Kluane Ranges bedrock geology, White River area (Parts of NTS 115F/9, 15 and 16; 115G/12 and 115K/1, 2)

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ABSTRACT

The Kluane Ranges, located in southwest Yukon, are underlain by Late Paleozoic to Late Triassic volcanic and sedimentary rocks assigned to Wrangellia. Bedrock mapping completed within the White River area indicates Wrangellian rocks underwent several phases of deformation between Late Triassic and Miocene time. Middle Triassic marine, fine-grained sedimentary rocks are preserved in grabens where they are overlain by basal conglomerates and breccias of the Nikolai formation. The grabens are related to uplift associated with the deposition of Nikolai formation flood basalts and intrusion of ultramafic bodies. Late Jurassic to Early Cretaceous compression resulted in structural stacking of older rocks and northeast- and southwest-verging overturned folds. Latest (?) Cretaceous to Miocene dextral strike-slip along the Denali fault system led to the formation of steeply dipping faults, extensional and compressional basins and refolding of older regional scale folds. Reactivation of Jura-Cretaceous faults also occurred at this time. An enigmatic pre-Middle Triassic deformation event is believed to be preserved locally in rocks of the Hasen Creek Formation.

RÉSUMÉ

Les chaînons Kluane du sud-ouest du Yukon se composent de roches volcaniques et sédimentaires du Paléozoïque tardif au Trias tardif assignées à Wrangellia. La cartographie du substratum rocheux complétée dans la région de la rivière White révèle que les roches de Wrangellia ont subi plusieurs phases de déformation entre le Trias tardif et le Miocène. Des roches sédimentaires de milieu marin à grain fin du Trias moyen sont conservées dans des grabens où elles ont été recouvertes par les conglomérats et les brèches de base de la Formation de Nikolai. Les grabens sont reliés au soulèvement associé au dépôt des basaltes de plateau de la Formation de Nikolai et à l'intrusion des corps ultramafiques. Une compression du Jurassique tardif au Crétacé précoce a engendré un empilage structural de roches plus anciennes et la formation de plis déversés de vergence nord-est et sud-ouest. Le plus récent (?) rejet horizontal du Crétacé au Miocène le long du réseau de failles de Denali a entraîné la formation de failles au pendage abrupt, et de bassins d'extension et de compression ainsi qu'un nouveau plissement de plis plus anciens d'échelle régionale. Il y a également eu à cette époque une réactivation de failles jurasso-crétacées. Un énigmatique épisode de déformation antérieur au Trias moyen pourrait être préservé par endroits dans les roches de la Formation de Hasen Creek.

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INTRODUCTION

The Kluane Ranges bedrock mapping project is a multi-year study focused on the mountainous terrain south of the Denali fault (Fig. 1). The aim of the project is to provide detailed 1:50 000-scale bedrock mapping in an area that has undergone only regional 1:250 000-scale mapping. Reconnaissance 1:250 000-scale geological maps covering the Kluane Ranges and surrounding areas were completed by Muller (1967) and later by Dodds and Campbell (1992a,b,c). Limited 1:50 000-scale maps for the area between the Donjek and Jarvis rivers were produced by Read and Monger (1976) and were built upon during this study in 2004 and 2005 (Israel and van Zeyl, 2004; Israel *et al.*, 2005).

Mapping for the Kluane Ranges bedrock project is focused on upper Paleozoic to Upper Triassic stratigraphy of Wrangellia along with Jura-Cretaceous overlap

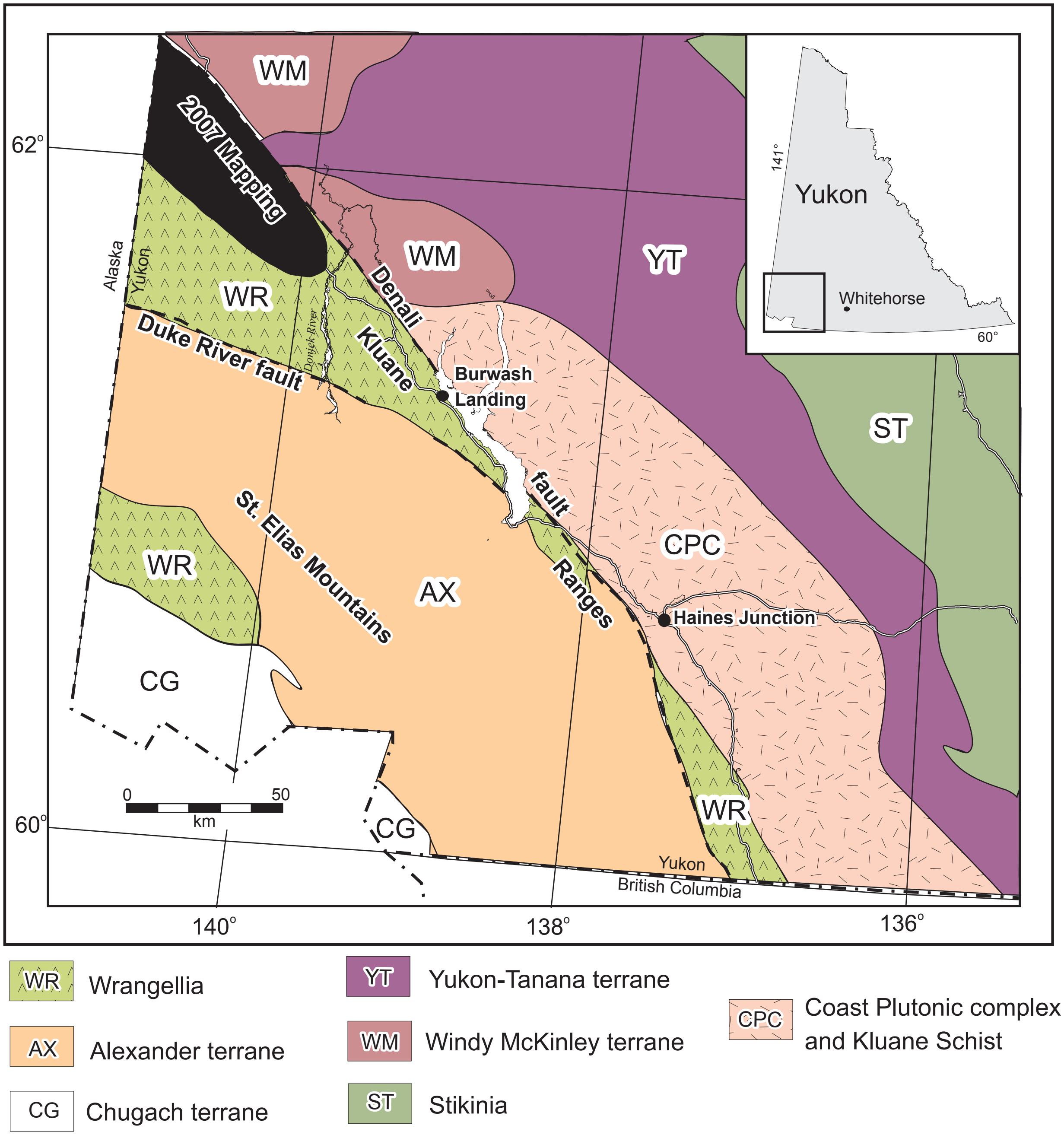

Figure 1. *Tectonic terrane diagram for southwestern Yukon illustrating the location of 2007 bedrock mapping.*

assemblages, Cenozoic sedimentary and volcanic deposits, and lower Paleozoic to Triassic rocks of the Alexander terrane (Fig. 1). The purpose of the Kluane Ranges project is to gain a better understanding of the stratigraphic and structural relationships within Wrangellia through detailed bedrock mapping. This data will be used to determine the tectonic framework of southwest Yukon and to better interpret the mineral potential of the area.

Mapping of the White River area, including the portion of the Kluane Ranges between the Donjek River and the Yukon/Alaska border, was conducted during the latter part of the 2006 and the 2007 field seasons (Fig. 1). In this region, the Kluane Ranges form rugged foothills that extend to the high, ice-covered St. Elias Mountains farther to the south. Topography varies greatly with rugged, long ridges separated by narrow and wide valleys. Outcrop on ridges and north-facing slopes is plentiful, while valleys and southern aspects are variably covered by vegetation. Access to much of the area is by helicopter only, with very few trails and rare roads reaching the base of the mountains.

REGIONAL GEOLOGICAL FRAMEWORK

Wrangellia underlies most of the project area. It consists of upper Paleozoic to Upper Triassic volcanic and sedimentary rocks (Jones *et al.*, 1977). Upper Paleozoic volcanic rocks comprise the Skolai arc, a volcanic arc that is the lowest exposed tectonic entity within the Yukon portion of Wrangellia (MacKevett, 1971; Read and Monger, 1976; Hulbert, 1997). The basement to Wrangellia is nowhere exposed. Upper Triassic flood basalts unconformably overlie the Paleozoic units and are associated with large mafic to ultramafic intrusive complexes that intrude the older rocks. These flood basalts are considered the hallmark of Wrangellia; they characterize the terrane from Vancouver Island to Alaska. The basalts are considered to be part of a large igneous province that may have a mantle plume origin (Richards *et al.*, 1991). In southwest Yukon, Wrangellia is juxtaposed next to the Alexander terrane across the Duke River fault. The Alexander terrane here is composed of lower Paleozoic volcanic and sedimentary rocks that are variably metamorphosed and deformed (Dodds and Campbell, 1992a). In Alaska, a Pennsylvanian pluton intrudes rocks of the Skolai arc and metamorphic rocks interpreted as part of the Alexander terrane, tying the two terranes together by this time (Gardner *et al.*, 1988). Wrangellia and the Alexander terrane were accreted to the western margin of the Intermontane terranes, including Stikinia, Quesnellia and the Yukon-Tanana terrane, as early as Middle Jurassic time (van der Heyden, 1992; Gehrels, 2001). Upper Jurassic-Lower Cretaceous sedimentary assemblages overlie both Wrangellia and the Alexander terrane and, in Yukon, are at least in part syntectonic with respect to compressional deformation. Large Early Cretaceous intrusions related to the Kluane arc intrude the older units. As much as 400 km of latest Cretaceous to present dextral motion along the Denali fault system juxtaposes Wrangellia next to the Windy-McKinley and Yukon-Tanana terranes (Fig. 1; Lowey, 1998). Terrestrial coarse-grained sedimentary rocks were deposited within transtensional and compressional basins formed between the Duke River and Denali faults in Cenozoic time (Ridgway *et al.*, 1992). Late Cenozoic subduction of the Yakutat terrane beneath southern Yukon and Alaska resulted in the eruption of voluminous volcanic rocks of the Wrangell arc.

LITHOLOGIC UNITS

Figure 2 illustrates the distribution of the main lithologic units within the White River area. The oldest unit is the Upper Paleozoic Skolai Group consisting of the lower Station Creek Formation and the upper Hasen Creek Formation. The Skolai Group is exposed extensively across the map area. It generally occurs as northwest-trending packages and is structurally interleaved with Upper Triassic volcanic rocks of the Nikolai formation and Upper Triassic carbonate of the Chitistone Limestone and the McCarthy Formation. Mafic and ultramafic intrusions related to the Nikolai formation intrude the Skolai Group and are found as northwest-striking bodies in the northern part of the map area. The Chitistone Limestone and the McCarthy Formation are restricted to the southwest portion of the map area, where they are overlain by Jura-Cretaceous sedimentary rocks of the Dezadeash Formation. A Late Triassic granodiorite to granite pluton intrudes rocks of the Skolai Group in the north-central White River area and large diorite to quartz diorite plutons of the Early Cretaceous Kluane Ranges Suite intrude all older rocks.

SKOLAI GROUP

The Skolai Group includes volcanic and sedimentary rocks of the Station Creek and Hasen Creek formations. The group is named for Skolai Creek in Alaska (Smith and

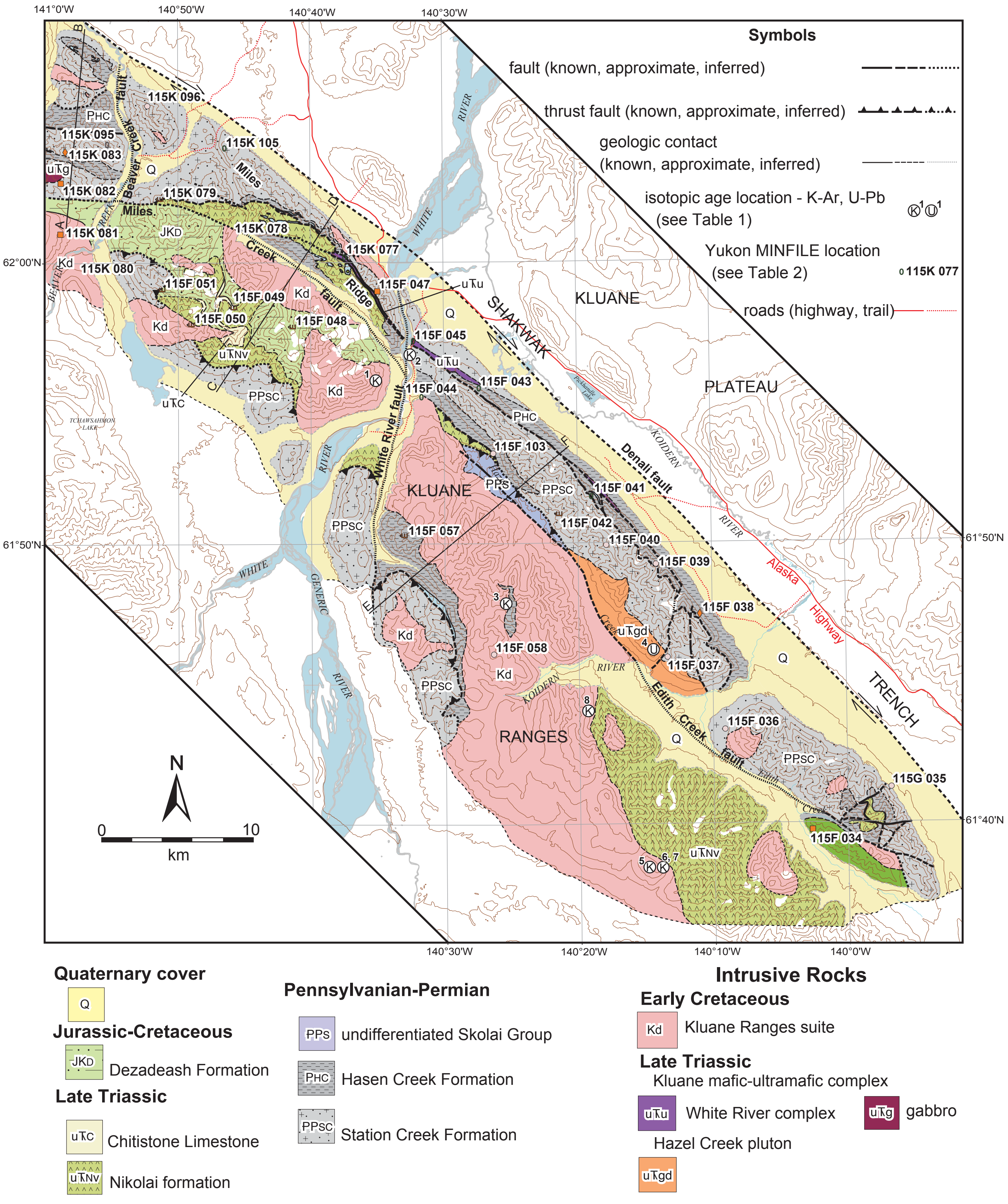

Figure 2. Generalized geology map for the White River area, modified from Israel et al., 2007a,b. Note, McCarthy Formation included within Chitistone Limestone.

MacKevett, 1970). Rocks of the Skolai Group are the most abundant within Wrangellia in southwest Yukon and extend from northern British Columbia into Alaska. The Skolai Group was first described in detail by Muller (1967). He assigned the rocks, with some hesitation, to the Cache Creek Group based on age and lithologic similarities with rocks in northern British Columbia. Subsequent work by Read and Monger (1976) led to the re-assignment of the rocks to the Skolai Group as described by Smith and MacKevett (1970).

Skolai Group undivided

A sequence of strongly deformed metavolcanic and metasedimentary rocks, located on the south side of Hazel Creek, is assigned to the Skolai Group (Fig. 2). These rocks are thrust to the northeast over less deformed and metamorphosed Skolai Group and volcanic rocks of the Nikolai formation. To the south, the sequence of metamorphic rocks is intruded by a large Early Cretaceous pluton. This sequence includes structurally interleaved chlorite schist, dark grey and brown phyllite, and metagabbro (Fig. 3a). All rocks are cut by extensive quartz and epidote veins. Deformation and metamorphism does not allow for differentiation between the volcanic and sedimentary rocks.

Station Creek Formation

The Station Creek Formation outcrops extensively in the White River area and consists primarily of volcanic breccia, tuff, volcaniclastic sandstone, and basalt to andesite flows. Work by Read and Monger (1976) elsewhere in the Kluane Ranges, suggests that the formation is dominated by volcanic flows in the southeast and by more volcaniclastic rocks in the northwest. Thickness of the Station Creek Formation is not known as the base of the unit is not exposed. However, Read and Monger (1976) and Smith and MacKevett (1970) suggest a thickness of at least 1000 m for the Station Creek Formation in southwest Yukon and Alaska. Although the thickness of the Station Creek Formation is difficult to assess due to the complex structural relationships in the White River map area, it is likely on the order of 1000 m thick as suggested by these authors.

Table 2. *Yukon MINFILE occurrences from the White River area. See Figure 2 for locations.*

Mineral Occurrences					
115K 078	◆	Chair	prospect	Ag, Pb, Zn	vein
115K 079	⬣	Nutzotin	prospect	Cu	skarn
115K 080	◆	California	unknown	Au	intrusion
115K 081	■	Wrangell	anomaly		porphyry
115K 082	■	Nikki	drilled prospect	Cu, Au	porphyry
115K 083	▲	Rip	showing		ultramafic
115K 095	▽	Nutz/Sea	showing		VMS
115K 096	○	Gruber	unknown		
115K 105	▲	Yellow	showing		ultramafic
115F 034	■	Garlic	prospect	Au	porphyry
115F 035	○	Nox	unknown		
115F 036	○	Hankins	unknown		
115F 037	○	Koidern	unknown		
115F 038	◆	Liberty	showing	Au, Cu	vein
115F 039	○	Quebec	unknown		anomaly
115F 040	○	Duensing	unknown		
115F 041	▲	Cats and dogs	showing	Cu	ultramafic
115F 042	⬣	Mexico	showing		skarn
115F 043	▲	Pickhandle	drilled prospect	Cu, Ni	ultramafic
115F 044	▲	Sevensma	anomaly		
115F 045	▲	Canalask	deposit	Cu, Ni, PGE	ultramafic
115F 047	■	Epic	showing	Cu, Mo	porphyry
115F 048	⬣	Arn	drilled prospect	Au, Cu	skarn
115F 049	⬣	Sampete	prospect	Cu	skarn
115F 050	⬣	Monday	prospect		skarn
115F 051	⬣	Az/Hump	drilled prospect	Cu, Au	skarn
115F 057	⬣	Lep	drilled prospect	Zn, Cu	skarn
115F 058	○	Down	unknown		
115F 077	▲	Onion	drilled prospect	Ni, Cu, PGE	ultramafic
115F 103	○	Harjay	unknown		anomaly

In the White River area, the dominant rock types in the Station Creek Formation are volcanic breccia and tuff. Clast types and composition of the volcanic breccia vary greatly. The most abundant breccia in the Station Creek Formation consists of green/grey-weathered, dark green, fresh pyroxene porphyry (Fig. 3b). Clasts range in size from <1 cm to 50 cm and are angular to sub-rounded

Table 1. *Isotopic age determinations from samples within the White River area. See Figure 2 for sample locations; labels are marked numerically with corresponding U or K, which represents U-Pb and K-Ar respectively.*

	Type	Station #	Age	Mineral	Interpretation	Reference
1	K-Ar	W169	121.3±3.6	hornblende	cooling	Farrar *et al.*, 1988
2	K-Ar	White River	225±14	biotite	cooling	Campbell, 1981
3	K-Ar	WN-136-74	108±5	biotite	cooling	Stevens *et al.*, 1982
4	U-Pb	06-SI-040	211.7±2.5	zircon	crystallization	R. Friedman, pers. comm., 2007
5	K-Ar	MV-164-102	114±4	biotite	cooling	Stevens *et al.*, 1982
6	K-Ar	WN-135-74	112±4	biotite	cooling	Stevens *et al.*, 1982
7	K-Ar	WN-135-74	115±5	hornblende	cooling	Stevens *et al.*, 1982
8	K-Ar	W167	123.7±2.5	biotite	cooling	Farrar *et al.*, 1988

Figure 3. (a) *View towards the southeast of deformed and metamorphosed volcanic and sedimentary rocks included in the Skolai Group (undivided).* ***(b)*** *Volcanic breccia of the Station Creek Formation; clasts are entirely composed of augite-phyric mafic volcanic rock.* ***(c)*** *Polymictic volcaniclastic breccia from the Station Creek Formation.* ***(d)*** *Very fine-grained, green/grey tuff from the upper portion of the Station Creek Formation.* ***(e)*** *Interbedded dark grey and brown siltstone and mudstone from the Hasen Creek Formation.* ***(f)*** *Folded limestone unit near the top of the Hasen Creek Formation.*

within a fine-grained matrix that has a similar composition as the clasts. The breccia varies from clast-supported to matrix-supported and it is commonly difficult to distinguish clasts from the matrix. Units of pyroxene-porphyry breccia can be up to tens of metres thick.

Interbedded with the breccias are coarse-grained volcaniclastic sandstone units that include thick layers of polymictic breccia. The sandstone weathers grey/green in colour and contains coarse fragments of plagioclase, quartz and lesser amounts of pyroxene±hornblende. The sandstone units are well bedded to massive with the thickness of individual beds ranging from 1 cm to 20 cm. Polymictic breccia interbedded with the sandstone are mainly matrix-supported and weather to a light to medium grey. Clasts are generally <10 cm and include sub-rounded to angular, black, aphanitic volcanic rocks, dark grey siltstone, coarse-grained volcaniclastic sandstone and light grey chert (Fig. 3c). The matrix is coarse-grained and contains phenocrysts of plagioclase, quartz and pyroxene up to 2 mm.

Thick sections of fine-grained tuff are abundant in the Station Creek Formation and generally overlie the coarser grained units, but are not always present. Contrasting light grey/green- and maroon-weathering colours in the tuff accentuate bedding (Fig. 3d). Bedding ranges from <1 to 10 cm thick, but is generally on the order of a few centimetres thick. Some beds are crystal-rich with phenocrysts of feldspar and rare occurrences of quartz.

Volcanic flows are rare in the Station Creek Formation of the White River area. They locally form sequences that are several tens of metres thick with individual flows up to 1 m thick. The flows are composed of basalt to andesite that weather to a light green/grey or dark green with varying amounts of pyroxene and plagioclase phenocrysts. They are generally massive, but locally are strongly amygdaloidal; amygdules are filled with chlorite and quartz±calcite. Flows are commonly interbedded with light grey-weathering carbonate up to 50 cm thick.

The age of the Station Creek Formation is not well constrained. A late Pennsylvanian to Early Permian age is suggested based on fossils retrieved from interbedded siltstones in Alaska and the fact that the gradationally overlying Hasen Creek Formation is Early Permian in age (Smith and MacKevett, 1970).

Hasen Creek Formation

The Hasen Creek Formation is dominantly a sedimentary unit characterized by siltstone, mudstone, sandstone, carbonate, pebble conglomerate, rare volcanic flows, tuff and minor chert. In the northwest corner of the map area, it gradationally overlies the Station Creek Formation, the contact being drawn where sedimentary rocks dominate over volcanic rocks (Smith and MacKevett, 1970; Read and Monger 1976). Everywhere else in the study area, the two formations are in fault contact (Fig. 2).

The Hasen Creek Formation is variable in thickness. In southwest Yukon, it is up to 800 m thick (Read and Monger, 1976). Locally, Triassic rocks overlie and are in direct contact with the Station Creek Formation, with no intervening Hasen Creek Formation (Read and Monger, 1976).

Laminated dark grey to brown-weathering siltstone and mudstone and interbedded light grey to brown-weathering sandstone comprise the majority of the Hasen Creek Formation in the White River area (Fig. 3e). Fine-grained siltstone and mudstone beds range in thickness from <1 cm to 10 cm. Locally, siltstone dominates and forms beds up to several metres thick. Primary sedimentary features such as flame structures, load casts and cross-bedding are common. Near fault zones, the fine-grained rocks become phyllitic and have a penetrative platy cleavage. Interbeds of medium- to coarse-grained sandstone occur throughout the siltstone/mudstone unit and can be up to several metres in thickness, but are more commonly less than 1 m thick. The sandstone is composed of lithic fragments from older units, quartz and feldspar grains, and occasional 2 to 3 mm chert clasts. Siltstone rip-up clasts are common near the base of sandstone beds. Beds are massive to graded with sharp basal contacts and only rarely have laminations and cross-bedding. Locally, the sandstone beds coarsen upwards to a matrix-supported pebble conglomerate. Clasts within the conglomerate are well rounded to subangular and are composed of siltstone, aphanitic mafic and intermediate volcanic rocks, carbonate, and dark grey to black chert. Beds of conglomerate are between 1 and 5 m thick.

Several carbonate horizons occur within the Hasen Creek Formation. These range from thin (≤1 m) featureless units, to very thick (≤100 m) fossiliferous limestone. Thin carbonate horizons weather light grey and commonly contain clasts of underlying rocks. These beds are laterally discontinuous and form lenses in the surrounding siliciclastic rocks. The fossiliferous limestone units are commonly located near the top of the formation. They weather light grey and are massive to well bedded. Bedding, where evident, is defined by alternating light and

***Figure 4. (a)** Boulder conglomerate from the basal section of the Nikolai formation. **(b)** Matrix-supported polymictic conglomerate from the base of the Nikolai formation.*

dark grey layers up to 30 cm thick. The dark grey layers are more argillaceous and locally display faint laminations. Thick limestone units commonly stand out as resistant bands that continue along strike for several hundreds of metres (Fig. 3f).

Rare beds of dark grey to black chert occur near the top of the Hasen Creek Formation and are associated with limestone horizons. The thickness of these upper chert layers is poorly constrained, however, at one locality, several metres of black chert occur unconformably below Triassic volcanic rocks of the Nikolai formation.

The Hasen Creek Formation is Early Permian in age based on abundant fossil collections (Smith and MacKevett, 1970; Read and Monger, 1976; Dodds *et al.*, 1993; Israel and van Zeyl, 2005).

NIKOLAI FORMATION

Subaerial to submarine basalt flows characterize Wrangellia from southern Vancouver Island to Alaska (Smith and MacKevett, 1970; Read and Monger, 1976; Jones *et al.*, 1977; Nikolai greenstone or basalt of MacKevett, 1971). In Yukon and Alaska, these are assigned to the Nikolai formation (Read and Monger, 1976). Correlative units on Vancouver Island are known as the Karmutsen Formation (Carlisle, 1963; Muller, 1977). Previous descriptions of the Nikolai and Karmutsen formations focused on the basalt. Subsequent work showed that these formations also contain a basal volcanic conglomerate and breccia, and interbedded argillite and carbonate (Carlisle and Suzuki, 1974; Read and Monger, 1976; Greene *et al.*, 2005; Israel and van Zeyl, 2005; Israel *et al.*, 2006). In the White River area, the Nikolai formation consists largely of basalt with minor amounts of basal breccia and conglomerate. It is either in fault contact with, or unconformably overlies older units. Rocks of the Chitistone Limestone unconformably overlie the Nikolai formation.

Observations of the basal conglomerate and breccia during the 2007 season were limited to a single ridge above Edith Creek (Fig. 2). Outcrops are not large enough to be mapped separately at 1:50 000 scale and are thus included in the undivided Nikolai formation. The basal conglomerate and breccia consist of very angular to well rounded pebbles to boulders of siltstone, carbonate, mafic and intermediate plagioclase±augite porphyritic volcanic rocks, and dark grey to black chert (Fig. 4a). The conglomerate/breccia unit is typically clast-supported, but is locally matrix-supported. Matrix composition varies from coarse-grained sandstone to crystal-rich volcaniclastic material (Fig. 4b). Deposition of the conglomerate and breccia unit is laterally restricted and appears to be fault-controlled (see Discussion).

Basalt comprises the majority of the Nikolai formation in the White River area. Individual flows are up to 2 m thick and can be identified by vesicular bases and tops and more massive centres. Vesicles are most commonly filled with quartz±calcite. The basalt weathers a deep olive-green to maroon and is dark green to dark grey on fresh surfaces. The flows are locally plagioclase-phyric and contain small (1 mm) olivine phenocrysts in only a few localities.

The age of the Nikolai formation is bracketed by fossils found in bounding and interbedded units elsewhere in Wrangellia that include a poorly preserved Middle Triassic sedimentary unit occurring beneath the basalt, and from carbonate interbedded with basalt near the top of the formation that host Norian (Late Triassic) conodonts (Read and Monger, 1976; Israel *et al.*, 2006; Nixon and Orr, 2006).

CHITISTONE LIMESTONE AND MCCARTHY FORMATION

Both the Chitistone Limestone and the McCarthy Formation get their names from the McCarthy quadrangle in Alaska, just across the border from the White River map area (Smith and MacKevett, 1970; MacKevett, 1971). The units were not closely examined during the present study and are only briefly described here. More complete descriptions of these units in the Kluane Ranges are given by Israel *et al.* (2006) and Read and Monger (1976) and in Alaska by MacKevett (1971).

The Chitistone Limestone is exposed near Hump Mountain where it forms horizons several hundred metres thick between the Nikolai and Dezadeash formations. It unconformably overlies the Nikolai formation, and consists of massive to well bedded limestone and calcareous argillite. The carbonate is pale grey to beige, and unlike older limestone units, this unit is devoid of macrofossils. It is locally brecciated with clasts of siliceous carbonate occurring in a medium-grained crystalline carbonate matrix. The Chitistone Limestone is Norian (Late Triassic) in age, based on abundant conodont collections from the Kluane Ranges and Alaska (Dodds *et al.*, 1993).

The McCarthy Formation is characterized by interbedded light and dark grey calcareous, carbonaceous argillite and carbonate layers. The McCarthy conformably overlies the Chitistone Limestone, and in places, the two units can not be distinguished. The McCarthy Formation is Late Triassic to Early Jurassic based on fossil collections from southwest Yukon and Alaska (MacKevett, 1971; Dodds *et al.*, 1993).

DEZADEASH FORMATION

The Dezadeash Formation was not examined during the present study; however, it is included in this paper as there is a significant amount of exposure of Dezadeash Formation along several ridges south of the Miles Creek fault (Fig. 2). Detailed descriptions of the unit are mainly from previous authors describing outcrops of the Dezadeash in the Kluane Ranges southeast of the present study area. The relationship between the Dezadeash Formation and underlying units is unknown; elsewhere in the Kluane Ranges outside the study area, the base of the formation is not exposed, or is faulted (Eisbacher, 1976). The Lower to Middle Jurassic Tatamagouche succession of Israel *et al.* (2006) may in fact be the basal component of the Dezadeash Formation, but more work needs to be done in order to confirm this. The Dezadeash Formation is correlative with the Nutzotin Mountain sequence in Alaska (Eisbacher, 1976; Ridgway *et al.*, 2002) and is part of a series of Jura-Cretaceous basins that occur along the western edge of Wrangellia and the Alexander terrane (McClelland *et al.*, 1992).

The Dezadeash Formation consists of up to 3000 m of turbidites that include siltstone, mudstone, sandstone and conglomerate (Eisbacher, 1976; Lowey, 1992). It is, at least in part, syntectonic with respect to Early Jurassic to Early Cretaceous compressional deformation and constitutes a basin formed in a retroarc depocentre (Trop and Ridgway, 2007). The Dezadeash Formation is Late Jurassic to Early Cretaceous based on fossil collections from the Kluane Ranges (Eisbacher, 1976; Dodds *et al.*, 1993).

INTRUSIVE ROCKS

Three main intrusive complexes are present in the White River area. These include the Late Triassic Kluane mafic-ultramafic complex, a Late Triassic granodiorite to granite body, and the regionally extensive Early Cretaceous Kluane Ranges Suite. Several isotopic ages exist for these complexes and preliminary results of new U-Pb data are presented below. Ages and locations of samples are shown on Figure 2.

Kluane Mafic-Ultrmafic Complex

Mafic and ultramafic bodies have been recognized throughout the Kluane Ranges since early exploration of southwest Yukon (Muller, 1967). These bodies are associated with significant nickel-copper-platinum group element (PGE) mineralization throughout the Kluane Ranges. They intrude rocks of the Skolai Group and are Late Triassic in age (Hulbert, 1997). An extensive study of the complex was undertaken by Hulbert (1997) who described the largest of the intrusions and examined the chemistry and mineralization associated with each. These intrusions overlap in age with basalt of the Nikolai formation and are considered to be the magmatic feeders to the basalt. The mafic-ultramafic bodies are described as zoned intrusions with a dunite core, passing outwards into peridotite and olivine pyroxenite, and rimmed by a gabbro phase (Hulbert, 1997). This zoning is difficult to observe in the field as many of these bodies are either altered and/or deformed.

In the White River area, the fault-bounded White River complex (Hulbert, 1997) occurs on the north side of Miles Ridge and continues along strike for roughly 20 km (Fig. 2). It is faulted against rocks of the Station Creek, Hasen Creek and Nikolai formations. The complex is up to 300 m wide and is altered and deformed between the White River and areas to the northwest (Fig. 5a). The White River complex is cut by the White River fault, but is exposed to the southeast across the fault suggesting possible normal offset of the complex. It is composed primarily of strongly altered ultramafic rocks, making it difficult to identify the protolith. Locally, peridotite occurs in the least-altered areas. Southeast of the Canalask deposit (Fig. 2), less altered pyroxenite and peridotite with disseminated pyrite occur sporadically in creek bottoms. The age of the White River complex is not known, however a ^{40}Ar/^{39}Ar age from phlogopite extracted from a similar intrusion to the southeast yielded an age of *ca.* 228 Ma (Israel and Ullrich, unpublished data).

Light to dark-grey-weathering gabbro dykes and sills intrude the Station Creek and Hasen Creek formations throughout the White River area. These represent the more mafic part of the Kluane mafic-ultramafic complex. They range in size and thickness from 1 m to several tens of metres. The gabbro forms blocky outcrops which are composed of equigranular, fine to medium-grained pyroxene and plagioclase. Plagioclase is variably altered to light green epidote. Where fine grained, it is difficult to distinguish the gabbro from crystal tuff of the Station Creek Formation. Similar gabbro bodies in other areas of the Kluane Ranges have yielded U-Pb zircon ages of *ca.* 232 Ma (Mortensen and Hulbert, 1991).

Hazel Creek Pluton

A granodiorite to granite pluton is exposed just north of Hazel Creek where it intrudes rocks of the Station Creek Formation and is juxtaposed with diorite of the Kluane Ranges suite across the Edith Creek fault (Fig. 2). The Hazel Creek pluton consists of medium to coarse-grained biotite±hornblende granodiorite to granite. It weathers to light grey and has a salt-and-pepper appearance on fresh surfaces. Country rocks near the pluton are hornfelsed and minor dykes and apophyses extend from the main intrusive body. Zircons from this pluton yielded a U-Pb age of *ca.* 212 Ma (Israel and Friedman, unpublished data). Magmatism of this age is not documented elsewhere in Wrangellia in southwest Yukon or eastern Alaska. More work is needed to determine the tectonic significance of the Hazel Creek pluton.

Kluane Ranges Suite

Medium-grained granitic rocks of the Kluane Ranges Suite form extensive exposures in the central and western portions of the White River area (Fig. 2). The granitic rocks intrude all units in the area and a well developed

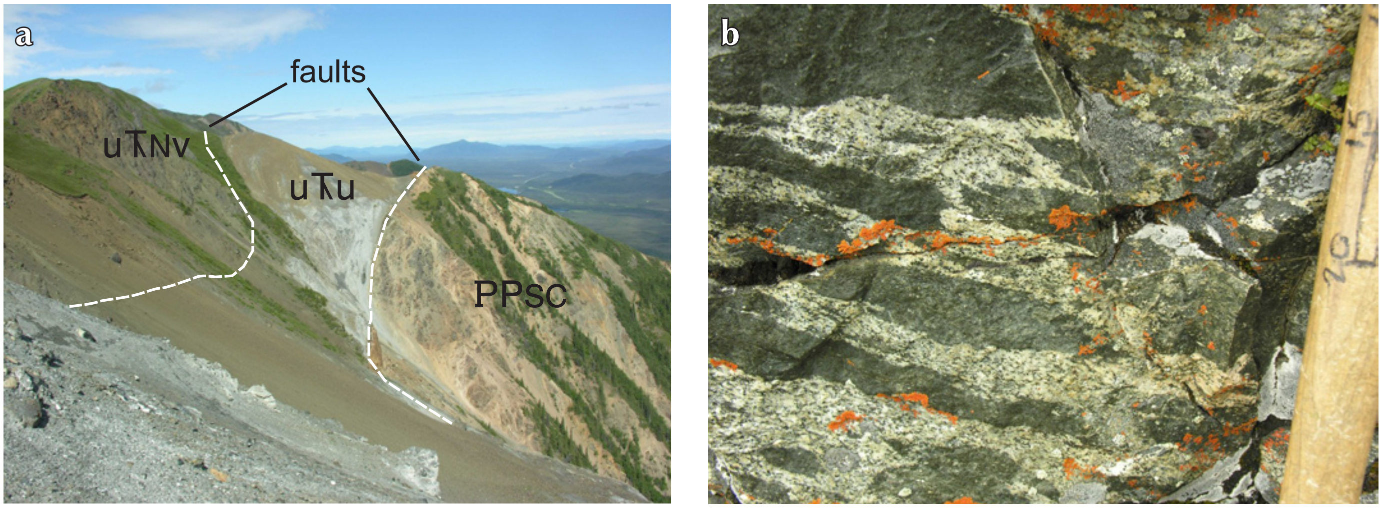

Figure 5. (a) *A view looking northwest at a fault-bounded ultramafic body (uTRu) of the White River complex on Miles Ridge. For unit descriptions, see Figure 2.* ***(b)*** *Hornfelsed Nikolai formation basalts near the contact with a Kluane Ranges Suite diorite intrusion.*

hornfels occurs around the main body (Fig. 5b). The Kluane Ranges suite is characterized by medium-grained, light grey-weathering hornblende diorite and hornblende±biotite quartz diorite. It has a salt-and-pepper appearance on fresh surfaces with little alteration of the mafic minerals. It is devoid of penetrative fabric, except near its margins where a magmatic foliation is locally defined by alignment of mafic minerals. K-Ar ages from the White River area range from 124 to 112 Ma (Stevens *et al.*, 1982; Farrar *et al.*, 1988). The Kluane Ranges Suite is likely a southeastern extension of the Early Cretaceous Chisana arc in eastern Alaska (Plafker *et al.*, 1989a).

STRUCTURE

The White River area has experienced several phases of deformation resulting in structural stacking, folding and lateral dissection of units (Fig. 6). Large northwest-dipping faults place older rocks over younger rocks and northeast and southwest-verging map-scale folds are developed throughout the area. A penetrative foliation is only developed near faults and an axial-planar cleavage is not consistently developed. Map-scale, steeply dipping strike-slip and extensional faults separate rock units into northwest-trending blocks. Timing of the main deformational episodes is constrained as pre-Late Triassic, Late Triassic, Jura-Cretaceous and Late Cretaceous to present; these events are described below.

PRE-LATE TRIASSIC DEFORMATION

Evidence for a pre-Late Triassic deformational event is locally preserved in the Kluane Ranges. Evidence consists of the following: 1) local absence of Hasen Creek stratigraphy between the Station Creek and Nikolai formations, suggesting uplift and erosion prior to deposition of the Nikolai basalt; 2) an unconformable contact between the Hasen Creek and a suspected Paleozoic gabbro in the Steele Creek area, suggesting erosion of the Station Creek Formation prior to the Permian (Read and Monger, 1976; Israel *et al.*, 2006); 3) apparent folding of upper Paleozoic strata prior to deposition of Nikolai formation (Israel *et al.*, 2006); and 4) the absence of Lower Triassic strata in the Kluane Ranges and Middle Triassic strata unconformably overlying the Hasen Creek Formation suggests possible pre-Middle Triassic uplift and erosion. These older structures are difficult to identify because of the intensity of the younger deformation. However, this older event likely played an important role in the intrusion of ultramafic sills and dykes which are targets for mineral exploration. More detailed studies should be undertaken in order to determine the nature and extent of pre-Late Triassic deformation.

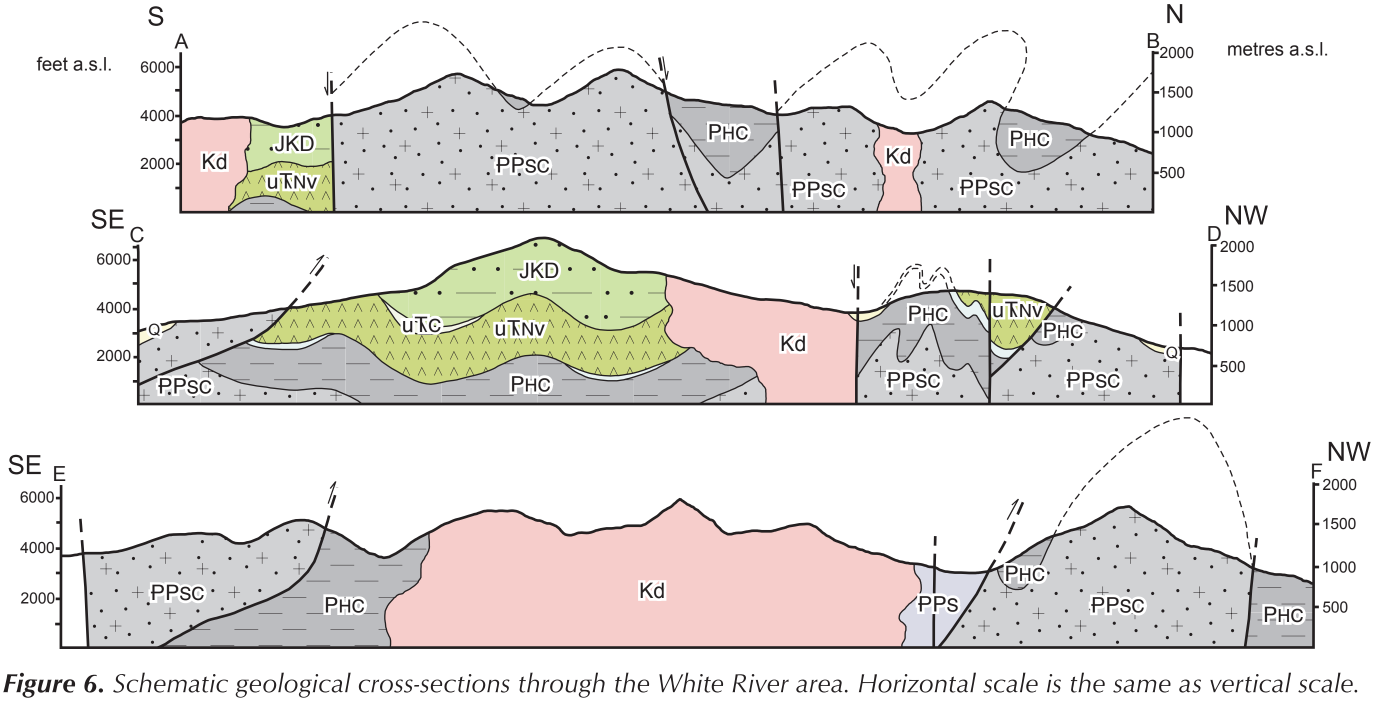

Figure 6. *Schematic geological cross-sections through the White River area. Horizontal scale is the same as vertical scale. Locations of sections are indicated on Figure 2. See Figure 2 legend for unit descriptions. a.s.l. = above sea level.*

LATE TRIASSIC

Late Triassic deformation is related to uplift and extension during deposition of the Nikolai formation and intrusion of the Kluane mafic-ultramafic complex. Laterally discontinuous grabens are defined mainly by the presence of Middle Triassic strata and thick accumulations of basal conglomerate and breccia of the Nikolai formation. Middle Triassic and basal Nikolai strata always occur in proximity of a fault (Fig. 2; Read and Monger, 1976). The basal conglomerate and breccia are interpreted as syntectonic deposits related to graben formation. The faults bounding these grabens were extensively reactivated during younger deformation.

LATE JURASSIC-EARLY CRETACEOUS

Late Jurassic-Early Cretaceous compression has produced the main structures in the Kluane Ranges. Northeast and southwest-verging faults and folds occur along the entire belt of Wrangellia in southwest Yukon. In the White River area, several northwest-striking, southwest-dipping faults place older rocks over younger rocks (Fig. 2). These faults have also locally re-activated stratigraphic contacts (*e.g.,* Nikolai formation over Hasen Creek Formation). Tight, northeast-verging overturned folds and upright, open folds are well developed in the Skolai Group. Folds trend northwest and are refolded and offset by younger structures. In the Kluane Ranges, re-activation of thrust faults into strike-slip faults is indicated by nearly horizontal slickenside and fault-groove lineations. Timing of deformation postdates the Upper Jurassic-Lower Cretaceous Dezadeash Formation, but predates intrusion of crosscutting plutons of the Kluane Ranges suite.

LATE CRETACEOUS TO PRESENT

Post-Cretaceous deformation is associated with the development of the Denali fault system, which includes the Duke River fault. Post-Late Cretaceous dextral strike-slip displacement on the order of 350-400 km is interpreted along the Denali fault (Plafker *et al.*, 1989b; Lowey, 1998). However, fabrics developed in a mid-Cretaceous pluton along the Denali fault suggest a more complicated deformational history including sinistral, dextral and normal displacements (C. van Staal, pers. comm., 2007). Several parallel strike-slip faults, and kinematically linked extensional and compressional structures, were developed concurrently. Terrestrial sedimentary and volcanic deposits accumulated locally in transtensional and transpressional basins that developed along the Denali fault.

In the White River area, steeply dipping strike-slip faults juxtapose units of varying ages and crosscut earlier structures. The amount of offset and exact kinematics across the fault zones are difficult to assess due to a lack of marker horizons. The Miles Creek fault is the largest fault in the White River area after the Denali fault (Fig. 2). This fault is largely inferred based upon the juxtaposition of Dezadeash and Station Creek formations. This geometry implies a component of normal displacement along this fault. The White River intrusive complex is bounded both to northeast and southwest by steeply dipping fault zones (Fig. 2). These faults are defined by several metres of gouge and clay alteration and may be responsible for a significant landslide that occurred in a northeast-facing drainage near the south end of Miles Ridge (see Bond *et al.*, this volume).

Several north- to northeast-striking faults are inferred to occupy large valleys in the White River area (Fig. 2). The White River and Beaver Creek faults are two examples. There are no direct kinematic observations on these faults, but mapping relationships suggest normal displacement (east-side down) with minor strike-slip motion. Elsewhere in the Kluane Ranges, these large north-trending valleys are interpreted as the site of normal faults (J. White, pers. comm.). The relationship between these structures and the Denali fault is currently unknown.

Folds related to strike-slip faulting are steeply, north to northwest-plunging tight folds. Refolding of Late Jurassic-Early Cretaceous structures occurs in the Cottonwood Mountain area and along Miles Ridge (Fig. 2). In places, it is difficult to distinguish between Jura-Cretaceous folds and post-Cretaceous folds as deformation along the Duke River fault resulted in northwest-trending, northeast-verging folds affecting the Wrangell lavas and underlying strata (Ridgway *et al.*, 1992; Israel *et al.*, 2006).

MINERALIZATION

Several different styles of mineralization occur within the White River area (Fig. 2, Table 2; Yukon MINFILE[1], 2007). The most prominent targets for exploration have been magmatic nickel-copper-PGE mineralization associated with the Kluane mafic-ultramafic complex and copper-gold porphyries related to Early Cretaceous granitic intrusions.

Here we discuss briefly the White River complex and mineralization associated with the ultramafic rocks. The

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[1] *http://www.geology.gov.yk.ca/databases_gis.html*

reader is referred to Hulbert (1997) for a more complete description of the deposits and mineral occurrences related to the Kluane mafic-ultramafic complex. The Canalask deposit occurs in the Hasen Creek Formation, near an ultramafic body, just east of the White River. Historical reserves are calculated at 390 232 tonnes grading at 1.35% Ni (Yukon MINFILE[2], 2007). High-grade showings at the northwest end of the ultramafic body (Discovery and Onion showings) include samples assayed at 4.69% Ni, 0.8% Cu and 6.83 g/t PGE, and 27.4% Ni and 30.61 g/t Au.

In the White River area, skarns are developed in association with Early Cretaceous granitic plutons and dykes that intrude the Upper Triassic Chitistone Limestone and Nikolai formation. The Arn property, located near Mount Taylor, has undergone the most exploration to date and contains copper and gold mineralization. Drilling in 2002 by ATAC Resources Ltd. intersected 12.67 m of mineralized skarn grading 11.92 g/t Au and 0.22% Cu, including a 1.98 m interval of 64.42 g/t Au and 1.16% Cu (Yukon MINFILE[2], 2007).

CONCLUSIONS

The White River area is underlain by upper Paleozoic to Upper Triassic volcanic, sedimentary and intrusive rocks of Wrangellia; these are overlain by Jura-Cretaceous overlap assemblages. All strata are intruded by granitic plutons of the Early Cretaceous Kluane Ranges Suite.

Several phases of deformation have resulted in structural stacking and dissection of units into northwest-trending, mainly fault-bounded belts. The main deformational episodes include Late Triassic extension, Late Jurassic to Early Cretaceous northeast compression, and prolonged Late Cretaceous to present strike-slip faulting with associated extension and compression. Northeast-verging overturned folds related to Jura-Cretaceous deformation are refolded by steeply plunging tight folds associated with post-Cretaceous strike-slip faulting.

Mineralization associated with ultramafic bodies is widespread, including the Canalask nickel-copper deposit. Several copper-gold porphyry showings and prospects associated with the Early Cretaceous Kluane Ranges suite are found in the western part of the White River area and need further investigation.

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[2] *http://www.geology.gov.yk.ca/databases_gis.html*

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