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Middle Eocene sedimentary and volcanic infilling of an evolving supradetachment basin: White Lake Basin, south-central British Columbia

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Introduction. The middle Eocene White Lake and Skaha Formations within the White Lake Basin (WLB), British Columbia, record the sedimentary and volcanic infilling of a supradetachment basin that developed during the latter stages of Okanagan metamorphic core complex uplift. The Okanagan is a highly extended region of high-to-low-grade metamorphic rocks and Eocene volcanic and sedimentary strata that has been the focus of numerous geologic investigations (Fox et al., 1976; Armstrong, 1982; Coney and Harms, 1984; Templeman-Kluit and Parkinson, 1986; Parrish et al., 1988; Fox and Rinehart, 1988; Bardoux and Mareschal, 1994; Cook, 1995). Documentation of tectonic, igneous, and metamorphic features has greatly improved the understanding of the regional geology of this area, but due to poor exposures of stratified rocks, few investigations have sufficiently detailed the record of sedimentation and volcanism that accompanied core complex uplift. Investigations of syntectonic and synvolcanic stratigraphy within Tertiary extensional basins in the U.S. southern Cordillera have demonstrated that an integrated analysis of the sedimentary record lends valuable insight into the timing and evolution of sedimentary-volcanic deposits, extensional basin formation, and core complex uplift (Miller and John, 1988; Nielson and Beratan, 1990; Dickinson, 1991; Topping, 1993; Fedo and Miller, 1992; Fillmore et. al, 1994, Friedmann and Burbank, 1995; Horton and Schmitt, 1998; Gawthorpe and Leeder, 2000). Geologic evidence gathered from critical examination of the White Lake and Skaha Formations indicates that the White Lake Basin formed as a localized supradetachment basin during the late stages of uplift of the Okanagan metamorphic core complex along the Okanagan Valley Fault (OVF). Sedimentary-volcanic strata deposited within this basin accumulated on gravity and fluvial dominated alluvial plains/fans that were strongly influenced by a combination of active volcanism, seismic activity, and a moist middle Eocene climate. The primary purposes of this paper are to: (1) evaluate and reconstruct the paleoenvironments of sedimentary and volcanic deposition; and (2) document the sedimentologic-tectonic evolution of the White Lake Basin.

Study Area. The White Lake Basin is an 11 km by 6 km east-northeast trending extensional basin that preserves middle to upper Eocene volcanic and sedimentary strata that are juxtaposed with the footwall of the Okanagan Valley Fault and high-grade metamorphic rocks of the Okanagan metamorphic core complex (Fig. 1). Eocene deposits of the Springbrook Formation, Marron Group, White Lake Formation, and Skaha Formation are exposed within the White Lake Basin and rest unconformably upon footwall gneiss of the Okanagan Valley Fault and Quesnellian rocks that host Mesozoic plutons (Church, 1973). Upper plate strata of the White Lake Basin have been folded into an east-dipping (25°), east-west trending syncline that has been pervasively cut by late-stage normal, reverse, and strike-slip faults, that apparently radiate from the shear zone detachment (Templeman-Kluit and Parkinson, 1986).

White Lake Formation. The 1.4 km thick White Lake Formation rests with minor angular unconformity upon and onlaps rocks of the Marron and Marama Formations. The White Lake Formation is characterized by volcanogenic fluvial, sheetflood, sediment gravity flow deposits, and lava beds deposited during a period of heightened volcanism and coeval erosion of early Eocene strata. Four facies associations are recognized in the White Lake Formation and are interpreted to represent: (FA1) Sediment gravity flow-dominated alluvial plain deposits; (FA2) Fluvial channel deposits; (FA3) Fluvial overbank and paludal deposits; (FA4) Sheetflood deposits.

Facies Association 1. Deposits of FA 1 are predominantly exposed along the eastern margin of the WLB (Fig. 1) and consist of single or multistory depositional units of matrix and clast supported breccia and conglomerate, tuffaceous conglomerate, and intercalated lava beds. Conglomerate and breccia are characterized by poor sorting, an overall lack of stratification, a fine-grained crystal-lithic matrix, and bi-modal grain size distribution indicating rapid deposition from non-cohesive volcanogenic debris flows and hyperconcentrated-flood-flows. Near the OVF breccia/conglomerate beds are coarse-grained, clast-supported, and are commonly interbedded with thick lava beds. To the west breccia/

conglomerate beds display a decrease in average clast size and an increase in percentage of matrix support. Additionally, intercalated lava beds and tuffaceous conglomerates decrease in thickness and frequency away (west) from the OVF. The textural gradation of breccia/conglomerate and decrease in frequency of lava beds west of the OVF indicates that debris flows were derived from eastern sources and were deposited in proximal to medial reaches of an alluvial plain/fan complex that formed near an active volcanic center.

Facies Association 2. FA 2 deposits are exposed in central to western portions of the WLB and interfinger with FA 1 to the east. This facies association consists of moderately-to-well sorted and cross-stratified gravelly sandstone and clast-supported, pebble-cobble conglomerate deposited in fluvial channels. The abundance of amalgamated sets of trough cross-strata, planar cross-strata, and plane beds indicate successive deposition and erosion cycles likely related to flashy, ephemeral discharge in broadly unconfined braided stream channels. Flashy discharge patterns likely reflect flash floods, seasonal fluctuations, or intermittent volcanism that affected both long- and short-term flow conditions.

Facies Association 3. FA 3 is exposed along White Lake Road (Fig. 1), has limited areal extent, and accounts for a minor volume of strata in the WLB. This facies association consists of well stratified organic rich, laminated and cross-rippled siltstone, tuffaceous shale, pebble-rich conglomerate, and massive sandstone deposited in fluvial overbank and paludal settings. The diversity and abundance of floral macrofossils, root traces, coal seams, and air-fall tephras preserved within this association indicates that overbank areas were persistently swamp-like. Low-energy paludal areas with sufficient vegetation to baffle clastic input served as catch basins for air-fall tephra erupted from regional volcanic centers. The common occurrence of fluvial channel facies deposits (FA 2) interstratified with overbank facies suggests that channels frequently shifted their positions on the floodplain, which muted floodplain relief and helped minimize soil development. Such geomorphic and pedologic attributes are typical of streep-gradient, coarse-bedload dominated braided streams (Allen, 1965).

Facies Association 4. Strata of FA 4 are exclusively exposed in the western WLB where they are interbedded with fluvial channel deposits of FA 2 (Fig. 1). This facies association consists of planer bedded, laterally persistent siltstone and sandstone-to-pebble conglomerate couplets deposited during sheetflood events. The limited occurrence of channel sand, lack of rapid lateral changes in sediment texture, and prevalance of planer stratification, indicates that sheetfloods were broadly unconfined. Sand-filled channel forms inset within siltstone couplets likely formed as the result of gullying of soft sediment surfaces during the latter stages of floods. Incision during waning flow is indicated by pulse-like, multiple fining upwards successions, common intraclasts, and capping lower flow regime ripple cross-laminated coarse silt and fine sand. Thin, interstratified carbonaceous layers within these deposits are interpreted as pause planes, that signal periods of little or no discharge and have been thought by other workers to indicate ephemeral stream sedimentation (Dreyer, 1993; Miall, 1977).

Provenance. Sedimentary clasts in the White Lake Formation consist predominantly of volcanic rocks derived from hanging wall blocks composed of early to middle Eocene volcanic strata exposed in the hanging wall of the OVF. Clast composition of White Lake strata is characterized by abundant quantities (90-95%) of rhyodacite, hypocrystalline andesite, and anorthoclase rhomb porphyries derived from the Marama and Marron Formations. Subordinate percentages of low green-schist grade meta-chert, detrital quartz, and plutonic igneous clasts also are present. Stratigraphically, the lowermost deposits of the White Lake Formation are dominated by rhyodacite clasts derived from the Marama Formation. These clasts represent erosion of the youngest volcanic rocks that immediately preceded deposition of the White Lake Formation. Upsection volcanic lithologies change from hypocrystalline andesites and anorthoclase rhomb porphyries reflecting the downward erosion into the oldest units of the Marron Formation. Precise source area determination for these clasts remains problematic due to the widespread occurrence of Marama and Marron rocks across the Okanagan Highlands.

Skaha Formation. The 0.3 km thick Skaha Formation overlies the White Lake Formation with minor erosional unconformity and is characterized by deposits of coarse breccia and conglomerate that record an apparent increase in brittle tectonism. Two facies associations are recognized in the Skaha Formation and are interpreted to represent: (SK-FA 1) monolithic megabreccias deposited as rock avalanches and landslides; (SK-FA 2) heterolithic breccias and conglomerates deposited by hyperconcentrated-flood-flows.

Facies Association 1. Facies Association 1 consists of monolithic clast supported cobble-to-boulder megabreccia and brecciated megablocks. Stacked and interfingered units of megabreccia with pervasive crackle and jigsaw textures were emplaced by rock avalanches. Megablocks up to 600 m across rest on top of and intertongue with megabreccia facies that were emplaced as rock slides. The spatial relations between megablocks and rock avalanche deposits suggests that deposits of SK-FA 1 accumulated near the base of bedrock slopes, or in portions of a steeply dipping alluvial fan(s) or apron. Catastrophic slope failures probably were encouraged by highly weathered and fractured bedrock and over-steepened surface relief in nearby highlands. Failure of bedrock edifices may have been triggered by seismic activity, climatic fluctuations, volcanism, or some combination of the three.

Facies Association 2. Megaclast-and boulder-rich breccia of SK-FA 2 overlies coarse-grained and shattered avalanche Sk-FA 1deposits. Diffuse strata contacts and the weak clast-supported framework in these deposits suggests they were emplaced by hyperconcentrated-flood-flows. The sheet-like character and mega-boulders within SK-FA 2 is consistent with deposition onto steep portions of an alluvial fan(s). An overall lack of channel deposits in this association and paucity of sedimentary structural evidence of tractional transport suggest flood events were short-lived and declined rapidly in flow power over the unconfined reaches of these fan(s). Bursts of sediment transport to fan surfaces in the form of hyperconcentrated-flood-flows were most likely associated with episodes of intense rainfall.

Provenenace. Gravel clast compositions of the Skaha Formation consist of high percentages of metamorphic and plutonic clasts and subordinate percentages of volcanic detritus. Rock avalanche and gravity glide deposits of SK-FA 1 were derived from three hanging wall sources: pre-Tertiary metamorphic basement, Mesozoic-Cenozoic plutonic suites, and volcanic cover rocks. The lowermost deposits of SK-FA 1 reflect the stripping of volcanic cover sequences and of metamorphic basement rocks. Up-section avalanche deposits consist entirely of granite indicating downward erosion into deeper plutonic roots. Deposits of SK-FA 2 are compositionally similar to SK-FA 1, but also contain high-grade metamorphic carapace rocks, reflecting the exposure of core complex sources along the footwall of the OVF. The widespread distribution and lack of distinctive lithologies did not allow us to pinpoint exact source areas.

Basin evolution. The following sequence of events is inferred for the evolution of the White Lake Basin and deposition of the White Lake and Skaha Formations (Fig. 2).

Onset of Extension and Basin Opening (A). Phase A displays the onset of extension and basin opening during the late Paleocene. These events immediately followed Mesozoic to late Paleocene compression and intrusion of Mesozoic batholiths.

Deposition of Springbrook Formation (B). The widespread distribution of the Springbrook Formation across the Okanagan Highlands indicates that these deposits accumulated within a wide depositional trough generated by early stage extension across southern B.C. Post-depositional structural dissection and block rotation of this trough are indicated by strong angular unconformities these strata have with overlying volcanic rocks of the Marron Formation. Parrish et al. (1988) suggests that dismemberment of this basin may have been accomplished on multiple extensional faults rather than solely along the OVF.

Deposition of Marron and Marama Formations (C). Marron and Marama volcanic rocks were deposited as part of a widespread volcanic arc that streched from southern B.C. through northern Washington during the early-to-middle Eocene. These rocks accumulated in incipient half-graben basins that developed concurrently with motion along the OVF (Bardoux and Irving, 1989) and intrusion of the synkinematic Coryell Syenite (51.7 +/- 0.5 Ma) (Carr et al. 1987).

Deposition of the White Lake Formation (D). The character and spatial relations of facies associations of the White Lake Formation indicate that these strata were deposited within a relatively rapidly subsiding asymmetric half-graben basin. Sedimentary and volcanic strata accumulated on a west-sloping, alluvial plain/fan complex fed by ephemeral braided stream systems that drained hanging wall source areas. Deposition was controlled by a combination of nearby volcanism, a moist Eocene climate, and active tectonism. Footwall uplift of the OVF is implied by lateral facies changes from coarse basin margin debris flows along the OVF to more finely-grained fluvial and sheetflood deposits at basin margins distal to the OVF.

Deposition of the Skaha Formation (E-F). The waning of White Lake volcanic and sedimentary deposition was marked by an apparent increase in tectonic activity and subsequent deposition of the Skaha Formation within a supradetachment basin. Megaclast-and boulder-rich rock avalanches, colluvial slides, gravity-driven glide blocks, debris flows, clast composition, and the overall lack of sheetflood facies indicate that Skaha beds likely accumulated on coalesced alluvial fans, shed from both hanging wall and footwall sources exposed along the OVF. The coarse-grained and shattered nature of these deposits implies that they were emplaced following catastrophic slope failure, triggered by earthquakes or moist, slope-destabilizing high-moisture events. The presence of high-grade metamorphic carapace rocks within upper Skaha deposits indicates that continued downward erosion and movement along the OVF exposed footwall sources by this time. Interbedded Volcanic strata are rare to absent within the Skaha Formation, suggesting deposition occurred during a tectonically active, but largely volcanically quiescent time.

Post-Depositional Folding and Faulting. The initiation of dextral strike slip-faulting along the Fraser River Fault after 46.5 Ma resulted in post depositional folding and faulting of WLB strata (Cook, 1995). Late stage movement along the OVF apparently continued during this time as the east-west trending White Lake syncline was tilted 25º eastward into the OVF.

Summary and Conclusions. The middle Eocene White Lake and Skaha Formations preserve a detailed record of synextensional sedimentation and volcanism intimately associated with uplift of the Okanagan metamorphic core complex. The limited spatial extent and overall lithologic character of these strata indicate that deposition occurred in a localized extensional basin residing adjacent to the OVF. Clasts of high-grade metamorphic carapace rocks imply rapid and significant uplift along the OVF which exposed the mylonitic detachment zone of the Okanagan core complex. Strata of the White Lake and Skaha Formations are similar to the apparently coeval Klondike Mountain Formation in northernmost Washington (Suydam and Gaylord, 1997). White Lake Basin strata, however, are more complexly interstratified, more severely disrupted by post-depositional faulting and folding, and contain a more complete record of core complex unroofing. Such differences underline the difficulties of developing a general sedimentary-tectonic-volcanic model for this region.

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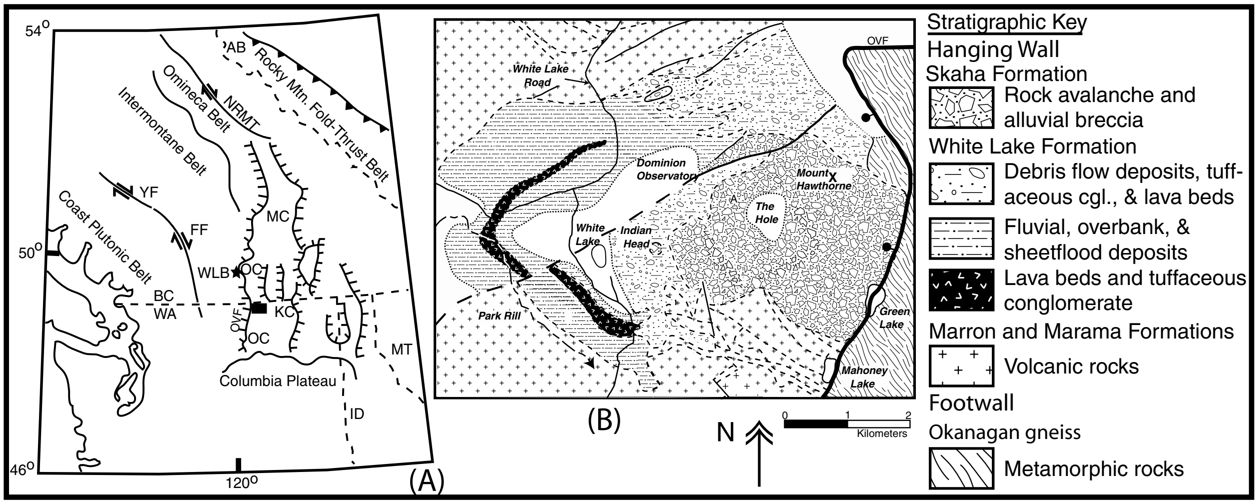

Figure 1: A: Regional map showing the location of the White Lake Basin (WLB) and major structural components. **(**OC) Okanagan metamorphic core complex, (OVF) Okanagan Valley Fault, (FF) Fraser River Fault. B: Geologic map of the White Lake Basin modified from Church 1973.

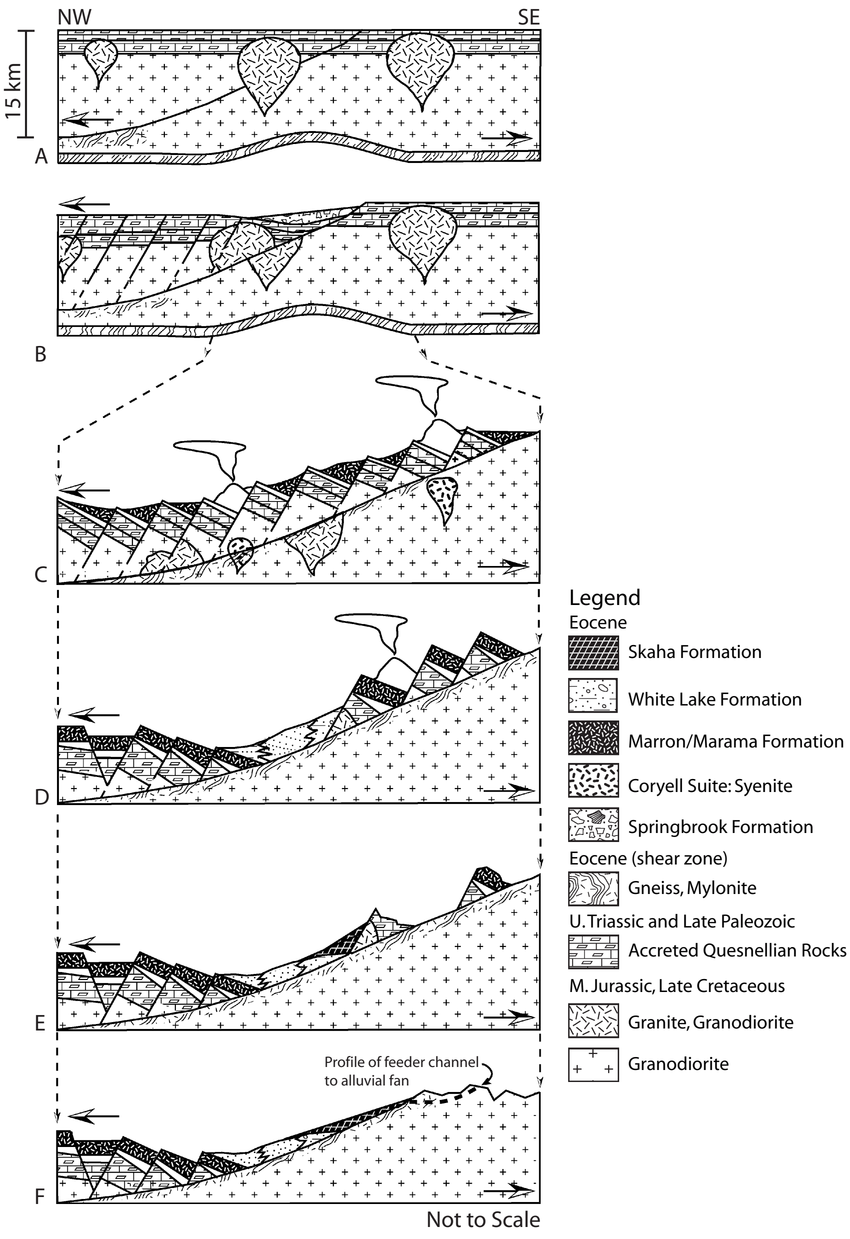

Figure 2. Interpretive sketches to show probable evolution of the White Lake Basin and coeval deposition of the White Lake and Skaha Formations. Note sedimentary sections and fault relations are not to scale. A: Onset of extension and basin opening during the late Paleocene. B: Generation of regional depositional trough and accumulation of the Spring-brook Formation. C: Postdepositional dissection of trough and deposition of Marron and Marama Formations. D: Enlargement of central portion of C; Formation of localized assymetric half-graben basin and deposition of the White Lake Formation. Sediments derived from hanging wall rocks only. E: Deposition of Skaha rock avalanche and landslide blocks in an evolving supradetachment basin. Sediments derived from hangingwall blocks only. F: Continued slip on the OVF and deposition of Skaha FA 2 breccias. Erosion has breached OVF. Sediments now derived from a combination of hangingwall and footwall sources.