Appendix A:
Regional Geology, Geoarchaeology, and Artifact Lithologies from Benson Island, Barkley Sound, British Columbia

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Introduction

This paper considers the lithologic character, geological context, and archaeological significance of artifacts and possible artifacts recovered from the Ts'ishaa site, from both the Main Village and Back Terrace areas. The west coast of Vancouver Island is complex in terms of bedrock geology and has also been glaciated, therefore a wide variety of lithic materials is locally available. Through glacial and fluvial action they are often found in combination in detrital deposits. Reliable identification of artifact lithology and probable lithic sources depends upon an understanding of regional geology as well as proper interpretation of the relationships between metamorphic and igneous rocks. Inasmuch as thin-sectioning for microscopic work was not feasible for this sample, identifications were made on the basis of hand-specimen examination, the limitations of which are outlined below. The Ts'ishaa sample includes examples identified as basalt, andesite, gabbro, diorite, granodiorite, granite, obsidian, slate, phyllite, schist, biotite gneiss, nephrite, hornfels, quartzite, chert, argillite, sandstone (greywacke), and jet.

Discussion of Rock Types and Identification Problems

Rocks fall into three major groupings: igneous, sedimentary, and metamorphic. Subdivision of rock types in these major classes is based upon (1) *texture* and (2) *composition*. Texture combines two considerations: (1) *granularity/crystallinity*, the size and shape of constituent minerals and/or particles making up the rock, and (2) *fabric*, the arrangement, orientation and geometrical relationships among the constituents of the rock and, where relevant, the degree of glassiness. Whereas "composition" in minerals is the chemical formula, in rocks the term refers to the *percentage occurrence* of the various minerals. Thus most rock types are arbitrarily divided segments of a continuum, analogous to segments of the colour spectrum, and there can be as many occurrences on a boundary between adjacent categories as there are in the "centre" of any category. It is therefore not surprising that a geologist may experience difficulty in putting a "precise" name on a rock. Rock in a single outcrop may grade compositionally from one type to another (*e.g.*, from granite to granodiorite). In fact, that could happen within a single hand specimen, if an analyst were to measure percentage composition carefully in several areas of the specimen. The same is true of texture because these characteristics, too, are continuously variable. In practice, a geologist must therefore name a specimen based upon an "averaged" impression of its overall characteristics. For certain rock types it is not possible to give a full diagnosis without some knowledge of larger-scale contextual features. Migmatites and agmatites, for example, exhibit mixing of textural types, either through partial melting or incomplete mixture of magmas, and their true nature is best assessed from outcrops.

Determination of "sources" from an archaeological perspective also demands comparable understandings of geological context. For example, sedimentary rocks identified as breccia and conglomerate include clasts (transported grains) of varied provenance and lithologies so that a large basalt clast (igneous) might have been derived by a flintknapper not from its original igneous setting but from a gravel deposit or even from a conglomerate derived from the lithification of a gravel deposit.

A continuum also exists between metamorphic rocks and their protoliths (rocks of origin), such that it may be difficult to find unanimity among analysts as to the name of a rock specimen. Such disagreements are, however, of minor consequence. Mudstones (sedimentary) become metamorphosed to slates and thence to phyllites and schists; however, the hazy zone between sedimentary and metamorphic rocks is the domain of "argillite." Reports from the region under consideration use the terms "mudstone" and "argillite" interchangeably because of the low grade of metamorphism represented.

Direct visual examination is frequently sufficient for identification of the general type of rock (*e.g.*, granite, volcanic tuff, sandstone, chert, etc.) used for stone artifacts. However, in order to identify the precise source of the rock, a much closer determination of texture and composition using more sophisticated means must be undertaken. Petrological examination under a binocular microscope may be sufficient to reveal both, but in other cases a petrographic thin section may be necessary to allow such determinations. The overall appearance of a rock sample is suggestive of a given texture and composition, but actual percentages, grain relationships and estimates of glassiness require grain-by-grain examination of minerals and/or contained rock fragments (clast composition). Thus there is no "diagnostic test" for a particular rock type. The diagnoses reported below were made from hand specimens under low magnification, with limitations of both time and access to the material. Thin-sectioning was not feasible and all identifications are offered as provisional estimates. The categories selected are accordingly in some cases broader than those used in comparable reports by other authors.

Vancouver Island Bedrock Geology

British Columbia is situated on the western margin of the North American tectonic plate and this is, in terms of plate movements, the "leading edge" of the continent. Much of the geology of British Columbia is therefore tied to activity along the plate margin. Offshore from southern British Columbia, including Vancouver Island, the margin is a subduction zone, with oceanic crust slipping beneath the continent at a steep angle (Hyndman *et al.* 1990). Partial melting of rocks in this subducted plate provides magma that feeds the linear Cascade Volcanic chain, inland from the coast. This same magma source has also produced, in the past, major intrusive bodies or batholiths of felsic (silica-rich) igneous rocks such as granite and granodiorite. North of Vancouver Island the plate margin becomes a transform boundary; that is, it has strike-slip or lateral movement. Given the dynamic setting it is understandable that activity along the plate margin has been different in the past.

Through much of British Columbia one sees a history of augmentation of the North American plate through collision with, and accretion of, formerly separate island arcs, uplifted ocean floor fragments, and microcontinental masses. These "exotic terranes" had their own distinctive geological histories before joining the North American plate, whereas after their docking they shared in the subsequent geological history (Clowes *et al.* 1987; Hyndman *et al.* 1990; Gabrielse *et al.* 1991; Monger *et al.* 1982, 1991; Tipper *et al.* 1991; Wheeler *et al.* 1991; Wheeler and McFeely 1991; Monger 1993; Monger and Journeay 1994, 1998; Journeay and Monger 1998).

Vancouver Island makes up the major part of the Insular Belt, one of the westernmost of several geologically distinct elements of the Canadian segment of the Cordillera, and in plate-tectonic terms is dominated by the Wrangellia terrane (Brandon 1989a:1521; Monger 1993). The geological history of the Insular Belt includes both the history of Wrangellia before its "docking" with North America and its history subsequent to docking. This history is marked by two igneous complexes, each of which includes both volcanic units and associated plutonic masses (intrusions, such as batholiths) (Carson 1973; Muller 1980a, b). The two complexes, respectively, are of middle Paleozoic and Jurassic ages, the latter being much more extensive than the former, and were preceded by a metamorphic (gneiss-migmatite) terrane. Each complex is topped by an erosional unconformity and overlain by clastic sediments, respectively of Permo-Pennsylvanian and Cretaceous ages. In the first sequence, the Paleozoic (Late Devonian) Sicker Group represents a volcanic island arc with lavas, tuffs, and sedimentary rocks that were subsequently metamorphosed. The island arc sequence was eroded to a lowland and was succeeded by Carboniferous to Permian clastic and carbonate sediments (Buttle Lake Group) and local Triassic argillites (Monger and Journeay 1998, part 2:1). This sequence was rifted apart in the Triassic (Muller 1980a, b), when new basaltic lava was extruded, at first under water (as pillow lavas) and then onto an emerging land mass, likely a large oceanic platform (Muller 1980b:6; Monger and Journeay 1998, part 2:1). The Triassic basalts (Karmutsen Formation) were then carpeted with marine carbonates (Quatsino Formation) and clastic sediments (Parsons Bay and Harbledown Formations). The second igneous complex was emplaced in the Jurassic period when a new chain of volcanoes appeared. This time the volcanic rocks ranged from basalt through andesite to dacite, suggesting a volcanic chain alongside a subduction zone. These rocks, comprising the Bonanza Group, were in turn eroded and were covered by Cretaceous marine sediments (Muller 1980b:6–7). The sequence was then covered along the west coast by Tertiary clastic sediments. Smaller intrusions (plutons) of Tertiary age are also present as part of the Coast Plutonic Complex (Late Cretaceous and Tertiary), which is better represented on the British Columbia mainland (Monger *et al.* 1982). Wrangellia docked with the North American plate in mid-Cretaceous times (Monger and Journeay 1998, part 5:1).

Small areas of Vancouver Island's west and south coasts are linked to a "Pacific Belt" of Mesozoic mélange units (heterogeneous, sheared assemblages of rocks of mixed origins), more extensively represented in Alaska and the western states of the continental U.S. This belt locally comprises narrow fault slices such as the Pacific Rim Complex, Pandora Peak unit, and Leech River schist (Brandon 1989a: 1521–1522) that, in contrast to the Insular Belt, are made up of deformed late Jurassic and Cretaceous continental slope and possible trench deposits (clastics, chert and tuff, some metamorphosed to schist), bounded to the south and west by Eocene oceanic basalts and associated intrusives of mafic igneous rocks (i.e., dominated by dark ferromagnesian minerals) (Muller 1977a:Sheet 3; Hyndman *et. al.* 1990:315; Monger and Journeay 1998, part 2:2). Muller (1977b) interpreted portions of this assemblage as oceanic trench deposits and they have at times been assigned to distinct exotic terranes (Pacific Rim/Leech River and Crescent terranes) associated with subduction underplating along the west ("outboard") margin of the Wrangellia terrane during the Eocene epoch (Clowes *et al.* 1987). The Pacific Rim terrane extends along the west coast of Vancouver Island, largely offshore, but includes a small portion of the coast north of Barkley Sound (separated from Wrangellia by the West Coast Fault) and an east-west trending band near the southern end of Vancouver Island (bounded to the north from Wrangellia by the San Juan Fault and to the south from the Crescent terrane by the Leech River Fault). The Crescent terrane makes up a second narrow band offshore from the Pacific Rim, but also makes up the extreme southern tip of Vancouver Island, south of the Leech River Fault (Hyndman *et al.* 1990:315). Brandon (1989a, b) disagreed with the identification of these bands as terranes, reinterpreting them as mélanges produced by submarine slumping onto an older volcanic basement. He argued that they were formed in the Washington State area on the "inboard" side of Wrangellia prior to its docking and then were displaced northwestward to a location west of a portion of Wrangellia by faulting (lateral, or transcurrent offset). The terrane view appears, however, to have prevailed (*e.g.*, Monger 1993).

Based upon this overview, potential bedrock lithic types on western Vancouver Island include a full range of igneous intrusives (from granite to gabbro) and extrusives (from rhyolite to basalt), metamorphics from low to high grade (argillite through schist to gneiss), and both clastic and carbonate sedimentary rocks (sandstone, shale, limestone, chert). Not only do they occur as bedrock outcrops, but these rock types can also be expected to occur widely as redeposited clasts up to cobble or even boulder size in surficial deposits of glacial, fluvial, and other origins.

Barkley Sound Area Bedrock Geology

Islands in Barkley Sound display bedrock of the Wrangellia terrane, with the West Coast Fault crossing the mouth of the Sound and with Pacific Rim and Crescent terrane rocks forming bands offshore, separated by the Tofino Fault (Hyndman *et al.* 1990:315). Local Wrangellian rocks include limestones of the Upper Triassic Quatsino Formation, Jurassic mafic intrusives and metamorphics of the Westcoast Complex (hornblende-plagioclase gneiss, quartz diorite, agmatite, amphibolite), and younger Jurassic felsic intrusives of the Island Intrusions (granodiorite, quartz diorite, granite, and quartz monzonite) (Carson 1973). Agmatite is a breccia-like migmatite produced by incomplete mixing of coeval mafic and felsic magmas. Bedrock in areas immediately around Barkley Sound also includes Triassic volcanics of the Karmutsen Formation (basalts up to 6 km thick, pillow lava, breccia, and tuff), Jurassic volcanics and clastics of the Bonanza Group (basaltic through andesitic to rhyolitic lava, tuff, breccia, minor argillite, and greywacke), and Tertiary felsic intrusives of the Sooke Intrusions (quartz diorite, trondhjemite, agmatite, and porphyry). Even greater diversity of rock types is found within a few tens of kilometres away from the Sound (Carter 1973:442; Muller 1977:Sheet 2; Monger and Journeay 1998, pt. 2:1). Tertiary sediments are found locally on the coastal plain, capping the sequence described above, and form a widespread unit offshore in the Tofino sedimentary basin, which extends almost to the end of the continental shelf. These sediments are generally mudstones and sandstones of Eocene to Pliocene age (Carter 1973:442). Northward from Ucluelet through Tofino to Vargas Island a narrow band of rocks of the Pacific Rim Complex is exposed and is separated from the Wrangellian rocks by the West Coast Fault (Brandon 1989:1523; Hyndman *et al*. 1990:315).

The outermost islands within the Sound are underlain by the Quatsino Formation and the Westcoast Complex, so local rock types in the Broken Group should include limestone and chert as well as intrusive igneous rocks (quartz diorite and agmatite) and metamorphics (hornblende-plagioclase gneiss and amphibolite). Limestones in the Barkley Sound area tend to be highly altered from the influence of nearby intrusions. Quatsino Formation limestones are dominantly calcilutites (i.e., carbonate muds) with ammonites and other fossils and the formation represents shallow-water continental shelf deposition, representing a large oceanic platform with minimal siliciclastic input (Monger and Journeay 1998, pt. 2:1). Any chert in these rocks would be of replacement origin (diagenetic) rather than being of primary precipitation, and therefore could be diagnosed as such using thin sections. On Cree, Howell, Wouwer, Benson and Clarke Islands in the Broken Group, complexly deformed and metamorphosed but still well-bedded limestones and silty argillites are in contact with Westcoast Complex amphibolite-gneiss (Muller 1974:21). Nearby, where the Quatsino limestones come into contact with the intrusives (quartz diorite), the limestones are altered into coarse marble and skarn (lime-bearing silicates) (Dolmage 1920:15B; Carson 1973:7). Associated diorite and granodiorite dikes are metamorphosed to gneisses that exhibit garnet, tremolite and actinolite (Dolmage 1920:15B). Karmutsen volcanics have also been influenced locally by contact metamorphism (Kunioshi and Liou 1976). Migmatitic rocks of the Westcoast Complex underlie most of the islands of Barkley Sound and a coastal strip about 8 km or more wide between Bamfield and Port Renfrew (Muller 1974:21). These rocks began as sediments and volcanics of the Paleozoic Sicker Group and the Triassic Vancouver Group (which includes the Quatsino Formation) and were intensely deformed and recrystallized under heat and pressure at considerable depths to migmatites, some evolving further through partial or complete melting to become granitic rocks by the end of the early Jurassic. They include a range from agmatite and amphibolite gneiss to biotite-hornblende quartz diorite, often with several different textural types in a single outcrop. Usually, light-coloured quartz diorite or granodiorite intrudes dark fine-grained amphibolite, diorite or gabbro (Muller 1974:21). Their deformation appears to have been tied to the history of a volcanic island arc that was distinct from the North American plate. Once the arc (as part of Wrangellia) was accreted to the leading edge of the North American plate, these rocks underwent uplift and erosion to expose the intensely deformed rocks of the intrusive "roots" of the arc (Muller 1977:Sheet 3).

The Pacific Rim Complex may extend under a portion of Barkley Sound but is well represented by outcrops not far to the north (Ucluelet to Vargas Island). As a mélange, the sequence includes a wide variety of sedimentary lithologies as blocks of various sizes and shapes in a finer-grained matrix. The sequence is resolved into three units: (i) the Ucluth Formation, lower Mesozoic arc-volcanics; (ii) unit 1, Lower Cretaceous mudstone-rich mélange; and (iii) undated sandstone-rich mélange. The Ucluth Formation has been hydrothermally metamorphosed to the greenschist grade, with epidote, chlorite, calcite and white mica as metamorphic minerals, and has been cut by diorite intrusions. The name "greenschist" is a general term based upon the minerals present (especially chlorite) and is not restricted to schist as a rock type. From the metamorphism the Ucluth volcanics and associated intrusives tend to have a patchy green appearance from the epidote. The entire sequence has been affected by very low temperature – high pressure metamorphism (with prehnite, lawsonite, calcite and white mica) and is also extensively cut by dikes. The Ucluth Formation is taken to be "basement" rock coeval with the Karmutsen basalts and Quatsino limestone of Wrangellia and consists of fragmental volcanics with interbeds of limestone and rare ribbon chert. Unit 1A is dominated by black mudstone but includes interbeds of chert, sandstone, and green tuff as well as exotic blocks, mostly derived from the Ucluth Formation but also including Jurassic pillow basalt and rare ultramafite (serpentinized clinopyroxenite). Unit 1B, which is laterally equivalent, is more chaotic with interbeds of mudstone, turbidite sandstone, conglomerate, pebbly mudstone, and rare ribbon chert. Unit 2, which overlies Unit 1 gradationally, is dominated by massive, thick-bedded sandstone with minor mudstone and rare ribbon chert and no exotic blocks (Brandon 1989a:1523–1526, 1528; 1989b).

Quaternary History, Landscape Evolution and Surficial Deposits

Vancouver Island is dominated geomorphically by the Island Mountains, which rise to elevations between 1,000 and 2,000 m. Most of the island was glaciated during the Pleistocene, with ice extending across the Georgia Depression from the mainland and, in the southern part of the Island, flowing in a generally southwestward direction (Clague 1989; Jackson and Clague 1991:276). Local icecaps on peaks in the Island Mountains gave rise to ice tongues that extended down valleys that are now fjords or are occupied by finger lakes. As a result of glacial scouring, the island's west coast is deeply cut by fjords and evidence of scouring extends beyond the modern shoreline onto the marine platform. Past ocean transgressions associated with isostatic depression reached more than 50 m above modern mean sea level, but sea-level lowering at the height of glaciation also exposed large areas of the continental shelf that are now submerged. Glaciation therefore also affected lands now below sea level, because they were above sea level near times of glacial maximum.

Barkley Sound, which is formed by the coalescence of several fjords, is continuous westward with glacially scoured basins and valleys on the continental shelf (Carter 1973). This means that glacial deposits such as tills and outwash are present or have been winnowed to gravel lag deposits on the continental shelf and would include a wide variety of clast lithologies from sources to the east-northeast, where igneous, metamorphic, and sedimentary sources were all available. Tertiary sediments and rocks were once widespread along the west coast of Vancouver Island and many were conglomeratic, derived from erosion of rising mountains to the east along the "backbone" of the island. They were largely stripped off by glacial action but are still present below sea level (Muller 1974:23; Carter 1973:442). They are in turn overlain by unconsolidated sediments of Quaternary (Pleistocene and Holocene) age.

Glaciers covered this area of the west coast to a height of about 240 m at the last maximum (Vashon Stade of the Fraser Glaciation; ca. 15,000 yr BP) and striae indicate a fairly uniform southwesterly flow direction, essentially perpendicular to the coastline (Muller 1973:35). Muller (1980b:8) suggested that the maximum glaciation was older, likely early Wisconsinan (>37,000 BP), but dates from beneath till on the west coast of Vancouver Island show that it occurred just after 16,000 yr BP (Clague *et. al.* 1980, 1988; Ward *et. al.* 2003). Expansion of the Cordilleran ice sheet in southwestern British Columbia did not begin until after 19,000 yr BP, although lowland glacier tongues were present already adjacent to the Coast Range between 22,000 and 20,000 BP (Armstrong *et. al.* 1965; Mathews *et. al.* 1970; Clague *et. al.* 1980, 1988; Roberts 1991). Maximum expansion of ice to the west coast of Vancouver Island was of brief duration, perhaps only 1000 to 2000 years (Ward *et. al.* 2003). Ice coalesced in Barkley Sound from lobes that advanced down Alberni, Effingham, and Pipestem inlets; then extended southwestward about 30 km onto the continental shelf. Outwash plains extended southwestward from the ice front during both advance and retreat phases, so two bodies of outwash gravel are separated by intervening till and stony marine clays, the younger outwash unit being about 12,000–11,000 yr old (Carter 1973:443).

Extensive deposits of sand and gravel occur along the southwestern coast of Vancouver Island and represent material eroded from the island's varied bedrock units. The percentage of sand and gravel as opposed to finer sediments (silt/clay) rises northward and southward from Barkley Sound, with deposits seaward from the Sound being typically less than 75% sand and gravel. A small area in the floor of the Sound immediately northwest of the Broken Group rises to >98% sand and gravel but these sediments are still dominantly sandy. Many of the marine cobble deposits appear to represent tills winnowed by bottom currents and by wave action at lower stands of sea level whereas the sandier areas are to be found out from the mouths of formerly glacier-fed rivers (Milliman 1976). The main body of sediment in the floor of Barkley Sound is an olive-green organic-rich mud (silty clay), occasionally rich in H_2S, likely from organic decomposition in locally oxygen-poor conditions (Carter and Murray 1969:13; Carter 1973:447).

The banks and outer shelf beyond Barkley Sound are also mantled locally by sands and gravels, with a trend from poorly sorted gravels on the inner shelf to well sorted sands near the shelf margin. Gravel clasts from the shelf surface exhibit surface textures consistent with glaciation and are lithologically equivalent to those in glacial drift on land, indicating winnowing from till (Carter 1973:448–449). Pebble and cobble surface characteristics include crescent-shaped percussion scars and angular pits, striations, and faceting. Quartz sand grains also display conchoidal fractures of widely varying sizes, some with stepping, from crushing (Carter 1973:451). Conchoidal fracturing of pebbles and cobbles is also a diagnostic characteristic of tills, producing pseudo-artifacts (Wilson and Burns 1999:216–218), and such is to be expected here as well. Tsunamis have also occurred many times along this tectonically active coastline during the Holocene (Clague 1997) and have had the power to move boulders inland from offshore gravel deposits, as well as to flake them through impact. These “floaters” could be expected almost anywhere on surfaces within several or even many metres of past or present sea levels.

Relative sea level change along the Pacific Coast of British Columbia is a complex product of (i) eustatic (absolute) sea level fall and rise, (ii) isostatic depression and rebound of the land in response to ice loading and unloading, (iii) migration of isostatic forebulges from arching of land in response to nearby loading and unloading, (iv) local to regional tectonic influences such as movement on fault zones, and (v) geoidal effects (gravitational influences) of ice masses upon nearby bodies of water. The sea level curve for the Haida Gwaii region (Queen Charlotte Islands) differs from that of southern Vancouver Island in that Haida Gwaii is much more strongly influenced by forebulge effects as well as being in a different tectonic setting (strike-slip or transform fault boundary as opposed to the Cascadia subduction zone to the south) (Josenhans *et. al.* 1995, 1997; Fedje and Josenhans 2000; Fedje *et. al.* 2001). Relative sea levels at the close of the Pleistocene on western Vancouver Island were much higher than at present, reaching a limit of about 32–34 m above modern sea level at Hesquiat Harbour, where wood from marine silt 25 m amsl was dated to 13,000±110 yr BP (GSC-2976; Clague *et. al.* 1982:611). Evidence from a variety of sites suggested emergence of 1 m or less in the last 1500 years and some 2–4 m in fewer than 4000 years (*ibid*.:612). Data from Clayoquot Sound and Ucluth Peninsula (Barkley Sound) extended this information, indicating a pattern of early postglacial falling sea level, then a mid-Holocene transgression followed by renewed emergence. Marine silts thought to be coeval with those from Hesquiat are 50 m asl at Tofino (Friele and Hutchinson 1993; Bobrowsky and Clague 1992:326). The evidence suggests late Pleistocene to mid-Holocene emergence (*ca*. 13,000 to 8000 yr BP), with sea level falling to the modern level by 10,000 BP and exposure of lands now below sea level between 10,000 and 6,000 BP. A slow transgression (relative sea level rise) began about 8000 ^{14}C yr ago, passing modern sea level shortly after 6000 yr BP and culminating around 3000 yr BP at no more than 10 m above modern sea level. This was followed by a slow regression (emergence) from about 3000 BP to present. Submerged stumps in the Tofino area have been dated to 7900±100 yr BP (GSC-5106) and 7070±120 yr BP (AECV-1205C; Bobrowsky and Clague 1992:325), documenting the early Holocene period of emergence. The pattern differs from that of rapid isostatic rebound, then submergence, noted along southern British Columbia and Washington coasts, and might suggest migration of a proglacial forebulge. Isostatic recovery of the west coast of Vancouver Island appears to have been largely complete by 10,000 to 8,000 yr BP, marking a period when elastic rebound of the land exceeded eustatic sea level rise before the later Holocene events of submergence and emergence documented at Clayoquot and Barkley Sounds (Bobrowsky and Clague 1992:325–326; Friele and Hutchinson 1993:838–839). It is cautioned that even over relatively short distances the emergence curves could differ as a result of tectonic factors (folding and faulting).

Soils and Sediments on Benson Island

A red brown silty clay unit at the base of the sampled deposits is associated with the early component on Benson Island. The upper portion of red brown silty clay contains carbonaceous material interpreted as charcoal stringers (barely into it) dated to 5050 radiocarbon years BP (calibrated range 5900–5650 years BP). The colour and texture change laterally from bright red-brown clay to brown silty clay. Such colours could be either of pedogenic origin or from groundwater influence. In the former instance they would represent a downward-developing zone of residual iron oxides as would be left in a podzolic soil profile (spodosol) through leaching of other more mobile chemical compounds under forested conditions. In the latter instance they could reflect the influence of oxygenated groundwater upon previously reduced iron oxides or sulphides associated with former shallow marine sediments or waterlogged soils on land. The lateral color change may be related to the difference in clay content and hence a difference in porosity. The unit reaches 1 m or more in depth but its base was not reached in excavation. Likely the color horizon does not coincide perfectly with the texturally defined depositional unit into which it was developed; so, for example, the silty clay unit may extend considerably below the lower boundary of the color horizon, which is probably determined by water table and an oxidation/reduction boundary.

If strictly pedogenic, these colors and their relative intensity suggest that the back terrace was forested at some time in the past with a coniferous cover; but the development of these colors would postdate the charcoal streaks or stringers, possibly by a considerable amount. It is sparsely treed today with broken coastal forest but perhaps supported a more continuous forest in the past with large trees along the water's edge, which was closer to the ridge than today. The back terrace was once a shoreline from which sea level has retreated (a regression). Although salt water *per se* would not enhance tree growth, coastal lowlands can benefit from downslope flow of groundwater and the underground "pooling" of freshwater above sea water, as the two tend not to mix without turbulence.

There is, therefore, a clay to silty clay mantle directly over bedrock on the back terrace under the cultural deposits. Much of the area of Pacific Rim National Park is mantled by outwash deposits over till and stony clay (Muller 1973:35), so there could be such deposits at depth here beneath the silty clays. The silty clays could be of marine origin, with minor aeolian reworking on emergence, then surface stability with development of the forest cover. The carbonaceous stringers could be burned roots or even marine organics. The date on the carbon, when considered in light of the Tofino emergence curve (Bobrowsky and Clague 1992:326), suggests that the silty clay may have been near sea level *ca*. 5000 yr BP and might have been submerged for a time during the mid- to late Holocene transgression. However, Friele and Hutchinson (1993) argue that the Tofino curve applies to Barkley Sound, suggesting little or no transgression after 5000 BP.

Artifact Lithologies at Ts'ishaa

The lithic assemblage from Ts'ishaa is characterized overall by expedient use of local materials, most of which would be classed as of "poor to medium quality" from the standpoint of the flintknapper. Phaneritic igneous rocks (i.e., those with visible crystals: granite, granodiorite, diorite, and gabbro), while clearly flaked, would have presented obstacles to flintknapping in terms of their degree of crystallinity, with cleavage of feldspar, amphibole, and pyroxene crystals influencing shock-wave propagation. Aphanitic rocks (i.e., those with extremely fine crystalline texture: rhyolite, andesite, and basalt) would have been preferable from this standpoint and were used when available, but there is clearly no predominance of such types in the assemblage; thus it appears that local availability and expediency prevailed over other issues. Similarly, metamorphic rocks include both macroscopically crystalline types (gneiss and schist) as well as a few examples of finer-grained rocks (hornfels, quartzite and argillite), with even the more coarsely crystalline examples flaked into choppers. Sandstone abraders in the sample are mostly litharenites (greywackes), a lithology widely found in Vancouver Island sequences and likely widespread also in cobbles carried in by fluvial or glacial agency from areas to the east of Barkley Sound. Green chert was obtainable in the surrounding region (see below) and is represented by cores and debitage. Vein quartz is of ubiquitous occurrence in association with hydrothermal activity along fracture zones and was available locally. Hornfels and quartzite are non-foliated metamorphic rocks often associated with contact metamorphism. Such metamorphism has been documented in proximity to intrusions in the Barkley Sound area and even in the Broken Islands, so both materials may be available locally. More clearly exotic materials (obsidian and schist) are treated in the next section.

Dewhirst (1980:120–121) reported from the Yuquot sample (Nootka Sound, west coast of Vancouver Island) evidence for the making of stone celts from rounded, tabular basalt beach cobbles that were flaked, then ground to shape. Beach stones of similar character were also used as wedges (*ibid*.:126–128). Remaining cortex on many Ts'ishaa specimens also indicates frequent use of beach cobbles as raw material.

Many of the Vancouver Island sandstones are both texturally and compositionally immature and thus belong within the greywacke subgroup. Compositional immaturity is often signalled by relatively high feldspar percentages reflecting igneous source rock for the sands and relatively short distances of transport. Feldspar percentages could not be assessed readily for the specimens at hand given the lack of freshly broken surfaces but their "dirty" appearance (i.e., the abundance of dark rock fragments, likely chert) signalled that they were litharenites (=greywackes), as was the case at Yuquot.

Black mudstones of Unit 1 in the Pacific Rim Complex, Ucluelet to Vargas Island, are metamorphosed to a degree and therefore approach "argillite" status (Brandon 1989a). Argillites also occur in the general region, if not locally, in Triassic rocks (Monger and Journeay 1998, pt. 2:1). Also present within the Pacific Rim sequence are cherts and what has been described as green tuff. Brandon (1989:1529) has pointed out that "tuff" is a misnomer for these fine-grained volcanics, which are not pyroclastic but are sedimentary rocks made up of metavolcanic and metaplutonic clasts. "Tuffs" in this instance can be grouped according to three distinct source rocks: (i) microcrystalline basalt altered to chlorite; (ii) plagiophyric andesite with plagioclase partially altered to chlorite; and (iii) medium-grained diorite with minor epidote. Additional study may reveal that some of these "tuffs" are represented at Ts'ishaa, but their identification would require source-area sampling and petrographic thin-section comparisons.

Rock Lithologies as Evidence of Trade from Non-local Sources

Rock lithologies can serve as a guide to past trade or human movements when materials can be related back to their sources. Typically it is expected that these are "bedrock" sources, as is indeed often the case. Nevertheless, for each material there is actually a zone of detrital dispersal through natural erosional processes, so what is viewed as a "point source" is actually a more dispersed occurrence. For example, glaciers will have distributed a material in a "train" from its source, a realization that has led to important economic mineral discoveries in formerly glaciated areas. The "train" of glacial erratics can be followed upflow to establish the location of the source, which may remain hidden beneath glacial drift. Similarly, rivers redistribute material and cobble-sized clasts may be found long distances from the source. The vectors of movement can be plotted as *detrital dispersal vectors* and an outline can be drawn surrounding the zone of probable detrital distribution, or *detrital dispersal envelope* (Wilson 1990:68–69).

Non-local materials include schist, obsidian, nephrite, and jet, of which only the schist specimens were examined by the author. Obsidian samples from the site have been identified as coming from three sources in south-central Oregon (*see* artifact descriptions, Chapters 4 and 5, this volume). The fact that obsidian is unavailable locally, coupled with the chemical "fingerprint" identifying the source, is clear proof that trade and importation of exotic lithic materials did occur at Ts'ishaa. Nevertheless, the predominance of local rock types suggests that such activities were not a major economic concern.

Nephrite, like obsidian, is a material that was widely traded on the Northwest Coast as well as in other areas of western North America. It is not possible at present to speculate as to a source for the Ts'ishaa nephrite sample, which comprises 3 celt fragments. There appears to be no local source.

Schist is another rock type not available in local bedrock and unlikely to have been found in displaced clasts such as glacial erratics. Some 17 examples of schist or phyllite artifacts were recovered from the site, 14 from the back terrace and three (including a phyllite chopper and a schist knife) from the main village area. Additional pieces of schist were frequently observed during excavations on the back terrace but showed no evidence of modification into tools. Specimens from the back terrace exhibit silvery sheens, occasionally weathered to brown, and range from phyllite (N=1, #868) to low-grade schist with small muscovite crystals barely visible to the naked eye. One has small, equant (blocky) weathered porphyroblasts (crystals of newly formed minerals in a more finely crystalline groundmass) that may have been garnets but are now altered to pseudomorphs (#742). Two others exhibit small equant grey porphyroblasts, *ca.* 1 mm in diameter (#453, 806). Some are slightly darker grey, indicating lower muscovite content, and one of these (#597) exhibits very small white lath-shaped porphyroblasts. One specimen from the main village area (#842) is greenish and is identified as chlorite phyllite.

Given that schist and phyllite do not occur in the bedrock geology of the Benson Island, these materials could have been imported through human activity. Schist and phyllite may have been traded or carried along the coast from bedrock sources in the Pacific Rim Complex (Ucluth Formation) of the Ucluelet-Vargas Island trend discussed above, or in the Pacific Belt southeast of Barkley Sound (Leech River Schist). The Ucluth and Leech River rocks are both correlative with the Mesozoic Pacific Rim Complex of the Pacific Rim terrane, which accreted to the North American plate (Muller 1973:36–37; 1974:21; 1977). Ucluth Formation metamorphics are described as having a patchy green appearance from epidote (Brandon 1989a, 1989b) and schist *per se* does not appear to be present (Muller 1973:30, 36). To the southeast, the Leech River Schist is a shear-folded metagreywacke-slate complex with some metavolcanics, found south of the San Juan Fault, which follows the north slope of San Juan River valley.

The metavolcanics are chlorite-actinolite schist with minor quartz and plagioclase. Schists in this zone are "usually light coloured, greenish or grey, fine grained rocks, frequently weathering brown on exposed surfaces" (Clapp 1912:39). Metamorphism in the San Juan block rises in grade (degree) southward toward Leech River Fault, from phyllitic greywacke and slate in the north to garnetiferous quartz-biotite schist which, locally near Leech River fault, exhibits porphyroblasts of andalusite and staurolite, reaching the lower blueschist grade. The blueschist facies is identified through the presence of the mineral glaucophane and indicates high pressures but relatively low temperatures, typical of rapid subsidence of cool oceanic crust into subduction zones. If a source in the Ucluth Formation is ruled out, this gradation in the landscape may make it possible through detailed sampling and comparison to link site materials with specific zones of the Leech River Schist.

A common rock type in the Leech River complex is a "black, schistose slate," the color of which is derived from both magnetite and graphite. Some occurrences "are so carbonaceous, black, and lustrous, as to resemble graphitic coal" (Clapp 1912:39). Such a material might be identified in an archaeological sample as "jet." However, this metamorphic material would be considerably more dense than the more easily worked lithified lignites otherwise identified as "jet." The "jet" specimen from Ts'ishaa is light, not dense. Muller (1980b) discussed jet of the latter type from Yuquot and suggested on circumstantial grounds that it might have originated in Jurassic or Cretaceous coal deposits from Vancouver Island (Nanaimo Basin). The specimen from Ts'ishaa could be of similar origin.

A Tertiary conglomerate near Owen Point includes large redeposited blocks (clasts) of chert, a "ribbon-chert" characteristic of the Pacific Rim Complex (Muller 1974:23; Brandon 1989). Similar cherts are found in bedrock close to Barkley Sound in the Pacific Rim Complex between Ucluelet and Vargas Island. They are well exposed on Frank Island, Box Island, and smaller islands between Wickaninnish Bay and Schooner Cove, as well as on both sides of Ucluelet Inlet. Typical occurrences have chert beds 2.5 to 5 cm (occasionally more than 15 cm) thick, abruptly lensing laterally, and interbedded with thin laminae of black argillite (mudstone). Fresh surfaces are light green, grey, black, or (rarely) reddish brown; while weathered surfaces are bright white to grey. These cherts may represent siliceous tuffs deposited on deep slopes or the ocean floor near a volcanic island arc and may be of Jurassic age (Muller 1973:33). Given the presence of cherts and black argillites in this zone, the area might profitably be examined for possible quarry sites; however, these materials are widely distributed and could have been readily available at coastal wave-cut outcrops, regularly renewed by storm activity.

Concluding Comments

The Barkley Sound area is geologically complex and presents a varied tableau of rock types representing the three major rock groups. Not only are varied types available from in-place bedrock; there are also significant detrital cobble deposits of glacial and fluvial origin, some of which are likely reworked from even earlier (Tertiary) conglomerates. Locally available lithic materials are well suited to expedient use but also include cherts and fine-grained igneous rocks with good flaking qualities.

The Ts'ishaa lithic sample can be broadly divided into four categories (i) rocks from the immediate site vicinity; (ii) rocks from the surrounding Barkley Sound area; and (iii) rocks regionally available in southwestern Vancouver Island, and (iv) extra-regional rocks such as obsidian (Table 1). Most of the sample likely belongs in the first category, given that detrital cobbles from glacial deposits extend the variety available from local bedrock. The quest for good-quality chert may have extended to the surrounding Barkley Sound area but chert does occur in conglomerates and as Quaternary detrital cobbles. Reworking and transport in glacial settings do tend to create flaws in chert (cones of percussion from "shatter marks" reflecting impact in transport) so bedrock sources may have been sought in areas such as Ucluelet Inlet. The quest for litharenites (greywacke-type sandstones) likely also led to areas surrounding the Sound, if certain surface textures were specifically sought for optimal use in abrading. Further afield, it has been demonstrated that Ts'ishaa obsidian specimens came from Oregon sources. A less distant but nevertheless exotic origin is likely for the nephrite.

The schist specimens may reflect trade from (or travel to and from) the zone of the Leech River Schist in southern Vancouver Island. Direct comparisons of archaeological specimens with samples from the Leech River Schist may provide additional insight as the the dynamics of lithic procurement, trade, and use in the region. A potentially productive line of inquiry for future research would be to undertake a comparative study of Ts'ishaa schist specimens with samples from the Leech River Schist and, if these comparisons warrant further investigations, to examine coastal outcrops of the latter for evidence of quarrying. Similar work may be possible in the case of the cherts, which must first be analyzed in thin section to determine whether they are of primary deposition or replacement origin. Given their resistance to abrasion, it is likely that chert pebbles and cobbles occur widely in detrital deposits, so specification of source(s) may be difficult.

Table 1. Potential bedrock availability of lithic materials represented at Ts'ishaa.*

Lithic Type	Benson Island/ Broken Group	Barkley Sound	Regional, S.Vancouver I.	Extra-regional
IGNEOUS				
basalt		Karmutsen Fm.; Bonanza Gp.; Pacific Rim Complex	X	X
gabbro	Westcoast Complex	Westcoast Complex	X	X
andesite		Bonanza Gp.	X	X
diorite	Westcoast Complex	Westcoast Complex; Sooke Intrusions	X	X
granodiorite		Island Intrusions	X	X
granite		Island Intrusions	X	X
obsidian				Oregon (sources identified)
METAMORPHIC				
slate		Pacific Rim Complex	Associated with Leech River Schist	X
phyllite		Pacific Rim Complex	Associated with Leech River Schist	X
schist		?Pacific Rim Complex	Leech River Schist	X
gneiss	Westcoast Complex	Westcoast Complex	X	X
nephrite			?	X
hornfels	?contact metamorphics	Contact metamorphics around intrusions	X	X
quartzite	?contact metamorphics	Contact metamorphics around intrusions	X	X
SEDIMENTARY				
chert	Quatsino Formation	Quatsino Formation; Pacific Rim Complex	X	X
argillite (~metamorphic)	Quatsino Formation	Quatsino Formation; Bonanza Group; Pacific Rim Complex	X	X
sandstone (greywacke/litharenite)		Bonanza Group; Tofino Basin; Pacific Rim Complex	X	X
jet (lithified lignite)			?Jurassic/Cretaceous of Nanaimo Basin	X

* detrital sedimentary sources for boulders, cobbles or pebbles (glacial drift, alluvium, tsunami "floaters", etc.) are more widespread and are not considered in this table.

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