Preliminary geologic report on the Harris Lake Area, Northeastern Minnesota

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Illustrations

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ABSTRACT

Intense faulting and fracturing in the Harris Lake area, northeastern Minnesota, are documented by detailed field studies. Faults are identified chiefly by the disruption of mappable layers within sequences of plagioclase and plagioclase-olivine cumulates. Most layers grade from olivine-rich bottoms to plagioclase-rich tops and were probably deposited by density currents. Faults trend principally N35°E, N05°W, and N40°W. The recognition of intense faulting and fracturing in this region and an understanding of the currents responsible for cumulate deposition establish a basic geologic framework with important local and regional implications.

INTRODUCTION

This report accompanies the preliminary geologic map of the Harris Lake area (Plate 1) and briefly describes the nature and significance of some of the more important geologic relationships in this area. The Harris Lake area is located in northeastern Minnesota, within the Duluth Complex (Fig. 1). The Duluth Complex

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Figure 1 near here.

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is a 220 km long, arcuate-shaped composite intrusive that represents one of the world's largest mafic igneous bodies. It is located on the western flank of the midcontinent gravity high and is thought to be the result of a 1.1 b.y. old rifting event (Green, 1972; Chase and Gilmer, 1973; Cooper, Morey, and Weiblen, 1977).

Early work in the Duluth Complex by Grout (1918a,b) and the more recent work of Taylor (1964), Green and others (1966), Phinney (1969), and Bonnichsen (1969, 1970) identified the principal rock types and established the regional geologic relationships within the complex. Recent studies have focused principally on the region's petrology, tectonic setting, and economic potential. Of particular importance has been the recognition by Taylor (1964) of two different magma series (an older anorthositic and a younger troctolitic series). Studies by Bonnichsen (1969, 1970, 1972a, 1974a), Green and others (1966), and Phinney (1969, 1970, 1972) document multiple intrusive episodes within the troctolitic series. Chase and Gilmer (1973), Weiblen and Morey (1975), Weiblen and Cooper (1977b), Cooper, Morey, and Weiblen (1977) and Cooper (1978) have linked the emplacement of the Duluth Complex to a major episode of continental rifting. The nature and the economic potential of Cu-Ni sulfides near the base of the complex have been described by Bonnichsen (1972b, 1974b) and Weiblen and Morey (1976).

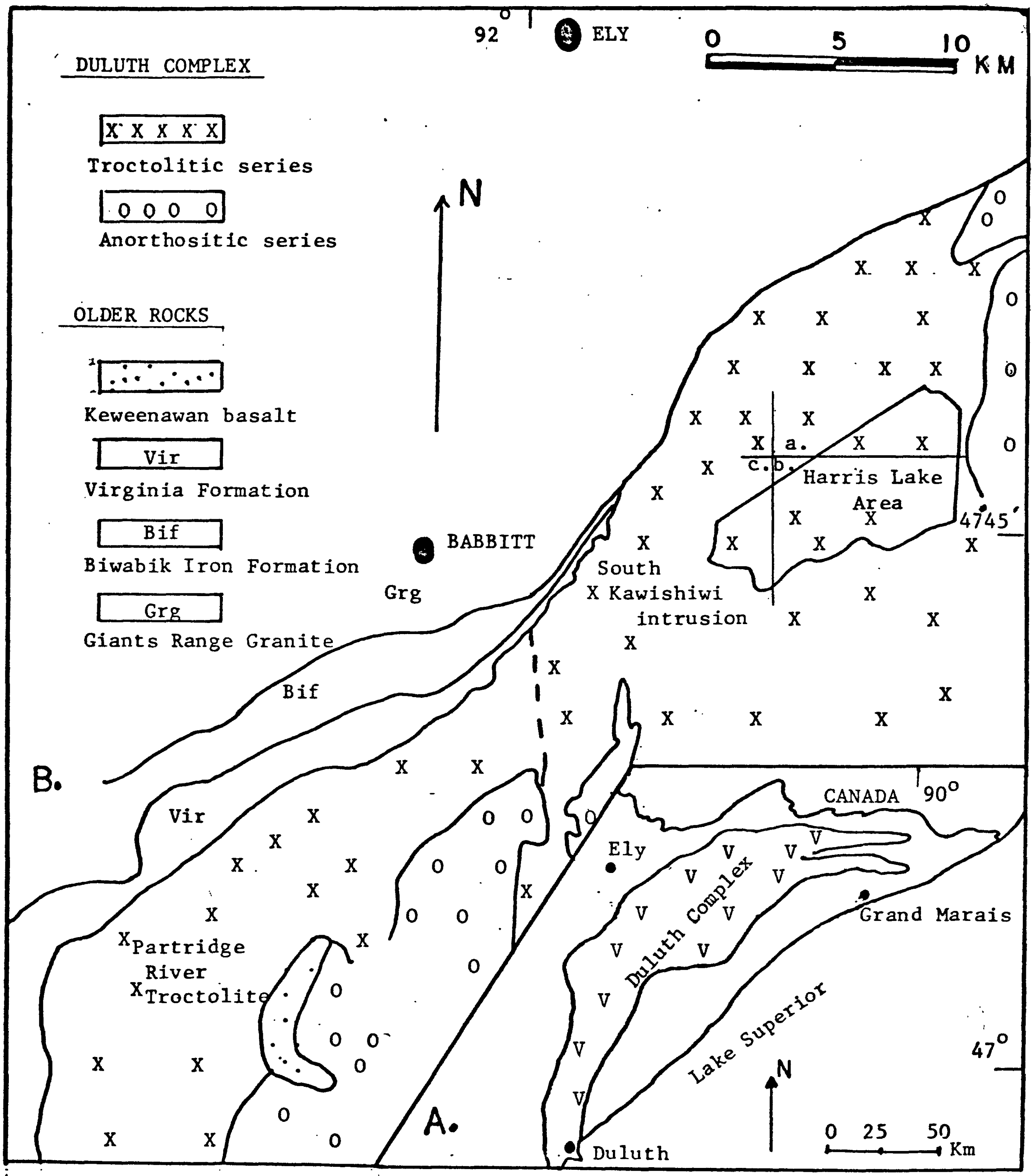

Figure 1. Location map of the Duluth Complex and the Harris Lake area. A. Location of the Duluth Complex in northeastern Minnesota. B. Generalized geology of part of the Duluth Complex (modified from Bonnichsen (1974b) showing the location of the Harris Lake area within the South Kawishiwi intrusion. Also showing parts of the Gabbro Lake quadrangle (a), the Greenwood Lake quadrangle, (b), and the Babbitt NE quadrangle, (c).

Although rift-related faulting has been considered important in the evolution of the Duluth Complex, very few faults have actually been documented by ground-controlled mapping (Weiblen and Morey, 1975). Largely this has been due to lack of exposure, absence of traceable layering, or insufficiently detailed mapping. The main goals of this study were to demonstrate that extensive faulting does occur within the complex and that an understanding of the fault structures is essential in any work on, or interpretation of, the Duluth Complex. The Harris Lake area was selected for detailed study primarily because of its unusually good exposures and because reconnaissance by one of us (RWC) had indicated that traceable layering might exist there. Detailed mapping at 1:12,000 (Plate 1) confirmed the existence of persistent, mappable layers that have been disrupted by complex faults. Many of the exposures display features similar to those found in sedimentary turbidites, and it is proposed that density currents analogous to those producing turbidites were responsible for depositing most of the mapped layered sequences.

AREA SETTING

The Harris Lake area (Fig. 1; Plate 1) is a 48 km^2 region located approximately 23 km southeast of Ely, Minnesota. It includes part of the Gabbro Lake and Greenwood Lake 15-minute quadrangles and the Babbitt NE 7½-minute quadrangle. The area is accessible via Minnesota Highway 1 and the Tomahawk road. Respectively, these define the area's northeastern and southern boundaries. Principal access into the central part of the area is provided by jeep trails, which intersect the Tomahawk road.

The topography and bedrock exposures within the Harris Lake area are typical of many glaciated Precambrian terrains. The area is one of generally low relief and poor drainage. Where swamps and glacial deposits occur, bedrock exposures are almost nonexistent. Such areas are found particularly in the southeastern and northern parts of the mapped area. Locally, however, glacial erosion has exposed bedrock ridges, and outcrops are excellent. Further, clear-cutting in many of these well-exposed areas has removed virtually all vegetation and much of the top soil to produce local areas with nearly continuous exposure. Well-exposed clear-cuts occur principally in the central part of the map area and were the critical areas in which many of the detailed geologic relationships were established.

Rocks in the Harris Lake area are part of the South Kawishiwi intrusion (Fig. 1). This intrusion has received considerable attention (Green and others, 1966; Phinney, 1969; Bonnichsen, 1969, 1970, 1974a; Fukui, 1976; Fellows, 1976; Cooper, 1978), and it is believed to be one of a number of intrusions which together make up the Duluth Complex. It is composed of a 70 to 400 meter thick sulfide-bearing basal zone of mixed ultramafic and mafic rocks and hornfels, which is overlain by several hundred meters of cumulates predominantly composed of 65 to 85 percent plagioclase (An 45-70) with lesser amounts (8 to 30 percent) of olivine (Fo 45-65) (Phinney, 1969; Bonnichsen, 1974a). Within this sequence, the abundance of interstitial pyroxenes and oxides decrease upwards (Phinney, 1969; Bonnichsen, 1974a). Due to faulting, the stratigraphic position of the Harris Lake area within this sequence is not precisely known, but probably it is between 700 and 1,000 meters above the basal contact.

Mapping of the region proceeded on an outcrop by outcrop basis. Where detailed relationships could be worked out, in areas of good exposure, an attempt was made to visit every outcrop. In poorly exposed areas, where detailed relationships could not be established, traverses defined the basic rock types. Whenever possible, contacts between rock layers were followed as far as exposures permitted. Field work began in early October, 1977, and continued into the middle of November, at which time heavy snowfalls forced a termination of mapping.

ROCK UNITS

The distribution and description of rock types within the Harris Lake area are treated on Plate 1. Based on the cumulate minerals present, two groups of rock types are recognized. Troctolites (cumulates composed mostly of plagioclase with lesser amounts of olivine) are the most abundant and could be further subdivided into two groups based largely on their intercumulus mineralogy. Troctolites, which are mostly medium to coarse grained, have well-developed ratio layering (layering that is defined by a change in the proportion of cumulus minerals), and contain between 3 to 10 percent intercumulus pyroxene and oxides, form a lower sequence (POC_X, Plate 1). Overlying this is a sequence of medium- to fine-grained troctolites that display weakly developed ratio layering and usually have little or no intercumulus pyroxene or oxides (POC_L and POC_U). A thin horizon of troctolite with distinctive 3 to 10 cm large oikocrysts (POC_O) occurs within this upper sequence.

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Anorthosites (plagioclase cumulates) are the only other rock group recognized. They occur chiefly as thin layers or as clasts and blocks included within a troctolite matrix. The majority of anorthosites are found in the upper troctolite sequence, where they most often form thin, continuous layers or, less commonly, occur as clasts, which usually do not exceed 5 m across. In contrast, anorthosites are relatively rare in the lower troctolite sequence (POC_x, Plate 1). When present, most anorthosites are either large (5 to 20 m) clasts or blocks in troctolite or bodies whose relationships with surrounding troctolites could not be determined.

Continuous, mappable layering was observed only within the upper troctolite sequence. Individual layers commonly have abundant cumulus olivine at the base and decreasing amounts of olivine upward. In places, nearly pure plagioclase cumulates form the top of layers and are in sharp contact with the olivine-rich base of overlying layers (Fig. 2). Scour structures occur along some of the layer contacts, and

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Figure 2 near here.

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clasts of olivine-poor plagioclase cumulates are often found in the olivine-rich, basal portions of layers. Layer thickness varies markedly from less than 1 m to over 50 m. Thin layers commonly pinch out over short distances along strike, but in some areas of good exposure, the contact between anorthositic tops and overlying olivine-rich basal troctolites is a mappable horizon that can be followed laterally for several kilometers. One of these anorthositic layers is nearly 10 m thick and provided a marker horizon that could be traced through much of the map area (PC_1, Plate 1).

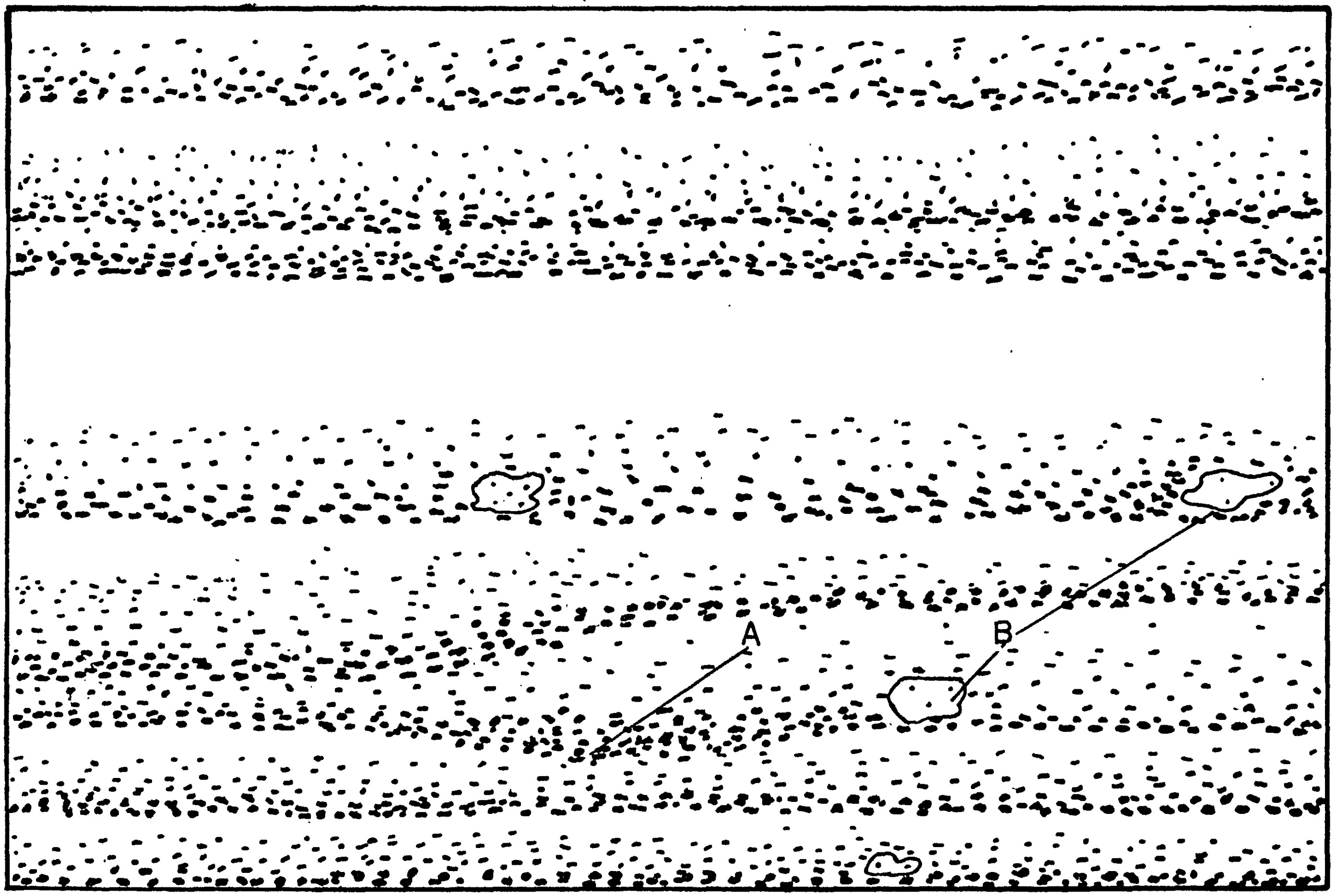

Figure 2. Schematic diagram of troctolite layering. Cumulus olivine (black) concentrates toward layer bottoms and decreases upwards as plagioclase (white) increases. Scour structures (A) occur along layer contacts, and some layers are truncated by overlying layers. Clasts of olivine-poor troctolite (B) are found included in a matrix of olivine-rich troctolite. Diagram is not to any scale; plagioclase-rich layers range from less than 1 m up to 10 m in thickness.

We propose that most of the layering developed by processes similar to those that form sedimentary turbidites. It is probable that cumulates of unconsolidated plagioclase and olivine crystals were poured into magma chamber depressions either in response to unstable deposition of cumulates on high areas or perhaps as a result of fault uplifts of the magma chamber floor. A new graded layer formed as the dense olivine settled out quickly, forming an olivine-rich troctolitic base. Slower settling of the less dense plagioclase produced an upward decrease in olivine content and, in some cases, a nearly monomineralic anorthosite top. Successive pulses of cululate-laden density currents formed sharp contacts with underlying layers. Locally, scour structures formed along the contact, and beheading of the upper parts of lower layers produced inclusions of olivine-poor troctolites in the olivine-rich basal zones. Similar layering has been reported from a number of other mafic intrusions (for example, by Jackson, 1961; Wager and Brown, 1967; Ford, 1976). The widespread distribution of this layering and the large size of some of the incorporated clasts clearly indicate a dynamic depositional environment for rocks in this part of the Duluth Complex.

STRUCTURES

Faults and fractures are the most abundant and important structural features in the Harris Lake area (Plate 1). Recognition of these structures required detailed mapping of individual plagioclase-rich layers. However, additional confirmation of faulting was obtained by noting local variations in the attitude of mineral laminations, the occurrence of gouge, and the presence of marked topographic lineaments.

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Three major directions of faulting were noted in the Harris Lake area (Fig. 3).

Figure 3 near here.

The principal direction trends N30°-40°E and is subparallel to the basal contact of the Duluth Complex in this region. The largest offsets are noted along these northeast-trending structures, and they were the only faults with extensively developed gouge. Further, prominent topographic lineaments are commonly associated with the larger faults, and some can be traced on aerial photographs and topographic maps as far as 20 km beyond the mapped area. For example, several of the northeast-trending structures that pass through Harris Lake extend northwards and form some of the prominent northeast-trending inlets within Gabbro Lake, 17 km to the north of Harris Lake. Less prominent faults are generally oriented N05°W and N40°W, although virtually any direction of faulting might occur locally. Displacements on all faults appear to be small, usually less than 200 m. The general lack of offset of one fault by other faults indicates that most displacements may have been largely the result of nearly vertical, block movements.

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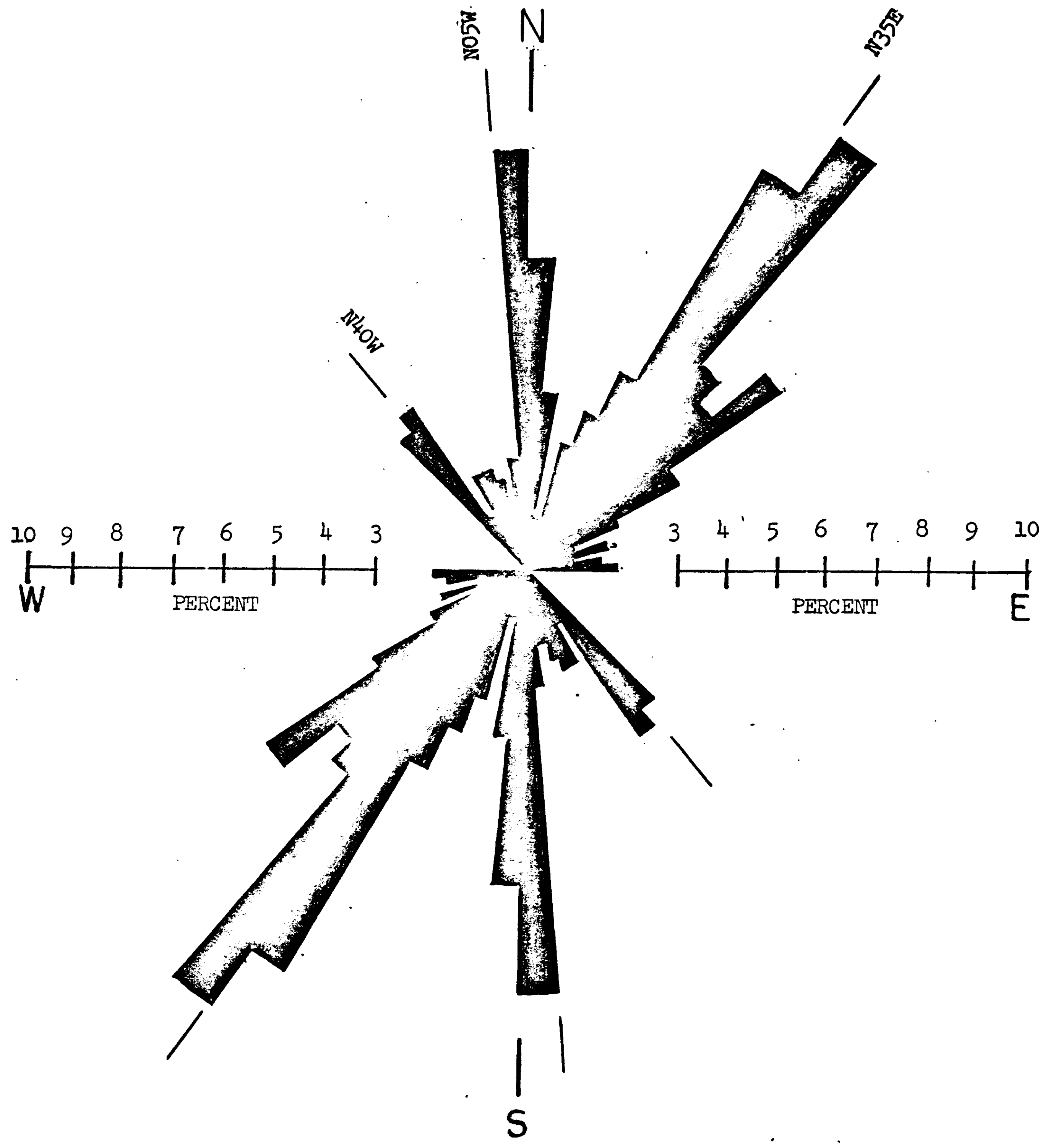

Figure 3. Harris Lake area fault directions. All mapped faults are shown. Faults were divided into 300 m long segments, and segment directions were plotted as percentages of the total length of mapped faults. Maxima occur at N35°E, N05°W, and N40°W.

Division of the Harris Lake area into northern, central, and southern segments (Fig. 4) reveals some changes in the fault pattern. Although the northeast, north,

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and northwest trends appear in all areas, their relative importance exhibits some variation. In the northern and central areas (Figs. 5 and 6), the northeast-trending

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Figures 5 and 6 hear here.

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faults predominate, while in the southern area, north-trending faults are most abundant (Fig. 7). From north to south, the orientation of the northeast-trending

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Figure 7 near here.

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faults shifts from N35°E (Fig. 5), to N35°-40°E (Fig. 6), to N50°E (Fig. 7). The north-trending faults shift slightly from N05°E in the north (Fig. 5) to N05°W in the south (Fig. 7). The direction of the northwest-trending faults appears to remain virtually unchanged.

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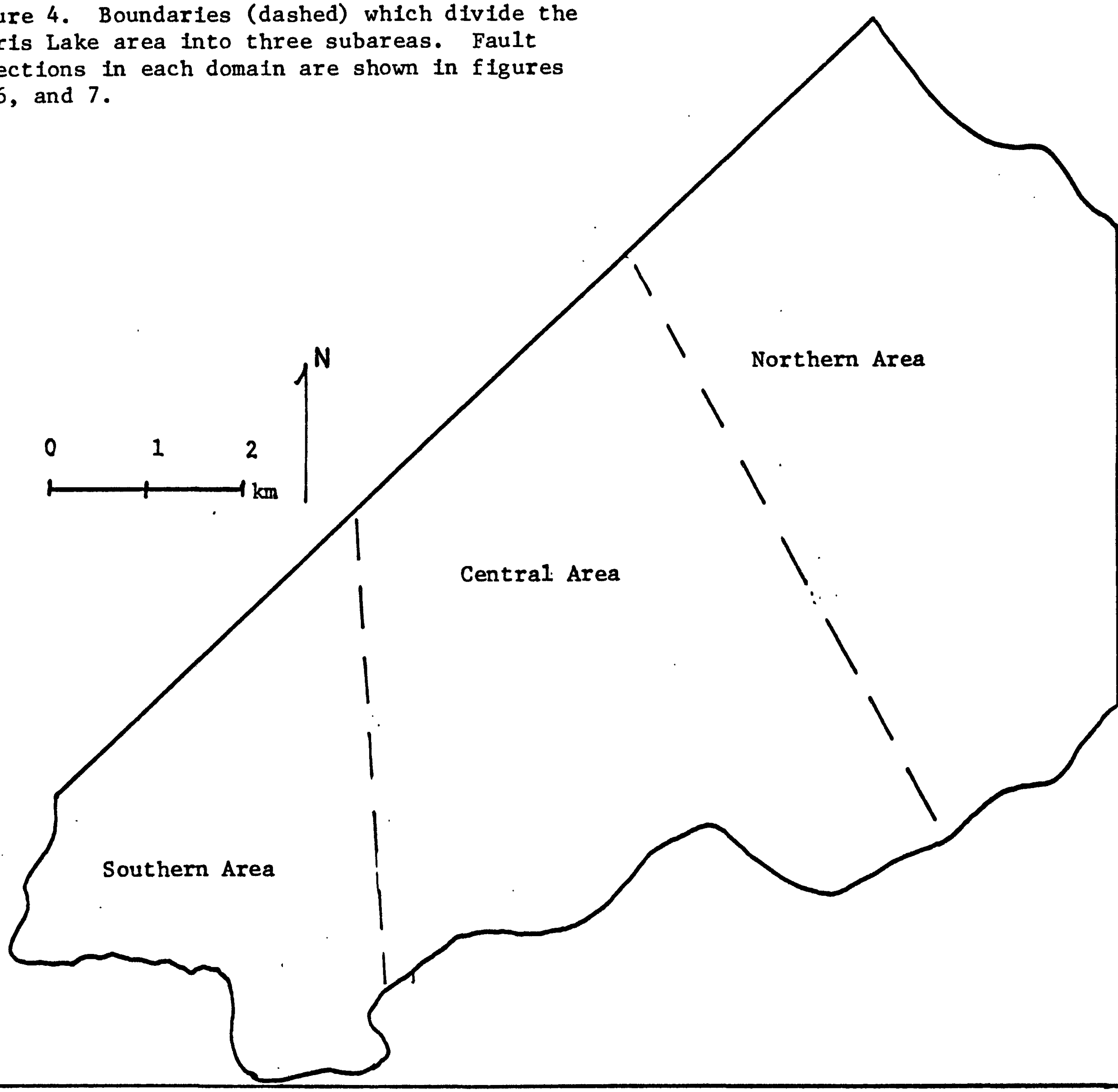

Figure 4. Boundaries (dashed) which divide the Harris Lake area into three subareas. Fault directions in each domain are shown in figures 5, 6, and 7.

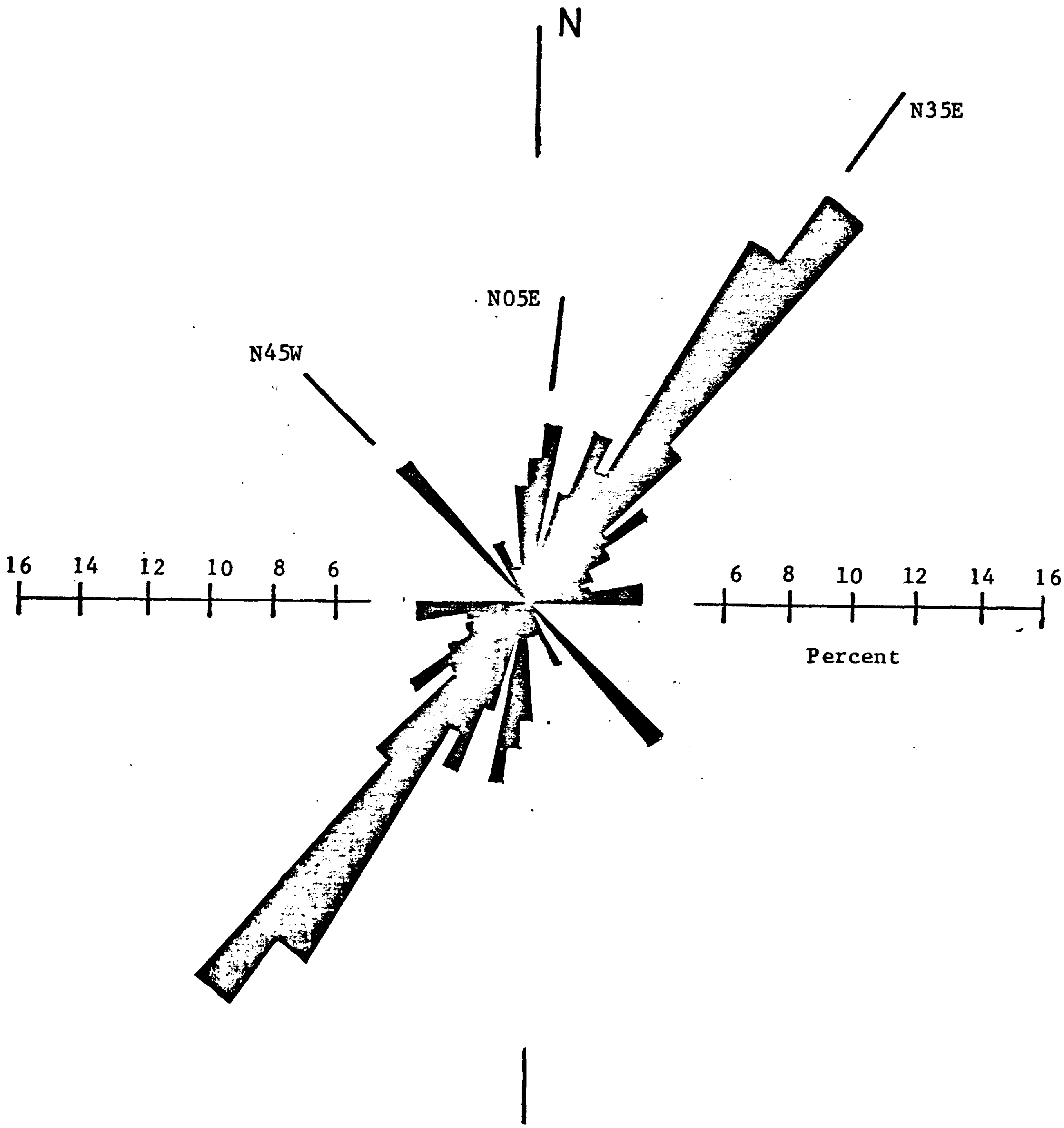

Figure 5. Northern area fault directions. Fault maxima occur at N35°E, N05°E, and N45°W.

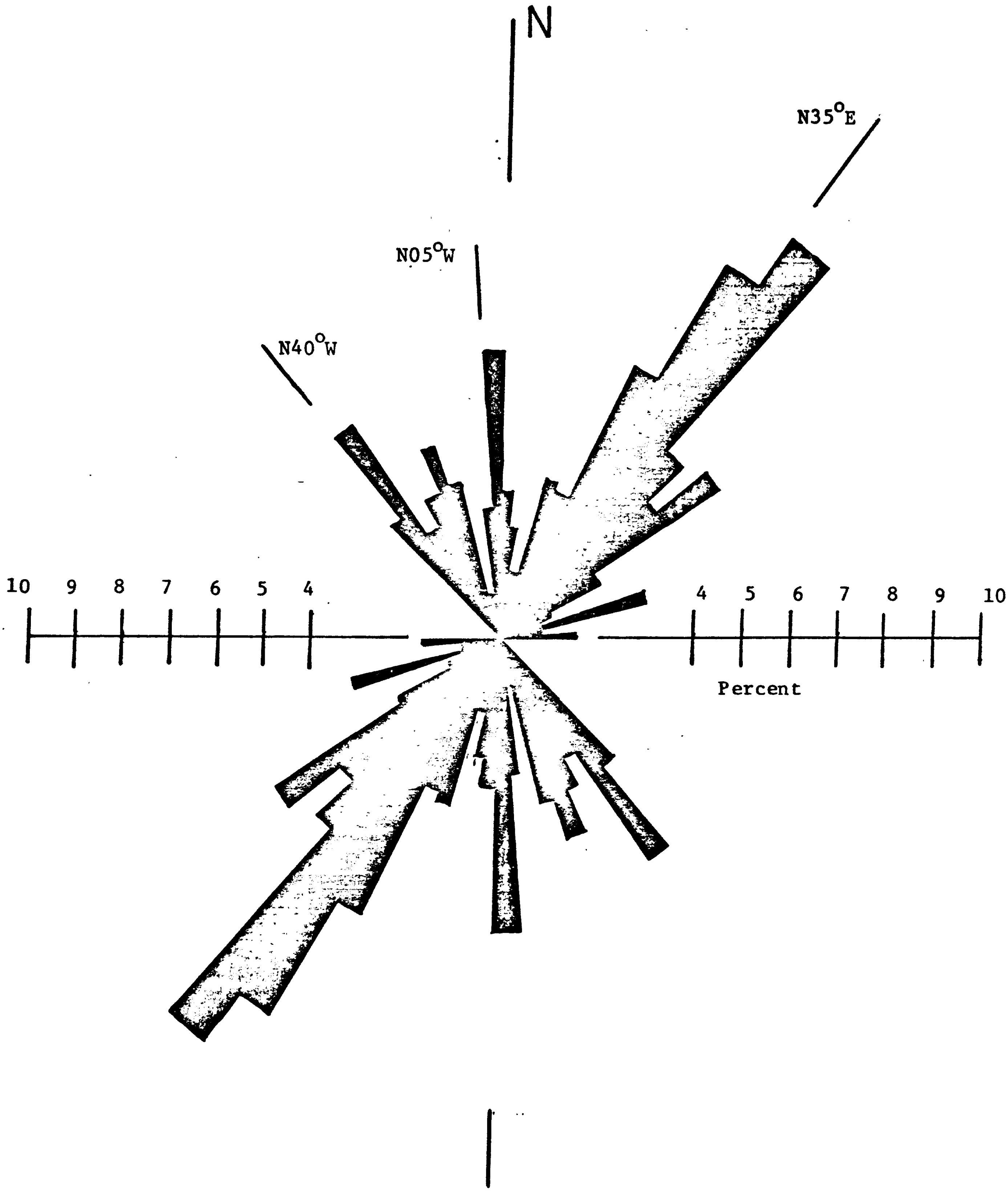

Figure 6. Central area fault directions. Fault maxima occur at N35- 40°E, N05°W, and N40°W.

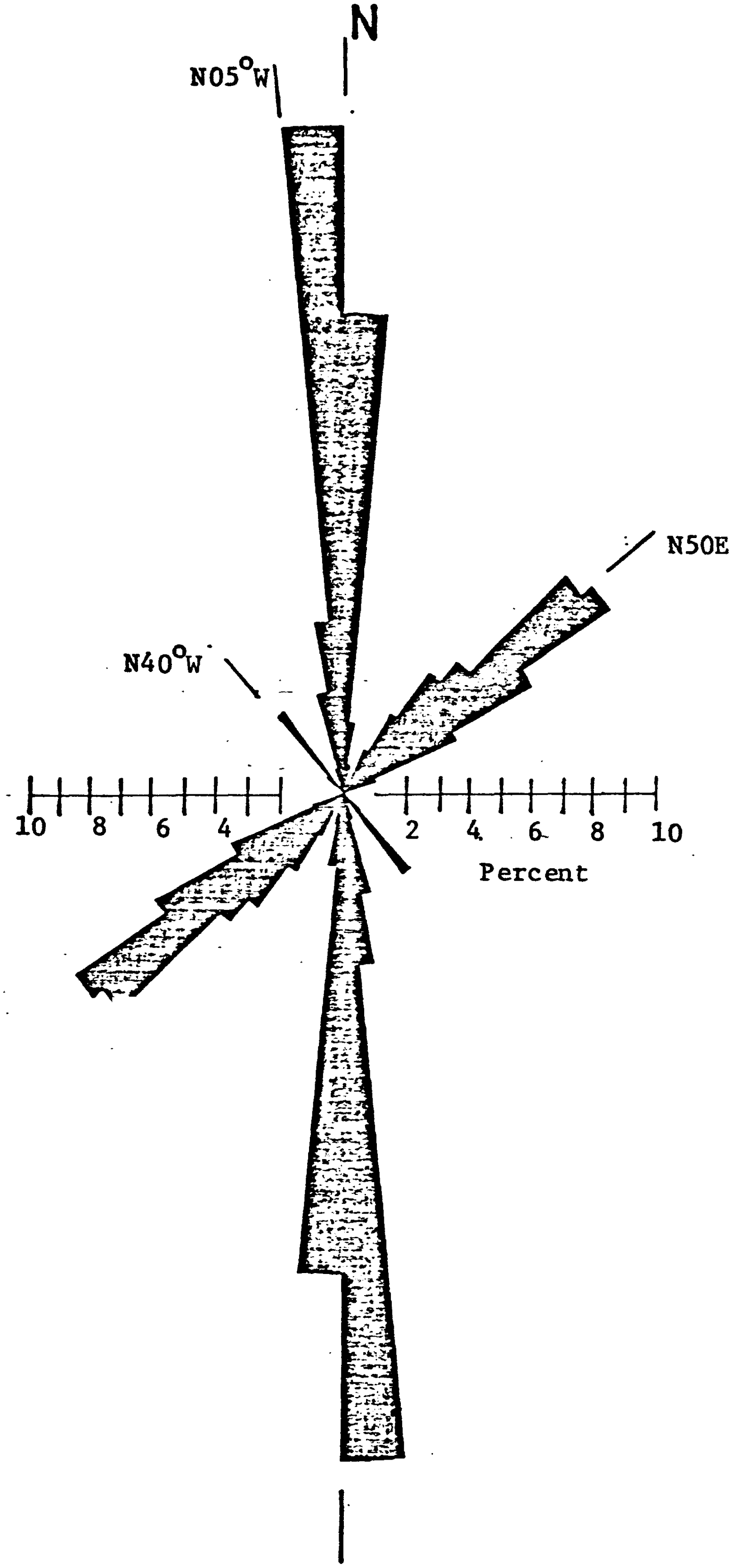

Figure 7. Southern area fault directions. Fault maxima occur at N50°E, N05°W, and N40°W.

The style of faulting in the Harris Lake area is schematically shown in Figure 8. Although the diagram is designed to portray the mapped fault pattern

Figure 8 near here.

as accurately as possible, the actual direction and magnitude of displacements of most faults shown are not known. The pattern is one of intense block faulting and is compatible with regional extension. However, the stress system that produced the faulting and its relationship with Keweenawan rifting have not been determined.

A few minor folds are associated with faults. They are open flexures that range up to 100 m in wavelength. Fold axes are nearly horizontal, and axial surfaces dip steeply; invariably, the fold axes are subparallel to the surface trace of adjacent major faults, and it is probable that they are secondary structures produced during faulting. Although most folds observed appear to be minor features, it is probable that the two bodies of PC_1 that occur along the southern shore of Harris Lake (Plate 1) are deformed by large, open synclines.

The faults and associated minor folds are interpreted to have formed after deposition and consolidation of the cumulates. This interpretation is supported by the lack of strongly disturbed mineral laminations within layered rocks near faults and the continuity of mineral layering within the fold structures. Although these rocks appear to have been consolidated at the time of faulting, it is possible that liquid was still present in upper levels of the magma chamber. Faulting may have occurred in response to the rifting event that was also responsible for the emplacement of the Duluth Complex.

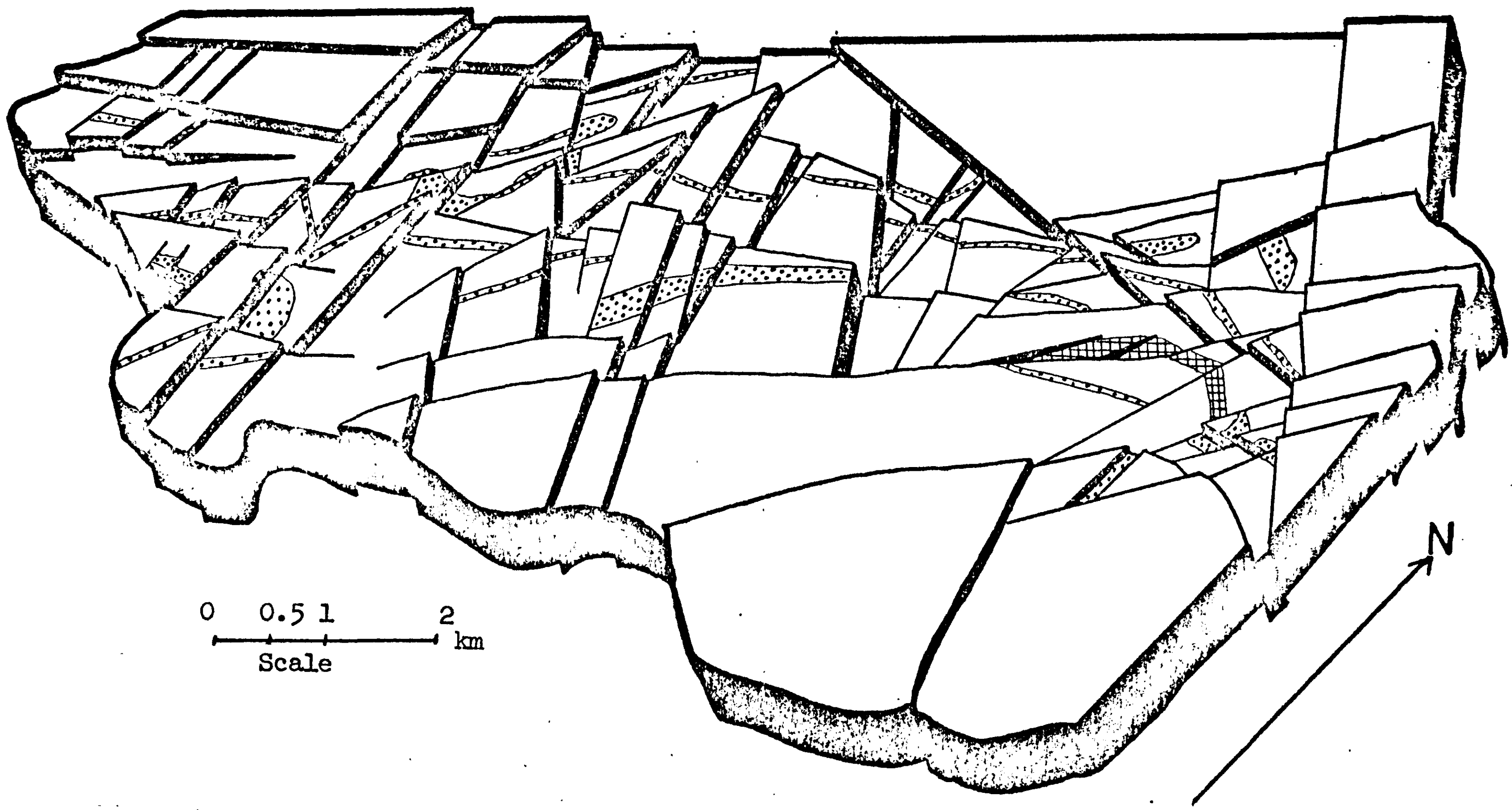

Figure 8. Schematic block diagram of faulting in the Harris Lake area. The diagram corresponds in general, but not in detail, with the fault patterns shown on Plate 1. The direction and magnitude of fault displacements are largely inferred, as most could not be determined in the field. Some plagioclase cumulate layers are shown (stippled), and a horizon of oikocrystic troctolite (POC_o, Plate 1) is shown cross-hatched.

GEOLOGIC IMPLICATIONS

The recognition of extensive faulting and fracturing in the Duluth Complex is important to understanding the local and regional geologic setting. Although the area studied is quite small, the observed structural pattern appears to be geologically reasonable, based on similar complex faulting observed in the country rock (Sims, 1976a, b; Morey and Cooper, 1977) and on the region's suggested origin in a rift environment. As noted above, many lineaments associated with mapped faults can be traced outside of the study area. Several of these form the prominent north- and northwest-trending shorelines of Birch Lake and the northeast-trending shores of Gabbro Lake (17km to the north of Harris Lake). Elsewhere in the region, some of the topographic lineaments are oriented parallel to the major fault directions (Fig. 3) identified by this study. Cooper (1978) has concluded from a study of the relationship between bedrock geology, topographic lineaments, aeromagnetic lineaments, and joint patterns that much of the surrounding area was intensely faulted and fractured. Thus, the relationships observed in this small area may establish a structural style that is common over much of the region. Previously, only a few faults had been identified by geologic mapping (Weiblen and Morey, 1975; Cooper, 1978), largely owing to the great difficulty in carrying out detailed field work on the Duluth Complex. However, the existence of extensive faulting and fracturing must be considered in any future work on, and interpretation of, the Duluth Complex.

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Locally, the recognition of faulting may contribute to understanding the distribution and genesis of copper-nickel sulfides within the Duluth Complex. These deposits are mainly confined to a narrow zone along the basal contact of the Duluth Complex. Most workers have considered the sulfides to be the product of the settling of immiscible sulfides within a crystallizing magma (Bonnichsen, 1972b; Boucher, 1975). However, recent work by Weiblen and Morey (1976) suggests that the introduction of sulfur-rich vapors along faults and fractures might also have been another mechanism important in forming and concentrating these deposits. Recognition of intense faulting within the Duluth Complex is compatible with, but does not prove, the latter hypothesis. It does, however, clearly indicate the need to understand the relationship between sulfide genesis, by either mechanism, and faulting. Also, understanding the distribution and character of the faulting is important, as these structures may affect ore continuity in the sulfide deposits.

The Duluth Complex is situated on the northeast-trending midcontinent gravity high that has been interpreted as part of a 1.1 b.y. old rift system. Emplacement of the complex is thought to be a part of this rifting event (Weiblen and Morey, 1975; Weiblen and Cooper, 1977; Cooper, Morey, and Weiblen, 1977). Weiblen and Morey (1975) suggest that large voids formed near or along fault-bounded, keystone-shaped blocks as a result of rifting. Magma flowed into these voids forming a body composed of multiple intrusions. Although a regional lineament analysis by Cooper (1978) indicated the probable existence of large fault structures, little field evidence of rift-related structures were found. The present study provides convincing evidence that extensive faulting and fracturing occurred within the Duluth Complex.

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