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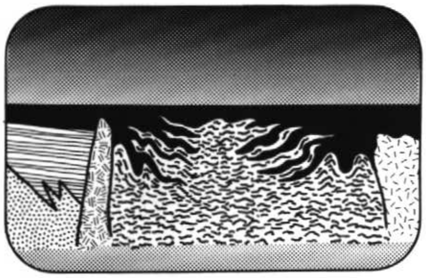
Article abstract

Geophysicists generally agree that one ormore supercontinents were in motion duringthe Proterozoic. A more controversial issueis whether these supercontinents were attimes internally fragmented into smallercrustal units that subsequently collided andsutured in the manner of Phanerozoicplates. Several sutures or join lines betweencollided continental fragments have beenproposed in the Canadian Shield. These areall of Proterozoic age although severalauthors have suggested that some form ofprimitive plate tectonics was operative in theformation of Archean crust of the Superiorprovince. A wide variety of geological andgeophysical evidence has been advancedin support of the proposed sutures. Viewedcollectively, the evidence makes a convinc-ing argument for plate tectonics in theProterozoic. However, it appears that con-clusive evidence for relative motions bet-ween units of the Shield in this period will beforthcoming only from more precisepaleomagnetic and geochronologic studiesof critical rocks



Proterozoic Sutures in Canada

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Summary
Geophysicists generally agree that one or more supercontinents were in motion during the Proterozoic. A more controversial issue is whether these supercontinents were at times internally fragmented into smaller crustal units that subsequently collided and sutured in the manner of Phanerozoic plates. Several sutures or join lines between collided continental fragments have been proposed in the Canadian Shield. These are all of Proterozoic age although several authors have suggested that some form of primitive plate tectonics was operative in the formation of Archean crust of the Superior province. A wide variety of geological and geophysical evidence has been advanced in support of the proposed sutures. Viewed collectively, the evidence makes a convincing argument for plate tectonics in the Proterozoic. However, it appears that conclusive evidence for relative motions between units of the Shield in this period will be forthcoming only from more precise paleomagnetic and geochronologic studies of critical rocks.

Introduction
The role of plate tectonics in the Proterozoic is currently in dispute (e.g., Dewey and Spall, 1975; Briden, 1977; Kröner, 1977). Several authors have attempted to explain the formation of Proterozoic orogenic belts by lithospheric plate subduction and plate convergence; others have argued for ensialic orogeny by crustal reworking and rejuvenation. Paleomagneticians generally agree that the continents were moving in Proterozoic time in much the same way as present day plates. However, one school of thought believes that the bulk of Precambrian shields formed a single Proterozoic supercontinent prior to about 1000 m.y., whereas another believes that several continental blocks were in relative motion and were breaking up occasionally and colliding. These views are important, because the former tends to support the formation of Proterozoic orogenic belts by ensialic processes in an intracontinental domain whereas the latter permits their formation by plate tectonic processes at plate margins and by intercontinental collision. Our purpose here is to focus attention on the growing literature describing proposed Proterozoic sutures in the Canadian Shield, to outline very briefly the types of supporting evidence and to present a schematic map showing their locations (Fig. 1). Several authors have also proposed that some form of primitive plate tectonics was active in the Archean and that evidence of this activity may still be recognized within the Superior province (e.g., Talbot, 1973; Goodwin and West, 1974; Langford and Morin, 1976; Blackburn, 1980). The examples that follow are, however, confined to the Proterozoic. They are grouped in two categories – those located at or near structural province boundaries of the Shield and those within provinces.

Sutures At or Near Structural Province Boundaries
Several authors have suggested that the boundaries between structural provinces of the Canadian Shield (Stockwell, 1970) may be ancient sutures formed by the agglomeration of separate continental fragments. Apparently, the first such suggestion was made by Dietz (1966) who described the Grenville rocks as peripherally emplaced against the older portion of the Canadian Shield. Later Hess also proposed that the "Grenville belt" might be the remains of a continent/continent collision (Vine and Hess, 1968), and Wilson (1968) suggested that the Hudson Bay arc and James Bay might represent the line of junction of two continental fragments that joined together in Precambrian time.

Studies by Gibb and Thomas (1976) suggest that similar gravity signatures across structural province boundaries in the Canadian Shield originate from essentially identical structures formed by plate convergence, cratonic collision, and suturing. Three major geosutures have been proposed, partly on the basis of gravity studies, at or near structural province boundaries; these are the circum-Superior suture at the boundary between the Superior and Churchill provinces, the Grenville suture near the boundary between the Superior and Grenville provinces, and the Thelon suture at the boundary between the Slave and western Churchill provinces. The gravity signature across these boundaries has been explained as an edge-effect between juxtaposed, isostatically compensated crustal blocks of different mean density and crustal thickness (Gibb and Thomas, 1976). A fourth major suture has been proposed, wholly on the basis of geological studies, near the boundary between the Slave and Bear provinces (Hoffman, 1979).

Gibb and Walcott (1971) and Gibb *et al.* (1978) have described the circum-Superior belt as an ancient suture (Ia-e, Fig. 1) on both geological and geophysical grounds. This proposed suture is perhaps the most easily recognized; it is 3200 km in length and extends from the Thompson Nickel Belt (Nelson front) (1a, Fig. 1), across the Hudson Bay Lowlands (1b, Fig. 1) (Gibb, 1975), to the Belcher foldbelt of eastern Hudson Bay (1c, Fig. 1) (Mukhopadhyay and Gibb, 1980) and thence to the Cape Smith foldbelt (1d, Fig. 1) (Thomas and Gibb, 1977a, 1977b), and Labrador Trough (1e, Fig. 1) (Kearey, 1976). It contains distinctive Aphebian (Lower Proterozoic) geosynclinal and oceanic sedimentary, volcanic and ultramafic rocks and their metamorphosed equivalents. Interpretation of this zone as a suture, therefore, depends on the juxtaposition of rocks typical of the plate accretion environment with those developed at continental margins. Baragar and Scoates (1981) give further geological evidence from the composition and distribution of the sedimentary and volcanic rocks, supporting an origin for the circum-Superior belt which is consistent with plate tectonics, although their model is different in detail from previously proposed models. Burke and Dewey (1973) have suggested that reactivated Hudsonian crystalline rocks of the eastern and western Churchill province are analogues of the Tibetan plateau terrain formed by the collision of India and Asia. The eastern Churchill province apparently also has a close analogue in the Central Andes of Peru where the Nazca plate continues to thrust below the South American plate (Thomas and Kearey, 1980; Thomas *et al.*, 1978). This tectonic framework has been used to explain several geological features within the eastern Churchill province and at its boundaries with the older Superior and Nain provinces.

A second major suture has been suggested at or near the Grenville front (2a, Fig. 1). Schenk (1971) suggested that the Atlantic Ocean may have opened and closed several times from the Archean to the present time and that the Grenville province and other Precambrian blocks in the Maritime Provinces may be remnants of an African shelf which was crumpled during an ancient collision, equated with the Grenville orogeny. In a series of fairly recent studies, paleomagnetic poles from the Grenville province have been interpreted in two main ways. Irving *et al.* (1974), for example, favoured a two-plate model in which part of the Grenville province was separated from the rest of the Shield 1150 m.y. ago and then rejoined it about 1000 m.y. ago. This proposal requires that a suture, formed by a dominant strike-slip motion, must lie within the Grenville province, south of a region of Grenville rocks which are considered to be metamorphosed equivalents of rocks within the adjacent, older structural provinces, and north of the sampling sites used to determine Grenville poles (2b, Fig. 1). In this interpretation the Grenville front is not a suture. Despite the lack of surface indications, Thomas and Tanner (1975) have inferred the position of a suture (2c, Fig. 1) within this zone, near the northeastern portion of the front, from a study of gravity anomalies. Earlier, Krogh and Davis (1971) using geological and isotopic age considerations, and Chesworth (1972) on the basis of metamorphic zones had proposed that the southwestern portion of the Grenville front itself is an ancient plate margin or contact. A number of paleomagneticians including Morris and Roy (1977) have questioned the two-plate model and favour a one-plate model. To explain discordant Grenville poles, these authors propose a Grenville loop in a single apparent polar wander (apw) path for North America.

Dewey and Burke (1973) and Baer (1976) also believe that the Grenville front is not a collisional suture because rocks of the Labrador Trough to the north have been traced across the front into the Grenville province; they suggest rather that a Grenville collisional suture (2d, Fig. 1) must lie somewhere to the southeast of present day exposures of Grenville basement. In this model the Grenville front marks the northern limit of reactivated crust. Seyfert (1980) has also postulated that a collisional suture is located at the southeastern margin of the Grenville province. In his model the Grenville province was overriden by Gondwanaland as far as the Grenville front.

A third major suture has been postulated in the vicinity of the Thelon front (3, Fig. 1).

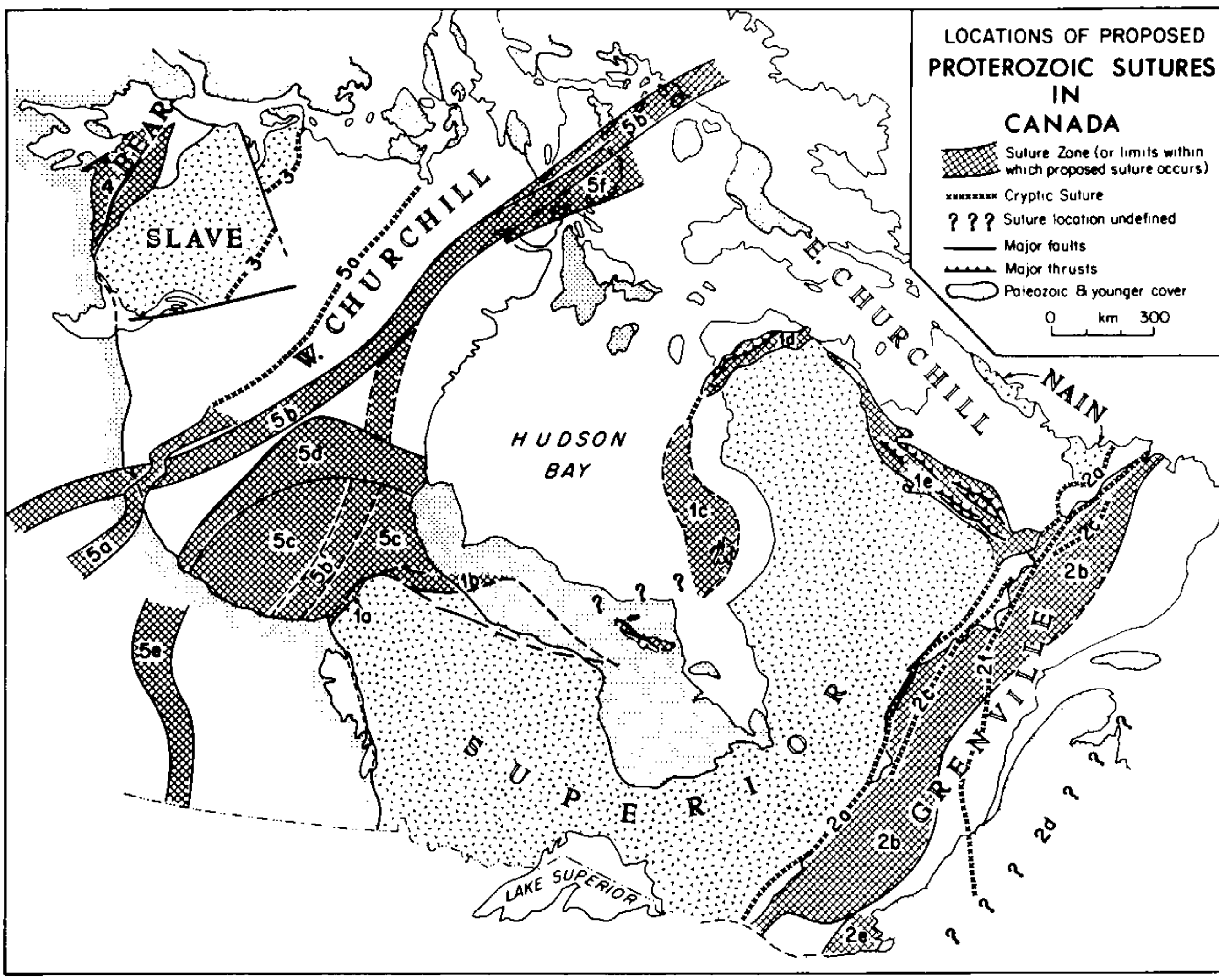

Figure 1
1) Circum-Superior suture: 1a) Nelson front, 1b) Fox River belt and Hudson Bay Lowlands (Gibb, 1975); 1c) Belcher foldbelt (Wilson, 1968, Mukhopadhyay and Gibb, 1980), 1d) Cape Smith foldbelt (Thomas and Gibb, 1977 a,b), 1e) Labrador Trough (Kearey, 1976). 2) Grenville province sutures: 2a) Grenville front (Dietz, 1966; Vine and Hess, 1968, Schenk, 1971, Krogh and Davis, 1971, Chesworth, 1972); 2b) Irving et al. *(1974); 2c) Thomas and Tanner (1975); 2d) Dewey and Burke (1973); Baer (1976); Seyfert (1980); 2e) Brown* et al. *(1975), 2f) Rondot (1978). 3) Thelon front (Gibb and Thomas, 1977). 4) Wopmay orogen (Hoffman, 1973, 1979, Hoffman and McGlynn, 1977; Hoffman* et al.*, 1978; Sutton and Watson, 1974, Burke* et al.*, 1977). 5) Churchill province sutures: 5a) Fond du Lac suture (Walcott and Boyd, 1971) and its northeasterly extension (Gibb and Halliday, 1974). 5b) Cavanaugh and Seyfert (1977), 5b') (revised position) Seyfert and Cavanaugh (1978). 5c) Stauffer (1974), Gibb and Halliday (1974), West in Donaldson* et al. *(1976), Ray and Wanless (1980). 5d) Wollaston foldbelt (Weber in Donaldson* et al.*, 1976); 5e) Camfield and Gough (1977). 5f) Foxe foldbelt (Henderson in Donaldson* et al.*, 1976)*

the boundary between the Slave and Churchill provinces in the Northwest Territories (Gibb and Halliday, 1974; Gibb and Thomas, 1977). According to these authors the Thelon front represents a cryptic suture formed by continental collision much like the proposed suture associated with the Superior-Grenville boundary which has a similar gravity expression and is similarly related to a metamorphic front. Gibb (1978) applied an analogous model of plane indentation (McKenzie, 1972; Tapponnier and Molnar, 1976) to the proposed collision of the Slave craton and western Churchill craton. The model successfully predicted several large scale deformational features of the collision zone and the pattern of deformation within the Churchill province.

The usual approach of paleomagneticians has been to plot poles and apw paths for areas of continental dimensions. In a recent study, however, Burke *et al.* (1976) have used published pole positions to test the conclusion that the Wilson cycle has been in operation since early Precambrian time. They compiled a map showing suture locations and plotted poles for suture-bounded blocks rather than for continents. They predicted, independently of paleomagnetic evidence, when particular oceans had closed to form sutures and compared the results with apw paths for different blocks. In general their predictions for Proterozoic examples were successful. In Canada, they showed that the Slave and Superior cratons had a common apw path after 1600 m.y. but had different paths before that date back to 2700 m.y.

Previously Irving and McGlynn (1976) had argued, from paleomagnetic evidence, against large relative movements between units of the Canadian Shield for the period 2300 to 1850 m.y., however, in a recent review (Irving and McGlynn, 1981), they concluded that the paleomagnetic data for this period are in disarray and that it is not possible at present to determine whether or not the Slave and Superior provinces have common or separate paths of apw. Their paleomagnetic results are consistent with the Shield, except for the Grenville, being a single entity since 1800 m.y., and with the entire Shield being together since 980 m.y.

A fourth major suture (4, Fig. 1) has been proposed near the boundary between the Bear and Slave provinces of the Shield where Hoffman (1973, 1979), Hoffman *et al.* (1978), Sutton and Watson (1974) and Burke *et al.* (1977) have interpreted the Wopmay orogen as a product of Andean-type orogeny or as a product of the Wilson cycle of ocean opening and closing. According to Hoffman (1979), the Hepburn and related batholiths of the Bear province were formed above a westerly dipping subduction zone. Subduction finally led to collision of the Bear microcontinent with the Slave craton and to deformation of the Coronation geosyncline. Following this collison, easterly dipping subduction was initiated at the western margin of the Bear microcontinent and a final collisional suture, cryptically located in the Cordillera, may be related to a conjugate fault system of regional extent (Hoffman, 1979).

Sutures within Structural Provinces

Sutures have also been proposed, partly on geophysical (mainly gravity and paleomagnetic) evidence and partly on geological evidence, within the Churchill and Grenville provinces.

Gibb and Halliday (1974) have suggested that fundamental differences in tectonic style, structure, metamorphism and geophysical signatures in the western Churchill province may be explained in

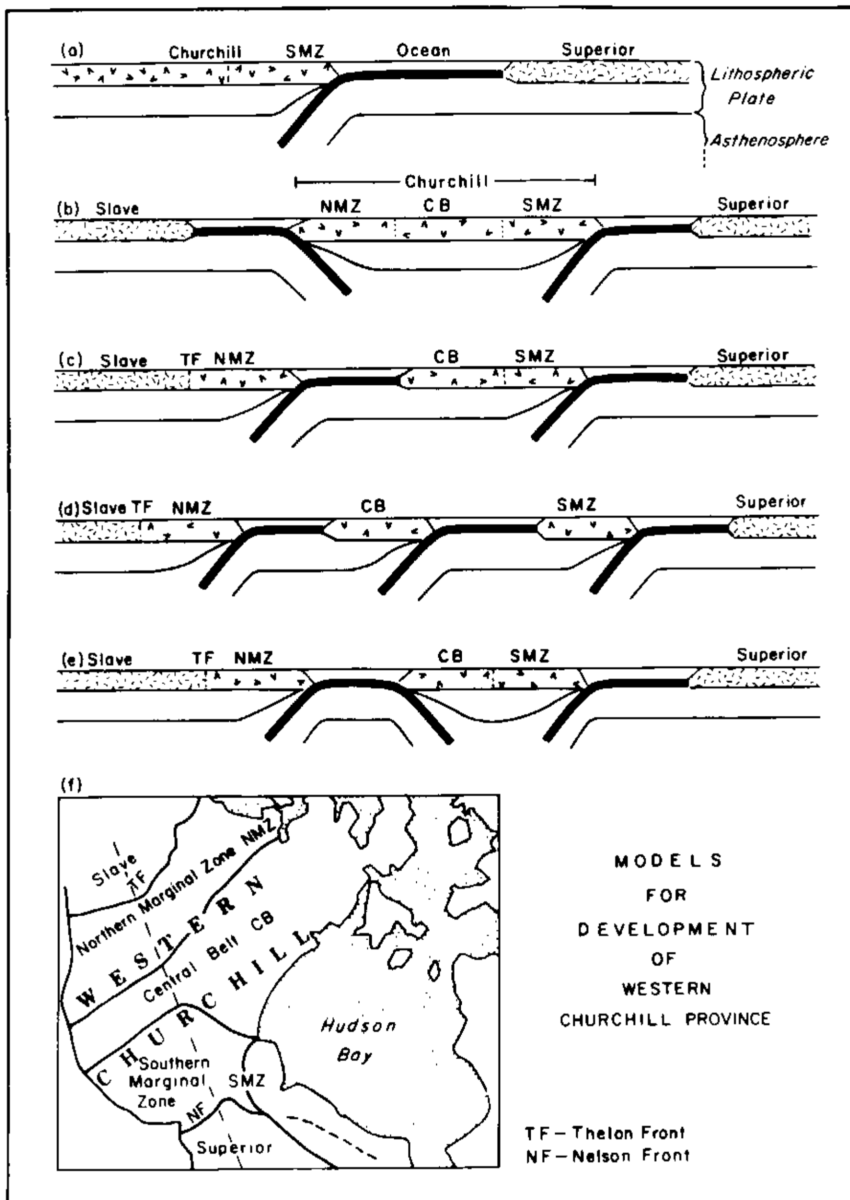

Figure 2

a) Unilateral model for convergence of Superior and western Churchill protocontinents. b) Bilateral model for convergence of both Superior and Slave on Churchill protocontinent. c,d,e) Alternative models in which northern marginal zone is regarded as a deformed part of the Slave protocontinent and in which Churchill is regarded as fragmented. f) Map showing line of sections. Boundaries between provinces and between zones are cryptic sutures or define the limits of overprinting and reactivation above subducted lithosphere (after Gibb and Halliday, 1974).

terms of plate interaction either as a result of northward convergence of the Superior craton (Fig. 2a), or by the convergence of both Superior and Slave protocontinents on the Churchill (Fig. 2b), or by more speculative models for the development of the western Churchill province (Figs. 2c, d, e). A linear belt of negative gravity anomalies, named the Fond du Lac low (Walcott, 1968), flanked by five discrete positive anomalies extends for 400 km from Lisgar Lake in the southwest to Baker Lake in the northeast (Gibb and Halliday, 1974). The tectonic significance of this major lineament is not clear but Walcott and Boyd (1971) and Gibb and Halliday (1974) have suggested that it may mark the site of a suture (5a, Fig. 1). The lineament corresponds at least in part to a major fault zone. In a recent study, Cavanaugh and Seyfert (1977) and Seyfert and Cavanaugh (1978) have suggested that apw paths of the Slave and Superior are independent prior to about 1750 m.y. They found that poles of the northwestern part of the Churchill province lie on the Slave path and poles from the southeastern Churchill, Wyoming, and Nain provinces fall on the Superior path. Thus prior to 1750 m.y. a northern Slave/Churchill plate was separated from a southern Superior/Churchill/Wyoming/Nain plate. According to their interpretation, collision occurred about 1750 m.y. causing orogeny in the western Churchill province. Their proposed line of suturing (5b, b' (revised position), Fig. 1) lies between the Foxe and Committee foldbelts. To the north it extends across Baffin Island and to the south it traverses the western Churchill province near the location suggested by Walcott and Boyd (1971). Roy *et al.* (1978) disagreed with the interpretation proposed by Cavanaugh and Seyfert (1977) preferring a more conservative approach to the selection and interpretation of paleomagnetic poles and a single polar path for the Slave and Superior provinces for the past 2200 m.y.

Within the Churchill province other possible Proterozoic paleosutures have been recognized. The Amisk Group of northern Manitoba has been interpreted as an Aphebian island arc (Stauffer *et al.*, 1975) which may have developed on the western side of the circum-Superior suture, perhaps as one of several subduction zone complexes (5c, Fig. 1) that formed as the Churchill block collided with the older Superior craton (Stauffer, 1974). Later, Weber (in Donaldson *et al.*, 1976) suggested that the Wollaston foldbelt, comprising Archean basement mantled by Aphebian cover rocks, collided with the northwestern edge of the Superior craton during the Hudsonian event (5d, Fig. 1). This resulted in deformation of the Kisseynew gneiss belt interpreted by Weber to be a eugeosynclinal zone of Aphebian volcaniclastic turbidites. Camfield and Gough (1977) have mapped a zone of very high electrical conductivity extending for 1400 km from southeastern Wyoming to the edge of the Canadian Shield in Saskatchewan. They have interpreted it as a major fracture zone in the lithosphere and suggest it may mark the site of a Proterozoic continental collision or geosuture (5e, Fig. 1). At its southern end, Hills *et al.* (1975) claim to have identified a Proterozoic suture zone from a study of the age and composition of the basement rocks. At its northern end the conductive zone is collinear with the Wollaston foldbelt. Ray and Wanless (1980) have also presented a plate tectonic model to explain lithological differences of presumed Aphebian supracrustal rocks in northern Saskatchewan. Their model invokes late Archean – early Aphebian crustal separation and development of an ocean basin. Following a period of spreading and deposition of shelf and deeper water sediments at the opposing continental margins, subduction below an island arc at the northwestern (Wollaston) continental margin was initiated, accompanied by emplacement of granite and acid volcanism. Continued subduction led to closure of the ocean and continental collision. In this model a collisional suture (5c, Fig. 1) is located within the La Ronge domain about 100 km southeast of the Wollaston foldbelt.

The Thompson lineament, the Split Lake lineament and the Kisseynew sedimentary gneiss belt of northern Manitoba have been interpreted as arms of a triple junction that developed above a Proterozoic mantle hot spot (West in Donaldson *et al.*, 1976). In this model the southern and eastern arms did not develop to any great extent but the western arm developed into a wide basin in which the Kisseynew sediments were deposited. Considerable basic volcanism was associated with the rifting before the whole system closed during the Hudsonian orogeny (5c, Fig. 1).

According to J.R. Henderson (in Donaldson *et al.*, 1976), deformation and metamorphism of the Foxe foldbelt of Melville Peninsula could have resulted from collision and suturing (5f, Fig. 1) of two Archean continents during the Hudsonian orogeny. However, this was only one of several possible models proposed to explain this structure.

Other locations have been suggested on geological grounds for sutures within the Grenville province. In their model of tectonic evolution for part of the province in southeastern Ontario, Brown *et al.* (1975) have interpreted geological data in terms of subduction beneath an island arc complex producing calc-alkaline volcanics and granodioritic intrusions followed by later deposition of miogeoclinal sediments. Subsequently the miogeocline was deformed by continental collision. They present evidence for relict oceanic lithosphere preserved in the terrain northeast of Madoc (2e, Fig. 1).

More recently Rondot (1978) has postulated a suture within the Grenville province marked by the La Bostonnais Complex comprising various basic and ultrabasic rocks with the characteristics of an ophiolite assemblage. Rondot views these rocks as possible vestiges of oceanic crust. The proposed suture (2f, Fig. 1) extends for about 2000 km from Groswater Bay in the northeast to Manicouagan Lake and thence south to the Adirondacks.

Concluding Remarks

This brief account of Proterozoic sutures in Canada indicates the considerable number of different sites proposed and the variety of evidence presented in attempts to understand the evolution of the Shield. The proposed sutures range in complexity from wide zones, between collided cratons, containing distinguishable rocks formed originally at plate margins to deeply eroded cryptic sutures (Dewey and Burke, 1973) separating reactivated crust from non-reactivated crust where no trace of a former ocean is preserved. In view of the proliferation of proposed suture sites in the Canadian Shield it is now incumbent on geologists and geophysicists alike to review the validity of these proposals by critical re-examination of the evidence for Precambrian collision orogenies. Important contributions could be made by comparing the essential characteristics of Phanerozoic collision orogenies with suspected Precambrian examples. In our opinion uniformitarian arguments in favour of plate tectonic processes operating during the Proterozoic appear to outweigh arguments to the contrary; there appears to be no incontrovertible evidence to indicate that the tectonic processes that forged Proterozoic mobile belts were any different from those operating in the Phanerozoic. Many authors have examined alternative mechanisms for ensialic orogenesis, but have been forced to conclude that some form of plate tectonic processes may have occurred. In conclusion we agree with Dewey's (1976) succinct statement that "ad hoc non-plate tectonic orogenic mechanisms such as loading and self-melting fail to account for the exceedingly complex time-space templates that characterize the evolution of all orogenic belts", but at the same time it should be emphasized that conclusive evidence for relative motions between cratons or provinces of the Canadian Shield during the Proterozoic must come from more precise paleomagnetic and geochronologic studies of critical rocks.

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