

# EVIDENCE OF HYDROTHERMAL ALTERATION IN WHITE CHANNEL SEDIMENTS AND BEDROCK OF THE KLONDIKE AREA, WEST-CENTRAL YUKON

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## INTRODUCTION

The stratigraphy and sedimentology of the Pliocene to early Pleistocene White Channel gravelly deposit in the Klondike area was first described by R.G. McConnell (1905, 1907) and has been subsequently described by Milner (1976), Naldrett (1981), Dufresne and Morison (1985) and Morison (1985). Alteration in White Channel sediments and underlying bedrock on Dago Hill has been described by Tempelman-Kluit (1982), Dufresne and Morison (1985) and Dufresne (1986).

Field mapping during the 1984-85 field season has shown that three distinct alteration zones are present in White Channel sediments and underlying bedrock on hills such as Dago, Preido, Paradise, and Nugget (Fig. 1). In addition, low temperature hydrothermal veins are present in altered bedrock below altered White Channel sediments on these hills. The field relationships, mineralogy and chemistry of the alteration zones and associated veins suggest that they are the result of Pliocene to early Pleistocene hydrothermal processes. This report outlines evidence supporting hydrothermal alteration of White Channel sediments and bedrock in the lower Hunker Creek drainage basin (Fig. 1).

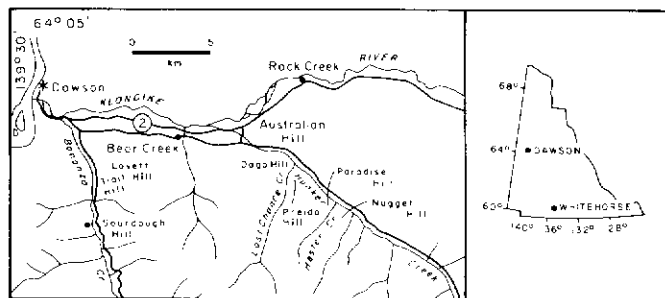


Figure 1. Location map of lower Hunker and Bonanza Creeks, Klondike area.

## ALTERATION

High level terraces in the Klondike area contain White Channel alluvium which ranges in thickness from a few metres to over 35 metres. Within White Channel sediment is a distinct post-depositional alteration product which varies from 20 to 25 m in thickness and extends 5 to 10 m into the underlying bedrock. Alteration is characterized by the development of secondary clay minerals, and is divided into 3 zones termed the Bleached Zone, the Iron Zone and the Footwall Zone.

### Unaltered Sediments and Bleached Zone

An iron-stained fluvial gravel unit which unconformably

overlies White Channel alluvium (Fig. 2) lacks significant clay alteration except at the surface within the soil profile. Surface clay alteration and iron-staining of this upper fluvial gravel unit is probably the result of weathering and seepage of meteoric fluids since the pre-Reid glacial interval (Rutter *et al.*, 1978). Unaltered White Channel gravelly sediments are generally yellow to light brown with lithofacies relationships and sedimentary structures clearly distinguishable (Dufresne and Morison, 1985). Felsic porphyry and mica schist gravel clasts are usually competent to friable and commonly iron-stained, and the gravel matrix has little secondary clay development (Dufresne and Morison, 1985). The mineralogy of the unaltered gravel matrix (determined by X-ray diffraction) consists of quartz, muscovite (10Å mica), potassium feldspar and plagioclase (Fig. 2). A trace amount of clay minerals (less than 1wt.%) occurs within the gravel matrix in the less than 2µm size fraction, and consists of approximately equal amounts of smectite, illite (10Å mica) and kaolinite (Fig. 2). Poorly developed diffractometer patterns for these clay minerals indicate low crystallinities. The Hinckley (1963) crystallinity index (HCI) of kaolinite in the less than 2µm size fraction for primary unaltered gravel matrix is generally less than 0.3 which is characteristic of poorly crystallized kaolinite.

Unaltered White Channel sediments are underlain by intensely altered Bleached Zone sediments with a sharp, thin (20 to 50 cm thick), brown to purple alteration boundary separating the two units (Fig. 2). The alteration boundary follows and cuts across lithofacies contacts and sedimentary structures, indicating that alteration processes were post-depositional (Dufresne and Morison, 1985; Morison, 1985). Alteration of White Channel alluvium is completely isolated from the iron-stained fluvial gravel unit and the surface weathering zone, with exceptions such as at the north end of the Dago Hill exposure (Dufresne and Morison, 1985). At that point, the iron-stained fluvial gravel unit truncates altered White Channel overbank silty-clay sediments. This demonstrates that alteration processes predate sedimentation of the iron-stained gravel unit.

White Channel sediments cut by the Bleached Zone have a characteristic white to grey colour. The zone generally extends downward to within 2 to 4 m of the bedrock contact. Within the Bleached Zone, schist and porphyry gravel clasts are soft and have been replaced by secondary clay minerals (Tempelman-Kluit, 1982; Dufresne and Morison, 1985). Lithofacies characteristics have been masked or destroyed due to volume changes associated with pervasive secondary clay development within the gravel matrix (Dufresne and Morison, 1985).

Gravelly matrix samples from the Bleached Zone usually contain 10 to 15 wt.% secondary clay minerals in the less than 2µm size fraction. Mineralogy of the matrix is dominantly quartz, muscovite and kaolinite with minor illite and trace feldspars (Fig. 2). Kaolinite is the dominant secondary mineral phase in the Bleached Zone. The HCI of kaolinite in this zone generally ranges

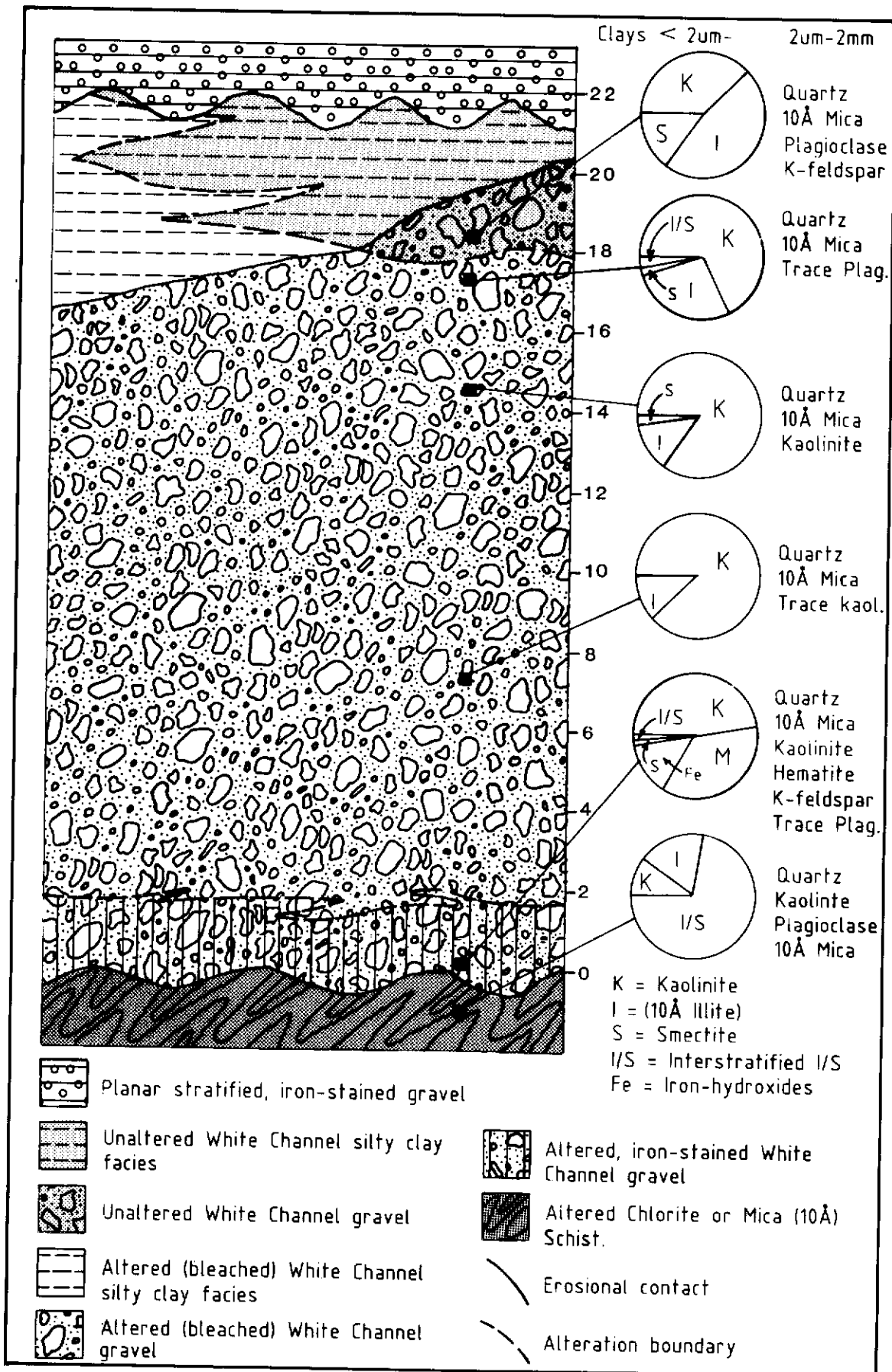


Figure 2. Idealized section of alteration at Dago Hill showing the distribution of clay minerals in the less than  $2\mu\text{m}$  size fraction and mineralogy of the  $2\mu\text{m}$ -2mm size fractions.

from less than 0.3 to 0.6.

Chemical analyses indicate that the Bleached Zone gravel is depleted in Mg, Ca, Na and K relative to unaltered White Channel gravel, whereas little or no change occurs in the concentration of Fe, P, S, Ba, Mn and As (Dufresne, 1986).

### Iron Zone

On Dago Hill, a 2 to 4 m horizon of altered and iron-stained White Channel gravel immediately above bedrock is termed the Iron Zone (Fig. 2). Gravel matrix within this zone contains abundant quartz, muscovite and feldspar with varying amounts of kaolinite, illite, smectite, hematite, lepidocrocite and goethite (Fig. 2). Hematite occurs as a post-depositional cement in several outcrops of Iron Zone gravel on Dago Hill. However, as in the Bleached Zone gravel, a large percentage of the Iron Zone gravelly matrix (i.e. 5 to 15 wt.%) is present in the less than 2 $\mu$ m size fraction. This size fraction is dominantly composed of kaolinite, illite, lepidocrocite and goethite with minor smectite. The HCl of kaolinite in this zone is generally high, ranging from 1.0 to 1.6, and is indicative of well-crystallized kaolinite. In addition, illite, goethite and lepidocrocite exhibit sharp and symmetric peaks on their diffractogram patterns, which also indicates well-crystallized and ordered minerals.

On Nugget Hill, (Fig. 1), a similar zone of alteration and iron-staining occurs in the lower 2 and 3 m of altered White Channel gravel and upper 2 m of bedrock. Intense iron addition has resulted in the cementation of the gravel by iron-hydroxides. In this zone, the gravel matrix contains trace to low amounts of secondary clay minerals in the less than 2 $\mu$ m size fraction. In the less than 2 $\mu$ m size fraction, quartz, goethite and adularia are abundant, with only trace amounts of illite and kaolinite. In the coarser size fractions, quartz is the dominant mineral with minor muscovite, goethite, illite and trace amounts of plagioclase and adularia.

The abundance of adularia in the less than 2 $\mu$ m size fraction and its absence in the coarser size fractions may indicate a secondary origin. Botryoidal goethite (Fig. 3a), and coarse secondary muscovite (1 to 2mm in size, Fig. 3b) are also visible in thin section. Goethite appears to cement clasts and matrix, but muscovite is a minor cement, commonly occurring as rims on clasts and intergrowths with goethite (Fig. 3c). Although only trace amounts of clay minerals are present in the 2 to 3 m zone of iron-stained and cemented White Channel gravel on Nugget Hill, the higher Bleached Zone gravel is intensely clay altered.

Altered rhyolite porphyry gravel clasts within the Iron Zone of Dago Hill contain greater than 30wt.% clay in the less than 2 $\mu$ m size fraction. This size fraction is dominantly composed of quartz, adularia and kaolinite, with minor illite. Kaolinite and adularia are the dominant secondary minerals; HCl of kaolinite in the clasts ranges from less than 0.3 to 1.3. Unaltered cobbles or rhyolite bedrock contain little or no kaolinite and adularia.

Chemical analyses of matrix samples from both the Dago Hill and Nugget Hill Iron Zone gravels (Dufresne, 1986), indicate that concentrations of Fe are enriched, but the concentrations of Mg, Ca, Na and K are unchanged relative to primary unaltered White Channel gravel. In addition, the concentrations of P, S, Ba, Mn and As are higher by an order of magnitude in the Iron Zone gravel relative to unaltered gravel. Significant amounts of Sb, Hg and Co have also been detected in the Iron Zone gravel.

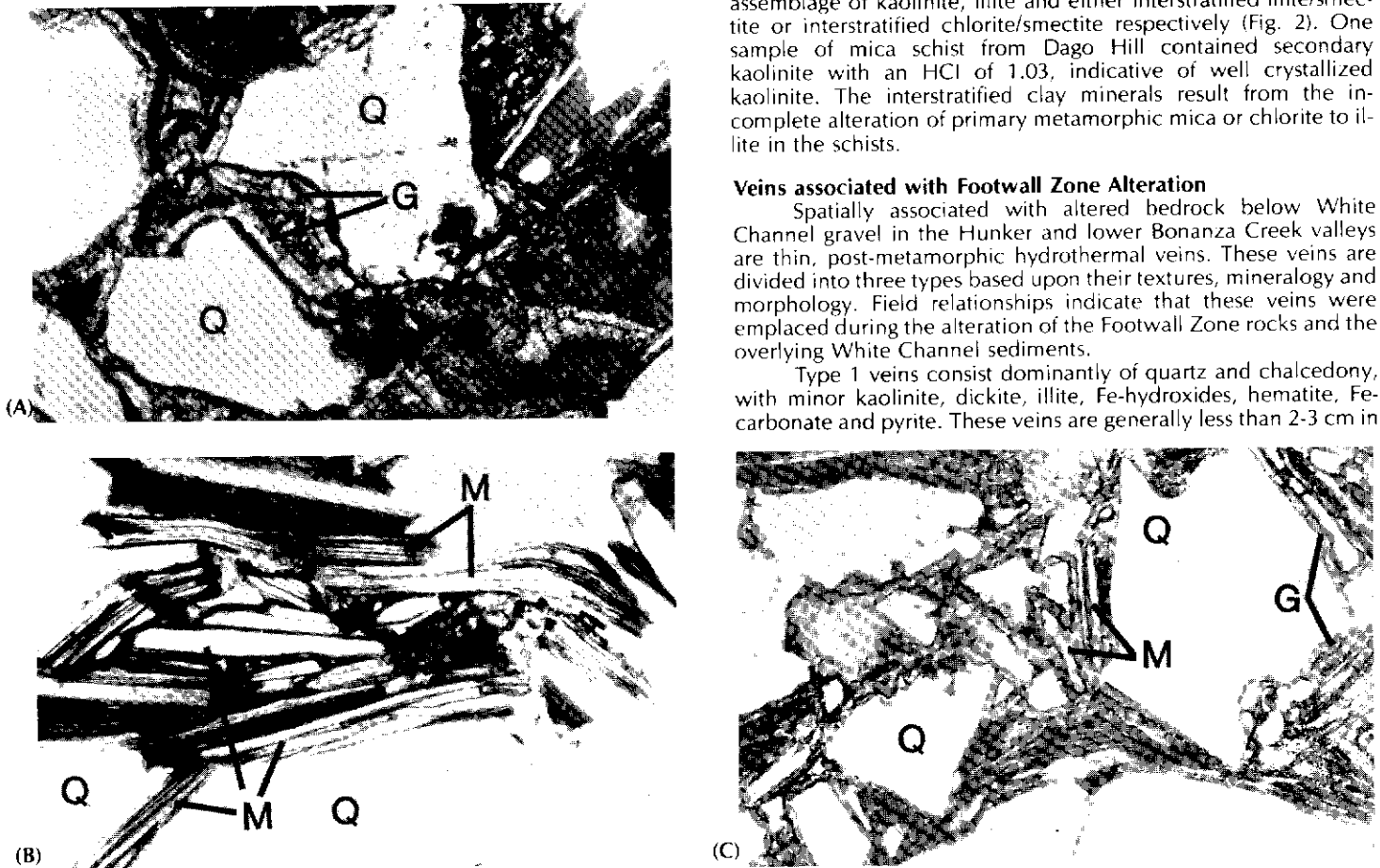
### Footwall Zone

Intense alteration in bedrock often extends 5 to 10 m into bedrock below the gravel contact. Below this, alteration is commonly restricted to zones of highly fractured bedrock. Altered schist typically contains 10-15 wt.% material in the less than 2 $\mu$ m size fraction, compared to less than 1 wt.% for unaltered schist. Mica and/or chlorite schist bedrock show a progressive alteration in the less than 2 $\mu$ m size fraction to a secondary clay mineral assemblage of kaolinite, illite and either interstratified illite/smectite or interstratified chlorite/smectite respectively (Fig. 2). One sample of mica schist from Dago Hill contained secondary kaolinite with an HCl of 1.03, indicative of well crystallized kaolinite. The interstratified clay minerals result from the incomplete alteration of primary metamorphic mica or chlorite to illite in the schists.

### Veins associated with Footwall Zone Alteration

Spatially associated with altered bedrock below White Channel gravel in the Hunker and lower Bonanza Creek valleys are thin, post-metamorphic hydrothermal veins. These veins are divided into three types based upon their textures, mineralogy and morphology. Field relationships indicate that these veins were emplaced during the alteration of the Footwall Zone rocks and the overlying White Channel sediments.

Type 1 veins consist dominantly of quartz and chalcidony, with minor kaolinite, dickite, illite, Fe-hydroxides, hematite, Fe-carbonate and pyrite. These veins are generally less than 2-3 cm in



**Figure 3.** Photomicrographs of iron-stained and cemented White Channel gravel on Nugget Hill showing: (A) Botryoidal goethite cementing detrital quartz grains; (B) Coarse muscovite (10 $\text{\AA}$  mica 1-2mm in length) rimming detrital quartz grains; (C) Intergrown goethite and muscovite (10 $\text{\AA}$  mica) cementing the matrix of the iron-stained gravel. Q = quartz, M = muscovite and G = goethite

thickness (in places 10-20 cm thick) and lack iron-stain. Characteristic of type 1 veins are vugs with euhedral quartz, and banding, cockscomb, cockade and crustiform textures. Type 2 veins are dominantly composed of siderite and quartz, with minor amounts of ankerite, calcite, goethite, hematite, gypsum, pyrite and clay minerals. Type 2 veins are intensely iron-stained and are generally less than 1-2 cm thick; however, associated concretions are 10 to 30 cm thick. Common textures exhibited by type 2 veins include botryoidal growth structures, replacement banding and vugs. Type 3 veins, minor in occurrence, consist of microfractures containing either the smectite group minerals and goethite, or amorphous silicates and goethite. Lussatite (a variety of opal) is present in several veins from the Trail Hill Footwall Zone. Type 3 veins are generally less than 1-2 cm in thickness, and show few textures.

Fluid inclusion analyses of these veins indicates that they were deposited from low temperature (approx. 125°C), dilute hydrothermal fluids. Also, the veins contain anomalously high concentrations of trace elements such as S, Ba, As, Sb and Au.

Types 1, 2 and 3 veins cross-cut all structural fabrics in the Klondike Schist. Types 1 and 2 veins in places contain fragments of partially clay altered and visibly bleached Footwall Zone rocks. In addition, siderite and quartz concretions related to type 2 veins contain various stages of replacement of clay altered schist and diabase on Jackson Hill. These relationships indicate that cementation and/or replacement of partially or completely clay altered bedrock must have occurred during clay alteration. In addition, there is a positive correlation between increased alteration and abundance of the veins, further suggesting that types 1, 2 and 3 veins were emplaced during alteration of the Footwall Zone rocks.

## DISCUSSION

The field relationships, mineralogy and chemistry of alteration in White Channel gravelly sediments contrasts with the observed features of surface weathering horizons and residual kaolin deposits. Bleached Zone alteration in the White Channel sediments is completely isolated from the surface weathering zone. In addition, the relationship of unaltered sediments overlying altered sediments (with a sharp boundary separating the two units) is zoned contrary to what would be expected in a surface weathering environment. Alteration from the percolation of surface fluids should result in a gradational change from altered to unaltered material with increasing depth below the surface.

In some respects, the intense kaolinization of Bleached Zone White Channel sediments is similar to the lower zones of laterites developed during weathering in locations such as the Tertiary sediments of South Carolina and Georgia (Harder, 1952; Hassanipak and Eslinger, 1985) and the Ordovician sandstones of the Chateaubriant area of Brittany (Esteoule-Choux, 1983). In lateritic type deposits, kaolinization is accompanied by the development of ironstone pisolites or concretions consisting of kaolinite, iron-oxides, iron-hydroxides and occasionally iron-carbonates. The entire kaolinite zone of laterites is usually pervasively iron-stained due to residual enrichment and oxidation of iron. These features develop during surface weathering, from either downward-percolating meteoric fluids or a fluctuating water table (Loughnan and Bayliss, 1961). In contrast, however, the kaolinized White Channel sediments appear to be bleached and show no evidence of enrichment and oxidation of iron relative to unaltered sediments, except in a 2 to 3 m horizon of altered gravel at the bedrock contact. This further suggests that alteration of the White Channel sediments was not the product of surface weathering processes.

The mineralogy of the Bleached, Iron and Footwall Zones shows surface differences with that of residual deposits in the surface weathering zone. For example, residual kaolin deposits, laterites and bauxites are usually characterized by the presence of minerals such as kaolinite, diaspore, gibbsite, iron-oxides and iron-hydroxides. The crystallinity of these minerals is generally poor, with minerals such as kaolinite and the iron-hydroxides exhibiting broad, ill-defined peaks on their X-ray patterns. Kaolinite produced from the supergene alteration of clastic sediments in Devon, England (Vincent, 1983); Chateaubriant, Brittany (Esteoule-Choux, 1983; Keller, 1976a) and South Carolina and Georgia (Hassanipak and Eslinger, 1985; Hinckley, 1963; Keller, 1976b) is characterized by low crystallinities with Hinckley (1963) crystallinity indexes generally less than 0.3.

In contrast to the above residual deposits, secondary kaolinite from the Iron and Footwall Zones generally has an HCl of greater than 1.0. In addition, well crystallized illite and iron-hydroxides are also present in the Iron and Footwall Zones. The high crystallinity index of kaolinite is very similar to that of hydrothermally produced kaolinite from Japan (Keller, 1977), Mexico (Hanson *et al.*, 1981; Keller and Hanson, 1968, 1969) and England (Bristow, 1977; Vincent, 1983). The high crystallinity of lepidocrocite is similar to the well crystallized hydrothermal lepidocrocite reported at the Enfield Bell Mine of Nevada (Birak and Hawkins, 1985). Interstratified illite/smectite or chlorite/smectite, present in the Iron and Footwall Zones, has also been reported in the hydrothermal alteration zones of northeast Japan (Inoue *et al.*, 1983; Inoue and Utada, 1983; Matsuda *et al.*, 1981a, 1981b). Adularia, present in the Iron Zone and altered rhyolite cobbles, is commonly reported as a hydrothermal phase often associated with muscovite and kaolinite in hydrothermal vein deposits and the upper levels of alteration halos associated with geothermal hot-spring deposits (Berger, 1985; Buchanan, 1980, 1981); Thus, White Channel alteration contrasts to what one would expect in a surface weathering environment, and bears a distinct resemblance to hydrothermal alteration zones associated with vein deposits and geothermal systems.

Trace element concentrations of the Iron Zone gravel are similar to the chemical signatures of many epithermal vein deposits and geothermal systems. The near-surface geothermal environment, including sinters, hot-spring pools and argillic alteration halos, typically contains high levels of Au, As, Sb, Hg, Ti, Fe, Mn, Ba, Co, P, S and F (Weissberg *et al.*, 1979; White, 1981, 1985). Precious metal vein deposits contain a similar enrichment of these trace elements in veins and alteration halos formed near the paleosurface and at low temperatures (less than 200°C) (Berger, 1985; Buchanan, 1980, 1981). Within the Iron Zone gravel, anomalous concentrations of Fe, Mn, As, Sb, Hg, Co, Ba and S were introduced during alteration. The similarities of this trace element enrichment to the trace element suite commonly found in the near-surface hydrothermal environments described above also suggests that similar hydrothermal processes were responsible for the alteration of the White Channel gravels.

The presence of types 1, 2 and 3 veins in the Footwall Zone lends further support to a hydrothermal origin for alteration of the White Channel gravels. Replacement textures, incorporated clay altered bedrock and their spatial relationship to Footwall Zone rocks suggest that the veins were emplaced during alteration of the footwall rocks and the overlying sediments. In addition, the presence of chalcedony and/or opal, and banding, cockscomb, cockade and crustiform textures is characteristic of veins and associated alteration halos formed by low temperature hydrothermal fluids within 100-200 m of the surface (Berger, 1985; Buchanan, 1980, 1981; Hedenquist and Henley, 1985). Consequently, types 1, 2 and 3 veins were deposited by low temperature (less than 200°C) hydrothermal fluids during the post-depositional alteration of the White Channel gravels and underlying footwall rocks.

## SUMMARY

A post-depositional hydrothermal alteration product in White Channel sediments and underlying bedrock is divided into 3 zones. These zones termed the Bleached Zone, the Iron Zone, and the Footwall Zone are characterized by the development of secondary clay minerals with moderate to high crystallinities. Trace element concentrations of Fe, Mn, As, Sb, Hg, Co, Ba and S are anomalously high in the Iron and Footwall zones. Three types of low temperature, post-metamorphic veins appear to be spatially related to both the distribution and intensity of alteration. Field relationships of altered and unaltered White Channel sediment show zoning patterns which cannot be explained by surface weathering and percolation of meteoric surface fluids.

Economic implications of the alteration of White Channel alluvium are that there may be a hydrothermal style of gold mineralization, in addition to gold which was initially deposited in a placer environment. Testing and exploration of altered White Channel alluvium should be done with this in mind, particularly for extremely fine-grained gold which may accompany the alteration product.

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