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Structural geology of the Stanley Head region, western Cornwallis Island, Nunavut

Michael Henrichsen and Lori Kennedy

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Abstract: The geology of the Stanley Head map area is dominated by a previously unrecognized, shallow-level fold and thrust fault that creates the distinctive topography in this area. Three phases of deformation have been documented in the study area: 1) northeast-verging fold and thrust faults, 2) folding associated with a north-south compressional event resulting in local refolding of northeast-verging folds, and 3) normal faulting associated with east-west extension. The main structure in the study area is the Stanley Head anticline that is cored by evaporite of the Bay Fiord Formation. This anticline is characterized by kink-style fold geometry, and has an approximate wavelength of 2 km and a length of 9 km. There are numerous normal and strike-slip faults in the area, which define several fault blocks that collectively offset the Stanley Head anticline. Calcite veining is pervasive and barite veining is localized throughout the study area.

Résumé : Le trait géologique dominant de la région cartographique de Stanley Head est lié à la présence à faible profondeur d'un couple pli et faille de chevauchement qui n'avait pas été jusqu'à ce jour identifié et dont dépend la topographie particulière de cette région. Trois phases de déformation ont été documentées dans la région d'étude : 1) des plis et des failles de chevauchement à vergence nord-est, 2) un plissement associé à un épisode de compression nord-sud ayant engendré un nouveau plissement local des plis à vergence nord-est et 3) le jeu de failles normales associées à une distension est-ouest. La principale structure de la région d'étude est l'anticlinal de Stanley Head, dont la zone axiale est occupée par les évaporites de la Formation de Bay Fiord. L'anticlinal est caractérisé par une géométrie de plis en chevrons; sa longueur d'onde est d'environ 2 km et sa longueur de 9 km. Il y a dans la région de nombreuses failles normales et failles de coulissage délimitant de nombreux blocs qui, ensemble, décalent l'anticlinal Stanley Head. Dans la région d'étude, on trouve un peu partout des veines de calcite et, par endroits, des veines de barytine.

INTRODUCTION

This report outlines the preliminary results of 1:10 000-scale mapping in the Stanley Head (NTS 68 H/1) map area located on western Cornwallis Island in the central Arctic Islands lead-zinc district (Fig. 1). The study area is south and along strike of the Polaris Pb-Zn mine, a late Devonian Mississippi Valley-type Pb-Zn deposit on Little Cornwallis Island. This study is a component of the joint GSC and Canada-Nunavut Geoscience Office study of "The Regional Dynamics of the Polaris Zn-Pb system" undertaken during the summer of 2001. The purpose of this study is to better understand the regional mineralizing system, focusing on the structural controls that led to the creation of a plumbing system and the migration of mineralizing fluids.

Mapping in the Stanley Head area of Cornwallis Island by the first author was undertaken to document the stratigraphy, structural geology, and possible structural controls on fluid migration in the study area. The purpose of this paper is to report the preliminary results of 1:10 000 mapping, including a description of the major map units and structures of the area, with preliminary interpretations of the structures. Specifically we describe previously unrecognized fold and thrust deformation that dominates the structures in the area.

Physiography

The study area is composed of a linear series of northwest-trending hills, that have a length and width of 9 km and 2 km, respectively. These hills exhibit from 50–150 m relief with respect to the surrounding topography of 25–50 m above sea level. Exposure of rock formations on the hills is fair to good, allowing for detailed geological mapping. The areas surrounding the northwest-trending hills is composed of flat to undulating glacial cover, with little to no exposure of rock formations. Streams in these areas have eroded 10–30 m deep channels that produce variable degrees of outcrop exposure.

Regional tectonic setting

Three major tectonic events have affected the central Arctic Island Archipelago from the Cambrian to the present. They are the Boothia Uplift, the Ellesmerian Orogeny, and the Eurkean Orogeny. The Boothia Uplift is characterized by northwest-trending structures formed during the Late Silurian to Early Devonian (Kerr, 1977). It extends north, from the Boothia Peninsula to the Grinnell Peninsula on Devon Island and forms the Cornwallis fold belt. The Boothia Uplift was created by the reactivation of fault-bounded basement blocks of the craton during compression associated with the

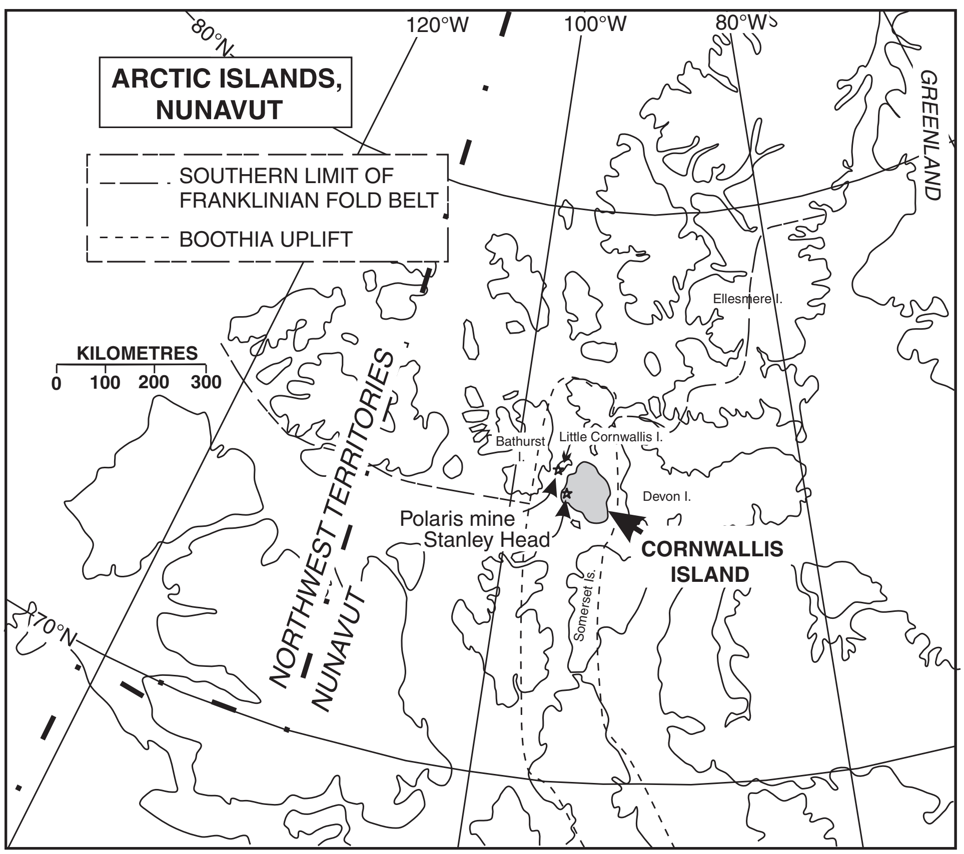

Figure 1. *Location of the study area on western Cornwallis Island.*

Caledonian Orogeny (Okulitch et al., 1986). The Ellesmerian Orogeny formed during the Late Devonian to Early Carboniferous and is characterized by the east-striking Parry Islands fold belt (Harrison et al., 1991). The Eurekan Orogeny is an orogenic and extensional event that occurred from the Late Cretaceous–Early Tertiary. The Eurekan Orogeny is characterized by compressive deformation in the northern Arctic Islands and extensional deformation in the southern Arctic Islands, and has been attributed to the counterclockwise rotation of Greenland away from North America (Okulitch and Trettin, 1991).

Previous work

The study area was mapped at 1:250 000 by Thorsteinsson (1986) as part of the Geological Survey of Canada mapping program of the Arctic Islands. The Stanley Head structure was interpreted as a predominantly north-northwest-trending, structurally bounded block of Thumb Mountain Formation, (Middle–Upper Ordovician), surrounded by down-faulted blocks of Cape Phillips Formation (Upper Ordovician–Upper Silurian).

Geological setting

The area of study is composed of the same unmetamorphosed marine carbonate and shale strata as found at the Polaris mine site. Deformation in the study area is brittle and characterized by highly fractured, veined, and faulted rocks, with a pervasive fracture cleavage (Fig. 2).

MAP UNIT DESCRIPTIONS

The formations found within the area of study were first formally defined by Thorsteinsson (1958) and Kerr (1967). Informal subdivisions employed by exploration companies are shown in Héroux et al. (2000). In this report, the formations are further subdivided and the formation descriptions are modified to reflect the rocks exposed in the area of study.

Figure 2. *Characteristic highly fractured and veined rock. Foreground of photograph is 7 m across.*

Bay Fiord Formation: Middle Ordovician

The Bay Fiord formation is here divided into three units described below in ascending order of age.

Bay Fiord Formation, unit A

Bay Fiord Formation, unit A is composed entirely of gypsum that displays a well foliated texture in part defined by alternating white and dark grey-brown bedding planes that range from 2–10 mm in thickness. White bands consist of fine-grained crystalline gypsum, whereas the darker bands are composed primarily of fine-grained crystalline gypsum with a component of greyish brown argillaceous material. Typically, these rocks are extremely weathered in outcrop and are disintegrated into a mass of sediment.

Bay Fiord Formation, unit B

Bay Fiord Formation, unit B is composed of lime mudstone and wackstone displaying variable bedding thickness, with beds typically between 5–50 cm thick. The rock has a bimodal grain size distribution consisting of 70–90% dark grey lime mudstone, and 10–30% brachiopod, gastropod, and crinoid fragments ranging from 5–40 mm. Weathered surfaces are typically rough and uneven, tan to light grey with variable red-brown, irregular burrow mottling. Mottles are predominantly calcitic and variable in modal abundance, ranging from 20–35%, and ranging from 10–30 mm in diameter. Fresh surfaces are medium to dark grey. Shaly partings are observed throughout the formation and are 1–5 mm in thickness and laterally continuous parallel to bedding. Calcite veining is present throughout the formation, but variable. Veins range from 1 mm to 5 cm thick and are both planar and irregular, and constitute 1–25% of the rock. The degree and size of veining changes with the proximity of the rocks to fault zones.

Bay Fiord Formation, unit C

Bay Fiord Formation, unit C consists of thinly bedded, green, calcareous shale beds that are in sharp contact with the overlying Lower Thumb Mountain Formation.

Thumb Mountain Formation: Middle–Late Ordovician

Lower Thumb Mountain Formation

Lower Thumb Mountain Formation consists of fossiliferous lime mudstone that display variable bedding thickness; beds are typically massive, and with bedding between 5–30 cm thick. The rock has a bimodal grain-size distribution consisting of 90–98% dark to medium grey micritic lime mud, and 2–10% trilobite, crinoid, and coral fragments ranging from

1–3 mm in size. Weathered surfaces are typically rough and uneven, light grey with variable light brown, irregular burrow mottling. Mottles are predominantly calcitic, with mottles occasionally exhibiting chert replacement in laterally discontinuous horizons. Mottles are variable in modal abundance ranging from 5–15%, and size ranging from 1–15 mm in diameter. Fresh surfaces are medium to dark grey and occasionally exhibit a poorly developed fenestral fabric. Argillaceous partings, 1–2 mm thick, are typically laterally discontinuous and parallel to the bedding plane. Calcite veining is present throughout the formation, but variable in abundance. Veins range from 1 mm to 5 cm thick and are both planar and irregular, and constitute 1–25% of the rock. The degree and size of veining changes with the proximity of the rocks to fault zones.

Upper Thumb Mountain Formation

The Upper Thumb Mountain Formation is subdivided into two units, A and B, based on the modal abundance and size of fossils found within the chert-bearing, fossiliferous, lime wackestone or mudstone.

Upper Thumb Mountain (unit A) consists of 95% dark to medium grey lime mudstone and 5% fossil grains. Fossil fragments include crinoid and coral fragments that are matrix supported, calcitic, white, and typically 1–3 mm in size. Upper Thumb Mountain (unit B) consists of 60–85% dark to medium grey lime mudstone and 15–40% fossil fragments. Fossil fragments include solitary and colonial corals, brachiopods, gastropods, cephalopods, and rare stromatoporoids. They are matrix supported, calcitic and/or siliceous, and range from 5 mm to 15 cm in size. Fossil fragments replaced by chert are a light brown-cream colour and display pronounced relief on exposed bedding planes. Calcitic fossil fragments are white. Weathered surfaces are typically very rough, pitted, and uneven. Fresh surfaces are medium to dark grey. Calcite veining is present throughout the formation, but variable; veins range from 1 mm to 5 cm thick, are both planar and irregular, and constitute 1–25% of the rock. The degree and size of veining changes with the proximity of the rocks to fault zones.

Irene Bay Formation: Upper Ordovician

The Irene Bay Formation consists of very recessively weathered green shale. In the area of study the shale was weathered to such a degree that outcrop was not present. The Irene Bay Formation was identified based on its stratigraphic relationship with the underlying Upper Thumb Formation and the overlaying Cliff Member of the Cape Phillips Formation.

Cape Phillips Formation: Upper Ordovician–Upper Silurian

The Cape Phillips formation is here informally subdivided into two members.

Cliff member

The Cliff member is composed of nonbedded, fossiliferous lime wackestone, and displays an orange tan colour, with variable light brown, irregular burrow mottling. The rock has a bimodal grain-size distribution consisting of 80–90% micritic lime mud and 10–20% crinoid ossicles and brachiopod and trilobite fragments, ranging from 5–25 mm in size. Weathered surfaces are typically very rough, pitted, and uneven, with fresh surfaces exhibiting a dark to medium grey colour. Mottles are predominantly calcitic, with 10–15% of mottles composed of dolomite. Mottles compose 15–25% of the rock and range from 5–25 mm in diameter. The Cliff member is composed of 2–5% vugs that are commonly filled with both calcite and dolomite. Minor calcite veining is observed sporatically throughout the member.

Cape Phillips shale

The Cape Phillips Formation is predominantly composed of grey to black calcareous siltstone and shale. These rocks are commonly laminated on a millimetre scale and contain concretions ranging from 1 cm to 1 m in diameter. Sedimentary structures are infrequent, but include rip-up clasts and scour surfaces. Graptolites are found throughout the formation and can be used to further divide the Cape Phillips Formation. A trilobite-rich horizon located stratigraphically above the Cliff member was used as a marker bed.

Figure 3. *Distinctive topography of north-northwest-trending Stanley Head anticline. Person with all-terrain vechicle in centre right of photograph for scale.*

STRUCTURAL GEOLOGY

The Stanley Head structure that creates the distinctive topography in this area is characterized by a north-northwest-trending anticline, with a strike length of 9 km and a wavelength of 2 km (Fig. 3). The Stanley Head anticline is offset by numerous normal and strike-slip faults that divide it into several fault-bounded blocks. Two localities in the area of study exhibit superimposed folding (Fig. 4).

Stanley Head anticline and associated F_1 structures (= F_1)

The Stanley Head anticline is an open, cylindrical, subhorizontal, moderately inclined, northeast-verging fold with a sharp to angular hinge zone. The calculated axial-plane and fold axis of the fold are 301/04, and 123/57 respectively. The eastern limb of the anticline strikes northwest and dips steeply to the northeast; the western limb of the anticline strikes southeast and dips shallowly to the southwest (Fig. 5). The anticline is cored by a subplanar, fairly continuous

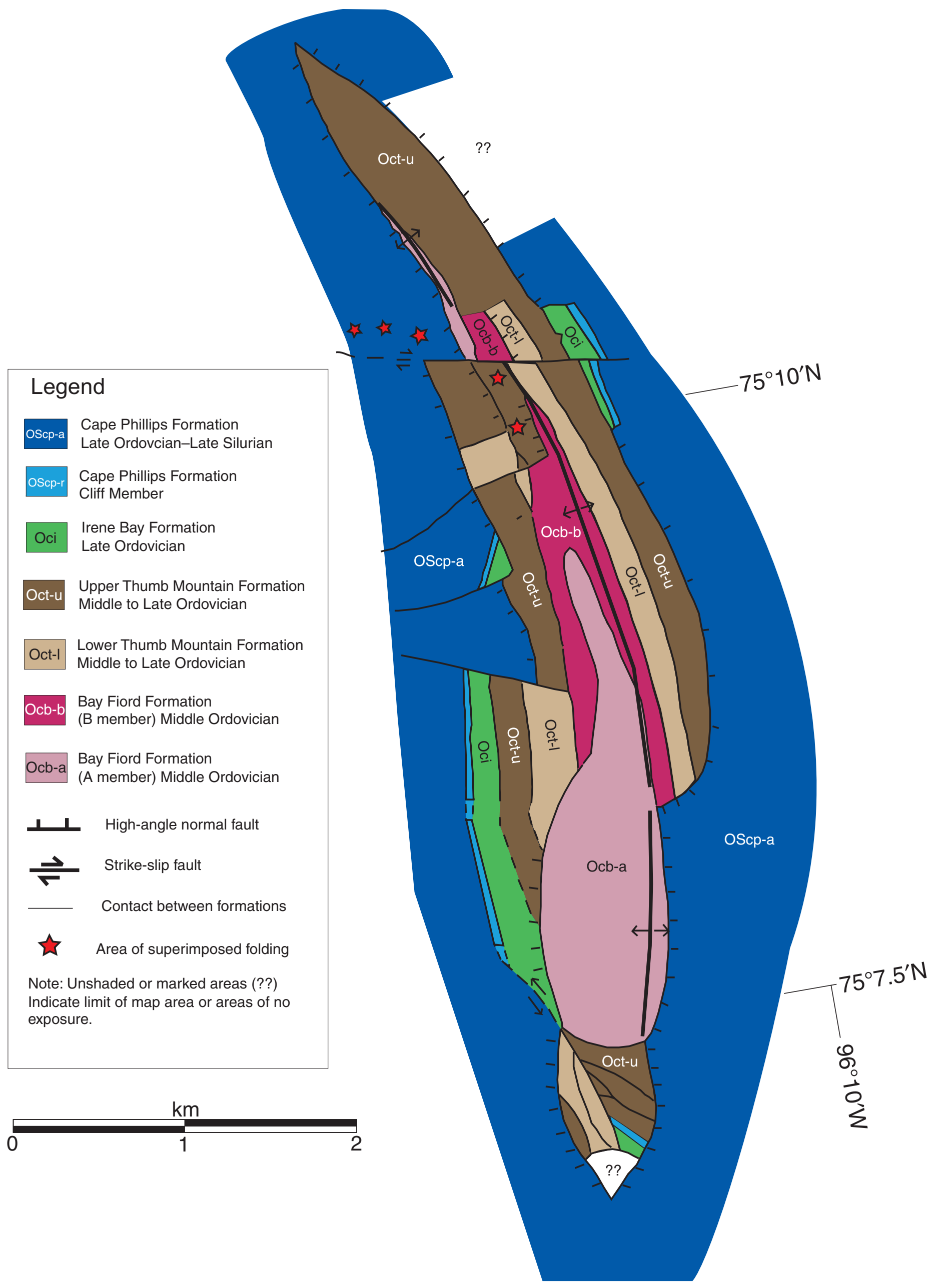

Figure 4. Geological map of the Stanley Head area, based on 1:10 000-scale mapping.

distribution of foliated gypsum, which is oriented roughly parallel to the axial surface of the fold. Adjacent to the gypsum, a well developed fault surface within Bay Fiord Formation, unit B also strikes southeast, and has slickensides that plunge moderately southwest (Fig. 6). Calcite fibres on the fault surface indicate top to the northeast sense of shear, consistent with the sense of vergence of the Stanley Head anticline.

Several smaller scale folds, associated with the Stanley Head anticline, are present within the Cape Phillips Formation to the east of the main structure (Fig. 7, 8). These folds exhibit kink to angular style fold geometries and typically have wavelengths of 10–100 m and 2–15 m amplitudes. They are open folds that verge to the northeast, are gently inclined to subhorizontal, plunging gently to the north-northeast, displaying similar orientations to the Stanley Head anticline (Fig. 9).

Small-scale east-verging thrust faults are observed within the Cape Phillips Formation to the west of the anticline. These thrust faults have on the order of 5–10 m displacement and display characteristic ramp-flat geometry and associated folding in the hanging wall. One of these minor thrust faults exhibited a thrust duplex geometry that contained a series of three horses. Ramp orientations of these small-scale thrusts are somewhat variable, but range between approximately 195/25 and 135/15.

These structures are collectively interpreted to be kinematically linked and to represent a part of a northeast-verging fold and thrust system. The fold style and geometry of the Stanley Head anticline and the associated smaller scale folds are typical of structures expected in a shallow-level fold and

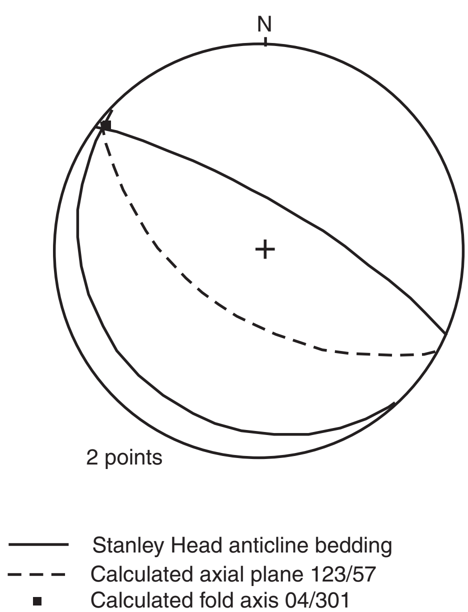

Figure 5. *Equal-area stereographic projection of F_1 structural data.*

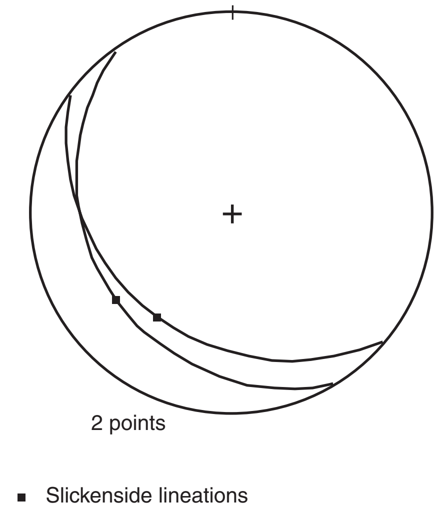

Figure 6. *Equal-area stereographic projections of structural data: fault planes and associated slickensides within Bay Fiord Formation, unit B.*

Figure 7. *Small-scale fold associated with the Stanley Head anticline, Cape Phillips Formation shale.*

Figure 8. *Small-scale fold associated with the Stanley Head anticline, Cape Phillips Formation shale.*

thrust system. The smaller scale thrust faults in the Cape Phillips Formation and fault planes observed within Bay Fiord Formation, unit B support this interpretation. The Stanley Head anticline is interpreted as a fault propagation fold. The thrust fault responsible for the propagation is inferred to be the well foliated, sheared gypsum layer that everywhere is parallel to subparallel to the axial surface of the fold.

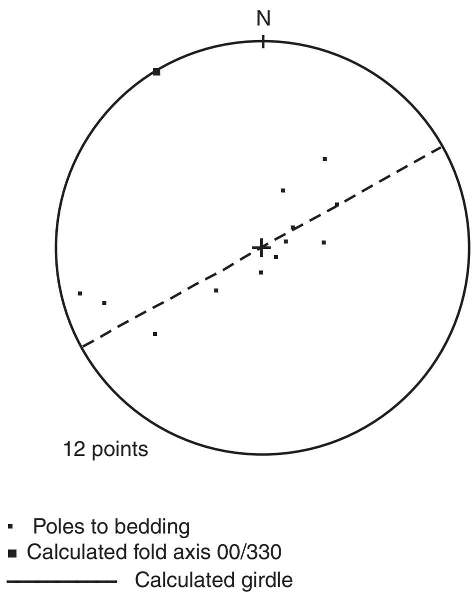

Figure 9. Equal-area stereographic projections of structural data; smaller scale folds associated with the Stanley Head anticline.

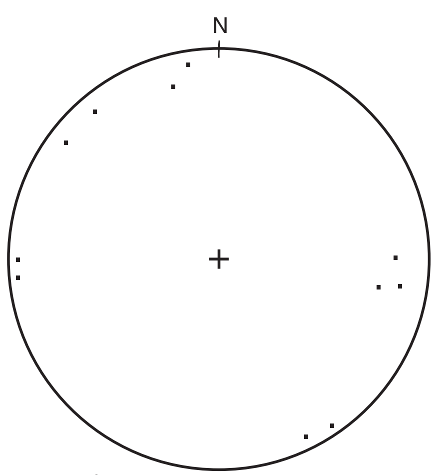

Figure 10. Equal-area stereographic projections of structural data; fold axes from superimposed folding within the Cape Phillips Formation.

Superimposed folding (=F_2)

Superimposed folding occurs in the northwest quadrant of the study area in two separate localities (Fig. 4). One region occurs in a fault-bounded block of the Upper Thumb Mountain Formation within the margins of the Stanley Head anticline, and the other region occurs to the east of the Stanley Head anticline within the Cape Phillips Formation. In both regions the refolding is characterized by two distinct orientations of fold axes: north-northeast trending, and east trending. North-northeast-trending fold axes plunge either towards the north-northeast, or to the southwest (Fig. 10, 11). Folding geometry is open in the Upper Thumb Mountain Formation fault-bounded block, leading to classic dome-and-basin geometry, whereas folding is tighter in the Cape Phillips Formation. Preliminary results suggest that an original shallowly plunging, northwest-trending fold axis, typical of the Stanley Head anticline, has been subsequently folded by a second folding event, as they are moderately plunging towards the south or to the southeast.

Areas of superimposed folding are interpreted to have occurred from a north-south compressional event that resulted in local refolding of the northeast-verging folds. This north south compressional event is given the F_2 designation in the area of study.

Normal faults

There are numerous steeply dipping north- and east-trending normal faults in the study area which define several fault blocks that collectively offset the Stanley Head anticline. Normal faults bound the majority of the eastern and western margins of Stanley Head anticline. The eastern margin of the anticline is bounded by two large, normal fault blocks, separated by a region of continuous stratigraphy in the northwest. These faults juxtapose the Upper Thumb Mountain Formation with the Cape Phillips Formation. Faulting occurred

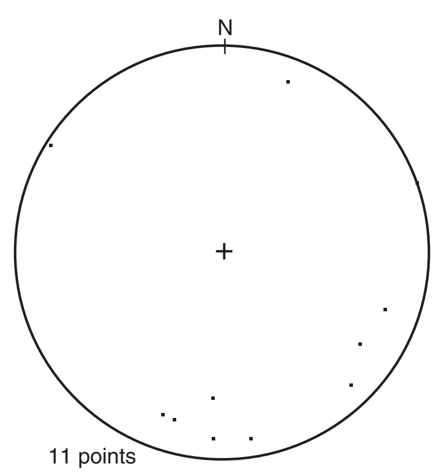

Figure 11. Equal-area stereographic projections of structural data; fold axes from superimposed folding within the Upper Thumb Mountain Formation.

within the middle of the Cape Phillips Formation, as indicated by uniserial graptolites found on the eastern margin of the anticline. The six normal fault blocks that bound the western margin of the anticline have variable displacement as deduced by the juxtaposition of the Lower and Upper Thumb Mountain formations as well as Bay Fiord Formation evaporite with the Cape Phillips Formation. East-trending lateral ramps associated with these normal faults produce a dextral sense of displacement in plane view.

Southern structural block

An isolated and prominent fault block lies in the southernmost region of the study area. The southern structural block is characterized by the terminating zone of a strike-slip fault that is bounded by normal faults that juxtapose both Lower and Upper Thumb Mountain formation against the Cape Phillips Formation. The strike-slip fault strikes to the northeast and dips steeply towards the northwest, with slickensides plunging shallowly towards the southeast (Fig. 12). The strike-slip fault terminates into a series of normal faults that produce a flower structure, suggesting that normal faults in the block are concave-up. Minor east-trending fold axes are observed within the Lower Thumb Mountain Formation.

Normal and strike-slip faulting of the Stanley Head anticline are interpreted as the last deformational event to effect the study area. Superimposed folding contained within isolated normal fault blocks within the Stanley Head anticline indicate that the superimposed folding occurred prior to normal faulting.

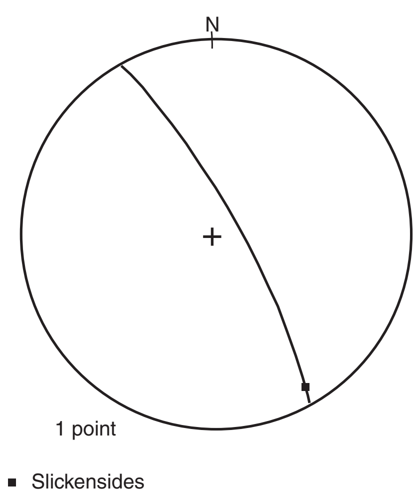

Figure 12. *Equal-area stereographic projections of structural data; strike-slip fault plane and associated slickensides.*

FLUID HISTORY

Calcite veining is pervasive throughout the Stanley Head anticline, with the degree of the veining increasing with increasing proximity to fault zones. Brecciated rocks are found immediately adjacent to fault zones and are generally characterized by angular limestone fragments that are supported by a white calcite matrix. Fracture cleavage associated with faulting is invariably lined with calcite veins that are typically 2–5 mm thick. In addition, a stockwork network of veining is present in varying degrees throughout the study area, with some outcrops exhibiting a shattered appearance. There are minor and isolated occurrences of hydrothermal dolomite within the Stanley Head anticline.

Within the southern structural block, barite and calcite veins are associated with the main strike-slip fault. Barite veins oriented parallel to subparallel to the strike-slip fault range from 2 mm to 10 cm thick, and are invariably crosscut by calcite veins. Stockwork calcite vein networks are extremely well developed along the perimeters of the block, with outcrops commonly having a shattered appearance.

CONCLUSIONS

The area of study is defined by three phases of deformation: 1) northeast-verging thrust faults and folds are correlated to an F_1 event; 2) a north-south compressional event resulting in local refolding of F_1 folds is correlated to an F_2 event; and 3) normal and strike-slip faulting is related to east-west extension, and is correlated to a third deformational event. Structures associated with folding and thrusting are the Stanley Head anticline and smaller scale kinematically linked kink-style folds, and small-scale thrusting within the Cape Phillips Formation to the east of the main structure. The north-south compressional event is characterized by areas of superimposed folding that exhibit both north- and east-trending fold axes. Extension is characterized by normal faulting that typically juxtaposes Upper Thumb Mountain Formation with the Cape Phillips Formation. Within the southern block, a prominent strike-slip fault terminates in a normal flower structure.

ACKNOWLEDGMENTS

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