APPLICATION OF LANDSAT TM THERMAL IMAGERY TO STRUCTURAL INTERPRETATIONS OF THE TINTINA TRENCH IN WEST-CENTRAL YUKON

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ABSTRACT

The structure of the Tintina Fault Zone (TFZ) within the Tintina Trench in west-central Yukon is almost completely unknown, due largely to very poor exposure, and thick overburden cover. In this study, we have used digitally enhanced Landsat Thematic Mapper thermal imagery as a basis for a preliminary structural interpretation of the Tintina Trench in the Dawson-McQuesten area. Linear features visible on the enhanced images are divided into first order (obvious, long strike-length), second order (less obvious, shorter strike-length), and third order (subtle, very short strike-length) lineaments. The images show major, NW-SE trending first and second order lineaments within the Trench which we interpret to be separate strands of the TFZ. Sag ponds and fresh fault scarps in glacial drift along these lineaments attest to relatively recent fault activity. NE-SW trending first and second order lineaments that cut obliquely across the Trench are considered to be late faults and fracture zones which formed after major strike-slip displacement on the TFZ. Third order lineaments show strong preferred orientations over large portions of the image area, and are thought to reflect overall structural grain (bedding or foliation trends and/or regionally-developed joint patterns).

RÉSUMÉ

La structure de la zone faillé de Tintina (ZFT) à l'intérieur du sillon de Tintina dans la partie centrale ouest du Yukon est presque totalement inconnue, principalement parce que très mal mise à nu ainsi qu'en raison de la présence d'épais morts-terrains. Dans le cadre de cette étude nous avons utilisé l'imagerie thermique numériquement améliorée de l'appareil de cartographie thématique du Landsat pour effectuer une interprétation structurale préliminaire du sillon de Tintina dans la région de Dawson-Mcquesten. Les entités linéaires visibles sur les images accentuées se répartissent en linéaments de premier ordre (évidents; longs dans l'axe), de deuxième ordre (moins évidents, plus courts, dans l'axe) et de troisième ordre (ténus, très courts, dans l'axe). Les images montrent des linéaments majeurs des premier et deuxième ordres orientés NW-SE que nous interprétons comme étant deux branches distinctes de la ZFT. Des étangs occupant des dépressions et des escarpements de failles récents dans le drift glaciaire le long de ces linéaments témoignent d'une activité relativement récente le long de ces failles. Les linéaments des premier et deuxième ordres orientés NE-SW qui recoupent obliquement le sillon sont considérés comme étant des failles et des zones de fracture tardives qui se sont formées après le décrochement majeur le long de la ZFT. Les linéaments de troisième ordre présentent des orientations préférentielles marquées dans de grandes parties de la région imagée et l'on pense qu'ils reflètent le grain structural général (tendances de la stratification ou de la schistosité et configurations des diaclases régionales, ou les deux).

INTRODUCTION

The Tintina Trench is an elongated topographic depression which follows the trace of the Tintina Fault Zone (TFZ) for much of its length in Yukon. The TFZ is a major zone of Late Cretaceous and/or Early Tertiary dextral displacement. It separates two very different crustal blocks: to the northeast are strata of the North American miogeocline, and to the southwest lies an assemblage of crystalline rocks belonging to the Yukon-Tanana Terrane (e.g. Monger and Berg, 1987; Wheeler et al., 1988). In west-central Yukon there is almost no outcrop in the Tintina Trench and little is known about the detailed structure of the TFZ.

The Tintina Trench is of economic interest for two main reasons. First, several small lignite-grade coal deposits, some of which have been mined on a limited scale (MINFILE 116B 005,030,031), occur within faulted Paleocene-Eocene sediments in the Tintina Trench in the Dawson area (e.g. Mortensen, 1988a) and near Ross River (MINFILE 105F 048)(Hughes and Long, 1980)(Fig. 1). Second, epithermal precious metal mineralization associated with Eocene volcanic and sedimentary rocks has recently been discovered in the Grew Creek area within the Tintina Trench in east-central Yukon (Fig.1)(e.g. Duke and Godwin, 1986; Jackson et al., 1986)(MINFILE 105K 009). The suggestion that these Eocene volcanic rocks may be genetically related to the TFZ (e.g. Mortensen, 1988c) has focused attention on the mineral potential of the Tintina Trench elsewhere in western Yukon and eastern Alaska. An understanding of the overall structure of the TFZ will be critical to evaluating this potential.

The Tintina Trench in western Yukon approximately coincides with the southwest extent of Pleistocene glaciation. The region northeast of the Tintina Trench was glaciated and displays rugged relief and excellent bedrock exposure, whereas the area southwest of the Trench escaped glaciation, and generally shows low relief, very poor exposure and deep surface weathering. Much of the Tintina Trench in this area is mantled by glacial drift shed from the Ogilvie Mountains to the northeast. These factors complicate recognition and interpretation of surface features in the area.

This paper is an outgrowth of geological studies of the Klondike District and southwest Dawson map area (Fig. 1) by JKM (Mortensen, 1988a, b; 1990) and remote sensing studies of this and other areas of Yukon by PVG (e.g. Von Gaza and Eyton, 1988; Von Gaza, 1989). In this contribution we present a preliminary interpretation of the structure of the TFZ in west-central Yukon based on analysis of Landsat TM imagery. We hope that this work will both shed new light on the geology of this complex region and focus attention on some structural features in the area which may be of economic importance. The study also provides an example of how remote sensing may be applied to geological interpretation in areas of poor exposure in the northern Cordillera.

GEOLOGY OF THE TINTINA TRENCH IN THE DAWSON-MCQUESTEN AREA

The Tintina Trench in the Dawson-McQuesten area is a region of low relief ranging from 5 to nearly 20 km wide. In several places it is bounded on one or both sides by steep slopes that may represent eroded fault scarps. The bottom of the Tintina Trench is generally covered by glaciofluvial deposits and till (including the "Flat Creek Beds" and "Klondike Gravels" of McConnell, 1905, 1907) or by recent alluvial deposits (e.g. Hughes, 1987). Locally the unconsolidated deposits reach 200 m in thickness (Hughes, 1987). Rare bedrock exposures within Tintina Trench in this area consist of immature clastic sediments, including pebble conglomerate, sandstone, siltstone and mudstone. Seams of lignite grade coal occur in a number of localities (Fig. 1), and Paleocene to Eocene palynomorphs have been recovered from several exposures of coal-bearing clastic strata in this area (Hughes and Long, 1980). In many cases the clastic rocks are very poorly indurated, and decomposed outcrops of the coarser-grained units are commonly difficult to distinquish from glacial outwash gravels. All known outcrops of these Early Tertiary rocks display evidence of strong deformation: fault zones, folds, and locally overturned bedding are well developed (Bostock, 1935-1937 unpublished field notes, 1964; Hughes and Long, 1980; Mortensen, 1988b). Observed faults and fold axes are generally sub-parallel to the Tintina Trench.

The Tintina Trench ends just northwest of Chandindu River (Fig. 1), and between there and the Yukon-Alaska border the trace of the TFZ is marked by almost continuous exposure in outcrop and felsenmeer of the Early Tertiary sediments described above (Green, 1972; Hughes and Long, 1980; Mortensen, 1988a, b, 1990). Granitic and metamorphic rocks exposed along the banks of the Stewart River within the Tintina Trench near McQuesten (Fig. 1) imply that Early Tertiary rocks must be thin or absent in this area. About 50 km farther to the southeast (south of Stewart Crossing; Fig. 1), there is semi-continuous exposure of Mesozoic granite and Paleozoic and older metamorphic and sedimentary wall rocks right across the trace of the TFZ. The Early Tertiary strata apparently do not reappear in Tintina Trench until near the Pelly River, some 80 km farther to the southeast (Fig. 1)(e.g. Gordey and Irwin, 1987; Pride, 1988).

The region southwest of Tintina Trench in west-central Yukon is mainly underlain by low to medium grade metamorphic rocks of the Yukon-Tanana Terrane (e.g. Monger and Berg, 1987; Mortensen, 1988a, b, 1991). Three distinct magmatic events of relatively young age have been recognized in the area southwest of the TFZ (Woodsworth et al., 1989; Mortensen, 1988a, b, 1990). Intermediate to felsic volcanic and plutonic rocks which yield mid-Cretaceous (110-85 Ma) or Late Cretaceous (70-64 Ma) ages are widespread in this area. A suite of bimodal dykes, plugs, and minor subaerial volcanic rocks which yield mid-Eocene ages (59-53 Ma)(Mortensen, 1988a, b, unpublished data), is present in the Klondike District and parts of southwest Dawson map-area (Mortensen, 1988a, 1991) (Fig. 1). This magmatism is

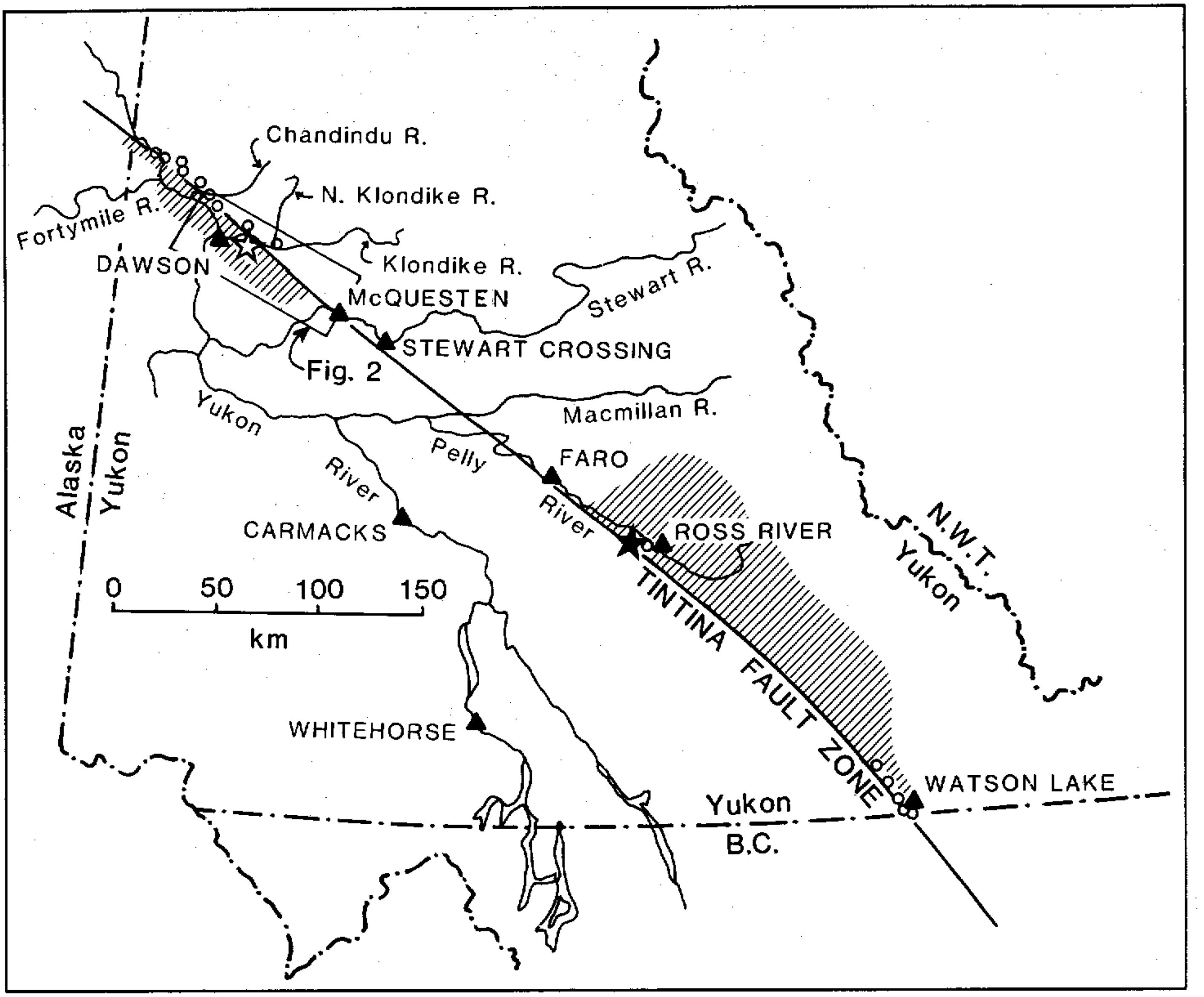

Figure 1. Location of study area (box). Limit of Eocene magmatism adjacent to the Tintina Trench is hachured. Location of the Grew Creek epithermal Au-Ag occurrence is shown by solid star; location of zone of epithermal-style alteration in the northern Klondike District shown by open star; location of coal occurrences within Tintina Trench is shown by open circles.

spatially and probably genetically related to the TFZ (Mortensen, 1988c). It is also identical in lithological association, composition and age to the igneous suite which hosts the Grew Creek epithermal precious metal deposit. Volcanic members of this suite in the Dawson area interlayered with immature clastic sediments that are indistinguishable from those in the Tintina Trench.

The area northeast of the Tintina Trench is underlain by an almost complete stratigraphic sequence from Proterozoic through Jurassic age (Green, 1972; Thompson and Roots, in preparation). Alkaline plutonic rocks which intrude this sequence in the Ogilvie Mountains (Tombstone Suite, Woodsworth et al., 1989) yield mainly mid-Cretaceous ages (90 $\pm$ 10 Ma). Quartz monzonite intrusions which are also mid-Cretaceous in age (85 Ma) occur sporadically throughout the area southeast of the North Klondike River on the north side of the TFZ (Fig. 1). Eocene igneous rocks have not been recognized in this area.

Geological mapping and analysis of conventional aerial photographs show little evidence of linear structures southwest of the Tintina Trench, which is surprising in an area so close to a major fault zone where subsidiary strands might reasonably be expected. A possible exception in the area between the Yukon River and Tintina Trench south of Chandindu River is documented by Mortensen (1988b).

Despite relatively good exposure northeast of the trench, geological mapping has yielded little evidence for strands of the TFZ outside of the Tintina Trench itself (e.g. Green, 1972; Thompson et al., in preparation).

STRUCTURAL INTERPRETATION OF THE TINTINA TRENCH USING LANDSAT TM IMAGERY

The use of Landsat Thematic Mapper (TM) imagery for structural interpretation has three main advantages. First, individual images cover a much larger area than conventional aerial photographs (a full TM scene represents 180 km E-W by 175 km N-S) allowing easier recognition of regional-scale patterns and large individual features. Second, a typical Landsat image is evenly illuminated across the entire scene, using a low sun angle which can enhance important structural features which have a topographic expression. In contrast, mosaics of aerial photographs usually show a variety of illumination patterns that can make interpretation difficult. Third, the TM imagery is acquired in seven spectral bands consisting of three visible bands, three near-infrared bands (reflected solar radiation), and a thermal infrared band (emitted terrestrial radiation). Using simple processing techniques these bands can be enhanced and viewed individually or in combination with other bands. The multispectral capability is valuable for enhancing lineaments where subtle changes in surface material such as soil or vegetation reflect underlying geology but the difference in image contrast is very low.

However, remote sensing techniques can be abused, by failure to recognize that some features may be artefacts, features produced during data acquisition and/or subsequent data manipulation. Ground checking of the satellite image-based interpretation is critically important.

Application

The digital image data set used for this study was captured by the TM multispectral scanner onboard the Landsat 4 satellite on June 14, 1986, at approximately 9:30 a.m. (path 63; row 15). A half to a full Landsat scene (two quadrants), with a footprint of approximately 85 km by 180 km, was obtained from the Canada Centre for Remote Sensing (CCRS) satellite receiving station located in Prince Albert, Saskatchewan.

We selected the segment of Tintina Trench between Chandindu River and McQuesten (Fig. 1) as a test area because of poor bedrock exposure and because known epithermal-type alteration occurs in Eocene volcanic and sedimentary rocks on the southwest margin of the Trench in the Dawson area (Fig. 1), and related mineralization may occur within the Trench.

The thermal band was the most successful in penetrating the thick vegetation cover of this unglaciated, geomorphically mature area. Thermal band data has a spatial resolution of 120 metres and is centred on a portion of the electromagnetic spectrum (11 μm) which detects changes in topography (sunlit slopes are "hot" and shadowed slopes are "cold") and gross changes in vegetation. This band does not appear to be significantly affected by subtle changes in the type of surface cover. The visible and reflected infrared bands, however, are affected by the "spectral clutter" of the regional vegetation response which masks subtle topographic changes.

Most of the interpretation that follows is based on analysis of the thermal band data. Each linear feature was assigned to one of three groups which reflect the degree of confidence placed on the interpretation. The classification is based on criteria such as length and/or clarity of the linear feature, supporting geological evidence, and whether the feature can also be recognized on other spectral bands or conventional aerial photographs.

First order lineaments are prominent on the thermal band without enhancement, and portions of these features can also be detected on other spectral bands. On the thermal image, first order lineaments can generally be followed continuously for more than 10 km along strike. Segments of first order features generally coincide with obvious topographic features such as aligned drainages, and are also usually visible on conventional aerial photographs. We believe that first order lineaments correspond to major through-going faults or fracture zones. Second order lineaments are somewhat more subtle, but can generally be recognized with minimal enhancement of the imagery. Second order features cannot always be recognized on other spectral bands. They also usually have shorter strike lengths, and are thought to represent minor faults and fracture zones.

Third order lineaments are subtle features that were only distinguished using a non-topographic hillshading technique (Von Gaza, 1989). This technique treats the digital image data as an actual topography, which is artificially illuminated by a single light source using a computer-assisted cartographic hillshading procedure. The shading of the digital image data provides an added depth clue that greatly improves the interpreter's ability to perceive subtle details in the image data. Various user-defined solar azimuths and solar elevations were used to identify third order lineaments.

To check the possibility that these third order features might represent artefacts produced by the enhancement technique, a digital lineament mask produced by the enhancement technique was overlaid on the contrast-stretched raw thermal image. In all cases, third order features were found to correspond with specific topographic features, usually short drainage segments, breaks in slope, or segments of ridge crests.

A variety of other lineaments that appear on the satellite image were examined on conventional aerial photographs and proved to be man-made features or natural surface features such as fluvial channels and levees or edges of old forest fire burns. These lineaments have been excluded from further discussion.

Figure 2 shows an enhanced thermal image of the study area, as well as a line sketch of the same area identifying the main first and second order linear features. Some of these features have been named where they coincide with named topographic features (e.g. Gravel Creek lineament, Barlow Lake lineament, etc.).

Two main orientations of first and second order lineaments are evident, generally trending to the NW-SE or NE-SW. The NW-SE trending lineaments occur only within

Figure 2a. NW area. Linearly contrast-stretched image of the TM Band 6 (thermal) data for the study area.

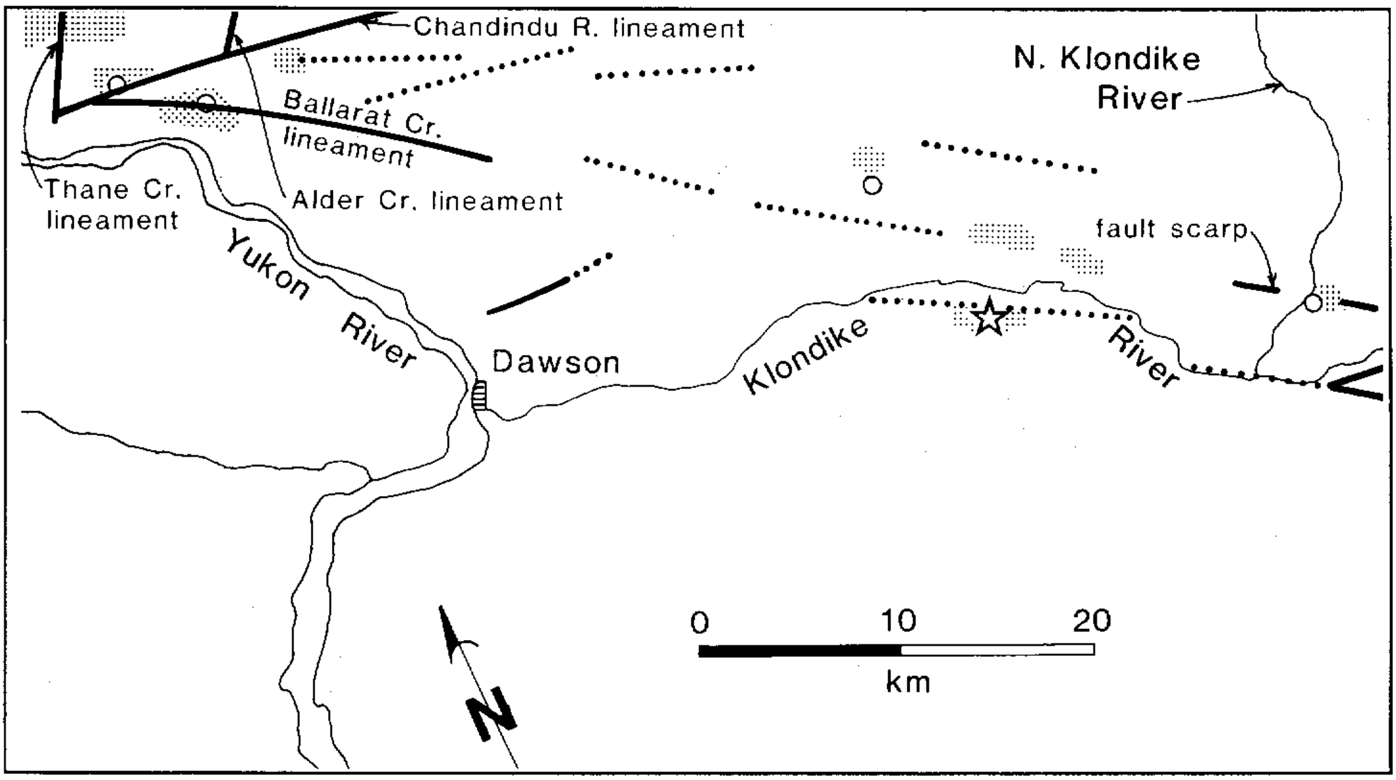

Figure 2b. NW area. Line sketch of the same area (same scale) showing the major first order (solid lines) and second order (dotted lines) lineaments identified in this study. Open star shows location of the zone of epithermal-style alteration; open circles show locations of coal occurrences. Areas of light stipple show outcrops of Eocene sedimentary rocks.

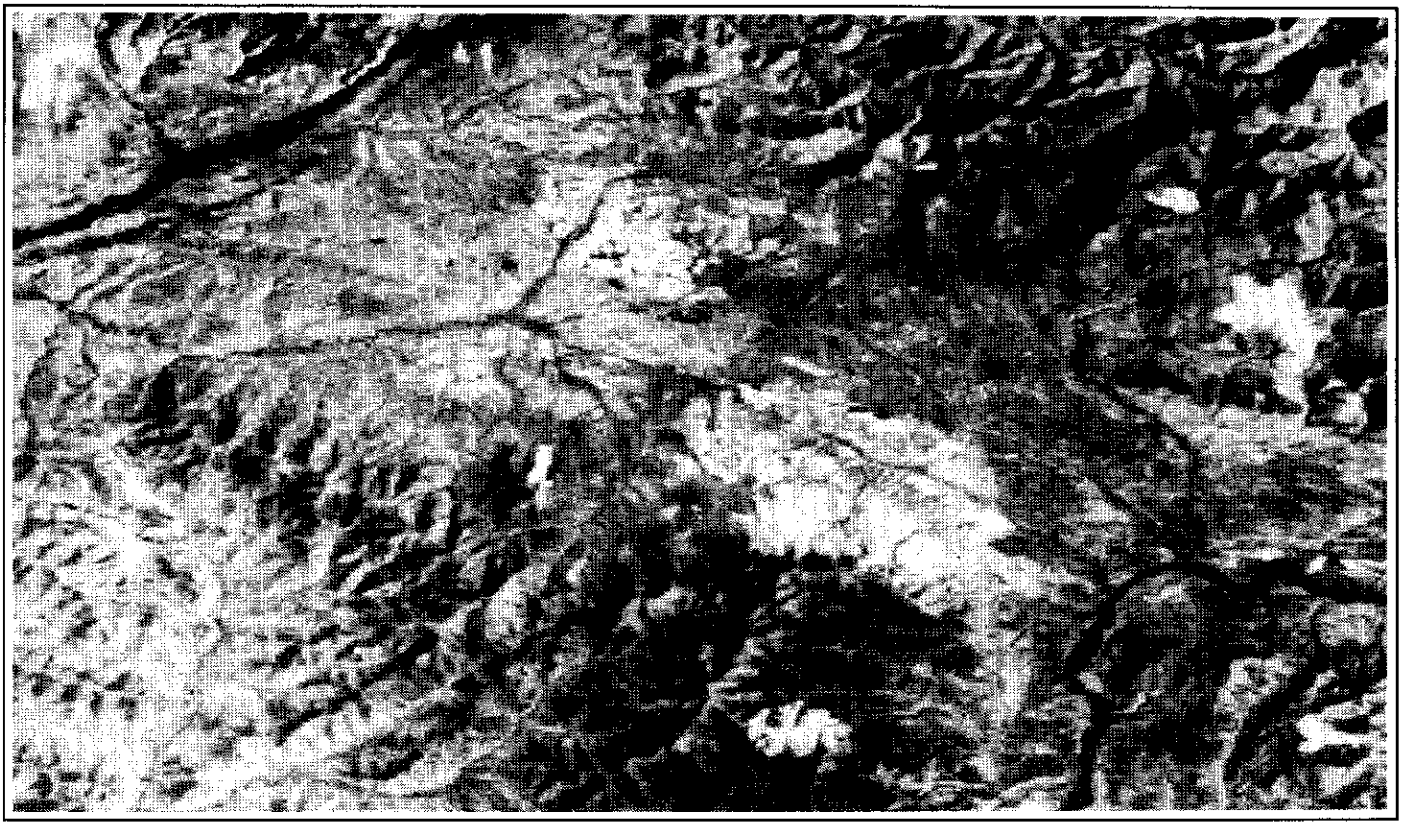

Figure 2a. SE area. Linearly contrast-stretched image of the TM Band 6 (thermal) data for the study area.

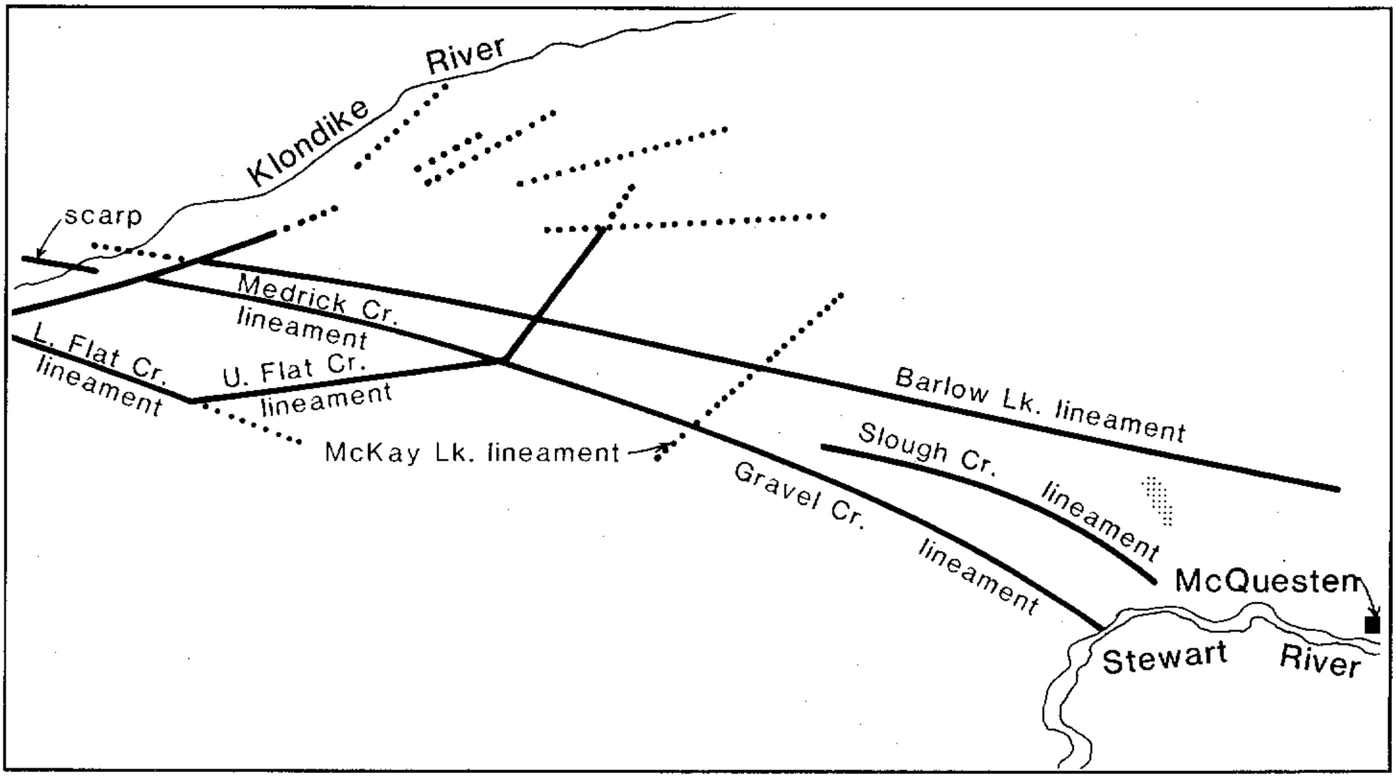

Figure 2b. SE area. Line sketch of the same area (same scale) showing the major first order (solid lines) and second order (dotted lines) lineaments identified in this study. Open star shows location of the zone of epithermal-style alteration; open circles show locations of coal occurrences. Areas of light stipple show outcrops of Eocene sedimentary rocks.

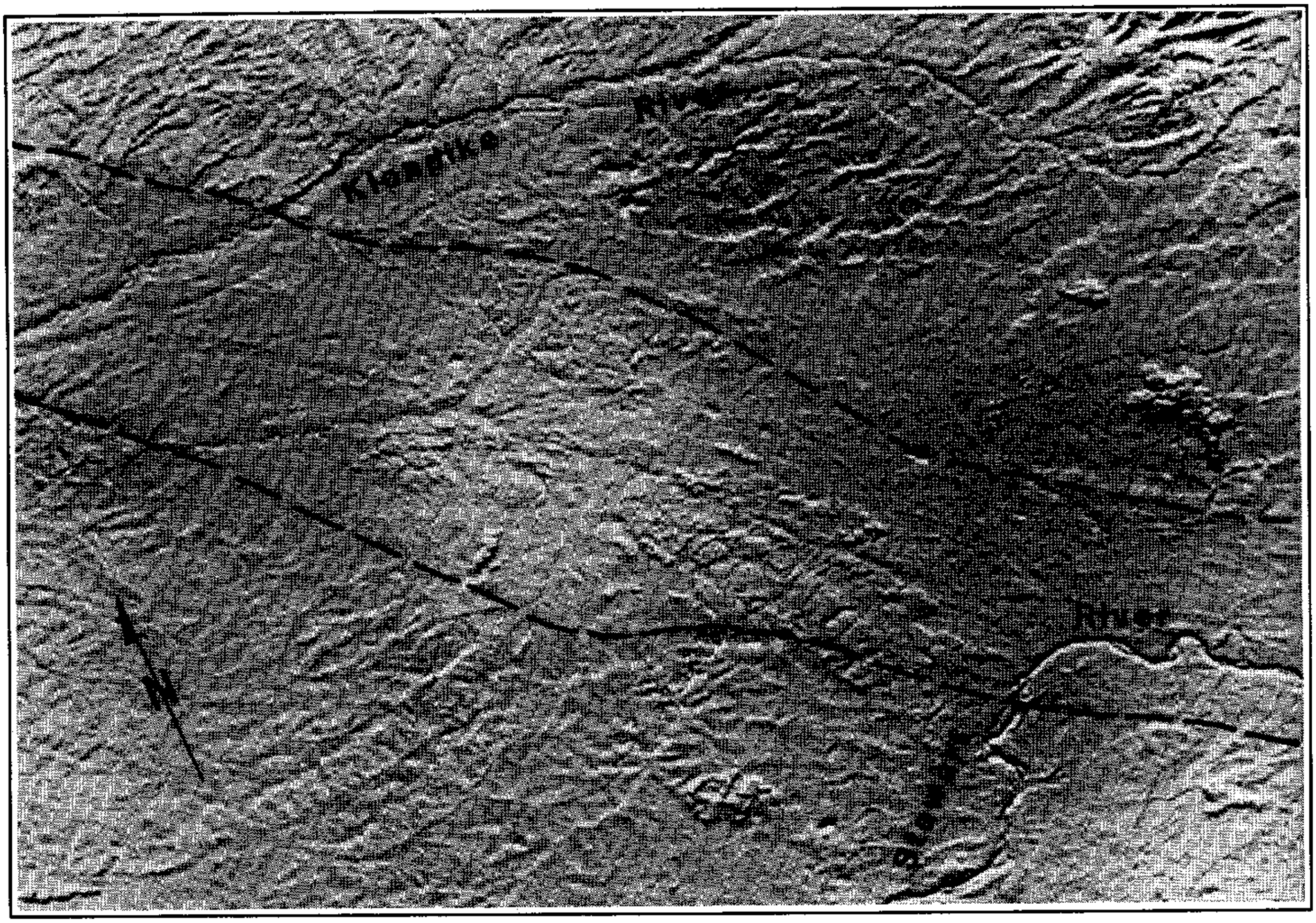

Figure 3. A non-topographically hillshaded image of TM Band 6 data for the southeast half of the study area, using sun angle = 0° and sun azimuth = 30°. The third order linear "fabric" is visible oriented at aproximately N-S and E-W in the north and southwest portions of the image area. Dashed lines show the approximate limits of the Tintina Trench.

or immediately adjacent to the Tintina Trench. The Barlow Lake lineament (Fig. 2) is one of the most obvious of these. At the southeast edge of the image, the lineament coincides with a prominent escarpment which forms the northeast edge of the Tintina Trench, and is probably an eroded fault scarp. A series of aligned, shallow lakes (including Barlow, Gravel, Lenore, and Strickland lakes) marks the northwest extension of the Barlow Lake lineament. These aligned lakes resemble "sag ponds" developed over small pull-apart zones in major strike-slip fault zones elsewhere in the world (e.g. Sylvester, 1988).

The Slough Creek, lower Flat Creek, and Gravel Creek-Medrick Creek lineaments are mainly marked by aligned drainages; however, clusters of small ponds which may also represent sag ponds are present along both of these features. Firm evidence that the Medrick Creek lineament is at least partially related to faulting is found at its northwest end, where the lineament crosses a small area of bedrock exposed during construction of the South Klondike ditch. The outcrop consists of strongly sheared and contorted Eocene sedimentary rocks. Shear planes generally parallel the Tintina Trench and dip vertically. Approximately 3 km farther to the northwest, immediately northwest of the Dempster Highway, a prominent scarp marks the trace of a normal fault down thrown at least 3 m to the south. The fault scarp can be traced for over 1 km along strike and is easily visible on aerial photographs (No. A37497:51-52). A similar but less obvious fault trace can be followed from the exposure of sheared Eocene sediments southeast to the Klondike River, a distance of 3 km (Fig. 2).

Some strong oblique lineaments are also evident. These are oriented at a moderate to high angle to the trend of the Tintina Trench. Some of the oblique lineaments, such as the upper Flat Creek lineament (Fig. 2), are confined to the Trench, and appear to connect pairs of the main NW-SE trending lineaments. Other features such as the McKay lineament (Fig. 2), however, cut right across the Trench and extend into topographically higher areas either side of the Trench. There is no evidence that the NW-SE trending features in the Trench are offset by this second set of lineaments, or vice versa.

Lineaments are less evident in the area northwest of the North Klondike River. Short segments of second order lineaments were identified crossing upper Rock Creek and Coal Creek. The Ballarat Creek, lower Chandindu River, and Alder Creek lineaments are all prominent features, and there is good field evidence at least along lower Ballarat Creek for significant normal fault offset (Mortensen, 1988b).

Two sets of third order lineaments showing approximate north-south and east-west trends are visible in large parts of the study area but appear to be poorly developed or absent within the Tintina Trench. These lineaments are visible on a non-topographically hillshaded thermal image (Fig. 3). They define an almost pervasive "fabric" across most of the area northeast of the Trench and parts of the region to the southwest. This fabric is defined by the preferred orientation of a great number of relatively short topographic lineaments which are not visible on conventional aerial photographs.

All of the first and second order lineaments identified on Figure 2 are interpreted as fault or fracture zones cutting bedrock. The NW-SE trending lineaments are believed to be individual strands of the main TFZ, and mark zones of substantial strike-slip displacement. Some of the oblique features such as the upper Flat Creek lineament may also represent anastomosing strike-slip faults or "step-over zones" between main strands of the fault zone. Because the lineaments which cut all the way across the Trench do not appear to offset the NW-SE lineaments, they must represent relatively young faults or fractures, with little or no strike-slip displacement.

Third order lineaments are probably an expression of the main structural fabric of large bodies of bedrock (such as bedding, foliation planes and joint sets). This may explain why they do not appear to be developed in the unconsolidated material within Tintina Trench itself.

The development of sag ponds and apparently very young fault scarps in unconsolidated Plio-Pleistocene glacial deposits within the Tintina Trench attests to recent fault activity in this area. Maps of recent earthquake activity in Yukon show a concentration of epicentres which roughly coincides with the TFZ, indicating that the zone is still seismically active.

DISCUSSION AND CONCLUSIONS

This study shows there is evidence for a variety of structures within the Tintina Trench in the Dawson-McQuesten area. Most of these are interpreted as steep faults and fracture zones cutting bedrock. The most prominent structures are outlined on the Landsat thermal image by first and second order lineaments which are sub-parallel to the TFZ. These features are almost entirely confined to the Tintina Trench, and probably represent individual strike-slip strands of the TFZ itself, some of which have apparently experienced late normal offset. First and second order lineaments which cut obliquely across the Trench do not appear to be offset by the Trench-parallel lineaments, and probably represent younger faults or fracture zones which post-date the major strike-slip movement. Third order lineaments are thought to reflect the overall structural "grain" of underlying bedrock.

This study demonstrates that enhanced Landsat TM thermal imagery can yield important structural information even in heavily vegetated areas of with thick overburden. Some of the lineaments identified in this study may represent possible loci for structurally controlled epithermal precious metal mineralization. The evidence of recent fault activity in the Tintina Trench may also have significance for geological hazard assessment in west-central Yukon.

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