Ground penetrating radar investigation of the upper Yukon River valley between White River, Yukon and Eagle, Alaska

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ABSTRACT

Ground penetrating radar (GPR) profiles were collected along mid-channel and side-channel bars from the confluence of the Yukon and White rivers in the Yukon, to Eagle, Alaska, a distance of 270 km. These profiles, although preliminary, demonstrate little variation in the thickness of valley-fill gravel (depth to bedrock) over that distance. Surveys show little difference in gravel thickness between the largest sediment source (White River) and more distal downstream reaches. The average thickness is approximately 10 m, which is equivalent to the maximum scour depth of the river. GPR surveys across the Tintina Fault along the Yukon River indicate a similar depth of fill compared to the upstream and downstream reaches from the fault zone, suggesting no significant recent vertical movement. These observations, when combined with the uplift history of the region (rates of 50-70 mm/ka determined in the Klondike area), suggest the region is likely undergoing either very slow uplift or is stable. No differential uplift is detectable within the error limits and sampling density of the GPR valley-fill method used in this study.

RÉSUMÉ

Des profils géoradar (PG) ont été recueillis sur les barres de mi-chenal et riveraines entre la confluence du fleuve Yukon et de la rivière White, au Yukon, et Eagle, en Alaska, soit sur une distance de 270 km. Bien que préliminaires, ces profils montrent que l'épaisseur du gravier comblant la vallée (profondeur au socle rocheux) varie peu sur cette distance. Les relevés indiquent que l'épaisseur du gravier varie peu entre la plus importante source de sédiments (la rivière White) et les tronçons aval plus éloignés. L'épaisseur moyenne est approximativement de 10 m, ce qui est équivalent à la profondeur d'affouillement maximale du cours d'eau. Les levés d'établissement de PG sur la faille de Tintina, le long du fleuve Yukon, indiquent une profondeur de comblement similaire à celles observées en amont et en aval de la zone faillée, ce qui suggère qu'il n'y a eu récemment aucun déplacement vertical important. Lorsque combinées à l'histoire du soulèvement de la région (vitesses de 50 à 70 mm/ka déterminées dans la région du Klondike), ces observations suggèrent que la région subit vraisemblablement un soulèvement très lent ou bien qu'elle est stable. Aucun soulèvement différentiel n'est détectable, au delà des limites d'erreur et de la densité d'échantillonnage, au moyen de la méthode PG utilisée dans la présente étude.

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INTRODUCTION

Timing and magnitude of late Cenozoic crustal movements in west-central Yukon have been poorly understood when reconstructing the geomorphic history of the Yukon River valley and its gold-bearing tributaries. Whether terraces along the Yukon River and its tributaries were produced by either large-scale regional uplift, or more localized uplift or subsidence (e.g., normal faulting, Tintina graben) has significant implications for the construction of new exploration models of placer gold deposits. This paper is a summary of GPR data collected along the Yukon River in west-central Yukon as part of a Ph.D thesis on the Plio-Pleistocene history of the Yukon River in western Yukon and central Alaska.

Previous investigations of the upper Yukon River in west-central Yukon have suggested that large-scale regional uplift downstream of the Dawson area during the Pleistocene may have resulted in the displacement of terraces by as much as 240 m (Hughes, 1970; Hughes et al., 1972; Fuller, 1995). This hypothesized regional tilting has been suggested to explain the presence of downstream terraces which occur at higher levels, than what have been argued to be their upstream equivalents (Hughes et al., 1972; Fuller, 1995). Alternatively, models of a southerly flowing Yukon River (opposite to the present-day flow direction), rerouted to the northwest by an advancing southern ice sheet, has been suggested to account for these terrace elevation differences (Tempelman-Kluit, 1980). This paper is a preliminary report of results of a geophysical survey of the modern Yukon River valley-fill between the White River/Yukon River confluence and Eagle, Alaska. The purpose of this survey was to determine the present influence of tectonics on the modern Yukon River, and in particular, whether evidence of past regional tectonism was present in the form of mappable variations in the valley-fill of the upper Yukon River.

REGIONAL SETTING

The study reach of the Yukon River is located within the Yukon-Tanana upland, corresponding to the Yukon-Tanana Terrane in western Yukon. The study reach begins at the confluence of the Yukon and White rivers, and continues to where the Yukon River intersects the Tintina Fault, near the border of Alaska (Fig. 1). The Tintina Fault is a zone of Late Cretaceous to early Tertiary dextral strike-slip displacement by as much as 450 km (Gabrielse, 1985). This fault separates highly metamorphosed rocks of the Yukon-Tanana Terrane to the southwest, from sedimentary strata of the Selwyn Basin to the northwest (Tempelman-Kluit, 1980). The Tintina Trench is a more recent (late Tertiary) graben developed along the Tintina Fault (Tempelman-Kluit, 1980).

Physiographically, the Yukon-Tanana upland is a largely unglaciated, gently sloping plateau, consisting of concordant summits, which are connected by ridges and separated by deeply incised v-shaped valleys. This plateau is considered an uplifted erosional surface produced from extensive sub-aerial erosion in the early-mid Tertiary. Tempelman-Kluit (1980) hypothesized that during this time, a south-flowing paleo-Yukon River existed, connecting the area north of the Tintina Trench with the Pacific Ocean. He argued that southerly drainage of the plateau may have persisted through uplift of the southwestern Yukon ranges, and was likely diverted to the northwest by the advance of late Cenozoic ice sheets.

APPROACH TO CHARACTERIZING RECENT CRUSTAL MOVEMENTS

The approach adopted in this study to characterize vertical movements along the Yukon-Tanana upland is based on the simple assumption that relative uplift or subsidence along the river valley will result in variable thickness of the alluvial fill. That is, the valley-fill will be thinnest over areas of active uplift and thickest over areas of subsidence; furthermore, the influence of these variations may be mapped using ground penetrating radar (GPR) in order to examine any upstream or downstream influences. A second objective was to use the GPR valley-fill data to determine whether the modern valley might intersect a portion of the southerly flowing pre-glacial Yukon River valley. This would be indicated by a deepening valley-fill to the south. The third objective was to look for vertical displacement of the Tintina Fault where it crosses the Yukon River.

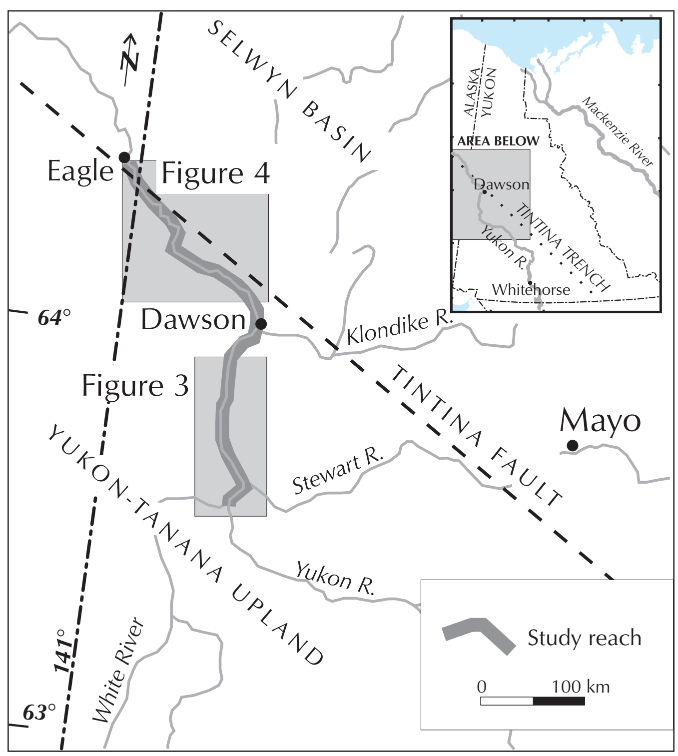

Figure 1. *Study reach of Yukon River in west-central Yukon. Grey boxes correspond to more detailed maps in Figures 3 and 4.*

YUKON RIVER

The Yukon River drains an area of nearly 300 000 km^2 (upstream of Eagle, Alaska), representing roughly 60% of the Yukon Territory (Fig. 1). The Donjek and White rivers, originating in the St. Elias Range, provide the largest single sediment source in the upper Yukon River basin. In contrast to most rivers in Canada, the Yukon River has a relatively simple valley morphology. Most valleys in the Canadian Cordillera were strongly affected by late Quaternary glaciation, resulting in diversion of drainages (e.g., Duk-Rodkin and Hughes, 1994), complex valley fills with multiple depositional environments, or distribution of Quaternary sediments that the rivers may still be adjusting to (e.g., Church and Slaymaker, 1989). The study reach of the Yukon River, between the White River/Yukon River confluence, and the Alaska border, has been in its present position for at least the last 2.6 Ma (Froese et al., in press), and in addition, is outside the furthest limit of glaciation in western Yukon (Duk-Rodkin, 1999).

Rates of Quaternary uplift are poorly understood in the Cordillera, but have been documented from the record of fluvial incision in the Dawson area. On the basis of incision of terraces by the Klondike River near its junction with the Yukon River, rates of 40-50 mm/ka are estimated over the last 2.6 Ma and an average rate of <75 mm/ka over the last 40 ka (Froese, 1997). These rates would suggest that if the rate of lateral migration and erosion by the river is even moderate, the valley fill should be relatively uniform, and bedrock relief should be low. This would indicate that variations in the bedrock profile (a potential source of error in using valley-fill thickness as an indicator of uplift/subsidence) should be minimized. This last assumption appears to hold true, since reports from drilling of the Yukon River channel near the Dawson area show relatively uniform valley depth (2 m of relief). Vertical relief in any GPR profile in a main valley setting did not exceed that value (Yukon Territorial Government, Geotechnical Services report, unpublished; McKinney, 1974).

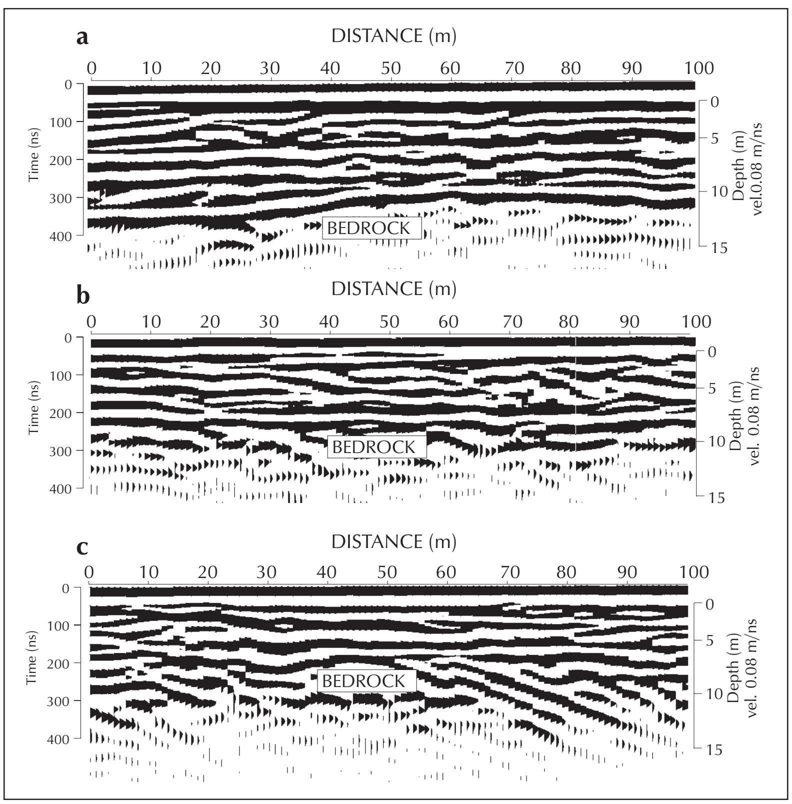

***Figure 2**. Typical bedrock profiles imaged with GPR along the Yukon River. a) 25 MHz survey along mid-channel bar upstream of Fortymile River (km 75, Fig. 4). Profile shows prominent reflector (bedrock) at 350 ns, ~11-12 m depth. b) 25 MHz profile at mouth of Coal Creek (within the Tintina Fault zone). Profile shows prominent reflector at 225-250 ns, ~8 m depth. c) 25 MHz survey along mid-channel bar near km 40, immediately downstream of Tintina Fault intersection with Yukon River. Profile shows prominent reflector at approximately 200-225 ns, with refracted reflections below ~7-8 m depth.*

METHOD

A pulseEKKO IV radar system in reflection survey mode with antennae frequencies of 25, 50, and 100 MHz were used with a 1000-volt transmitter. Profiles 100 to 500 m long were collected at mid-channel bars and along channel edges within 0.5 m of the water table. Each location (vertical trace on profiles) was vertically stacked 64 times with a sampling rate of 1600 picoseconds. Profiles were processed and plotted using pulseEKKO IV (software with constant gain), and an average near-surface velocity of 0.08 m/nanosecond was determined by common mid-point survey at all profiles. Surveys were conducted during 1998 and 1999 field seasons.

GPR works similar to seismic methods with the major difference being that it uses an electromagnetic (EM) rather than an acoustic energy source. A number of detailed accounts provide a review of the theory and methodology behind GPR that is beyond the scope of this paper (Annan and Davis, 1976; Ulriksen, 1982; Daniels et al., 1988). In a GPR survey, short bursts of high frequency EM energy (generally 10-1000 MHz) are transmitted into the ground. Where there are changes in the electrical properties of subsurface materials, reflections of energy are returned which are detected at the surface. This effect enables subsurface stratigraphy to be inferred from the character of the radar return signals. Variations in the dielectric properties of the subsurface results in a return signal that is proportional to the electrical contrast, allowing the contact between bedrock and the alluvial gravel of the Yukon River to be generally well-defined (Fig. 2).

In resistive, coarse-grained materials (e.g., coarse gravel free of silt or clay matrix), depths of penetration up to 70 m may be attained at low frequencies (12.5 MHz; Smith and Jol, 1995).

Three typical profiles collected with 25 MHz antennae are shown in Figure 2. Each profile is processed using a deconvolution filter and amplified by a constant gain. In each profile, bedrock can be reliably interpreted from a high-amplitude reflector occurring between 200 and 350 ns. Below the high amplitude reflector, the signal is refracted and loses its flat-lying to low-angle character.

LONGITUDINAL TRENDS ABOVE DAWSON CITY (WHITE RIVER TO DAWSON CITY)

From the confluence of the White and Yukon rivers, to the mouth of the Klondike River (a distance of approximately 120 km; Fig. 1), the Yukon River shows a changing surface morphology with distance from the White River. The upstream reach consists of unstable gravel braid bars and channels, changing to more stable forest-covered islands separated by braided channels. In this reach we wanted to know: (1) what is the variability in valley-fill thickness; and (2) could the pre-glacial (hypothesized south-flowing) Yukon River valley be imaged below the modern river channel bed.

GPR profiles were collected from the Yukon River above the White River (km 265), at the mouth of White River, and 7 more downstream between kilometres 250 and 160 (Fig. 3). Rather than a downstream thinning of gravel from the mouth of White River, sediment thickness was relatively uniform and within the error limit of the GPR method (discussed below). These depths coincide approximately with the maximum scour depth of the river in each reach. The only significant sediment thickness variation (about 6 m) occurs at the mouth of the Stewart River, immediately below the confluence of the Stewart and Yukon rivers at km 240. This sort of variation was anticipated because deep scour holes commonly occur at channel confluences. Other than the Stewart River, the other main gold-bearing tributaries (Sixtymile, Indian and Klondike rivers) show no variations in their base level control.

The hypothesized paleo-divide of the pre-glacial Yukon River has been suggested to occur within western Yukon between the Fortymile and Fifteenmile rivers, located approximately 150 km northwest of the White River/Yukon River confluence (Tempelman-Kluit, 1980; Duk-Rodkin, 1997). Assuming a conservative slope of 1m/km for the paleo south-flowing Yukon River, this would suggest a decrease in elevation of the ancient valley floor toward the White River. Near Dawson City, the Pliocene bedrock surface is about 100 m above the present river level. This suggests that 100 km to the south, it should be near the intersection point with the modern river valley floor (assuming no differential uplift of the southerly region relative to Dawson City). If this was the case, and the paleo Yukon River valley were encountered, a deepening of the valley-fill in the direction of the paleo river would be expected (to the south). The GPR data show no evidence of any deeper fill to the south, suggesting that either the slope assumption of the river is too high, or differential uplift has occurred during the Plio-Pleistocene relative to Dawson City. Additional data from further south, and/or independent age control of terraces near the junction is required to resolve this question.

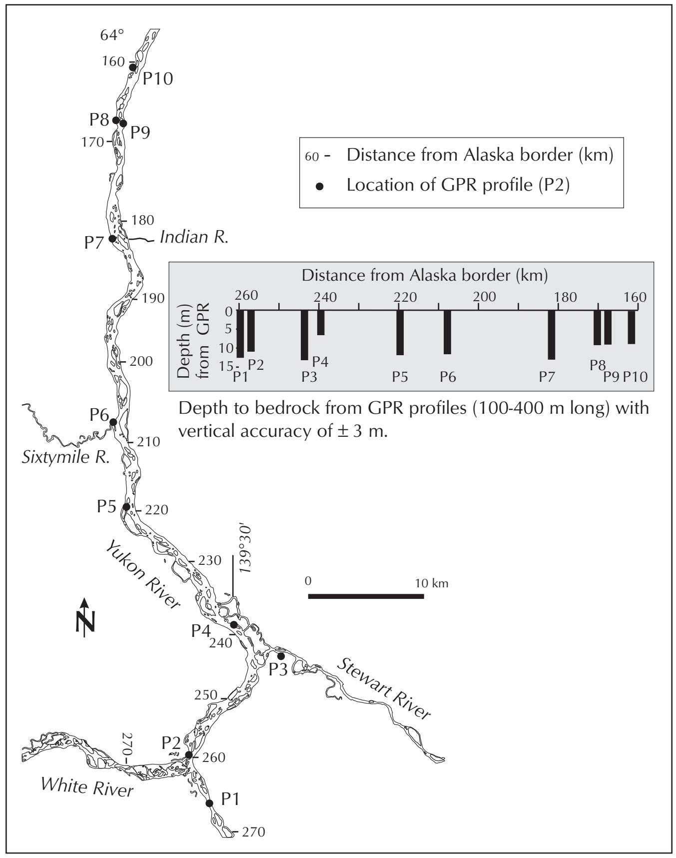

Figure 3. *Location of White River confluence with Yukon River, and GPR survey positions along the upstream reach, descending down river to near Dawson City. Depth to bedrock GPR profiles: The only significant deviation in the profile is about 6 m at the mouth of the Stewart River between P3 and P4. The upper White River gravel thickness is no different from the rest of the Yukon River.*

LONGITUDINAL TRENDS, DAWSON CITY TO EAGLE, ALASKA

A second objective of this study was to examine recent channel-bed changes along the Tintina Fault (as it intersects the Yukon River) to determine recent vertical movement, and its zone of influence. Interest in the Tintina Fault stems largely from a number of suggested connections between the graben and models for the origin of the Klondike goldfields. Tempelman-Kluit (1980, 1982) suggests that development of the Tintina graben resulted in a drop in local base level, which was transferred upstream to the Klondike River valley, and caused the incision and preservation of White Channel gravel in the late Pliocene. This, arguably, could have been conceivable in either the southerly pre-glacial drainage configuration of Tempelman-Kluit (1980), or in the present Yukon River position. In order to look at the feasibility of these arguments, and determine if there may be a present-day analogue for the goldfields, a series of depth to bedrock measurements were surveyed over the long profile of the Yukon River between the Klondike River junction and Eagle, Alaska.

If vertical deformation is occurring along the Tintina Fault zone, then a greater depth to bedrock would be expected over the zone of deformation, thinning upstream to the undisturbed reach. Unexpectedly, GPR profiles imaged above and below the fault zone show no increase in the depth to bedrock (Fig. 4). A modal value of approximately 11 m occurs between km 20 and km 55, which is no different from the upstream profiles at km 75 and km 90. These data strongly suggest that vertical movement of the Tintina Fault has not recently (late Quaternary) occurred, however, some horizontal movement could still be accommodated within the dataset.

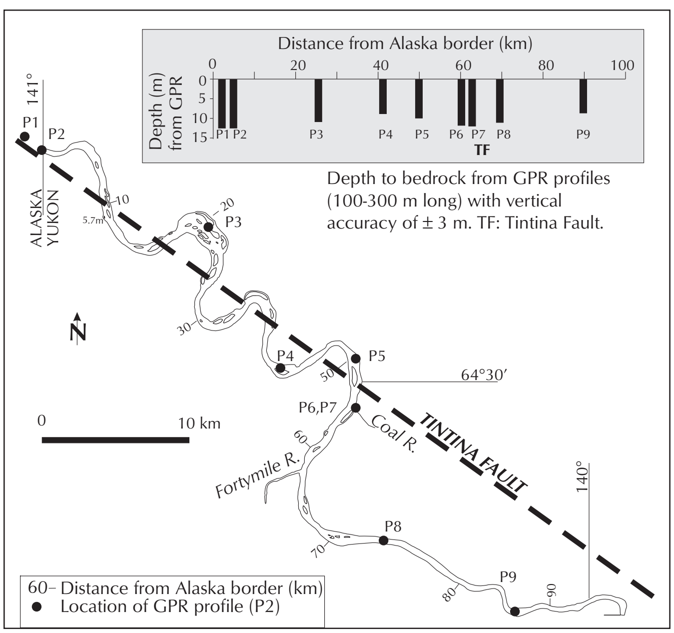

Figure 4. *Location of Tintina Fault at intersection with the Yukon River and GPR profiles collected in the area. Within the vertical accuracy of the GPR method (+/- 3 m), there is no difference in valley-fill thickness between upstream, downstream, and within the Fault area, indicating no significant recent vertical movement.*

DISCUSSION

In this study, a conservative vertical error of ± 3 m has been assigned to the representativeness and confidence of vertical GPR measurements. This was established on the basis of: (1) wavelength of induced wave (frequency of 25 MHz), giving a minimum vertical resolution of approximately 1 m (assuming all coarse, saturated gravels have the same radar wave propagation velocity of 0.08 m/ns); and (2) the vertical relief of bedrock (2 m) along any single valley cross-section. The vertical relief of bedrock was determined from both borehole data at Dawson City (Yukon Territorial Government Geotechnical report, unpublished, McKinney 1974), and the measured bedrock contact from approximately 5000 m of GPR data collected in this study.

The remarkable similarity in depth-to-bedrock over the 270 km of river investigated indicates that external forces on the river (primarily tectonism, investigated in this paper) are not readily apparent. The possibility that the thin valley-fill of the Yukon River is the result of active uplift of the Yukon-Tanana upland can be partially rejected by the low uplift rates calculated in the Klondike area. These low rates, coupled with the similarity of valley-fill-depth GPR results along the 270 km reach, suggest an equivalent process may be occurring along the entire study reach. However, this conclusion must be forgone until better uplift rates can be determined at additional sites along the Yukon River.

The lack of encountering a south-flowing pre-glacial valley-fill in the upper Yukon River is somewhat surprising. Projection of a slope of 1m/km to the south for the pre-glacial Yukon River would suggest an intersection point with the modern valley-fill in the vicinity of the Stewart/White rivers. However, it is not precisely known whether the paleo-Yukon River flowed south in its present valley south of Stewart River, or flowed toward the Tintina Trench via the present-day Stewart River valley (Fig. 1). If the latter is the case, additional GPR data along the Stewart River should be collected to test pre-glacial drainage reconstruction models.

The lack of variation in valley-fill thickness across the Tintina Fault suggests little recent vertical movement in the area. This observation is consistent with a lack of tilting of Plio-Pleistocene strata exposed in the Tintina Trench to the east (A. Duk-Rodkin, pers. comm., 1999). This does not necessarily indicate a lack of seismic activity in the area. Fault scarps up to 3 m are known to intersect Reid-age (ca. 200 ka) outwash near the Dempster Highway (Mortensen and von Gaza, 1993). In addition, the prevalence of landslides within the trench may suggest some recent fault activity (Mortensen and von Gaza, 1993).

CONCLUSIONS

- GPR profiles collected over 270 km of the upper Yukon River show little variation in the depth to bedrock between the White River, Yukon and Eagle, Alaska.
- The consistency of depth-to-bedrock measurements coupled with measured uplift rates in the Klondike area suggest a model of low uplift (~50-100 mm/ka) may be appropriate at a regional scale.
- No evidence of southerly flowing pre-glacial Yukon River was found in the southern portion of the study reach.
- There is no evidence of vertical displacement of the Yukon River across the Tintina Fault.

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