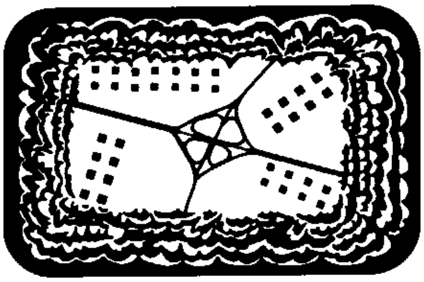

Geology of the Flin Flon Area: A New Look at the Sunless City

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Summary

Although economic development has initiated more geological work in the Flin Flon area than any other part of the Precambrian Shield in Saskatchewan, it is only recently that the detailed geological, geophysical, and geochemical work necessary to gain a firm understanding of the area has begun. The results of this work are far from conclusive at present. However, a tentative geotectonic setting can be interpreted for the development of the area.

During Aphebian time, the Amisk Group of volcanic rocks were deposited as an island-arc complex. Continued closure of the Aphebian "Churchill Ocean" and concomitant subduction zone processes resulted in intrusion, uplift, and formation of the Missi Group of coarse clastic sediments as a molasse deposit. Finally, abutment of this complex with either older Aphebian arc complexes or the Archean Superior Province craton resulted in metamorphism, intrusion, and at least three phases of deformation during the Hudsonian orogeny.

Introduction

Flin Flon, Manitoba takes its name from a turn-of-the-century novel called "The Sunless City". The sunless city was a subterranean wonderland with streets of gold, and the novel so impressed prospector Tom Creighton that when he discovered copper ore in 1915 at what is now the Flin Flon Mine he derived the name of the orebody from the novel's hero, *Flin*tabatty *Flon*atin.

Although geological work in the Precambrian rocks near Flin Flon (Fig. 1) dates back to the early part of this century (Tyrrell, 1902), Bruce (1918) published the first geological map of the area, in which he outlined the now classical Kisseynew (medium-grade metamorphic rocks), Amisk (meta-volcanic rocks), and Missi (meta-clastic sedimentary rocks) Groups (Fig. 2). These are intruded by numerous gabbroic to granitic bodies, most of which are pre- to syn-orogenic. Prospectors previously had found encouraging sulphide showings, and in 1917 the Mandy Mine was opened; later, in 1930, the Hudson Bay Mining and Smelting Co. began to exploit the Flin Flon Copper-Zinc ore body. Since then, numerous smaller mines have been opened in a 180-mile long belt from Flin Flon to Snow Lake, most of which are in the Amisk Group.

Economic development has acted as a catalyst for geological work, and Bruce (1918) was followed by numerous other geologists, notably Ambrose (1936a, and 1936b), Stockwell (1960), and Byers *et al.* (1965). A complete list of references up to 1965 is given by Byers *et al.* (1965). Most of this work was restricted to rock-type mapping, preliminary thin-section petrology, and reconnaissance structural mapping. As a result, all the major rock types and some of the major structures were identified. Also, the general depositional, intrusive, and orogenic histories, and concepts of ore genesis were worked out, although these are being modified and elaborated on at present.

Since the middle 1960s, work has included detailed structural analysis and stratigraphy, gravimetry, seismology, and geochemistry. The purpose of this paper is to outline the results of such work done to date and to speculate on the geotectonics of the region.

In the immediate vicinity of Flin Flon, the Amisk and overlying Missi

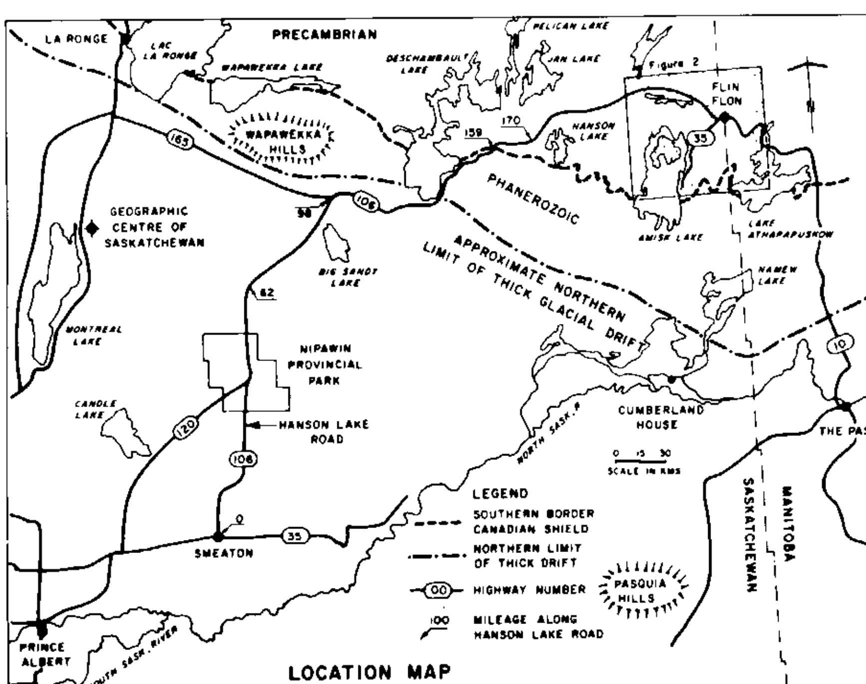


Figure 1

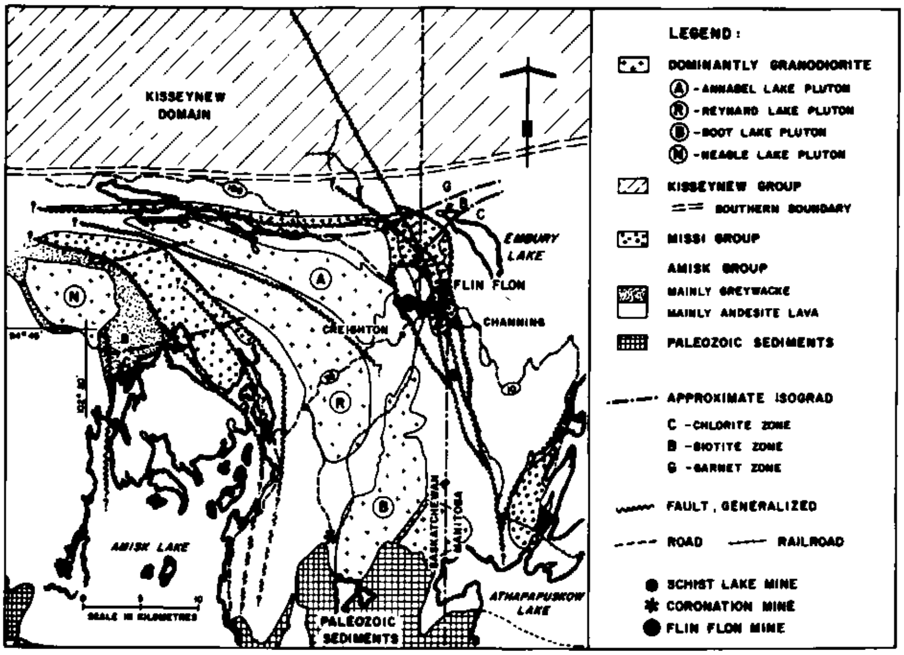


Figure 2
Geological Map of Flin Flon – Amisk Lake – Athapapuskow Lake area.

Groups have been subjected to low-grade metamorphism and at least three phases of locally intense deformation (Stauffer and Mukherjee, 1971). Although the ages of these rocks are uncertain as yet, they appear to be Aphebian (Mukherjee *et al.*, 1971). Major granitic intrusion, metamorphism, and all three phases of folding probably occurred during the Hudsonian Orogeny (Mukherjee *et al.*, 1971). The geological history is shown in chart form on Table I, although some aspects of the chart are subject to future modification.

North of Flin Flon, the Kisseynew rocks are even more complexly deformed and more highly metamorphosed (Pearson, 1972). Stratigraphic and tectonic relationships with the Amisk and Missi Groups are not yet clear; however, as no new data is available at this time, the Kisseynew is not discussed further in this paper.

In the following discussion, the Amisk Group is discussed first, the Missi Group second, the orogenic history and metamorphism third, and the intrusive rocks fourth. This is followed by a section on geophysical attempts to determine something about the shape and structure of the various rock groups. The final section describes a highly speculative geotectonic history of the region.

Almost all the rocks have been metamorphosed, but in most places the original lithology is discernible. Because of this, the prefix "meta" is left off the rock type names throughout this paper.

Table I

Event or Environment	New Rock Group	New Rock Type
HUDSONIAN OROGENY (metamorphism, P2, P3 and probably P1 deformation phases)	4th Intrusive Group (1800 m.y.)	large granodiorite stocks, small diorite to felsic dykes and stocks
FLUVIATILE	Missi Group (probably Aphebian)	arkosic sandstones and polymictic conglomerate
Disconformity		
UPLIFT ↑	3rd Intrusive Group 2nd Intrusive Group 1st Intrusive Group	granitoid complex hypabyssal dykes and sills gabbro to tonalite stocks
ISLAND-ARC	Amisk Group (possibly Aphebian)	mainly andesitic volcanic rocks

Amisk Group

Between Flin Flon and the western side of Amisk Lake, the Amisk Group is at least 9,000 m thick, although the base is not exposed. It consists of about 80 per cent andesitic lava flows and pyroclastics, 10 per cent dacites to rhyodacites, <5 per cent basalts, and <5 per cent rhyolites. Greywacke beds (turbidites) occur throughout the group but most common near the top (Byers and Dahlstrom, 1954). Porphyritic pillow lavas are the most common single rock type, followed by massive flows and agglomerates; tuffs, flow breccias and volcanogenic (greywacke-turbidite) sediments are less common.

The range in rock types and volcanic structures discussed above indicates a dominantly marine, possibly island-arc environment of deposition. This is substantiated by the "island-arc tholeiitic series" geochemistry found by Stauffer *et al.* (in press).

Preliminary Rb/Sr dating of the Amisk Group has yielded an age of 1775$\pm$ 89 m.y. (Mukherjee *et al.*, 1971). However it is not yet clear whether this is the age of volcanism or is a metamorphically updated age. Sangster (1972) obtained a Pb/Pb model age of 1850$\pm$44 m.y. from the Flin Flon ore body, a volcanogenic sulphide deposit within the Amisk Group (Koo and Mossman, in press). This appears to substantiate an Aphebian age for Amisk volcanism; however, it is possible that Pb was remobilized during metamorphism, in which case the model age is not a valid age of volcanism.

The Amisk Group is intruded by a wider range of intrusive rock types than is the Missi Group. Some of these intrusions are probably associated with Amisk volcanism, but will be discussed later.

Missi Group

The Missi Group crops out in three major structural basins (Fig. 2) and in numerous minor fold and fault inliers. It consists of up to almost 2700 m of mainly medium- to coarse-grained, subarkosic sandstones with polymictic pebble-to-boulder conglomerates, minor greywacke, and very minor quartzite. Rocks within the Group vary from thin bedded to massive, and are locally intensely cross-bedded.

This Group lies with disconformity (possibly angular unconformity) on the Amisk Group, and a pre-Missi weathered zone is exposed in several places along the contact. In some places, even where there are no faults, bedding within the two groups is discordant; however, this is probably the result of either original lack of horizontality or minor tilting of the Amisk volcanics during the uplift that must have occurred prior to Missi sedimentation. Amisk and Missi rocks appear to have had the same history of folding, faulting, and metamorphism (Byers and Dahlstorm, 1954; Mukherjee, 1971); thus no major angular unconformity appears to exist between them.

Stratigraphic position within the Missi can be roughly determined from the proportion of clasts (all fragments larger than sand-sized) to sand, and from the ratio of mature clasts (quartz, chert, felsic igneous rock types) to immature clasts (mainly intermediate to basic igneous rock types). On these criteria, the Missi Group can be sub-divided into two tentative "Formations" and five tentative "members" as outlined below in a preliminary table (Table II and Fig. 3; formal formation and member names will be proposed in a later paper). This stratigraphic subdivision is based on sections measured in the Flin Flon Basin but is consistent with sections measured at the north end of Amisk Lake and at Athapapuskow Lake.

Both the A and B Formations decrease upwards in overall grain size, and increase in maturity of clasts. They are probably best interpreted as alluvial fan to alluvial plain deposits, as indicated by the lensing nature of

Table II
Stratigraphy of the Missi Group

FORMATION B member 5 (min. 350 m)	Mainly pebbly arkose. Clasts approx. 15% of volume and are of variable proportions but approx. average 1:1 mature to immature.
member 4 (10-80 m)	Mainly cobble conglomerate, clasts 60% of volume, and average approx. 1:1 mature to immature.
FORMATION A member 3 (900-1400 m)	Mainly arkose, with some quartzite and rare pebble beds. Pebbles approx. 1% of volume, and average approx. 3:1 mature to immature.
member 2 (60-700 m)	Mainly pebbly arkose. Clasts average approx. 15% of volume, and are of variable proportions but average approx. 1:1 mature to immature.
member 1 (0-150 m)	Mainly cobble conglomerate. Clasts approx. 60% of volume, and are 1:3 mature to immature.
Disconformity AMISK GROUP	

the beds, their overall arkosic composition, the variation in sorting from good to poor, and the array of sedimentary structures they contain (i.e., small- to medium-scale cross-bedding, scour and fill structure, graded bedding, and some reversed-graded bedding; but no ripple marks or flute casts). The thickness of the Missi Group suggests that it may have been deposited as a molasse deposit in either an active graben structure, at the front of an active tectonic mountain belt, or within an intermontane basin. Each formation may be the result of renewed uplift in the source area which probably lay to the west (the group appears to thicken westward). The source area was largely composed of the Amisk Group (about 75 per cent of the clasts in the Missi are of Amisk type lithologies), but must have included a complex variety of other rock types because there are also clasts of granite, granitic gneiss, amphibolite, rare taconite iron formation, and in some places chert and jasper (especially at Athapapuskow Lake), as well as clasts of vein quartz and Missi-type lithologies. The jasper and taconite clasts are of considerable interest because massive Precambrian metamorphosed iron formation (mainly hematite and quartz) has been found in subsurface under nearly 2/3 km of Phanerozoic cover about 200 km southwest of Flin Flon. This may corroborate the previous interpretation of a general westerly source for the Missi Group.

The high hematite and magnetite content of the Missi Group is also of special interest. Some sandstone beds contain as much as 30 percent euhedral to subhedral black iron oxide grains, mostly concentrated in laminae or thin beds, although some fill small veinlets. The overall concentration of these iron oxides is difficult to determine, but is about 3 per cent of the total volume of the Missi Group. At Athapapuskow Lake, some of the nearly unmetamorphosed sandstones have red earthy ferruginous cement. This appears to indicate that the Missi Group was deposited as a red bed in an oxygen-bearing environment and that the original ferruginous cement has been metamorphically recrystallized over most of the area.

Tectonic and Metamorphic History

Although some small amount of faulting, perhaps some tilting, and possibly minor folding occurred in the Amisk volcanics prior to Missi sedimentation, most of the folding and faulting, and apparently all of the metamorphism occurred after Missi deposition, during the Hudsonian Orogeny (Mukherjee *et al.*, 1971).

Tectonic deformation in the Missi Group near Flin Flon can be divided into three sequential phases (Stauffer and Mukherjee, 1971) and each phase is represented by a particular style of structure (Fig. 3).

Phase 1 (the earliest) – tight folds that probably originally trended approximately E-W and had moderate- to steeply-dipping axial planes (no metamorphic effects are observable).

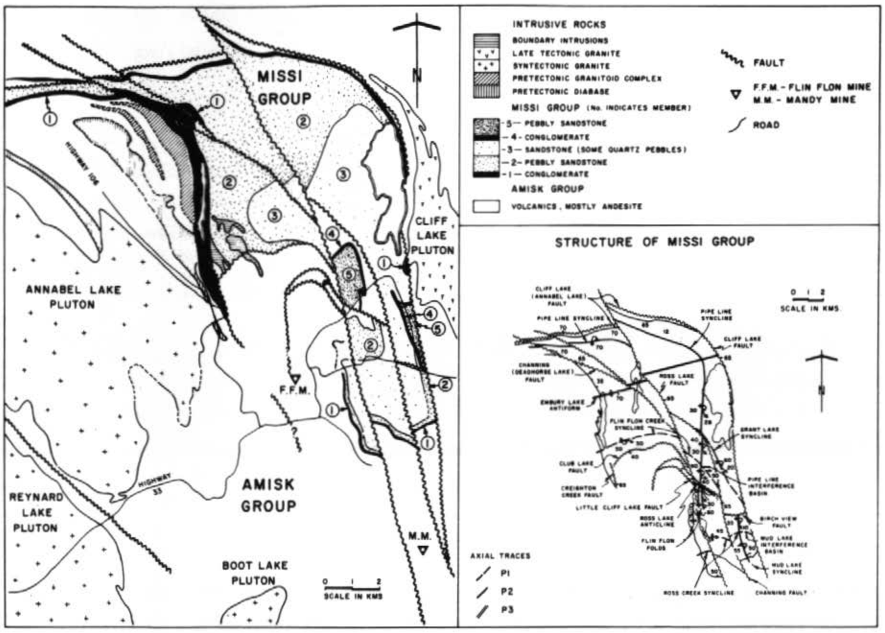
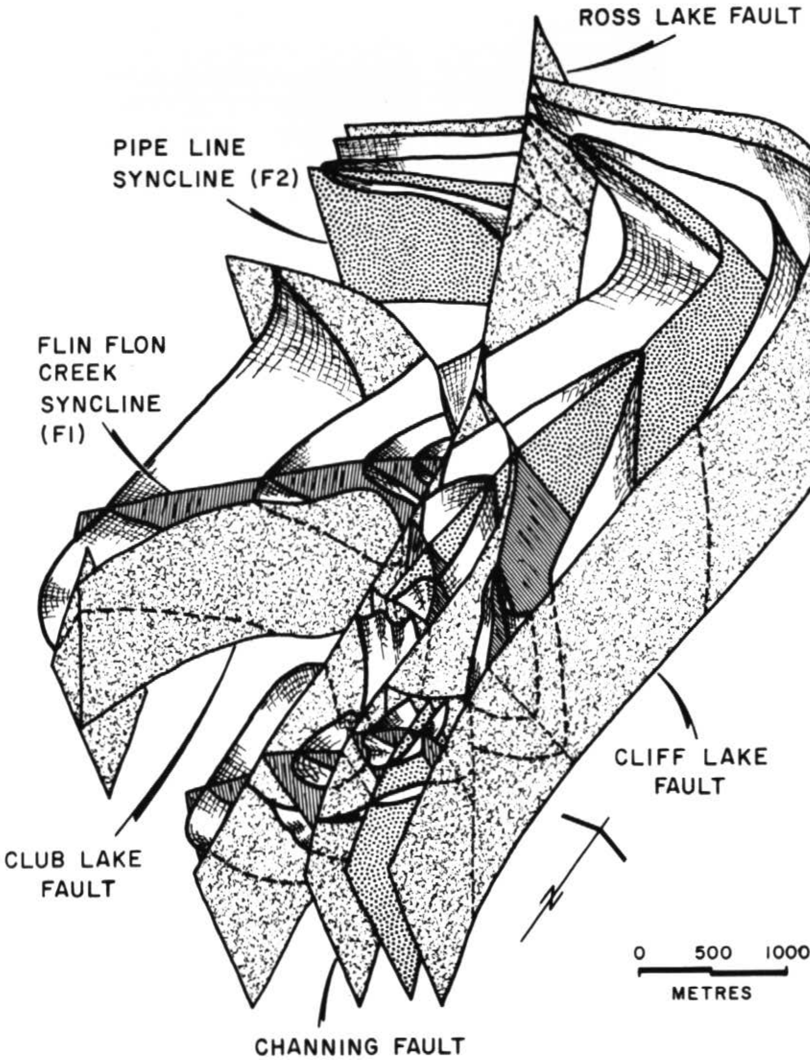


Figure 3
Flin Flon Basin.



Phase 2 – tight folds (mainly synclinal in this area), with moderately dipping, originally N-S trending axial planes, these refold Phase 1 folds and as a result both F1 and F2 fold axes vary considerably in plunge from place to place; progressive metamorphism increases from chlorite grade in the south to garnet grade in the north (Fig. 2), schistosity parallels axial planes, well-developed lineation due to stretching of pebbles and sand grains (especially in the north).

Phase 3 – one large, open fold (the Embury Lake antiform, Fig. 3) plus possibly all the faults and some minor folding along fault zones; chlorite-grade alteration along fault zones, and shear foliation that locally obliterates the P2 schistosity; the Embury Lake fold causes P2 structures to bend to the west in the northwestern part of the area. (Fig. 3) and it is one of a series of very large folds that trend NE-SW that may be seen on the geological map of Saskatchewan between Flin Flon and Reindeer Lake.

The three dimensional structure of the Flin Flon Basin is shown in Figure 4. So far, no folds or faults have been found in the Amisk Group that cannot be ascribed to one of the above phases determined in the Missi Group. Thus, even though Amisk and Missi strata are oblique to one another in some places, there is no compelling evidence to indicate a major pre-Missi orogenic event.

Also, all three deformational phases have been recognized in the Missi Group at Athapapuskow Lake, and phases 2 and 3 structures have been mapped at the northern end of Amisk Lake; these will be fully described in a later paper.

Regional metamorphism associated with phase 2 deformation varies from almost none in some places at

Figure 4
Three-dimensional sketch of the Flin Flon Basin. Surfaces with irregular stippling are faults; lined surfaces are axial planes of F1 folds; stippled surfaces are axial surfaces of F2 folds; unshaded surfaces are bedding form-surfaces, the outermost of which represents the base of the Missi Group (Redrawn from Stauffer and Mukherjee, 1971).

Athapapuskow Lake to the almandine-amphibolite zone just south of the amphibolite gneisses of the Kisseynew domain (Fig. 2). Approximate isograds are shown on Figure 2, and although these are based mainly on metamorphic mineral assemblages within the Missi Group, they can be mapped through the Amisk andesites. The large syntectonic (P2) granodiorites have metamorphic halos of up to nearly two km in the case of the eastern Boot Lake pluton (Heywood, 1966), but these effects have been ignored in drawing the isograds shown in Figure 2.

This regional metamorphism appears to have been essentially isochemical as there is no discernible variation in the chemical compositions of Amisk andesites within the various metamorphic zones (Stauffer *et al.*, in press).

Metamorphism in the P3 fault zones has resulted in locally intense chloritization, concomitant with considerable elemental remobilization in the Amisk rocks (Stauffer *et al.*, in press).

Intrusive Rocks

Intrusive rocks in the Flin Flon region can be categorized into four groups on the basis of lithology, cross-cutting relationships, xenolith compositions, and metamorphism (Table I). The three oldest groups are pre-Missi and pre-P2 tectonic. The youngest (and major) group is post-Missi and although mostly syn-P2 tectonic varies to possibly post-P3 tectonic.

Small irregular stocks of gabbro to tonalite that intrude Amisk volcanic rocks comprise the oldest group. A part of the Boot Lake Pluton (Fig. 2) belongs to this group, although most of the pluton is younger. In many places, these contain a metamorphic foliation that is parallel to the regional P2 metamorphic foliation. Numerous hypabyssal (mainly diabase) intrusions cut these stocks as well as the Amisk volcanic rocks, and comprise the second group of intrusive rocks. The larger two of these crop out NE of the younger Annabel Lake pluton (Fig. 3). These also contain P2 foliation. The third group of intrusive rocks is represented by a heterogeneous granitoid complex that crops out just west of the Flin Flon Basin (Fig. 3). This complex cuts the hypabyssal rocks and also contains P2 foliation. It is nonconformably overlain by the Missi Group, thus it and the older two intrusive groups are pre-Missi as well as pre-P2 tectonic. As yet, it is unknown whether any of these three groups are related to Amisk volcanism. The fourth group includes all post-Missi intrusive rocks: the subbatholithic Annabel Lake and Reynard Lake plutons (Figs. 2 and 3), the Neagle Lake pluton, most of the Boot Lake pluton, the Boundary Intrusions of Stockwell (1960), and numerous small porphyritic felsic dykes. The plutons are dominantly composed of granodiorite, whereas the Boundary Intrusions are small bodies that range in composition from ultramafic to granitic. Some of the intrusions belonging to this group are highly P2 foliated, some contain no foliation, and a few contain a primary flow foliation oblique to the surrounding metamorphic foliation.

The age of the Cliff Lake pluton (Fig. 3) is not yet firmly established and it may belong to either the first or fourth groups discussed above.

Petrologic, geochemical, and geochronological work is presently being done on these intrusive groups and the results of this, as well as formal rock groups names, will be presented in later papers.

Radiometric dating has been attempted on rocks belonging to the post-Missi group of intrusions. K/Ar dates on two members of this group average 1785 m.y. (Lowdan *et al.*, 1963; Wanless *et al.*, 1965). A Rb/Sr date of 1805 was obtained from late phase rocks of the Annabel Lake pluton (Mukherjee *et al.*, 1971), and a preliminary Pb/Pb age of 1835 m.y. has been obtained by combining samples from several bodies belonging to this group (R. McQuarrie, pers. comm.). This clearly establishes metamorphism, intrusion, and at least the P2 and P3 phases of deformation as being Hudsonian. The pre-metamorphic P1 deformational phase is not suitably dated by the above ages.

Geophysics

Gendzwill (1968a and b) attempted to determine the depth to the bases of the Amisk Group and various large plutons in the area. Among the more interesting conclusions of his study are: a) the Amisk Group is floored by less dense material at depths between three and five km (the depth does not appear to be controlled by any of the large folds); and b) the granodioritic plutons exposed at the surface are floored at shallow depths by more dense (probably Amisk volcanic) rocks.

There are many ways to interpret the surprisingly shallow 3-5 km depth for the base of the Amisk Group; among those thought most probable are: a) the underlying material is a pre-Amisk sialic crust; b) the underlying material is a large batholith (in which case the various syn-P2 tectonic plutons could be cupolas to it); and c) the underlying material consists of Amisk rocks that are either granitized or so highly intruded by felsic bodies that their overall density has been lowered significantly.

Hajnal and Stauffer, in an attempt to adapt seismic reflection techniques for subsurface mapping in the Canadian Shield, have been able to map subsurface sections of the folded unconformity between Amisk and Missi rocks, and have traced one fault to a depth of over one km. This work is being extened to other rock bodies in the area, and may prove useful for mapping strataform ore deposits. Papers describing this work will be published in the near future.

Irving and Park (personal communication) are studying various aspects of rock magnetism between Flin Flon and Hanson Lake.

Geotectonic History

Gibb (1971) suggested that the Slave Province was located in the great arc of eastern Hudson Bay during Kenoran time (2490 m.y. ago), and that the Slave and Superior Provinces drifted apart during Aphebian time, with an oceanic crust developing between them. The Churchill Province then formed by accretion of new material and the coalescence of older crustal fragments during subsequent closure (Hudsonian Orogeny) of this Aphebian ocean.

Gibb's model predicts lithospheric consumption and the formation of island-arcs during the closure stage of this Aphebian ocean, particularly within the Churchill province near its contacts with the Slave and Superior Provinces.

The interpretation of the Amisk Group as an Aphebian island-arc deposit (Stauffer *et al.*, in press), is consistent with Gibb's model. According to this hypothesis, the Amisk island-arc developed on the western side of the Moak Lake-Kettle Rapids suture zone that marks the contact between the Churchill and Superior Provinces (Gibb and Walcott, 1971), perhaps as one of several subduction zone complexes that formed as the developing Churchill Province collided with the older Superior craton.

The initial abutment of the Amisk island-arc against older material may have resulted in uplift, erosion, and subsequent deposition of the fluviatile Missi Group. Further abutment resulted in deformation and metamorphism, concomitant with intrusion of the granodiorite plutons. The sequence of events appears similar to that ascribed by Dewey and Bird (1970) to mountain building resulting from the collision of an island-arc with an older craton.

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