Introduction to the special issue of Canadian Journal of Earth Sciences: The Nechako NATMAP Project of the central Canadian Cordillera

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Abstract: The Canadian Cordillera in central British Columbia has seen the Mesozoic subduction of an oceanic terrane; the amalgamation of volcanic-arc terranes; continued intermittent Mesozoic compression and magmatism; and Tertiary wrenching, extension and magmatism. Except in its northernmost mountain ranges, the area is extensively covered in glacial drift and thin veneers of Tertiary volcanic rocks. In 1994, a group of scientists and technologists believed they could understand that cover, see through it, and discover the components of that collision and extensional orogen. They would apply modern techniques of isotopic and paleontological geochronology; lake-sediment, till, and plant geochemistry; detailed gravity, magnetic, radiometric, paleomagnetic, and electromagnetic surveys; and isotopic and trace element lithochemistry, as they conducted extensive bedrock and surficial mapping. This special issue summarizes a cross-section of the scientific contributions derived from that mapping conducted under the auspices of the Nechako NATMAP Project. It demonstrates the absolute necessity of applying modern isotopic and paleontologic geochronology to understand the Phanerozoic geology of the Cordillera. It emphasizes the necessity of detailed aeromagnetic surveys (500 m or less line spacing) in looking through covered terranes at anything more than 1 : 250 000 scale. And, it shows the immense utility of applying various geochemical techniques to solve geological problems and establish baselines for future research and economic development. Bedrock and surficial mapping in the central Cordillera, using these and other techniques, have established the nature and timing of Mesozoic crustal growth, Tertiary crustal thinning, and the associated formation of mineral deposits.

Résumé : Au Mésozoïque, la Cordillère canadienne du centre de la Colombie-Britannique a subi la subduction d'un terrane océanique, la fusion de terranes d'arcs volcaniques, de la compression et du magmatisme intermittent et, au Tertiaire, du décrochement, de l'extension et du magmatisme. À l'exception des chaînes de montagnes les plus septentrionales, la région est abondamment recouverte de sédiments glaciaires et de minces placages de roches volcaniques datant du Tertiaire. En 1994, un groupe de scientifiques et de technologues ont cru qu'ils pouvaient comprendre ces recouvrements, les percer et découvrir les composantes de cet orogène de collision et d'extension. Ils appliquèrent des techniques modernes de géochronologie isotopique et paléontologique; de géochimie des sédiments de lac, des tills et des plantes; des relevés gravimétriques, magnétiques, radiométriques, paléomagnétiques et électromagnétiques détaillés ainsi que de la lithochimie isotopique et d'éléments traces, alors qu'ils entreprirent une vaste cartographie de la roche-mère et de la surface. Ce numéro spécial résume une vue d'ensemble représentative des contributions scientifiques dérivées de cette cartographie effectuée dans le cadre projet NATMAP Nechako. Il démontre le besoin absolu d'effectuer de la géochronologie isotopique et paléontologique moderne afin de comprendre la géologie du Phanérozoïque de la Cordillère. Il met l'emphase sur la nécessité de relevés aéromagnétiques détaillés (espacement des lignes de 500 m ou moins) pour étudier des terranes recouverts lors de travaux à une échelle plus grande que 1 : 250 000. Il démontre aussi la très grande utilité d'utiliser diverses techniques géochimiques pour résoudre des problèmes géologiques et établir les lignes de référence pour la recherche et le développement économique futurs. Par l'utilisation de ces techniques et autres, la cartographie du roc et des dépôts de surface de la Cordillère centrale a établi la nature et le séquencement de la croissance de la croûte au Mésozoïque, de l'amincissement de la croûte au Tertiaire et de la formation de gisements de minéraux associée à ces événements.

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Fig. 1. Simplified terrane map of the Canadian Cordillera with the location of the five geomorphological belts and the project area.

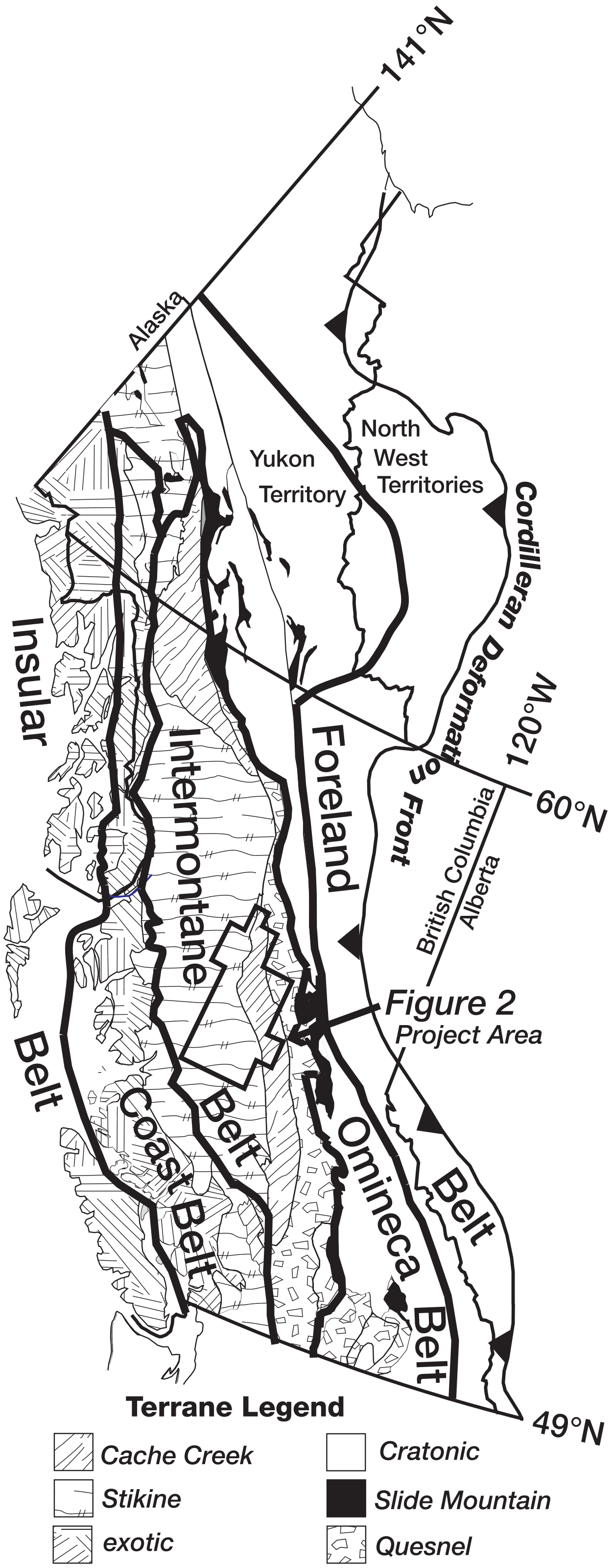
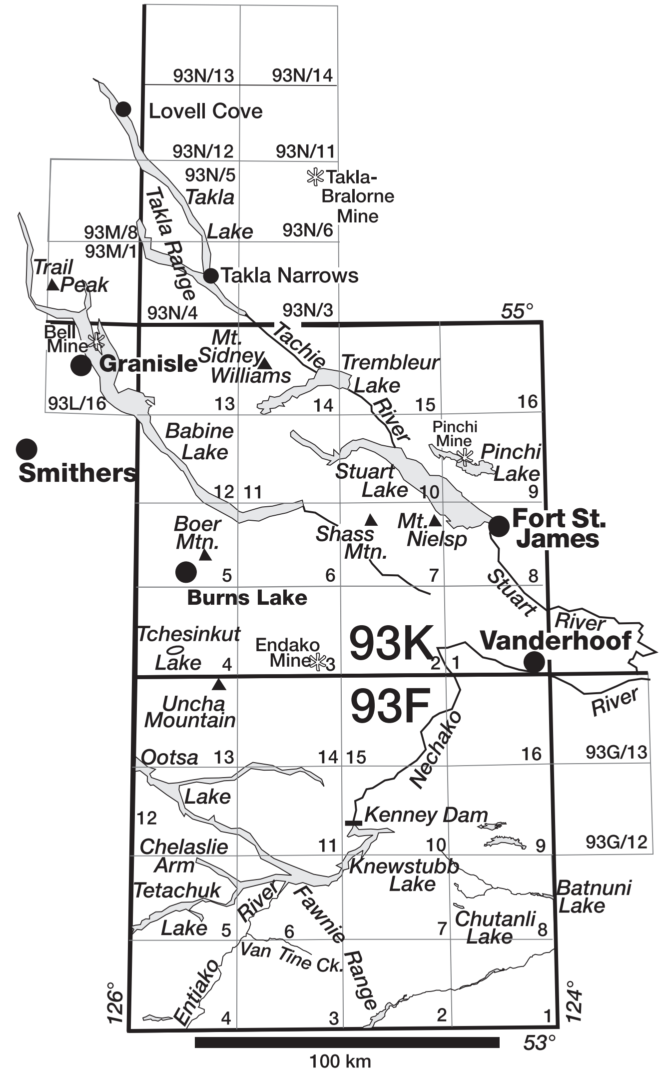


Fig. 2. Identification of the NTS map areas of the Nechako NATMAP Project and the location of some geographic features mentioned in the text. The location of these map areas is shown in Fig. 1. NTS map areas are Manson River (93N), Smithers (93M), Hazelton (93L), Fort Fraser (93K), Nechako River (93F) and Prince George (93G).



Introduction

Earth scientists from several government agencies, eleven universities, and four companies joined forces, formally and informally, from 1995 to 2000 to study Eocene tectonics in the central Canadian Cordillera in British Columbia (Fig. 1). They conducted their research under the auspices of the Geological Survey of Canada's National Geoscience Mapping Program (NATMAP) as the Nechako Project.

The project was jointly coordinated and principally funded by the Geological Survey of Canada (GSC) and British Columbia Geological Survey (BCGS). It gained immensely from the large contributions of university researchers and from various companies.

The scientific contributions reported in this volume come from research directed at key geological issues, whose resolution relied on regional and detailed mapping. Results of bedrock and surficial mapping were integrated with site- and area-specific studies of metallic and industrial mineral deposits, biostatigraphy, geochronology, lake-bottom sediment, till and tree geochemistry, airborne and ground geophysics, paleomagnetism, and Geographic Information System (GIS) interpretations. New regional and detailed geological and geophysical maps were published for the Nechako River (93F), Fort Fraser (93K), and parts of Prince George (93G/12,13), Smithers (93L/16), Hazelton (93M/1,8), and Manson River (93N/4,5,12) map areas (Fig. 2). In addition to hardcopy maps and reports, all data are in computer-accessible, GIS-compatible format and are being made available on CD-ROM and through the BCGS MapPlace and GSC CORDLink Internet web sites.

As originally envisaged, Nechako Project set out to test 5 hypotheses and in doing so to make more detailed geological maps (Struik and McMillan 1996). Those hypotheses were that in central British Columbia:

(1) The Eocene volcanic complex represents the tectonic–magmatic expression of a regional north-northwest-directed extensional event, whose rocks and structural environments have potential for precious metal epithermal and intrusion-related copper–gold and molybdenum deposits.

(2) The Triassic–Jurassic volcanic-arc sequence of the east–west Skeena Arch through the Nechako area has further potential for copper–gold mineralization.

(3) The boundary between Stikine and Cache Creek Terranes is a regional east-dipping thrust fault.

(4) The Permo-Triassic Sitlika Assemblage is equivalent to the Kutcho Formation of northern British Columbia and has the potential to host volcanogenic massive sulphide deposits.

(5) The regional Pleistocene glacial ice flowed in various easterly directions throughout its history and those flow directions can be used for drift prospecting.

The project addressed and contributed to each of these hypotheses and, as expected, came up with several surprises outside the realm of these hypotheses. The papers in this volume provide information and evaluation of several of these hypotheses and the context for the rock suites involved. Some key ideas have been published elsewhere (e.g., Selby and Creaser in press; Villeneuve et al. in press). References to these publications can be found in the papers included in this volume. Further releases from this project include two more compilation CD-ROM's of digital maps, reports, and datasets; a GSC bulletin on the paleontology; and several journal papers on Eocene extension, the Endako Group, Sitlika Assemblage, and the Quaternary ice flow history.

Tectonic setting

The Canadian Cordillera is interpreted to be a collage of oceanic and island-arc crustal fragments or terranes accreted to ancestral North America (Monger et al. 1972; Monger and Nokelberg 1996) sometime in the early Mesozoic. The ancestral North American rocks occur mainly in two geomorphological belts — the Foreland fold and thrust belt and the Omineca crystalline belt (Fig. 1); accreted rocks comprise the Intermontane, Coast, and Insular belts.

The study area is within the Intermontane Belt (Fig. 1) and includes the Stikine (Stikinia) and Quesnel (Quesnellia) volcanic-arc terranes separated by the oceanic Cache Creek Terrane (Fig. 1). Stikine Terrane comprises Carboniferous to Middle Jurassic island-arc volcanic and sedimentary rocks of the Asitka, Takla, and Hazelton groups and the related Topley, Stern Creek, and Spike Peak plutonic suites (Schiarizza and MacIntyre 1999). Cache Creek Terrane consists of Carboniferous to Lower Jurassic ultramafic, metavolcanic, and metasedimentary rocks of the Sitlika Assemblage, Tezzeron succession, and Cache Creek Complex, where Cache Creek Complex is interpreted as part of an oceanic accretionary complex (Struik et al. this volume; Tardy et al. this volume). Quesnel Terrane is made up of Carboniferous to Middle Jurassic extensional to volcanic-arc volcanic, sedimentary, and plutonic rocks (Struik 1987; Monger and Nokelberg 1996).

Stikine Terrane is overlain by postaccretion Upper Jurassic to Upper Cretaceous marine and nonmarine sedimentary rocks of the Bowser Lake, Skeena, and Sustut groups (Fig. 3). Both Stikine and Cache Creek terranes are cut by postaccretion plutons of the Middle Jurassic Stag Lake and Late Jurassic – Early Cretaceous François Lake plutonic suites (Whalen et al. this volume). Cache Creek Terrane is also cut by Early Cretaceous Mitchell Range intrusive suite (Schiarizza and MacIntyre 1999). Both terranes are overlapped by Upper Cretaceous and Paleocene continental volcanic-arc and related sedimentary rocks of the Kasalka and Sustut groups and Eocene volcanic-arc-influenced, extension-generated volcanic and minor sedimentary rocks of the Ootsa Lake and Endako formations (Fig. 3).

Quesnel Terrane lies east of Cache Creek Terrane, and they are separated primarily by the steeply dipping Pinchi Fault. Quesnellia at the latitude of Nechako Project consists mainly of Middle Triassic to Lower Jurassic volcanic-arc rocks, interpreted to have formed above subducting Cache Creek Terrane oceanic rocks, and to the northeast contains upper Paleozoic arc-like volcaniclastic rocks (Ferri and Melville 1994).

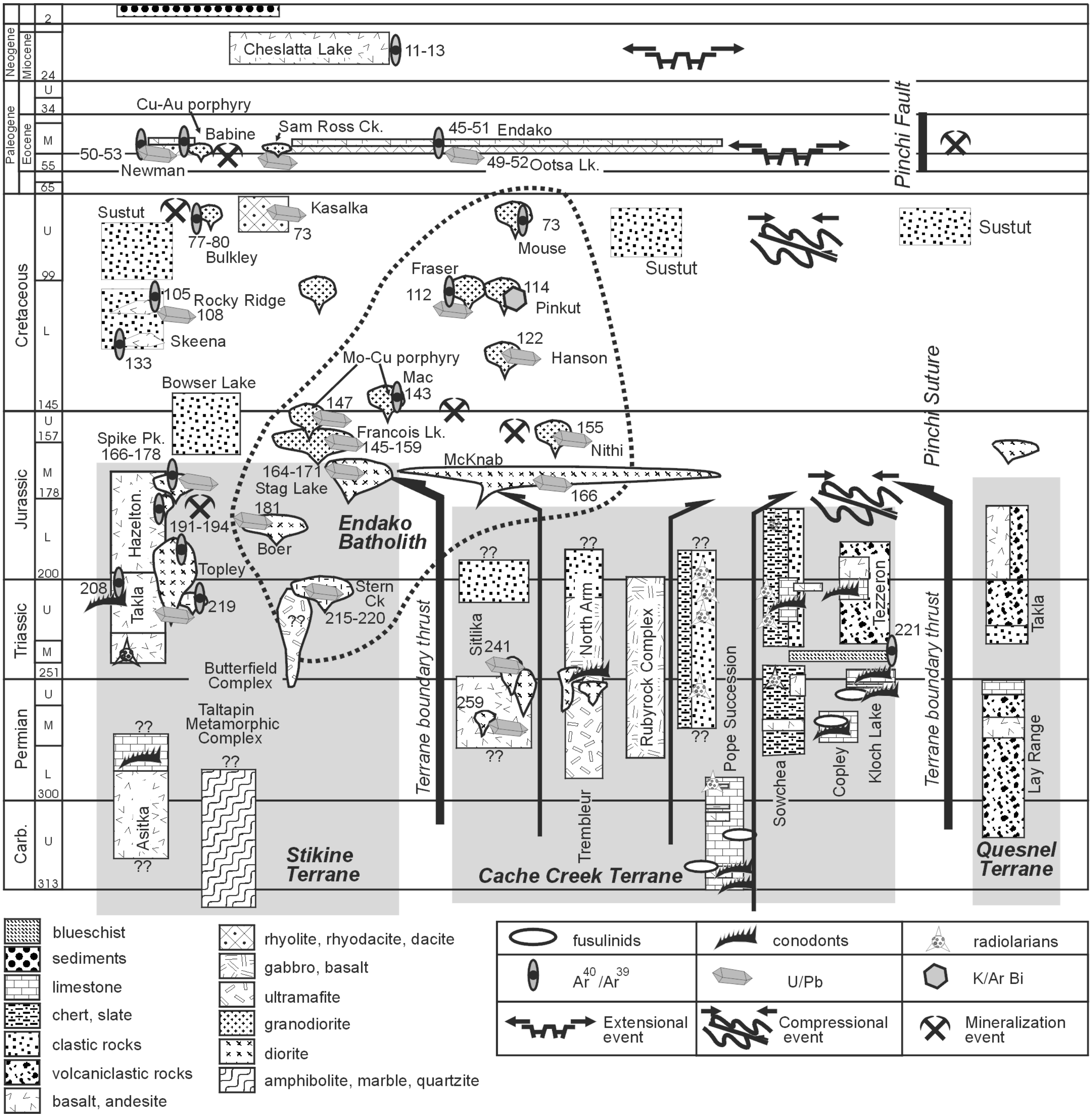
Nechako NATMAP Project area spans the zone of westward-directed thrust faulting that marks the boundary between the Stikine and Cache Creek terranes. This structural imbrication occurred prior to 165 Ma (Schiarizza and MacIntyre 1999), as indicated by isotopic ages for plutons that cut the bounding fault between the terranes. Folds and thrust faults related to this imbrication are offset by a complex pattern of high-angle faults. The timing of this faulting and its relationship to regional Late Cretaceous to Eocene transpressional and transtensional tectonics is discussed more fully in MacIntyre and Villeneuve (this volume) and Lowe et al. (this volume).

Summary of project contributions

The starting hypotheses of the Nechako Project can be rewritten based on our present understanding of the geology of the central Canadian Cordillera as follows (changes in italics):

(1) The Eocene volcanic complex *is confined to 9 million years between 54–45 Ma and* represents the tectonic–magmatic expression of a regional north-northwest-directed

Fig. 3. Summary time chart of stratigraphic, magmatic, and tectonic events for central British Columbia, as seen by the Nechako NATMAP Project. U, Upper; M, Middle; L, Lower. Numbers on the chart indicate ages (in Ma).



extensional event *influenced to the west by continental-arc magmatism and* whose rocks and structural environments have potential for precious metal epithermal and intrusion-related copper–gold and *possibly* molybdenum deposits.

(2) The Triassic–Jurassic volcanic-arc sequence of the Skeena Arch has further potential for copper–gold mineralization.

(3) The boundary between Stikine and Cache Creek Terranes is *probably* a regional east-dipping thrust fault *that follows the western boundary of the Sitlika Assemblage*.

(4) The *Permian part of the* Sitlika Assemblage is equivalent to the Kutcho Formation of northern British Columbia, *although it contains less felsic volcanic rocks* and has *some* potential to host volcanogenic massive sulphide deposits.

(5) The *last voluminous* regional Pleistocene glacial ice flowed *west and east from the crest of an ice dome located from northern Babine Lake to just east of*

Cheslaslie Arm of Tetachuck Lake, and those flow directions can be used for drift prospecting

Nechako Project has generated a multitude of other contributions to understanding this area and some of these are summarized in the next sections.

Eocene extension

Eocene rocks and structures of the Nechako area were generated during north-northwest-directed crustal extension. Detailed isotope geochronology has constrained the extensional event primarily to the time from 55 to 45 Ma (Struik et al. 2000). U/Pb and 40Ar/39Ar methods were used to date volcanics, metamorphic rocks, and plutons of this time interval, and the work for this and other isotopic dating for Nechako Project was done at laboratories at GSC-Ottawa (M. Villeneuve), University of Alberta, Edmonton, Alta. (R. Creaser, N. Grainger, L. Heaman, M. Hrudey, and D. Selby), and University of British Columbia, Vancouver, B.C. (R. Friedman).

The extension is wide spread and expressed by the juxtaposition of fault blocks containing rocks from very different crustal levels and with different deformational and metamorphic histories. These blocks are separated by north-northwestly and northeasterly trending faults mostly of unknown amounts and senses of displacement. Where displacement can be determined, the north-northwesterly trending faults are typically steeply dipping and have dextral strike-slip motions, whereas the northeasterly trending faults are moderately to shallowly dipping and have extensional downdip motions. Lowe et al. (this volume) describe the distribution and nature of the Tertiary fault pattern as derived from geophysical and outcrop observations. In general, local highlands are composed of pre-Eocene rocks, and expansive valleys are covered by Eocene and Miocene volcanic and sedimentary rocks. Such features are well defined in the Babine porphyry copper district (MacIntyre and Villeneuve this volume) and south of Tetachuk and Eutsuk lakes (Diakow et al. 1995). A single, well-defined metamorphic complex (Vanderhoof Complex) formed and was uplifted during less than 8 million years of the early Eocene (Wetherup 1997; Struik et al. 2000). The Vanderhoof Complex gneisses were found to be in shallow fault contact with overlying ultramafic rocks of the Cache Creek Complex (Wetherup and Struik 1996).

The Eocene volcanic complex was generated during the same time as the extension and uplift recorded in the Vanderhoof Complex. Grainger et al. (this volume) describe the rhyolite and andesite complex and, with Villeneuve and MacIntyre (1997) and MacIntyre and Villeneuve (this volume), establish its nine million year time span. Anderson et al. (1998) outlined some of the preliminary chemical signatures of this suite, as defined by the volcanics and the few plutons. The environments of deposition and intrusion they describe range from within-plate to arc, as derived from classical variation diagrams.

Eocene magmatism and tectonics formed the Babine porphyry copper district and superimposed it onto a Jurassic copper–gold porphyry environment and a mid-Cretaceous magmatic event with potential for volcanogenic massive sulphide mineralization (MacIntyre and Villeneuve this volume). The extent and nature of the mid-Cretaceous magmatism was one of the project's surprises.

Faulting and hydrothermal alteration affected the Eocene volcanic rocks. The age of these events is constrained as post-45 Ma and pre-15 Ma. The faulting is mostly steep to moderately dipping, follows the trends of other early Eocene faults, and does not appear to offset Miocene rocks. A description of the hydrothermal fluid system, with its low pH and temperature and high water-flow volumes, has been made by Barnes and Anderson (1999).

Babine Porphyry Copper District

The northerly trending Babine porphyry copper district lies west of the north–south-trending Takla Fault in western Nechako Project area and includes several major prospects and two past producing mines — Bell and Granisle. Copper–gold mineralization is associated with small porphyritic intrusions known to be Eocene in age. Our contribution to understanding the nature of the mineralization has been to clearly define the restrictive age range of the Babine intrusions and coeval Newman volcanic rocks (54–50 Ma) using $^{40}Ar/^{39}Ar$ isotopic dating (MacIntyre and Villeneuve this volume) and lithological associations. Block faulting has displaced Eocene plutonic and volcanic rocks and associated mineral deposits during post-mineralization extension related to strike-slip faulting. The most prospective areas for mineral exploration are within grabens formed by this faulting. The better exposed, uplifted blocks expose deeper, less fertile, crustal levels.

Mid-Cretaceous bimodal volcanism

U/Pb and $^{40}Ar/^{39}Ar$ isotopic dating in the Babine district defines a distinct magmatic event at 107–104 Ma (MacIntyre and Villeneuve this volume). This event involved emplacement of rhyolite domes into submarine volcanic rocks of the Rocky Ridge Formation of the Skeena Group. The rhyolite, previously mapped as Eocene, is reinterpreted to be part of a previously unrecognized Mid-Cretaceous submarine caldera that could host important shallow-water volcanogenic massive sulphide deposits of the Eskay Creek type. As a follow-up to the Nechako Project, other areas in central British Columbia are currently being reassessed as potential target areas for the occurrence of similar bimodal submarine volcanic centers of Mid-Cretaceous age.

Stikine Terrane of Skeena Arch

In Nechako Project area, Stikinia ranges in age from Lower Carboniferous to Middle Jurassic. Its Mesozoic arc was built over east-dipping subduction, and eastern exposures of Stikinia contain ultramafic rocks in several locations. Project mapping has increased details of the stratigraphy, plutonism, and distribution of Stikine Terrane rocks. For example, MacIntyre et al. (this volume) now describe the Saddle Hill Formation of the Hazelton Group as a thick volcanic succession of subaerial to submarine, porphyritic andesite flows, volcanic breccias, and rhyolitic ash-flow tuffs that have isotopic ages between 185 and 174 Ma.

Metamorphic rocks of Stikine Terrane, mainly south of Babine Lake, have been identified separately as the Taltapin Complex and consist of amphibolite, marble, calc-silicate, and lesser amounts of meta-rhyolite and muscovite schist. One of the meta-rhyolite tuff exposures yielded U/Pb isotopic ages on zircon ranging from 325 to 345 Ma (M.

Villeneuve, personal communication, 1998). Taltapin Complex is interpreted to range in age throughout the upper Paleozoic and to include equivalents to the Permian Asitka Group.

The younger components of the Upper Triassic to Middle Jurassic volcanic-arc succession of Stikinia are built upon the redefined Topley intrusive suite constrained by new U/Pb and 40Ar/39Ar ages to be between 218 and 193 Ma, and the newly identified Spike Peak intrusive suite ranging in age from 179 to 166 Ma. Volcanic rocks of similar age to these intrusives have been identified throughout the Babine district in western Nechako Project area. The most economically important of these is the rhyolite–andesite couplet of the Lower to Middle Jurassic Saddle Hill Formation, which is the same age as Jurassic sequences in northwestern British Columbia that host the Eskay Creek mine. This confirms the hypothesis that rocks exposed along the Skeena Arch uplift are also prospective for this type of volcanogenic massive sulphide deposit.

Two localities of pyroxenitic ultramafic rocks, referred to as the Butterfield complex (Schiarizza and MacIntyre 1999; Hrudey et al. 1999), occur in Stikinia, immediately west of the Cache Creek Terrane. In the south, the meta-pyroxenite is intruded by 219 Ma Stern Creek plutonic suite (Whalen et al. this volume). Postaccretionary Jura-Cretaceous sedimentary and volcanic rocks, such as the Bowser Lake, Skeena, and Kasalka groups (Anderson et al. 1999; Schiarizza and MacIntyre 1999), are involved in Jura-Cretaceous contraction, like the Skeena fold belt to the north (MacIntyre 1998).

Cache Creek Terrane

Nechako Project recognized, from west to east, three principle units in the Cache Creek Terrane of central British Columbia: Sitlika Assemblage, Cache Creek Complex, and Tezzeron succession. Those units form an oceanic accretionary complex bound to the west and east by arc suites. It was confirmed that Sitlika Assemblage, first defined by Monger and Paterson (1974), is equivalent to Kutcho assemblage of northern British Columbia, and that Sitlika Assemblage and Cache Creek Complex are likely thrust westward over Stikine Terrane. In addition, we recognize within Cache Creek Complex thrust sheets composed of distinct depositional environments, and that the suture zone between the Cache Creek oceanic plate and the Quesnel volcanic-arc terrane is primarily obscured by the Tertiary Pinchi Fault. Large tracts formerly mapped as western Cache Creek Complex have been recognized to be part of Stikine Terrane and Sitlika Assemblage (Struik et al. this volume).

Geochronological sampling confirmed and increased the size of unique conodont, radiolaria, and fusulinid fossil collections made in previous years in the Sitlika Formation, Cache Creek Complex, and Tezzeron succession. These collections contain Permian and Early Triassic faunal assemblages rare or previously unknown in western North America and that are particular to these rock assemblages (Orchard et al. this volume).

Sitlika Assemblage

Sitlika Assemblage consists of Permian volcanic rocks and Triassic and Lower Jurassic sedimentary rocks, and lies along the westernmost belt of Cache Creek Terrane in central British Columbia. Because the Permian volcanic rocks consisted of a bimodal suite of basalt and lesser amounts of rhyolitic rocks, and because it lay along the west side of Cache Creek Terrane, it was thought to be equivalent to the Kutcho Formation of northern British Columbia (Bellefontaine et al. 1995). This correlation has been confirmed within this project, based on isotopic age dating (Childe and Schiarizza 1997), fossil ages (Orchard et al. this volume), and lithological and chemical correlations (Childe and Schiarizza 1997).

Nechako NATMAP Project extended the distribution of the Sitlika Assemblage and thus the area prospective for Kutcho Creek-type volcanogenic massive sulphide deposits southward from Takla Lake through Fort Fraser map area (Schiarizza and MacIntyre 1999; Hrudey et al. 1999). Rocks of the assemblage in this southern area had been mapped mainly as undifferentiated Cache Creek Complex. Chemistry of the Sitlika basalt and rhyolite is indicative of ocean-floor to arc generation (P. Schiarizza, personal communication, 2000).

Cache Creek Complex

The total age range of the Cache Creek Complex in central British Columbia has been extended to lowest most Upper Carboniferous (Bashkirian) to upper Lower Jurassic (Toarcian) using conodonts, radiolaria, fusulinids, and various macrofossils (mainly corals and pelecypods). The same fossil determinations used to establish this age range were instrumental in determining older-over-younger thrusting in parts of Cache Creek Complex. Paleontology played a critical role in understanding the geology of the Cache Creek Complex and other sedimentary units of the Nechako Project area.

Limestone of the Cache Creek Complex has been constrained to four time intervals: earliest Upper Carboniferous to Early Permian, Late Permian, Early Triassic, and Middle to Upper Triassic. Upper Carboniferous to Early Permian Cache Creek Complex limestone is most voluminous and is generally clastic, shallow- to moderately shallow-water facies and thought to have developed on basaltic ocean islands (Sano and Rui this volume). Early and possible Middle Triassic crustal upheaval are recognized through identification of limestone conglomerate and breccia that contain mixed conodont fauna as young as Triassic (Sano and Rui, this volume; Orchard et al., this volume).

From new lithogeochemistry, basalts of Cache Creek Complex represent a suite of various oceanic magmatic environments and for the Fort St. James area, are mainly of ocean-island and ocean-plateau type (Tardy et al., this volume). Ophiolitic successions have been recognized in several places, and the majority of the complex appears to be composed of dismembered ophiolite, ocean plateaus, islands and atolls, and accretionary sedimentary assemblages. Thrust faults verge both easterly (eastern part of terrane) and westerly (western part of terrane).

Blueschist and eclogite of the Cache Creek Complex have been dated as 221 Ma by Ghent et al. (1995), and they form a narrow zone through Pinchi Lake along the eastern part of the Cache Creek Complex. They are interpreted to form part of a lower thrust sheet of Cache Creek Complex exposed by displacement along the Tertiary Pinchi Fault.

Tezzeron succession

Upper Triassic to Lower Jurassic sedimentary and volcaniclastic rocks formerly mapped as Takla Group along the eastern boundary of Cache Creek Complex have been reclassified as Tezzeron succession and are interpreted to have been an overlap onto the accretionary oceanic assemblages of Cache Creek Complex (Struik et al. this volume). These rocks are overthrust by ultramafic rocks that locally form klippe and the highest structural levels of Cache Creek Terrane.

Endako Batholith

Isotopic dating completed as part of the Nechako NATMAP Project has shown that the Endako Batholith spans more than 75 million years (Whalen et al. this volume; Villeneuve et al. in press). Lithologically and chemically distinct pulses of magmatism are recognized at 220–215 Ma (Stern Creek Plutonic Suite), 181–165 Ma (Stag Lake Plutonic Suite), 159–145 Ma (François Lake Plutonic Suite), and 115–70 Ma (Fraser Lake Plutonic Suite) (Whalen et al. this volume). The batholith is noted for its association with molybdenum mineralization, although this is confined to a short time at the end of the Jurassic (Selby and Creaser in press). The main mass of the batholith consists of Middle through Late Jurassic diorite and granodiorite, and intrudes Stikine and Cache Creek terranes. Near the Endako molybdenum mine Stikine Terrane country rock has been completely replaced by Middle Jurassic to Eocene plutons. Based on Nd isotopes and other chemistry, the batholith initiated during subduction-generated magmatism in Early Jurassic time and ended in intraplate plutonism of the Eocene. These results build on the geological understanding built by Kimura et al. (1976) and Carter (1982).

Radiometric surveys over the high-K plutons, which are mostly covered with glacial deposits, were ineffective in differentiating most of the plutonic suites, although they picked up areas of high concentrations of K associated with alteration. Associated aeromagnetic surveys were useful in locating buried faults within the batholith and extending known faults, such as the northwest trending dextral Casey Fault, that truncates the eastern margin of the Endako ore body (Lowe et al. this volume). Biogeochemical surveys over the batholith have recognized the world's largest known biogeochemical anomaly for molybdenum, centred on the Endako Mine (C. Dunn, personal communication, 1999; Dunn and Hastings 1998, 1999).

Bulkley Plutonic Suite

In addition to contributions to understanding the metallogenesis and developing exploration techniques of the Endako and Babine mineral camps, U/Pb dating of plutons in the southwestern part of the project area has confirmed that metal-rich Late Cretaceous Bulkley plutons extend eastward into western Nechako River map area (Billesberger et al. 1999; Friedman et al. 2000; this volume).

Glaciation

A late Pleistocene ice divide was discovered in western Nechako Project area (Levson et al. 1998; Levson this volume; Plouffe and Levson this volume). Ice had flowed west and east away from a Greenland style ice dome, whose high point was centred about a north-northwesterly line from northern Babine Lake to west of Cheslaslie Arm of Tetachuck Lake in Nechako River (NTS 93F) map area. The westerly ice flow overrode the Coast Mountains. Drift prospecting in till derived from this phase of glaciation requires clear knowledge of the position of the ice divide through time. Glacial striations, roches moutonnées, and erratics found in the Fawnie Range all indicate a general eastward ice movement. This new information suggests that the ice divide identified by A. Stumpf and V. Levson, which extended from the Babine Lake to the Ootsa Lake valleys during the last glacial maximum, probably never migrated as far east as the Fawnie Range (Plouffe 1999; Plouffe and Levson this volume)

Drift prospecting programs can take advantage of the much more detailed maps of the distribution of latest Pleistocene lake sediment (Plouffe and Williams 2001). Lake sediments locally overlie and mask till deposits, which are the best material for drift prospecting, because till is transported along the direction of paleo-ice flow (Plouffe and Levson this volume; Mate and Levson this volume). The maximum elevation of continuous glacial lake sediment cover decreases to the west.

Till geochemical sampling programs throughout the project area have, as reconnaissance and detailed coverage, given base lines for regional economic development and environmental assessment (Cook et al. 1999; Levson this volume; Plouffe and Williams 2001). Detailed till, lake sediment, and water geochemical surveys in the Babine district have defined numerous precious and base metal geochemical anomalies, some in underexplored parts of the district. Those data have been released in various reports (see Levson this volume) and will be collated with the bedrock geology on a CD-ROM (Struik et al. In press).

Metals in the environment

Nechako Project was able to capitalize on its unique geographic location to conduct limited studies on the distribution of mercury and molybdenum. The Pinchi Fault has long been known to have yielded mercury, precipitated mainly as hydrothermal cinnabar. The Endako area was known for its regional distribution of molybdenum (Hastings et al. 1999). In addition to these sites C. Dunn (personal communication, 1998) discovered a large area with high backgrounds of mercury in lodgepole pine north of Ootsa Lake and south of François Lake. The potential for such an anomaly was brought to our attention by C.A. McDevitt of British Columbia Research Inc. who had done chemical analyses for mercury in various aquatic life of a few of the area's lakes.

A. Plouffe, under the auspices of the GSC Metals in the Environment (MITE) program, undertook a study along the Pinchi Fault to (1) determine if anthropogenic mercury existed in the humus horizon; (2) identify the different phases of mercury in soil profiles developed on till and glaciofluvial sediments; (3) establish the mobility of these phases; (4) develop criteria to distinguish between natural and anthropogenic mercury; and (5) provide a framework to measure mercury flux to the atmosphere (Plouffe 1998). Selective leach analyses showed that mercury dispersal is confined to the humus portion of soil near inactive Pinchi and Takla–Bralorne Mines. Biogeochemical samples were collected along the Pinchi fault zone as part of a nationwide survey of natural mercury emissions to the atmosphere (P. Rasmussen, personal communication, 1997).

Miocene mantle upwelling

Miocene basalt in central British Columbia occurs as scattered volcanic centres and some extensive flows, mainly in the southern part of the Nechako Project area (Anderson et al. this volume). As part of Nechako Project, they have been dated using $^{40}Ar/^{39}Ar$ and found to range in age from 15–13 Ma (Anderson et al. this volume). K/Ar ages from equivalent rocks to the east in Prince George and Mcleod Lake map areas range in age from 13–9 Ma (Mathews 1989). These rocks, which are similar to but slighter older than the Chilcotin Group in southern British Columbia, have yielded chemistry and xenolith compositions that suggest they were derived from distinctly different mantle on either side of the Pinchi Fault (Resnick 1999). Xenoliths and xenocrysts appear to be derived from both mantle and crustal sources.

GIS interpretations

The project used computer technology extensively to assist in the mapping and the interpretation, dissemination, and archiving of information. Nechako Project used digital models of topography to study lineaments and as a map base for lithological data (Lowe et al. this volume; Hastings et al. 1999). It used aeromagnetic relief models in combination with lithology to assist in the interpretation of structures and rock distribution in covered areas (Lowe et al. 2000). The Internet was used to disseminate information on the project, including reports and maps. CD-ROM data sets presently available include bedrock and surficial mapping, geophysics and geochemistry of areas of the Triassic–Jurassic volcanic arc of the Quesnel Trough (Williams 1996), and surficial geology and till geochemistry of the Manson River and Fort Fraser map areas (Plouffe and Williams 2001). In addition, a CD-ROM release of all the project geochemistry and bedrock mapping as of 1998 is scheduled for eminent release (Struik et al. in press), and a complete CD-ROM compilation will be made available. The CD-ROM products include a map and data viewer, and have reports in web browser format.

Hydrogeology

As a trial study, we looked at the immediate subsurface of the Vanderhoof area using water well data and Quaternary stratigraphy (Mayberry 2000). These studies demonstrated the capability of the existing information to reveal several unique aquifers and their characteristics and thereby the potential groundwater resources. In addition, we could confine the carving of the Nechako River valley at Vanderhoof to predeposition of Miocene basalt (pre-13 Ma).

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Appendix on following page

Appendix

List of geologists and technical people who worked on the Nechako NATMAP Project 1994–2001

In many ways, this list fails to reflect everyone who contributed to this project. Many people in the managerial and administrative units of the institutions involved in this project are not catalogued here. These people laid out foundations of our processes, did our staffing, paid our bills, initiated and followed through on the contracts, supplied the field gear, ran the lab equipment, shipped the samples, did the archiving of materials, supplied library services, etc… Running a project like the Nechako Project is an enormous task. Out of these people I would like to highlight Mike Cherry and Dan Richardson who headed the NATMAP secretariat and who worked very hard to make the NATMAP program and the Nechako Project successful.

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Hillary Taylor,
Francois Therrien,
Derek Thorkelson,
Brian Traub,
Shelton Udayakumara,
Mike Villeneuve,
Brian Ward,
Shireen Wearmouth,
Gordon Weary,
Ian Webster,
Ralph Westera,
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