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GEOLOGY OF THE HAZELTON VOLCANIC BELT IN BRITISH COLUMBIA: IMPLICATIONS FOR THE EARLY TO MIDDLE JURASSIC EVOLUTION OF STIKINIA

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Abstract. The Hazelton Group is an Early to Middle Jurassic volcanic and sedimentary succession that was deposited on the Stikine Terrane (Stikinia) of the Canadian Cordillera. The group is distributed across the entire width of Stikinia, a distance of about 300 km. Prior to post-Hazelton contractional deformation, the width across which volcanism had occurred was at least 450 km. A review of chronologic and stratigraphic information corroborates an earlier suggestion that the Hazelton Group formed as a pair of coeval, partly subaerial volcanic chains separated by a subsiding, mainly sedimentary marine basin (Hazelton Trough). The trough developed in response to extension of Stikinia during the latest Triassic and/or earliest Jurassic, and remained the locus of moderate extension during deposition of the Hazelton Group. Volcanic rocks of the group are diverse, comprising subaerially and subaqueously deposited lavas and volcaniclastic rocks of mafic to felsic composition. Calc-alkaline to tholeiitic characteristics, and depletion of high-field-strength elements relative to alkali and alkaline earth elements indicate a subduction-related origin. The degree of alkalinity (medium- to high-K) is fairly consistent throughout the group. The original width across which volcanism occurred is two to five times greater than widths of modern volcanic arcs. The anomalous width cannot be accounted for by time transgression of a single volcanic arc, because the two volcanic chains were coeval. Extremely low-angle subduction of a single oceanic plate is also rejected as an explanation because alkalinity does not differ significantly between the two volcanic chains. Genesis of the Hazelton Group above a single subduction zone is therefore considered unlikely. We propose a model in which a pair of oceanic plates were subducted beneath Stikinia from opposite sides, in a manner analagous to the tectonic regime of the Philippine archipelago. Subduction angles of the two downgoing plates are postulated to be 30° to a depth of 150 km, a configuration consistent with a postulated forearc width of about 175 km on each side. Stikinia is thereby considered to have been an 800-km-wide microplate on which two island arcs developed. The Hazelton Trough was a back-arc region common to both volcanic arcs. During deposition of the Hazelton Group, Stikinia was not part of the Intermontane Superterrane, an amalgam composed of more inboard terranes. Rather, it belonged to an oceanic microplate that accreted to the inboard terranes in late Early Jurassic to early Middle Jurassic time, during which Hazelton volcanism waned and ended.

INTRODUCTION

Ancient volcanic belts are important indicators of paleotectonic conditions and can place constraints on genetic models involving subduction, rifting, or collision. Ideally, a given volcanic field should be evaluated by integrating data from throughout its distribution. In particular, the data should include findings of stratigraphic, petrologic, and structural studies. In the Canadian Cordillera, ancient volcanic belts have received considerable attention, although in some successions critical information is lacking or has not been comprehensively integrated.

On the Stikine Terrane (Stikinia), the largest accreted terrane in British Columbia (2000 x 300 km; Figure 1), widespread Lower to Middle Jurassic volcanic and related sedimentary rocks are known as the Hazelton Group. The group comprises several volcano-sedimentary successions that together form a semicontinuous belt extending from approximately 52°N to 58°30'N. Many workers have studied parts of the Hazelton Group, and their combined contributions provide a regional view of volcanic and sedimentary deposition. Of particular importance is a comprehensive synthesis of Hazelton Group evolution in the central part of the Hazelton belt by Tipper and Richards [1976], which served as a benchmark for subsequent stratigraphic summaries [e.g., McGuigan and Harrison, 1986] and discussions of volcanism and tectonics [e.g., Brown, 1987; Mihalynuk, 1987]. Our paper provides a geological overview of the Hazelton Group and evaluates the tectonic setting of the group in terms of modern analogues.

Much of the western Canadian Cordillera (Figure 1) is composed of numerous suspect terranes [Monger, 1984]. Some may be inliers of attenuated Precambrian North American basement [Wanless and Reesor, 1975], while others are considered to be parautochthonous, pericratonic successions [Struik, 1986; Wheeler and McFeely, 1987]. In contrast, many of the terranes have oceanic rather than continental characteristics. These terranes, which include Quesnellia, Stikinia, Wrangellia and Cache Creek, probably represent, at least in part, late Paleozoic to Mesozoic island arc and back-arc systems. Evidence from paleomagnetic [Marquis and Globerman, 1988; Irving and Thorkelson, 1990; Irving and Wynne, 1990], and faunal studies [Monger and Ross, 1971; Smith and Tipper, 1986] suggests that some of these terranes spent parts of their histories at more southerly latitudes and have since been accreted to the Mesozoic North American margin and transported northward (although not necessarily in that order).

Stikinia, as it is generally recognized [Monger et al., 1982; Wheeler and McFeely, 1987], extends for 2000 km from

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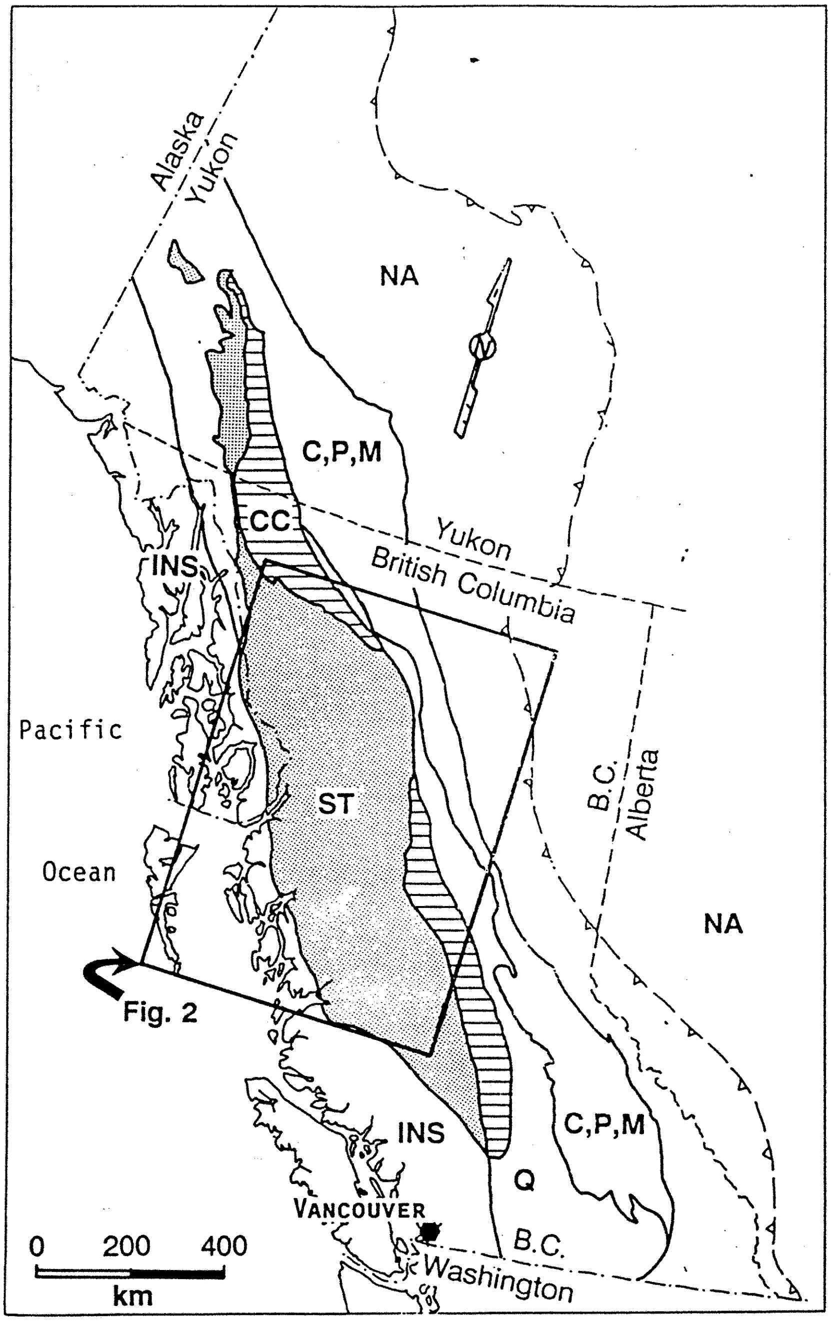

Fig. 1. Simplified terrane map of British Columbia, showing position of Stikinia and location of Figure 2 [after Wheeler and McFeely, 1987]. Terranes are NA, ancestral North America; C,P,M, terranes of continental, pericratonic, and marginal basin affinity (includes Nisling Terrane in the west and Yukon-Tanana Terrane in the north); Q, Quesnellia; CC, Cache Creek; ST, Stikinia; and INS, insular terranes.

south central British Columbia to the southern Yukon. In northern British Columbia it reaches a maximum width of approximately 300 km. Its oldest rocks, the Stikine assemblage [Souther, 1971; Monger, 1977; Gunning, 1990; Brown et al., 1991], comprise Devonian to Permian volcanic and sedimentary strata. However, in most regions this assemblage is absent or poorly exposed, and Stikinia is more commonly characterized by younger and more widely distributed volcanic and sedimentary rocks of the Upper Triassic Stuhini and Lewes River groups [Monger and Church, 1977; Monger, 1980; Tempelman-Kluit, 1979; Anderson and Thorkelson, 1990].

On the east, Stikinia is faulted against mainly the Quesnellia and Cache Creek terranes. The Cache Creek Terrane, characterized by strata of oceanic affinity [Monger, 1974; Thorstad and Gabrielse, 1986; Jackson et al., 1990], is regarded as vestiges of an ocean basin that separated Stikinia from Quesnellia and more inboard terranes. The accretion of Stikinia to ancestral North America could have occurred no sooner than the collapse of this basin. The earliest definite linkage between Stikinia and the Cache Creek Terrane is a succession of conglomeratic rocks of the Bowser Basin which were derived from the Cache Creek Terrane and deposited on Stikinia in Bajocian (early Middle Jurassic) and younger time [Souther and Armstrong, 1966; Currie, 1984; Gabrielse, 1991]. Initial stages of accretion occurred a few million years earlier, probably in the Toarcian [Tipper, 1978; Thorstad and Gabrielse, 1986; Ricketts and Evenchick, 1991; this paper] and certainly after the beginning of the Jurassic [Cordey et al., 1987; 1991; Hart et al., 1990; Jackson et al., 1990]. Therefore Stikinia was not part of a composite terrane (Intermontane Superterrane) which was shown by Monger et al. [1982] to have become amalgamated in the Late Triassic and juxtaposed with the ancestral margin of North America in the Early Jurassic. Rather, it belonged to an independent microplate until the late Early Jurassic when it began to impinge on a deforming assemblage of allochthonous terranes that was accreting to the ancestral North American continental margin [cf. Gabrielse, 1991].

The poorly defined western margin of Stikinia lies mainly within the Coast Plutonic and Metamorphic Complex, where contact relations with insular terranes are generally unclear. In northern British Columbia and the Yukon, however, recent field studies indicate that western Stikinia was juxtaposed with the Nisling Terrane (a constituent terrane of unit C,P,M in Figure 1) by the Late Triassic [Hart and Radloff, 1990; Mihalynuk and Mountjoy, 1990; Gehrels et al., 1990]. Both the southern and northern limits of Stikinia are poorly defined, and the original extent of Stikinia within the Cordillera is only generally known.

Mortensen [1992] showed that in the Yukon and Alaska, much of Yukon-Tanana Terrane (northern part of unit C,P,M) has a similar late Paleozoic and early Mesozoic history to that of Stikinia. He suggested that the Jurassic plutonic rocks of the Yukon-Tanana could have formed in the same magmatic arc as coeval igneous rocks on Stikinia. Similarly, Gehrels et al. [1990] and Jackson et al. [1991] speculated that the Nisling terrane could form the substratum to parts of Stikinia. Wernicke and Klepacki [1988] and Klepacki and Wernicke [1989] suggested that Stikinia and Quesnellia could have belonged to the same terrane prior to mid-Jurassic time, a notion contradicted by Mortimer [1986] and McGroder and Umhoefer [1989].

The validity of these and other terrane correlations is certain to be addressed by ongoing work. Ultimately, a thorough evaluation of the Hazelton magmatic belt will depend on appropriate terrane correlations and Mesozoic restorations. However, without a proper understanding of the Hazelton Group itself, correlations with Jurassic igneous rocks on other terranes may be premature. Indeed, detailed studies of Hazelton strata are likely to place constraints on models of terrane origin and interaction. We therefore limit our analysis of Lower and Middle Jurassic magmatism to volcanic rocks on what is conventionally regarded as Stikinia.

HAZELTON GROUP

Nomenclature

Jurassic stratigraphic nomenclature in north central British Columbia was clarified by Tipper and Richards [1976, p. 5], who redefined the Hazelton Group as "...basaltic to rhyolitic volcanic rocks, sedimentary rocks, their tuffaceous equivalents, and minor limestone that were deposited in Early and Middle Jurassic (Sinemurian to early Callovian) time." Since then, many geologists working in Mesozoic rocks of northern and central British Columbia have adopted that terminology. We concur and broaden that description by defining the Hazelton Group as all Lower to Middle Jurassic volcanic and related sedimentary rocks on Stikinia, south of about 58°30'N. This definition is designed to include basinal sedimentary equivalents of the volcanic successions and to exclude distal strata whose origin is generally unrelated to Hazelton volcanism. It is also consistent with a suggestion by H. W. Tipper (personal communication, 1991) that the top of the Hazelton Group should be placed at the end of early Bajocian time. The degrees to which a given sedimentary succession is temporally, spatially, and lithologically associated with volcanism are the criteria upon which its inclusion in the Hazelton should be based.

One important example of a unit that should belong to the Hazelton Group, under our definition, is a flysch succession in the Spatsizi River map area. The flysch, which is partly tuffaceous, overlies and interfingers with Lower Jurassic volcanic rocks and was formally named the Spatsizi Group by Thomson et al. [1986]. The volcanic rocks were regarded by those authors and subsequent workers [Evenchick, 1987; Thorkelson, 1988, 1992] as correlatives of the Hazelton Group as defined by Tipper and Richards [1976]. To be consistent with the dual volcanic and sedimentary character of the Hazelton Group, the Spatsizi flysch succession should be included in the Hazelton Group, perhaps as a set of formations, a view shared by C. A. Evenchick (personal communication, 1987); the term Spatsizi Group should be abandoned.

Other Lower and Middle Jurassic sedimentary successions, however, are not directly related to Hazelton volcanic rocks. The most obvious of these is the Bowser Lake Group, a molasse succession that postdates Hazelton volcanism [Tipper and Richards, 1976; Eisbacher, 1981]. Another unit that should perhaps be excluded is the Takwahoni Formation, a Lower Jurassic conglomeratic sequence deposited north of the Stikine arch (Figure 2). Although this voluminous succession is broadly correlative with the Hazelton Group, it is only locally intercalated with volcanic rocks (H. Gabrielse, personal communication, 1990) and was derived in large part by erosion of older rocks of the Stikine arch [Souther, 1971].

In northernmost British Columbia and the Yukon (Figure 1), rocks generally correlative with the Hazelton and Takwahoni are known as the Laberge Group. Like the Takwahoni, the Laberge comprises predominantly sedimentary rocks with minor volcanic members [Tipper,

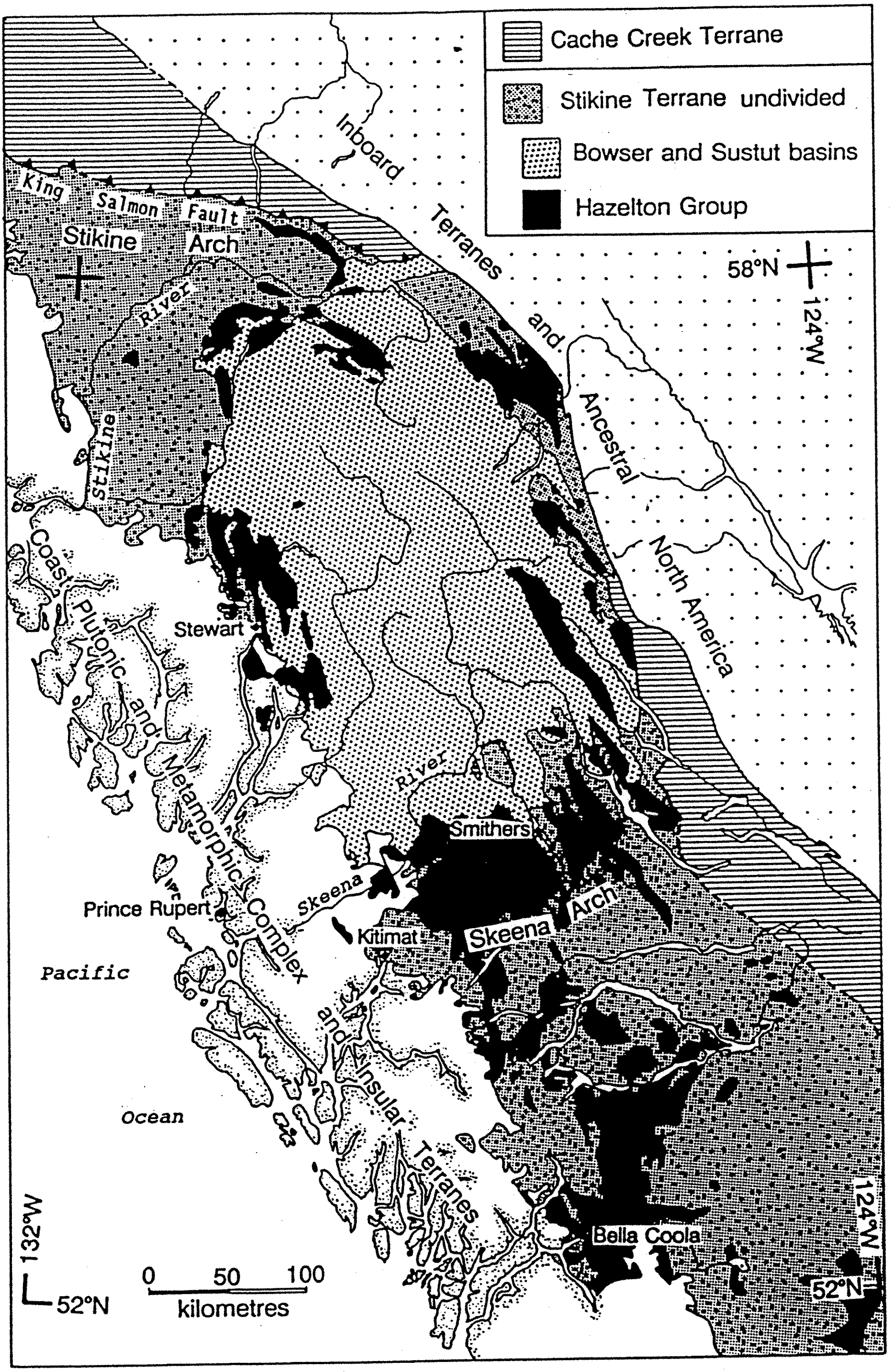

Fig. 2. Distribution of the Hazelton Group in northern British Columbia, in context of selected geological features (modified from Wheeler and McFeely [1987]). The Stikine Terrane (Stikinia) on which the Hazelton Group was deposited was thrust beneath the Cache Creek Terrane in Middle Jurassic time. Tectonic relationships between Stikinia and terranes to the west are largely obscured by the Coast Plutonic and Metamorphic Complex.

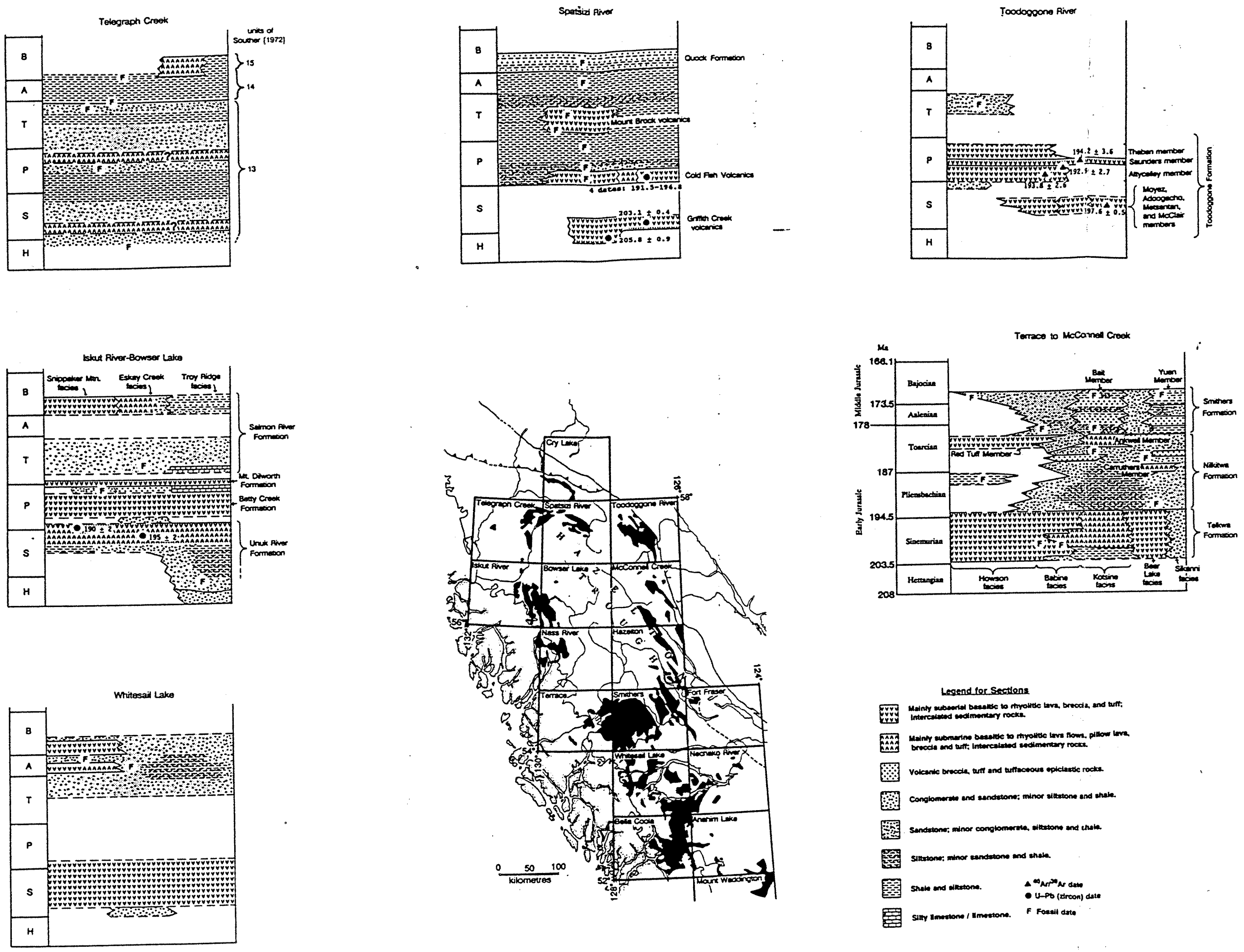

Plate 1. Generalized stratigraphic sections of the Hazelton Group. Age control, from fossil determinations and isotopic model ages, is indicated. Sources of information are given in text.

1978; Bultman, 1979; Hart and Radloff, 1990]. However, the sedimentary rocks are generally related not to Jurassic volcanism but rather to gradual erosion of a Triassic magmatic complex [Tempelman-Kluit, 1980; Hart and Radloff, 1990]. Thus north of the Stikine arch the influence of Jurassic volcanism on deposition was minimal. It may be preferrable to restrict the name Hazelton Group to rocks mainly south of the arch and to consider Lower Jurassic rocks north of the arch as part of the Laberge Group.

The Hazelton Group comprises many different facies and stratigraphic units which range in age from Hettangian or lower Sinemurian to Bajocian, spanning about 35 m.y. [Harland et al., 1990]. The Hazelton is exposed discontinuously over much of Stikinia, the various regions of outcrop being separated by areas of younger strata or deeper level rocks (Figure 2). Because individual lava and volcaniclastic units can be traced for relatively small distances, specific lithologic correlations from one region of volcanic rocks to the next are generally not possible. Rather, each volcanic succession can be related to its neighbors on the basis of age, general lithological character, and stratigraphic relations. Conversely, some of the sedimentary rocks of the Hazelton have been deposited as recognizable units over much larger areas and are useful as regional marker units.

A well-documented succession lies along the southeastern margin of the Bowser Basin, in the Smithers, Hazelton and McConnell Creek areas [Tipper and Richards, 1976]. There, the Hazelton Group is divided into three formations and several members and facies (Plate 1). The oldest formation is the Telkwa, a Sinemurian to (?)lower Pliensbachian succession of subaerial to marine, volcanic, and subordinate sedimentary rocks. The overlying Nilkitkwa Formation extends to the middle Toarcian and shows greater marine, sedimentary character. Capping the sequence is the volcaniclastic Smithers Formation which grades upward into sandstone of the Ashman Formation of the Bowser Lake Group, a transition that occurred in Bajocian and Bathonian time.

It is tempting to apply the nomenclature of this succession to other regions. For sedimentary rocks, correlations may be valid and useful. For example, the Yuen member of the Smithers Formation is a distinctive, thinly bedded, black and light grey tuffaceous siltstone unit of Toarcian to middle Bajocian age. Rocks of similar age and lithology are known in the Spatsizi River area as the Quock Formation [Thomson et al., 1986] and in the Iskut River area as the Troy Ridge facies of the Salmon River Formation [Anderson and Thorkelson, 1990].

Correlation of volcanic rocks is more difficult for two reasons. First, the volcanic piles are likely to have been far less laterally extensive, probably forming volcanoes or volcanic fields separated by sedimentary basins. Second, determining age equivalence may be hampered by an absence of reliable isotopic or fossil dating. Correlations are further complicated by the lack of close agreement between fossil and isotopic ages, as indicated by the large (5-15 m.y.) uncertainties of Early to Middle Jurassic stage boundaries on the Harland et al. [1990] time scale. Poor agreement is also indicated by inconsistencies of up to 4 m.y. between that time scale and those of Palmer [1983] and Cowie and Bassett [1989]. We have used the Harland et al. [1990] scale for correlations made in this paper.

Until equivalent methods of precise age determination are used, and agreement between fossil and isotopic dating is demonstrated, correlations between volcanic rocks in different areas will be difficult. Exacerbating this problem is the likelihood of episodic volcanism, with durations of igneous activity shorter than the resolution offered by even the most accurate techniques of dating. Consequently, the problems of age equivalence and abrupt facies changes tend to limit the validity of formation names to areas where stratigraphic continuity is recognized.

Stratigraphy

Regional mapping, principally by the Geological Survey of Canada and the British Columbia Geological Survey Branch, provides a secure basis for a stratigraphic summary of the Hazelton Group. In most regions, the Hazelton has been metamorphosed to zeolite or prehnite-pumpellyite grades [Tipper and Richards, 1976; Mihalynuk, 1987; Read, 1988; Marsden, 1990; Thorkelson, 1992] and primary textures are typically well preserved. In spite of widespread block faulting, and in most areas, folding and thrust faulting, stratigraphic relations and environments of deposition are generally understood. Ages of most units are broadly known, and many have been dated to within a few million years.

A discussion of Hazelton stratigraphy begins with a review of the succession in the Terrace to McConnell Creek areas and progresses clockwise around the Bowser and Sustut basins. Various formations, members, and facies are discussed in relation to the geographical areas located in Plate 1.

Terrace, Smithers, Hazelton, and McConnell Creek areas. Tipper and Richards [1976] and Woodsworth et al. [1985] recognized three formations in the Terrace to McConnell Creek region. The oldest formation, the Sinemurian and possibly younger Telkwa Formation, unconformably to conformably overlies older rocks. In places, the base of the Telkwa is marked by heterolithic conglomerate containing clasts of rocks derived from the Permian Asitka Group, the Triassic Stuhini Group, and undated plutonic rocks. In the Terrace area, where chert, limestone, and granitoid-bearing conglomerates overlie Permian and Triassic rocks, some blocks of Stuhini argillite show evidence of soft sediment deformation during conglomerate deposition [Mihalynuk and Ghent, 1986]. That relationship suggested to G.J. Woodsworth [Mihalynuk, 1987] that the conglomerate was Triassic in age. The conglomerates are gradationally overlain by volcanic sandstone and tuff.

To the northeast, in the central part of the area, MacIntyre et al. [1987] described polymictic conglomerate containing clasts of greenstone and leucogranite derived from underlying, perhaps Stuhini Group rocks. The conglomerate grades upward into maroon crystal and lapilli tuffs of the Telkwa [MacIntyre et al., 1989]. In the Hazelton and McConnell Creek areas, similar coarse clastic rocks containing clasts of granite and Permian limestone are included in the Telkwa Formation as the Sikanni facies [Tipper and Richards, 1976]. In part, they fill channels eroded in Stuhini rocks and are thought to be of Sinemurian age [Monger and Church, 1977]. Elsewhere in that area, conglomeratic deposits are absent, and dominantly grey-green volcaniclastic rocks of the Stuhini Group grade upward into more reddish volcanic breccias of the Telkwa Formation.

Tipper and Richards [1976] showed that above the basal units, the Telkwa Formation consists of a predominantly volcanic succession with striking lateral variations. The Howson facies, in the Smithers area, is almost entirely subaerial. It consists mainly of mafic to felsic volcaniclastic rocks and subordinate lava. Mihalynuk [1987] included breccias of coarse augite-phyric basalt and overlying lavas of bladed feldspar porphyry in the Howson facies in the adjacent Terrace area. Those units share both lithologic character and stratigraphic order with Stuhini (western Takla) rocks in the McConnell Creek and other areas [Monger and Church, 1977] and are probably Triassic. In the Smithers area, however, the Howson facies has yielded Lower Jurassic fauna and is inferred to be Sinemurian where it grades into fossiliferous marine strata of the Babine facies.

The Babine facies, a mix of subaerial and marine volcanic rocks, reefal limestone and tuffaceous strata, crops out in the eastern part of the Smithers area. Farther northeast, in the Hazelton area, the Telkwa Formation is represented by the Kotsine facies, an entirely marine succession of basalt, tuffaceous shale, and greywacke. At the northeastern end of the region, mainly in the McConnell Creek area, the Kotsine gives way to a second region of predominantly subaerial deposits represented by the Bear Lake facies and the Sikanni facies. The Bear Lake, a mafic to felsic volcanic pile similar to the Howson facies, is flanked to the northeast by the conglomeratic and volcaniclastic Sikanni facies. Although the ages of the Kotsine, Bear Lake, and Sikanni facies are not well constrained, Tipper and Richards [1976] considered them to be correlative with the western facies of the Telkwa, i.e., Sinemurian to lower Pliensbachian.

In early Pliensbachian time, the voluminous and widespread volcanism of the Telkwa Formation was succeeded by more restricted and predominantly marine strata of the Nilkitkwa Formation [Tipper and Richards, 1976]. Sedimentary deposition was concentrated in the northwest trending Nilkitkwa depression, a marine trough inherited from the Kotsine facies of the Telkwa. Within the depression, two units of mafic lava were erupted: the upper Pliensbachian to lower Toarcian Carruthers member and the middle Toarcian Ankwell member. To the southwest, upper Pliensbachian marine sedimentary rocks atop the Telkwa Formation were succeeded by the Red Tuff member, a basaltic to rhyolitic, largely subaerial volcanic succession. Overall, the Nilkitkwa Formation represents a period of marine transgression and reduced volcanic activity, relative to the Telkwa succession.

In the middle Toarcian, following Ankwell and Red Tuff activity, deposition of lava and proximal volcanic rocks gave way to accumulation of more medial- and distal-facies sedimentary strata of the Smithers Formation [Tipper and Richards, 1976]. Although volcanic breccia and tuff are common, much of the Smithers consists of marine sandstone and siltstone derived from eroding highlands of older Hazelton formations. Sedimentation of this cycle thickened the earlier marine sequences and transgressed to the southwest over previously terrestrial parts of Nilkitkwa and Telkwa rocks. By late Bajocian time, a shallow sea had been established everywhere in the Smithers to McConnell Creek areas except along the Skeena arch (Figure 2), which remained emergent to the south.

Whitesail Lake, Nechako River and Bella Coola areas. In the Whitesail Lake area south of the Smithers area, Hazelton-age rocks have been correlated with the Telkwa and Smithers formations [Tipper, 1979; Diakow and Mihalynuk, 1987; Diakow and Koyanagi, 1988]. Like the Howson facies, the Telkwa correlatives in the Whitesail area are subaerially deposited, basaltic to rhyolitic lava and pyroclastic rocks. They gradationally overlie a maroon, basal conglomerate [Woodsworth, 1979]. The rocks correlated with the Smithers Formation differ from those in the type area by the presence of volcanic members. Some of those members are pyroclastic and are interbedded with epiclastic rocks of Aalenian age; others overlie Aalenian feldspathic sandstone. The latter volcanic succession, dominated by red and green tuffs and breccias, and rhyolitic lavas, indicates local emergence of a volcanic center within the otherwise shallow marine succession. Rocks equivalent in age to the Nilkitkwa Formation have not been recognized.

East of the Whitesail area, in the Nechako Lake region, the Hazelton Group consists of a generally marine sequence of rhyolitic to basaltic lava and fragmental volcanic rocks intercalated with various sedimentary rocks [Tipper, 1963]. On the basis of ammonite and pelecypod fossils, it is early Bajocian in age. A unit rich in chert clasts and previously thought to form a lower formation is now considered to be Cretaceous and not part of the Hazelton Group (H. W. Tipper, personal communication, 1991).

From the Bella Coola area, to the south, Baer [1973] described a succession of lava, breccia, and marine sedimentary rocks bearing early Bajocian ammonites. To the east, in the Anahim Lake area, van der Heyden [1991] obtained preliminary $^{207}Pb/^{206}Pb$ (zircon) ages of 189 ± 2 and 191 ± 2 Ma from Hazelton rhyolite. However, in these areas and those farther to the south and east, the Hazelton Group is poorly understood.

Iskut River, Bowser Lake and Nass River areas. Northwest of Smithers, in the Iskut River, Bowser Lake and Nass River areas, the Hazelton Group is divided into four formations extending from the Hettangian or Sinemurian to the Bajocian [Grove, 1986; Brown, 1987; Britton and Alldrick, 1988; Anderson and Thorkelson, 1990]. The lowest unit, the Unuk River Formation, consists of turbiditic sedimentary rocks overlain by mafic to intermediate lava and volcaniclastic deposits. The sedimentary section hosts rare fossils of (?) late Hettangian age [Grove, 1986; H. W. Tipper, personal communication, 1990] and spans an interval from near the Triassic-Jurassic boundary to perhaps the Pliensbachian [Anderson and Thorkelson, 1990]. Because the lower part of the sedimentary sequence may largely predate Hazelton volcanism, both locally and throughout Stikinia, arguments could be made to exclude it from the Hazelton Group.

The upper part of the Unuk River Formation includes andesitic lava and tuffaceous rocks and is capped, in some sections, by subaerial extrusions of hornblende-plagioclase-orthoclase andesite and (?)dacite dated by U-Pb (zircon) at 190±2 Ma [Brown, 1987]. Correlative, widespread intrusive rock known as the Premier porphyry was also dated by U-Pb (zircon) at 194.8±2 Ma [Alldrick et al., 1987], restricting the age of the Unuk River Formation to Pliensbachian or earlier. Overall, the Unuk River is a poorly defined formation with little paleontological control. The volcanic succession is probably largely marine and may be correlative with the Telkwa and/or Nilkitkwa Formations of the Smithers-Hazelton region.

Previously, some Upper Triassic volcanic and sedimentary rocks were included in the Unuk River [Grove, 1986; Alldrick et al., 1987, 1989]; those rocks are more appropriately regarded as part of the Stuhini Group [Anderson and Thorkelson, 1990]. A disconformity between the Stuhini Group and the Unuk River Formation is marked in places by conglomeratic deposits, some of which contain clasts of monzonite [Britton et al., 1989; Anderson and Thorkelson, 1990].

The Betty Creek Formation disconformably to (?)conformably overlies the Unuk River Formation and postdates emplacement of the Premier porphyry. It consists largely of maroon to green breccia, lava, lahar, tuff, and sandstone. Most of the lavas are andesitic and dacitic, although some contain serpentinized olivine [Anderson and Thorkelson, 1990] and may be basaltic. Upper Pliensbachian fossils were collected from near the top of the Betty Creek Formation [Smith and Carter, 1990].

Alldrick [1989] depicted the Unuk River Formation as a set of andesitic stratovolcanoes and restricted the Betty Creek Formation to an overlying, mainly epiclastic succession deposited in a sedimentary basin. However, if emplacement of the Premier porphyry was followed by a hiatus in volcanic activity, as suggested by Anderson [1989], then the Betty Creek Formation could be more suitably defined as products of the next volcanic cycle, i.e., predominantly subaerial volcanic and related sedimentary rocks not crosscut by Premier porphyry dykes (and stratigraphically beneath the next youngest formation). If that distinction is used, then the Betty Creek would include thick accumulations of maroon lava and would be favorably regarded as a composite volcanic pile.

Above the Betty Creek is the thin but widespread Mount Dilworth Formation, a marker unit comprising ash tuff overlain by welded and nonwelded dacitic ignimbrite, and (?)rhyolitic lava. Locally, this predominantly subaerial unit is separated from the Betty Creek by beds of limestone and/or chert [Anderson and Thorkelson, 1990]. The age of the Mount Dilworth is constrained by the upper Pliensbachian fossils in the underlying Betty Creek Formation and by Toarcian fauna in the overlying Salmon River Formation.

The Salmon River Formation is the youngest part of the Hazelton Group in the Iskut River area. As defined by Anderson and Thorkelson [1990], it includes a belemnite- and *Weyla*-bearing limy sandstone unit of Toarcian age and an overlying volcano-sedimentary succession of probable Bajocian age. The latter unit comprises three facies: a tuffaceous turbidite sequence in the east (Troy Ridge facies), a pile of felsic and mafic pillow lava in the center (Eskay Creek facies), and a possibly correlative (?)subaerial section of andesite to the west (Snippaker Mountain facies) mapped by Lefebure and Gunning [1989]. The Troy Ridge facies and correlative rocks in the Nass River area grade upward into Bowser basin strata [Anderson and Thorkelson, 1990; Greig, 1991]. Plutonic rocks from the Iskut River area have yielded U-Pb (zircon) isotopic ages of 186±2 Ma, 190±3, and 195±1 Ma, confirming an Early Jurassic, probably Pliensbachian to Toarcian, magmatic event.

Telegraph Creek area. Farther to the north, in the Telegraph Creek area, Souther [1972] divided a succession of predominantly marine volcanic and sedimentary rocks into three units. His lowest unit consists of granitoid bearing conglomerate, greywacke, and mafic, fragmental volcanic rocks. It yielded ammonites and pelecypods of Hettangian to upper Toarcian age. Recent mapping by Read et al. [1990] in the southeastern Telegraph Creek area showed that this unit includes possibly correlative andesitic to rhyolitic volcanics that extend southward into the Iskut River area. Souther's [1972] middle unit, comprising mostly shale and siltstone, hosts fossils of upper Toarcian and early Bajocian age. It conformably overlies the lower unit, and, in eastern Telegraph Creek, is conformably overlain by or faulted against [Evenchick, 1991] an upper unit of sedimentary rocks and mafic pillow lava. Altogether, this succession suggests that marine deposition of Hazelton strata occurred, perhaps uninterrupted, from Hettangian to the early Bajocian. The upper sequence of pillow basalt is part of a narrow, north trending belt of marine lava that extends southward into the Iskut River area as the Eskay Creek facies [Anderson and Thorkelson, 1990].

In northwestern Telegraph Creek, Brown et al. [1990] described a sequence of four Hazelton Group units with both subaerial and submarine affinities, and striking similarities to strata in the Iskut River area. They suggested correlations with the Salmon River and Mount Dilworth formations. Their lowest unit, a maroon lava and volcaniclastic formation, may be equivalent to nonmarine facies of the Unuk River or Betty Creek formations. Unlike the disconformable relations between the Hazelton and Stuhini groups in the Stewart area, modestly deformed Hazelton rocks in the northwestern Telegraph Creek area lie with angular unconformity on tightly folded Stuhini sedimentary strata [Greig and Brown, 1990].

Spatsizi River area. In the Spatsizi River area, east of Telegraph Creek, three temporally distinct volcanic successions of Hettangian to early Sinemurian, early Pliensbachian, and early to middle Toarcian ages occupy a northwest trending belt between the Jura-Cretaceous Bowser Basin and Late Cretaceous Sustut Basin [Gabrielse and Tipper, 1984; Thomson et al., 1986; Evenchick, 1986, 1987; Thorkelson, 1988; 1992; Read and Psutka, 1990]. The Hettangian to lower Sinemurian rocks, informally called the Griffith Creek volcanics [Thorkelson, 1992], consist of subaerial, and possibly marine, mafic and intermediate lava and clastic deposits. Some dacitic ignimbrites and related sills and dykes contain abundant quartz, hornblende and biotite, i.e., minerals which are rare in younger Spatsizi River area rocks (but common in dacitic rocks of the Toodoggone River area). The age of the Griffith Creek volcanics is known from two U-Pb (zircon) analyses of 203.1±0.4 and 205.8±0.9 Ma [Thorkelson et al., 1991; Thorkelson, 1992]. The succession overlies the Stuhini Group with apparent disconformity, as suggested by basal or near-basal conglomeratic strata containing undated chert and granitoid clasts, and Permian and Upper Triassic limestone clasts [Thorkelson, 1988; D.J. Thorkelson and M. J. Orchard, unpublished data, 1991].

The lower Pliensbachian succession, found exclusively in fault contact with older rocks, comprises bimodal volcanic rocks, limestone, and basinal epiclastic strata. The volcanic pile, known as the Cold Fish Volcanics, is mostly of subaerial origin and consists mainly of mafic lava flows, rhyolitic sills, lava, airfall tuff and ignimbrite [Thorkelson, 1992]. Its age was determined from intercalated sedimentary rocks that host abundant ammonite and pelecypod fossils [Thomson et al., 1986; H. W. Tipper, personal communication, 1986; Evenchick, 1991].

Stratigraphically above the volcanic pile is a conformable sequence of conglomerate, sandstone, siltstone, tuff, and shale yielding early Pliensbachian to early Bajocian fossils. Thomson et al. [1986] recognized these rocks as basinal equivalents of the Hazelton Group but named them Spatsizi Group. Because of their association with coeval volcanic rocks, they should be regarded as a sedimentary facies of the Hazelton Group.

In the northwestern part of the Spatsizi River area, the Toarcian part of the sedimentary sequence is intercalated with volcanic rocks called the Mount Brock volcanics [Read and Psutka, 1990; Thorkelson, 1992]. The volcanic strata were mainly subaerially deposited and consist of mafic to intermediate lava flows and subordinate felsic clastic deposits including welded ignimbrite. They differ from those of the Cold Fish Volcanics in their (younger) age and greater abundance of lavas with intermediate compositions. Very locally, Aalenian or Bajocian volcanism may have succeeded eruption of the Mount Brock volcanics.

Cry Lake area. In the Cry Lake area, north of Spatsizi, the Hazelton Group comprises volcanic and fossiliferous sedimentary rocks of early and late Sinemurian, early and late Pliensbachian, early Toarcian, Aalenian(?) and early Bajocian ages [Tipper, 1978, personal communication, 1991; Gabrielse et al., 1979]. The lowest part of the section consists of conglomerate rich in volcanic, granitic, chert, and limestone clasts, probably derived mainly from Triassic and upper Paleozoic rocks. The overlying strata consist of various epiclastic rocks of largely volcanic provenance, pyroclastic rocks, and possibly lava. Proximal volcanism seems to have been concentrated in the late Sinemurian, Toarcian, and early Bajocian. In the southwestern part of the area, Toarcian sedimentary rocks nonconformably overlie Upper Triassic granitic rocks [Anderson, 1980].

A succession of maroon and green volcanic rocks that gradationally overlie Upper Triassic strata and are overlain by Sinemurian rocks may also belong to the Hazelton Group [Monger and Thorstad, 1978; Anderson, 1983]. However, on lithologic grounds, they are more favorably regarded as Upper Triassic in age, and part of the Stuhini Group (H. Gabrielse, personal communication, 1990).

Toodoggone River area. In the Toodoggone area, to the southeast of the Cry Lake area, Hazelton rocks were informally divided by Carter [1972] into a western felsic to intermediate sequence which he named the Toodoggone volcanics, and an eastern succession considered to consist of undivided Hazelton Group rocks. Subsequently, stratigraphic nomenclature has been refined [e.g., Diakow, 1985; Diakow et al., 1991; Marsden, 1990] such that the Toodoggone volcanics are now informally regarded as the Toodoggone formation and seven constituent volcanic members [Diakow et al., 1991].

Diakow et al. [1991] divided the Toodoggone Formation into two volcanic cycles. Rocks of the older cycle include the partly coeval Adoogacho member (mainly dacitic ignimbrite), the Moyez member (mainly airfall tuff), the Metsantan member (mainly an andesitic stratovolcanic succession), and the McClair member (andesitic lavas, and epiclastic rocks). The younger cycle consists of predominantly pyroclastic rocks of the Attycelley member and a widespread dacitic ignimbrite known as the Saunders member. The locally recognized Jock Creek section of Marsden [1990], is part of the Attycelley member. Capping the succession is the seventh unit, the Theban member, which comprises andesitic lava flows, coarse debris flow deposits, and finely laminated turbidites [Marsden, 1990]. This member may be partly correlative with the undivided Hazelton Group rocks in the eastern part of this area.

Numerous K-Ar (biotite and hornblende) isotopic dates obtained from the Toodoggone area range from 204±14 to 182±8 Ma, with older dates generally being derived from lower strata [Gabrielse et al., 1980; Diakow et al., 1985]. Subsequently, more precise $^{40}Ar/^{39}Ar$ dates have been obtained. From the same sample of the Adoogacho member that yielded the 204±14 Ma K-Ar date, Shepard [1986] obtained a $^{40}Ar/^{39}Ar$ date of 197.6±0.5 Ma, equivalent to the Sinemurian stage. More recently, Clark and Williams-Jones [1991] obtained $^{40}Ar/^{39}Ar$ dates on rocks of the second cycle [Diakow et al., 1991]. The Jock Creek section of the Attycelley member yielded a date of 193.8±2.6 Ma, the Saunders member was dated at 194.2±3.6 Ma, and a unit near the base of the Saunders member was dated at 192.9±2.7 Ma, all of which correlate with upper Sinemurian or lower Pliensbachian stages (uncertainty of all dates at 95% confidence level).

From an anomalous outcrop of marine sandstone with uncertain field relations, H. W. Tipper [1978 and personal communication, 1990] identified middle to late Toarcian ammonites. The undivided Hazelton succession to the east of the subaerial Toodoggone Formation has not been studied in detail and may include subaqueously deposited rocks.

Regional Distribution of Lithofacies

During the Early and Middle Jurassic, various deposits of the Hazelton Group probably covered most of the southern half of Stikinia. Presently, however, the Hazelton Group crops out in a discontinuous pattern resembling the scattered pieces of a jigsaw puzzle. Perhaps the greatest obstacles to a reconstruction of the Hazelton Group are the Bowser and Sustut basins (Figure 2) [Eisbacher, 1981; Evenchick, 1991]. Deposits of the Hazelton Group are exposed around the periphery of these vast basins and may extend beneath them. In our attempt to produce a unifying model, we have assumed that depositional environments were relatively continuous and that Hazelton Group rocks on one side of the basins are related in a simple manner to those on another. Assumptions regarding the extent and type of Hazelton strata beneath the Bowser and Sustut basins are essential to the development of a depositional model.

In the Smithers to McConnell Creek areas, deposition of the Hazelton Group began in Sinemurian to early Pliensbachian time as a pair of broadly coeval, subaerial volcanic fields separated by a marine basin (Figure 3). Within the basin, mafic submarine volcanism and sedimentation occurred in the Sinemurian as the Kotsine facies. From Pliensbachian through Bajocian time, this area, called the Nilkitkwa Depression by Tipper and Richards [1976], was the site of continuing marine deposition. Only briefly, in late Pliensbachian to early Toarcian time, did

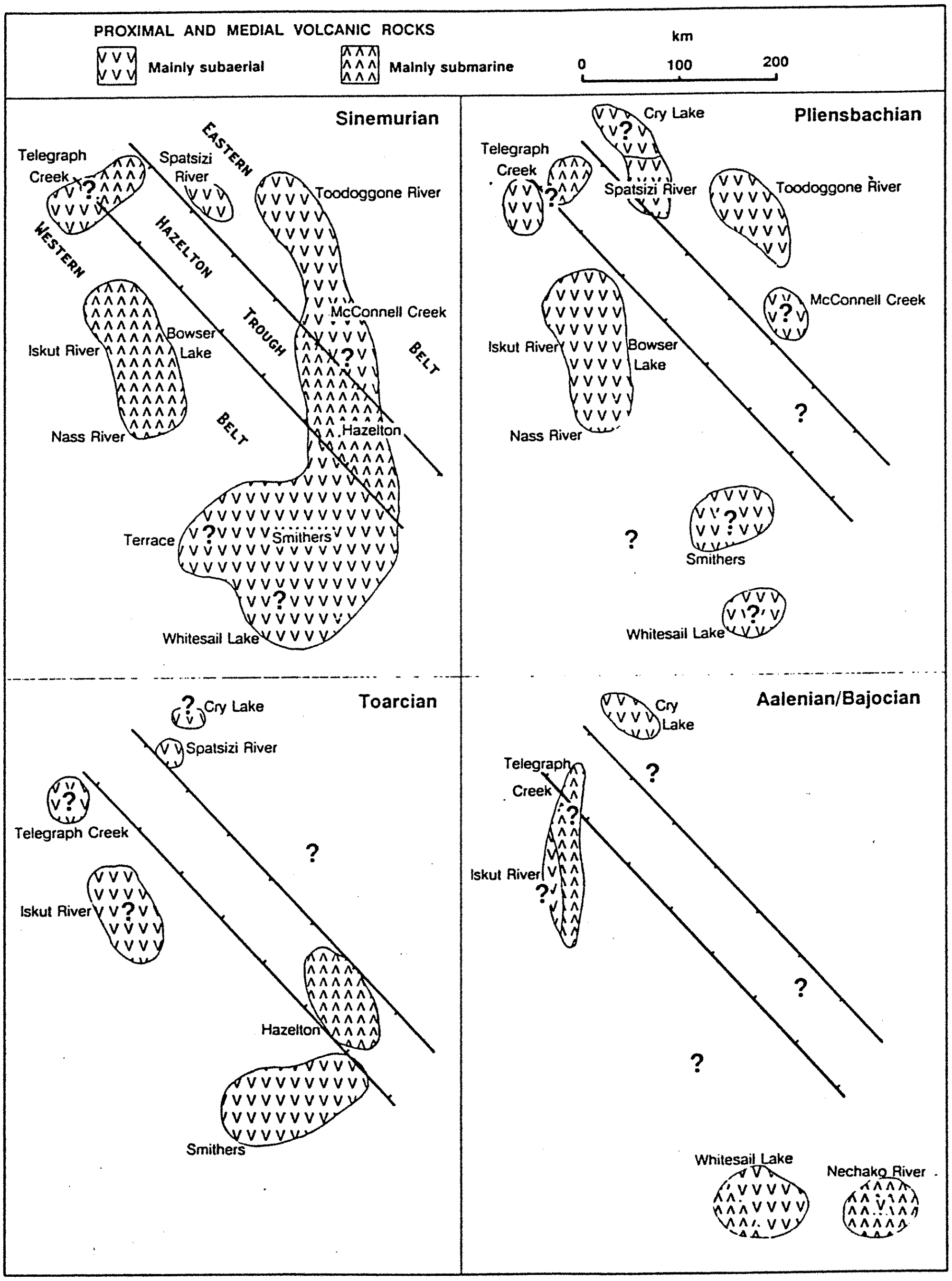

Fig. 3. Interpretive distribution of proximal and medial Hazelton volcanism on central Stikinia in Sinemurian, Pliensbachian, Toarcian, and Aalenian/Bajocian time. The Hazelton Trough, delineated mainly by depositional facies in Sinemurian to Toarcian time, is shown schematically in all frames.

subaerial conditions occur. In general, the sedimentary rocks in the depression are more shaly than those of the eastern and western belts, suggesting a persistently deeper water environment. To convey that this basin was flanked to the east and west by shallower marine and subaerial facies, Tipper and Richards [1976] used the term Hazelton Trough.

The flanking areas were sites of both marine and nonmarine deposition. The northeastern side of the trough, in the McConnell Creek area, was emergent for at least part of Sinemurian to early Pliensbachian time, when composite volcanic strata were deposited. Subsequently, deposition in that area occurred in a submarine environment. The southwestern side of the trough, in the Smithers and Terrace areas, was a more persistent locus of emergence and subaerial volcanism. Accumulation of composite volcanic strata took place during intervals in both the Sinemurian to early Pliensbachian and the middle to late Toarcian. Marine deposition occurred in parts of the Smithers area during late Pliensbachian and Bajocian times.

Tipper and Richards [1976] speculated that the Hazelton Trough was a regional, northwest trending feature. Although much of the evidence for this configuration is covered by the Bowser and Sustut basins, existing stratigraphic data from the peripheral areas tend to support this model of paleogeography. The axis of the trough may have trended northwestward from the Hazelton area toward the western side of the Spatsizi River area (Plate 1 and Figure 3). Although the depositional environment of Hazelton rocks in western Spatsizi River is generally not known, evidence for mainly marine conditions in that vicinity comes from immediately adjacent regions. In central Spatsizi River area, exposures of Pliensbachian to Bajocian marine sedimentary strata lie mainly to the southwest of nonmarine volcanic sequences. To the west, in the eastern Telegraph Creek area, strata record marine deposition from the (?)upper Hettangian to the early Bajocian.

Shallower marine and subaerial conditions were prevalent in the regions flanking the inferred trough axis. To the east, nonmarine volcanic successions of Pliensbachian, Toarcian and Bajocian age accumulated as islands or coastal edifices within, or adjacent to, marine sedimentary basins. In the central Spatsizi River area, following an earlier episode of Hettangian to lower Sinemurian nonmarine volcanism, lower Pliensbachian volcanic rocks accumulated as a mainly subaerial volcanic pile. After volcanism ceased, the volcanic strata subsided and were overlain by a Pliensbachian to Bajocian sequence of marine sediments. The sedimentation was interrupted by localized volcanism in the Toarcian which resulted in the emergence of yet another volcanic edifice. Similarly, volcanic and sedimentary deposits of the Cry Lake area record a history of mixed subaerial volcanism and marine sedimentation. In the Toodoggone River region, volcanism of Sinemurian, early Pliensbachian, and perhaps younger ages seems to have occurred in a primarily terrestrial environment, although shallow marine conditions were present, at least locally, in the Toarcian. As mentioned earlier, in the McConnell Creek area, subaerial volcanism in the Sinemurian or early Pliensbachian was succeeded by marine sedimentation. Together these relationships indicate that the eastern belt was characterized by episodic volcanism resulting in a chain of subaerial volcanoes, volcanic islands, and seamounts.

The western belt, like its eastern counterpart, was a long-lived volcanic chain, only parts of which were emergent or active at any given time. In the Sinemurian, for example, the Smithers and Terrace areas were sites of mainly subaerial accumulation. Lithologic correlations suggest that deposition of a similar, composite succession was also occurring to the south, in the Whitesail Lake area. In contrast, marine conditions were prevalent during sedimentation and volcanism in the Iskut River area, to the northwest. That distribution of facies was reversed in Pliensbachian time, when the Iskut River area and probably parts of the adjoining areas became new loci of subaerial volcanism, while marine sediments transgressed over parts of the volcanic successions in the Smithers and adjacent areas. Subsequently, intermittent marine and nonmarine volcanism during the Toarcian, Aalenian, and Bajocian were scattered throughout the western belt.

The existing data indicate that volcanic activity was greatest in the Early Jurassic, especially during the Sinemurian and Pliensbachian. Subsequent waning of magmatism may have been related to a decrease in the velocities of relative plate motions.

Emergence, Subsidence, and Extension

Subaerial conditions, in some cases, may have developed through the emergence of a volcanic island simply by the accumulation of lava and tephra. This process can explain the marine to nonmarine transitions in the Carruthers member of the Nilkitkwa Formation [Tipper and Richards, 1976] and the Unuk River/Betty Creek succession [Alldrick, 1989]. In other cases, however, nonmarine conditions were generated by causes other than volcano growth. In the Toodoggone area, for example, earliest Hazelton volcanism appears to have occurred on an already emergent landmass. A similar situation is evident throughout much of the Smithers and McConnell Creek areas [Tipper and Richards, 1976; MacIntyre et al., 1989] and in at least part of the Spatsizi River and Cry Lake regions. Indeed, widespread conglomeratic deposits near the base of the Hazelton Group indicate an increase in the amount of terrestrial landmass. Apparently, tectonism causing uplift, emergence and erosion of large areas of Stikinia preceded Hazelton volcanism [Tipper and Richards, 1976].

Uplift preceding or accompanying Hazelton volcanism also produced the Stikine and Skeena arches, a pair of elongate, emergent areas oriented at nearly right angles to the trend of the Hazelton Trough (Figure 2). The Stikine Arch, northwest of the Hazelton Trough, was the result of mainly Early Jurassic uplift, although some parts may have been emergent by the Late Triassic [Souther and Armstrong, 1966; Souther, 1971; Anderson, 1983]. Its erosion resulted in deposition of the conglomeratic Takwahoni Formation, north of the arch. Lower Jurassic plutonic rocks on the arch in the Cry Lake area [Anderson, 1983] imply that Hazelton volcanoes may have been located there. To the northwest of Figure 2, Lower and Middle Jurassic rocks are predominantly clastic, and coeval volcanic rocks are scarce.

To the south, the Skeena arch was the site of voluminous Jurassic magmatism. In the Sinemurian, this arch was emergent at its western end, where volcanic rocks of the Telkwa Formation were deposited. By the early Bajocian, uplift to the east had extended the arch across the Hazelton belt, exposing Lower Jurassic plutonic rocks and separating marine areas in the Whitesail and Nechako regions from areas to the north [Tipper, 1963; Tipper and Richards, 1976].

Submergence of parts of Stikinia is indicated by lithologic and faunal variations in Hazelton strata. In the Spatsizi River area, for example, Thomson et al. [1986] described periods of marine transgression in early Pliensbachian, late Pliensbachian, and Aalenian to Bajocian time. The early Pliensbachian transgression resulted in deposition of marine strata within and atop the Cold Fish subaerial succession. Synvolcanic subsidence is also indicated in the Toacican by marine strata within the maily subaerial Mount Brock succession [Read and Psutka, 1990]. In the Smithers and Hazelton areas, a major marine transgression occurred at the end of the Sinemurian. It resulted in marine deposition of the Nilkitkwa Formation over much of the subaerial facies of the Telkwa Formation. Subsequently, the Smithers Formation was deposited during a second period of submergence, in late Toarcian to Bajocian time. In other areas, such as Iskut River, the intercalation of marine and nonmarine strata (Plate 1) also indicates variable oceanic transgression and regression.

Subaerially deposited volcanic rocks in both the Telkwa and Cold Fish formations are directly overlain by marine strata. The absence of intervening successions of marine volcanic deposits infers that volcanism ceased prior to submergence. Most reasonably, the extinct volcanoes became submerged by a combination of subsidence, eustatic sea level rise, and erosion. Global sea level is inferred to have risen about 100 m during the Early Jurassic [Hallam, 1981; Vail and Todd, 1981], but this is far less than the combined thickness of some subaerially deposited Hazelton successions and their overlying marine sedimentary beds. For example, at least 800 m of subaerially deposited strata of the Cold Fish Volcanics are overlain by about 700 m of marine strata ranging in age from the early Pliensbachian to the Bajocian, indicating at least 1500 m of relative sea level rise. Similarly, the mainly subaerial Mount Brock volcanics are intercalated with marine horizons at stratigraphic levels at least 2000 m above the base of the formation. In neither case were the subaerially deposited volcanic rocks eroded by any significant amount prior to marine deposition. Subsidence is thereby indicated to have played a dominant role in the distribution of depositional facies.

Considerable evidence points to extension and block faulting of Stikinian lithosphere as a primary cause of subsidence. The geometry of the Hazelton Trough, and in particular the 4200 m of marine deposits in the Nilkitkwa Depression, prompted Tipper and Richards [1976] to invoke a model of crustal extension and graben development. They also cited the basaltic composition of the Ankwell and Carruthers members as evidence for extension. A similar argument could be made for the Spatsizi River area, where the Cold Fish Volcanics lie near the eastern margin of the trough. Their composition is strongly bimodal (mafic-felsic) and transitionally alkaline to tholeiitic [Thorkelson, 1988]. In the Iskut River and Telegraph Creek areas, incipient rifting in Bajocian time is indicated by a north trending belt of pillow lava [Anderson and Thorkelson, 1990].

Regional cooling related to waning magmatism may have contributed to subsidence. In both island arcs [Karig and Moore, 1975] and oceanic spreading centers [Crough, 1975], subsidence is a normal consequence of cooling after cessation of volcanism. Subsidence of volcanic fields may be also be caused by evisceration of underlying magma chambers, although this process is likely to produce local depressions such as calderas [Smith, 1979] rather than regional patterns of subsidence. Flexural depression of Stikinian lithosphere in response to overthrusting of the Cache Creek Terrane may have contributed to subsidence in Toarcian and later times [Ricketts and Evenchick, 1991].

The amount to which Stikinia extended during the Early and Middle Jurassic is likely to have been moderate; no sheeted dyke complexes, large areas of marine basalt, or other indicators of great extension have been reported. Neither the Stikine nor Skeena arches appear to have been split by rifting. Furthermore, extension appears to have been distributed over a broad area, consistent with incipient rather than advanced stages of rifting [Lee et al., 1990]. Indeed, the existence of a marine trough within Stikinia at the onset of Hazelton volcanism implies that some extension occurred earlier. Rifting is likely to have been initiated during the widespread uplift of Stikinia in an interval near the Triassic-Jurassic boundary. Uplift is known to have accompanied rifting of some Pacific island arcs [Carey and Sigurdsson, 1984]. The paucity of post-Bajocian Jurassic volcanism on Stikinia indicates that if extension continued after cessation of Hazelton volcanism, it is likely to have been minimal.

The Effect of Contractional Deformation on the Width of the Hazelton Belt

During Hazelton time, contractional deformation of the Hazelton Group may have been limited to the Cry Lake and Spatsizi River areas. In the Cry Lake region, southerly directed thrusting of Toarcian to Bajocian age is related to obduction of the Cache Creek Terrane along the King Salmon fault [Tipper, 1978; Thorstad and Gabrielse, 1986; Gabrielse, 1991]. In the Spatsizi River area, folding of unknown extent and significance occurred during Hettangian to early Pliensbachian time [Thorkelson, 1992].

Subsequently, telescoping of the Hazelton Group was widespread, although timing of deformation is not tightly constrained. In the Spatsizi River area, Evenchick [1986, 1987, 1991] showed that folding and thrust faulting occurred during Late Jurassic to Late Cretaceous or Tertiary time. The shortening, which involved Hazelton rocks, was estimated to average 44%. Evenchick [1991] further indicated that the deformation in the Spatsizi River area is part of the northwesterly trending Skeena Fold Belt, a regional feature embracing most of Stikinia south of the King Salmon fault. Because the amount of post-Hazelton shortening is likely to have exceeded the amount of syn- and post-Hazelton extension, the Hazelton belt is presently narrower than it was at the time of deposition. The width of the Hazelton belt as measured in composite transects perpendicular to the trend of the Hazelton Trough is presently about 350 km; it was probably between 450 and 550 km, at the beginning of Hazelton time (Hettangian) and somewhat wider by the end of the Bajocian.

Geochemistry

Several studies have shown that the chemical character of the Hazelton Group is generally calc-alkaline to tholeiitic and of arc affinity [e.g., Tipper and Richards, 1976; Forster, 1984; Brown, 1987; Thorkelson, 1988; Marsden, 1990; D. G. MacIntyre, personal communication, 1990]. From the Smithers-McConnell Creek area, Tipper and Richards [1976] described a northeastward increase in alkalinity of the Telkwa Formation. Most of their analyses, however, came from amygdaloidal lavas, breccias, tuffs, siltstones, and other samples not suitable for determining original magmatic composition. When analyses of only nonamygdaloidal lavas are plotted, the alkalinity trend is less apparent. Data from those samples and selected analyses from other sources are displayed on a total alkalies versus silica diagram (Figure 4). The data set comprises analyses from mainly lava and welded ignimbrite, i.e., rocks having low initial porosities, and presumably derived from individual batches of magma.

Data are grouped by geological regions. The eastern data represent Sinemurian to Pliensbachian rocks from the Toodoggone River area [Marsden, 1990] and Sinemurian to (?)Pliensbachian rocks from the McConnell Creek area [Tipper and Richards, 1976]. Data from the east-central and central areas were obtained from Toarcian, lower Pliensbachian, and (?)lower Sinemurian volcanic strata in the Spatsizi River area [Thorkelson, 1992], and the Hazelton area [Tipper and Richards, 1976], respectively. The western data were derived from (?) Sinemurian to Pliensbachian rocks in the Iskut River area [Brown, 1987] and Sinemurian to (?) Pliensbachian strata in the Smithers area [Tipper and Richards, 1976].

Data from all regions show considerable scatter and straddle the alkaline-subalkaline discriminant line of Irvine and Baragar [1971]. Much of the scatter is probably a result of alkali mobility during low-grade metamorphism. Rocks from the western belt appear to be slightly less alkaline than those from the other regions, but whether this difference is real or an artifact of alteration is unclear.

Examination of trace element profiles reveals that alkalinity does not vary significantly from region to region.

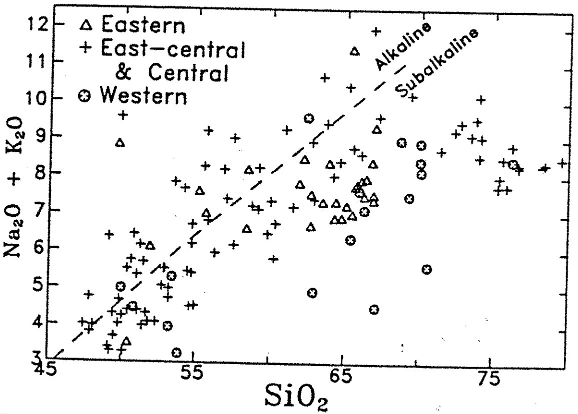

Fig. 4. Total alkalies versus silica diagram, showing alkalinity trends for eastern, east central and central, and western regions. Discrimination line is from Irvine and Baragar [1971]. See text for sources of analyses.

Figures 5a-5c show data from mafic and intermediate samples normalized to average mid-ocean ridge basalt (N-MORB values of Sun and McDonough [1989]) for three geological regions. Patterns from the western, east-central, and eastern areas show similar patterns, with alkali and alkaline earth elements generally enriched with reference to high-field-strength elements (Nb, P, Zr, Ti, Y). As illustrated by Pearce et al. [1984], this type of pattern is typical of moderately to highly alkaline arc lavas. In Figure 5d, the most mafic sample from the western set is compared with an andesite of similar MgO contents from each of the other two areas. The similarity in alkalinity and overall shape among the profiles is remarkable. Nb concentrations apparently increase from east to west, but whether this trend is real or a result of inaccurate Nb determinations is uncertain. In the western data set, for example, the reported concentrations of Nb range from 8 to 13 ppm, with a precision of about 11 ppm [Brown, 1987]. Variations in Sr levels are probably a result of plagioclase fractionation.

IN SEARCH OF A TECTONIC MODEL

Rejection of Actualistic Models

The overall marine setting, arc chemical signature, and apparent lack of continental influence on sedimentation suggest that the Hazelton Group evolved as an island arc. However, in our search for a modern analogue we realized that the Hazelton volcanic belt, at least 450 km wide, was significantly broader than any modern island or continental arc. The difference is greatest when the Hazelton is compared to island arcs generated by a single subduction zone, such as the Aleutian, Sunda, Kurile, Mariana, Tonga, Scotia, and Caribbean arcs. In those systems, the width of the modern arc is generally less than 50 km. In tectonically more complex areas, such as the Philippines and Papua New Guinea, or where volcanoes overlie continental crust, as in South America, Mexico, Japan, Kamchatka, and Iran, arc widths range up to 250 km. Even in wide arcs, however, volcanic activity tends to be concentrated within 100 km of the volcanic front and decreases sharply across the remaining distance [Sugimura, 1968; Gill, 1981].

Widths of arc and back-arc pairs commonly exceed the inferred width of the Hazelton field. An island arc-back-arc model is therefore appealing. However, back-arcs behind island arcs, such as those in the Sea of Japan, the Mariana Trough and the Lau Basin, are entirely submarine. Their lavas are more basaltic and generally more tholeiitic than coeval rocks of the arc [Gill, 1976; Eguchi, 1979; Saunders and Tarney, 1984]. Furthermore, back-arc basins commonly separate active arcs from submerged, extinct, remnant arcs [Karig, 1971]. Thus, if the Hazelton Trough was an area of marine back-arc extension, then one of the volcanic chains flanking the trough probably would have become extinct and submergent, while the other remained active. Systematic changes in composition would also be expected. Instead, intermittent, subaerial volcanism of similar chemical character occurred on both sides of the trough from Sinemurian to Bajocian time.

A continental arc and back-arc model for the Hazelton is also inappropriate. In terrestrial areas, such as the Andes,

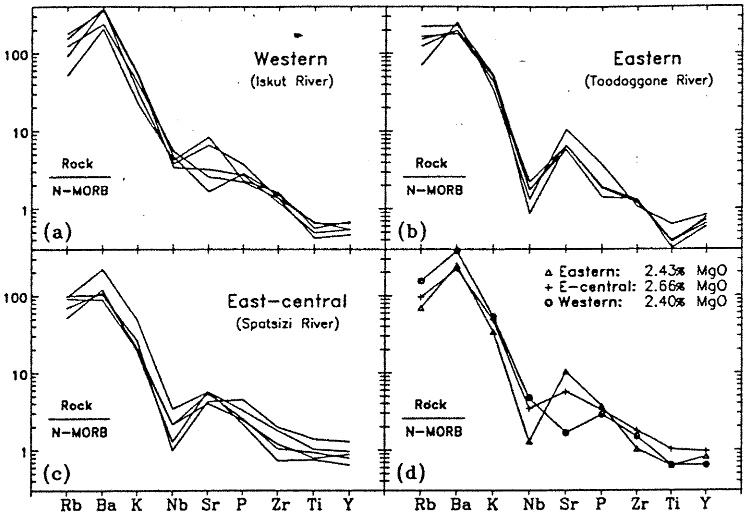

Fig. 5. Trace element profiles of the Hazelton Group: (a) western area, samples B-340, B-382, B-454, B-455, DB-105 (source is Brown [1987]); (b) eastern area, samples 89-33, 8-25-14, 8-50-16, 8-56-2, 9-2-5 (source is Marsden [1990]); (c) east central area, samples 86-23-5, 86-40-6, 86-40-8, 86-72-3, 86-M12-3 (source is Thorkelson [1992]); (d) comparison of samples B-340, 9-2-5, and 86-40-6.

and in coastal areas, such as Japan-Korea-China, back-arc activity is distinguished from arc volcanism by its greater distance from the trench, and shoshonitic to within-plate geochemical trends [Nakamura et al., 1989; Munoz and Stern, 1989]. Even if arc and back-arc are not clearly separable, as in the Eocene magmatic field of southern British Columbia [Ewing, 1981], progressive trenchward changes in composition, such as decreasing alkalinity, would be expected [Hatherton and Dickinson, 1969]. A wide arc produced by shallow subduction is also likely to show strong chemical trends and is thereby an unsuitable model for the Hazelton.

Some wide magmatic belts can be explained by changes in angle of subduction. For example, Coney and Reynolds [1977] explained the anomalous width of the Tertiary volcanic field in the western United States by relating steepening of the subducted slab to progressively trenchward younging of magmatism. In the Hazelton belt, the age of volcanism does not become consistently younger in any direction; volcanic rocks of Sinemurian, Pliensbachian, and Bajocian age crop out in both the eastern and western belts. If changes in slab dip were responsible for the unusual width, they must have been extremely rapid, resulting in alternate steepening and shallowing several times over a 35 m.y. period; this is an unlikely situation.

Hypothetically, a wide volcanic arc could be produced by rapid, oblique subduction of a slab that was segmented along transform faults. In that situation, the segments would have to be narrow, with alternate segments dipping at greatly differing angles. Where segmented slabs are present, such as beneath the Mexican [Nixon, 1982], Central American [Carr et al., 1982], and Andean arcs [Isacks and Barazangi, 1977], the segments are too wide and the angle of convergence too orthogonal to produce a broad volcanic field without significant across-arc variations in age.

Integrated Tectonic Model

No modern arc system is directly analogous to the Hazelton volcano-sedimentary succession. However, the great variety and complexity of island arcs worldwide suggests that many tectonic situations, not presently found, are possible. Accordingly, we have created a model based on modern tectonic and volcanic relations from several regions. Some of the main criteria that were used to develop the model are given below. Justifications for assumptions were made previously.

1. Hazelton Group volcanism began in the Hettangian to lower Sinemurian and ended in the Bajocian, an interval of about 35 m.y.
2. Hazelton deposition followed widespread uplift, block faulting and incipient rifting of Stikinia in the latest Triassic to earliest Jurassic. That tectonism produced an elongate marine basin called the Hazelton Trough.
3. The trough remained a locus of modest lithospheric extension and subsidence throughout much of Hazelton time. It was the site of marine sedimentation, and subordinate volcanic eruptions of basaltic to rhyolitic magma.
4. On both sides of the trough, volcanism was predominantly subaerial. Volcanic features included stratovolcanoes of basaltic to rhyolitic composition, felsic ignimbrite sheets, and seamounts.
5. Volcanism occurred across a width of at least 450 km and along a length of 800 km.
6. Uplift, mainly in the Early to Middle Jurassic, produced the Skeena and Stikine arches. These highlands trended across the axis of the Hazelton Trough, dividing Stikinia into subbasins and controlling patterns of sedimentation.
7. Stikinia was overthrust by the Cache Creek Terrane along the Nahlin, King Salmon, and other faults, beginning in Toarcian to Bajocian time.

8. Hazelton lavas, predominantly calc-alkaline to tholeiitic, have a strong arc signature. A progressive increase in alkalinity from one side of the Hazelton belt to the other is not apparent.

9. Volcanism was widespread, episodic, and approximately coeval in both belts.

Subduction. We suggest that Hazelton volcanism was generated by concurrent subduction of two oceanic plates beneath Stikinia from trenches on opposite sides (Figure 6). This arrangement could account for the anomalous width of the Hazelton volcanic field and the absence of regional trends in the age and composition of magmatism. Such inward dipping subduction is presently occurring beneath the Philippine archipelago (Figure 7) and the Caribbean region, and was proposed as a model for Neogene tectonics in the Solomon Island Arc [Musgrave, 1990].

Other regimes of paired subduction are inconsistent with Stikinian geology. For example, two subduction zones of the same polarity would be expected to produce a pair of volcanic arcs separated by an accretionary prism, trench and oceanic plate. That situation, similar to the pair of arc-trench systems on each side of the Philippine Sea Plate, could eventually result in collision of the two volcanic arcs. Ophiolites and deformed relics of the intervening sedimentary forearc region would likely form the core of the orogen. Similarly, two subduction zones dipping away from each other would also be expected to result in a deformed sedimentary wedge sutured between a pair of volcanic arc terranes. Such outward dipping subduction is presently occurring in the Molucca Sea, where a sedimentary basin is being compressed between the colliding Sangihe and Halmahera arcs [Silver, 1978].

The Hazelton Group, in contrast, does not represent a pair of amalgamated island arcs. Significantly, ophiolites and accretionary or collisional wedges separating one part of the Hazelton from another are absent. The Bowser Basin, the only reasonable candidate for such a wedge, was deformed mainly during an interval in Late Jurassic to Late Cretaceous time [Evenchick, 1986]. If it were an accretionary complex, deformation would have begun much earlier, occurring contemporaneously with Hazelton volcanism and basin sedimentation. Furthermore, the apparent continuity of Hazelton stratigraphy across the Terrace-McConnell Creek area seems to preclude the juxtaposition of different volcanic arcs. Most likely, Stikinia existed as a single block since at least the Late Triassic, when widespread deposition of distinctive Stuhini volcanic rocks occurred.

The modern Philippine archipelago (Figure 7) shares many similarities with our conception of Stikinia during Hazelton time. Like Stikinia in the Early Jurassic, the Philippines

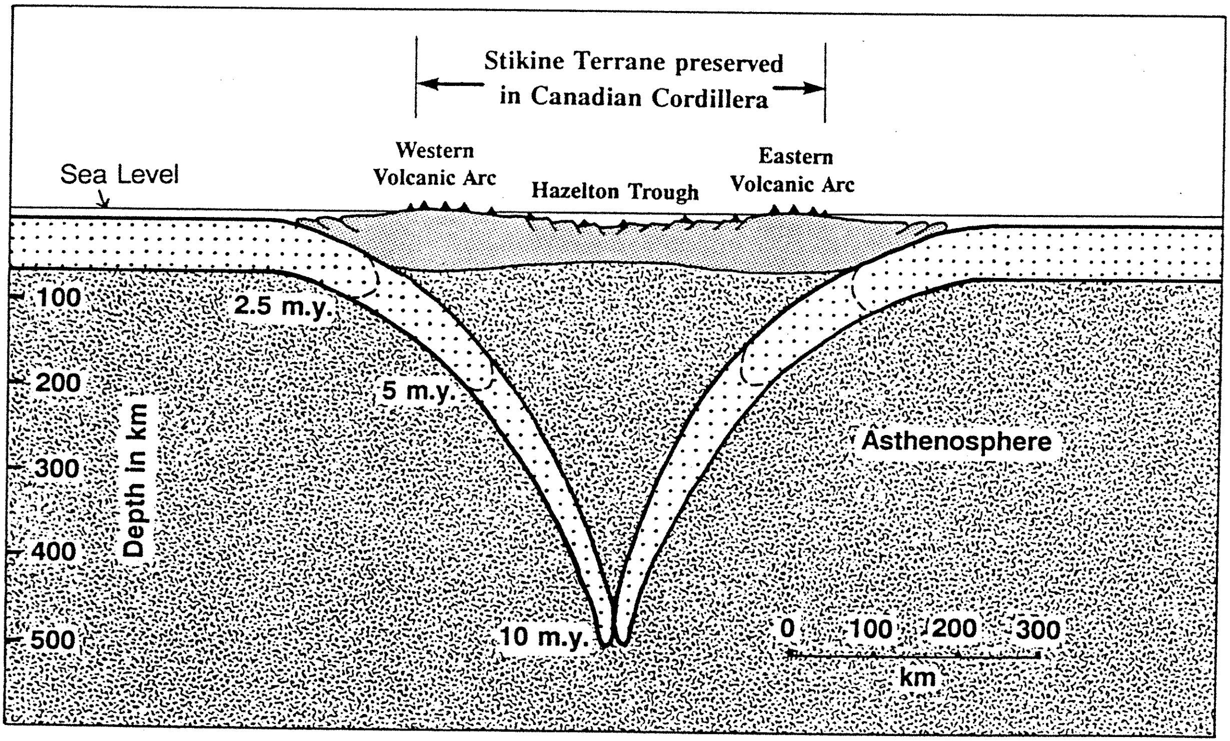

Fig. 6. Proposed tectonic setting of the Hazelton volcanic belt in the Early Jurassic, involving symmetrical, inward dipping subduction beneath the Stikinian microplate, beginning in early Hettangian time. Positions of the leading edges of the descending oceanic plates are indicated for 2.5, 5, and 10 m.y. of subduction, based on subduction rates of 7 cm/yr. Volcanism, beginning after about 2.5 m.y. of subduction, occurred in both the western and eastern arcs until Bajocian time, implying that subduction occurred either continuously or discontinuously for approximately 35 m.y.

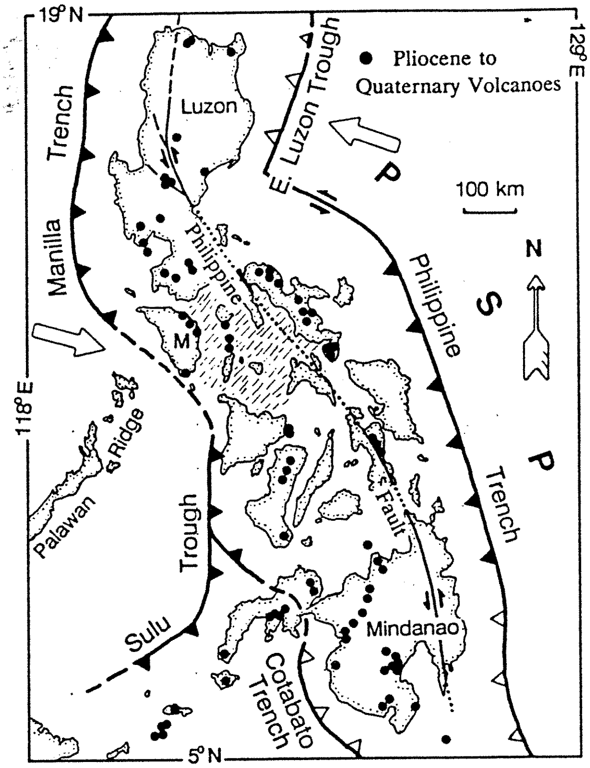

Fig. 7. Tectonics of the Philippine archipelago, showing zones of Neogene to recent subduction (solid teeth) and incipient subduction (open teeth). In the central part of the archipelago, Pliocene to Quaternary volcanoes form two chains generated by westward subduction along the Philippine trench and eastward subduction along the Manilla-Sulu trench system [after Divis, 1980; Cardwell et al., 1980; and Barrier et al., 1991]. Arrows show approximate relative plate motion directions. Shaded area near center of archipelago is the Marinduque Basin. M is island of Mindoru; PSP is Philippine Sea Plate.

comprise both large and small islands surrounded by marine channels and basins. Widespread volcanoes overlie older, variably deformed rocks of oceanic and arc origin. The volcanoes, generally of calc-alkaline character, form two chains which are related to inward dipping subduction of oceanic plates [Divis, 1980]. The northern part of the archipelago is undergoing extension [Cardwell et al., 1980].

One important difference between the Philippine archipelago and early Jurassic Stikinia is the length of time that opposing subduction zones are inferred to have been concurrently active. We speculate that the Hazelton arc was generated by synchronous subduction for about 35 m.y., whereas the opposing subduction zones of the Philippines have not been concurrently active for more than about 5 m.y. To the east of the archipelago, the Philippine Sea plate, having begun subduction only a few million years ago, has descended to a maximum depth of about 150 km along a west dipping Benioff zone [Cardwell et al., 1980]. Subduction is incipient at both the northern and southern ends. To the west of the Philippines, oceanic crust of the South China, Sulu and Celebes seas is descending along east dipping zones. Subduction at the Manilla trench and Sulu trough has been occurring for several million years [Karig, 1973; Hamilton, 1979] but is just beginning at the Cotabato Trench [Cardwell et al., 1980]. Progressive choking of the northwestern trench systems by the Palawan Ridge, and by the Asian continental shelf in the South China Sea, is resulting in gradual transfer of subduction to the eastern and southwestern systems.

If opposing subduction beneath a terrane the size of the Philippines were not interrupted, the descending slabs would likely intersect at some depth in the asthenosphere. It seems plausible that such intersection, especially at shallow depths, could cause slowing or termination of one or both of the subduction systems. In the Philippines, where paired subduction is occurring at dip angles of about 45°, from trenches that are 500 km apart [Cardwell et al., 1980], the slabs would meet at a depth of 250 km or more (depending on dip angles at greater depths). In such cases of paired subduction, a volcanic arc related to the descent of each slab would begin to form when slab depth reached about 100 km; activity in one or both of the arcs might diminish after slab intersection. If the subduction rate of each oceanic plate were 7 cm/yr, nearly 5 m.y. would pass between the time that both arcs became active, and intersection occurred. Thus, even for a small overriding plate, paired inward subduction could lead to a pair of well-developed, coeval volcanic chains.

At 500 km, the trench separation in the Philippines is significantly less than that in our model for Stikinia. Hazelton volcanism, occurring over a width of at least 450 km, is likely to have been generated above gently to moderately dipping subducted slabs. If their angles of subduction beneath Stikinia averaged 30° for the first 150 km of depth, then the arc-trench gaps on each side would be about 175 km, and the Stikinia microplate would have been at least 800 km wide. If subduction angles steepened to 65° with increasing depth, in a manner similar to several modern subduction systems [Isacks and Barazangi, 1977], then the slabs would have met at a depth of about 450 km (Figure 6). At reasonable subduction rates of 7 cm/yr, the volcanic arcs would have been concurrently active for about 6 m.y. prior to intersection. By the time the slabs met, however, they would have been considerably thinned and weakened by heating and deformation. Furthermore, they probably would have undergone phase changes as they descended below 400 km depth, causing them to become denser and to descend more steeply [Hsui, 1990]. As the slabs intersected, their leading edges may have rotated to vertical and sunk in tandem.

Frictional resistance to shear along the slab-slab interface may have tended to equalize the rates of descent, but may also have significantly increased resistance to relative horizontal motion. The degree of friction between the slabs would have been partly controlled by the amount of surface relief on the tops of the slabs. Relief in the area of intersection may have been inherited from bathymetric variations, especially those related to differences in lithospheric thickness across transform faults. Thus coalescence of the slabs may have tended to reduce the rates of convergence between the descending slabs, especially in the horizontal component of motion. This postulated decrease in relative plate motion may have been partly responsible for the observed trend of decreasing Hazelton volcanic activity in Pliensbachian to Bajocian time.

Inward dipping subduction is also occurring beneath the Caribbean plate. There, the Central American arc has formed in response to eastward subduction of the Cocos plate, and the Lesser Antilles arc has formed from west dipping subduction of the North American plate [Brown, 1976]. Hence the Caribbean plate is generally analogous to our model of Stikinia. However, the distance between the trenches flanking the Caribbean plate, 3000 km, is far greater than the 800 km minimum spacing suggested for Stikinia.

Extension and uplift in the Hazelton arcs. The Hazelton Trough may be generally regarded as a region of back-arc extension shared by both the eastern and western volcanic arcs. Aspects of the extension may be compared to intra-arc or back-arc rifting in several modern arc systems. On New Zealand, for example, back-arc rifting is occurring on the North Island. There, a set of andesitic stratovolcanoes lies immediately in front of the Taupo volcanic zone, a complex graben hosting recent, dominantly silicic volcanoes and ignimbrite sheets [Stern, 1985]. This zone of extension represents the southerly, landward continuation of the Lau-Havre trough, the back-arc basin to the Tonga and Kermadec island arcs. With continued rifting and subsidence, a narrow marine trough will probably develop within northern New Zealand.

The Taupo depression, only 50 km wide, represents rifting of a Mesozoic greywacke complex [Cole, 1979]. In contrast, the much larger Hazelton Trough developed on a more mature, largely crystalline terrane. This difference in basement type may explain the more favorable comparison of the Hazelton Trough to back-arc depressions located within continental or transitional crust. For example, in the East China Sea, rifting of the Asian continental shelf behind the Ryukyu Island Arc has produced a broad region of thinned continental lithosphere, the Okinawa Trough [Letouzey and Kimura, 1985]. Rifting began in the early or middle Miocene and continues today, a period of about 15 m.y. Tilting and foundering of crustal blocks and emplacement of mafic igneous rocks has occurred over widths up to 200 km. However, little if any oceanic crust has been produced. Thus both the breadth and longevity of Okinawa rifting are similar to those inferred for Stikinia.

Another broad, complex depression lacking a discrete spreading axis is found beneath the Aegean Sea. There, subsidence behind the Hellenic Arc has produced a shallow basin about 300 km wide. The basin is floored by attenuated sialic crust and widespread, mainly alkalic volcanic rocks. Although back-arc extension has occurred for about 15 m.y., crustal thickness remains at 25-30 km, and oceanic crust has nowhere been produced [Hsu, 1977; Lort, 1977]. Of course, both this region and the Okinawa Trough contrast with Stikinia by their relationship to single, not double, subduction systems.

Possible causes of rifting in the Hazelton Trough are as varied as the proposed mechanisms of lithospheric extension. They include slab hinge rollback, global plate kinematics, gravitational spreading, mantle convection, magmatic injection, oblique convergence, and collisional deformation (see discussions by Uyeda and Kanamori [1979], Wu [1978], Taylor and Karner [1983], and Wilson [1988]). Although any of these processes may have contributed to trough formation, the possibility of oblique convergence and partial coupling between Stikinia and the descending oceanic slabs seems particularly relevent.

Extension related to partial plate coupling is evident in the Philippines, where the eastern and western sides of the archipelago are being sinistrally offset along the Philippine fault (Figure 7) [Barrier et al., 1991]. Apparently, the eastern side of the Philippines is partially coupled to, and is being dragged northward by, the Philippine Sea plate. In the central part of the archipelago, the Philippine fault trends north-northwest. To the north, the trend becomes more northerly, resulting in a zone of transtension; as indicated by Cardwell et al. [1980], the northern part of the archipelago is extending. Sarewitz and Lewis [1991] suggested that the Marinduque basin, located south of Luzon Island, is an intra-arc pull-apart basin related to motion along splays of the Philippine fault. An example of more evolved extension is found south of Burma, where oblique subduction of the Indian plate has led to a complex pull-apart basin beneath the Andaman Sea [Curray et al., 1979].

Uplift and erosion of the Stikine and Skeena arches also accompanied Hazelton volcanism, but the origin and geometry of these highlands is unclear. The Stikine arch coincides closely with the northern limit of volcanism and appears to be a fundamental feature of Stikinia in the Early Jurassic. Possibly, it resulted from convergence between northern Stikinia and a landmass to the west, perhaps Nisling Terrane or other constituents of terrane unit C,P,M, in Figure 1. Alternatively, it may reflect (1) a change in the nature or orientation of the convergent zones flanking Stikinia, (2) tectonic underplating during subduction, or (3) contraction along a restraining bend in a strike slip fault system [cf. Greig et al., 1991].

An emergent area of the Philippines which is perhaps similar to the Stikine or Skeena arches comprises Mindoru and southern Luzon islands, northwest of the Marinduque Basin (Figure 7). Uplift of this region, which exposed deformed basement rocks [Faure et al., 1989], may be related to collision of the Palawan Ridge [Cardwell et al., 1980] or to an east-striking transcurrent fault extending across the archipelago [Divis, 1980].

Cessation of volcanism. The Cache Creek Terrane lies to the east of Stikinia, and the amalgamation of these terranes apparently marks the end to consumption of oceanic crust beneath the inboard side of Stikinia (Figures 2 and 6). As indicated by Tipper [1978] and Thorstad and Gabrielse [1986], the Cache Creek Terrane was thrust over Stikinia beginning in Toarcian to Bajocian time. A late Early Jurassic (Toarcian) time of initial amalgamation is supported by the paucity of Aalenian and Bajocian volcanism in the eastern arc (Figure 3) and by the "starved basin" facies Hazelton sedimentary rocks in the Spatsizi River area which were interpreted by Ricketts and Evenchick [1991] to indicate early stages of Cache Creek obduction. After middle Bajocian time, Hazelton volcanism ceased throughout Stikinia, not just on the inboard side, indicating that subduction at the outboard trench apparently stopped at about the same time.

To explain the demise of the outboard subduction system, we suggest that the accretion of Stikinia resulted in disruption and reorganization of microplate dynamics.

Significant changes in plate interactions would be expected, for example, if the Stikinian microplate underwent rotation (about a vertical axis) during collision. In support of this type of motion, we note that large rotations of Stikinia are suggested by paleomagnetic studies of the Hazelton Group [Monger and Irving, 1980; Vandall and Palmer, 1991].

Inactivity of the outboard subduction zone could also have been caused by collision of Stikinia with a more westerly terrane. Such an event is plausible because other terranes presently lie to the west of Stikinia and were accreted to Stikinia during intervals in the Mesozoic, conceivably in the Early or Middle Jurassic [van der Heyden, 1990; Currie, 1991]. Similarly, intersection of a spreading ridge with the outboard trench would have resulted in a new regime of relative plate motions and development of a slab window [cf. Dickinson and Snyder, 1979; Thorkelson and Taylor, 1989]. However, both of these scenarios require independent, synchronous intersections at both subducton zones and are therefore not favored. Whatever the causes, the demise of Hazelton volcanism is almost certainly linked to the accretion of Stikinia and to Jurassic contraction within and among more inboard terranes.

CONCLUSIONS

During the Early and Middle Jurassic, the Stikine Terrane (Stikinia) of the Canadian Cordillera was a partly emergent landmass on an oceanic microplate. This microplate, at least 800 km wide, was flanked on both sides by convergent margins along which oceanic lithosphere of neighboring plates was subducted. For about 35 m.y., paired subduction persisted, either continuously or discontinuously, producing episodic volcanism in a pair of island arcs. Subduction at both trenches must have begun in latest Triassic or earliest Jurassic time, i.e., a few million years before the onset of Hazelton volcanism. Hazelton volcanic activity began in the Hettangian or early Sinemurian, peaked in the Sinemurian to early Pliensbachian, decreased sharply in the Toarcian and Bajocian, and was extinct by the end of middle Bajocian time.

Prior to volcanism, Stikinia underwent incipient rifting that led to widespread uplift and erosion and subsequent development of an elongate marine basin (Hazelton Trough). Modest degrees of rifting continued throughout the period of volcanism and contributed to ongoing subsidence in and around the Hazelton Trough. The amount of extension decreased as volcanism waned, becoming insignificant toward the end of the volcanic activity.

The Stikine arch was an elongate highland oriented at nearly right angles to the axis of the Hazelton Trough. Its coincidence with the approximate northern limit of Hazelton volcanism underlines its importance as a fundamental feature of Stikinia in Hazelton time. It probably represents tectonically thickened lithosphere, possibly caused by underplating of Stikinia during subduction, interaction with other terranes, or uplift along a restraining bend in a transcurrent fault system. Transcurrent faulting, possibly the result of partial coupling between the Stikinia microplate and subducting lithosphere, may also have been responsible for uplift of the Skeena arch and for extension in the Hazelton Trough.

Cessation of Hazelton volcanism in the Bajocian coincided approximately with obduction of the Cache Creek Terrane onto Stikinia, an amalgamation that marks the termination of activity in the inboard subduction zone. Destruction of the outboard subduction zone is most reasonably explained by a general reorganization of microplate dynamics during accretion.

Voluminous chert detritus shed from the emerging Cache Creek Terrane was deposited in the Hazelton Trough, marking a new regime of sedimentation. The aerial extent of the resultant molasse succession generally defines the part of Stikinia that is regarded as the Bowser Basin.

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