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Stratigraphy of the Lower Cretaceous Monarch sequence at Mount Creswell in east-central Bella Coola map area, west-central British Columbia[1]

H.A. Sparks and L.C. Struik

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Abstract: Results of a detailed study of the Lower Cretaceous Monarch sequence at Mount Creswell, in Bella Coola map area (NTS 93 D), British Columbia, reveal large episodes of nonexplosive volcanism from nearby volcanoes alternating with relatively explosive volcanism from more distal volcanoes as major components of the sequence. Minor chaotic zones of sedimentation alternating with lava and pyroclastic flows may represent times of uplift and erosion followed by explosive eruptions from nearby sources and proximal volcanoes. The volcanic and sedimentary rocks from Mount Creswell are representative of the Lower Cretaceous volcanic rocks of the Bella Coola map area.

Résumé : Une étude détaillée de la séquence de Monarch du Crétacé inférieur, au mont Creswell, dans la région cartographique de Bella Coola (SNRC 93 D), en Colombie-Britannique, révèle que des composantes majeures de la séquence sont des produits d'éruptions non explosives de volcans avoisinants qui alternent avec des produits d'éruptions relativement explosives de volcans plus distaux. De petites zones chaotiques de sédimentation intercalées de coulées de lave et de matériaux pyroclastiques pourraient représenter des épisodes de soulèvement et d'érosion suivis d'éruptions explosives de volcans avoisinants et proximaux. Les roches volcaniques et sédimentaires du mont Creswell sont représentatives des roches volcaniques du Crétacé inférieur que l'on trouve dans la région cartographique de Bella Coola.

[1] Contribution to the Targeted Geoscience Initiative

INTRODUCTION

This report describes and interprets the petrography and depositional characteristics of the Monarch sequence of the eastern Bella Coola (NTS 93 D) map area, west-central British Columbia (Fig. 1). It concentrates on the stratigraphic section west of Mount Creswell (Fig. 2) examined during the 2001 field season. The study is part of the Bella Coola Targeted Geoscience Initiative (TGI) project (2000–2003) funded by the Geological Survey of Canada, the British Columbia Ministry of Energy and Mines, and the universities of British Columbia and Wisconsin at Eau Claire. This 1:50 000-scale bedrock mapping project was undertaken to investigate the geological environment, history, and volcanic-hosted massive sulphide potential of the eastern Bella Coola map area (Struik et al., 2002).

REGIONAL SETTING

The Bella Coola map area, originally mapped by Baer (1973) at a scale of 1:250 000, straddles the boundary of the Intermontane and Insular superterranes (Fig. 3). The eastern half of the map area, the focus of the Bella Coola TGI project, is dominated by extensive volcanic and sedimentary sequences of Middle Jurassic to Lower Cretaceous rocks. Middle Jurassic volcanic and lesser sedimentary rocks underlie the eastern margin of the map area and have been correlated regionally with the Smithers Formation of the Hazelton Group (Diakow et al., 2002). Lower Cretaceous rocks have been correlated regionally with the Monarch sequence to the southeast (Rusmore et al., 2000). The Lower Cretaceous rocks of the Bella Coola map area were deposited onto and intruded by multiple, generally intermediate-composition plutonic rocks of the Coast Plutonic Complex (Diakow et al., 2002; Hrudey et al., 2002; Struik et al., 2002). Rocks in the northernmost Bella Coola map area, composed of elongate northwest-trending dioritic stocks of probable Middle and Late Jurassic age, have been correlated regionally with plutonic rocks in the southernmost Whitesail Lake map area (NTS 93 E; Diakow et al., 2002). A system of well developed, northwest-trending, northeast-verging folds and subordinate thrust faults affects rocks through the central portion of the map area (Mahoney et al., 2002). Rusmore and Woodsworth (1994) inferred these northeast-verging fold systems to be Late Cretaceous, correlating them with structures in the eastern Waddington fold and thrust belt.

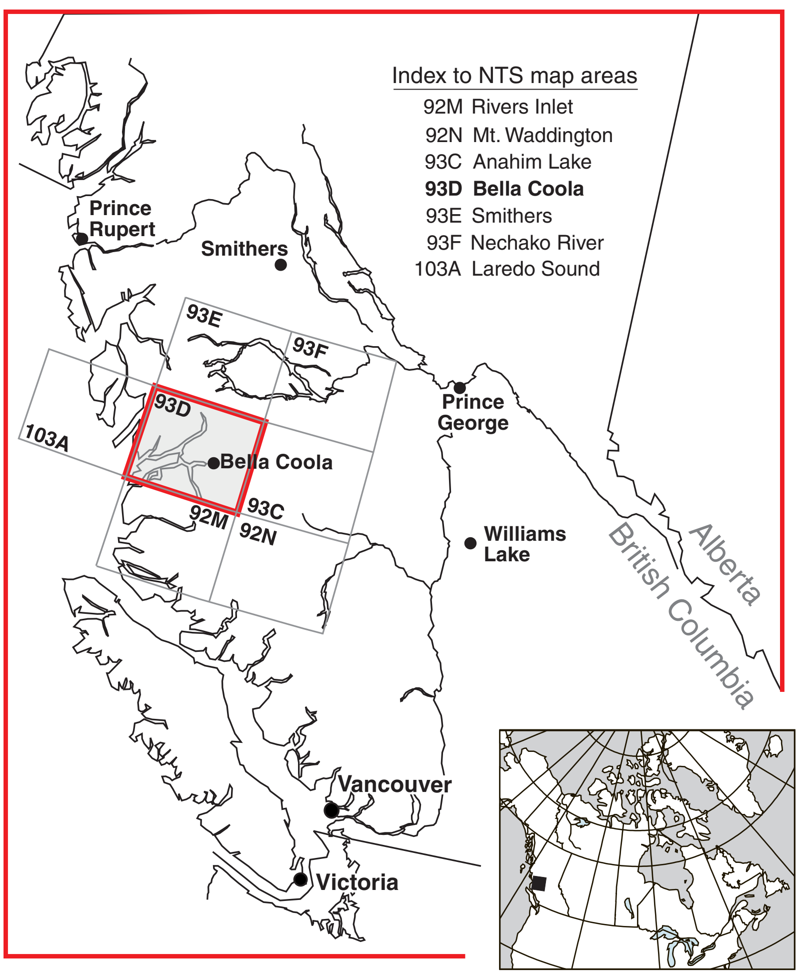


Figure 1.

*Location of the Bella Coola map area (NTS 93D) in west-central British Columbia with respect to adjacent map areas (*after *Struik et al., 2002).*

MONARCH SEQUENCE

Rocks of the Monarch sequence were first described briefly by Baer (1973), named by van der Heyden (1991), and described in more detail by Rusmore et al. (2000). This Early Cretaceous sequence was deposited on Jurassic to Lower Cretaceous plutonic rocks (Struik et al., 2002) and Middle Jurassic rhyolite and andesite of the Hazelton Group (Diakow et al., 2002). In a broad region west of Crag Creek and Noosgulch River and east of the Dean Channel (Fig. 2), the Monarch sequence consists of a thick succession of andesitic to lesser rhyolitic fragmental rocks and flows and clastic sedimentary rocks. The basal contact varies in nature throughout the map area, as would be expected of a sequence dominated by volcanic rocks. At Salloomt Peak, basal Monarch sequence is a polymictic conglomerate containing clasts of volcanic and plutonic origin, overlying a quartz diorite pluton dated at 134 ± 0.3 Ma (U-Pb zircon crystallization age, van der Heyden, 1990). The contact between Monarch sequence and Hazelton Group near Tzeetsaytsul Peak is inconspicuous

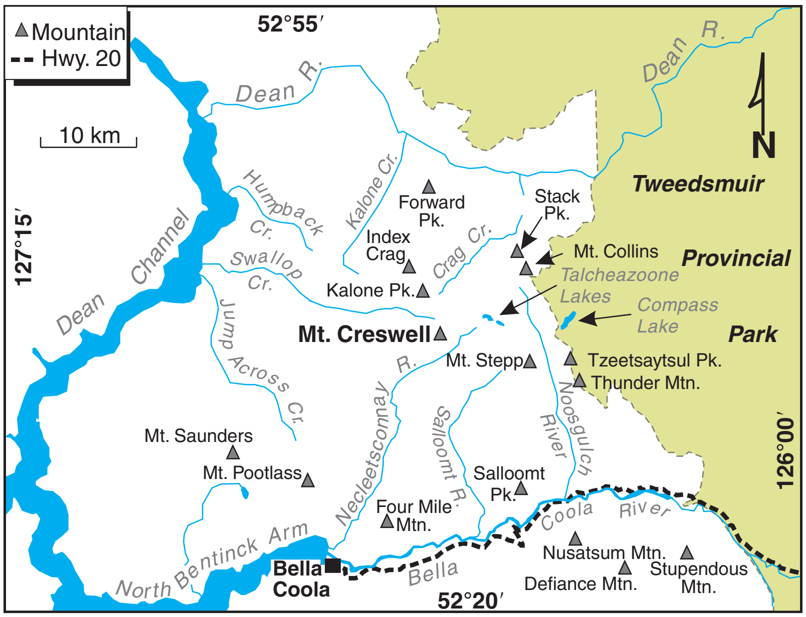
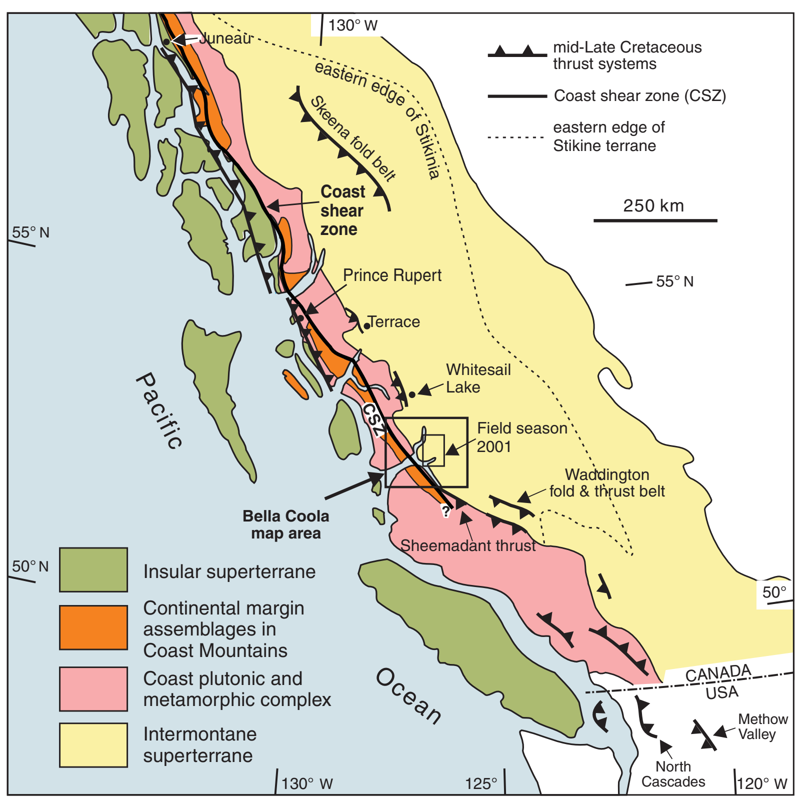


Figure 2.

*Northern portion of Bella Coola (east half) map area showing locations of geographical features referred to in the text, with emphasis on Mount Creswell (*after *Struik et al., 2002).*

Figure 3.

*Relationship of the Bella Coola map area and area mapped during 2001 to the physiographic and tectonostratigraphic terranes of the Canadian Cordillera (*after *Struik et al., 2002).*



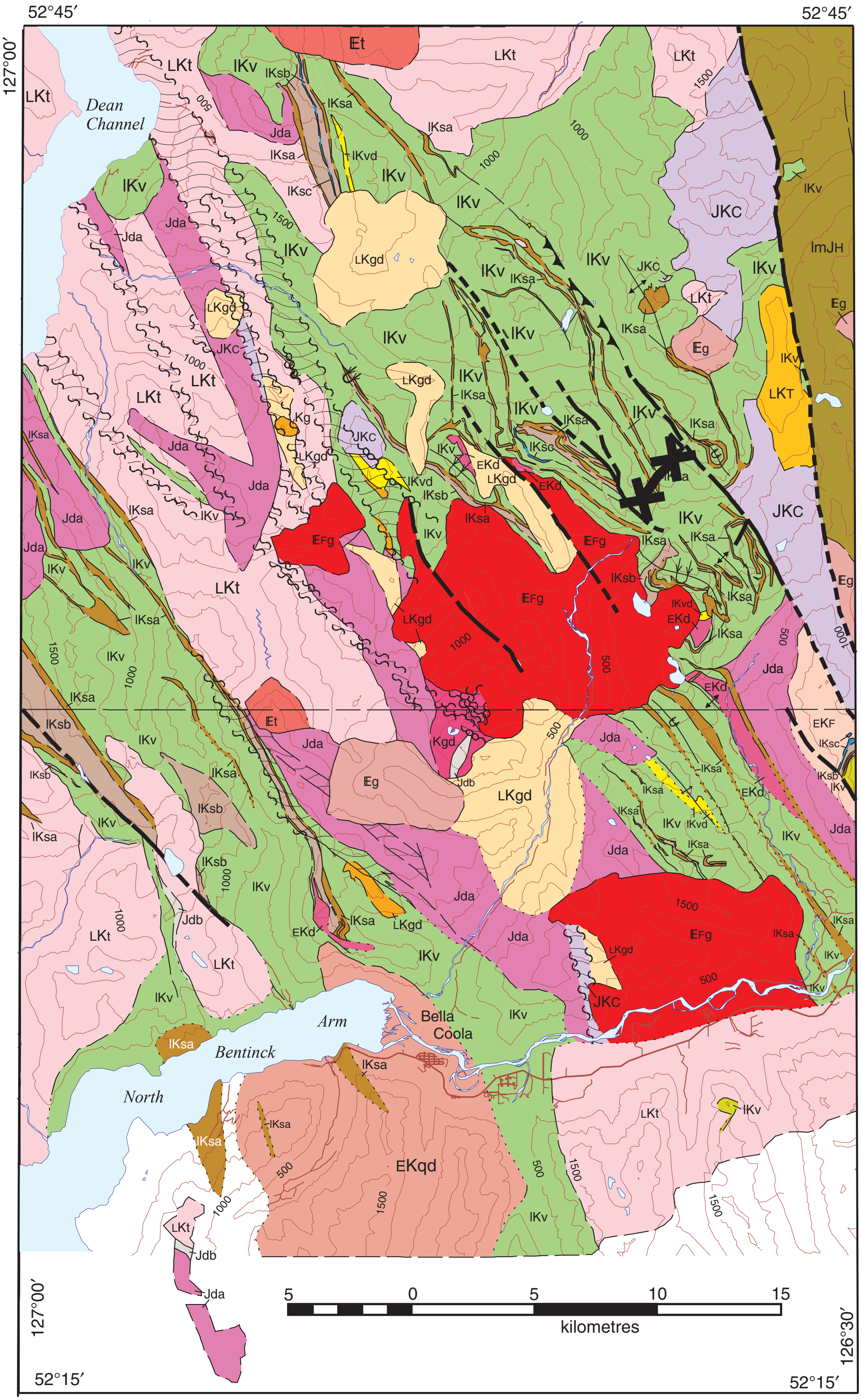


***Figure 4.** Geological map of NTS map areas 93 D/10 and part of 93 D/07 (*modified from *Struik et al., 2002). Contour interval is 500 m. The thick dark line terminated with crosses shows the Mount Creswell section.*

LEGEND FOR FIGURE 4

STRATIFIED ROCKS

LOWER CRETACEOUS

Monarch volcanic rocks (lKva - lKvd)

- **lKv** — *Andesite:* mostly fragmental breccia, lapilli and ash tuff, agglomerate, granule conglomerate, sandstone, and greywacke; pyroclastic rocks are dominated by heterolithic intermediate and locally abundant felsic pyroclasts; some flows, aphanitic to plagioclase±rare augite-phyric, locally calcite-chlorite-quartz-amygdaloidal, flow breccia, dykes, small microdiorite stocks; olive to olive-grey, locally maroon
- **lKvd** — *Rhyolite, dacite:* fine-grained tuff, sedimentary rocks
- **lKsa** — *Slate, argillite, siltstone, sandstone:* rusty argillite, laminated siltstone, feldspathic sandstone (arkose), minor granule-pebble conglomerate
- **lKsb** — *Sandstone:* feldspathic arkose, argillite
- **lKsc** — *Conglomerate:* rounded granule to cobble, feldspathic, granitic, and volcanic clasts

MIDDLE JURASSIC

- **mJH** — *Hazelton Group:* andesite, basaltic andesite; massive flows, aphanitic to plagioclase±augite-phyric lava, locally coarsely plagioclase-phyric, locally amygdaloidal, fragmentals, dykes, small microdiorite stocks, flow breccia, minor slate and volcaniclastic rock; olive-grey to dark grey, locally maroon

INTRUSIVE ROCKS

(?)EOCENE

- **EFg** — *Four Mile suite:* granite; biotite and muscovite±garnet; medium grained, equigranular; pink, weathers white
- **Eg** — *Granite, granodiorite:* biotite; medium grained, equigranular; weathers yellow
- **Et** — *Tonalite:* biotite; medium grained; white; sheet jointed

(?)CRETACEOUS

- **Kgd** — *Granodiorite:* biotite, hornblende; medium to fine grained, equigranular; grey
- **Kg** — *Granite and granodiorite:* biotite, hornblende; medium to fine grained, equigranular; grey

(?)LATE CRETACEOUS

- **LKgd** — *Granodiorite:* biotite, hornblende; medium grained, equigranular; light grey
- **LKt** — *Tonalite:* biotite, hornblende; medium to coarse grained, equigranular; grey; locally sheet jointed
- **LKT** — *Talcheazoone pluton:* quartz diorite: biotite, hornblende, medium grained; white; foliated; pendants of amphibolite

(?)EARLY CRETACEOUS

- **EKqd** — *Quartz diorite:* biotite, hornblende; medium grained, equigranular; grey; sheet jointed; ca. 119 Ma
- **EKd** — *Microdiorite:* hornblende, some gabbro and amphibolite, locally subvolcanic to Monarch sequence andesite; equigranular; light grey to grey
- **EKF** — *Firvale suite:* granodiorite: chlorite-epidote-altered hornblende, rare hornblende-quartz monzonite; medium grained, equigranular; off-white to greenish; ca. 134 Ma

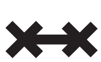
JURASSIC AND (?)CRETACEOUS

- **JKC** — *Crag Creek intrusive complex:* ±pyroxene, hornblende diorite, minor quartz diorite and gabbro invaded by hornblende granodiorite to monzogranite and younger rhyolite, plagioclase-phyric and aphanitic andesite and basalt; subvertical and locally sheeted dykes

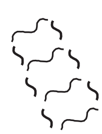
(?)JURASSIC

- **Jda** — *Diorite:* hornblende, ±biotite; medium grained, equigranular; foliated
- **Jdb** — *Hornblende diorite, gabbro, hornblendite:* heterogeneous, pegmatitic; medium and coarse grained; locally foliated

SYMBOLS



Location of partial stratigraphic section at Mount Creswell.



Location of shear zones

within a succession of andesite flows and fragmental rocks (Diakow et al., 2002). Struik et al. (2002) describe the local distribution of the Monarch sequence. Recent detailed work in the Bella Coola map area has expanded the extent of the Monarch sequence from that previously known.

Stratigraphy of the Monarch sequence is complicated by abrupt lateral facies changes and intense structural deformation recording episodic extensional, contractional, and transpressional tectonism (Mahoney et al., 2002). In this study, the volcanic and sedimentary rocks are subdivided into various lithofacies on the basis of their overall lithological character, continuity, original textures, and structures. These lithofacies consist predominately of fragmental rocks, lesser amounts of volcanic flows, dykes, and related breccia, and minor clastic sedimentary rocks (Fig. 4).

Fragmental rocks of ash to lapilli tuff and minor ignimbrite composed of andesite with lesser basalt and minor rhyolite and dacite dominate the sequence. They form aphanitic to plagioclase-phyric units (2 mm–2 m thick), weather olive-green to tan with local maroon beds, and commonly appear waterlain, exhibiting graded bedding, oscillatory ripples, and flame structures.

Volcanic flows, dykes, and related breccia composed mainly of andesite and basalt with lesser rhyolite and dacite make up a smaller component of the sequence. They form aphanitic to plagioclase-phyric to minor amygdaloidal units (2–200 m thick) of massive planar layers with sharp contacts, commonly with chill margins, and weather olive-green to olive-grey. Dykes are interpreted to be feeders to flows, fragmental volcanic rocks, and volcanoclastic rocks higher in the Monarch sequence (Struik et al., 2002). Breccia tends to be monomictic and is composed of very angular clasts and crystal fragments forming irregular deposits between flows.

Clastic sedimentary rocks of the Monarch sequence consist dominantly of sandstone, siltstone, and slate, with lesser conglomerate. The fine-grained clastic rocks are composed primarily of plagioclase, minor quartz, and amphibole or pyroxene derived from nearby sources, and weather dark grey to rusty orange. Conglomerate clasts are derived from nearby volcanic and plutonic sources and weather off-white to pink. The conglomerate forms a regionally mappable unit 0.01 to 40 m thick. Slate beds contain ammonites, bivalves, and plant fragments of probable Late Valanginian age (Struik et al., 2002). The clastic rocks form marker units that outline tight folds within the volcanic and sedimentary sequence.

Regionally, mafic rock assemblages contain secondary chlorite and epidote alteration. Original textures and structures are generally well preserved in the sedimentary units.

MONARCH SEQUENCE AT MOUNT CRESWELL

A partial stratigraphic section at Mount Creswell (Fig. 5) was constructed from traverse descriptions made along a topographic profile and from a detailed study of thin sections. The base of the Monarch sequence lies east of the easternmost observed point. The uppermost exposure of the Creswell section is an andesite package conformably overlying volcaniclastic sedimentary rocks. The top of the Monarch sequence is not exposed in eastern Bella Coola map area (Struik et al., 2002). Uncertainty in the thickness of individual units varies and is estimated to be approximately 1 to 2 m for both thick and thin units. The following sequence (Fig. 6) refers to rocks at Mount Creswell that have been divided into different lithological units and described in detail from the bottom (east) to the top (west) of the stratigraphic column.

Figure 5. Looking east toward Mount Creswell.

Aphanitic andesite

The lowermost unit (unit 1) of the studied stratigraphic sequence consists of olive-green, plagioclase-glomeroporphyritic andesite cut by white hornblende-porphyritic granodiorite dykes and sills. Euhedral plagioclase phenocrysts (An_{25}, <5 mm, 25% rock volume) with either Carlsbad or albite twinning are heavily altered to chlorite and epidote. Euhedral hornblende phenocrysts (<4 mm, 5% rock volume) have a sieve-like appearance as a result of extensive chlorite and epidote alteration. Opaque minerals consisting of either

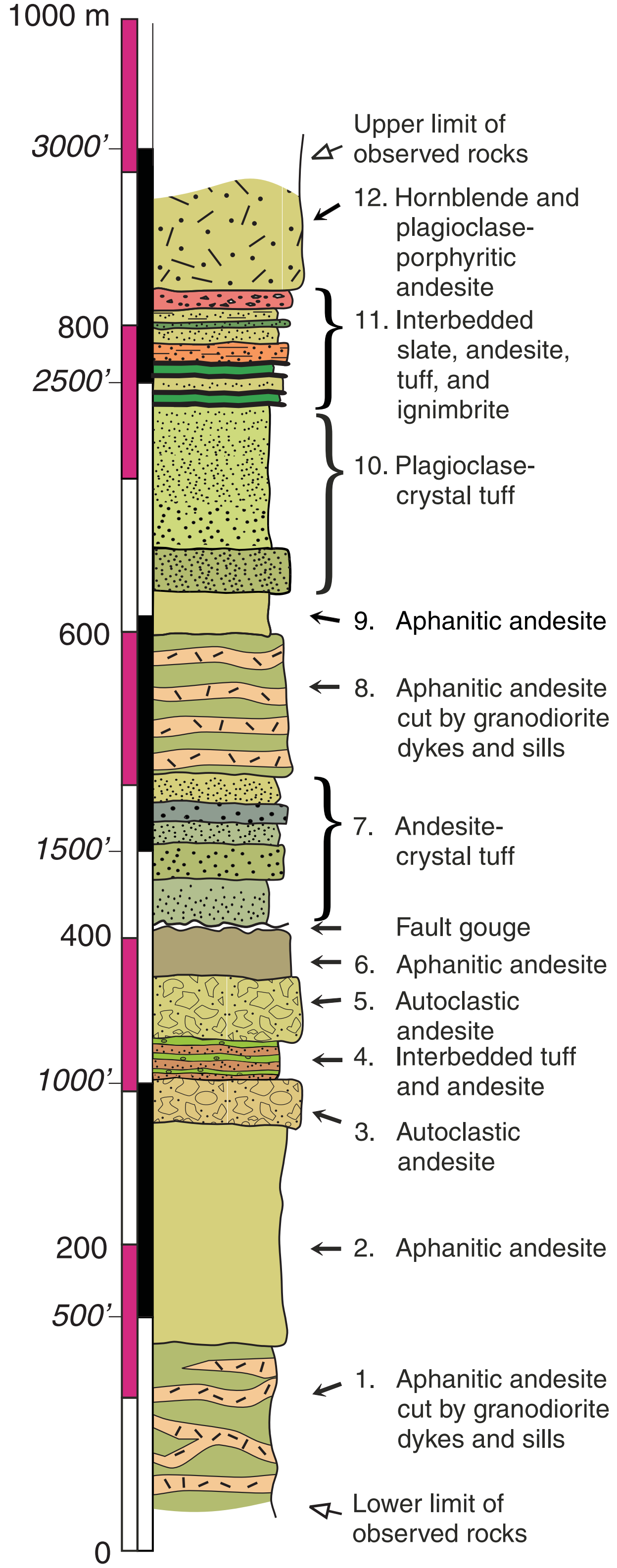


Figure 6. Compiled partial stratigraphic section of the Monarch sequence from the Mount Creswell area. See text for description of numbered units and Figure 4 for location of the stratigraphic section.

euhedral pyrite cubes or anhedral hematite blebs represent less than 2% of the rock volume. A felted network of anhedral to subhedral equigranular plagioclase laths (0.5 mm, 68% rock volume) makes up the groundmass, which has pervasive chlorite and epidote alteration. No preferred orientation in either groundmass or phenocrysts was observed.

Numerous northwest-trending granodiorite dykes and sills cut this unit preferentially, recording approximately 30% northeasterly directed extension. The intrusions are fine grained, range in width from 0.5 to 5 m, and are composed of 74% plagioclase, 20% quartz, 5% hornblende, and less than 1% euhedral magnetite crystals.

Aphanitic andesite

Approximately 150 m of olive-green, idiomorphic-granular, plagioclase-phyric andesite (unit 2) overlies the dyke-rich aphanitic andesite unit. Euhedral plagioclase phenocrysts (An_{26}, <2 mm, 50% rock volume) with either Carlsbad or albite twinning have extensive carbonate and chlorite and minor epidote alteration; 4% to 6% of these phenocrysts are bent. The opaque minerals are anhedral pyrite (<0.25 mm, 2% rock volume). Hornblende phenocrysts (0.5 mm, 1% rock volume) are intensely altered to chlorite. Interstitial anhedral plagioclase (<0.25 mm, 47% rock volume) making up the groundmass is mostly altered to carbonate and chlorite. No preferred orientation in either groundmass or phenocrysts was observed. This unit contains minor stockwork veining of quartz and epidote throughout.

Autoclastic andesite

Approximately 280 m upsection lies an autoclastic andesite unit (unit 3; Fig. 7). Plagioclase-phyric andesite clasts (<12 mm, 80% rock volume) constitute the majority of this unit, ranging from angular to very angular and of low sphericity with hornblende, quartz, and plagioclase crystal clasts. Plagioclase is euhedral and locally forms clots (An_{26}, 1.5–2 mm, 20% clast volume) with intense epidote and

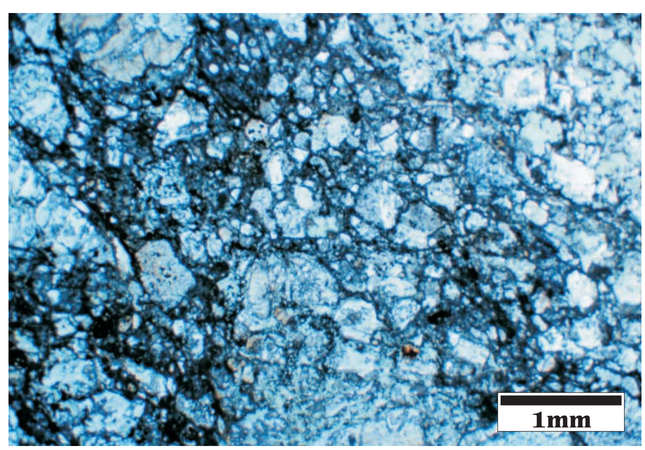


Figure 7. Photomicrograph of resedimented autoclastic andesite from unit 3. Note angularity and low sphericity of the monomictic clasts and crystals, indicating consolidation close to formation.

chlorite alteration. Large knots of chlorite form partial pseudomorphs of euhedral hornblende (<1.5 mm, 5% clast volume). Subhedral to anhedral felted plagioclase needles (0.25–0.5 mm, 75% clast volume) making up the groundmass are mostly replaced with epidote and chlorite. The phenocrysts and groundmass show varied degrees of alignment in different clasts.

Subangular hornblende crystals (<1.5 mm, 2% rock volume) showing low sphericity have intense epidote and chlorite alteration. Angular quartz crystals (<4 mm, 2% rock volume) appear fresh with cuspate edges. Angular plagioclase crystals (An_{26}, <3mm, 2% rock volume) have low sphericity and scalloped indentations along pre-existing cleavage or small, irregularly shaped cavities within the crystals. Opaque minerals consisitng of partially rusted euhedral pyrite cubes represent 1% of the rock.

This clast-supported unit has been generated by autobreccia fragmentation of andesitic flows. Andesite fragments and crystal-rich material were included during subsequent resedimentation. The anorthite content in the clasts and crystals suggests that they were derived from andesite flows. The angularity and low degree of sorting of clasts and crystals suggest that they were deposited and consolidated near their source.

Interbedded tuff and andesite

This package (unit 4) is approximately 30 m thick and is dominated by crystal-rich tuff to lithic lapilli tuff with minor interbedded andesitic flows. Plagioclase-crystal-rich tuff to andesite lithic lapilli tuff range in bed thickness from 3 to 5 m. These fining-upward sequences have sharp to wavy contacts between beds. Plagioclase crystals (1–3 mm, 20–30% rock volume) and subangular to angular plagioclase-phyric andesite fragments (<1–4 mm, 2–4% rock volume) are altered to chlorite. The andesite flows are olive-green, range in bed thickness from 0.5 to 2 m, and contain minor amygdales of chalcedony (2–3 mm, 3–5% rock volume) flattened parallel to bedding. This unit represents repeated intervals of explosive magmatism, resulting in airfall tuff and flows that were deposited in a subaqueous environment.

Autoclastic andesite

A 45 m thick unit of autoclastic andesite (unit 5) located approximately 330 m upsection is similar in all respects to the autoclastic andesite of unit 3, except that it lacks resedimentation characteristics.

Aphanitic andesite

Approximately 380 m upsection is a 30 m thick, olive-green, idiomorphic-granular, plagioclase-phyric andesite unit (unit 6), similar to unit 2. It is separated from the overlying andesite crystal tuff by approximately 10 m of fault gouge. The gouge exhibits brittle phacoidal to phyllitic cleavage along its walls, striking 166º and dipping 87º to the west. No lateral or vertical displacement was noted.

Andesite crystal tuff

Unit 7 comprises 105 m of varied plagioclase crystal tuff. Individual interbeds of fining-upward, olive-green, plagioclase-phyric, andesite-crystal-rich tuff vary in thickness from 40 to 80 mm. All beds strike 138º and dip 60º to the southwest.

Aphanitic andesite

Approximately 505 m upsection are 45 m of aphanitic andesite (unit 8) similar in character to unit 1.

Aphanitic andesite

Approximately 600 m upsection, olive-green, idiomorphic-granular, plagioclase-phyric andesite (unit9) 30 m thick is similar to rocks of unit 2.

Plagioclase-crystal tuff

Approximately 630 m from the base of the section are two units of plagioclase-crystal tuff (unit), with a total thickness of approximately 120 m. These fining-upward sequences have thin beds with wavy contacts and laminations, indicative of subaqueous deposition.

Interbedded volcanic and sedimentary unit

Approximately 750 m from the base of the section are 80 m of interbedded slate, andesite, tuff, and ignimbrite (unit 11; Fig. 8). The lower section is composed of rusty- to black-weathering slate (A in Fig. 8) interbedded with minor aphanitic andesite flows. The slate is cryptocrystalline with a well developed cleavage, local crenulations, and minor folds. Graded beds range in thickness from 10 to 50 mm and exhibit flame structures at bed boundaries. Unit 11 was used as a key marker horizon in the study area, reflecting the intense folding; most of the larger massive andesite packages do not reflect this intense folding. The presence of marine animals, such as ammonites of the genera *Dichotomites* and (?)*Polyptychites* and terrestrial conifer stems and wood fragments, suggests a probable shallow to outer-shelf marine environment (Struik et al., 2002).

Olive-green, holocrystalline, equigranular, microcrystalline plagioclase andesite flows (B in Fig. 8) are interlayered with the slate. Plagioclase crystals (<0.5 mm, 90% by volume) are pervasively replaced by sericite, chlorite, and carbonate, to the point where the plagioclase composition cannot be determined. These pseudomorphs show no preferred orientation; 5% of crystals are bent. Microcrystalline quartz (<0.5 mm, 3% by volume) appears to be a late-stage infilling. The groundmass has been entirely altered to sericite, chlorite, and carbonate.

Interbedded andesite tuff and flows form a medial unit (C in Fig. 8) within the slate units. Plagioclase-crystal-rich accretionary tuff makes up parts of this unit (Fig. 9a). These very thin, parallel-laminated beds contain plagioclase

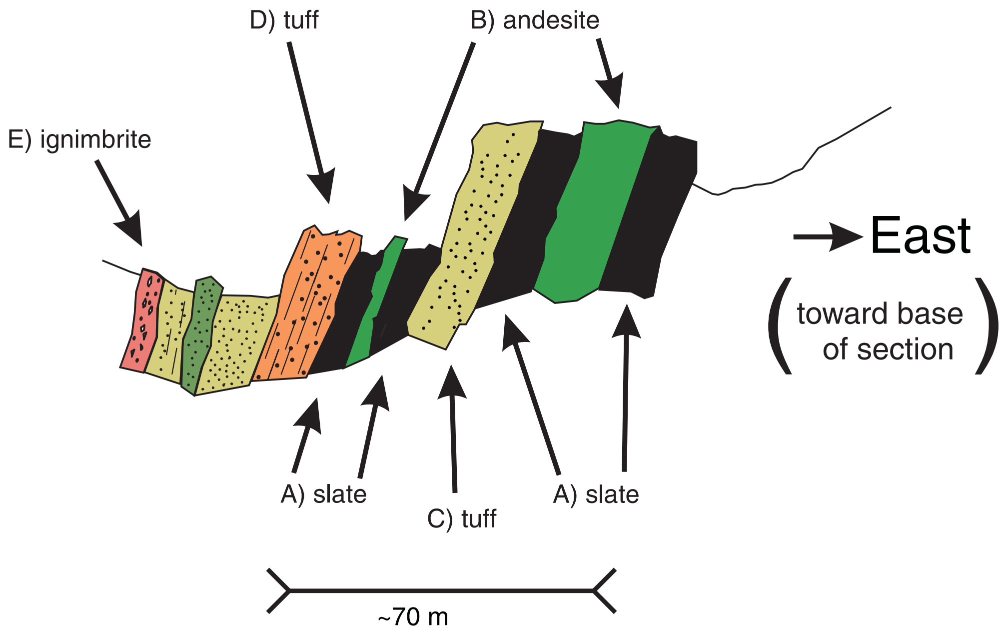


Figure 8. *Enlargement of unit 11 from Figure 6 to better illustrate the relationships of different units.* See *text for description of units.*

crystals (An_{31}, <0.5 mm, 10% by volume) with Carlsbad and albite twinning. The matrix is an amorphous mass of ash and microscopic crystals. This rock contains carbonate-filled dewatering sutures and late-stage minor quartz veining.

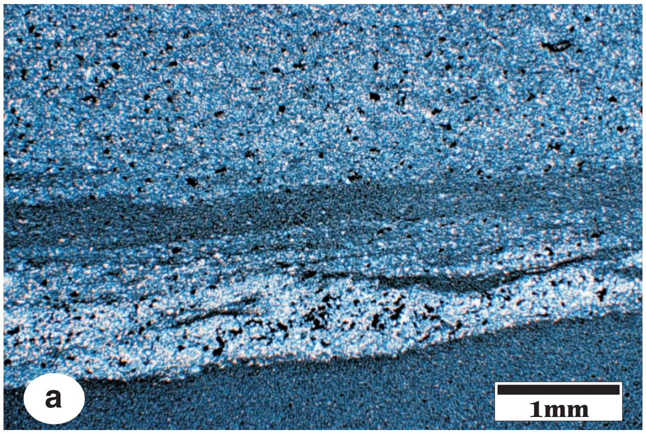
A detailed study of plagioclase-crystal anorthite content deposited in different bedding layers revealed two distinct compositions in two distinct locations within bedding. Plagioclase crystals containing less than 30% anorthite are physically distinct from those containing more than 40% anorthite. Crystals with $<An_{30}$ (<0.25 mm, 56% total number of crystals) located in the middle of beds were more altered to epidote and chlorite. Crystals with $>An_{40}$ (0.5 mm, 17% total number of crystals) found at the edge of beds are less altered.

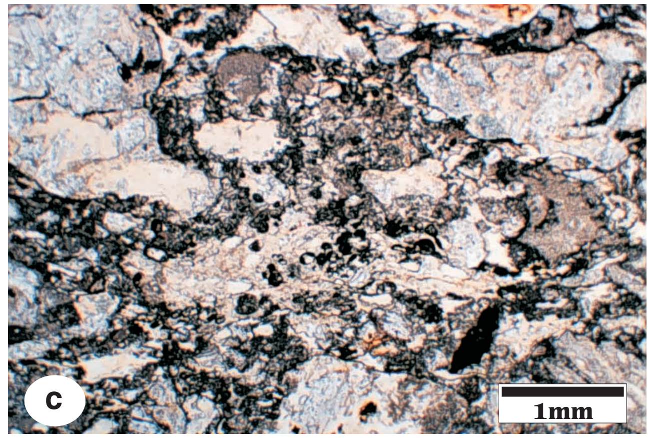
The bimodal anorthite composition may suggest two sources for the plagioclase. One explanation is that the plagioclase comes from two different volcanic magmas erupting from two nearby volcanoes. A second explanation is that the two plagioclase populations were differentiated suites within the same magma.

Approximately 770 m from the base of the section is a grey, fine-grained, well sorted, plagioclase- and quartz-crystal tuff (D in Fig. 8; Fig. 9b). Very angular plagioclase crystals (An_{34}, <1.5 mm, 25% by volume) show low sphericity and are fresh in appearance, having cuspate edges with only very minor epidote alteration. Angular lithic fragments (<2 mm, 20% by volume) contain plagioclase crystals (<2 mm, 10% of clasts) in an aphanitic groundmass, with minor chlorite alteration. Subhedral to euhedral pyrite cubes (<0.25 mm, 10% rock volume) represent the opaque minerals in this unit. Anhedral to subhedral calcite, ash, and biotite make up the groundmass of this matrix-supported rock. This unit contains flame structures between bed boundaries and ptygmatic veins filled with calcite.

Plagioclase crystal composition is distinctly bimodal in the crystal clasts. Low anorthite plagioclase ($<An_{35}$, <1 mm, 70% total crystal content) is heavily altered and occurs at the base of beds. More calcic plagioclase ($>An_{40}$, 2 mm, 30% total crystal content) is less altered and found at the tops of beds. Crystal fragments in this unit have cuspate edges, characteristic of a volcanic origin in which crystals are redissolved while in the magma chamber.

Units composed of a poorly sorted, crystal- and lithic-rich, moderately welded ignimbrite (E in Fig. 8; Fig. 9c) occur in the upper part of the volcano-sedimentary unit. The primary components are crystals, shards, and lithic fragments with brown, glassy, fine ash filling the interstices between the clasts. Most glass shards are cuspate and platy. Their delicate spines and cusps are largely undeformed and only slightly welded, showing a weak foliation defined by clasts. The lithic fragments are derived from underlying andesite flow and tuff units. Angular, foliated, plagioclase-phyric andesite (<2.5 mm, 25% by volume) constitutes the major clast component and appears to have been derived from the immediately underlying bed. Other lithic clasts consist of andesite tuff (<200 mm, 10% by volume) resembling underlying tuff units. This unit is heavily altered to calcite and chlorite.





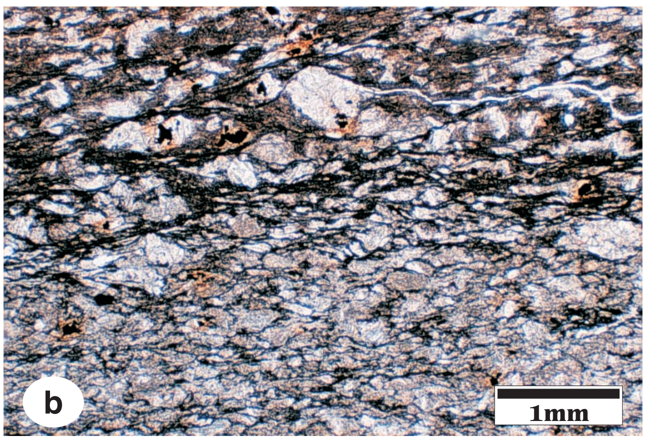


Figure 9. *Rocks typical of unit 11 of the Monarch sequence.* ***a****) Photomicrograph of plagioclase-crystal-rich accretionary tuff. Note the graded bedding and euhedral calcite crystals indicative of a subaqueous depositional environment.* ***b****) Photomicrograph of plagioclase- and quartz-crystal tuff. Note the sorting and fine laminations indicative of deposition in a subaqueous environment.* ***c****) Photomicrograph of ignimbrite. Note the cuspate and platy edges indicative of a pyroclastic environment.*

Hornblende and plagioclase-porphyritic andesite

Olive-green, hornblende and plagioclase-porphyritic andesite (unit 12) forms the top of the observed portion of the sequence. Euhedral plagioclase phenocrysts (An_{26}, <3.5 mm, 33% by volume) were the first to crystallize from the melt. They exhibit pericline, Carlsbad, and albite twinning with pervasive chlorite and sericite and minor epidote alteration. Anhedral to euhedral hornblende phenocrysts (<2 mm, 20% by volume) have intense carbonate alteration. The groundmass (<0.5 mm, 47% by volume) consists of microcrystalline plagioclase and hornblende, both heavily altered to chlorite and sericite. Neither phenocrysts nor groundmass have any preferred fabric.

REGIONAL IMPLICATIONS

On the basis of composition, stratigraphy, and age, the Monarch sequence from the Bella Coola map area can be correlated with rocks in the Whitesail Lake (NTS 93 E), Rivers Inlet (NTS 92 M), and Mount Waddington (NTS 92 N) map areas (*see* Struik et al., 2002, for references). It has been correlated with the Gambier Group exposed in southwestern British Columbia (Rusmore and Woodsworth, 1994). Its age is constrained by a U-Pb age of 136 Ma from volcaniclastic rocks in the southern Whitesail Lake area (van der Heyden, 1990), by volcanic and clastic rocks from the eastern Waddington fold and thrust belt containing Hauterivian fossils, and by Late Valanginian fossils (approximately 134–132 Ma) in eastern Bella Coola map area (Struik et al., 2002). This confirms the interpretation of Rusmore et al. (2000) of a 250 km long coherent volcanic belt stretching along the western edge of Stikinia during the Early Cretaceous.

DISCUSSION

The partial section of the Monarch sequence exposed at Mount Creswell records a complex series of Early Cretaceous volcanic and sedimentary events. Deposition changed from massive andesitic flows to interspersed andesitic fragmental and flow eruptions gradually dominated by fragmental eruptions into an aqueous environment, and ended with a decrease in volcanic activity as noted by periods of sedimentary deposition into marine basins.

Undeformed andesite flows form thick (up to 150 m) packages low in the sequence. They are massive, show little to no internal structure, have cryptic contacts, and are interpreted from their large thicknesses to represent several massive flows. This package is interrupted by a resedimented, clast-supported, autoclastic andesite. Poorly sorted, monomictic, angular, nonflow-banded to flow-banded clasts were likely fragmented from nonexplosive lava flowing in close proximity to the source vents, and later resedimented. It is unclear if this breccia is related to flows lower in the sequence, although the similar texture and mineralogy suggests that this is the case. The autoclastic unit is interrupted by a package of interbedded airfall tuff and minor vesicular flows representing an increase in the volatile content of the magmas. In general the volcanism becomes more explosive upsection.

The autoclastic andesite unit is overlain by aphanitic andesite flows, followed by a series of fining-upward plagioclase-crystal tuff beds. Several episodes of explosive volcanism produced varied quantities of airfall tuff deposited in subaqueous environments. The volcanism at this level of the stratigraphy was more volatile, creating predominately pyroclastic eruptions and forming repetitive andesite flows and fining-upward tuff layers.

Rocks above these tuff layers show that stable episodes of volcanic activity gave way to irregularly alternating episodes of sedimentation and minor volcanic activity. Near the top of the section at Mount Creswell, clastic sedimentary rocks are interbedded with minor andesitic flows, tuff, and pyroclastic rocks. Clastic sedimentation dominated deposition, indicating a decrease in volcanic activity. Deposition occurred in a marine environment, as indicated by the presence of ammonites and various bivalves. The low degree of sorting and sphericity of the crystal and lithic fragments indicates that they were deposited close to their source vents.

Within some tuff beds, anorthite compositions are bimodal, ranging from An_{23} to as high as An_{57} within crystal fragments. This is likely the result of different areas or levels within the magma chamber being tapped during explosive eruptions. Plagioclase clasts within pyroclastic units have cuspate edges, suggesting resorption within the magma chamber and indicating magma cycling and extended residence times.

At Mount Creswell, the top of the section is a thick package of andesite flows. Alternating andesite flows and tuff layers repeat throughout the section, suggesting repetition of similar volcanic conditions throughout the section.

In other localities, variations in the number of fragmental units and clast sizes are interpreted to represent changes in proximity to volcanoes and the duration of history recorded. As at other places underlain by Monarch sequence rocks, it is unclear how much time is represented by local sections or by the entire assemblage.

CONCLUSION

The sequence at Mount Creswell is representative of the volcanic style within Early Cretaceous rocks of the west-central Bella Coola area. The detailed study has shown that the Monarch sequence at Mount Creswell can be divided into three distinct depositional facies reflecting a probable continental arc volcano-sedimentary environment: regionally prominent pyroclastic sequences; extensive flows, related breccia, dykes, and sills; and sedimentary units interbedded with flows and pyroclastic deposits. The section consists mainly of units composed of andesite, basalt, minor rhyolite, and dacite intercalated with resedimented volcaniclastic and pyroclastic material forming intervals of sandstone, siltstone, slate, conglomerate, and ignimbrite. The rocks from Mount Creswell reflect the changing environments from nonexplosive volcanic activity, represented by massive andesite flows, to varied relatively explosive volcanic activity, represented as airfall tuff, to alternating irregular episodes of erosion and explosive to nonexplosive volcanism represented by sedimentary rocks and minor andesitic to pyroclastic flows.

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