1-1-1986

A paleomagnetic study of the Lynn Lake and Fraser Lake Gabbros, Northern Manitoba.

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A PALEOMAGNETIC STUDY OF THE LYNN LAKE AND FRASER LAKE GABBROS, NORTHERN MANITOBA

By
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A thesis submitted to the Faculty of Graduate Studies through the Department of Geology in partial fulfillment of the requirements for the Degree of Master of Science in Geology at the University of Windsor

Abstract

The Proterozoic (Aphebian) Lynn Lake Greenstone Belt in the Churchill Province of northern Manitoba hosts numerous mafic intrusions that cut the Wasekwan Group of metavolcanics and metasediments, and are overlain by the Sickle Group metasediments. Paleomagnetic methods were used to study the "A" Plug (29 sites) and the "EL" Plug (10 sites) that both host Ni-Cu mineralization and the Fraser Lake Plug (11 sites) that appears to be barren of Ni-Cu mineralization. All three plugs recorded simple univectoral decay of their natural remanent magnetization to give mean directions of 154.9°, 60.9° (A_{95}=4.2°), 161.7°, 52.5° (A_{95}=12.9°) and 160.1°, 59.5° (A_{95}=2.1°) respectively. This result supports the theory that the three plugs are coevolutionary, i.e. the mineralized and non-mineralized plugs do not differ in age or tectonic history. Their combined pole position of 86.4° W, 17.8°N (δp=5.5°; δm=6.7°) is consistent with emplacement during the termination of the Hudsonian Orogeny at about 1900 Ma ago. This result fits within the limiting ages given by U-Pb zircon age determinations for the Wasekwan and Sickle Groups. The simple univectorial decay implies that no thermal or chemical alteration led to a subsequent remagnetization of the plugs The apparent polar wander path for North America at that time is derived primarily from rock units in the Superior Province. The results also show that the Superior and Churchill Provinces

were welded into a single craton by 1900 Ma and therefore were not subjected to differential relative rotations and/or translations.

Acknowledgements

I thank Dr. D.T.A. Symons for his patience and guidance during this thesis study. The help of Mr. A. Timmins, both in the field and the laboratory, was greatly appreciated. The cooperation of Paul Pauliw at Sherritt Gordon's mine in Lynn Lake during the field work phase was also appreciated. I thank my wife, Donna, for typing the manuscript and for her encouragement and tolerance throughout my MSc. program. Special thanks go out to Tom and Lynn White for allowing me the use of their office facilities and to my parents for all their support during my studies.

This study was financed by the National Science and Engineering Research Council of Canada and by the University of Windsor through grants to Dr. D.T.A. Symons.

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Units and Nomenclature

metre	m
kilometre	km
degree (angular)	$^{\circ}$
degree (temperature, centigrade)	$^{\circ}C$
percentage	%
alpha	α
gamma	γ
sigma	σ
angular standard deviation	ASD
magnetic intensity, amperes/metre/cm	Am^{-1} cm^{-3}
milliTesla	mT
natural remanent magnetization	NRM
viscous remanent magnetization	VRM

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Introduction

The Churchill Province of the Canadian Precambrian Shield contains numerous Aphebian greenstone belts. Many of these belts contain mafic intrusions which have been a significant source of nickel sulphide ores. Delineation of these host rock mafic intrusions could prove useful in finding new deposits of economic nickel sulphide ores.

Paleomagnetic studies are very useful for the determination of the tectonic movement of rock units (rotation and translation) and/or their relative ages from their remanent magnetization direction. This technique for studying geological terranes can help to determine the sequence of geologic events within an area and, in conjuction with other types of geological studies, can help to determine the terrane's geologic history in terms of absolute ages and tectonic movements.

This study looks at the relationship between two mineralized gabbroic plugs known as the "A" plug and the "EL" plug that are collectively called the Lynn Lake Gabbro, and the Fraser Lake Gabbro. The Fraser Lake Gabbro, although petrologically similar to the Lynn Lake Gabbro, is without known economic mineralization. The object of this study is to paleomagnetically date the three plugs for comparison with existing radiometric ages for other rock units, and thereby enclose the plug within a restricted time window. The analysis also yielded data on the tectonic motion of the plugs since emplacement.

The comparison of the results from the plugs would either support coevolution and tectonic history or not. If the latter is true, then the Fraser Lake Gabbro may not contain economic mineralization. If it is possible to distinguish between mineralized and non-mineralized gabbro using the paleomagnetic method, then the comparison of the geological information for these three gabbroic plugs with the other mafic plugs in the greenstone belt may lead to an exploration rationale for selecting certain other plugs as hosts for nickel sulphide ores.

Location and Access

Lynn Lake is located in northern Manitoba (Figure 1) in an area of forest and muskeg with low relief and limited outcrop. The boundaries of the study area are latitudes 56°45'N to 56°52'N and longitudes 101° 00'W to 101°12'18"W.

Lynn Lake is a small mining community, accessible by train, airplane and motor vehicle. It has limited rail service by Via Rail. It is served by both a small airport and seaplane base near the town. Access by car is provided by provincial Highway 391 (Figure 1). This highway is paved as far north as the town of Leaf Rapids and then is graded gravel for the remaining 106km to Lynn Lake. The closest urban centre is Thompson which is the province's third largest city and is 320km SE from Lynn Lake. Winnipeg, the province's largest city, is 1,058km south from Lynn Lake and is approximately an eleven-hour journey by car.

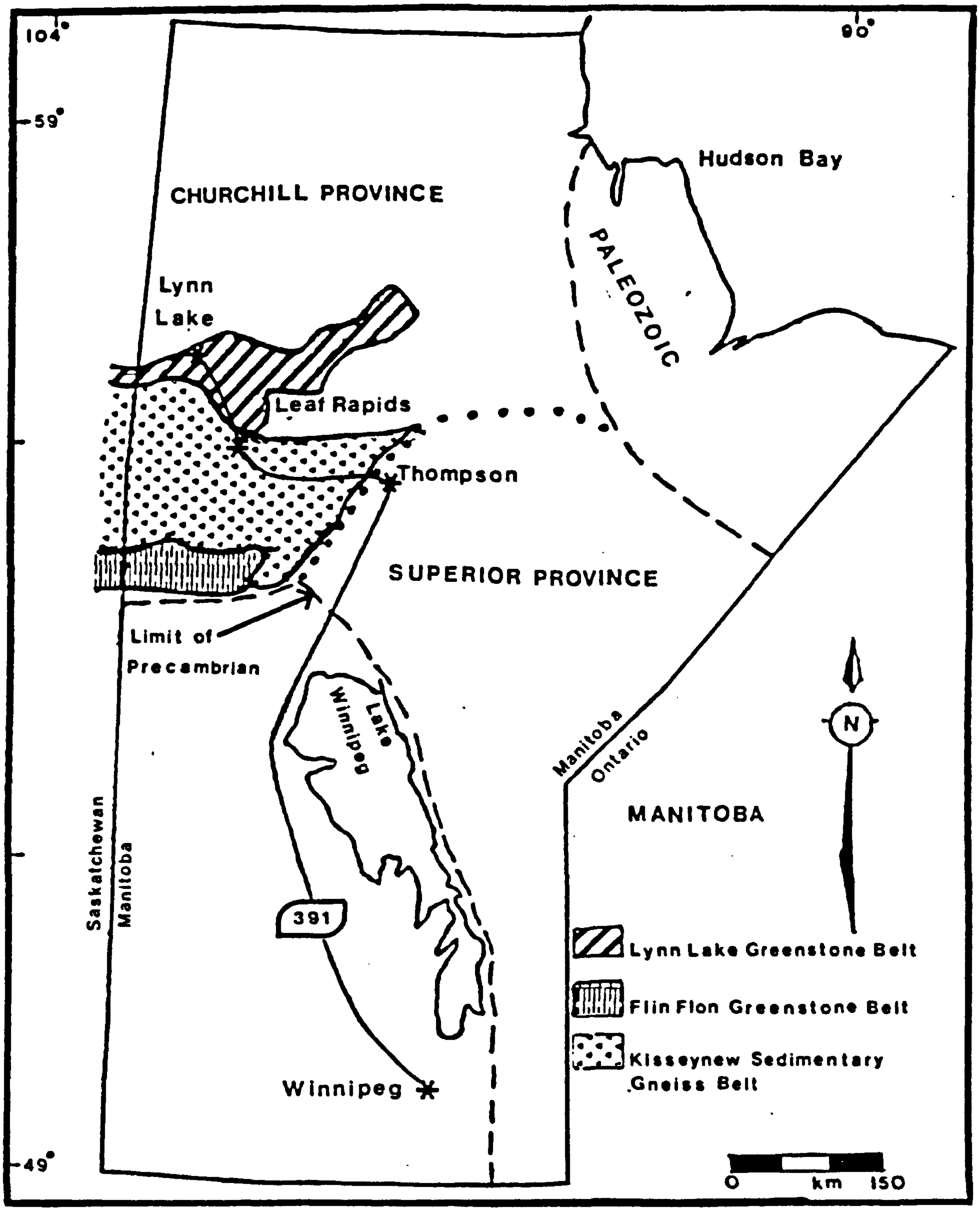


Figure 1 Location and General Geological Map

Previous Geological Work

The first geological work was carried out in the Lynn Lake area in 1932 by Norman and Henderson (1933) of the Geological Survey of Canada. In 1941, J.B. Bateman remapped the area and was responsible for naming the "Wasekwan Series" (Bateman 1945).

J.D. Allan published a report on the geology of the Lynn Lake area in 1946 and after further work, wrote a doctorate thesis on the ore and gabbros at Lynn Lake (Allan 1946, 1948).

The Sherritt Gordon Company started to explore for gold in the Lynn Lake area in the mid 1930's. However, Austin McVeigh located an outcrop with massive sulphides in 1941 which eventually led to the development of the nickel-copper mine at Lynn Lake. In the winter of 1945-46, magnetometer surveys conducted over the area revealed only two anomalies. One anomaly defined the outcrop found by McVeigh and the other defined a small body to the south now known as the "EL" plug. Sherritt Gordon then pursued an aggressive exploration program and by 1950 had outlined all the ore bodies in these plugs. After the delineation of the ore, Dorian (1950) studied the geochemistry of the sulphides and oxides of the nickel-copper deposits.

Milligan (1960) wrote a comprehensive Ph.D. thesis on the Lynn Lake district which has since become the main reference for general geology. Emslie (1961) studied the petrology and economic geology of the mafic intrusions at Lynn Lake. Emslie, in conjuction with

J.M. Moore wrote another report (Emslie and Moore 1961) on the geology of the area between Lynn Lake and Fraser Lake.

The first radiometric dating of the rocks in the Lynn Lake area was done by Moore et al. (1960) and shortly thereafter by Lowden et al. (1963) (Table 1). Turek (1967) dated the age of mineralization (Table 1). Since then, Clark (1980) and Baldwin et al. (1985) have extended the dating evidence.

In 1972, Campbell (1972) wrote a report on the stratigraphy and structural aspects of the Lynn Lake area which was augmented by Zwanzig (1974). Next, Gilbert (1977) compiled a report on the Lynn Lake area for the Manitoba Mineral Resources Division. Shortly after Pinsent (1980) reported on the geochemistry of the nickel-copper mineralization in the Lynn Lake gabbros, Gilbert et al. (1980) described the geology of the metavolcanic and volcaniclastic sediments in the Lynn Lake area. No paleomagnetic work has been done in the Lynn Lake area previously.

	U-Pb/Pb-Pb	Rb-Sr	K-Ar
Sickle Group	Rusty Lake Sediments 1872 ± 2 (1)	Arkose 1760 ± 85 (2)	
Felsic Intrusions	Hughes Lake Quartz Diorite 1876 ± 6 (1)	Berge Lake Granodiorite 1768 ± 100 (2)	
	Norrie Lake Tonalite 1876 ± 9 (1)	Pool Lake Quartz diorite 1825 ± 210 (2)	
		Tonalite 1940 ± 75 (2)	
Mafic Intrusions			1640, 1700, 1740 (4)
	1830 (1980), 1770 1795 (3)		1720, 1745 (5)
Mineralization			1669 on biotite (6)
		1668 on biotite (6)	1669 on clinopyroxene (6)
		Lynn Lake Rhyolite 1835 ± 75 (2)	
Wasekwan Group	Lynn Lake Rhyolite		
		Quartz Plagioclase Porphyry	
	1910 ± 15 (1)	1790 ± 35 (2)	

Note: (1) U-Pb zircon method, Baldwin et al. (1984), (2) Rb-Sr whole rock, Clark (1980), (3) Pb-Pb using Cummings and Richard (Stacey and Kramers) model, Sangster (1978), (4) Moore (1960), (5) Lowden (1963), (6) Turek (1967).

Table 1 Ages of Rock Units in the Lynn Lake Greenstone Belt

General Geology

A. Introduction

The Lynn Lake and Fraser Lake gabbros are located in the Churchill Structural Province of the Canadian Shield (Figure 1). The oldest rocks in the province are Archean in age. These rocks are dominantly basic to intermediate volcanics, overlain by flysch-type greywackes and shales. The Archean belts trend north to northeast and have been metamorphosed to varying degrees during the Kenoran Orogeny at the end of Archean time.

Deposition of Aphebian rocks in the Churchill province is thought to have occurred in an euogeosynclinal environment. These rocks are exposed in a number of small belts and are composed of basal quartzites, greywackes, argillite and basic volcanic rocks. They rest unconformably on the deeply eroded Archean basement. The Aphebian rocks have been folded and metamorphosed to varying degrees during the Hudsonian Orogeny. McGlynn (1970) has suggested that the Archean rocks may also have been affected by the Hudsonian Orogeny. The boundaries of the Churchill province are marked by unconformities and orogenic fronts.

Three Aphebian belts are associated with the gabbroic plutons of this study. They are the Lynn Lake Greenstone Belt in which the plutons are located, the Flin Flon Greenstone Belt and the Kisseynew Sedimentary Gneiss Belt (Figure 1) (Table 2). Although direct correlation is not possible, the geological similarities and coincident

LYNN LAKE Greenstone Belt		KISSEYNEW Gneiss Belt		FLIN FLON Greenstone Belt
Sickle Group Metasandstone Metaconglomerate		Sickle Metamorphic Suite Metasandstone Metaconglomerate		Missi Group Metasandstone Metaconglomerate
Unconformable	INTRUSIVES	Conformable	INTRUSIVES	Unconformable
Wasekwan Group (1910 ± 15) Intrusives (Felsic 1876 ± 9) Metavolcanics (mafic) Metasediments Subvolcanic intrusions		Burntwood River Suite Metagraywacke Mudstone		Amisk Group Intrusives Metavolcanics Metasediments
Archean		Archean		Archean

Table 2 Stratigraphic Outline of the Lynn Lake Greenstone Belt and Associated Belts (after Clark 1980)

radiometric ages for all three belts are such that their co-evolution is emphasized in most of the recent geologic reports (Clark 1980, Table 2).

B. Lynn Lake Greenstone Belt

The Lynn Lake Greenstone Belt is made up of two groups of rocks: Wasekwan and Sickle. The Wasekwan Group is composed of metavolcanics and metasediments and are the oldest rocks in the belt (Bateman 1945). They have been intruded by acidic and basic plutonic rocks of two ages. A series of sandstones and conglomerates of the Sickle Group (Norman 1933) rests unconformably on the above plutons and on the Wasekwan Group. Regional metamorphism of both groups of rocks varies from upper greenschist to upper amphibolite facies throughout the belt. At the edges of the belt, extensive deformation has occurred as well as a third period of plutonism. All of the rocks in the Lynn Lake Greenstone Belt including intrusions, are of Aphebian age as is the metamorphism and deformation (Clark 1980).

C. Flin Flon Greenstone Belt

The Flin Flon Greenstone Belt is also divided into two groups, the Amisk and Missi Groups. Based on similar lithologies, ages and stratigraphic position, the Amisk and Missi Groups are correlated with the Wasekwan and Sickle Groups of the Lynn Lake Greenstone Belt respectively. Although the volcanic belts may have separate sources (McGlynn 1970), whole rock Rb-Sr isochron ages (Moore 1977), mineral ages (Mukherjee 1971; Josse 1974; Bell et al. 1975) and model lead ages on the ore sulphides from both belts (Sangster 1972; Stauffer 1974), all indicate contemporaneous late Aphebian ages for the rocks of both belts.

D. Kisseynew Sedimentary Gneiss Belt

The Kisseynew Sedimentary Gneiss Belt is divided into two divisions, the Burntwood River Metamorphic Suite and the Sickle Metamorphic Suite (McRitchie 1974). The Burntwood River Metamorphic Suite overlies amphibolite derived from the Aphebian mafic volcanics and sediments (Clark et al. 1974). Quartzofeldspathic paragneiss and migmatites from greywackes and mudstone make up most of the suite. This sequence of sediments was probably deposited at the same time as the volcanic and sedimentary rocks of the Wasekwan and Amisk Groups of the two flanking greenstone belts (Bailes 1971; McRitchie 1974).

The Sickle Metamorphic Suite conformably overlies the gneiss of the Burntwood River Metamorphic Suite. The Sickle Suite is made up of quartz and feldspathic gneiss derived from lithic sandstones, arkose and conglomerate. These gneisses occupy the same stratigraphic position as the Sickle and Missi Groups of the associated greenstone belts.

Geology of the Lynn Lake Greenstone Belt

The Lynn Lake Greenstone Belt extends from Laurie Lake in the west for 130km east to Magrath Lake. It has a maximum width of 60km between Eagle Lake and Beaucage Lake (Figure 2). This Aphebian greenstone belt is subdivided into a southern belt and a northern belt by a series of east-west trending intrusions of acidic to intermediate composition (Figure 2). The Wasekwan and Sickle Groups can be distinguished in both the southern and northern belts.

A. Wasekwan Group

1. Southern Belt

The Wasekwan Group consists mainly of volcanic flows and forms the major unit in the southern belt. These volcanics contain numerous thin intercalated epiclastic beds (Milligan 1960), particularly near the top of the succession. Most geologists consider the Wasekwan to be mainly subaqueous in origin.

a)Cockeram Lake and McVeigh Lake Basalts

At the base of the volcanic assemblage is a predominantly aphyric tholeiitic basalt unit called the Cockeram Lake Basalt (Table 3). This unit contains massive, pillowed and brecciated phases that are commonly intercalated, however some parts of the flows are dominated by a single phase. The Cockeram Lake Basalt reflects the

Legend

APHEBIAN

INTRUSIVE ROCKS (I.U.G.S. CLASSIFICATION)

Post-Sickle and similar rocks of unknown age

20 Granodiorite, granite

19 Tonalite, granodiorite

18 Gabbro, diabase diorite, minor ultramafic rocks

Pre-Sickle and similar rocks of unknown age

17 Granite, granodiorite, aplite, pegmatite, syenite

16 a) Diorite, quartz diorite

b) Tonalite, granodiorite

15 Gabbro, norite, diorite, pyroxenite, peridotite

14 Hornblende diorite, quartz diorite

13 Gabbro, diabase

METASEDIMENTARY ROCKS

Sickle Group

12 Sandstones and derived gneisses

a) arkose, pebbly arkose, muscovite schist, sillimanite gneiss

b) feldspathic greywacke, siltstone, biotite gneiss

c) hornblende-biotite-blastic arkose and siltstone, hornblende-biotite gneiss

11 Polymictic conglomerate

Rocks of uncertain age: late Wasekwan or Sickle

10 a) Polymictic conglomerate

b) Staurolite schist, greywacke

Wasekwan Group

9 Fine-grained sedimentary rocks

a) hornblende-blastic greywacke, siltstone, pebbly greywacke

b) biotite-blastic greywacke, siltstone, schist

c) siltstone and amphibolite

d) mafic sandstone, mudstone, amphibolite

8 Conglomerate

METAVOLCANIC ROCKS

Wasekwan Group

7 Rhyolite: a) massive and brecciated flows; b) tuff

6 Dacite: a) flows; b) breccia and tuff

5 Intermediate and felsic rocks: a) andesite; b) dacite; c) pyroclastic breccia; d) tuff

4 Mafic and intermediate rocks: a) porphyritic and aphyric basalt, flows and breccias; b) interlayered mafic and intermediate flows and breccias; c) tuff; d) mafic schist

3 Mafic and minor ultramafic rocks, predominantly porphyritic (hornblende after pyroxene $\pm$ plagioclase): a) massive and brecciated porphyritic flows, minor tuff; b) interlayered porphyritic and aphyric flows

2 Aphyric basalt: a) flows, commonly pillowed, pillow breccia; b) tuff

METASEDIMENTARY ROCKS, VOLCANIC ROCKS AND DERIVED GNEISSES AND MIGMATITES
(Probable Wasekwan age, Burntwood River Supergroup in part)

1 B) Layered and massive amphibolite, minor felsic tuff, greywacke, ultramafic rocks, marble

A) Greywacke, mudstone, paragneiss, migmatite

Symbols

Area of no outcrop

Geological contact

Fault (approximate or inferred)

Metamorphic gradient lines:

a) approximate limit of sillimanite in greywacke, mudstone

b) approximate limit of anatexis

c) approximate limit of extensive anatexis

Axial trace of anticline (approximate, overturned)

Axial trace of syncline (approximate, overturned)

Road

if Iron formation

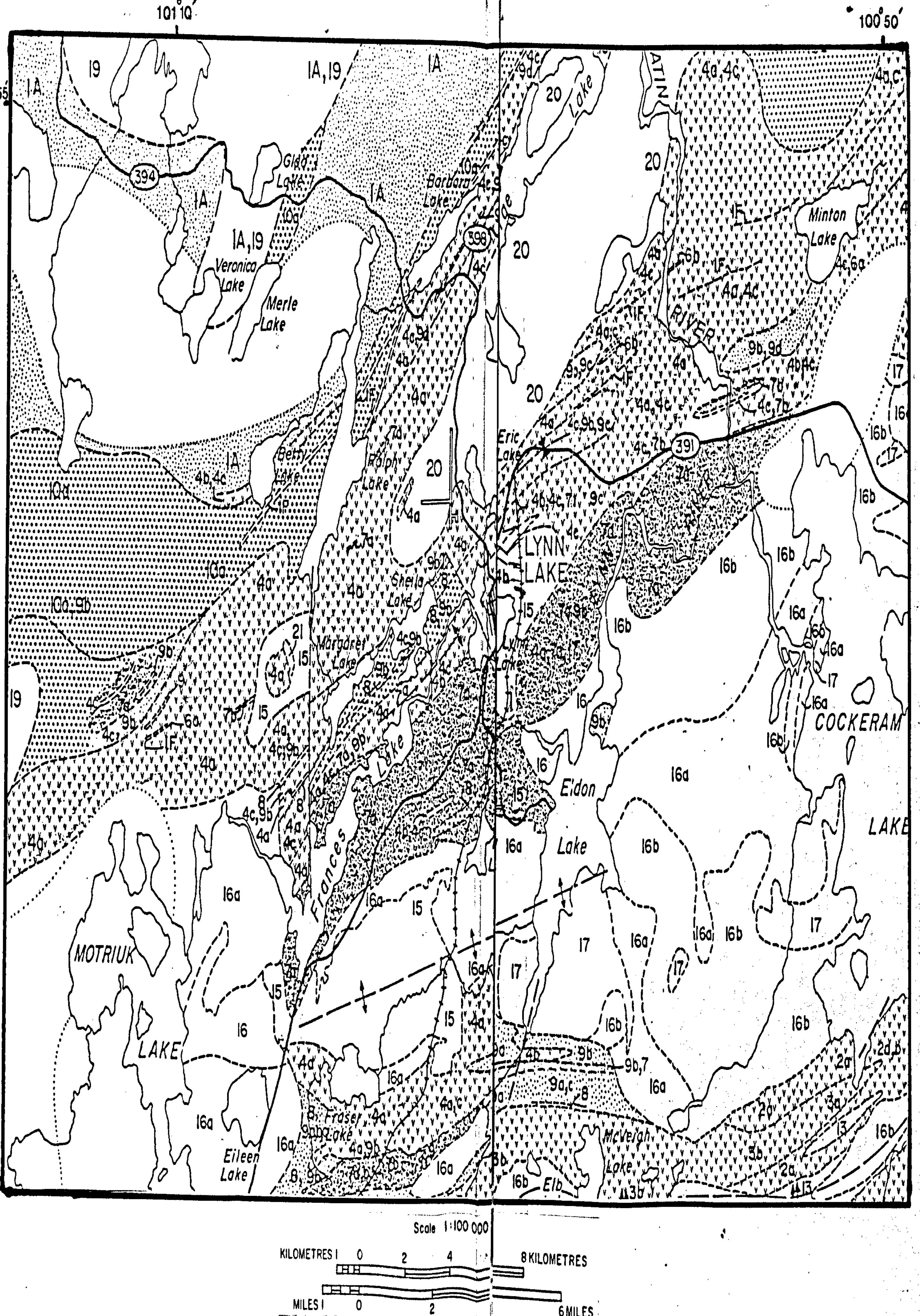

101°10′
100°50′
56°55′
56°46′
LYNN LAKE
Gilda Lake
Barbara Lake
Veronica Lake
Merle Lake
Betty Lake
Ralph Lake
Sheila Lake
Margaret Lake
Eric Lake
Lynn Lake
Frances Lake
Eldon Lake
Minton Lake
COCKERAM LAKE
MOTRIUK LAKE
Fraser Lake
Eileen Lake
McVeigh Lake
RIVER
394
398
391
Scale 1:100 000
KILOMETRES 1 0 2 4 8 KILOMETRES
MILES 1 0 2 6 MILES

Figure 2 Geological Map of the Lynn Lake Area (Adapted from Pinsent 1980) second largest volume of extrusives in the entire Lynn Lake Greenstone Belt (Gilbert et al. 1980) and it forms a mafic volcanic platform for the rest of the Wasekwan Group. Gilbert et al. (1980) believe that the Cockeram Lake Basalt represents an Aphebian shield that is similar to modern Cenozoic island-arc shield volcanos.

Interfingered with the Cockeram Lake Basalt unit is a porphyritic basalt known as the McVeigh Lake Basalt unit. The McVeigh Lake Basalt rests conformably on the Cockeram Lake Basalt where they are not intercalated (Gilbert et al. 1980) (Table 3). The McVeigh Lake Basalt is composed of a mixed lava and pyroclastic morphology and is more calc-alkline than the underlying Cockeram Lake Basalt. The porphyritic flows form thick massive layers, contributing to the formation of the overall mafic platform.

The Cockeram Lake and McVeigh Lake Basalts may define either two individual eruptions or two eruptive centres. They also represent an overall tholeiitic to calc-alkline progression that is typical of an island-arc cycle (Windley 1977).

b) Fraser Lake Felsic Volcanic Body

The Fraser Lake Felsic Volcanic Body is predominantly rhyolite in composition with some dacite and it is concentrated in the centre of the southern belt. These volcanics are considered to be a distinct period of rhyolite effussion from a separate eruptive centre (Gilbert et al. 1980). The sequence includes massive aphyric, porphyritic and tuffaceous rocks. It rests conformably on the Cockeram Lake and McVeigh Lake Basalts (Table 3).

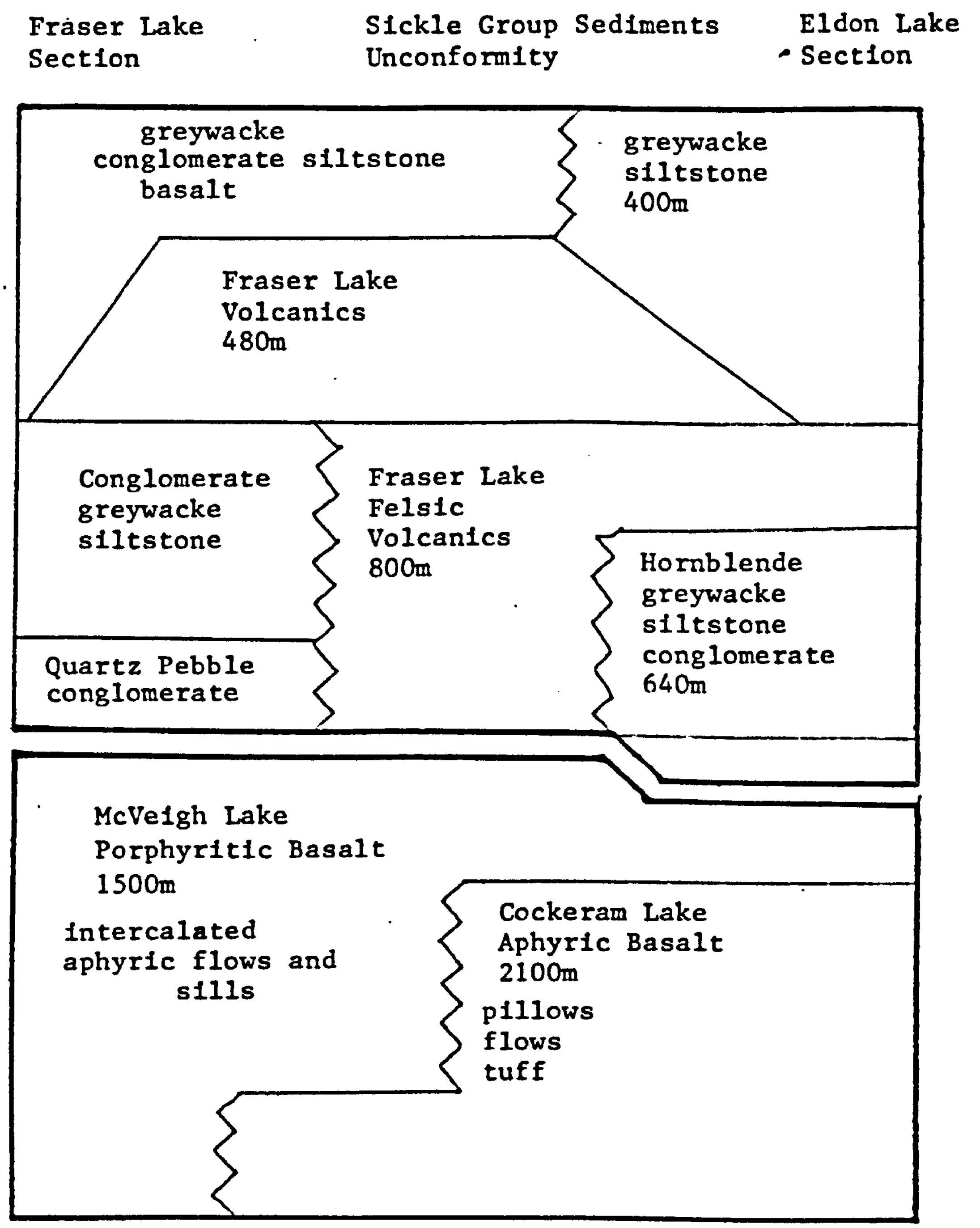


Table 3 **Southern Belt Stratigraphy of the Wasekwan Group**

(after Gilbert *et al*. 1980)

c) Fraser Lake-Eldon Lake Sediments

The Fraser Lake-Eldon Lake Sediments are a group of epiclastic rocks derived from the Fraser Lake Felsic Volcanic Body. This layer is composed of proximal conglomerate facies and a distal greywacke facies which are intercalated with the Felsic Volcanic Body (Table 3).

The resulting pattern of volcanic centres and their associated volcaniclastic aprons are very typical of present day volcanic arcs (Dickinson 1974).

d) Fraser Lake Mafic Volcanic Body

The uppermost mafic unit in the southern belt is the Fraser Lake Mafic Volcanic Body. It rests on and is intercalated with the distal greywacke-silt stone facies (Gilbert et al. 1980) (Table 3). These volcanics are composed of brecciated, porphyritic and aphyric basalts and andesites with the breccias being the most abundant component. This mafic volcanic unit is very similar to the larger volumes of mafic volcanics found in the northern belt. Gilbert et al. (1980) have suggested that the mafic volcanics of both the southern and northern belts are similar and that they have been repeated by folding and faulting prior to being separated by the east-west granitoid axis.

2. Northern Belt

The northern belt of the Lynn Lake Greenstone Belt is dominated by mafic volcanics in a homoclinal structure with reverse folds in sediments (Gilbert et al. 1980). There are six stratigraphic divisions in the Wasekwan Group of the northern belt (Table 4).

a) Division "A"

Division "A" or the Lynn Lake Rhyolite are assumed to be the oldest rocks in the northern belt. The rhyolite is predominantly massive with some breccia and intercalated mafic volcanics. Gilbert et al. (1980) suggested that the rhyolite may be genetically related to some of the shallow, intrusive plutons in the area.

b) Division "B"

Division "B" consists of mafic to felsic volcanic flows and fragmental rocks resting conformably on the rhyolite flows of the "A" division (Table 4). Mafic tholeiitic flows are the most abundant rock type and are definitely iron-enriched. The fragmental rocks of this division are extremely coarse and possibly reflect the proximity of the volcanic centre (Gilbert et al. 1980).

c) Division "C"

This division consists of a series of sediments intercalated with and resting conformably on division "B" (Table 4). These sediments form an elongated body consisting of conglomerate, greywacke and siltstone interlayered with subordinate volcanics. Overall, the sediments are volcanogenic in origin and reflect a shallow-water environment with progressively deeper-water turbidity current flows (Gilbert et al. 1980).

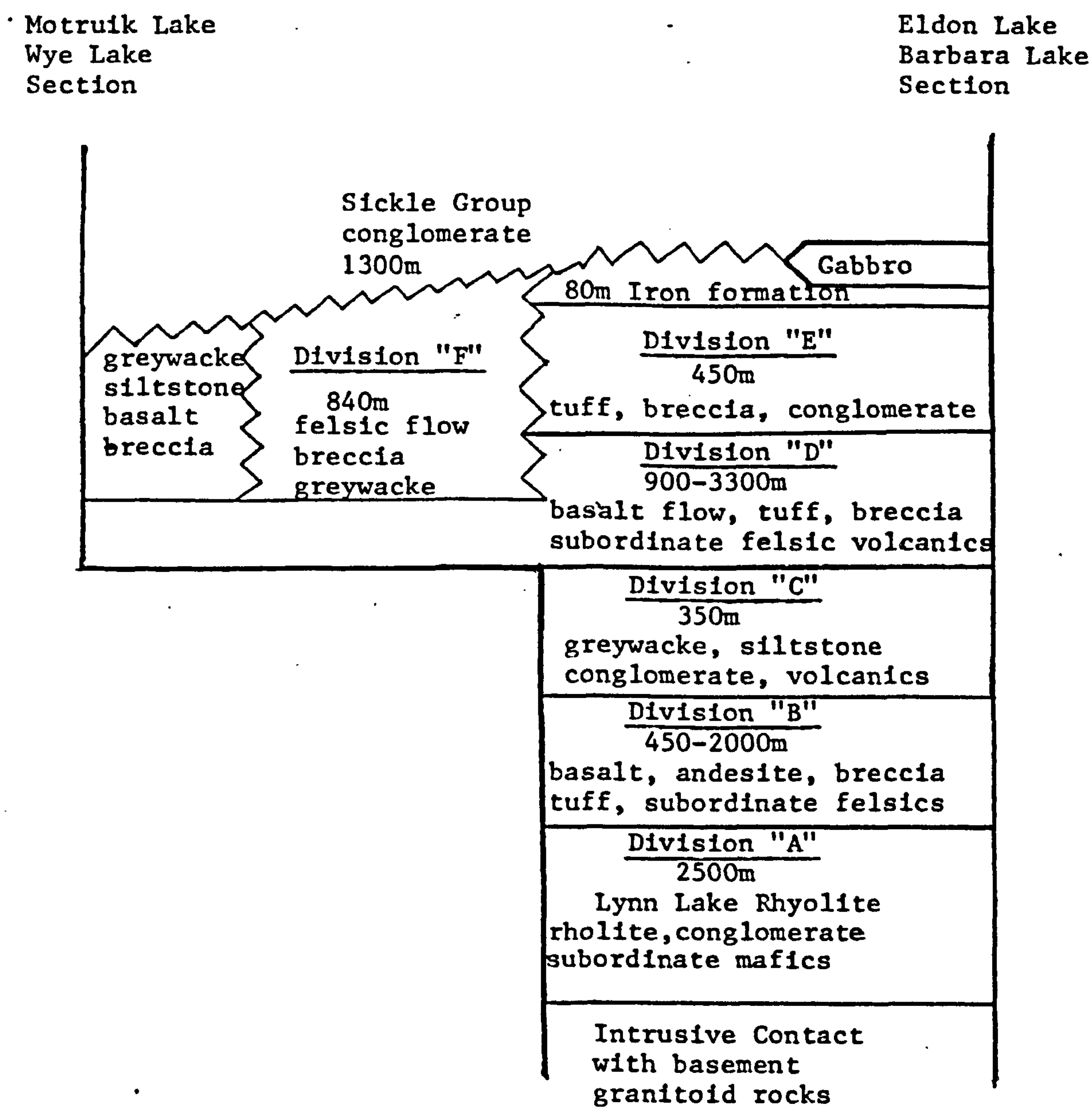


Table 4 **Northern Belt Stratigraphy of the Wasekwan Group**

(after Gilbert et al. 1980)

d) Division "D"

Division "D" conformably overlies "C" and is composed of a thick layer of mafic basaltic flows with minor breccia (Table 4). "D" is similar to division "B" in type and composition of the basaltic flows. These mafic flows of division "D" also represent the greatest volume of basalt in the northern belt.

e) Division "E"

Division "E" consists of mafic tuffs, flows, and breccia that overlie "D" (Table 4). Demarcation between "D" and "E" is based on the amount of mafic tuff present and suggests that the two divisions are time equivalent. The presence of more mafic minerals may represent the start of a new volcanic cycle (Gilbert et al. 1980).

f) Division "F"

Division "F" is a felsic volcanic unit similar in composition to that of the Lynn Lake Rhyolite of division "A". This felsic volcanic unit rests conformably on division "D" and is intercalated with division "E". The stratigraphic position of this division supports the possibility of a new volcanic cycle (Gilbert et al. 1980).

3. Post-Wasekwan

After development of the volcanic and volcaniclastic sedimentary stratigraphy of the southern and northern belts, the next geological event was a period of deformation and metamorphism of the Lynn Lake

Greenstone Belt. This was followed by a period of mafic intrusions (Lynn Lake gabbro, Fraser Lake gabbro) and then the large intrusion of acidic composition which creates the axis dividing the northern and southern belts.

B. Pre-Sickle Intrusives

1. Mafic Intrusions

The mafic intrusions of the Lynn Lake Greenstone Belt are classified as follows by Pinsent (1977 , 1980) (Figure 3).

1a) Differentiated Stocks

Three of the differentiated stocks - namely the Lynn Lake A, Lynn Lake EL and Fraser Lake plugs - are composite gabbroic plutons which have been intruded with varying degrees of discordance into the Wasekwan Group. The principal rock type is an uralitized gabbro associated with varying amounts of peridotite, diorite and mineralized norite. These associated rock types represent injections within the main gabbro. These intrusions are sheared adjacent to the country rock contact but are otherwise undeformed. These are the three plugs being analysed in this study, and they will be described in more detail later.

The Curr Lake plug is vertical stock surrounded by acidic to intermediate intrusions. It is an undeformed plug made up of

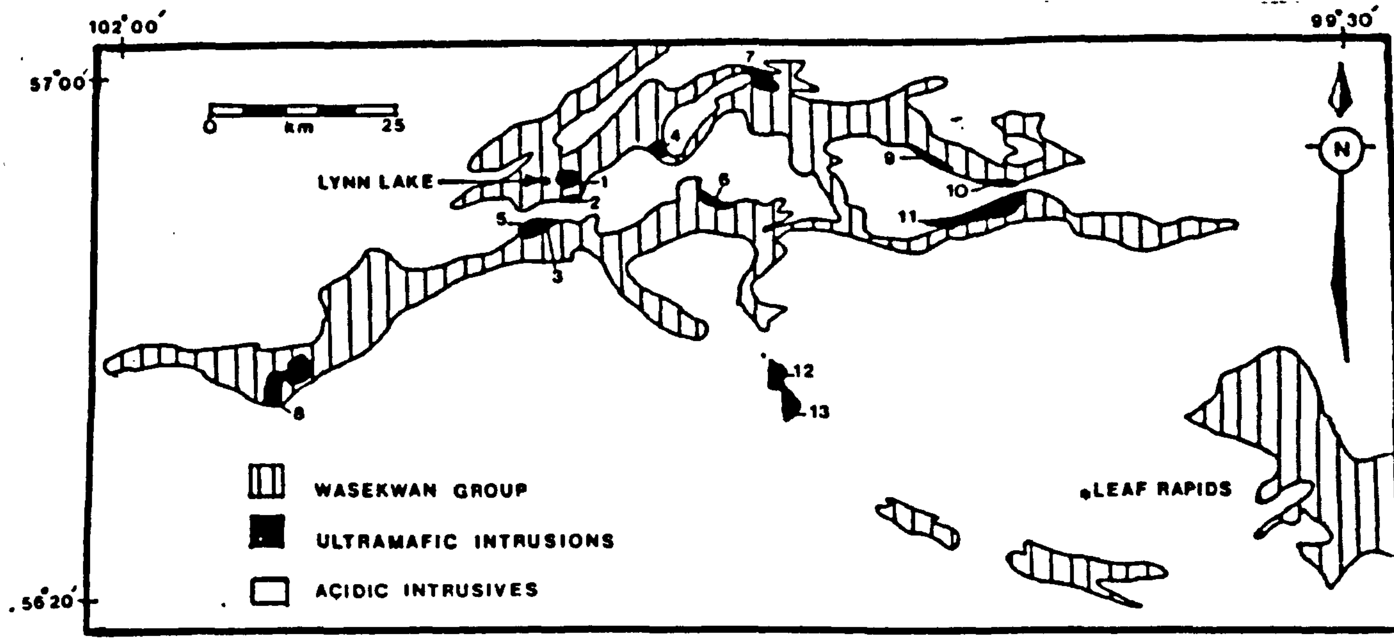


Figure 3 Occurrence of Mafic Intrusions in the Lynn Lake Area (Adapted from Pinsent 1980)

Group 1: Differentiated Intrusions

1a) Differentiated stocks
1) Lynn Lake A plug
2) Lynn Lake EL plug
3) Fraser Lake SE plug
4) Curr Lake plug

1b) Differentiated sills
5) Fraser Lake Main sill
6) Cartwright Lake sill

Group 11: Undifferentiated Intrusions

11a) Undifferentiated stocks
7) Tulune Lake plug

11b) Undifferentiated sills
8) Snake Lake sill
9) Nickel Lake sill
10) Larson Lake sill
11) Two Lake sill
12) Sickle Lake sill
13) Black Trout Lake sill

Table 5 Mafic Intrusions of the Lynn Lake Greenstone Belt feldspathic gabbro and norite. This plug is also cut by aphanitic diabase and aplitic granite dykes.

Even though all the plugs in this group are mineralized, none are as extensively mineralized as the "A" and "EL" plugs.

1b) Differentiated Sills

The "differentiated sills" (5 & 6 in Figure 3) consist of undeformed and differentiated gabbro overlain by a norite unit which displays a compositional layering. The norite unit includes feldspar and orthopyroxene-rich cumulate layers with a small amount of olivine. At the inferred top of the Cartwright Lake sill, there is a layer of abundant magnetite.

The Cartwright Lake sill is concordant with the local stratigraphy but disconcordant in terms of the regional structures (Syme 1976). It is a 700m wide, differentiated intrusion that is associated with a group of less differentiated sills. These have all been truncated by a younger complex of acidic intrusions.

The Fraser Lake Main sill has been studied by Emslie and Moore (1961) and Hulbert (1978). This plug appears to be a laterally-compressed, funnel-shaped layered intrusion located in the nose of a major syncline (Gilbert 1976). The plug has been truncated by a younger acidic intrusion which also intruded along the contact between the gabbro and the country rock.

Though much exploration has been done on these two intrusions, neither one appears to have economic mineralization.

11a) Undifferentiated Stocks

The Tulune Lake plug is a disconcordant vertical plug consisting of amphibolitized metagabbro. It is cut by a series of fine-grained metadiabase and aplitic granite dykes. The stock shows no mineralization at all.

11b) Undifferentiated Sills

All six examples (8-13 in Figure 3) appear to be stratigraphically concordant but are structurally deformed. The main rock type is a uniform metadiabase with a pronounced schistosity only in shear zones cutting the intrusions. These undifferentiated sills are thought to be subvolcanic intrusions that are directly related to the Wasekwan mafic volcanics. Even though they have some features in common with the differentiated group, none of them are mineralized.

2. Acidic-Intermediate Intrusions

The acidic to intermediate intrusions are large disconcordant composite plutons that intrude both the Wasekwan Group and the gabbros along an east-west trend (Milligan 1960) (Table 6). These intrusions divide the Lynn Lake Greenstone Belt into northern and southern belts. They range in composition from diorite and tonalite to a true granite. The intrusions appear to be structurally controlled between the mafic volcanics and the Lynn Lake Rhyolite flows. The contacts with the volcanics are generally sharp whereas the contacts with the gabbros

LYNN LAKE GREENSTONE BELT

faulting, northerly, e.g., Muskeg Lake, northwest, e.g., Lynn Lake

D5 continued development of foliation, cataclasis (northeasterly);
open cross folding

felsic intrusion e.g., Burge Lake
Rb-Sr w.r. age: 1765 ± 100 Ma

metamorphism locally retrograde

mafic to felsic intrusion, e.g., Laurie Lake

D4 shearing, faulting (east and northeasterly, e.g., Cartwright Lake)
formation of basins and domes (north- and east-trending)
e.g., Hughes Lake e.g., Eager Lake
development of foliation, regional metamorphism
anatexis, Rb-Sr w.r. age 1.74-1.78 ± 0.1 Ga

D3 thrusting at the belt margins
e.g., Tod Lake

diorite intrusion (Black Trout)

sedimentation

Sickle Group (shallow water, terrestrial)

D2 uplift, erosion, faulting, tilting

felsic intrusion e.g., Hughes Lake
Rb-Sr w.r. age: 1940 ± 75, 1825 ± 210 Ma

mafic intrusion, e.g., Lynn Lake

D1 folding faulting (east-northeasterly)

Wasekwan Group

mafic to felsic intrusion
mafic to felsic tholeiitic and calc-alkaline volcanism

felsic volcanism, faulting, sedimentation

mafic tholeiitic volcanism

Table 6 Tectonic Evolution of the Lynn Lake Greenstone Belt

(after Gilbert et al. 1980)

range from sharp with the presence of chilled margins to gradational hybrid zones. Exposure of these contacts is poor but inclusions of both the country rock and the gabbros have been found which is indicative of their stratigraphic position. Also, a series of related dikes with similar compositions to these intrusions, cut both the country rock and the gabbros (Emslie and Moore 1961).

This period of intrusion was followed by the deposition of the sedimentary rocks belonging to the Sickle Group.

C. Sickle Group

The Sickle Group is composed of 3900m thick unit of sedimentary rocks (Gilbert et al. 1980). These rocks rest unconformably on the Wasekwan Group and the gabbroic and granitoid intrusions (Milligan 1960). These sediments are composed of two layers, one of conglomerate and the other of arkosic sandstone. The conglomerate consists of subrounded pebbles and cobbles of quartz feldspar porphyry, granodiorite, mafic and felsic volcanics and arkose lenses. Conformably overlying the conglomerate is an arkosic sandstone which has been derived from a granitoid terrane. Milligan (1960) has suggested that the Sickle sediments were laid down in a gradually deepening basin.

D. Deformation and Metamorphism

The deformation of the Lynn Lake Greenstone Belt took place in two stages, one during and after the deposition of the Wasekwan Group and the other after the Sickle Group (Milligan 1960). The early block faulting during the formation of the Wasekwan Group is recorded in the conglomeratic turbidite that is infilling the tectonic depression formed during the island-arc activity. There is also an abrupt facies change from the thick lower mafic volcanics to the upper greywacke unit (Gilbert et al. 1980).

The Wasekwan Group was laid down in a synclinal structure and then isoclinally folded with steeply-dipping ENE trending axial surfaces (Gilbert et al. 1980). These folds are truncated by the large pre-Sickle granitoid plutons and the Lynn Lake gabbros (Table 6). Large folds with gently curved axial traces dominate the southern belt. These traces are parallel to the ENE regional trend of the greenstone belts. Two major antiforms in the mafic platform of the southern belt can be recognized and may represent the eruptive centre for the basaltic magmas.

The northern belt consists of a monoclinal structure with a younging sequence to the north (Gilbert et al. 1980). Milligan (1960) reports that minor folding is evidenced by reversal of the graded bedding in the volcanoclastic sediments of the northern belt.

The Wasekwan Group was next intruded by the gabbroic plutons and then by the granitoid plutons (Milligan 1960). The granitoid intrusions cut the main greenstone belt into its southern and northern subbelts, and created a E-W trending axis across the belt. The Sickle Group rests unconformably on top of the intrusions and the Wasekwan Group, truncating the ENE structures of the Wasekwan Group (DI) (Table 6). The Sickle Group was also folded to produce second generation folding in the Wasekwan Group (Milligan 1960).

The greenstone belt has been regionally metamorphosed from the upper greenschist to the middle amphibolite facies levels. Milligan (1960) has shown evidence for two periods of metamorphism - one before and one after deposition of the Sickle Group. He has contended that the intrusions have not contributed to the overall metamorphism of the Lynn Lake Greenstone Belt.

Plug Geology

A. Lynn Lake Gabbros

1. "A" Plug

The "A" plug is kidney-shaped mafic to ultramafic intrusion that hosts ten nickel-copper ore bodies in discrete ore pipes. The plug intrudes the Wasekwan Group with a slight discordance (Pinsent 1980) and appears to be structurally controlled between the Lynn Lake Rhyolite and the Cockeram Lake Basalts (Figure 4). The plug parallels the regional ENE trend and has sharp, vertical contacts. Inclusions of the country rock have been identified within the plug that define its relative position in the stratigraphic table (Milligan 1960) (Table 7).

The plug .s cut by the lower "O" and upper Lynn Lake reverse faults which trend N 45° W and dip 50° NE. These faults postdate the emplacement of the plug because some portions of the plug are thrust over the Wasekwan Group. The net slip along both faults is 570m. Between the two faults are a number of smaller faults that Pinsent (1980) has suggested postdate the two major faults. Displacement along these smaller faults was generally less than 35m, and they are the locus for postore acidic and mafic dikes. The plug also has been cut by the "Q H D" dikes (Quartz-Hornblende-Diorite following Sherritt Gordon Mines nomenclature). The age of these dikes is not definitely known (Vellet 1963). They appear to cut some of the ore bodies but they also provide conditions for localization of some of the ore bodies.

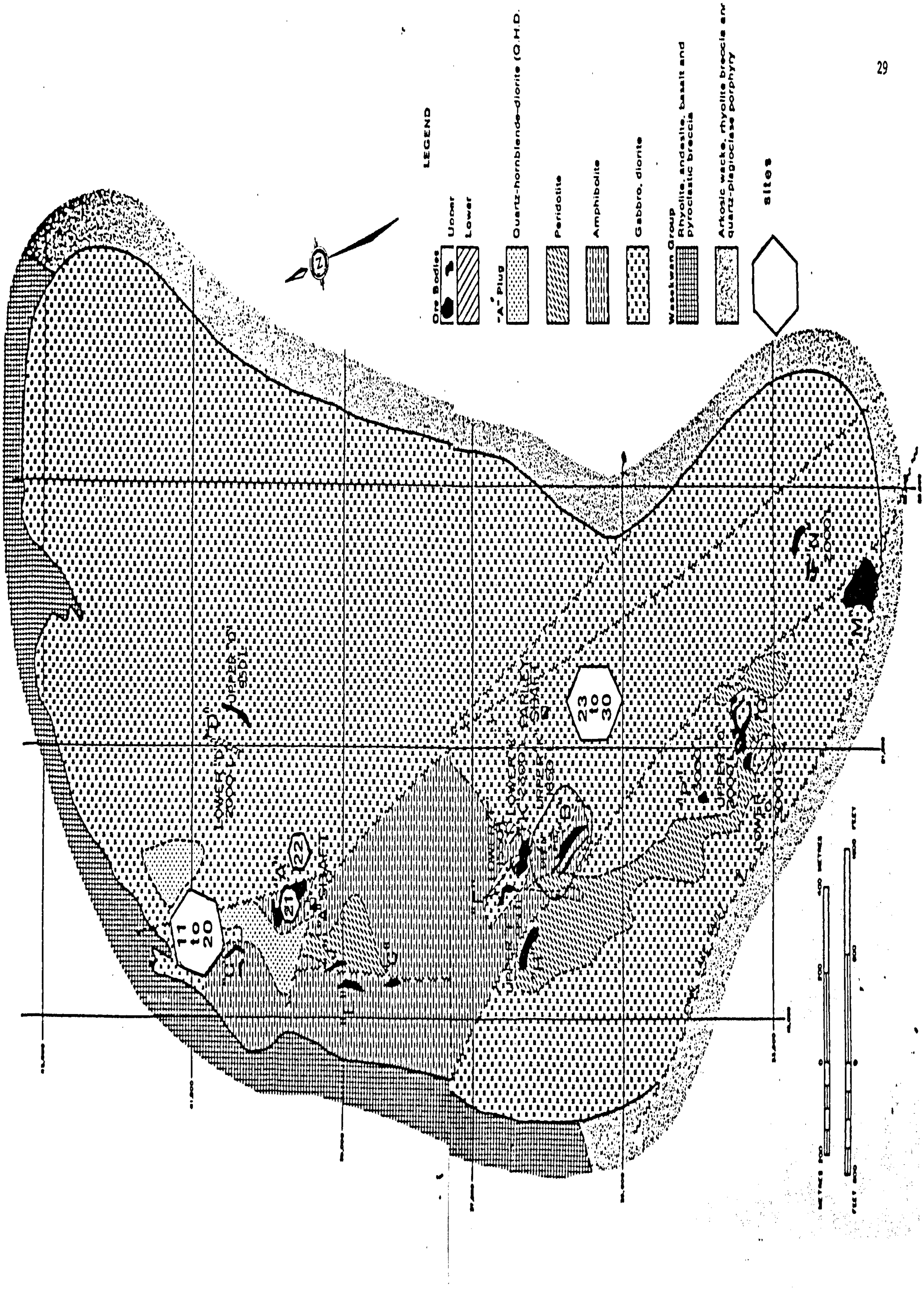

LEGEND
Ore Bodies
Upper
Lower
"A" Plug
Quartz-hornblende-diorite (Q.H.D.
Peridotite
Amphibolite
Gabbro, diorite
Wasekwan Group
Rhyolite, andesite, basalt and pyroclastic breccia
Arkosic wacke, rhyolite breccia and quartz-plagioclase porphyry
sites
11 to 20
21
22
23 to 30

Figure 4 A Plug Geology and Site Location (Adapted from Pinsent 1980)

The "A" plug is comprised of gabbro and amphibolite with associated peridotite, norite, siliceous gabbro, mottled gabbro and intermediate composition rocks (Pinsent 1977). The more mafic and ultramafic rocks occur in the western half of the plug where they are associated with the major portion of mineralization (Figure 4). These ore bodies yielded 28,410,570 tons of ore with a grade of 0.906% Ni and 0.489% Cu.

2. "EL" Plug

The "EL" plug is a discrete composite pipe which has disconcordantly intruded the Lynn Lake Rhyolite of the Wasekwan Group (Milligan 1960). This plug has also been cut by two major reverse faults (Figure 5) (Vellet 1963). The upper fault trends N 45 W and dips 35 NE. This is about the same as the Lynn Lake fault of the "A" plug, thereby indicating that it may be an extension (Pinsent 1977). This upper fault also cuts the main ore body in the "EL" plug, as the upper fault of the "A" plug cuts into its ore bodies (Vellet 1963). The lower fault also trends N 45° W but dips 60° to 80° N and again cuts the ore bodies in the "EL" plug. A series of small EW faults also cut the ore bodies between the main upper and lower faults.

The "EL" plug consists of three main rock types-peridotite, amphibolite and diorite. These have formed a conical structure with an outer margin of gabbro and diorite and an inner core of amphibolite and peridotite (Figure 6). The ultramafic core hosts most of the nickel-copper mineralization (Vellet 1963). A "Q H D" dike is found in the plug where it cuts both the ore bodies and the faults (Pinsent 1980). The contacts between the plug and the Wasekwan Group are vertical and show no signs of chilled margins (Figure 6) (Pinsent 1977). This plug appears to have been formed from multiple injections of a mafic to ultramafic cumulate crystal mush (Vellet 1963). A total of 1,909,673 tons of ore were removed from the "EL" plug at grades of 2.07% Ni and 0.76% Cu.

Emslie and Moore (1961) suggested that the Lynn Lake "A" and "EL" plugs were at one time part of the same gabbroic body. They suggested that the pluton was a layered gabbroic body that was tilted to the vertical and faulted into two separate bodies. Vellet (1963) and Pinsent (1977, 1980) have shown that the "A" and "EL" plugs are not only separate plutons but that they started out that way. These conclusions are based on studies of the geochemistry of the plug's and on the identification of different structures and rock types. They suggest that the intrusions are not simple layered plutons but rather a series of complex cumulate injections of differing mafic compositions. They contend the plugs have not been tilted since formation in the Aphebian. Table 8 shows the development of the "A" and "EL" plugs.

3. Petrology

The "A" and "EL" plugs consist of an internal amphibolite and gabbro complex with associated intrusions of mineralization and intermediate rock types (Pinsent 1980). These rock types have been derived from a series of multiple injections from a remobilized mafic cumulate magma. Vellet (1963) subdivided the gabbroic intrusions into four divisions. Later Pinsent (1980) reclassified the intrusions into

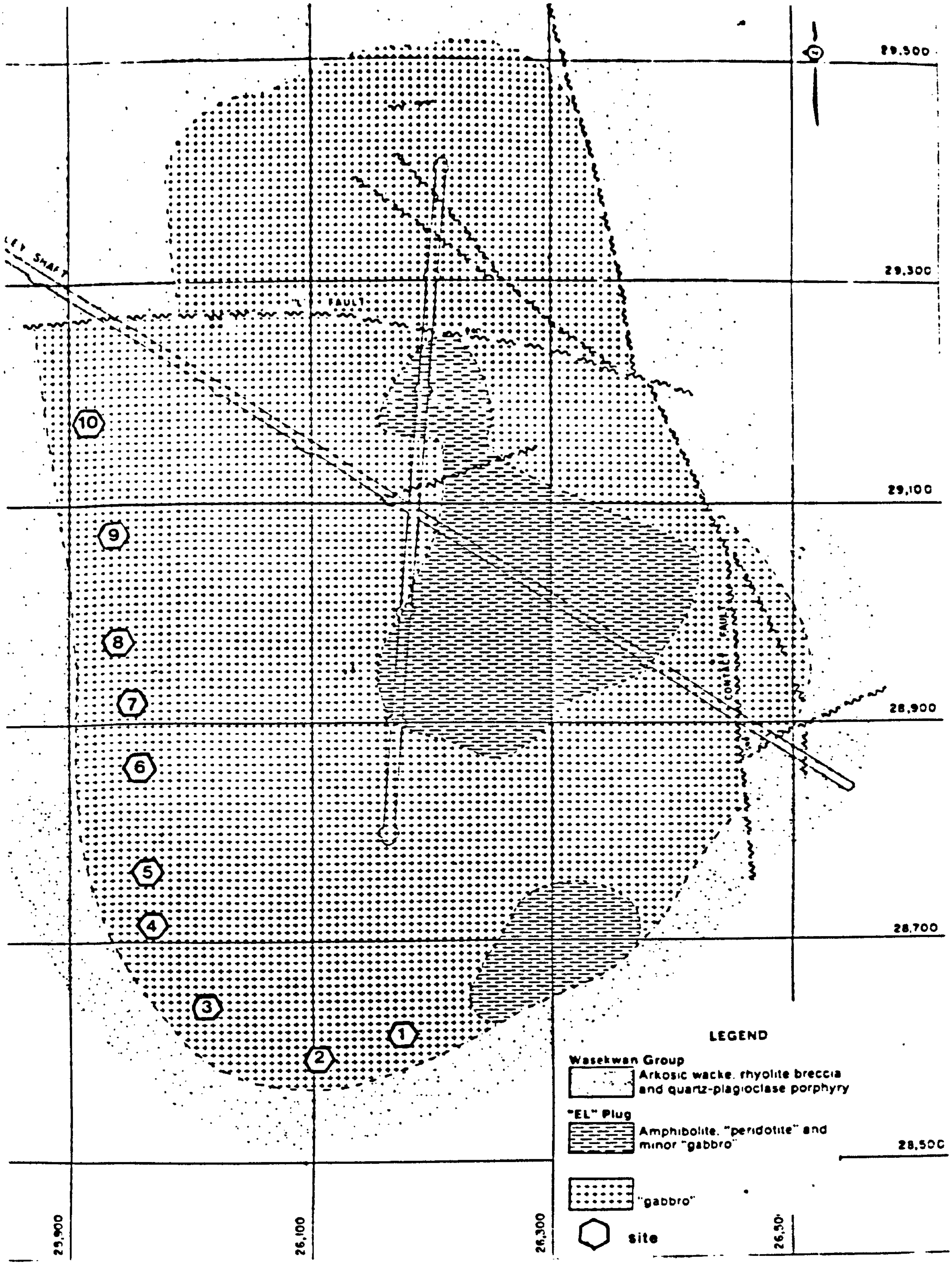


Figure 5 EL Plug Geology and Site Location (Adapted from Pinsent 1980)

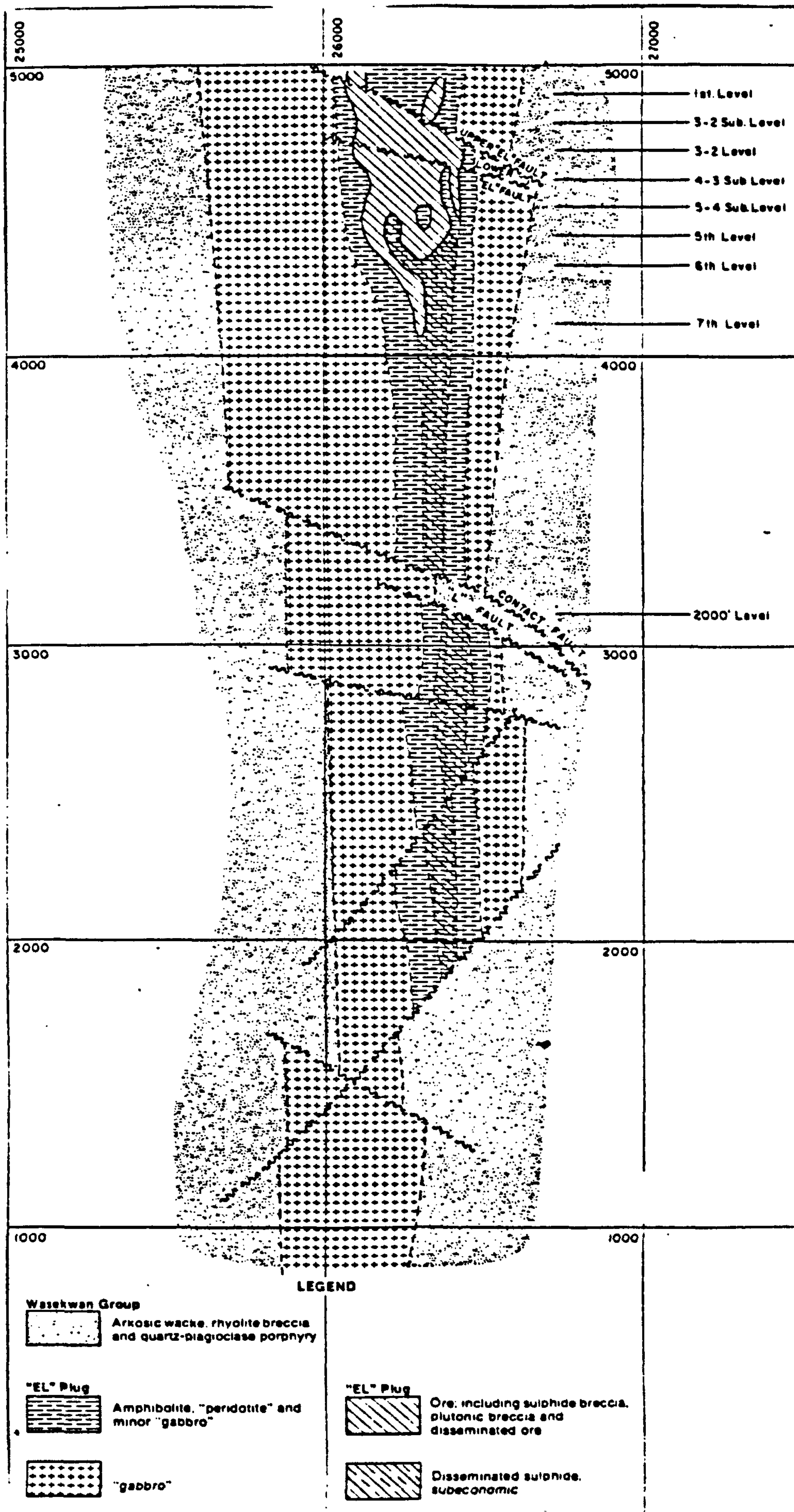


Figure 6. **EL Plug Cross Section (Adapted from Pinsent 1980)**

(1) Post-Wasekwan deformation, granite intrusion and metamorphism of Wasekwan Group metasediments and metavolcanics.

(2) Intrusion of "A" and "EL" plug "gabbro".

(3) Faulting(?).

(4) Intrusion of minor phases ("peridotite", "pyroxenite", "quartz-hornblende-diorite", "diorite").

(5) Partial, static, uralitization of "A" and "EL" plug "gabbro" and formation of siliceous felsite veins (ore-type 5).

(6) Intrusion of mineralized norite (ore-type 1) with (a) formation of contact breccia (ore-type 2) and (b) segregation of sulphide (ore-types 3 and 4).

(7) Further uralitization

(8) Deformation, with (a) disruption of siliceous felsite veins in plutonic breccia (ore-type 2), (b) further concentration of sulphide in plutonic breccia, (c) concentration of sulphides in fracture sets (ore-type 4) and d) segregation of granitic fluids into pods and veins.

(9) Intrusion of minor plutons of quartz-diorite and granodiorite and granodioritic batholiths in the axis of the Lynn Lake Greenstone Belt.

(10) Injection of late acid to basic dykes

(11) Post-mineral faulting

(12) Completion of hydrothermal activity.

Table 7 Geological History of the A and EL Plugs coarse-grained cumulate intrusives, coarse-grained intrusives and minor intrusives and veins.

a) Coarse-Grained Cumulate Intrusives

i) Peridotite (ultramafic olivine-rich metacumulate)

This rock type can be found in both plugs and ranges from olivine-rich peridotite to an olivine-poor amphibolite. The peridotite has retained its original cumulate texture and the primary mineral is olivine. Uralitization of the peridotite has caused the orthopyroxenes and clinopyroxenes to be replaced by tremolite and chlorite. Associated with the replacement of these minerals is the development of magnetite along the original cleavage planes of the pyroxenes. This rock is medium-grained, dull green and has generally formed in a high Mg and Fe environment.

ii) Amphibolite (ultramafic pyroxene rich metacumulate)

The amphibolites exhibit the replacement of pyroxene by a green fibrous amphibole with associated magnetite. Some of the original pyroxene crystal outlines are well preserved, as is the original texture of the rocks. The mineralized amphibolites contain interstitial blebs of sulphides, and tend to be more altered and recrystalized than the barren amphibolites. These rocks are generally medium-grained, equigranular and have again been formed in a Mg- and Fe-rich environment.

iii) Norite (norite cumulate)

The norites were originally classed as gabbro. They consist of a suspension of orthopyroxene crystals in a plagioclase and sulphide matrix. The crystals are randomly oriented and range in size from 0.5 to 5.0mm. The matrix contains various amounts of orthopyroxene (enstatite En_{80}), plagioclase feldspar (An_{75}), clinopyroxene (augite) and olivine (FO_{82}). The norites also contain primary hornblende which has magnetite within its crystal cores. The norites are medium-grained, dark grey hyposilicic rock and they contain the bulk of the mineralization in the "A" plug.

iv) Silicified Gabbros (silicified noritic cumulate-hybrid)

This unit is the most abundant rock in the plugs. It consists of a medium-grained homogenous gabbro and a mafic/felsic banded gabbro. The homogeneous gabbros contain equal amounts of secondary amphibole and recrystalized feldspar. Although the gabbros have been uralitized, they still retain their original igneous texture. The most common mineral is a green fibrous amphibole, replacing the original orthopyroxene. The gabbro is generally quartz-free except where intruded by veins of intermediate composition. This unit is barren to weakly mineralized and is the host rock for the more mineralized rock types.

The banded gabbros have a strong preferential crystal orientation reflecting the original pyroxenes and feldspars. They are most prominent on the western margin of the "A" plug where it contacts the

Wasekwan Group (Vellet 1963). These banded gabbros are a minor component in both plugs.

b) Coarse Grained Intrusive

i) Mottled "Gabbro" (High-alumina gabbro/norite)

These gabbros are distinguished from the rest on the basis of their dominant amphibole and mode of feldspar occurrence. The feldspar occurs in clusters which causes the mottled appearance of the gabbro. The amphibole is thought to be primary and to be formed prior to the uralitization of the normal gabbro.

ii) Diorite (High-alumina norite)

This is a fine-grained intrusive that occurs in the vicinity of the ore bodies. The rocks are homogeneous, equigranular and contain plagioclase and actinolite amphibole. The amphibole mineral is replacing the primary pyroxene of the diorite. The overall mineralogy is quite similar to that of the normal gabbro but there are definite differences in the grain size and texture.

c) Minor Intrusive

i) Q H D (Quartz Hornblende Diorite)

This term was adopted by the Sherritt Gordon Company to describe a wide variety of fine-grained mafic to intermediate composition rocks. The rocks are generally aphanitic and are composed of amphibole, altered plagioclase, biotite, chlorite, quartz and epidote. The intrusives are deformed and recrystallized, and they represent pre-ore dike swarms.

d) Summary

Generally the mineralization of both plugs is restricted to the norites that have primary mineral assemblages. The other rocks represent a metamorphic secondary assemblage dominated by amphiboles. This amphibole occurs in three types:

1) clinopyroxene replacement (normal gabbros)
2) primary amphibole (mottled gabbro, mafic, intrusives)
3) orthopyroxene replacement (amphibolite)

The alteration of the rocks seem to either precede and to take place at the same time as the ore emplacement. Therefore, the differentiation and hydrothermal activity appears to have been synchronous with the development of the plugs.

4. Geochemistry

The geochemical study done by Pinsent (1980) shows that the nickel-copper ore in the Lynn Lake gabbros is related to a mafic-ultramafic cumulate. This differentiate came from a Mg-rich high-alumina tholeiite magma. These two plugs consist of a remobilized cumulate which has had an early fractionation of olivine, orthopyroxene and clinopyroxene to produce peridotite and amphibolite. It then had a later fractionation of orthopyroxene to produce the gabbros and norites.

During this period, it also became enriched with Ti, Fe and Na.

This normal gabbro is slightly differentiated magma cumulate which has been intruded by remobilized mafic cumulate (peridotite, norite, amphibolite). The bulk of the mineralization is in the norites. These norites have a high orthopyroxene content which is consistent with the re-mobilization of an orthopyroxene suspension in a sulphide silicate magma.

a) Magma

The mafic cumulate and silicate-sulphide magma appear to have been formed in a magma chamber in the crust under its present position. This mafic cumulate assemblage was deformed and remobilized before it was completely solidified. The magma at this time was contaminated by a minor felsic fluid which would have had a great effect on the original Mg-rich olivine tholeiite during its crystallization (Irvine 1970, 1975). This may have started a segregation of an immiscible sulphide liquid during the precipitation and accumulation of orthopyroxene in the amphibolites and norites. Therefore, this would cause the peridotites and gabbros to be barren of any mineralization. Irvine (1975) suggested that contamination by silica into the tholeiitic magma would enhance the crystallization of orthopyroxene over olivine and plagioclase. This seems to be consistent with what has happened in the Lynn Lake gabbros. Green et al. (1967) stated that a high-alumina basalt would result in an early fractionation of orthopyroxene and again this reflected in the Lynn Lake gabbros.

Therefore, the work of Pinsent (1980) work and the other authors mentioned, suggests that the Lynn Lake gabbros formed from a mafic-ultramafic cumulate associated with a sulphide-silicate magma. It appears that this magma was intruded into the crust in a subvolcanic environment and equilibrated near the surface.

B. Fraser Lake Gabbro

The Fraser Lake Gabbro is a composite, concordant, uralitized gabbroic plug. It intrudes the Lynn Lake Rhyolite and the Fraser Lake Mafic Volcanics of the Wasekwan Group. The plug is truncated in the northeast and southwest by the intrusion of the large granitoid plutons (Figure 7). The contacts with the country rock are vertical and there is no evidence of chilled margins (Hulbert 1978). Inclusions of the country rock can be distinguished in the plug and within these inclusions are identifiable folds and schistosities (Emslie and Moore 1961). These structures indicate that the plug was emplaced after one major period of deformation and metamorphism (Hulbert 1978). The plug's emplacement also predates the main episode of the granitoid intrusions because inclusions of the plug have been identified within the granitoid intrusions (Emslie and Moore 1961).

The plug is composed of normal gabbro, peridotite, amphibolite and layered gabbro. These rock types are all similar to those found in the Lynn Lake Gabbros (Hulbert 1978). The major minerals of the Fraser Lake plug are a green fibrous amphibole which is replacing the original orthopyroxene and plagioclase. There are minor amounts of finely

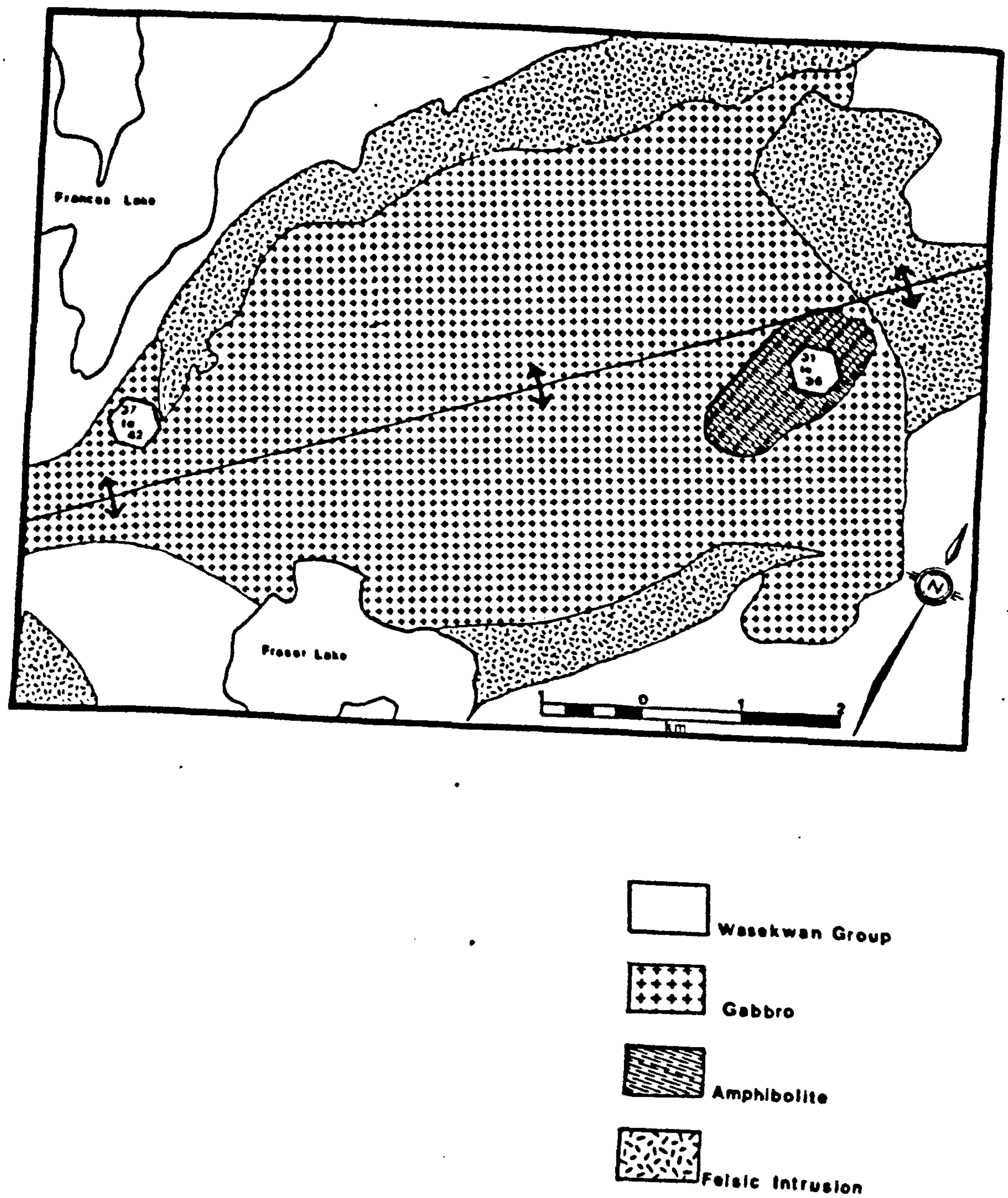


Figure 7 Fraser Lake Plug Geology and Site Location (Adapted from Milligan 1960)

disseminated sulphides and magnetite, but as of yet no major accumulation of sulphides has been discovered (Pinsent 1980). The rocks are medium-grained and have retained most of their primary textures despite being uralitized (Hulbert 1978). The plug seems to have had a similar genetic history as the Lynn Lake Gabbros (Emslie and Moore 1961).

The Fraser Lake Gabbro has an estimated thickness of 1067m (Emslie and Moore 1961) and has originated from a mafic-ultramafic cumulate (Hulbert 1978). The main parent magma was a high alumina basalt which formed the Fraser Lake plug by multiple injections. Hulbert (1978) states that the main difference between the Fraser Lake plug and the Lynn Lake plug is the temperature and depth of formation. The Fraser Lake plug appears to have equilibrated at a temperature of 958-1045° C and at a depth of 3.08km. Also the presence of scattered identifiable hornfels has led Hulbert (1978) to the conclusion that the present day surface expression is the top of the magma chamber. This is in contrast to the development of the "A" and "EL" plugs which differentiated at depth. Pinsent (1980) then suggests the magma chambers were then deformed and intruded into a shallower level of the crust .

Sampling and Measurement

A. Sampling

Forty-two sites (LL84 numbers) were collected from within the three plutons being studied in the project. Sites 1 to 10 (129 specimens) are from the "EL" plug, 11 to 30 (230 specimens) are from the "A" plug, and 31 to 42 (134 specimens) are from the Fraser Lake Plug. The sites were chosen to represent each plug from the available outcrop as well as possible (Figures 4,5,7).

The sampling was done by drilling five cores from each site using a converted two-horsepower Homelite chainsaw motor. After drilling, the cores were oriented in situ with respect to the geographic coordinates using a Canadian Astro Mk II sun compass as well as the Brunton compass. This method of sampling and orientation of cores reduces orienting errors to within $\pm$ 2 degrees.

The cores were then cut in the laboratory at the University of Windsor into specimens with a 2.54cm diameter and a 2.24cm length.

B. Measurement

If a primary magnetic component is to be preserved in a rock, then the rock must contain at least a trace of magnetic minerals and these magnetic minerals must then have relaxation times that are longer than the age of the rocks. The isolation of this primary magnetic remanence and the identification of the magnetic carriers allows for the eventual determination of a paleopole and type of remanence.

1. NRM

All the specimens were measured using the Canadian Thin Film (CTF) cryogenic magnetometer which operates at approximately 4° K. The University of Windsor model uses two superconducting quantum interference detectors (SQUIDs) to measure the magnetic moment of the specimen. This measurement is then fed directly into an Apple II computer which in turn generates the following data: declination, inclination, within-specimen angular standard deviation (ASD) and intensity of the magnetic vector for each measured specimen.

The initial measurement of the specimens is done before any type of demagnetization treatment. This gives a basic data base representing all of the components of the natural remanent magnetization (NRM). From this initial data, pilot specimens are selected for step demagnetization on the basis of their having a high vector intensity, low ASD and consistent remanence direction for the site. All the measurement and demagnetization procedures were conducted in a triple-shield nonmagnetic room. This room reduces the Earth's Magnetic Field (EMF) from its ambient value of $\sim$60,000γ by shielding to $\sim$60γ inside the room (Hushilt 1983) so that the EMF will have negligible effect on the specimens during measurements.

2. Demagnetization

Four pilot specimens were selected from each site, two for thermal step demagnetization and two for alternating field (AF) step demagnetization. The demagnetization process is used to isolate various components of the NRM by removing any viscous remanent magnetization (VRM) and by identifing the underlying magnetic carriers of the NRM.

a) AF Step Demagnetization

The pilot specimens were AF demagnetized with a Schonstedt GSD-1 demagnetizer using ten steps of 5, 10, 15, 20, 30, 40, 50, 60, 80, and 100mT. This type of demagnetization is used to dissect the remanent magnetization according to its coercivity spectrum. During the demagnetization, the low coercivity domains follow the applied demagnetizing field and as this decays the domains are left randomly oriented. Therefore, only the higher coercivity domains contribute to the measured remanence.

After determining the optimum field at which a given component or components of the NRM is isolated, the rest of the collection is demagnetized at this optimum field. This bulk cleaning then provides a large statistical data base for defining the isolated component.

The AF demagnetization method is excellent for determining the coercivity spectrum but is limited to the maximum output of the demagnetizer. The Schonstedt GSD-1 has a peak output of 100mT. This can define the low to medium coercivity spectra of magnetite ($2x10^{-1}$ T) but it is insufficient to isolate the higher spectra of magnetite or of hematite (3.5-6.5T).

b) Thermal Step Demagnetization

Thermal step demagnetization was done with a non-inductive shielded furnace (Schonsted Model TSD-1) by using 12 steps of 200, 300, 400, 450, 500, 525, 540, 560, 575, 625, 640, and 665° C. Thermal step demagnetization is used to dissect the remanent magnetization according to its blocking temperature (Tb) spectrum (Irving et al. 1961). Heating increases the energy of the thermal vibrations of the atoms thereby reducing the relaxation time of the domains in the magnetic minerals. This causes the minerals with low relaxation times to become randomly oriented and thus no longer contribute to the measured NRM. Eventually, all the relaxation times of the minerals are exceeded at the Curie temperature, and the specimen will no longer retain a stable vector (Tarling 1983). In most cases the stable primary remanent magnetization will reside in the minerals with long relaxation times ie. those with single domain or pseudosingle domain grain size. Each magnetic mineral has its own Curie temperature (magnetite 585° C; hematite 675° C) which is reduced by impurities. It should be noted that heating of any magnetic mineral may cause a chemical reaction in which the mineral is destroyed or new ones are created. Therefore, careful analysis of the data is essential.

Statistical Analysis

A. Introduction

In this study, two methods of statistical analysis were used. They are conventional specimen level screening and population level screening. The combination of these two methods enables the objective selection of reliably magnetized specimen directions. These directions are then analyzed to determine the remanence magnetization of the specimens (Stupavsky and Symons 1982).

B. Specimen Level Screening

Specimen level screening was used to select only homogenously magnetized specimens. Each specimen provided magnetic measurements composed of the Cartesian remanence components along the specimen's X, Y and Z axes. These measurements were then used to calculate each specimen's angular standard deviation (ASD) (Reed 1959). The maximum limiting ASD for the acceptance of a specimen's direction is 35°. Above this value there is an estimated 5% probability that the specimen contains no coherent magnetization (Harrison 1980). Based on the remanence characteristics of this collection, the limiting value can be changed to a more stringent optimum screening value of $\leq 30^{\circ}$. This modification to lower the screening level will generally enhance the remanence statistics.

C. Population Screening

Population screening uses all the specimen directions accepted by the specimen level screening. All the accepted specimens have been treated at a common demagnetization treatment. The directions for each demagnetized group are plotted on a Schmidt equal-area stereonet using both the upper and lower hemispheres. The point density is determined and contoured using a 1% area smoothing circle. These contours define an anomaly which specifically define a remanence component. Any grouped vector population (anomaly) is statistically significant at the 95% confidence level when defined by a closed contour defined of $(0.01N + 0.2N^{1/2})$ (100/N) or $E + 2\sigma$. This anomaly may be further defined at the 99% confidence level by $(0.01 + 0.3N^{1/2})$ (100/N) or $E + 3\sigma$, where N is the number of specimens plotted, E is the number of random vectors and is equal to $0.10N^{1/2}$ (Kamb 1959). It should be noted that an anomaly may be statistically but not paleomagnetically significant. The additional requirement for paleomagnetic significance is that the calculated anomaly must represent several sites with more than 5% of the population (Stupavsky and Symons 1982).

The population forming the contoured anomaly is further analyzed to determine the mean paleopole direction for that population. All the directions of that population are grouped together with the "up" direction being reversed to their "down" directions or antipodal positions. Averaging was done on each site for its N vectors to determine K, R, mean declination, mean inclinations and A(95) where N is the number of vectors averaged, K is the precision parameter for a

Fisherian Distribution (Fisher 1953), R is the length of the resultant vector and A(95) is the angular radius of the cone of 95% confidence about the calculated mean (Tarling 1983). This population mean is then used to calculate the paleopole position for the isolated remanence component using the dipole formula.

The paleopole is defined by its geographic longitude and latitude as well as its co-latitude and δm and δp where δm and δp are the semi-axis of the oval of 95% confidence perpendicular to and parallel to the site-pole great circle (Tarling 1983). This paleopole position is then plotted relative to the Apparent Polar Wander (APW) path for the North American craton.

Results

A. Lynn Lake Gabbros

1. "A" Plug

a) NRM

A total of 184 of the 230 specimen vectors or 80% were accepted using the ASD screening criterion. When plotted they produce a significant anomaly in the SE area of the stereonet. This anomaly is defined by the 2.4% density contour (i.e. the 95% confidence level) and with a peak density of >23% (Figure 13). The anomaly is slightly elongated towards the north which probably reflects a VRM due to the present Earth's magnetic field (EMF) acting on the low coercivity components. If this is a VRM then it should be removed during the demagnetizing process.

The mean direction of the anomaly is 152.8° (mean dec.), 54.7° (mean inc.). Given a peak of 23.1%, this anomaly is significant at >>99.99% confidence level (Figure 13). The average NRM intensity of the collection is 6.56E^{-2} Am^{-1} cm^{-3} .

There is no structural evidence to suggest that any of the three plugs being analyzed have been reoriented since emplacement, so that all of the remanence directions are referenced to their present attitude.

b) Step Demagnetization

The specimen level screening was used to analyze the AF and thermal step demagnetization data. There were 38 specimens selected for AF and 38 for thermal step cleaning from the "A" plug. Thirty-six specimens gave acceptable ASD values from the AF cleaning on treatment up to 100mT and 19 specimens were accepted from the thermal cleaning on treatment up to 625°C. The accepted maximum ASD value for both AF and thermal step cleaning was set at 30°.

The magnetic carriers showed a broad range of coercivities and blocking temperatures. The behavior was generally uniform for all the specimens from the "A" plug (Figures 5,8,9). The NRM resides in the magnetic carriers with a medium destructive field of 5mT ie. 50% of the NRM remains after treatment at 5mT. This rapid intensity decay indicates the presence of a relatively large unstable low coercivity component that is readily removed by the AF demagnetization process. Nevertheless, 15% of the NRM intensity remains at 100mT indicating retention of a stable component. During the thermal step cleaning most specimens retain only 12% of the NRM after treatment at 400°C with the rest removed between 575°C and 625°C (Figure 9). Response to both AF and thermal demagnetization support a magnetic mineralogy consisting of magnetite-titanomagnetite. The behavior of the specimens during the step demagnetization also reflects a high percentage of coarse-grained multidomain-size particles comprising the low coercivity component of the NRM. The stable NRM component is held by a discrete small percentage of fine-grained single- or pseudosingle-domain sized particles (Figure 10).

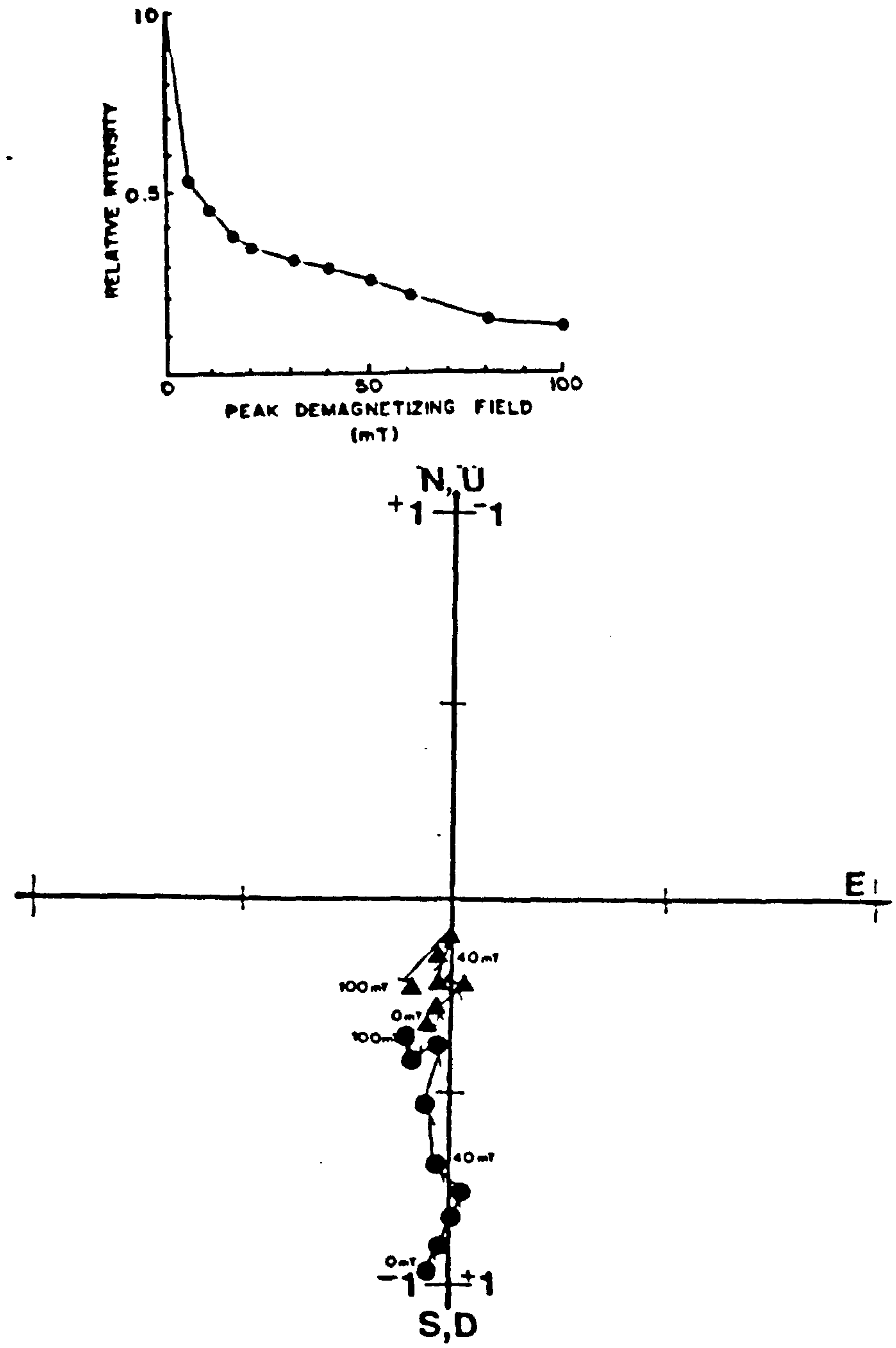
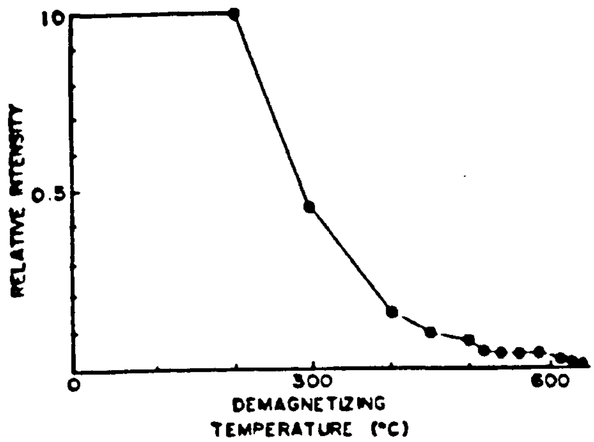


Figure 8 A Plug Average AF Step Demagnetization: Intensity VS Demagnetizing Field, Zijderveld (▲horizontal,●vertical components)



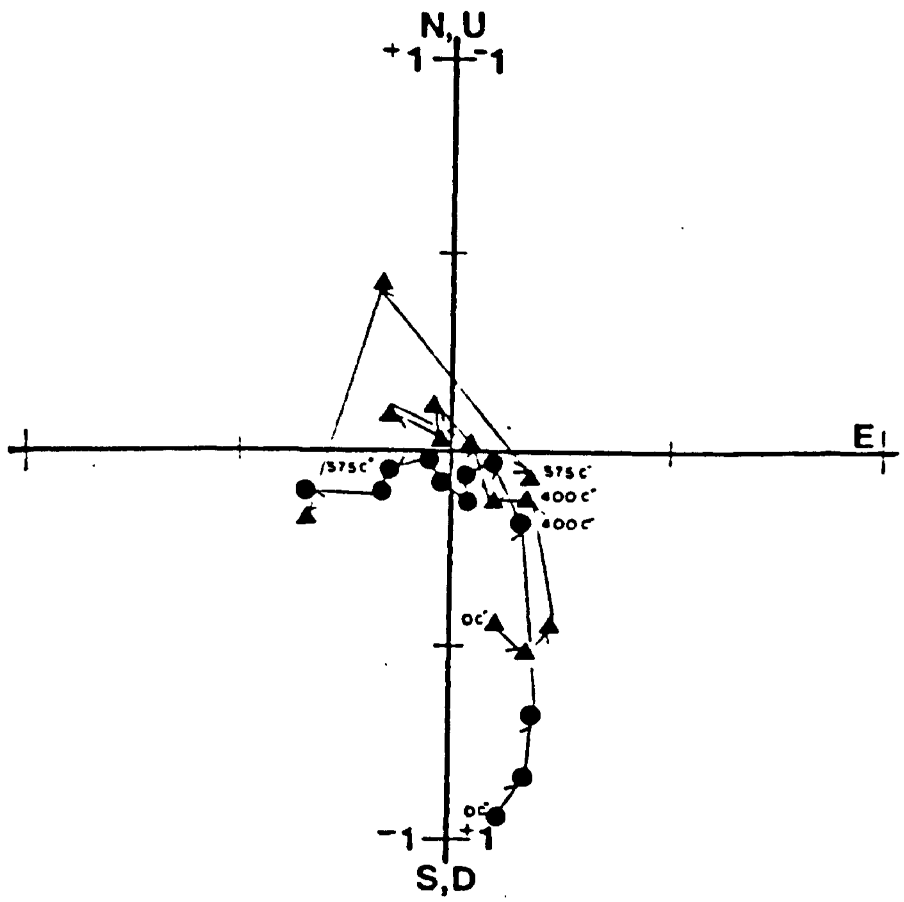


Figure 9 A Plug Average Thermal Step Demagnetization: Intensity VS Demagnetizing Field, Zijderveld (▲horizontal, ●vertical components)

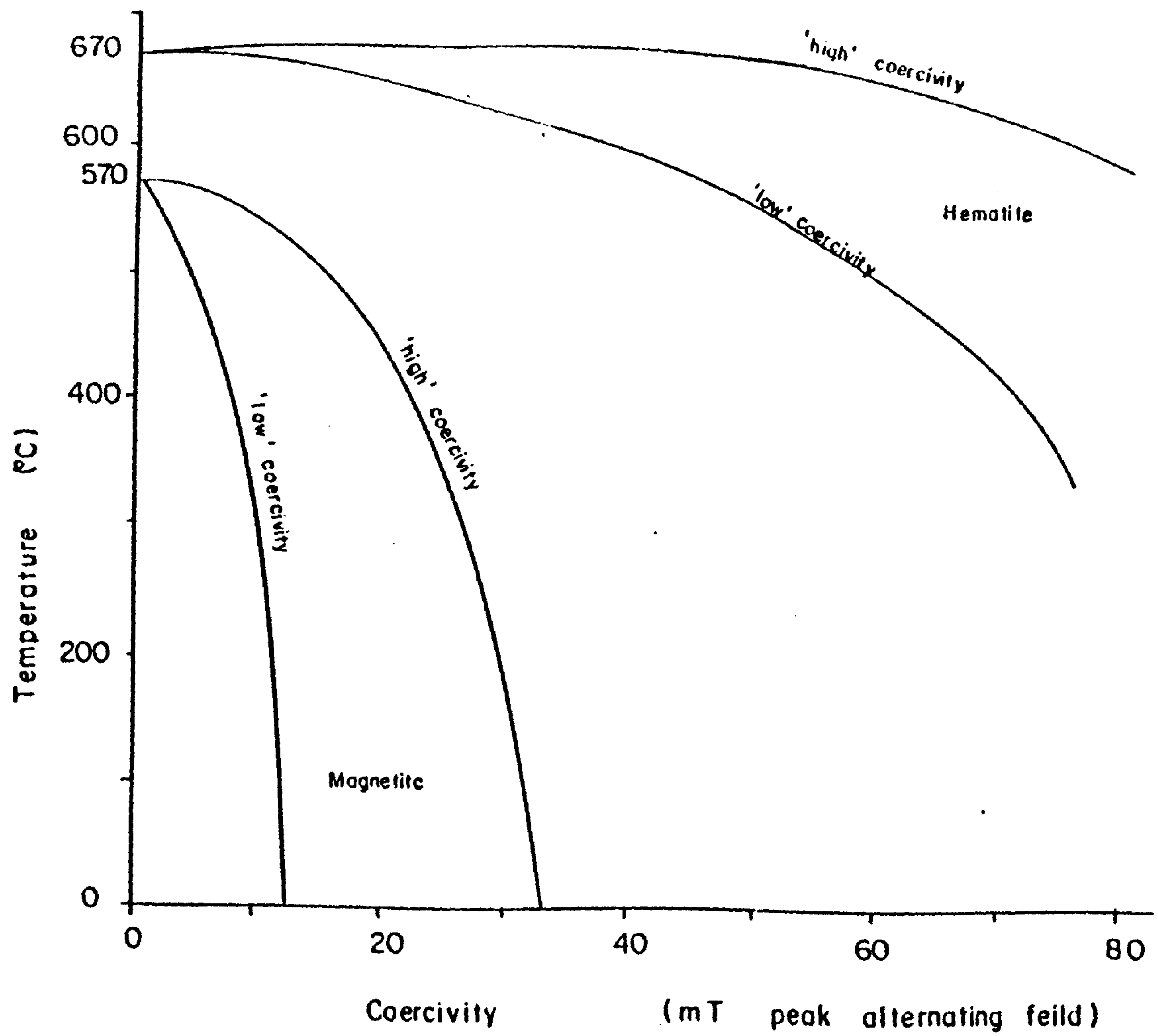


Figure 10 Blocking and Coercivity Spectrums of Magnetite and Hematite (from Tarling 1983)

The same mean remanence direction is isolated by both the AF and thermal step cleaning, thereby indicating only one common stable magnetic component (Figures 11a,b, 12a,b). An individual component of magnetization contributing to the NRM of a specimen is identified by its linear decay during demagnetization on a Zijderveld diagram (Zijderveld 1967; Dunlop 1979). The majority of the sites showed a stable NRM from 5mT to 100mT and up to 400° C with a univectorial decay representing a single component of magnetization (Figures 8,9). Three sites (21,22,26) showed an extremely stable NRM (Figure 12a,b) and 5 sites (14,25,28,29,30) displayed a lower NRM stability. Although these sites were less stable, the confinement of the vector within a single sector of the stereonet allows the estimation of a single component of magnetization (Tarling 1983) (Figure 11a,b).

c) 20mT AF Bulk Cleaning

A total of 192 vectors or 84% of the total population for the "A" plug were accepted using the 30° ASD screening level. When plotted these vectors produced a single stable directional anomaly in the SE area of the stereonet (Figure 13). The average remanence intensity is 1.45 E^{-1} Am^{-1} cm^{-3}. The anomaly is defined by the 2.4% density contour which is the 95% confidence level. It has a mean direction of 163.1° , 66.4° (declination, inclination). The peak density of >15.3% indicates a statistical significance for the anomaly of >>99.99% confidence (Figure 13) (Table 8).

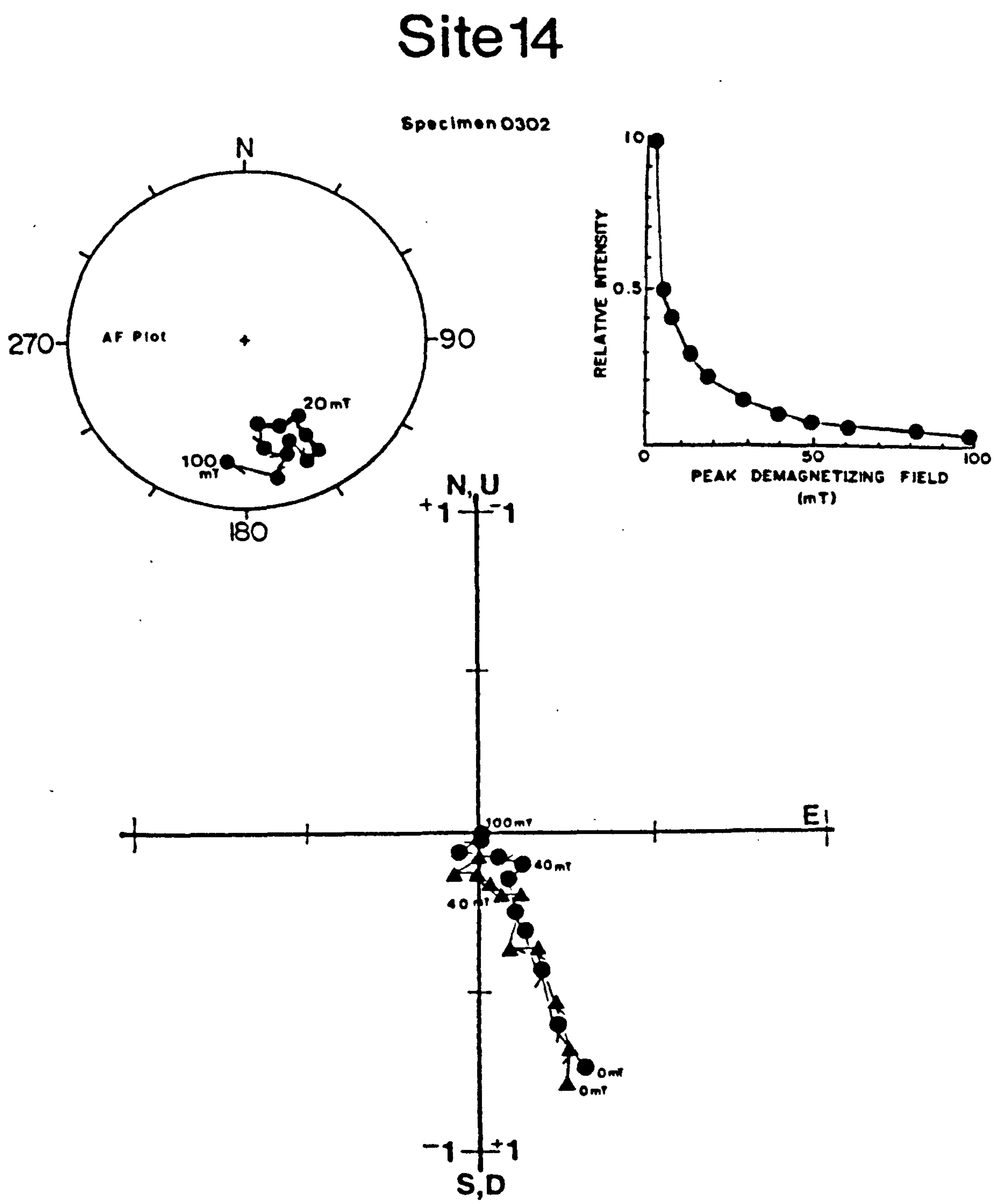


Figure 11a   A Plug AF Step Demagnetization Example Site 14: Intensity VS Demagnetizing Field, Zijderveld (▲ horizontal, ● vertical components)

Site 14

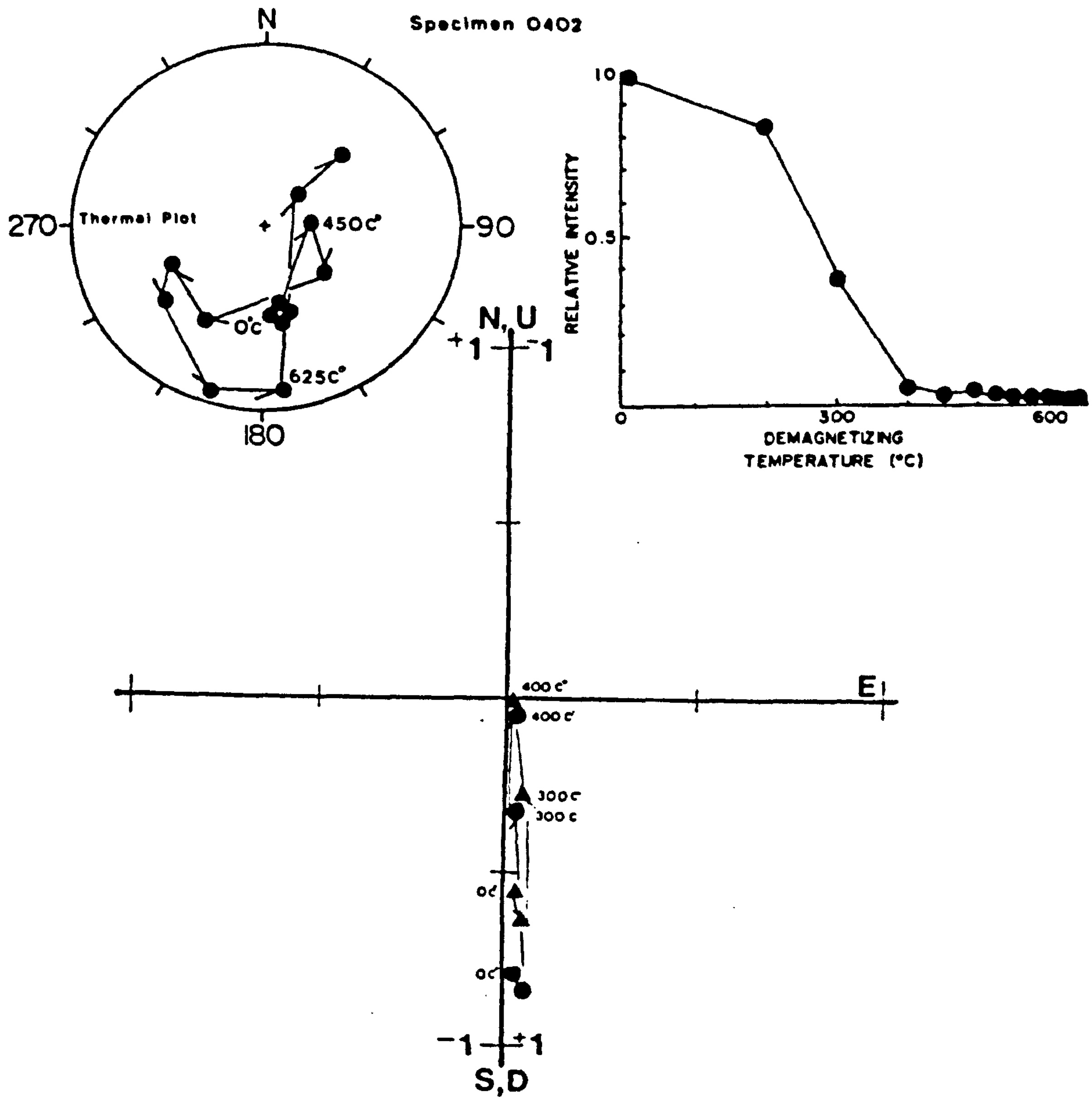


Figure 11b A Plug Thermal Step Demagnetization Example Site 14: Intensity VS Demagnetizing Field, Zijderveld (▲ horizontal, ● vertical components)

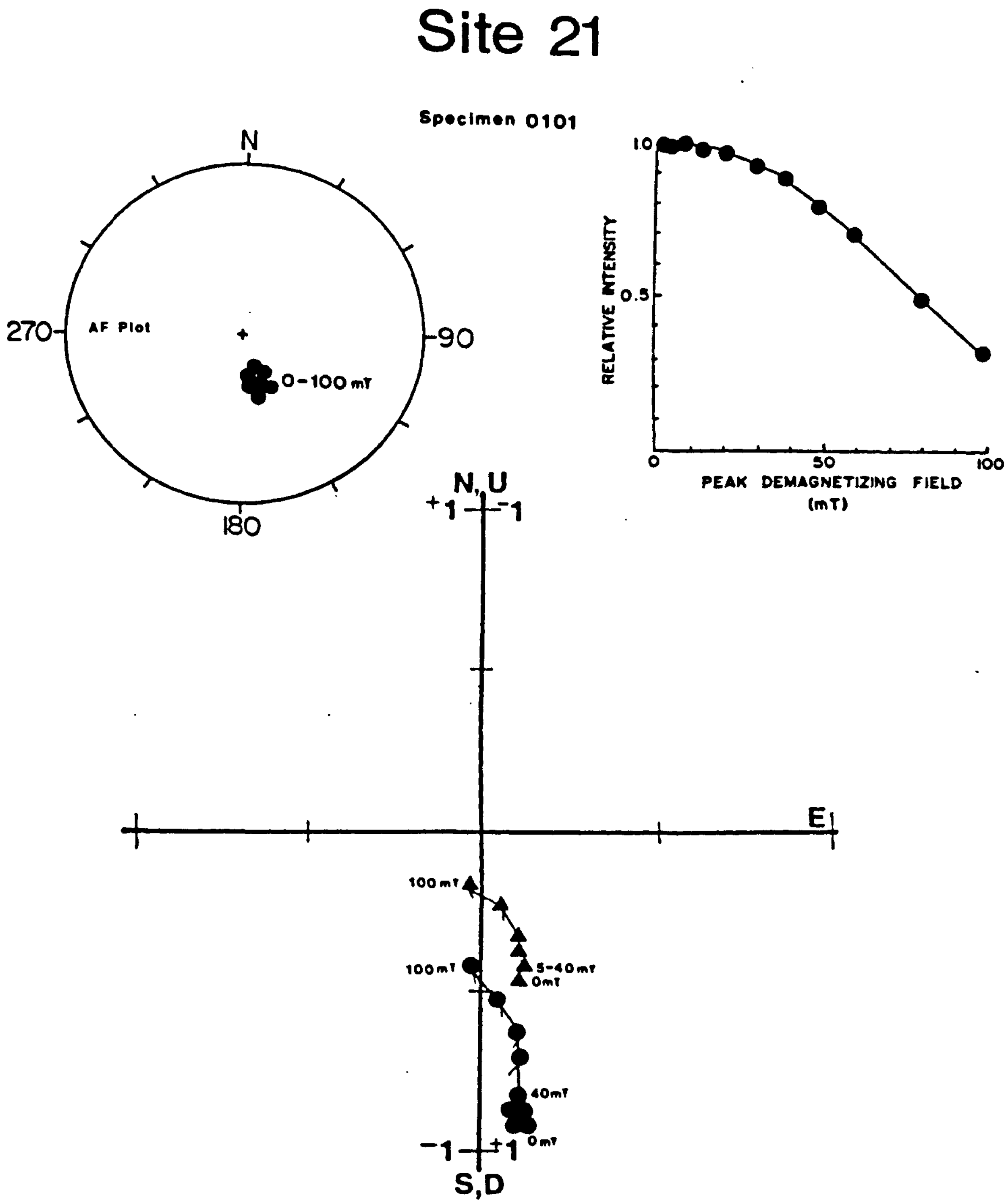


Figure 12a A Plug AF Step Demagnetization Example Site 21: Intensity VS Demagnetizing Field, Zijderveld (▲horizontal,● vertical components)

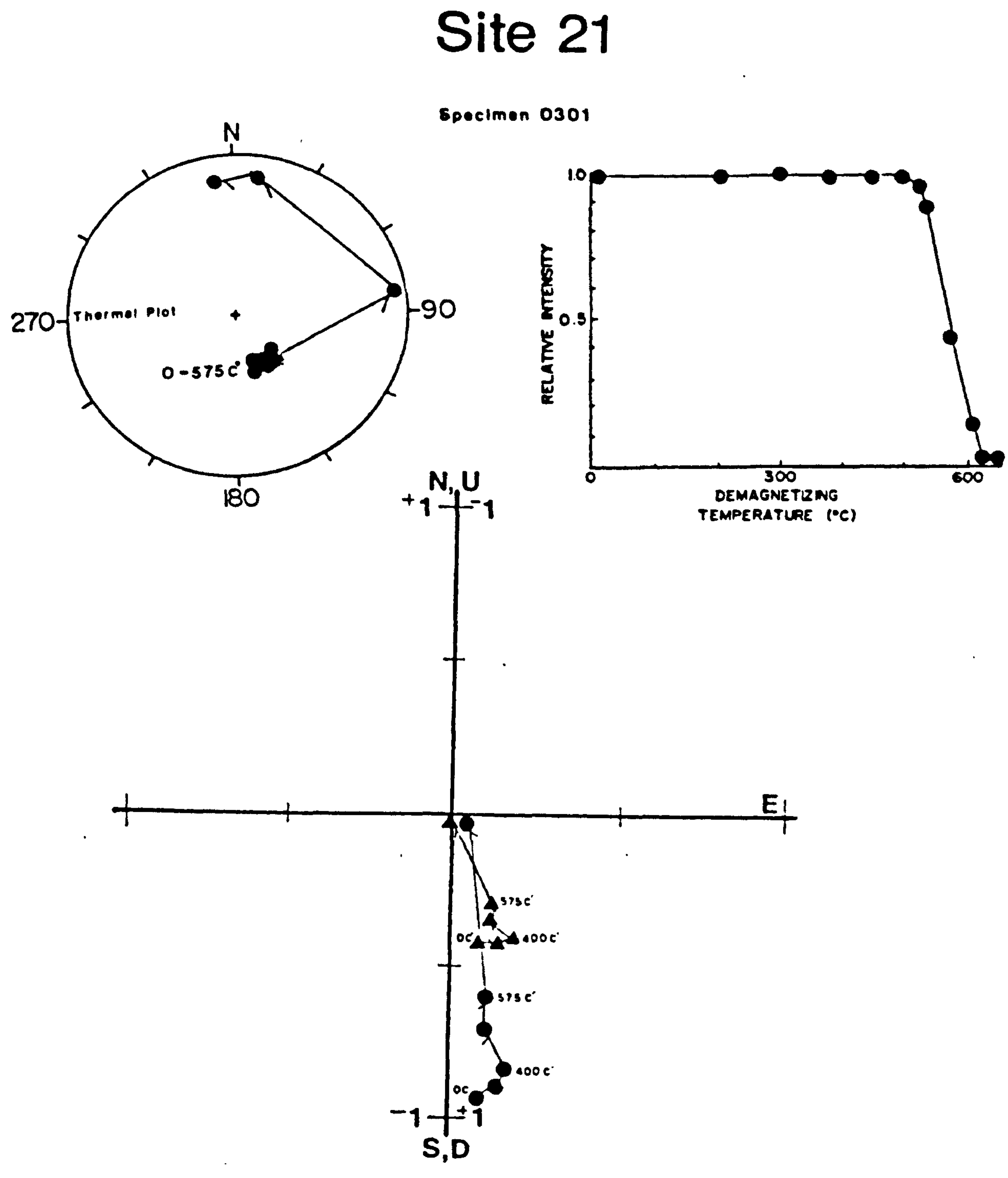


Figure 12b A Plug Thermal Step Demagnetization Example Site 21: Intensity VS Demagnetizing Field, Zijderveld (▲ horizontal, ● vertical components)

TABLE 8 A Plug 20 mT Bulk Cleaning Remanence Data

Site	N	Decl. °	Incl. °	R	K	A_{95} °
11	6	155.7	75.7	5.74	19.7	16.6
12	9	150.3	64.6	8.86	59.7	6.7
13	6	179.9	80.5	5.91	55.8	9.0
14	5	176.1	30.6	4.50	8.0	28.7
16	6	159.7	68.6	5.83	29.6	12.5
17	6	209.2	62.9	5.33	7.5	26.1
18	7	152.5	71.9	6.89	54.7	8.2
19						
20	6	44.6	88.0	5.60	12.6	19.5
21						
22	7	166.8	63.9	6.95	144.3	5.0
23	8	162.1	55.7	7.45	12.7	16.1
24	6	156.9	67.9	5.71	17.6	16.4
25						
26	6	139.6	52.5	5.67	15.2	17.7
27	9	154.4	61.2	8.02	8.1	19.1
28						
29						
30	11	141.6	64.0	10.89	92.0	4.7
Average	14	163.7	68.7	13.5	30.6	6.7

Fourteen of the 19 sites had A_{95} values of <30° on averaging the specimen remanence directions to obtain the site mean directions. The unit mean direction of the 14 sites for the plug is 163.7°, 68.7° with an A_{95} of 6.7° (Figure 14) (Table 13).

d) 40mT AF Bulk Cleaning

Bulk cleaning at 40mT led to the acceptance of 188 vectors or only 4 vectors less than were rejected after cleaning at 20mT. When plotted the accepted vectors again formed a single directional anomaly in the SE sector of the stereonet (Figure 13). The average NRM intensity is reduced by 17% to 1.24 $E^{-2} Am^{-1} cm^{-3}$. The anomaly's mean direction is marginally changed to 158.8°, 60.3°, however its peak density of >11.9% indicates a statistical significance of >>99.99% (Figure 13) (Table 9). These give a unit mean direction of 157.9°, 59.6° (A_{95} =7.8°).

e) Thermal Cleaning

The thermal step demagnetization treatment indicated that only sites 21, 22 and 26 were capable of withstanding bulk cleaning at temperatures of 500, 550, 600, 650°C (Figure 12b). These sites showed a single remanence component with a mean direction of 151.9°, 62.3° (A_{95} =0.6°) (Figure 14) (Table 13).

TABLE 9 A Plug 40mT Bulk Cleaning Remanence Data

Site	N	Decl. °	Incl. °	R	K	A_{95} °
11	6	183.7	62.0	5.36	7.8	25.5
12	9	168.6	67.5	8.67	24.3	10.6
13	6	153.2	70.5	5.67	15.5	17.5
14	6	181.5	30.3	5.76	20.8	15.0
16	6	132.0	71.7	5.89	46.0	9.9
17						
18	7	166.7	60.0	6.68	18.8	14.2
19						
20						
21						
22	7	157.1	62.3	6.98	389.0	3.0
23	7	143.7	60.2	6.28	8.3	22.2
24	7	158.4	59.3	6.14	6.9	24.5
25						
26	6	141.4	54.7	5.64	14.0	18.5
27	9	147.9	61.3	7.05	4.1	28.9
28	8	139.5	48.7	6.74	5.5	25.7
29	9	143.9	32.6	7.56	5.5	23.9
30	11	140.0	53.4	10.67	30.4	8.4
Average	15	157.9	59.6	14.2	24.4	7.8

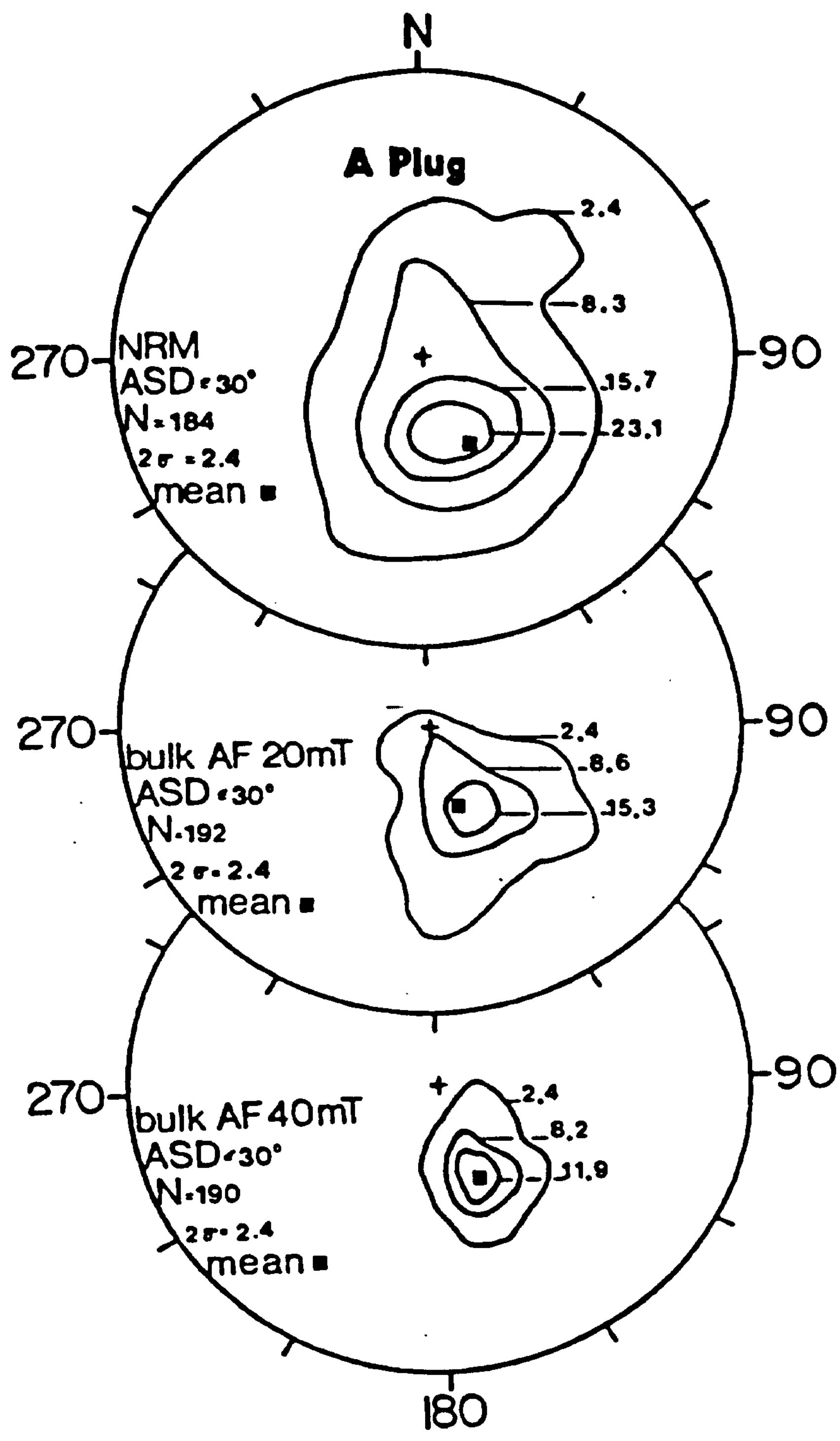


Figure 13 Steroplot of Vector Directions of the A Plug After Bulk Cleaning of 20mT and 40mT

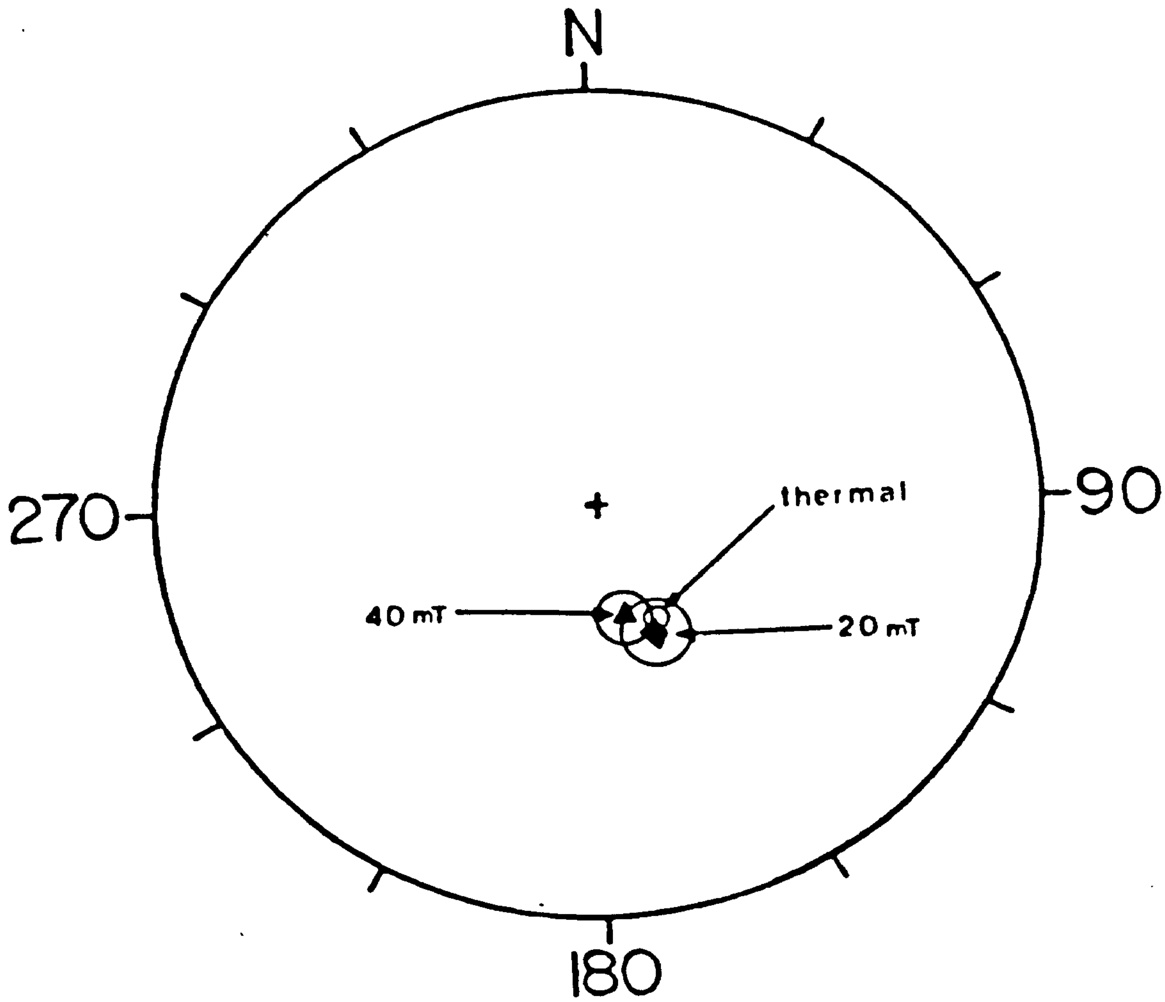


Figure 14 A Plug Mean Remanence Direction and A_{95}

2. EL Plug

a) NRM

The "EL" Plug is represented by 130 vectors which all had and ASD $\leq 30^{\circ}$. These vectors form an anomaly, defined by the 2.75% density contour, with a peak density of >9.7% or of >>99.99% confidence (Figure 19). The average NRM intensity is 5.13 E^{-2} Am^{-1} cm^{-3}.

b) Step Cleaning

Twenty specimens were selected for AF step demagnetization up to 100mT and 20 more specimens were thermally step cleaned up to 625° C (Figure 15,16). A total of 19 specimens gave acceptable directional coherency after AF step cleaning, and all 20 specimens were accepted after thermal cleaning. The NRM resides in the magnetic carriers with a low median destructive field so that only 42% of the NRM intensity remained after treatment at 5mT (Figure 15). This rapid intensity drop indicates the presence of a large, unstable, low-coercivity component that is readily removed by the AF demagnetization. After 20mT cleaning, only 9% of the NRM intensity remained indicating little retention of a stable component (Figure 15). During the thermal step cleaning only 4% of the NRM remained after treatment of >200° C (Figure 16). This also reflects the low stability of true remanence. From the response to both AF and thermal cleaning, it is clear that the majority of the NRM is held in soft magnetic carriers - likely coarse multidomain Ti-rich magnetites.

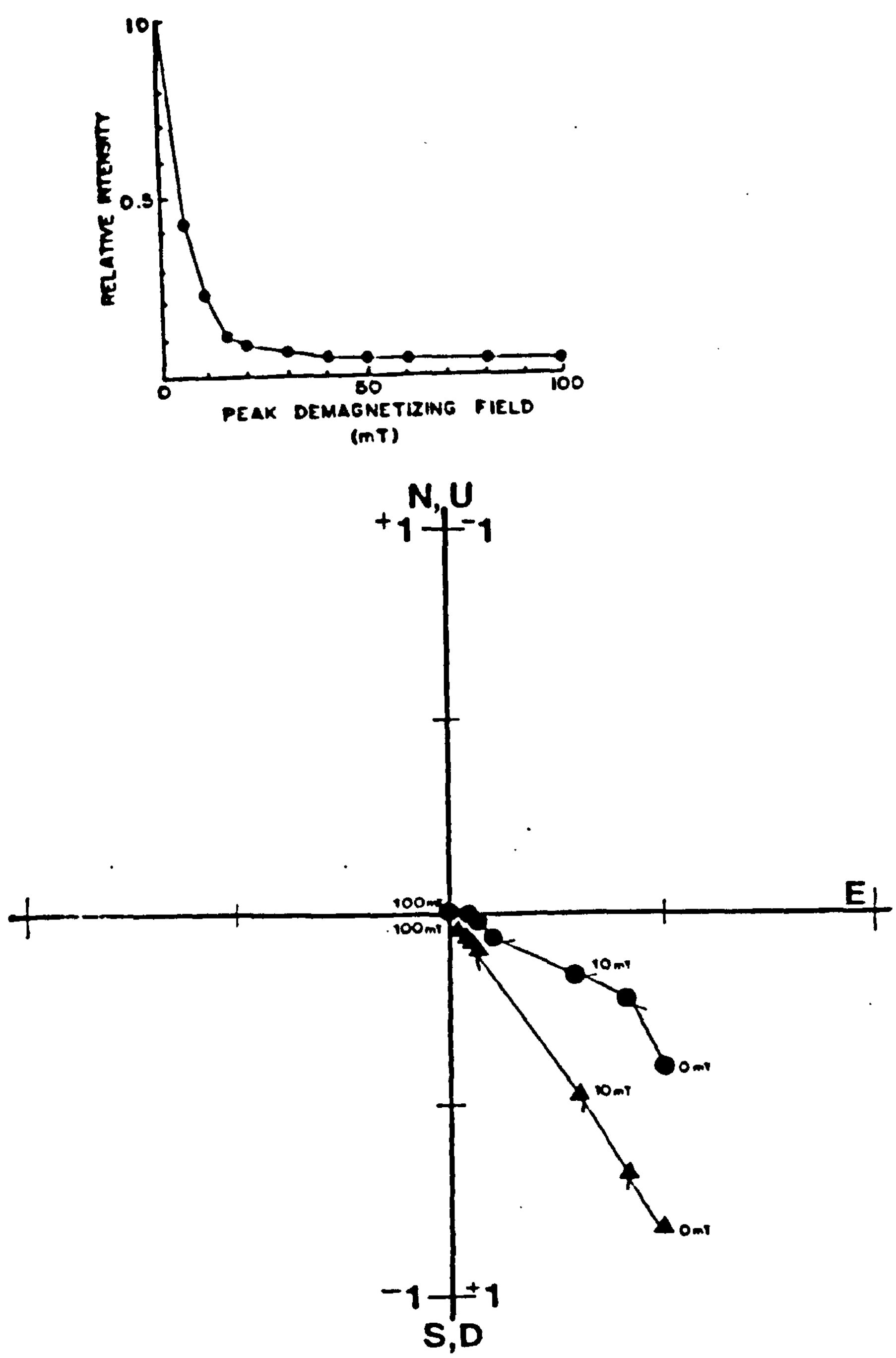
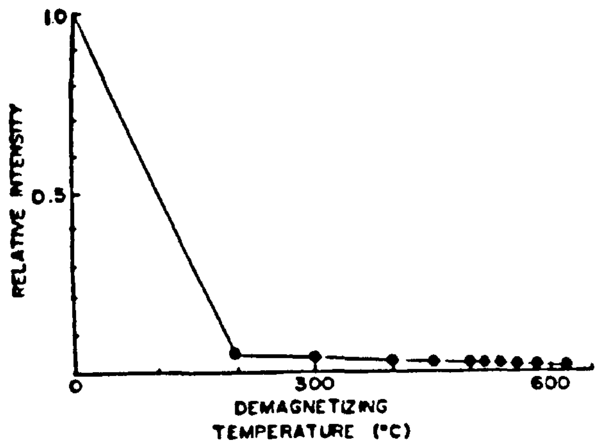


Figure 15 EL Plug Average AF Step Demagnetization: Intensity VS Demagnetizing Field, Zijderveld (▲ horizontal, ● vertical components)



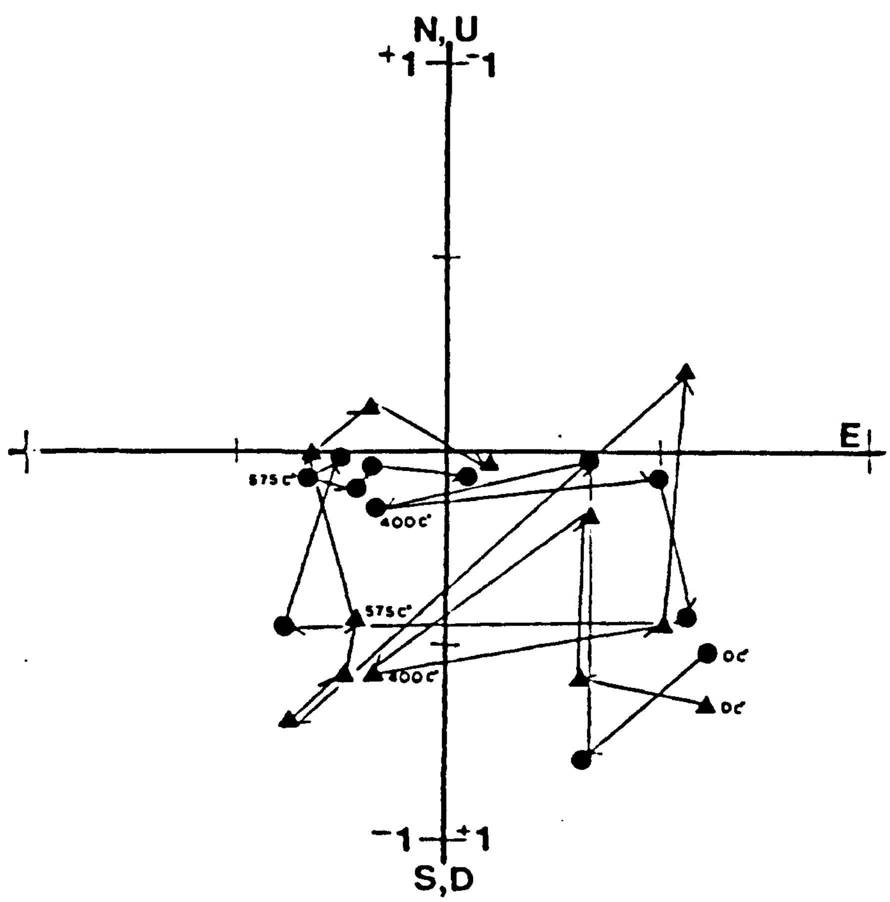


Figure 16 EL Plug Average Thermal Step Demagnetization: Intensity VS Demagnetizing Field, Zijderveld (▲ horizontal, ● vertical components)

Site 9

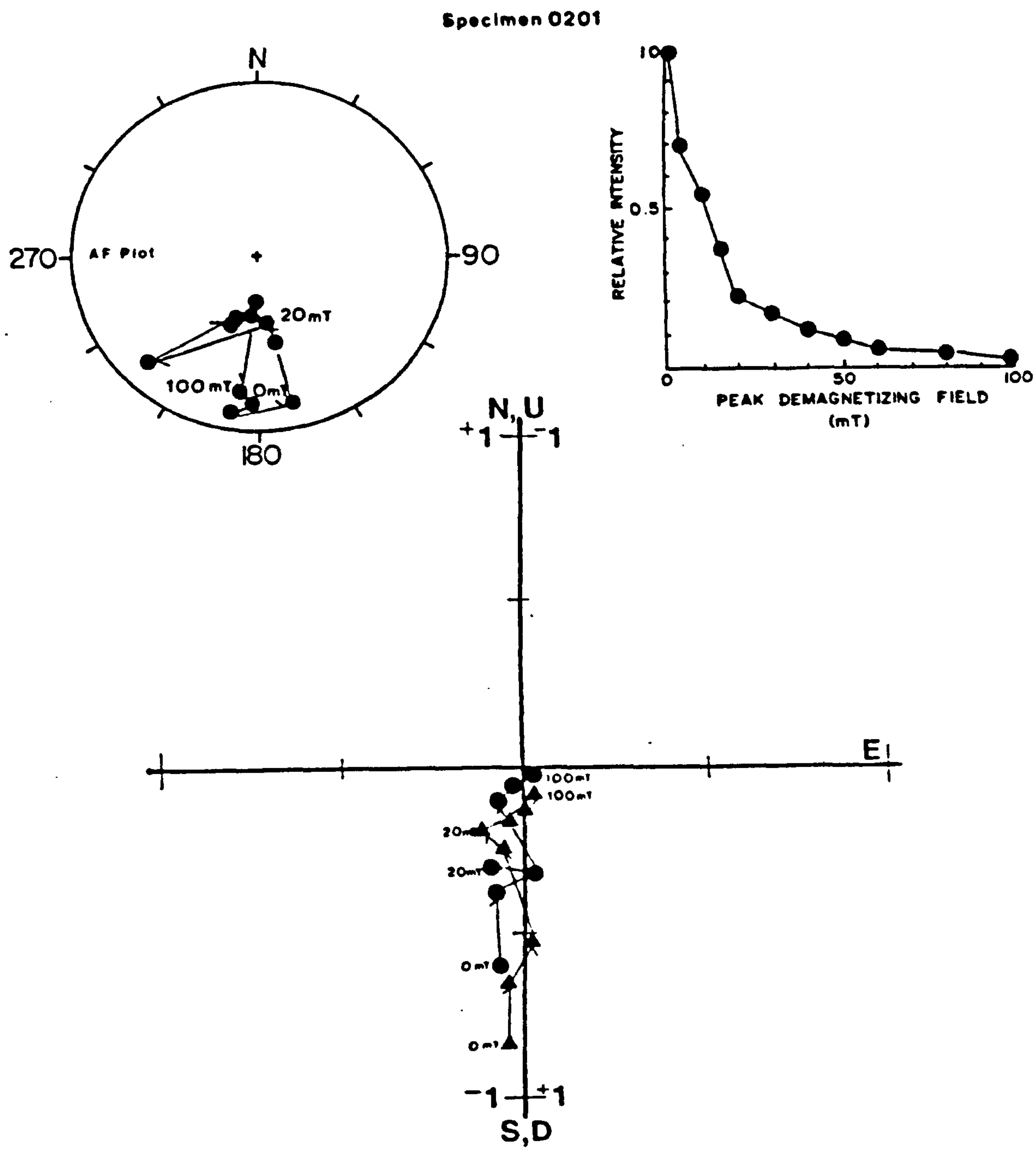


Figure 17a EL Plug AF Step Demagnetization Example Site 9: Intensity VS Demagnetizing Field, Zijderveld (▲ horizontal, ● vertical components)

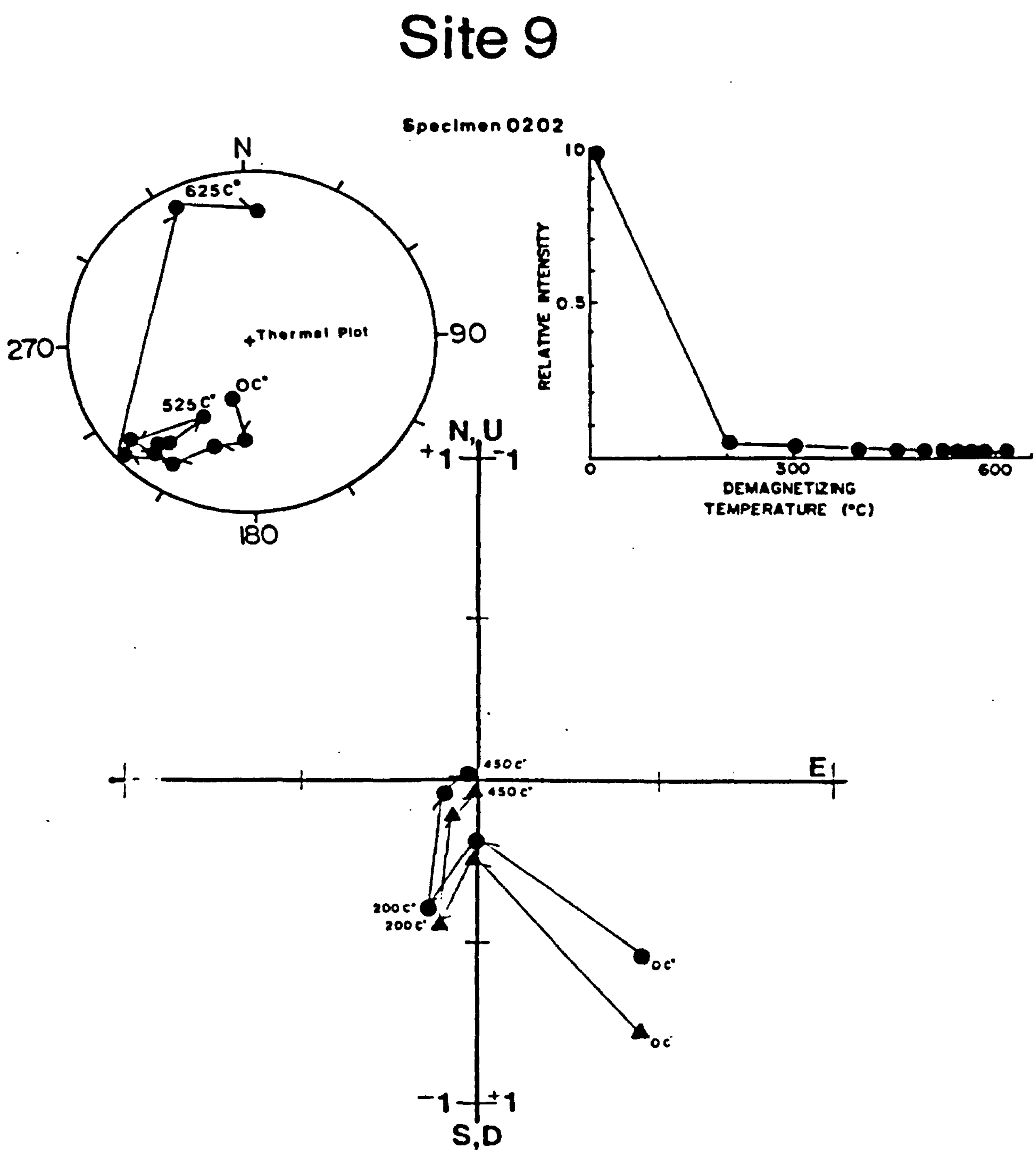


Figure 17b EL Plug Thermal Step Demagnetization Example Site 9: Intensity VS Demagnetizing Field, Zijderveld (▲horizontal,● vertical components)

Site 4

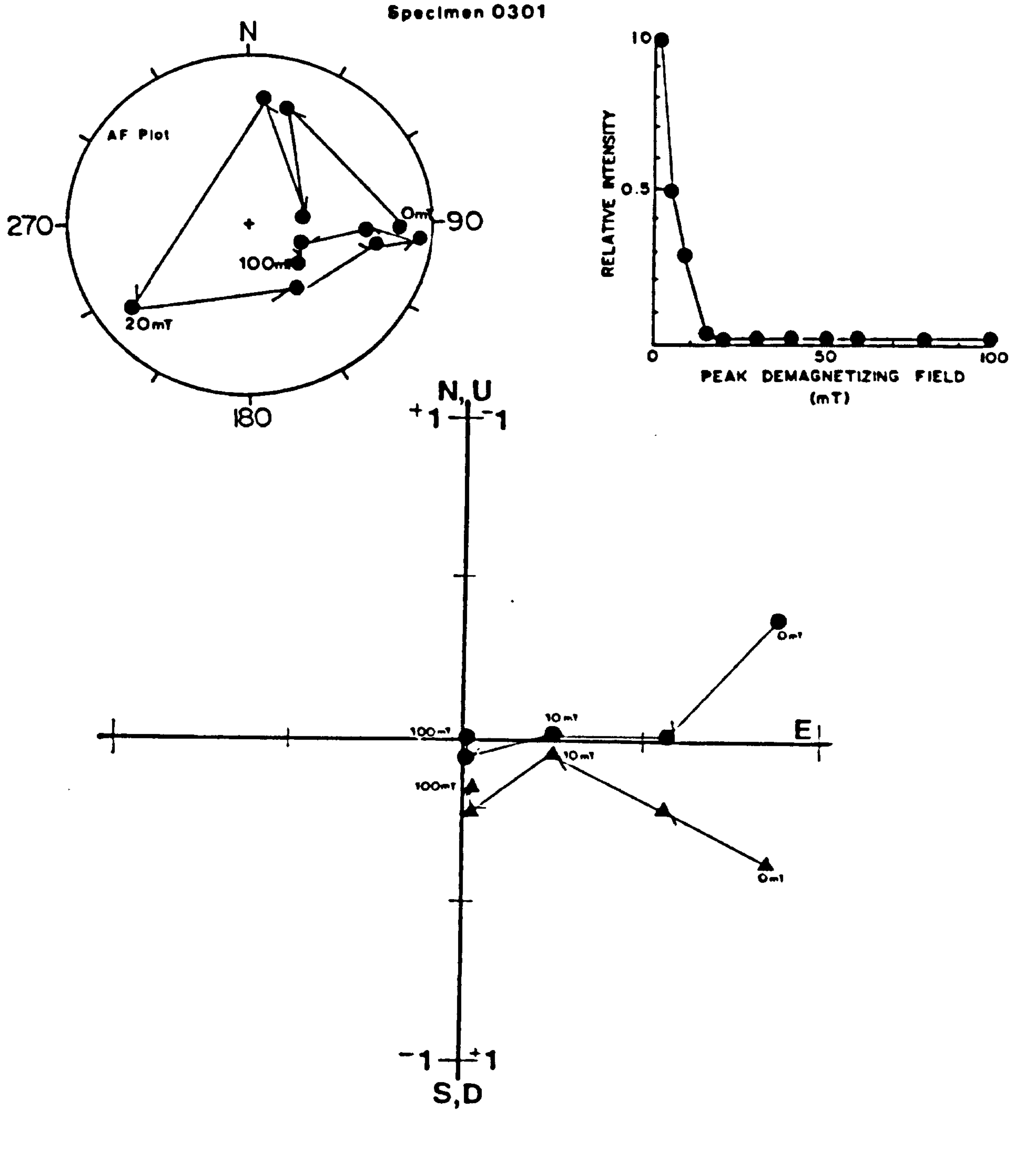


Figure 18a EL Plug AF Step Demagnetization Example Site 4: Intensity VS Demagnetizing Field, Zijderveld (▲ horizontal, ● vertical components)

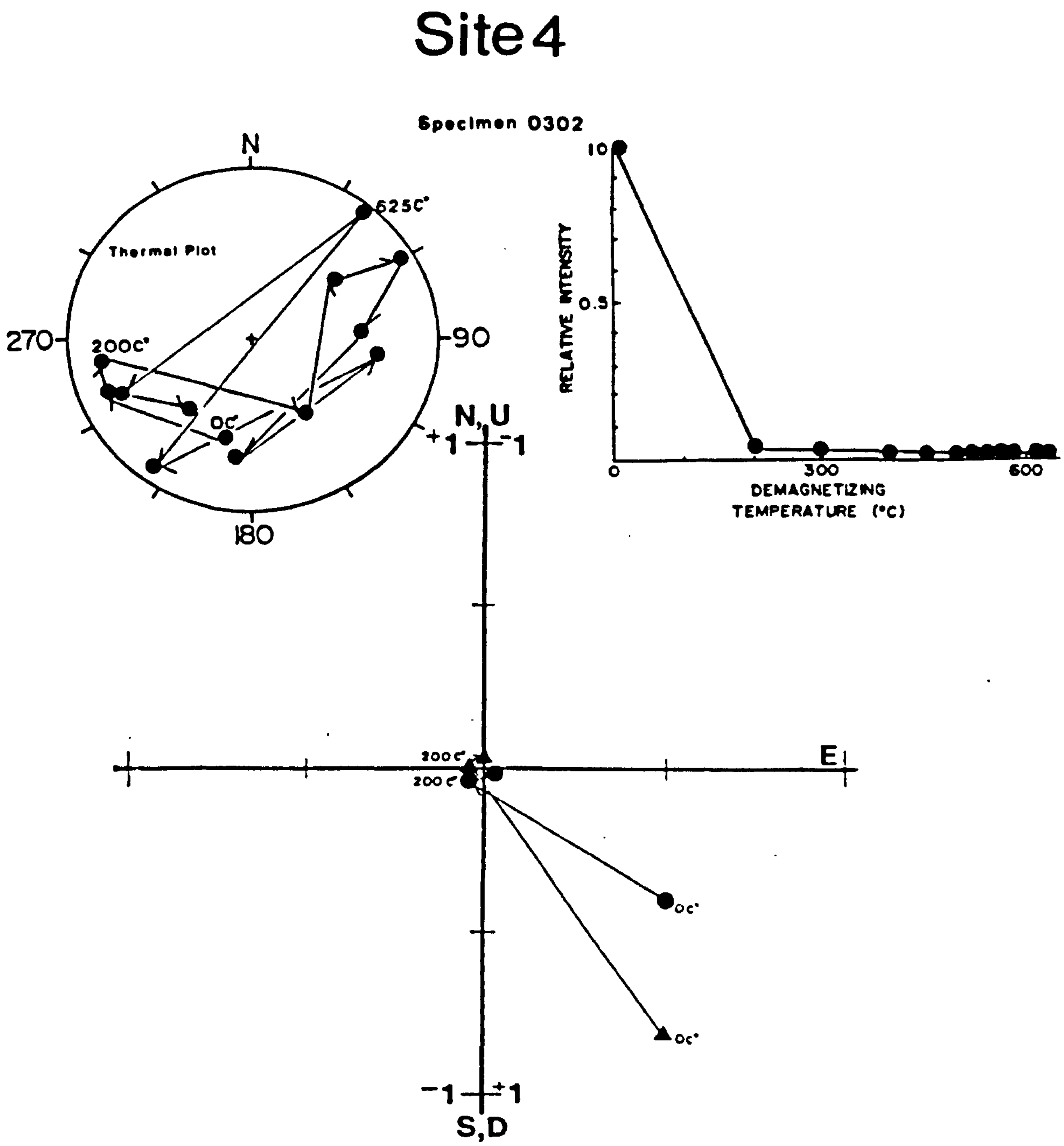


Figure 18b EL Plug Thermal Step Demagnetization Example Site 4: Intensity VS Demagnetizing Field, Zijderveld (▲horizontal, ●vertical components)

Most of the EL plug specimens during the step demagnetization revealed a semistable remanence (Figure 17a,b). The majority of the directions are confined to the same sector of the stereonet (Figure 17a,b). Tarling (1983) states that such behavior is indicative of a single NRM component. Specimens from these sites display a single remanence component when plotted on a Zijderveld diagram with the NRM decaying univectorially towards that origin of the plot (Figure 17a,b). Four sites (2,4,7 and 8) showed vector directions tracking randomly over the entire stereonet (Figure 18a,b), thereby revealing their unstable remanence.

c) AF Bulk Cleaning

Since the remanence of the EL plug was generally of low stability, both the 20mT and 30mT bulk cleaning data was combined and averaged to get a single data base. This type of analysis will allow for the removal of erratic vector directions that do not contribute to an identifiable remanence component. A total of 252 vectors were accepted with an ASD of $\leq 30^{\circ}$. The plot of these vectors produced a single anomaly defined by the 2.7% density contour or 95% confidence level (Figure 19). The peak density of >5.4% yields a statistical significance >99.99% confidence to the anomaly. The mean direction is 193.1° , 68.1° and the average intensity is 2.41 E^{-3} Am^{-1} cm^{-3} .

Six of the 10 sites gave mean directions with an $A_{95} \leq 30^{\circ}$ (Table 10). Using these, the unit mean direction for the EL plug is 161.3°, 53.0° (A_{95} = 12.9°) (Figure 20) (Table 13).

TABLE 10 EL Plug 20mT + 30mT Bulk Cleaning Remanence Data

Site	N	Decl. °	Incl. °	R	K	A_{95} °
1						
2						
3	10	123.4	55.3	8.97	8.8	17.2
4	8	156.4	30.2	7.27	9.5	18.8
5						
6	7	186.3	72.7	6.78	27.3	11.7
7	10	177.1	59.4	9.32	13.2	13.7
8	11	152.7	49.7	9.78	8.2	16.9
9	11	174.0	53.4	9.74	7.9	17.2
10						
Average	6	161.3	53.0	5.70	19.1	12.9

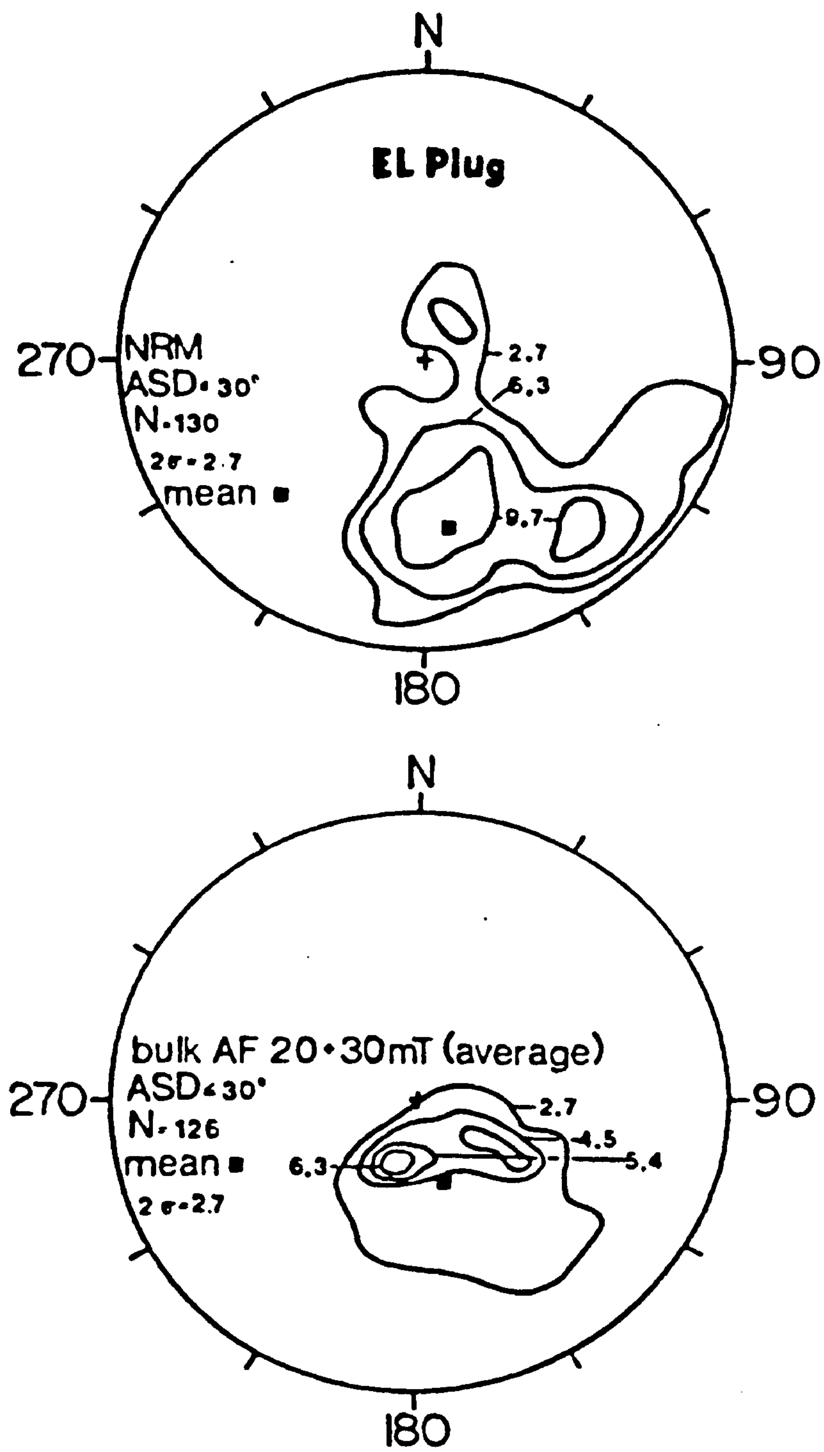


Figure 19 Stereoplot of Vector Directions for the EL Plug After 20mT and 30mT Bulk Cleaning

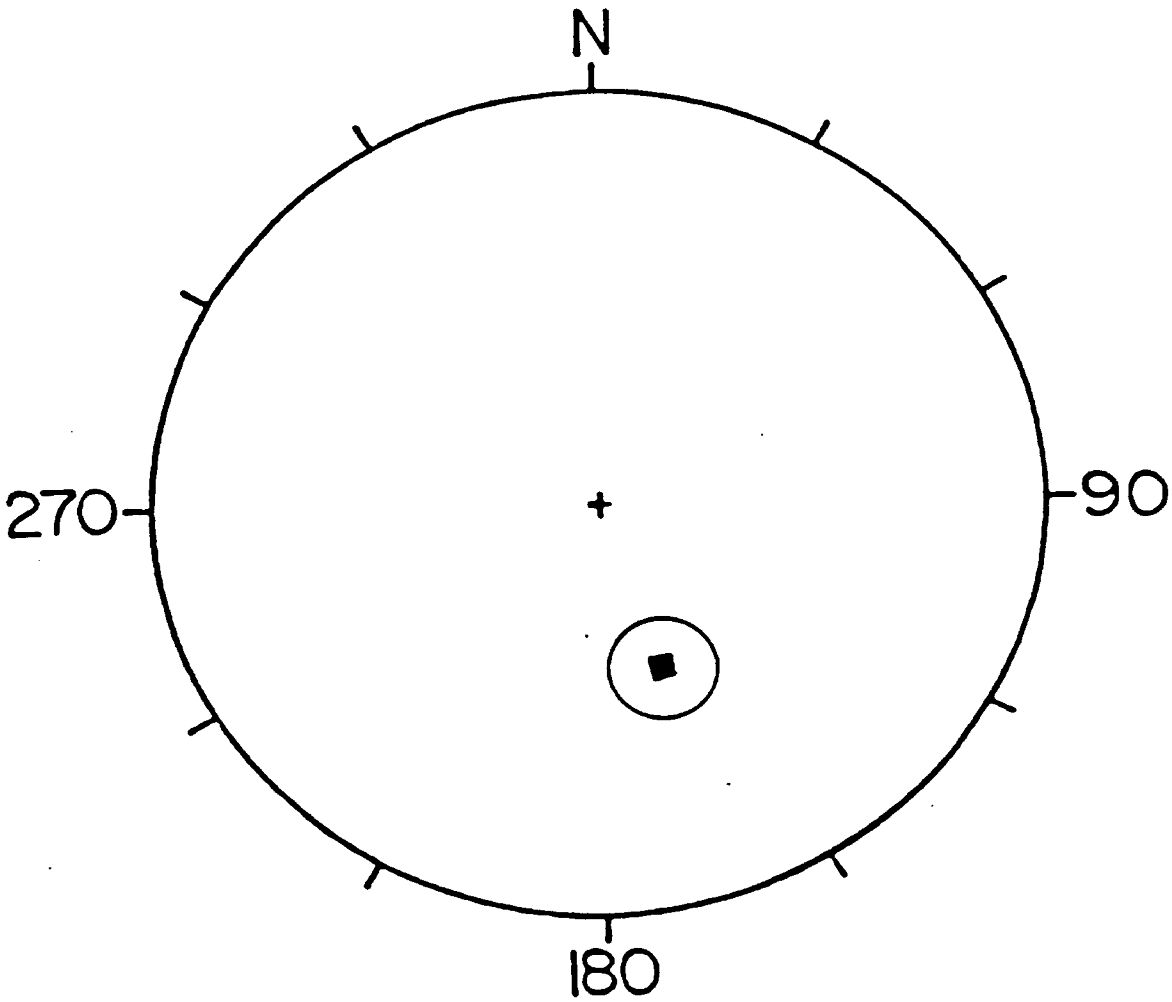


Figure 20 EL Plug Mean Remanence Direction and A_{95}

Given the low stability remanence on AF demagnetization, thermal cleaning was not considered appropriate for the EL plug collection. This is due to the large amount of pyrrhotite observed in the polished sections of the EL samples and thus is probably responsible for the remanence instability of the plug.

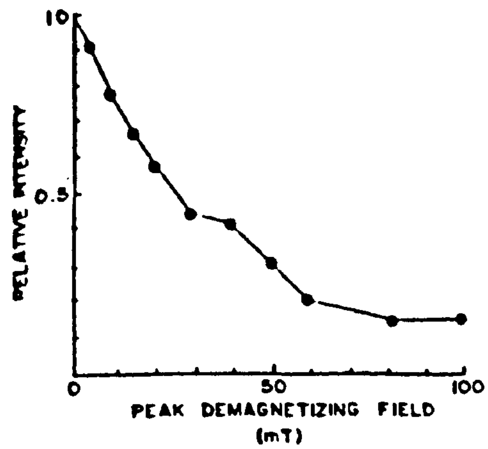
B. Fraser Lake Gabbro

a) NRM

A total of 134 vectors were measured and 97% of these were accepted at the 30° ASD screening level. Their average NRM intensity is 2.33 E^{-1} Am^{-1} cm^{-3}. When plotted, these vectors formed a single directional anomaly with a mean direction of 160.8°, 61.5° (Figure 25). The peak density of >22.4% yields a statistical significance of >>99.99% confidence to the anomaly (Figure 25).

b) Step Demagnetization

A total of 22 specimens were selected for AF step cleaning up to 100mT and 22 specimens for thermal step cleaning up to 625° C from the Fraser Lake Gabbros. Of these, 20 specimens met the 30° ASD specimen screening criteria and were accepted from the AF step



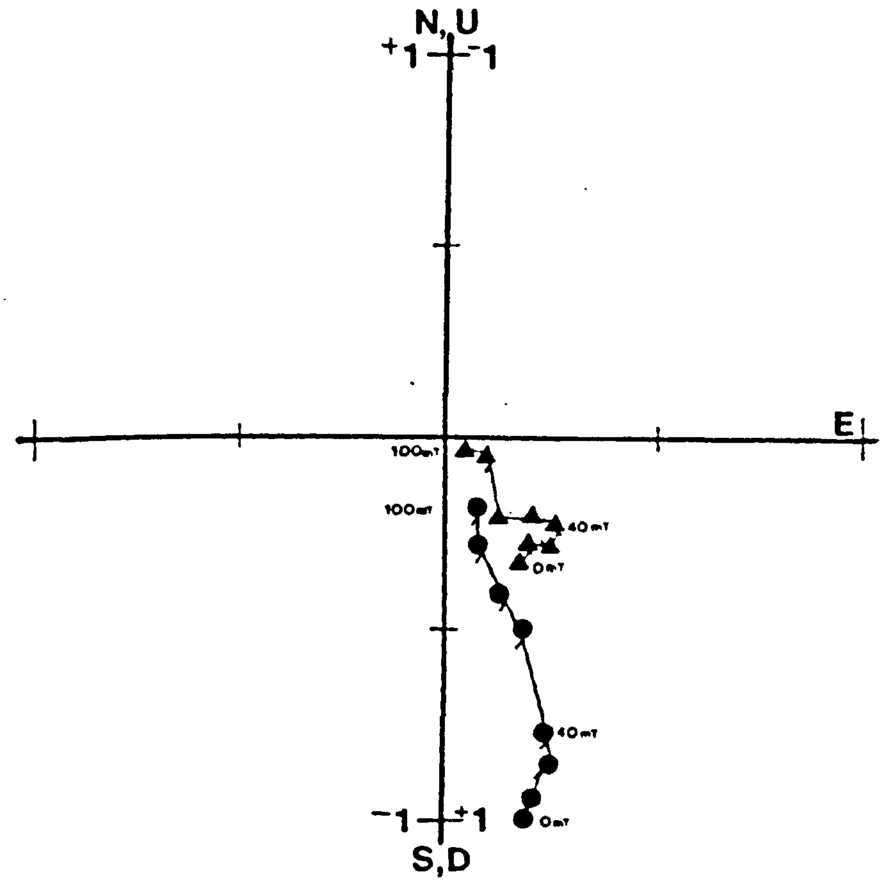


Figure 21 Fraser Lake Plug AF Step Demagnetization: Intensity VS. Demagnetizing Zijderveld (▲ horizontal, ● vertical components)

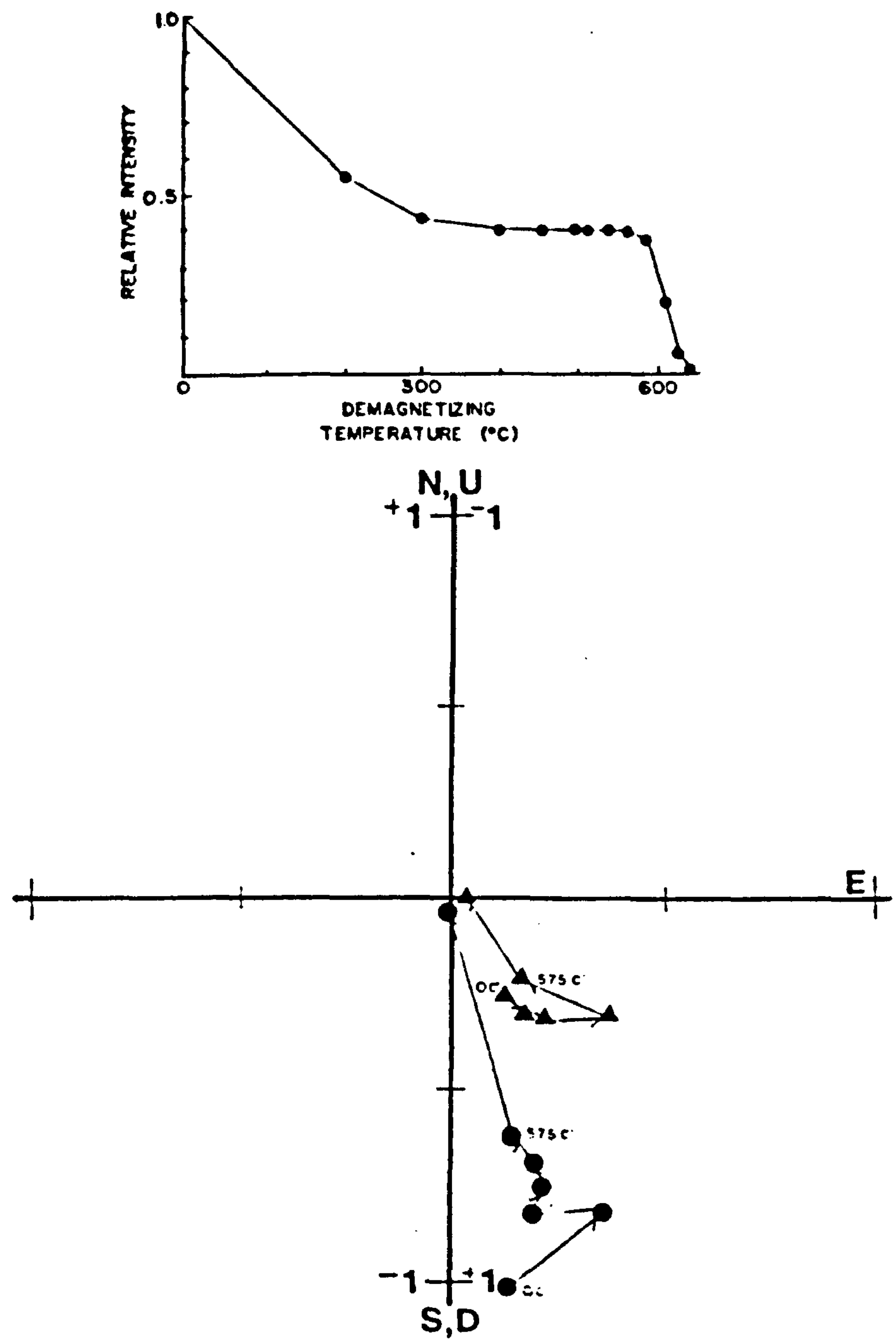


Figure 22 Fraser Lake Plug Thermal Step Demagnetization: Intensity VS Demagnetizing Zijderveld (▲ horizontal, ● vertical components)

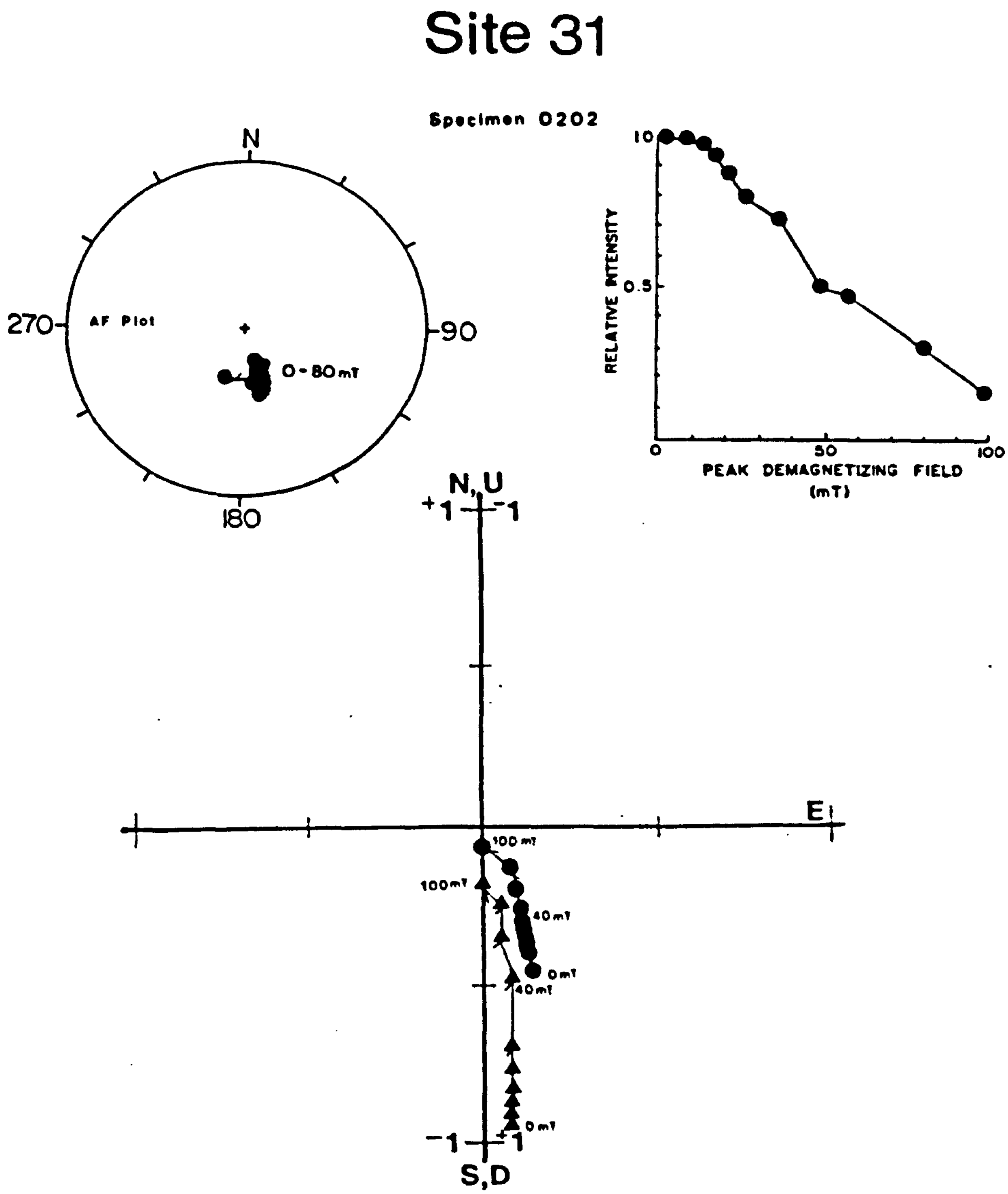


Figure 23a Fraser Lake Plug AF Step Demagnetization Example Site 31: Intensity VS Demagnetizing Field, Zijderveld (▲ horizontal, ● vertical components)

Site 31

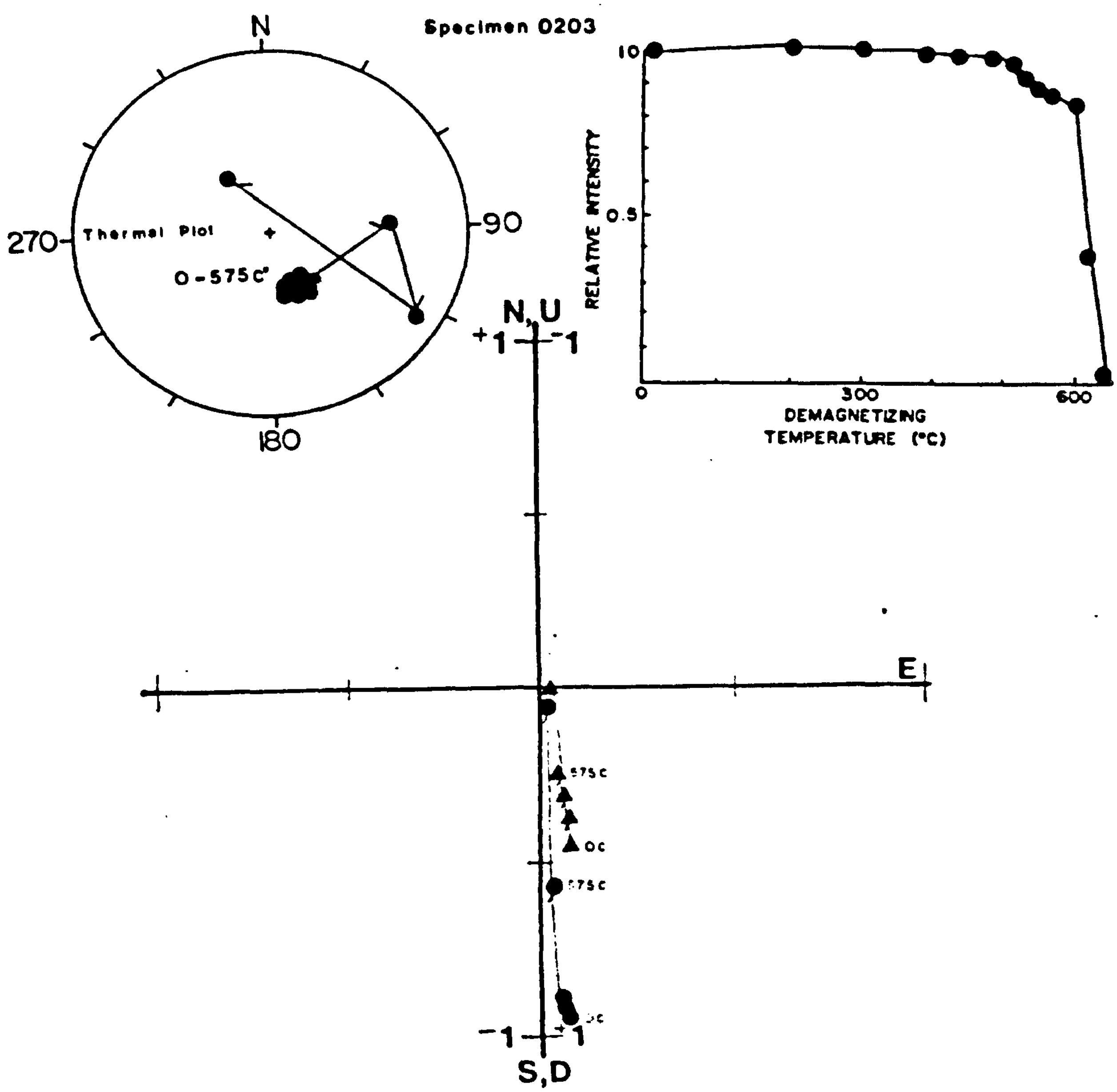


Figure 23b Fraser Lake Plug Thermal Step Demagnetization Example Site 31: Intensity VS Demagnetizing Field, Zijderveld (▲ horizontal, ● vertical components)

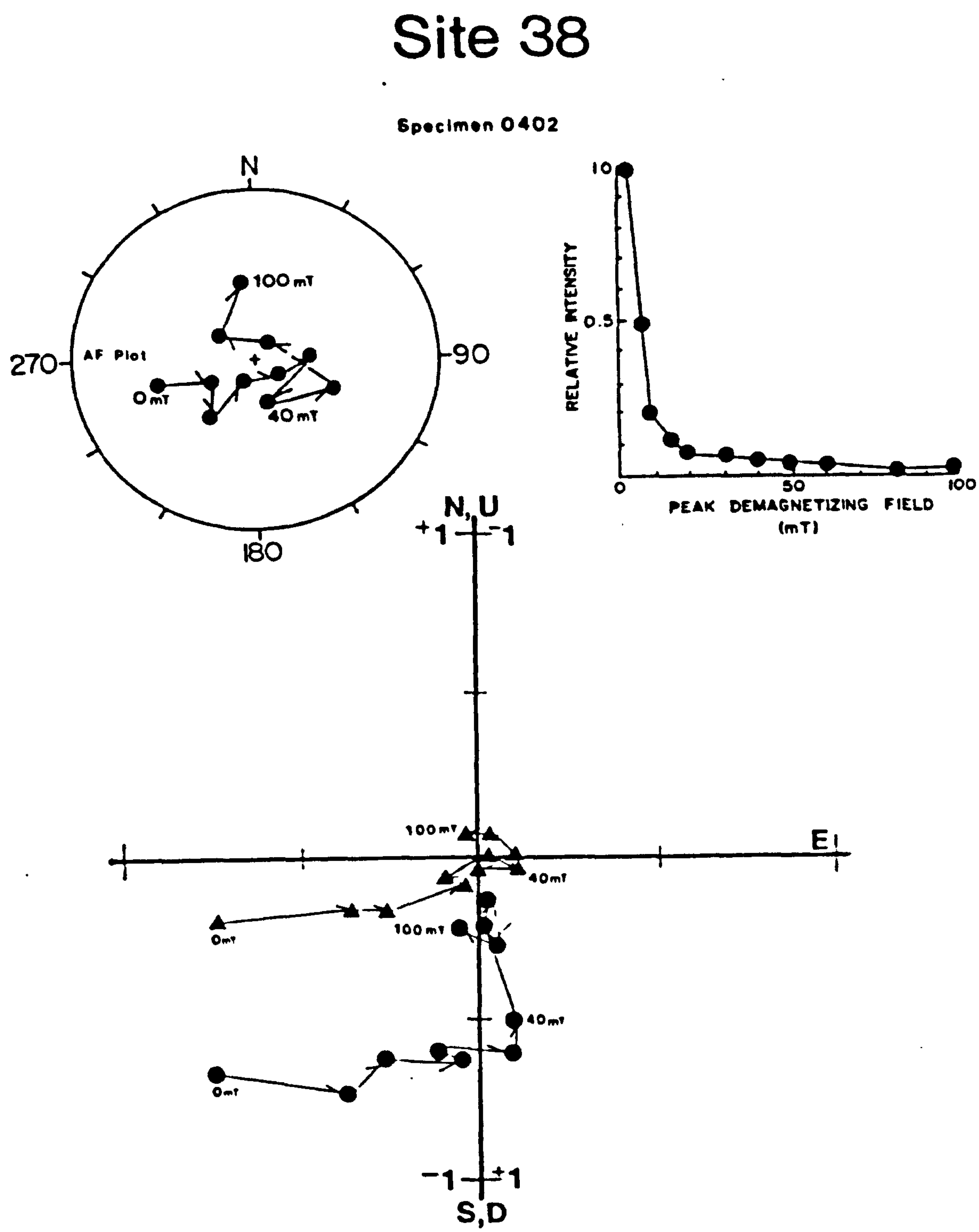


Figure 24a Fraser Lake Plug AF Step Demagnetization Example Site 38: Intensity VS Demagnetizing Field, Zijderveld (▲ horizontal, ● vertical components)

Site 38

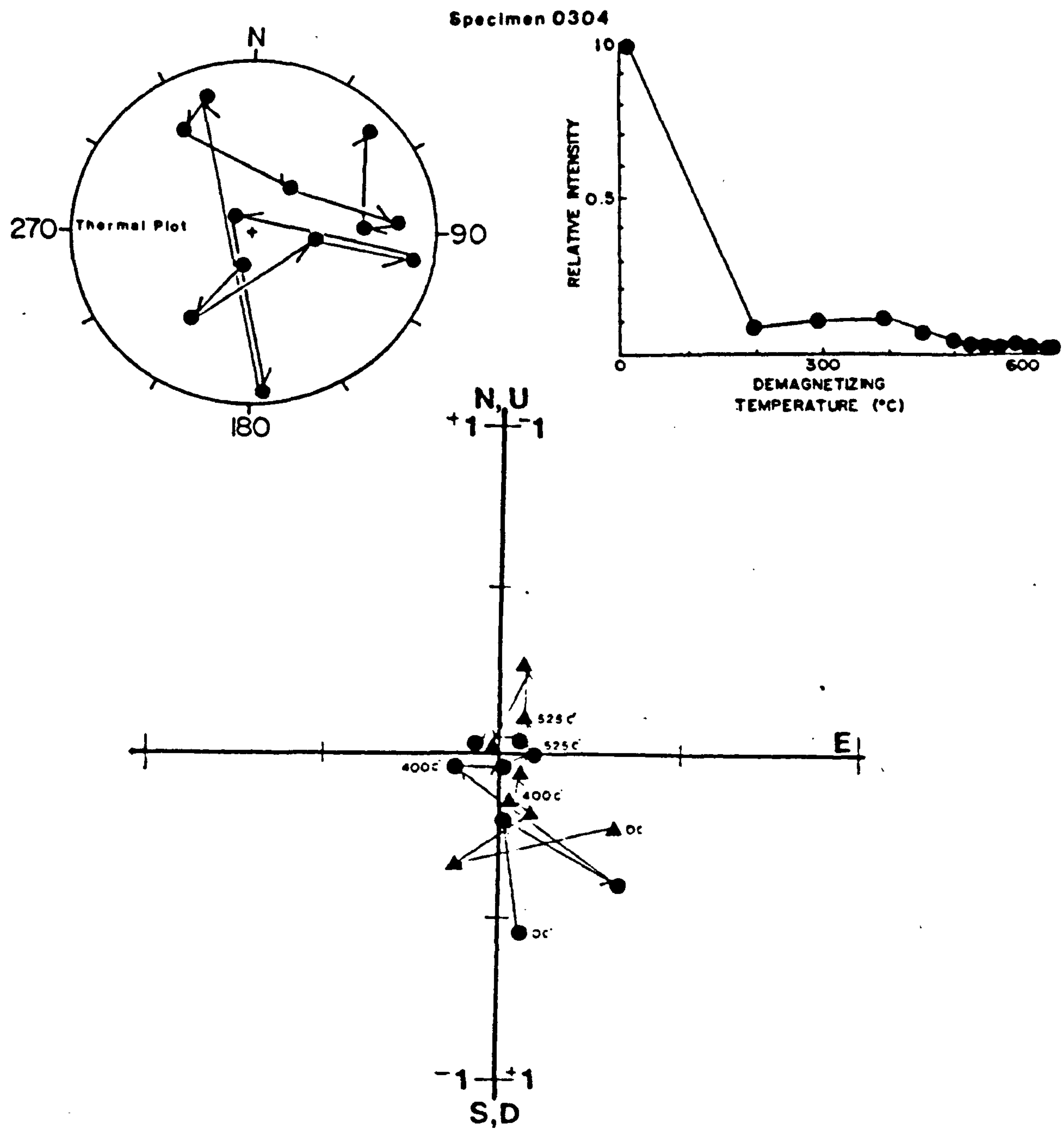


Figure 24b Fraser Lake Plug Thermal Step Demagnetization Example Site 38: Intensity VS Demagnetizing Field, Zijderveld (▲ horizontal, ● vertical components)

cleaning and 20 specimens were accepted from the thermal cleaning.

The magnetic carriers of most specimens showed medium destructive fields during the AF step cleaning between 30mT to 100mT (Figure 21) with 56% of the NRM intensity remaining after 30mT and 10% remaining after 100mT (Figure 21). This behavior indicates that a large, stable, high-coercivity component is present in the specimens.

During the thermal cleaning the specimens retained 68% of their NRM intensity up to 525° C with the remainder being removed by the 625° C treatment (Figure 22). The response to the step cleaning indicates a stable remanence component residing in a fine-grained, pure magnetite with single or pseudo-single domain behavior.

Most of the Fraser Lake specimens show an extremely stable single remanence component on both the AF and thermal step cleaning (Figures 23a,b) except sites 37,38 and 39 (Figures 24a,b). When plotted on the Zijderveld diagram, the remanence vectors decay univectorially to the origin of the diagram (Figures 23a,b).

c) AF 20mT Bulk Cleaning

After 20mT bulk cleaning, 134 vectors or 97% of the total population were accepted using the 30° ASD screening criteria. When plotted, these vectors formed a single directional anomaly with an extremely high peak density >35.9% and a mean direction of 160.2°, 64.5° (Figure 25).

Nine of the 11 sites yielded accepted site mean directions using

TABLE 11 Fraser Lake 20mT Bulk Cleaning Remanence Data

Site	N	Decl. °	Incl. °	R	K	A_{95} °
31	13	139.1	75.7	12.92	153.9	3.3
32	12	176.3	69.3	11.90	109.8	4.1
33	10	159.8	68.1	9.94	175.6	3.6
34	13	164.9	67.2	12.95	238.3	2.6
35	11	165.2	68.1	10.86	73.2	5.3
36	11	144.2	66.3	10.89	98.1	4.6
37	6	28.3	78.3	5.35	7.7	25.6
38						
39	7	274.8	70.1	6.27	8.2	22.3
40						
41						
42	4	156.5	83.7	3.99	340.0	4.9
Average	9	158.7	67.9	7.00	3.5	24.3

TABLE 12 Fraser Lake 40mT Bulk Cleaning Remanence Data

Site	N	Decl. °	Incl. °	R	K	A_{95} °
31	10	149.7	64.2	9.94	152.3	3.9
32	10	171.5	60.7	9.87	74.0	5.6
33	11	165.5	61.1	10.95	228.8	3.0
34	11	161.1	61.4	10.98	564.6	1.9
35	8	174.9	58.5	7.93	105.7	5.4
36	10	148.7	30.0	9.85	60.7	6.2
37						
38						
39						
40						
41						
42						
Average	6	160.1	54.8	5.9	132.1	5.0

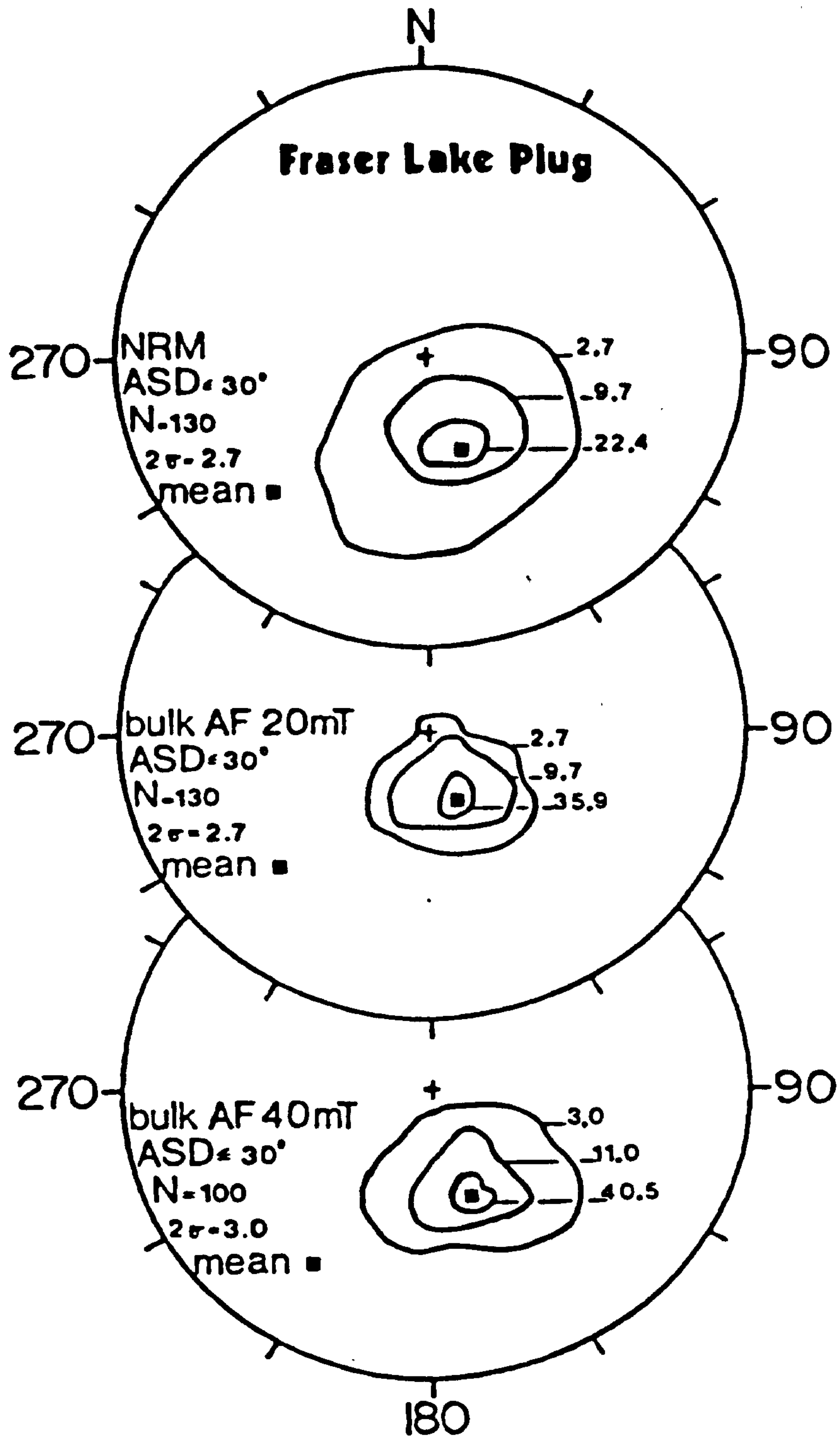


Figure 25 Stereoplot of Vector Directions for the Fraser Lake Gabbro after Bulk Cleaning of 20mT and 40mT

the A screening level of $\leq 30^{\circ}$ (Table 11). These accepted sites give a unit mean direction of 158.7°, 67.9° (A_{95} = 24.3°) for the Fraser Lake Gabbro (Figure 26).

d) AF 40mT Bulk Cleaning

From the 134 vectors treated at 40mT, only 100 vectors were accepted by the prescribed 30° ASD screening level. When plotted these vectors produced a single directional anomaly with a mean direction of 160.5°, 54.7° (Figure 25). The peak density of >40.5% yields a statistical significance of >>99.99% confidence to the anomaly (Figure 25). The average intensity is 1.73 E^{-1} Am^{-1} cm^{-3} after 40mT cleaning.

From the 11 sites, 6 site means were acceptable using the A_{95} screening level (Table 12). The unit mean direction of the Fraser Lake Gabbro that is defined by the 6 sites is 160.1°, 54.2° (A_{95} = 5.8°) (Figure 26).

e) Thermal Bulk Cleaning

Eight sites (31-36,40,41) were thermally bulk cleaned at temperatures of 500, 550, 600 and 650° C. The thermal cleaning isolated the same NRM as the AF cleaning (Figure 26) and had a mean direction of 160.2°, 64.1° (A_{95} = 1.5°)(Figure 26) (Table 13).

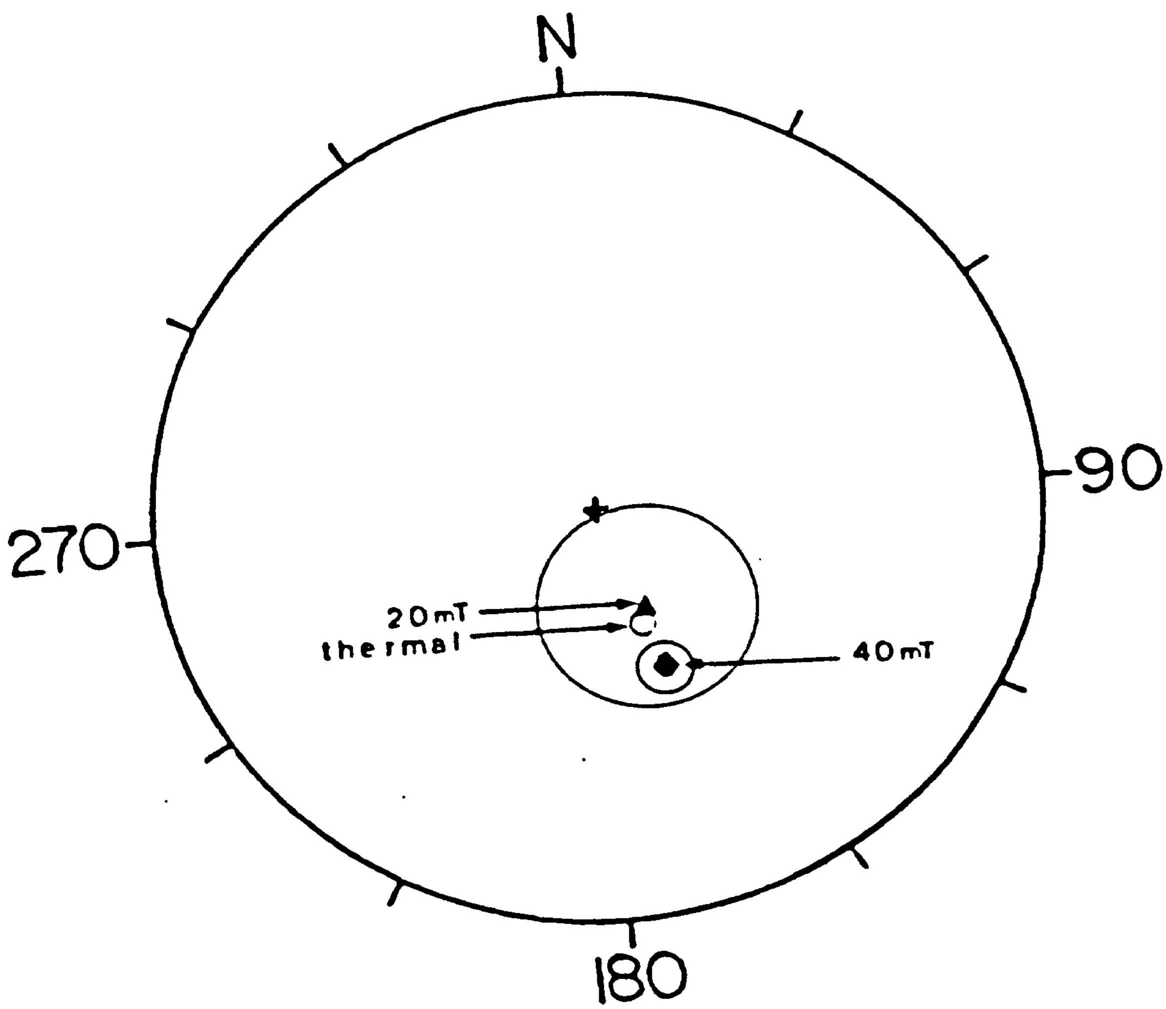


Figure 26 Fraser Lake Plug Mean Remanence Direction and A_{95}

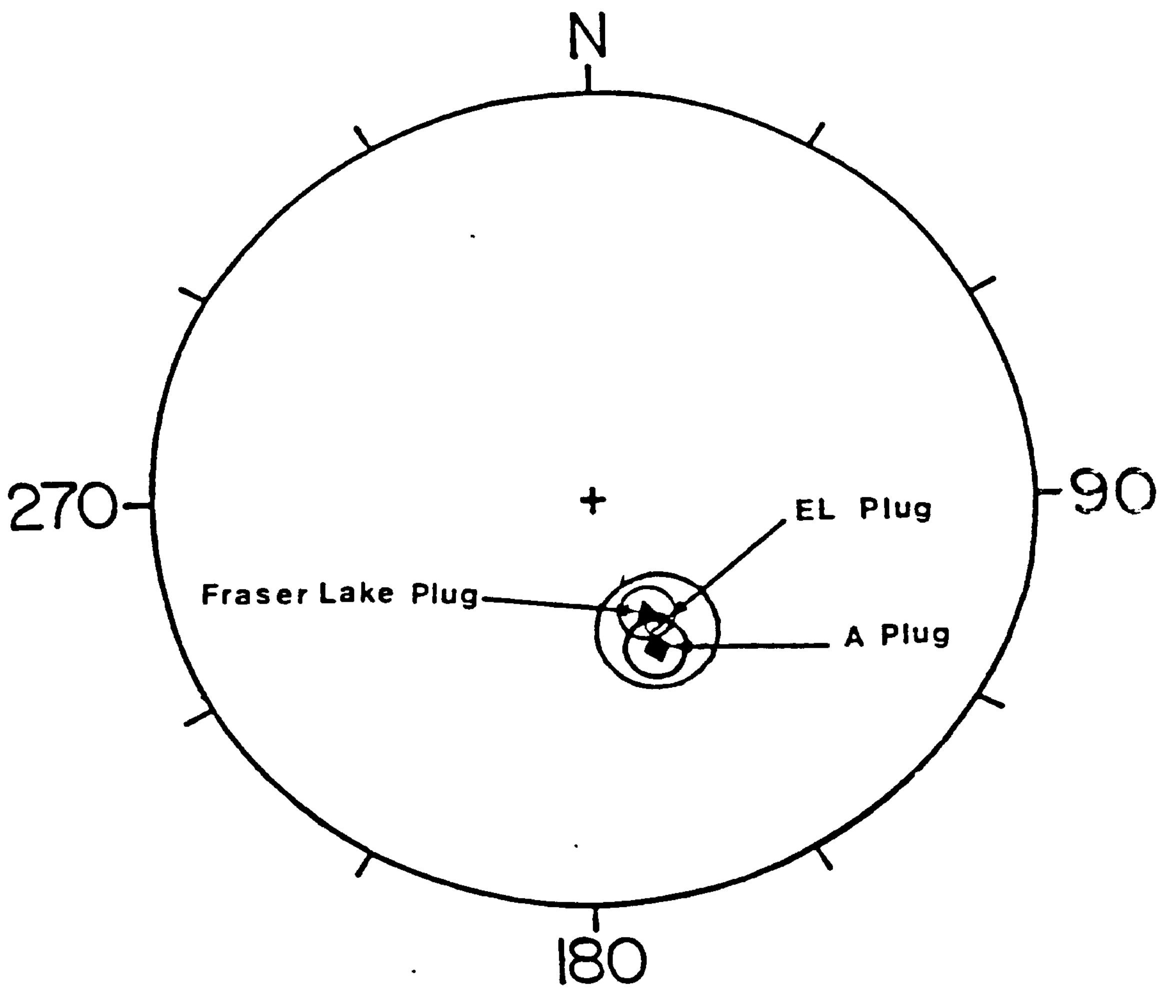


Figure 26b Average Mean Remanence and A_{95} Plot of the Three Gabbroic Plugs

Collection		Pop.	N	R	K	Decl. $^\circ$	Incl. $^\circ$	A_{95}	Long $^\circ$	Lat $^\circ$	δp $^\circ$	δm $^\circ$	co-lat $^\circ$
						Remanence Direction			Pole Position				
A Plug		20mT	14	13.5	30.6	163.1	68.7	6.7	87.8	7.2	9.4	14.5	37.9
	*	40mT	15	14.2	24.4	157.9	59.6	7.8	86.3	17.5	8.8	10.0	49.5
	*	Thermal	3	2.9	>999	151.9	62.3	.6	81.4	15.4	0.7	0.8	46.3
EL Plug	*	20+30mT	6	5.7	19.1	161.7	52.5	12.9	90.3	24.3	11.3	11.5	56.9
Fraser Lake		20mT	9	7.0	3.5	158.7	67.9	24.3	84.6	7.1	33.7	49.5	39.0
	*	40mT	6	5.9	132.1	160.1	54.8	5.0	89.4	22.2	5.0	5.0	54.6
	*	Thermal	8	7.9	>999	160.1	64.3	1.5	86.6	11.3	3.8	2.4	43.9
Average		Site *	38	36.4	20.9	158.3	58.7	5.5	86.4	17.8	5.5	6.7	50.5

C. Summary

The unit mean directions derived from the various types of cleaning treatment for each plug can be seen in Figures 14,20,26 and 26b and Table 14 and their paleopoles are shown on an APW for North America reported by Irving and McGlynn (1976; 1981) (Figure 27). The age indicated by the APW corresponds to the age of 1900 Ma magnetization of the rocks and therefore the rocks may be older. From this study, the nature of the NRM present in all three plugs appears to be a thermal-chemical remanence. The remanence was acquired during emplacement of the plugs and has not been altered since that emplacement. Thus the given ages should represent the maximum age of the three plugs.

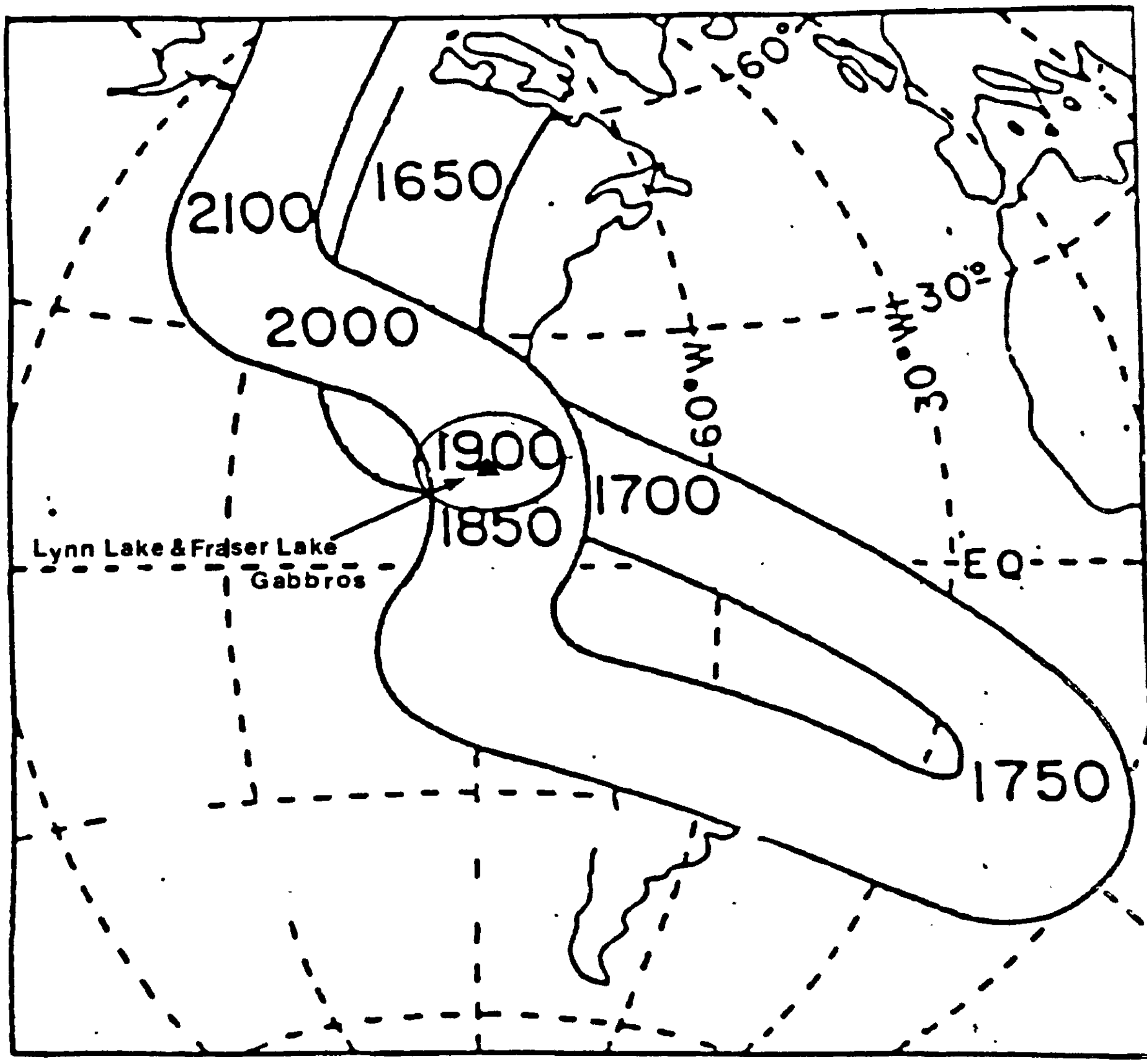


Figure 27 Virtual Geomagnetic Pole Remanence Component Plotted on Irving's (1979) APW Path for 1650-2200 Ma

Conclusions

A. Conclusions

The determined age of about 1900 Ma for the three plugs from the paleomagnetic data in this study does not change their position in the stratigraphic table by Gilbert et al. (1980) (Table 6). Therefore the geologic history of the Lynn Lake Greenstone Belt as reviewed in Chapter V remains valid. The three plugs intruded the Wasekwan Group and are pre-Sickle in age. The 1900 Ma age is consistent with the limits imposed by radiometric ages (Table 1). This study is significant because it shows that all three plugs are coevolutionary and that tectonically they have not been tilted subsequent to emplacement. The study shows that there is no reason to presume that the Fraser Lake plug does not contain sulphides, and that the lack of sulphides at the surface may reflect the depth at which equilibrium took place during emplacement. The results also suggest that some or all of the 13 mafic plugs in the area (Figure 3) may host sulphides.

Since there is no APW path for the Churchill Province, the use of an APW path based mainly on data from the adjacent Superior tectonic block permits only a relative magnetic date. It should be noted that the accuracy of the dating assumes a similar tectonic setting for the two tectonic blocks (Tarling 1983). In two recent papers, Thomas and Gibb (1985) and Green et al. (1985) suggested that the Churchill Province which contains the Lynn Lake Greenstone Belt has not moved differentially to the Superior Province whose APW path was used in this study. The agreement of the paleomagnetic data for all three plugs to the appropriate age on the path suggests that they are correct.

The univectorial paleomagnetics characteristics of the gabbro remanences also show that subsequent magnetic overprinting in these rocks is unlikely. Thus the regional metamorphism that formed the middle to upper greenschist assemblage in the Lynn Lake Greenstone Belt (Table 6) most likely predates or coincides with emplacement of the gabbros.

The study has led to a better definition of the time frame for emplacement of the gabbroic plugs and for their subsequent structural history. However it does not change the general stratigraphy. Therefore, in conclusion, the overall geologic history for the Lynn Lake area has not changed as a result of this study.

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