
1971: Temporal evolution and petrogenesis of an Archean crustal segment at Yellowknife, N.W.T., Canada; J. Petrol., v. 12, p. 177-217.

Gunning, H.C. and Ambrose, J.W.
1940: Malartic area, Quebec; Geol. Surv. Can., Mem. 222.

Henderson, J.F.
1941: Gordon Lake South, District of Mackenzie; Geol. Surv. Can., Map 645A.

Henderson, J.B.
1970: Stratigraphy of the Archean Yellowknife Supergroup, Yellowknife Bay – Properous Lake area, District of Mackenzie; Geol. Surv. Can., Paper 70-26.

1972: Sedimentology of Archean Turbidites at Yellowknife, Northwest Territories; Can. J. Earth Sci., v. 9, p. 882-902.

1975: Sedimentological studies of the Yellowknife Supergroup in the Slave structural Province; *in* Report of Activities, Part A, Geol. Surv. Can., Paper 75-1A, p. 325-330.

Heywood, W.W. and Davidson, A.
1969: Geology of Benjamin Lake map-area, District of Mackenzie; Geol. Surv. Can., Mem. 361.

Holubec, J.
1972: Lithostratigraphy, structure, and deep crustal relations of Archean rocks of the Canadian Shield, Rouyn-Noranda Area, Quebec; Krystalinikum, v. 9, p. 63-88.

Horwood, H.C.
1935: A Pre-Keewatin(?) tonalite; Roy. Soc. Can., Trans., v. 29, Series 3, Sect. 4, p. 139-147.

Hubregtse, J.J.M.W.
1973: Oxford Lake-Carrot River-Windy Lake area; *in* Summary of Field Work, Manit. Mines Br., Geol. Rep. 2/73, p. 16-18.

Hutchinson, R.W.
1955: Regional zonation of pegmatites near Ross Lake, District of Mackenzie, Northwest Territories; Geol. Surv. Can., Bull 34.

Jacobs, J.A., Russell, R.D. and Wilson, J.T.
1959: Physics and Geology; McGraw – Hill Book Co. Inc.

Krogh, T.E. and Davis, G.L.
1971: Zircon U-Pb ages of Archean metavolcanic rocks in the Canadian Shield; Carnegie Inst. Wash., Yearbook 70, p. 241-242.

Krogh, T.E., Ermanovics, I.F., and Davis, G.L.
Two episodes of metamorphism and deformation in the Archean rocks of the Canadian Shield; Carnegie Inst. Wash., Yearbook 73. (in press)

Lawson, A.C.
1913: The Archean geology of Rainy Lake re-studied; Geol. Surv. Can., Mem. 40.

McGlynn, J.C. and Henderson, J.B.
1970: Archean volcanism and sedimentation in the Slave structural province; *in* Symposium on Basins and Geosynclines of the Canadian Shield, Geol. Surv. Can., Paper 70-40, p. 31-44.

1972: The Slave Province; *in* Variations in Tectonic Styles in Canada; R.A. Price and R.J.W. Douglas (eds.) Geol. Assoc. Can., Spec. Paper 11, p. 506-526.

McRitchie, W.D., Weber, W., and Scoates, R.F.J.
1971: Summary of geological events, front table; *in* Geology and Geophysics of the Rice Lake Region, southeastern Manitoba; Manit. Mines Br., Pub. 71-1.

Milne, V.G.
1968: Geology of Black River area; Ont. Dep. Mines, Geol. Rep. 72.

Pettijohn, F.J.
1970: The Canadian Shield – a status report, 1970; *in* Symposium on Basins and Geosynclines of the Canadian Shield; Geol. Surv. Can., Paper 70-40, p. 239-255.

Prest, V.K.
1939: Geology of the Keezhik-Miminiska Lakes area; Ont. Dep. Mines, Ann. Rep., v. 48, Pt. 6.

1944: Geology of the Fort Hope area; Ont. Dep. Mines, Ann. Rep. 51, Pt. 3, p. 1-28.

Quinn, H.A.
1960: Island Lake, Manitoba – Ontario; Geol. Surv. Can., Map 26-1960.

Rousell, D.H.
1965: Geology of the Cross Lake area; Manit. Mines Br., Pub. 62-4.

Skinner, R.
1969: Geology of Sioux Lookout map-area, Ontario, A part of the Superior Province of the Canadian Shield; Geol. Surv. Can., Paper 68-45.

Stockwell, C.H.
1933: Great Slave Lake – Coppermine River area, Northwest Territories; Geol. Surv. Can., Sum. Rep. 1932, Pt. C, p. 37-63.

Stockwell, C.H. (cont.)
1938: Rice Lake – Gold Lake area southeastern Manitoba; Geol. Surv. Can., Mem. 210.

Stockwell, C.H., McGlynn, J.C., Emslie, R.F., Sanford, B.V., Norris, A.W., Donaldson, J.A., Fahrig, W.F., and Currie, K.L.
1970: Geology of the Canadian Shield; *in* Geology and Economic Minerals of Canadian; R.J.W. Douglas, (ed.), Geol. Surv. Can., Econ. Geol. Rep. 1, p. 44-150.

Turner, C.C. and Walker, R.G.
1973: Sedimentology, stratigraphy, and crustal evolution of the Archean greenstone belt near Sioux Lookout, Ontario; Can. J. Earth Sci., v. 10, p. 817-845.

Walker, R.G. and Pettijohn, F.J.
1971: Archean sedimentation: analysis of the Minnitaki basin, Northwestern Ontario; Geol. Soc. Am., Bull., v. 82, p. 2099-2130.

Wanless, R.K. and Eade, K.E.
1975: Geochronology of Archean and Proterozoic rocks in the southern District of Keewatin; Can. J. Earth Sci., v. 12, p. 95-114.

Weber, W.
1971: Geology of the Long Lake – Gem Lake area, southeastern Manitoba; *in* Geology and Geophysics of the Rice Lake Region, southeastern Manitoba, Manit. Mines Br., Pub. 71-1, p. 63-95.

Wilson, M.E.
1962: Rouyn-Beauchastel map-areas, Quebec; Geol. Surv. Can., Mem. 315.