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Buried Precambrian Basement in South-Central Saskatchewan: Provisional Results from Sm-Nd Model Ages and U-Pb Zircon Geochronology[1]

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Sm-Nd isotopic data from Precambrian basement terrains have allowed constraints to be placed on the time of separation of continental crustal components from their mantle source regions (e.g., McCulloch and Wasserburg, 1978; Allegre and Ben Othman, 1980; DePaolo, 1981; McCulloch and Compston, 1981; Collerson and McCulloch, 1982; Patchett and Bridgwater, 1984; Wilson et al., 1985; Patchett and Kouvo, 1986; Chauvel et al., 1987). Such studies in Early Proterozoic orogenic belts have permitted distinctions to be made between reworked Archean crust and crust formed by the accretion of juvenile (short-lived, mantle-derived) magmatic arcs (Patchett and Bridgwater, 1984; Patchett and Kouvo, 1986).

1. Background to Present Study

Comprehensive U-Pb zircon geochronological studies in the eastern part of the Thelon Segment (Reindeer Zone) of the Trans-Hudson Orogen in Saskatchewan by Van Schmus et al., (1987a) and Lewry et al., (1986) have demonstrated that lithotectonic belts southeast of the Wathaman Batholith (Lewry et al., 1985) were formed largely by accretion of juvenile volcanic and magmatic arcs, and by docking of suspect terrains during a very short time interval (ca. 1830 to 1890 Ma). Reconnaissance Nd and Pb isotopic data for these juvenile terrains (Chauvel et al., 1987; Thom et al., 1987) indicate that some of them contain an older (Archean) crustal component. Evidence of this component appears to increase systematically from the La Ronge magmatic arc in the southeast to the Wathaman Batholith in the northwest. These isotope systematics are interpreted to reflect mixing between juvenile Proterozoic crust and variable amounts of Archean crust, via sedimentary and volcanoplutonic processes. In contrast, terrains west and northwest of the Wathaman Batholith are interpreted on geological evidence as containing substantial amounts of variably reworked Archean crust (Lewry et al., 1985). This area is considered to have been a relatively coherent cratonic platform while late Early Proterozoic crust was forming in the Reindeer Zone of the Trans-Hudson Orogen (Lewry et al., 1985).

Geological relationships in the La Ronge, Glennie and Kisseynew Domains of the Reindeer Zone have recently been interpreted as reflecting thin-skinned tectonic activity driven by crustal shortening during orogeny (i.e., the development and transportation of complex allochthonous fold/thrust stacks and fold nappes). Chiarenzelli et al. (1987) and Lewry et al. (in press) have shown that windows of Archean gneisses are exposed at lowest structural levels within the Glennie Domain and Hanson Lake Block. These important relationships indicate that much of the southeast part of the Reindeer Zone may be underlain by Archean crust that was overridden by allochthonous juvenile Proterozoic crust subsequent to arc formation during terminal collision within the orogen.

The almost entirely unexposed "Dakota Segment" of the Trans-Hudson Orogen extends southwards from the exposed Precambrian Shield through central and southern Saskatchewan into Montana and the Dakotas. An understanding of the geological evolution of this segment of the orogen is therefore of critical importance for tectonic models to explain the configuration of the North American Craton during the Early Proterozoic (cf. Hoffman, 1988). Previous petrological and geochemical studies of basement specimens recovered from drill core in this region have been carried out by King (1966), Burwash and Culbert (1976), Burwash and Cumming (1974), Burwash and Krupicka (1969, 1970), Burwash et al. (1962, 1973), Rosholt et al. (1970), Peterman and Hedge (1964), and Peterman and Goldich (1982).

2. Objectives of Present Study

We are currently re-examining basement core samples from central and southern Saskatchewan so as to interpret them in the context of: 1) established lithotectonic elements of the exposed Shield to the north (Lewry, 1981, 1984; Lewry et al., 1985; Lewry and Collerson, in press); 2) U-Pb zircon geochronology (Van Schmus et al., 1987a); 3) Sm-Nd and Pb systematics for rocks from the Thelon Segment of the Trans-Hudson Orogen in northern Saskatchewan (Chauvel et al., 1987; Thom et al., 1987; Collerson et al., in prep); and 4) available subsurface geophysical data (Dutch, 1983; Arvidson et al., 1984; Green et al., 1985a,b; Klasner and King 1986)). This report gives provisional results of a U-Pb zircon and Sm-Nd isotopic and petrographic study of selected

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core samples. It provides information on the time of separation of the protoliths of the basement rocks from their mantle source region and their subsequent crustal evolutionary histories. Results will complement studies of the basement of the Western Canadian Sedimentary Basin in Alberta and southern British Columbia (Frost and O'Nions 1984; Ross et al., 1988), and should also provide a more complete understanding of the geological evolution of the concealed mid-continental region of the North American Craton (cf. Peterman, 1981; Nelson and DePaolo, 1985; Van Schmus et al., 1986; Sims and Peterman, 1986; Frost and Burwash, 1986; Peterman and Futa, 1987).

3. Methods of Study

Polished thin sections of cored basement rocks were examined to assess the degree of alteration, rock type and metamorphic grade. This initial petrographic investigation was carried out in order to determine the extent to which basement rock types could be correlated with lithotectonic elements in the exposed Precambrian Shield, thereby allowing an assessment to be made by Green et al. (1985a and b) of basement structure based on geophysical data. Despite the small data base compared to the northern Shield, several interesting features were identified which are discussed below in terms of broad geographic subdivisions.

U-Pb analyses on zircons separated from small splits of core were carried out using standard techniques of U-Pb geochronology in the Isotope Geochemistry Laboratory at the University of Kansas (Van Schmus et al., 1987a). Ages were calculated using the decay constants recommended by Steiger and Jager (1977).

Sm-Nd separation chemistry was carried out at the University of California, Santa Cruz and mass spectrometric measurements were made at the U.S. Geological Survey, Menlo Park. Sm-Nd isotopic analyses were undertaken using procedures described by McCulloch and Chappell (1982). Samples weighing 70 to 100 mg were spiked with a mixed $^{149}Sm/^{150}Nd$ tracer prior to digestion to ensure spike equilibration. Following an initial open beaker evaporation, they were further decomposed with HF in teflon bombs for several days at a temperature of ca. 205°C. After removal from the oven, $HClO_4$ was added and the $HF/HClO_4$ mixture was evaporated to dryness. Remaining insoluble fluorides were digested by treating the samples with 6N HCl in teflon bombs. The HCl solution was partially evaporated and then diluted to ca. 1.0N, the concentration required for ion exchange chemistry. These bomb procedures were adopted to ensure total dissolution of such refractory REE-bearing phases as zircon and monazite. Duplicate analyses with these digestion techniques agree within analytical uncertainty for both $^{147}Sm/^{144}Nd$ and $^{143}Nd/^{144}Nd$. Fractionation of isotope ratios were corrected using $^{146}Nd/^{144}Nd = 0.7219$. The decay constant for ^{147}Sm is 6.54×10^{-12} a^{-1}. Model ages were calculated with respect to a depleted mantle with $\varepsilon_{Nd}^{4.6\ Ga} = 0$ and $\varepsilon_{Nd}^{0} = +10$ (Goldstein et al., 1984).

4. Lithological Descriptions

Basement cores investigated in this study are identified in Table 1 and located in Figure 1.

a) Northwestern Area

Cores from this area include one orthopyroxene-hornblende-bearing quartzofeldspathic gneiss (SASK-35), a granulite facies garnet-cordierite-sillimanite-K-feldspar-bearing pelitic gneiss (SASK-38), a garnet-hornblende-bearing felsic gneiss (SASK-41), a biotite-muscovite-microcline-bearing granitic gneiss (SASK-40) and an augen granitic gneiss (SASK-32). These samples and their grade of metamorphism are consistent with the geology of much of the exposed Cree Lake Zone and with its extrapolation to the south and southwest (Figure 2).

b) Southwestern Area

Basement rock types in this area include hornblende-bearing (amphibolite facies) mafic tonalitic gneiss (SASK-43), a massive orthoquartzite (SASK-42), and a variety of undeformed granites (SASK-39, -36, -34, -137, -24) and felsic volcanics or high-level porphyry intrusions (SASK-24, -29, -30).

Age and metamorphic grade of the quartzite are equivocal. However, the presence of traces of diopside and the nature of recrystallized microstructures indicate am-

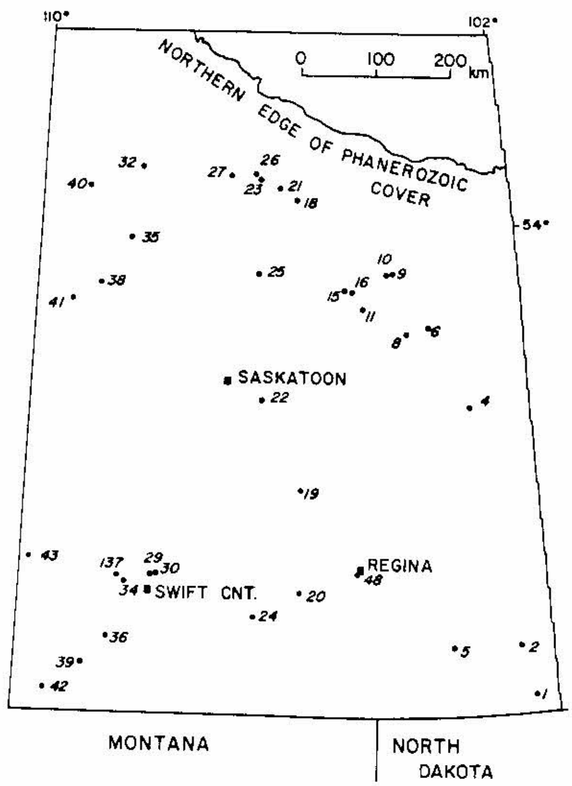

Figure 1 - Map showing distribution of specimens examined in this study.

Table 1 - Basement Core Samples from Saskatchewan

Spec. No.	*Location*	*Well Name*	*Lithology*
SASK-1	16-04-03-32W1	Socony Western Carievale	Granitic gneiss
SASK-2	8-30-08-33W1	SMUS South Parkman	Tonalitic gneiss
SASK-4	10-25-36-05W2	Ceepee Annette	Blastomylonite
SASK-5	3-27-08-08W2	Imp. Can. Superior Stoughton	Biotite-muscovite-cordierite gneiss
SASK-6	15-05-46-09W2	California Standard Bannock	Altered porphyritic microgranite
SASK-8	9-22-45-12W2	Peesane No. 2 Stratigraphic Test	Intermediate granulite
SASK-9	13-18-52-13W2	Triad Whitefox	Biotite-muscovite gneiss
SASK-10	12-15-52-14W2	Triad Whitefox	Garnet-cordierite-biotite-sillimanite gneiss
SASK-11	1-15-48-17W2	California Standard Ratner	Muscovite-biotite schist
SASK-15	8-09-50-18W2	Imperial et al., Fort à La Corne	Phyllite
SASK-16	4-10-50-18W2	Irex A	Banded iron formation
SASK-18	2-05-61-24W2	Great Plains Montreal Lake No. 25	Biotite-muscovite-garnet-carbonate-sulphide schist
SASK-19	1-14-10-27-25W2	Tide Water Stalwart Crown No. 1	Altered granite
SASK-20	2-11-15-26W2	Ceepee Baildon	Mesoperthite-biotite-bearing granite
SASK-21	5-22-62-26W2	Great Plains et al., Montreal Lake	Biotite-bearing tonalitic gneiss
SASK-22	4-16-37-01W3	White Roses et al., St. Denis	Granodiorite gneiss
SASK-23	3-18-63-01W3	Great Plains McDermott Home Hay	Garnet-biotite-sillimanite-cordierite gneiss
SASK-25	8-15-52-02W3	Mobil Oil von Mehren Lake X	Biotite-bearing tonalitic gneiss
SASK-26	8-08-64-02W3	Great Plains et al., Musquash	Biotite-bearing tonalitic gneiss
SASK-27	1-36-63-05W3	Great Plains et al., Smoothstone	Hornblende-biotite gneiss
SASK-29	1-09-17-14W3	B.A. Wilhelm	Hastingsite-bi-bearing microgranite
SASK-30	3-10-17-14W3	B.A. Sask Lndg Wilhelm	Porphyritic microgranite-rhyolite
SASK-32	8-30-64-15W3	Seaboard Meadow Lake Crown No. 3	Microcline-biotite granitic gneiss
SASK-34	2-21-16-17W3	M.U.S. Cantuar	Biotite-bearing microcline granite
SASK-35	7-14-56-17W3	Canadian Seaboard Divide No. 2	Charnockitic gneiss
SASK-36	2-04-10-19W3	Delhi et al., Rock Cr 2A	Granite
SASK-38	6-05-51-20W3	Husky D.H. Turtleford	Garnet-biotite-sillimanite-cordieite gneiss
SASK-39	9-32-06-22W3	M.O.W.S. Knollys	Albite granite
SASK-40	8-11-62-22W3	Imperial Goodsoil	Microcline-biotite granitic gneiss
SASK-41	6-01-49-24W3	Husky D.L. Lashburn	Garnet-biotite-plagioclase gneiss
SASK-42	4-31-03-26W3	Imperial et al., Battle Creek	Diopside-bearing quartzite
SASK-43	1-31-18-28W3	Mobile Oil North Richmond	Dioritic gneiss
SASK-48	3-08-17-19W2	Universiy of Regina	Megacrystic garnet-bearing granitic gneiss
SASK-137	15-03-17-18W2	Fosterton W.S. 15-3 "C"	Hastingsite-bearing granite

phibolite facies conditions of metamorphism. The quartzite yields a Nd crustal residence age of 2830 Ma (Frost and Burwash, 1986). This could be a provenance age and the unit could represent an Early Proterozoic shelf sequence, comparable with either the Snowy Pass Supergroup of the Medicine Bow Mountains in southeast Wyoming or parts of the Wollaston Group.

Significant and unexpected rock types in the southwest include posttectonic rapikivi granites, containing large compositionally zoned K-feldspar megacrysts, and porphyritic rhyolites considered to be high-level intrusives or extrusives. Ferrohastingsite appears in both the plutonics and the rhyolites. Previously published U-Th-Pb geochronological data for a granite from this suite indicated a crystallization age of ca. 1790 Ma (Rosholt et al., 1970). The same sample analyzed in this study has yielded a U-Pb zircon discordia age of 1763 ± 4 Ma (see below). Neodymium data for two of these granites (SASK-36, -39) reported by Frost and Burwash (1986) gave late Archean crust formation ages (2620 and 2580 Ma respectively). These data clearly indicate that the granites represent melts of Archean crust. The suite is tentatively correlated with post-Hudsonian anorogenic magmatism of the Dubawnt Group in the Thelon Segment of the Orogen (Donaldson, 1965; Blake, 1980) and provides a significant constraint on timing of tectonothermal activity in this part of the Orogen. Specimen distribution suggests that a major area of anorogenic plutonic and volcanic activity extends from Swift Current south towards Montana. This region, termed the **Swift Current Anorogenic Province** (Figure 2), lies on the northeasterly extension of the Great Falls Tectonic Zone (O'Neill and Lopez, 1985) which has been the locus of igneous activity and recurrent fault movements from Early or Mid-Proterozoic time through to the Holocene. It also straddles the postulated northeastern margin of the Archean Wyoming Craton.

c) South-Central Area

Cores from the Regina-Moose Jaw area (SASK-19, -20, -48) comprise weakly to moderately foliated, locally garnetiferous megacrystic and nonmegacrystic granites similar to rocks of the Wathaman Batholith.

Further east, the basement is characterized by tonalitic and granodioritic gneisses (SASK-27), medium- to high-grade supracrustal rocks (SASK-18, -21, -22, -23, -25, -26) and a variety of nondiagnostic pink granite and granodiorite. This marked change in lithological assemblage, similar to that occurring east of the exposed Wathaman Batholith, roughly coincides with the estimated position of the North American Central Plains

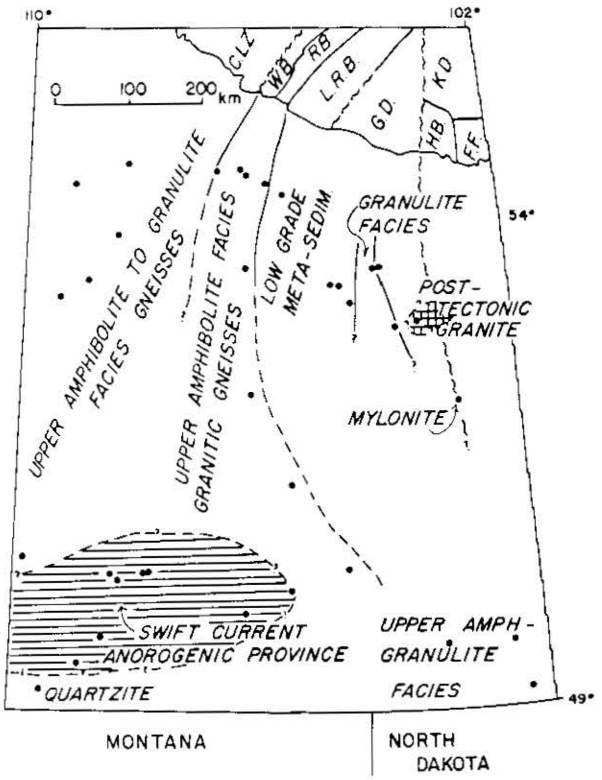

Figure 2 – Map showing variation in metamorphic grade and lithology in the sub-Phanerozoic basement in Saskatchewan.

Conductivity Anomaly (NACPCA) (Camfield and Gough, 1977).

d) Southeastern Area

Basement cores in the southeast include upper amphibolite to granulite facies tonalitic and granitic orthogneisses (SASK-2, -1), as well as cordierite-bearing gneiss (SASK-5) believed to be derived from a supracrustal sequence. There is no clear correlation between lithology and postulated geophysical boundaries. Two cores from North Dakota, immediately south of the Saskatchewan – United States border, contain zircons which yield U-Pb discordia intercept ages of ca. 2900 Ma, with lower intercepts of ca. 1650 to 1750 Ma (Peterman and Goldich, 1982). The cordierite gneiss SASK-5 from Imperial Stoughton 3-27 gives a Sr model age of ca. 2500 Ma (Peterman and Hedge, 1964).

e) North-Central and Northeastern Area

The north-central/northeastern part of the unexposed shield comprises granulite facies ortho- and paragneisses (SASK-4, -9, -10) and altered granite rich in accessory phases (SASK-6). These lie west of a blastomylonitic zone, tentatively related to the Trans-Hudson Orogen – Superior Province boundary zone, and west of the geophysically extrapolated subsurface extension of the Tabbernor Fault Zone. One extremely fresh intermediate granulite (SASK-8) has yielded abundant and virtually concordant zircon (see below). These high-grade rocks lie to the south of low-grade areas within the Glennie Domain. Their significance is currently unclear.

In the Choiceland area, west of this high-grade terrain, the metamorphic grade decreases abruptly. Several boreholes (SASK-11, -15, -16) intersect a low-grade metasedimentary assemblage that contains thick sequences of banded iron formation.

5. U-Pb Zircon Isotopic Results

U-Pb geochronological data for zircon fractions from several samples are presented in Table 2. Results are plotted in Figure 3.

Data from three fractions of SASK-2, a tonalitic gneiss, define a reasonable chord with a precise upper intercept of 1862 ± 4 Ma. Zircons from this sample are normal igneous-type zircons without cores or overgrowths. We interpret this age as dating primary crystallization of the tonalitic protolith.

Two fractions from the basic to intermediate granulite SASK-8 yield virtually identical and nearly concordant results; a chord passing through these two points and an assumed lower intercept of 500 Ma yields an upper intercept age of 1786 ± 4 Ma. This is only slightly older than the $^{207}Pb/^{206}Pb$ ages of the individual fractions and is insensitive to slope used for a discordia.

Four fractions of SASK-26 scatter significantly and yield a poorly defined upper intercept with an apparent age of 1914 ± 50 Ma. The zircons in these fractions contain distinct older cores. This result is within error of that obtained from HUD-83-17, a tonalitic gneiss in the Rottenstone Domain (Van Schmus et al., 1987a) which has yielded an apparent age of 1922 ± 24 Ma. Detailed processing of zircons from HUD-83-17, however, showed that the true U-Pb zircon age from a coreless fraction was ca. 1867 Ma, comparable to other plutonic units in the region. We therefore regard the apparent age of SASK-26 as a maximum metamorphic age, with

Table 2 – U-Pb Zircon Data for Basement Samples from Saskatchewan

Spec. No.	*Location*	*Lithology*	*Age (Ma)*[1]
SASK-2	8-30-08-33W1	Tonalitic gneiss	1862 ± 4
SASK-8	9-22-45-12W2	Intermediate granulite	1786 ± 4
SASK-26	8-08-64-02W3	Tonalitic gneiss	1914 ± 50
SASK-34	2-21-16-17W3	Posttectonic granite	1763 ± 4
SASK-35	7-14-56-17W3	Charnockitic gneiss	2484 ± 54
SASK-48	3-08-17-19W2	Megacrystic granitic gneiss	1822 ± 16

[1]Error given at 2σ confidence level

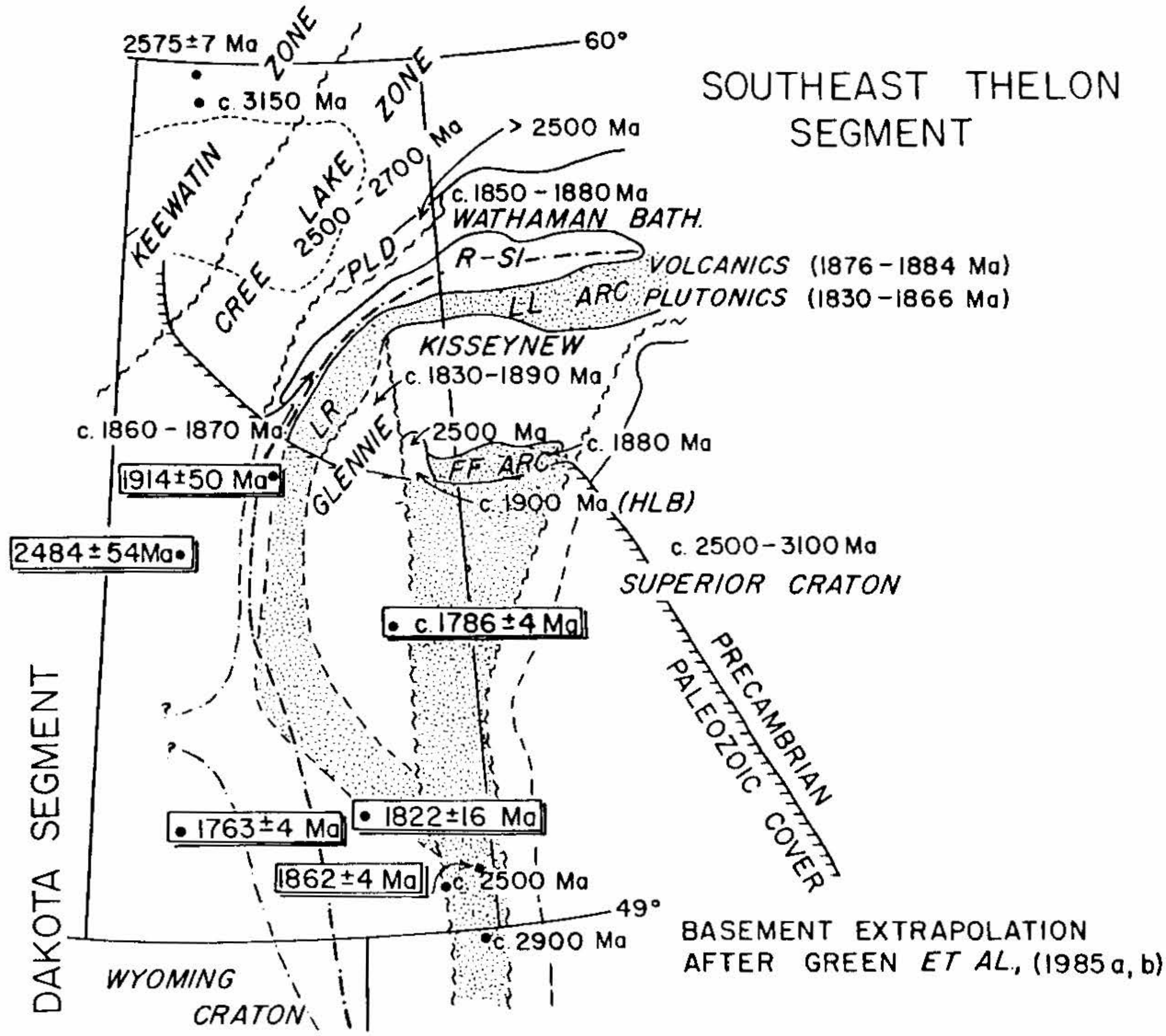

Figure 3 – Map showing previous geochronological data for the exposed shield and variation in U-Pb zircon age determinations for the sub-Phanerozoic basement.

the probable age closer to 1850 to 1870 Ma, based on the probable correlation of this sample with the Rottenstone Domain to the north. Unfortunately there are insufficient zircons to prepare a hand-picked coreless fraction for this sample.

Three fractions of zircons from SASK-34 yield a moderate to very discordant result, although they are nearly colinear and give a relatively precise upper intercept age of 1763 ± 4 Ma. However, since only three fractions are used and the data are very discordant, this age should be regarded as less certain than quoted. In any case, it appears that the age of this granite is very similar to the Pb-Pb total rock-microcline age and two point Rb-Sr age (1790 Ma and 1772 ± 50 Ma respectively) reported from the same drillhole by Rosholt et al., (1970). It is therefore distinctly younger than that typical of granites from the Trans-Hudson Orogen (ca. 1830 to 1880 Ma; Van Schmus et al., 1987a).

Five fractions from SASK-35 are only slightly discordant and form a short linear array with an upper intercept of 2484 ± 54 Ma. The large uncertainty results from the lack of "leverage" on the chord defined by the data in combination with a relatively high lower intercept. These features cause the chord to be subparallel to concordia at the upper end. Results on this sample are similar to those from the Sahli Granite in the Hanson Lake Block (HUD-83-8; Van Schmus et al., 1987a) which also shows evidence of a Late Archean to Early Proterozoic thermotectonic event.

Three discordant fractions from SASK-48 define an upper intercept of 1822 ± 6 Ma, but as in the case SASK-34, we consider this to be a minimum age. This sample is probably comparable in age to plutons of the Trans-Hudson Orogen at 1830 to 1870 Ma (Van Schmus et al., 1987a).

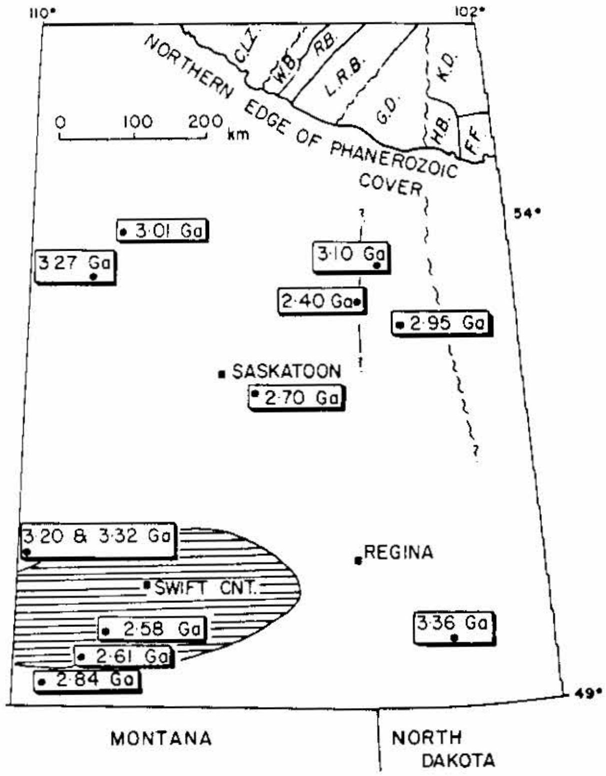

Figure 4 - Map showing crustal residence Nd model age data for basement samples.

6. Sm-Nd Isotopic Results

Sm-Nd isotopic data have been obtained for a reconnaissance suite of samples. Provisional crustal residence ages are presented in Figure 4. Crust formation ages ranging from ca. 3.4 Ga to 2.4 Ga for basement core samples show that the sub-Phanerozoic extension of the Trans-Hudson orogen is apparently not dominated by juvenile (ca. 1890 Ma) crust as suggested by Green et al., (1985a and b), or by Patchett and Arndt (1986). Instead, it appears to be dominated by Archean crust, albeit variably reworked by Hudsonian thermotectonism which produced growth of metamorphic zircon and the crystallization of zircon in penecontemporaneous crustal melts derived from source regions containing large volumes of earlier crust.

Nd isotopic data from the exposed Precambrian Shield in Saskatchewan (Chauvel et al., 1987; Collerson, unpublished data) are compared to data from the buried basement in Figure 5. Present-day ε_{Nd} values (DePaolo and Wasserburg, 1976) for the basement samples range from -21.5 to -34.4. In contrast, present-day ε_{Nd} values for juvenile Proterozoic rocks from the La Ronge Belt with broadly similar Sm/Nd ratios range from -15.6 to -23.3. The only suites that have present-day ε_{Nd} values similar to the basement data are the Sahli Granite in the Hanson Lake Block, and gneisses from the Rottenstone Domain, the Wathaman Batholith, the Peter Lake Domain, the Cree Lake Zone and Western Granulite Domain. Rocks in all these suites have Archean protoliths or are interpreted as having sources containing mixed Archean and Early Proterozoic components.

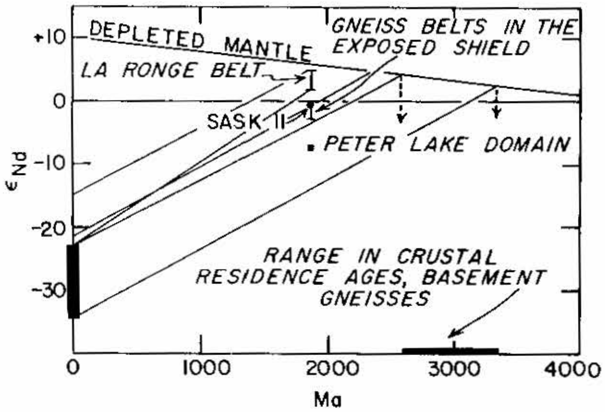

Figure 5 - ε_{Nd} versus time diagram showing comparison between the Nd isotope systematics of juvenile Proterozoic rocks from the La Ronge Belt, the Rottenstone Belt and Peter Lake Domain gneisses (Chauvel et al., 1986) and data for samples from the buried basement.

Also shown in Figure 5 are initial ε_{Nd} values calculated at 1.89 Ga. Negative ε_{Nd} values for the basement gneisses at this time clearly reflect the role of Archean crust. In contrast, positive ε_{Nd} values for juvenile Proterozoic rocks in the La Ronge Belt reflect the involvement of melts derived from depleted mantle sources. The only basement sample that possibly contains a Proterozoic crustal component is SASK-11, a biotite-muscovite schist which lies south of the Glennie Domain.

7. Discussion

Nd model ages give an estimate of the time that has elapsed since a crustal rock had the same $^{143}Nd/^{144}Nd$ ratio as its mantle source region. The approach assumes that there was only a short time interval between addition of material to the continental crust and fractionation of Sm/Nd during partial melting. Model ages are

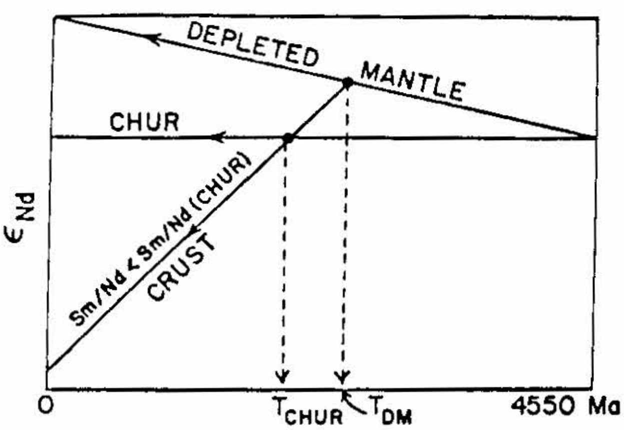

Figure 6 - ε_{Nd} versus time diagram showing graphical representation of Nd model ages assuming closed system evolution.

only valid if the assumptions concerning the source from which the crustal melts are derived are correct (Arndt and Goldstein, 1987). Initial $^{143}Nd/^{144}Nd$ ratios obtained for mantle-derived Archean and Proterozoic suites indicate derivation from light, rare earth-depleted mantle (DM) source regions with Sm/Nd ratios greater than that of a mantle reservoir with a chondritic Sm/Nd ratio (CHUR). This increase in Sm/Nd in the mantle is considered to be the result of depletion in Nd due to prior crust removal (McCulloch and Compston, 1981). The effect of this on the calculated model ages can be seen in Figure 6.

Although it has generally been considered that the Sm-Nd isotopic system is little affected by crustal processes, some fractionation of Sm/Nd ratio may occur under both metamorphic and anatectic conditions on both a mineralogical and whole rock scale (e.g., McCulloch and Black, 1984; Wilson et al., 1985; Collerson et al., 1988). As a result, Sm-Nd model ages may yield equivocal information about the time of crust generation and crustal residence.

The effect of isotopic homogenization due to redistribution of Nd and/or Sm during metamorphism will depend to a large degree on the scale of diffusion in relation to the scale of sample volume. The closed system evolution of two comagmatic rocks (wr_1 and wr_2) with different Sm/Nd ratios between the time of crust formation ca. 3400 Ma ago from a depleted mantle source and a period of metamorphism ca. 2700 Ma ago is shown in Figure 7. Both rocks evolve to negative ε_{Nd} values at T_{META}, because their Sm/Nd ratios are less than CHUR. During metamorphism, re-equilibration causes a decrease in the ε_{Nd} of WR_2 and an increase in the ε_{Nd} of WR_1 as a result of isotopic exchange. At the termination of the metamorphic event, the isochron is essentially reset to zero slope with a new initial $^{143}Nd/^{144}Nd$ ratio $I_{Nd}(2)$ controlled by the average ε_{Nd} of WR_1 and WR_2. The slope of the secondary isochron gives the age of T_{META}. In this analysis, the value of εNd (T_{META}) is a minimum value if the Sm/Nd ratios of the whole rock samples are less than CHUR. Samples with ε_{Nd} values <0 like those exhibited by the basement

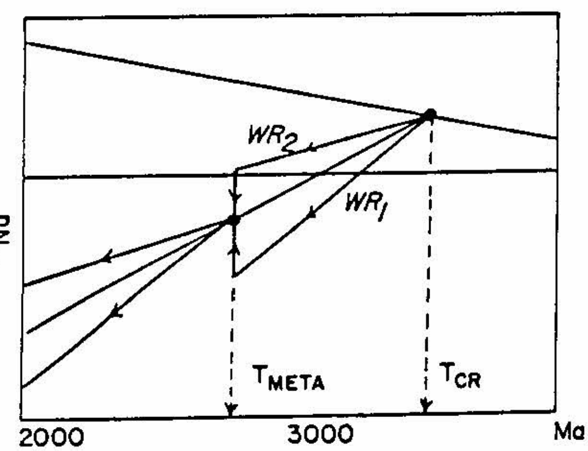

Figure 7 - εNd versus time diagram showing possible effect of later metamorphism on Nd isotope systematics.

data usually represent rocks with a significant crustal prehistory.

8. Conclusions

1) The buried basement in southern and central Saskatchewan appears to contain a significant Archean crustal component which was variably affected by Hudsonian thermotectonism.

2) Superior Province Archean crust occurs further west than had been previously thought on the basis of geophysical data (cf. Green et al., 1985a and b).

3) Late Hudsonian evolution in the Dakota Segment of the Trans-Hudson Orogen probably involved transcurrent movement in which the arc terrains exposed in the north were dismembered and obliterated (cf. Green et al., 1985a and b).

4) The Swift Current Anorogenic Province shows widespread evidence of partial melting of Archean crust during a late Hudsonian or post-Hudsonian event ca. 1760 Ma ago.

The presence of widespread Archean crust within the buried basement in central and southern Saskatchewan places severe constraints on 1) tectonic models for the evolution of the Trans-Hudson Orogen, 2) the extrapolation of lithotectonic elements within the buried basement based on geophysical data (cf. Green et al., 1985a and b), and 3) estimates of the volume of juvenile crust added to the continental crust during the Early Proterozoic (cf. Patchett and Arndt, 1986).

9. Acknowledgements

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10. References

Allegre, C.J. and Ben Othman, D. (1980): Nd-Sm isotopic relationship in granitoid rocks and continental crust development: a chemical approach to orogenesis; Nature, v286, p335-342.

Arndt, N.T. and Goldstein, S.L. (1987): Use and abuse of crust formation ages; Geology, v15, p893-895.

Arvidson, R.E., Bindschadler, D., Bowring, S., Eddy, M., Guinness, E. and Leff, C. (1984): Bouguer images of the North American craton and its structural evolution; Nature, v311, p241-243.

Blake, D.H., (1980): Volcanic rocks of the Paleohelikian Dubawnt Group in the Baker Lake – Angikuni Lake areas, District of Keewatin, N.W.T.; Geol. Surv. Can., Pap. 309.

Burwash, R.A. and Culbert, R.R. (1976): Multivariate geochemical and mineral patterns in the Precambrian basement of western Canada; Can. J. Earth Sci., v13, p1-18.

Burwash, R.A. and Cumming, G.L. (1974): Helium source-rock in southwestern Saskatchewan; Bull. Can. Petrol. Geol., v22, p405-412.

Burwash, R.A. and Krupicka, J. (1969): Cratonic reactivation in the Precambrian basement of western Canada: I. Deformation and chemistry; Can. J. Earth Sci., v6, p1381-1396.

Burwash, R.A. and Krupicka, J. (1970): Cratonic reactivation in the Precambrian basement of western Canada: II. Metasomatism and isostasy; Can. J. Earth Sci., v7, p1275-1294.

Burwash, R.A., Baadsgaard, H. and Peterman, Z.E. (1962): Precambrian K-Ar dates from the Western Canada Sedimentary Basin; J. Geophys. Res., v67, p1617-1625.

Burwash, R.A., Krupicka, J. and Culbert, R.R. (1973): Cratonic reactivation in the Precambrian basement of western Canada: III. Crustal evolution; Can. J. Earth Sci., v10, p283-291.

Camfield, P.A. and Gough, D.I. (1977): A possible Proterozoic plate boundary in North America; Can. J. Earth Sci., v14, p1229-1238.

Chauvel, C., Arndt, N.T., Kielinzcuk, S. and Thom, A. (1987); Formation of Canadian 1.9 Ga old continental crust 1: Nd isotopic data; Can. J. Earth Sci., v24, p396-406.

Chiarenzelli, J.R., Lewry, J.F. and Landon, M. (1987): Bedrock geology, Iskwatikan Lake area: evidence for Hudsonian juxtaposition of Proterozoic and Archean rocks along a ductile detachment surface; *in* Summary of Investigations 1987, Sask. Geol. Surv., Misc. Rep. 87-4, p46-51.

Collerson, K.D. and McCulloch, M.T. (1982): The origin and evolution of Archean crust as inferred from Nd, Sr and Pb isotopic studies in Labrador (abstract); Fifth Internat. Conf. Geochron., Cosmochron. and Isotope Geochem., Abstr., p61-62.

Collerson K.D., McCulloch, M.T. and Nutman, A.P. (1988): Sr and Nd isotope systematics of polymetamorphic gneisses from southern West Greenland and northern Labrador; Can. J. Earth Sci. (in press).

Donaldson, J.A. (1965): The Dubawnt Group, District of Keewatin and Mackenzie; Geol. Surv. Can., Pap. 64-20.

DePaolo, D.J. (1981): Neodymium isotopes in the Colorado Front Range and crust-mantle evolution in the Proterozoic; Nature, v291, p193-196.

DePaolo D.J. and Wasserburg, G.J. (1976): Nd isotopic variations and petrogenetic models; Geophys. Res. Lett., v3, p249-252.

Dutch, S.I. (1983): Proterozoic structural provinces in the north-central United States; Geology, v11, p478-481.

Frost, C.D. and Burwash, R.A. (1986): Nd evidence for extensive Archean basement in the western Churchill Province, Canada; Can. J. Earth Sci., v23, p1433-1437.

Frost, C.D. and O'Nions, R.K. (1984): Nd evidence for Proterozoic crustal development in the Belt – Purcell Supergroup; Nature, v312, p53-56.

Goldstein, S.L., O'Nions, R.K. and Hamilton, P.J. (1984): A Sm-Nd isotopic study of atmospheric dust and particulates from major river systems; Earth Planet. Sci. Lett., v70, p221-236.

Green, A.G., Hajnal, Z. and Weber, W. (1985a): An evolutionary model of the western Churchill Province and western margin of the Superior Province in Canada and the north-central United States; Tectonophysics, v116, p281-322.

Green, A.G., Weber, W. and Hajnal, Z. (1985b): Evolution of Proterozoic terrains beneath the Williston Basin; Geology, v13, p624-628.

Hoffman, P.F. (1988): United plates of America, the birth of a craton: Early Proterozoic assembly and growth of Laurentia; Annu. Rev. Earth Planet. Sci., v16, p543-603.

Jacobsen, S.B. and Wasserburg, G.J. (1980): Sm-Nd evolution of chondrites; Earth Planet. Sci. Lett., v50, p139-155.

King, H.L. (1966): Subsurface Precambrian of Saskatchewan; unpubl. M.A. thesis, Univ. Sask., 117p.

Klasner, J.S. and King, E.R. (1986) Precambrian basement geology of North and South Dakota; Can. J. Earth Sci., v23, p1083-1102.

Lewry, J.F. (1981): Lower Proterozoic arc-microcontinent collisional tectonics in the western Churchill Province; Nature, v294, p69-72.

Lewry, J.F. (1984): Continental platforms and suspect terrains in the Lower Proterozoic Trans-Hudson Orogen; Geol. Assoc. Can., Prog. Abstr., v9, p84.

Lewry, J.F. and Collerson, K.D. (in press): The Trans-Hudson Orogen: extent, subdivision and problems; *in* Lewry, J.F. and Stauffer, M.R. (eds.), The Early Proterozoic Trans-Hudson Orogen: Lithotectonic Correlations and Evolution; Geol. Assoc. Can., Spec. Pap.

Lewry, J.F., Sibbald, T.I.I., and Schledewitz, D.C.P. (1985): Variations in character of Archean rocks in the Western Churchill Province and its significance; *in* Ayres, L.D., Thurston, P.C., Card, K.D., and Weber, W. (eds.), Evolution of Archean Supracrustal Sequences; Geol. Assoc. Can., Spec. Pap. 28, p239-261.

Lewry, J.F., Collerson, K.D., Bickford, M.E. and Van Schmus, W.R. (1986): An evolutionary model of the western Churchill Province and western margin of the Superior Province in Canada and the north-central United States — discussion; Tectonophysics, v131, p183-197.

Lewry, J.F., Thomas, D.J., Macdonald, R. and Chiarenzelli, J. (in press): Structural relations in accreted terranes of the Trans-Hudson Orogen, Saskatchewan: telescoping in a collisional regime? *in* Lewry, J.F. and Stauffer, M.R. (eds.), The Early Proterozoic Trans-Hudson Orogen: Lithotectonic Correlations and Evolution; Geol. Assoc. Can., Spec. Pap.

McCulloch, M.T. and Black, L.P. (1984): Sm-Nd isotope systematics of Enderby Land granulites and evidence of the redistribution of Sm and Nd during metamorphism; Earth Planet. Sci. Lett., v1, p46-58.

McCulloch, M.T. and Chappell, B.W. (1982): Nd isotopic characteristics of S and I type granites; Earth Planet. Sci. Lett., v58, p51-64.

McCulloch, M.T. and Compston, W. (1981): Sm-Nd age of Kambalda and Kanowna greenstone and heterogeneity in the Archaean mantle; Nature, v294, p322-327.

McCulloch, M.T. and Wasserburg, G.J. (1978): Sm-Nd and Rb-Sr chronology of continental crust formation; Science, v200, p1003-1011.

Nelson, B.K. and DePaolo, D.J. (1985): Rapid production of continental crust 1.7 to 1.9 b.y. ago: Nd isotopic evidence from the basement of the North American mid-continent; Geol. Soc. Am. Bull., v96, p746-754.

O'Niell, J.M. and Lopez, D.A. (1985): Character and regional significance of Great Falls Tectonic Zone, east-central Idaho and west-central Montana; Am. Assoc. Petrol. Geol., v69, p437-447.

Patchett, P.J. and Arndt, N.T. (1986): Nd isotopes and tectonics of 1.9 - 1.7 Ga crustal genesis; Earth Planet. Sci. Lett., v78, p329-338.

Patchett, P.J. and Bridgwater, D. (1984): Origin of continental crust of 1.9 - 1.7 Ga age defined by Nd isotopes in the Ketilidian terrain of south Greenland; Contrib. Mineral. Petrol., v87, p311-318.

Patchett P.J. and Kouvo, O. (1986): Origin of continental crust of 1.9-1.7 Ga age: Nd isotopes and U-Pb zircon ages in the Svecokarelian terrain of South Finland; Contrib. Mineral. Petrol., v92, p1-12.

Peterman, Z.E. (1981): Dating of Archean basement in northeastern Wyoming and southern Montana; Geol. Soc. Am. Bull., v92, p139-146.

Peterman, Z.E. and Hedge, C.E. (1964): Age of basement rocks from the Williston Basin of North Dakota and adjacent areas; U.S. Geol. Surv., Prof. Pap. 475D, pD100-D104.

Peterman, Z.E. and Goldich, S.S. (1982): Archean rocks of the Churchill basement, Williston Basin, North Dakota; *in* Christopher, J.E. and Kaldi, J. (eds.), Fourth International Williston Basin Symposium Proceedings; Sask. Geol. Soc., Spec. Publ. 6, p11-12.

Peterman, Z.E. and Futa, K. (1987): Is the Archean Wyoming province exotic to the Superior Craton? Evidence from Sm-Nd model ages of basement cores; Geol. Soc. Am., Prog. Abstr., v19, p803.

Rosholt, J.N., Peterman, Z.E., and Bartel, A.J. (1970): U-Th-Pb and Rb-Sr ages in granite reference sample from southwestern Saskatchewan; Can. J. Earth Sci., v7, p184-187.

Ross, G.M., Parrish, R.R. Bowring, S.A. and Tankard, A.J. (1988): Tectonics of the Canadian Shield in the Alberta subsurface; Geol. Assoc. Can., Prog. Abstr., v13, p106.

Sims, P.K. and Peterman, Z.E. (1986): Early Proterozoic Central Plains Orogen: a major buried stucture in the north-central United States; Geology., v14, p488-491.

Steiger, R.H. and Jager, E. (1977): Subcommission on geochronology: convention on the use of decay constants in geo- and cosmochronology; Earth Planet. Sci. Lett., v36, p359-362.

Thom, A., Arndt, N.T. and Chauvel, C. (1987): Volcanic arcs and granitoids in the Reindeer Zone, Saskatchewan; Geol. Assoc. Can., Prog. Abstr., v12, p95.

Van Schmus, W.R., Bickford, M.E., Lewry, J.F. and Macdonald, R. (1987a): U-Pb geochronology of the Trans-Hudson Orogen in northern Saskatchewan; Can. J. Earth Sci., v24, p407-424.

Van Schmus, W.R., Bickford, M.E. and Zietz, I. (1987b): Early and Middle Proterozoic Provinces in the central United States; *in* Kroner, A. (ed.), Proterozoic Lithospheric Evolution; Am. Geophys. Union, Geodynamic Ser., p43-68.

Wilson, M.R., Hamilton, P.J., Fallick, A.E., Aftalion, M. and Michard, A. (1985): Granites and early Proterozoic crustal evolution in Sweden: evidence from Sm-Nd, U-Pb and O isotope systematics; Earth Planet. Sci. Lett., v72, p376-388.