Canadian Mineralogist
Vol. 27, pp. 81-92 (1989)

IGNEOUS STRUCTURES IN THE FALCON LAKE INTRUSIVE COMPLEX, SOUTHEASTERN MANITOBA

WILLIAM S. MANDZIUK AND WILLIAM C. BRISBIN
Department of Geological Sciences, University of Manitoba, Winnipeg, Manitoba R3T 2N2

R.F. JON SCOATES
Geological Survey of Canada, 601 Booth Street, Ottawa, Ontario K1A 0E8

ABSTRACT

The Falcon Lake intrusive complex (southeastern Manitoba), of Archean age, a composite body approximately 5 × 2 km, has an elliptical core and tapered, tabular extensions to the northeast and southwest. The body is the result of a series of intrusions, and ranges from gabbroic rocks (oldest) in the tabular extensions, through younger diorite–granodiorite in the outer core, to quartz monzonite (youngest) in the inner core. The rocks have either a cumulus or porphyritic texture. The compositions, distribution, and relative ages of the components indicate that the intrusions were drawn sequentially from a single differentiating magma. The complex, initially tabular, subsequently developed a larger, more cylindrical form, and in the waning stages, became progressively more constricted toward the core. The primary igneous structures include planar laminations, mineral lineations, lineate laminations, layering, local discordant intrusive contacts similar to angular conformities, trough bands, mafic-mineral clots, felsic-mineral segregations, xenoliths, cognate inclusions, dykes, and late-stage breccia pipes. The mineral-orientation structures and layering are concentric and dip steeply. The textures and primary structures indicate that each intrusion involved a crystal–liquid mixture, and that magmatic flow was responsible for the discordant features, the mineral orientations, and the layering. Periods of low-velocity laminar flow, yielding concordant fabrics, alternated with periods of high-velocity turbulent flow, which led to discordant structures. Possible origins of these fluctuations include intrusive surges, convection, the periodic slumping of sidewalls and the development of density currents.

Keywords: Falcon Lake igneous complex, concentric layering, igneous structures, gabbro, diorite, granodiorite, quartz monzonite, laminar flow, turbulent flow, Archean, Manitoba.

SOMMAIRE

Le complexe intrusif archéen du lac Falcon, dans le sud-est du Manitoba, composite et mesurant environ 5 × 2 km, possède un noyau elliptique et des prolongements tabulaires effilés vers le nord-est et le sud-ouest. Le complexe résulte d'une série d'intrusions qui ont donné des roches gabbroïques (les plus anciennes) dans les prolongements tabulaires, des diorites et granodiorites dans la partie externe du noyau, et des monzonites quartzifères dans sa partie centrale. Les roches ont soit une texture de cumulat, soit une texture porphyrique. La composition, la distribution et les âges relatifs des unités montrent que les intrusions ont été soutirées séquentiellement d'un magma au cours de sa différenciation. D'abord un massif tabulaire, le complexe a ensuite adopté une forme plutôt cylindrique et, dans ses stades tardifs, s'est progressivement pincé vers le noyau. Parmi les structures ignées primaires, nous trouvons: laminations planaires, linéations de minéraux, laminations linéaires, rubannement, contacts intrusifs discordants semblables à des discordances angulaires, litage associée à des chenaux, agrégats de minéraux mafiques, ségrégations de minéraux felsiques, xénolites, enclaves cogénétiques, dykes, et cheminées bréchiques tardives. Le rubannement et les structures d'orientation des minéraux sont concentriques et ont un pendage sub-vertical. Les textures et structures primaires révèlent que chacune des intrusions impliquait un mélange d'un bain fondu et de cristaux, et qu'un écoulement magmatique est responsable des contacts discordants, des structures d'orientation de minéraux et du rubannement. Des périodes d'écoulement laminaire, à faible vitesse, qui ont produit des structures concordantes, ont alterné avec des périodes d'écoulement turbulent, à vitesse plus élevée, qui ont produit des discordances. Ces fluctuations dans le débit seraient liées à des pulsations intrusives, la convection, un affaissement périodique le long des parois, et le développement de courants de densité.

(Traduit par la Rédaction)

Mots-clés: complexe igné du lac Falcon, rubannement concentrique, structures ignées, gabbro, diorite, granodiorite, monzonite quartzifère, écoulement laminaire, écoulement turbulent, archéen, Manitoba.

INTRODUCTION

The Falcon Lake Intrusive Complex is a small composite body located a few km west of the Manitoba–Ontario border in southeastern Manitoba (Fig. 1). Previous investigators (Brownell 1941, Davies 1954, House 1955, Haugh 1962, Gibbins 1971) referred to the body as the "Falcon Lake Stock" and interpreted it as a zoned body, consisting of two intrusive units, the emplacement and crystallization history of which were relatively simple. The present study, which results primarily from a field investigation, has identified six intrusive events, and has led to the recognition of primary structures

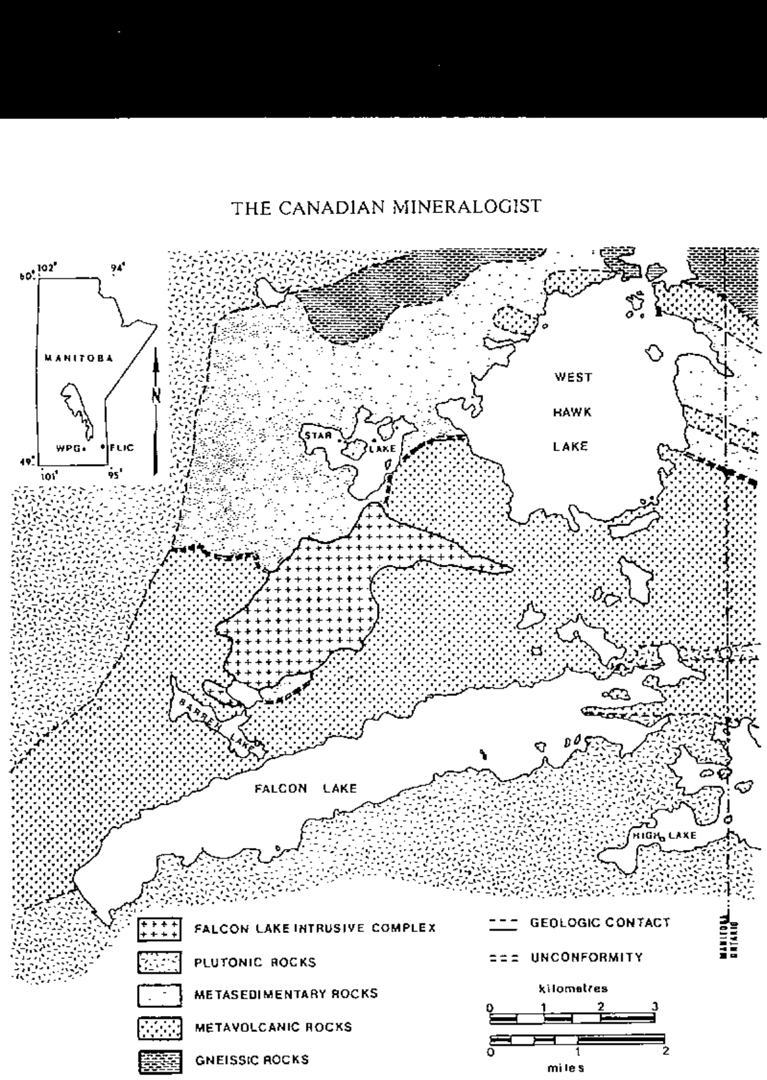

FIG. 1. Regional geological setting of the Falcon Lake Intrusive Complex.

that reflect a much more complicated history of emplacement and consolidation. Consequently the body has been renamed the "Falcon Lake Intrusive Complex" (FLIC). The objective of this paper is to document the character of the intrusive events and of the primary structures that together make up FLIC, and to interpret these features in terms of processes and conditions during the emplacement and consolidation of the body.

DIMENSIONS, GEOLOGICAL SETTING, AGE

FLIC is approximately 5 km long and 2 km wide. The body in plan is approximately elliptical, with tabular extensions at the northeastern and southwestern ends of the ellipse (Fig. 2). The complex was emplaced into Archean metavolcanic and metasedimentary rocks of the western part of the Wabigoon Subprovince of the Superior Province. These host rocks have been subjected to upper-greenschist regional metamorphism and contain folds with an axial planar schistosity that strikes northeasterly and dips steeply. The complex has truncated these structures on steeply dipping contacts and has upgraded the country-rock metamorphic level to amphibolite grade in a thermal contact aureole 0.5 to 1 km wide. Textures within the complex next to the contact are medium to coarse grained. Dykes and apophyses extend outward from the complex into the country rocks for several hundred meters. Xenoliths of schistose host-rocks are common throughout the complex. These relationships indicate that the complex was emplaced after deformation and regional metamorphism, and that its present pipe-like form and approximately vertical orientation are original. A K–Ar age determination on biotite from the center of the complex gave a minimum age of 2.3 Ga (Wanless *et al.* 1968).

DISTRIBUTION AND COMPOSITION OF INTRUSIONS

Six individual intrusions comprise FLIC. The tabular extensions of the complex consist of four intrusions, of which three (A, C and D) are gabbroic; the fourth (B) ranges from pyroxenite to melagab-

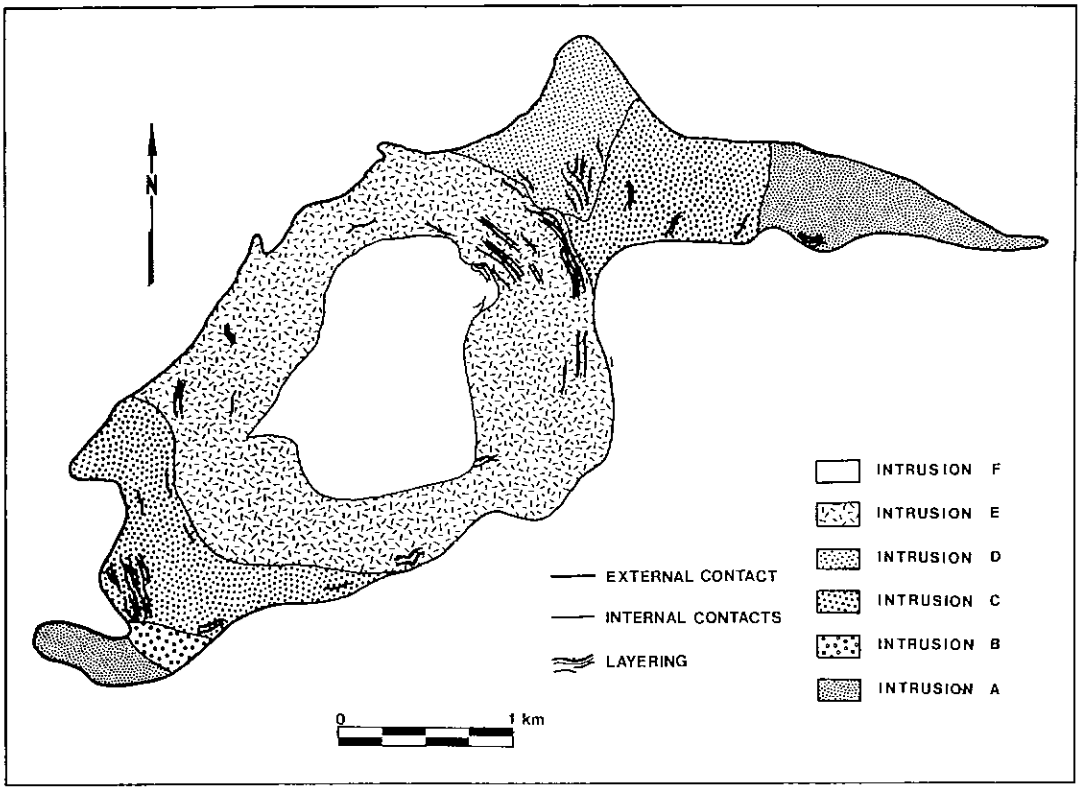

FIG. 2. Geology of the Falcon Lake Intrusive Complex. Layer symbols are shown only where layering was observed; other layering may be present. Layer dips are most commonly nearly vertical throughout the complex.

bro. The central part of the complex consists of an outer annular ring (intrusion E), which ranges from diorite to granodiorite, and an inner core (intrusion F), which contains quartz monzonite. The intrusions are designated from oldest (A) to youngest (F); their arrangement within the complex is shown in Figure 2.

The contacts between the intrusions are sharp and generally discordant, such that younger intrusions truncate mineral alignments and layering of older intrusions. These contacts, along with evidence from inclusions and from dykes, have been used to establish the intrusive sequence. Inclusions of older intrusive rocks become progressively more varied toward the core, so that the youngest intrusion (quartz monzonite) contains inclusions of all older lithologies of the complex. In contrast, the dyke assemblage within the complex becomes progressively more varied in composition away from the core.

Cumulus plagioclase ranges from An_{50} to An_{70} in the gabbros (intrusions A, B, C and D), and from An_{25} to An_{45} in the diorite–granodiorite (intrusion E). Plagioclase (An_{20}) in the quartz monzonite (intrusion F) occurs as sporadic phenocrysts. Potassium feldspar first appears in the granodiorite and is the predominant mineral in the quartz monzonite, where it occurs as phenocrysts and in the groundmass. Quartz is first observed in the intrusive sequence of the complex in the diorite–granodiorite and becomes a significant mineral in the quartz monzonite.

The main mafic mineral of the gabbros was clinopyroxene, now largely converted to hornblende. Much of the clinopyroxene was cumulate in character. Primary hornblende first appears in the youngest gabbro, and continues into the diorite–granodiorite, where it is accompanied by biotite. Hornblende is the predominant mafic mineral in diorite, and biotite is the predominant mafic mineral in granodiorite. The quartz monzonite contains less than 5% mafic minerals.

Accessory minerals in the gabbros include magnetite and apatite. In intrusion D, where magnetite makes up 5% of the intercumulus minerals, there are layers several cm thick composed of cumulus magnetite and apatite.

The progressive changes in mineralogy and rock type in the sequence of intrusions indicate a differentiation trend that suggests the presence of a single magma chamber that yielded periodic intrusive batches. Work by P. Tirschmann & N. Harden (pers. comm.) on the geochemistry of the complex shows major-element trends consistent with this idea. They also point out the possibility of further fractional crystallization occurring in each of the batches of magma after it has left the source chamber. The diorite–granodiorite intrusion (E) may represent a case in point.

TEXTURES

The gabbros (A, B, C and D) are medium to coarse grained and display predominantly orthocumulate textures. Cumulate textures give way to porphyritic textures in the diorite–granodiorite (E) and quartz monzonite (F). In these rocks, the phenocrysts are coarse, and the groundmass is medium grained.

PRIMARY STRUCTURES

FLIC exhibits a variety of primary structures. Although these structures occur in all intrusions of the complex, they are best developed and most easily identified in the outer gabbros (A, C, D).

Mineral-orientation structures

Intrusions of the complex are characterized by planar laminations, mineral lineations, and lineate laminations. Planar laminations in the mafic rocks are produced by the planar alignment of euhedral plagioclase crystals and, to a lesser degree, by the alignment of original clinopyroxene. Planar laminations in the diorite–granodiorite and quartz monzonite are produced primarily by feldspars and are not as well developed.

Mineral lineations are produced primarily by the alignment of the long axis of plagioclase crystals. The combination of the planar alignment of tabular faces and a linear alignment of the long axis of plagioclase crystals has led, in many locations, to the development of a perfect mineral alignment referred to in other bodies (Jackson 1967) as a lineate lamination.

The orientation of planar laminations, mineral lineations, and lineate laminations is generally steep and parallels intrusive contacts and spatially associated layering. The alignments are taken as evidence of laminar flow in a crystal–liquid mixture where orientation of flow laminae is influenced by intrusive contacts. Whether the linear aspects of the mineral orientations represent flow direction is problematic.

Layering and associated structures

Layering, which occurs within each intrusion of the complex, is best developed in the gabbroic rocks (Fig. 2). Layering in the quartz monzonite appears to be restricted to its outer contact (Fig. 2).

The scale and continuity of layering vary considerably. Layers range in thickness from a few mm to tens of meters. Some layers can be traced along strike for more than 100 m; other layers disappear within a single outcrop. At some locations, there is evidence that layers were disrupted in a relatively brittle fashion; several angular fragments, each containing small-scale layers, can be traced along a single horizon in larger-scale layering. At other locations, the layers have been deformed in a more ductile way; they pinch and swell, or have been pulled apart and rolled or folded.

The layering in the complex is produced by compositional variations and by grain-size changes. Con-

FIG. 3. Modally and grain-size-graded layers in gabbro (intrusion C), southwest detailed study-area. Core of the complex is to the right. Card width is 9 cm.

tacts between layers may be sharp or gradational. Many layers exhibit combined gradational modal and grain-size variations, similar to those in reversely graded sedimentary beds. The gradation is from a fine-grained mafic-mineral-rich base to a coarse-grained feldspar-rich top (Fig. 3). Top directions of layers predominantly face inward, toward the core of the complex. Nongraded layered sequences are common in the gabbros as well. They consist of unimodal layers of mafic minerals, a few cm thick, that alternate with layers of gabbro of uniform composition. Some sequences show well-developed repetitive alternations, and are best termed rhythmic sequences.

Layering in the complex dips steeply and is arranged in a generally concentric pattern (Fig. 2). The layering invariably tends to be parallel to neighboring intrusive contacts, and is accompanied by a planar or lineate lamination.

The origin of the layering in the complex is problematic. The orientation of the layering precludes an origin by simple crystal-settling. On the other hand, the mineral-orientation structures indicate that magmatic flow was a prevalent process at the time of layer formation, suggesting a genetic link between magmatic flow and layer development. Crystal–liquid separation, stimulated by laminar flow, is one possible explanation. Alternatively, side-wall crystallization coupled with changing composition of magma could account for the observed layering.

The intrusions of FLIC are characterized also by primary structures related to layering, such as local discordant intrusive contacts that are similar to angular unconformities (Fig. 4), and trough bands that are similar to scour channels in sedimentary sequences (Fig. 5). The trough bands occur along intrusive contacts, and represent scouring of the older rock unit. Layering of the younger intrusive material in the troughs adopts a buttress configuration against the margins of the scour channel. Angular unconformities and trough bands vary from less than a meter to dimensions that are so large that they cannot be observed in their entirety in several adjacent exposures.

The discordant intrusive contacts resembling angular unconformities usually have steep dips, have the same concentric arrangement as the layering, and almost without exception indicate an inward direction of younging in the complex. The axis of the trough bands along these contacts has a pitch between 0 and 90°.

These structural elements indicate that each of the component intrusions of the complex was characterized by relatively passive periods of laminar flow, crystallization, crystal accumulation and consolidation, alternating with more active periods of magmatic erosion and disturbance. Furthermore, the orientations of these structures imply steeply dipping flow laminae, and flow directions that vary from horizontal to vertical.

Clots of mafic minerals and segregations of felsic minerals

Concentrations of mafic minerals in irregular clots are common in the gabbro intrusions (Fig. 6). The clots may be isolated or in groups confined by neighboring layers to a given stratigraphic interval. Some

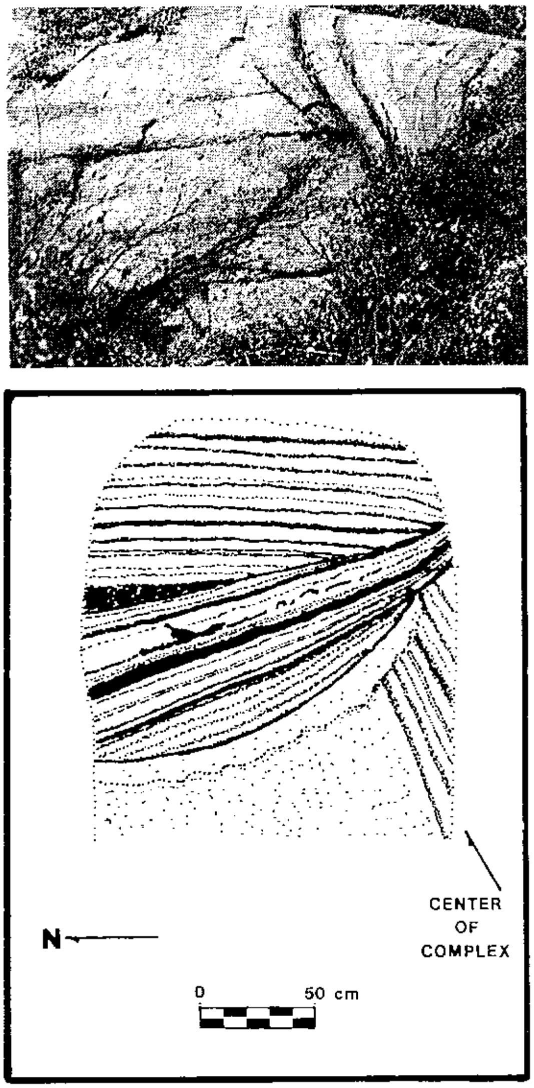

FIG. 4. Oblique view of discordant intrusive contacts similar to angular unconformities; layered gabbros (intrusion C) of the southwest detailed study-area. Center of the complex is to the right. Bottom: sketch showing detailed plan-view of the outcrop shown in the photograph above.

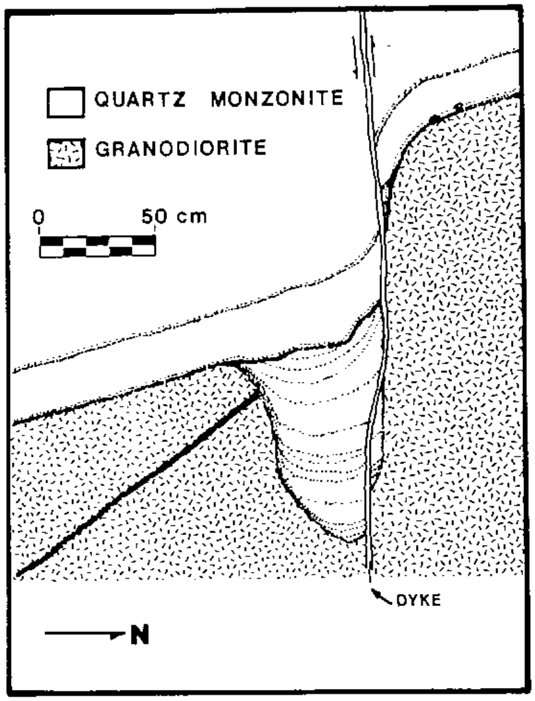

FIG. 5. Trough band along contact between granodiorite (intrusion E) and quartz monzonite (intrusion F), central detailed study-area.

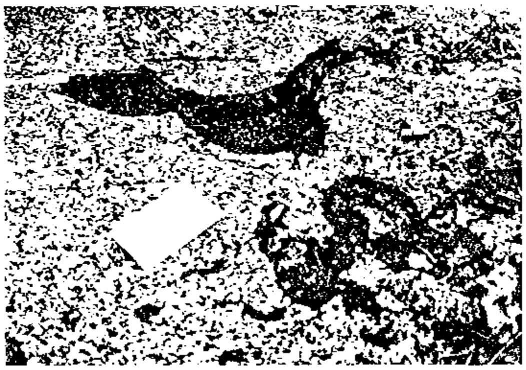

FIG. 6. Irregular mafic-mineral segregations from segregation-rich layer in gabbro (intrusion D), northeast detailed study-area.

of the clot contacts are sharp, and others are gradational. Isolated clots may represent partly resorbed inclusions. Clots occurring in groups confined to a particular interval are likely a product of mafic-layer disruption combined with some ductile deformation of the disrupted parts.

Segregations of felsic minerals that cut across layering are also typical of the gabbros. The segregations have irregular forms, gradational contacts, and pegmatitic textures; they likely represent evolved, volatile-rich liquids that developed late in the crystallization history of the gabbros.

Inclusions and dykes

Inclusions within the complex consist of xenoliths of the surrounding country rocks, and cognate inclusions derived from the component intrusions of the complex. The inclusions range in size from a few cm to several tens of m, and they tend to have angular shapes. They occur as isolated bodies, but more often are clustered, primarily close to the outer contact of the complex and to internal contacts. At some localities, cognate inclusions are restricted to a given stratigraphic interval, bounded by well-developed layers on either side. The relationships of the inclusions to the layering at such occurrences indicate two possible types of origins: dismemberment *in situ* of previously developed layering, or development of an inclusion-rich layer through availability of inclusions and increased capability of transportation *via* magmatic currents. The latter could result from increased velocity of flow, increased density or increased viscosity of the magma.

Dykes derived from member intrusions of the complex are present from place to place. They dip steeply and appear to radiate from the central part of the complex, although this has not been confirmed through systematic observation. The dykes have sharp contacts and show,evidence of dilation.

The inclusions and dykes reveal that consolidation of the magma, between intrusive events, had reached levels capable of supporting brittle, or quasi-brittle deformation. Furthermore; the presence of the inclusions and dykes suggests that stoping played a part in the evolution of the complex. The inclusions and dykes make their greatest contribution to our understanding of the complex through their age relationships with the different intrusions.

Breccia pipes

Two breccia pipes occur within the complex, both close to the core. These structures are characterized by breccia zones with milled-rock matrix, sheet fracturing, alteration and mineralization. The Sunbeam–Kirkland pipe is within quartz monzonite (F), and the Moonbeam pipe is along the contact between quartz monzonite (F) and granodiorite (E). Independent studies of these structures (Halwas 1984; J. Fingler, pers. comm.) have led to the interpretation that brecciation, mineralization, and alteration observed in these bodies represent a final volatile-rich period in the development of the complex.

RELATIONSHIPS BETWEEN PRIMARY STRUCTURES AND INTRUSIVE EVENTS

The relationships between structures and intrusive events have been studied in detail in three areas where exposure is exceptionally good. These areas are named the southwest, northeast, and central detailed study-areas. Each was mapped at a scale of 1:100; the results of the mapping form the basis of the three-dimensional interpretations that are presented in the following sections.

Southwest detailed study-area

This area includes the contact between host greenstones and intrusion C along the southwestern edge of the complex (Fig. 7). In this area, intrusion C can be subdivided into 6 units, each possessing characteristic properties. Table 1 presents the dominant characteristics of the units. All units have been cut by younger dykes that originated from intrusive activity in the more central parts of the complex. Mineral-orientation structures are common in this area, and they regularly have an orientation parallel to layering.

The arrangement of the units and their internal structures at this site raise some interesting points with regard to the development of the complex.

(a) Intrusion C is not a single intrusive event; instead, it is characterized by multiple intrusive episodes.

(b) Each intrusive episode is characterized initially by magmatic flow of sufficient strength to erode earlier rocks of the complex.

(c) Following the erosive period, layering and cumulate-mineral alignment have developed in steep to vertical orientations, most commonly parallel to the intrusive contact. These features and relation-

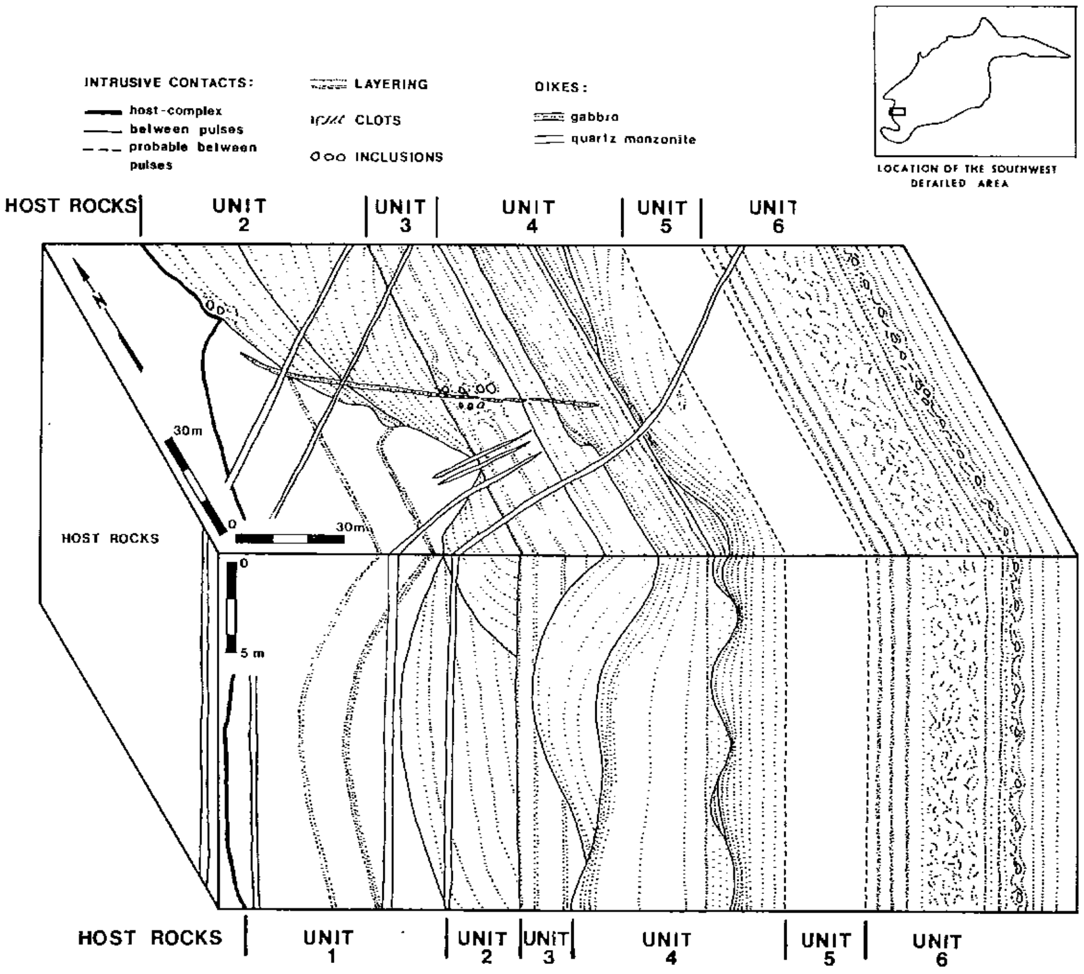

FIG. 7. Block diagram depicting the geology of the southwest detailed study-area.

TABLE 1. INTERNAL CHARACTER OF INTRUSIVE UNITS, SOUTHWEST DETAILED STUDY-AREA

Unit	Character
1	Contains concordant curviplanar layering parallel to outer contact. Predominantly coarse-grained gabbro layers >10m thick, subordinate modally graded gabbro layers <1m thick, and mafic laminae. Lenses of discordant pegmatitic gabbro.
2	Contains internal discordant intrusive contacts and curviplanar buttress layering, both products of large-scale trough bands. Interlayered modally graded gabbro, grain-size-graded gabbro, mafic laminae; layer thickness <3m.
3	Contains concordant planar layering parallel to planar intrusive contacts. Alternating layers of unimodal gabbro (>2m thick) and modally graded gabbro (<10cm thick), some mafic laminae. Localized zones of xenoliths with associated disturbed layering.
4	Internal discordant intrusive contacts resulting from large and small-scale trough bands (Fig. 8); layering predominantly concordant with intrusive contacts; some buttress layering. Interlayered rhythmic modally graded sequences, uniform gabbro and mafic laminae.
5	Single massive layer of coarse-grained, leucocratic to anorthositic gabbro. Contacts not observed.
6	Contains parallel planar layers; relationship to contact not observed. Interlayered homogeneous gabbro, modally graded gabbro, mafic laminae; single clot-rich layer, single inclusion-rich layer.

ships are best accounted for by laminar flow of the magma.

(d) Trough bands of differing scales and orientations give insight into the variability of size and direction of the magmatic currents producing them. Although most layering and erosion surfaces are steep (Fig. 8), the axes of trough structures have a variable plunge, and some are close to horizontal. Flow directions apparently varied from steep to shallow.

(e) The arrangement of the units of intrusion C is from an older margin to a younger center. Within this arrangement is a general progression from discordant contacts with trough bands in the outer part of this intrusion to regular concordant layering toward the core.

Northeast detailed study-area

Figure 9 illustrates the geology of the complex encompassing parts of intrusions C, D and E in this detailed study-area. Intrusion C is a massive gabbro without visible layering at this site.

Intrusion D consists of two gabbro units, both of which are layered. Unit 1 is characterized by a variety of layer types that are well developed, planar and steeply dipping. Layers consist of homogeneous gabbro, gabbro that is modally and grain-size graded, entrained elongate mafic clots, concentrations of inclusions, mafic laminae, and magnetite–apatite concentrations. Layer thickness varies from < 1 cm to >40 m. Layering in unit 2 is less distinct and less continuous. Mafic clots and inclusions are abundant near its contact with unit 1. The layering grades into a complex mixture of inclusions, mafic clots, and felsic segregations in a restricted area between unit 1 and intrusion E. Intrusion E at this location is diorite that exhibits a well-developed rhythmic sequence of modally and grain-size-graded layers close to its contact with the other intrusions.

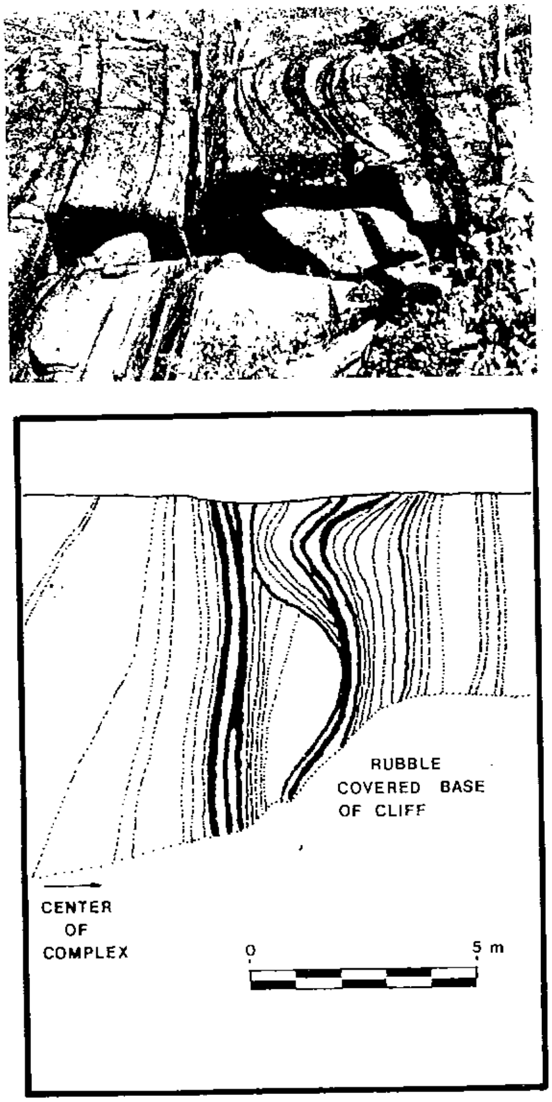

FIG. 8. Photograph of cliff face showing steeply dipping layers and shallow-plunging trough bands in unit 4, intrusion C, southwest detailed study-area. Bottom: sketch showing details of layering and intrusive contacts in the photograph.

All intrusions in this area contain mineral-

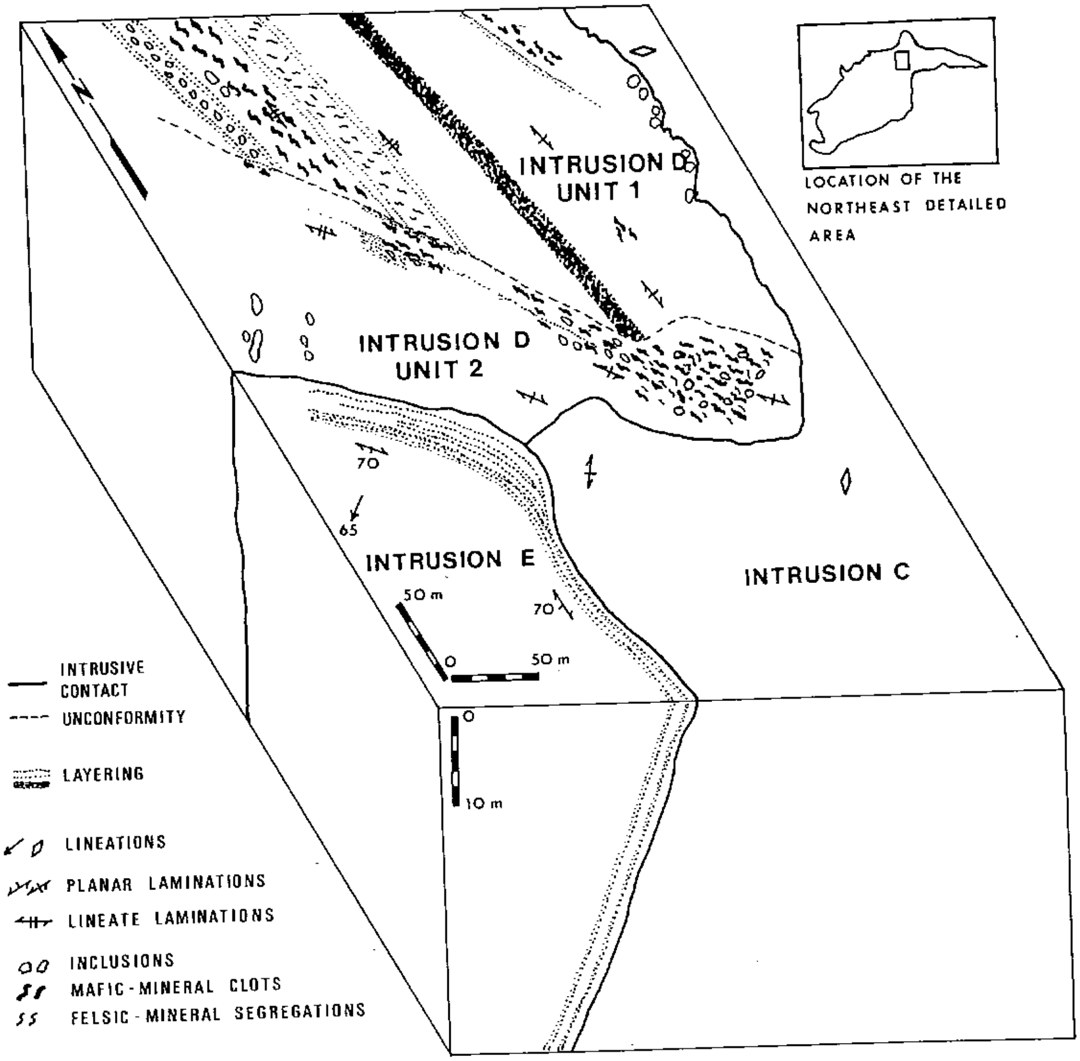

FIG. 9. Block diagram depicting the geology of the northeast detailed study-area.

orientation structures with steep dips and steep plunges. Invariably, these structures are parallel to layering. The configuration of contacts, layering, and mineral-orientation structures in this area lead to the following observations:

(a) All intrusive contacts in this area are discordant and show a younging-inward direction.

(b) All intrusive contacts suggest large-scale trough bands and imply magmatic flow with sufficient energy to erode large troughs.

(c) It seems reasonable to suggest that the clot- and inclusion-rich layers in unit 1 of intrusion D are products of transportation by magmatic flow. This inference, in turn, suggests that some combination of higher velocity of flow, or magma of higher density or higher viscosity may have been involved in the formation of these specific layers.

(d) The layering in unit 2 of intrusion D loses its continuity where it rests against intrusion C. The complexities observed in this confined region suggest conditions of turbulent rather than laminar flow.

Central detailed study-area

This area (Fig. 10) is located along the contact between intrusions E and F, near the core of the complex. At this site, intrusion E consists of thick layers (> 30 m) of porphyritic granodiorite, thin (< 20

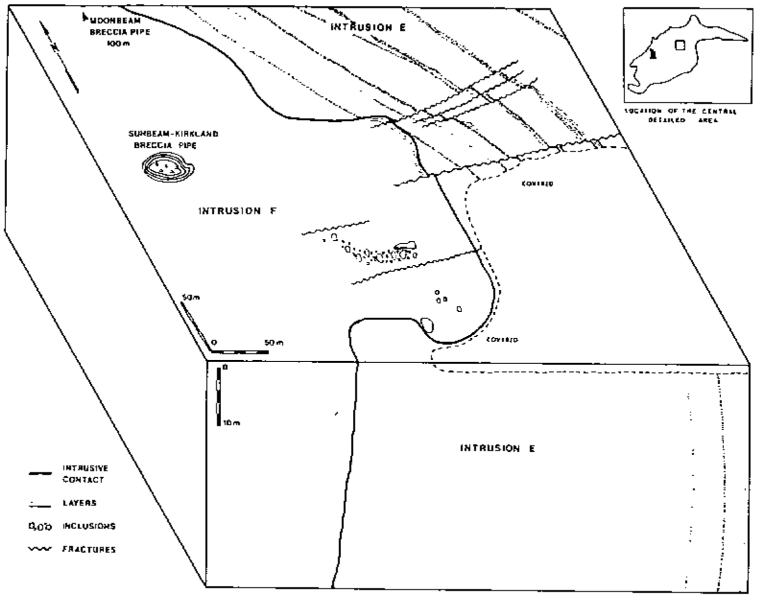

FIG. 10. Block diagram depicting the geology of the central detailed study-area.

cm), well-developed, modally graded layers of granodiorite, and mafic laminae. The layering is continuous, planar and steeply dipping. Mineral-orientation structures are difficult to see; however, petrofabric work by Haugh (1962) has indicated that they are present.

In the quartz monzonite of intrusion F, layering is present only in association with its contact. The layers are distinguished by grain-size differences, which may be gradational or sharp. The layering is parallel to the intrusive contact, which itself is irregular, discordant, and steeply dipping. Small-scale trough bands are present along the intrusive contact (Fig. 5) and within intrusion F. Intrusion F contains one of the largest concentrations of inclusions observed in the complex (Fig. 10).

The Sunbeam–Kirkland breccia pipe occurs just within the confines of the central intrusion of the complex. The Moonbeam pipe, which occurs immediately to the north of this detailed study-area, is on the contact between intrusions E and F.

The geology of this detailed study area leads to the following observations:

(a) Layering, although less well developed, occurs in the same form within the more felsic intrusions of the core as it does in the mafic outer intrusions. The orientation of layering remains steep and parallel to the intrusive contacts. Whatever its origin, layering seems to be independent of rock type.

(b) The large re-entrant of intrusion F into intrusion E has the form of a large-scale trough structure, again pointing to strong magmatic erosion, only this time during emplacement of intrusion F.

(c) Quartz monzonite magma, with a viscosity higher than that of the earlier gabbroic and dioritic-granodioritic magmas, presumably had an increased ability to transport large fragments. Such a condition could account for the concentration of large inclusions in this subarea.

(d) The mineralized breccia pipes are younger than intrusion F and resulted, in part, from hydrothermal activity associated with late stages of consolidation of the complex.

DISCUSSION OF DEVELOPMENT OF FLIC

The compositions, arrangement, and relative ages of the component intrusions of FLIC indicate a developmental history that involves a separate differentiating magma from which the intrusions were drawn sequentially. All that remains of the form of the first intrusion is dyke-like; succeeding intrusions gave the complex a more equant shape. In the last stages of development the active part of the complex became progressively constricted inward toward the core. This progression is shown diagrammatically in Figure 11.

The degree to which earlier component intrusions have been eroded by the emplacement of younger ones leads to the inference that much more magma than is now represented in place moved through the complex. This inference is supported by the wide thermal contact aureole around the complex.

The textures and primary structures indicate that

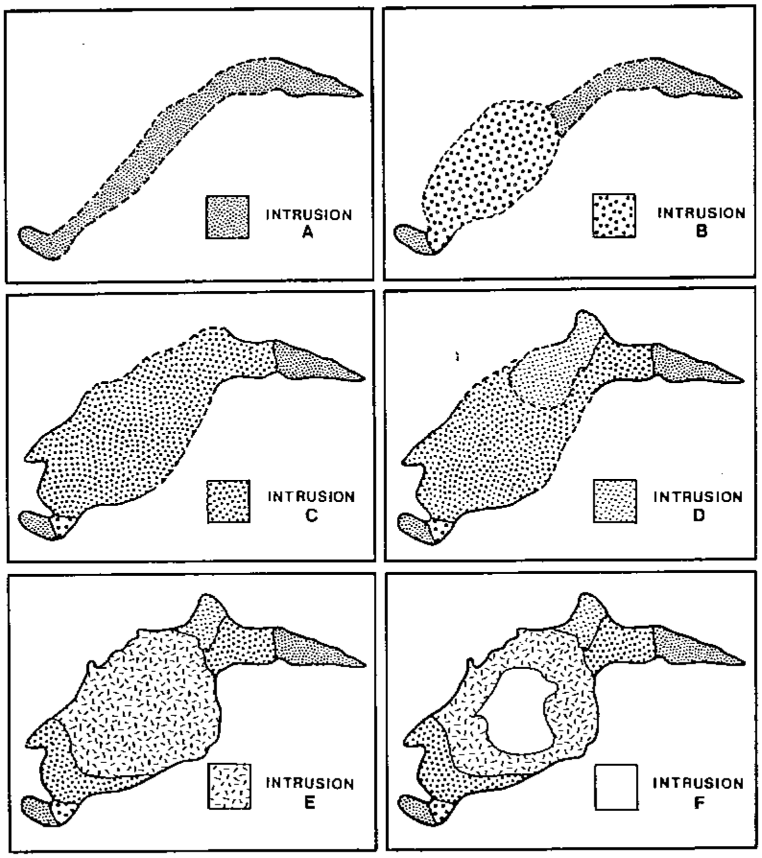

FIG. 11. Interpretation of the emplacement history of the Falcon Lake Intrusive Complex.

each intrusion consisted of a crystal–liquid mixture, and that magmatic flow was responsible for the erosional features, the mineral orientations, and the observed layering. Furthermore, the alternations between discordant and concordant structures within the complex signify conditions of fluctuating flow. The discordant structures and inclusions point to erosive conditions, possibly due to high velocity or turbulence. In contrast, the packages of concordant rocks within the complex suggest low-velocity laminar flow, controlled by the confining margins of each intrusion, and resulting in layering and mineral orientations with steep dips and a generally concentric arrangement. Other variations in the physical parameters of the magma, such as density or viscosity (or both), may also be represented by observed changes in layer characteristics; seldom, however, are these characteristics completely diagnostic.

Although flow processes seem to be the most likely explanation of most of the observed primary structures, the origin of the flow is problematic. Possible origins include intrusive surges of magma, *in situ* convection, or slumping of partly consolidated sidewalls, leading to the generation of density currents.

ACKNOWLEDGEMENTS

The authors acknowledge the helpful discussions with colleagues at the University of Manitoba and the Geological Survey of Canada. We also acknowledge the constructive criticisms of the referees. Financial support for this study was provided through a research contract to the University of Manitoba from the Geological Survey of Canada as part of the Canada–Manitoba Mineral Development Agreement (1984–1989), a subagreement under the Economic and Regional Development Agreement (ERDA).

REFERENCES

BROWNELL, G.M. (1941): Geology of the Falcon Lake Stock, southeastern Manitoba. *Can. Inst. Min. Met. Trans.* **44**, 230-250.

DAVIES, J.F. (1954): Geology of the West Hawk Lake — Falcon Lake area. *Manitoba Dep. Mines Nat. Resources* **53-4.**

GIBBINS, W.A. (1971): Geology of the Falcon Lake Stock, southeastern Manitoba. *In* Geoscience Studies in Manitoba (A.C. Turnock, ed.). *Geol. Assoc. Can., Spec. Pap.* **9**, 129-155.

HALWAS, D. (1984): *The Sunbeam-Kirkland Breccia Pipe, Southeastern Manitoba.* B.Sc. thesis, Univ. Manitoba, Winnipeg, Manitoba.

HAUGH, I. (1962): *A Petrographic Study of the Falcon Lake Stock, Southeasthern Manitoba.* M.Sc. thesis, Univ. Manitoba, Winnipeg, Manitoba.

HOUSE, A.D. (1955): *Radioactivity and Geology of the Falcon Lake Stock.* M.Sc. thesis, Northwestern Univ., Evanston, Illinois.

JACKSON, E.D. (1967): Ultramafic cumulates in the Stillwater, Great Dyke, and Bushveld intrusions. *In* Ultramafic and Related Rocks (P.J. Wyllie, ed.). John Wiley & Sons, New York.

WANLESS, R.K., STEVENS, R.D., LACHANCE, G.R. & EDWARDS, C.M. (1968): Age determination and geologic studies. K–Ar isotopic ages, Report 8. *Geol. Surv. Can. Pap.* **67-2**, *Part A*, 90-91.

Received December 23, 1986, revised manuscript accepted June 10, 1988.