APPLIED SURFICIAL GEOLOGY PROGRAM: AGGREGATE POTENTIAL MAPPING, SQUAMISH AREA (92G)

By V. M. Levson

KEYWORDS: Economic geology, surficial geology, land use, aggregate, stratigraphy, sand and gravel, exploration, Squamish.

INTRODUCTION

This paper outlines a new program of the British Columbia Geological Survey Branch in the field of applied surficial geology. Its objectives are to develop methodologies whereby information from about 2000 existing surficial geology maps, in conjunction with subsurface data, can be used to produce derivative products in applied fields such as aggregate resources, geological hazards, waste disposal and groundwater resources. Some of the most common applications of surficial geology maps are outlined in this paper; this project will define minimum information requirements and standards for producing derivative products in these applied fields. The program is designed principally to address the needs of land-use planners. Case study areas will represent regions experiencing high rates of urban growth where detailed surficial geologic data are required for resource management and planning.

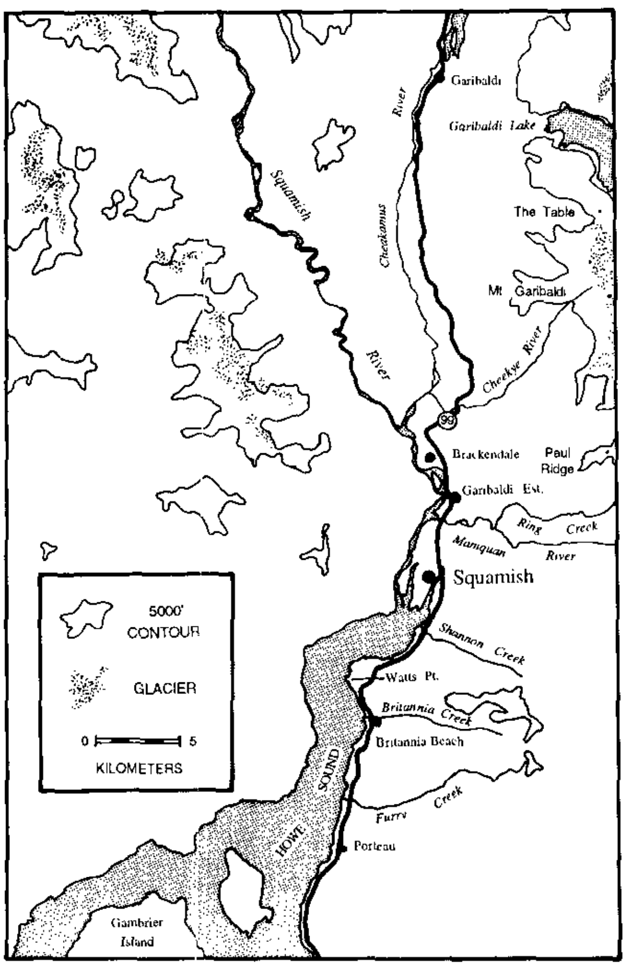

Figure 4-3-1. Location map of Squamish study area.

The Squamish - Sunshine Coast area (Figure 4-3-1) was selected as a case study area for the first phase of this program. The surficial geology of the area was mapped in the late 1970s by an experienced team of terrain mappers during the Quadra project which covered a large part of the southern Coast Mountains (30 NTS 1:50 000 sheets). The region is characterized by diverse and multiple land uses such as forestry, recreation and mineral exploration and was the focus of recent environmental science workshops and public meetings (Ferguson and McPhee, 1992). The area is also experiencing increasing land use pressures from new housing developments, recreational facilities and new highway alignments and major upgrades. Finally, the region is subject to a wide variety of geologic hazards such as debris torrents, floods, rockslides, earthquakes and glacial hazards.

This study will exemplify the multifaceted uses of existing 1:50 000-scale surficial geology data beginning with the field of aggregate resource management. Rapid urban expansion in many parts of British Columbia has resulted in increased pressures on existing sand and gravel reserves. This and related issues, such as a poor understanding of the three-dimensional configuration of exposed and buried aggregate deposits, can be addressed through the production of derivative products which take into account subsurface records. This type of information is needed for regional planning purposes in order to properly identify areas suitable for development, prevent sterilization of valuable resources and avoid unnecessary importing of sand and gravel supplies. Rapidly developing areas deserve immediate attention as post-development appraisals will not contribute to sound resource management and land-use planning.

APPLICATIONS OF SURFICIAL GEOLOGY MAPS

Surficial geology maps provide data on the areal distribution of different types of sediment, their geologic origin, texture (per cent clay, silt, sand and gravel), geomorphology, drainage and active geologic processes (*e.g.*, avalanching, gullying, flooding, ground subsidence, volcanism, etc.). This information can be used for a number of different applications including exploration for mineral resources, the study of geologic hazards, engineering and environmental applications. Examples of each of these are outlined in Table 4-3-1.

The applications and users of surficial geology data in British Columbia have recently been discussed by Boydell (1992) and Walmsley (1992). The principal users of surfi-

TABLE 4-3-1
APPLICATIONS OF SURFICIAL GEOLOGY MAPS

Mineral Resource Applications:
- determining aggregate (sand and gravel) potential
- evaluating earth-borrow potential (for roads, hydro developments, building foundations *etc.*)
- locating sources of mineral deposits (origin of geochemical anomalies and mineral-rich float in surface deposits)
- determining placer potential

Environmental Applications:
- identification of environmentally safe liquid and solid waste disposal sites
- determining groundwater aquifer potential
- evaluating contaminant migration hazard (as determined primarily by the permeability and porosity of the surficial materials)

Geologic Hazards Applications:
- susceptibility to flooding, shoreline erosion, gullying, piping and solution collapse
- susceptibility to mass movements (landslides, slumps, debris flows, debris torrents *etc.*)
- areas sensitive to earthquake-induced liquefaction, slope failure, settling and amplification of ground motions
- sites susceptible to surface soil erosion
- areas of recent volcanism and other geologic hazards

Engineering Applications:
- general construction capability (*e.g.*, for buildings)
- engineering characteristics (*e.g.*, soil compressibility, shear strength and plasticity)
- susceptibility to frost heave, ground ice degradation and solifluction
- ease of excavation (depth to bedrock, boulder content, water content *etc.*)
- evaluation of overburden drilling conditions

Other Applications:
- land-use planning (*e.g.*, municipal development planning and zoning)
- routing of transportation, pipeline, utility and communication corridors (for highways, forestry, mines, hydroelectric developments *etc.*)
- evaluating land capability for agriculture (*e.g.*, stoniness, clay content, relief, drainage *etc.*)
- locating areas with surficial materials such as peat and clay that are of potential economic significance
- fisheries applications (*e.g.*, preventing stream sedimentation and turbidity affecting fish and habitat)
- forestry uses (*e.g.*, identifying sites susceptible to logging-induced disturbance)
- wildlife uses (*e.g.*, biophysical inventory)

cial geology information in the province at present are the forest and mineral industries and there is a projected trend of increasing use by government agencies. Government organizations presently using surficial geology data include: Transportation and Highways; Forests; Energy, Mines and Petroleum Resources; Environment, Lands and Parks; British Columbia Hydro; Geological Survey of Canada; and regional and municipal planning departments. Surficial geology data are required by these users mainly for the design of transportation and utility corridors, layout of forest cutblocks, erosion control in community watersheds, protection of fish and wildlife habitat, waste management, aggregate resource identification and production of slope stability maps (Boydell, 1992; Walmsley, 1992). The surficial geology of approximately 60 per cent of the province has been mapped at a scale of 1:50 000 or larger. This database has been compiled by the British Columbia Geological Survey Branch and a listing of these maps was recently presented by Bobrowsky *et al.* (1992).

BEDROCK GEOLOGY

The bedrock geology of the study area was mapped by Roddick and Woodsworth (1979) and the geology of the Coast Mountains has recently been summarized by Monger (1990). The area is underlain mainly by Middle to Late Jurassic and Early to mid-Cretaceous granodiorite and quartz diorite of the Coast Plutonic Complex. These plutons intrude Early Cretaceous rocks of the Gambier Group (mainly andesite, greenstone and argillite with minor conglomerate, limestone and schist) and pre-Late Jurassic greenstone (with minor chert and greywacke) of the Bowen Island Group. The structural geology of the region is characterized by north-northwest trending shear zones such as the Ashlu Creek shear zone north of Squamish and the Britannia shear zone southeast of Britannia. Pliocene to Recent volcanic rocks of the Garibaldi Group dominate the Garibaldi Park area northeast of Squamish. The late Cenozoic history of volcanism in this area was discussed by Green (1990). The presence of these young volcanic rocks has important implications for the study of both geologic hazards and aggregate resources in this region.

QUATERNARY GEOLOGY

The surficial geology of the Squamish area was mapped by Thomson (1980a, b). McCammon (1977), Ryder (1980) and Thomson (1980c) mapped the surficial geology of the Sechelt region. Sand and gravel deposits on the Sunshine Coast area were investigated by McCammon (1977). Exposed bedrock and colluvial deposits dominate the region as a result of the typically high relief and steep slopes. Morainal deposits are restricted mainly to small valleys and lower slopes in large valleys. The bottoms of main valleys such as the Squamish and Cheakamus River valleys are dominated by fluvial and alluvial fan deposits.

Glaciers covered the study area during the Late Wisconsinan up to an elevation of about 2000 metres. Glacial erosional features resulting from this period of ice cover typify the landscape. During glaciation a number of volcanic eruptions occurred producing several unusual icecontact volcanic features including collapsed supraglacial tuff-breccia cones, anomalously thick lava flows formed by ponding of lava against ice, a table-shaped complex developed by flooding of lava into a thawed pit in the glacier and esker-like basaltic flows possibly formed by extrusion of lava into tunnels thawed in the ice by heated meltwaters (Mathews, 1951, 1952a, b, 1958; Green, 1990). Glacial depositional features such as well developed moraines are relatively rare, presumably reflecting the rapid retreat of glaciers from the region.

Immediately following deglaciation, sea level was up to about 200 metres higher than present due to glacial isostatic depression (Clague, 1989). Raised glaciofluvial deltas, formed during this period of relatively high sea level, are a major source of sand and gravel deposits in the region today. Postglacial volcanic activity resulted in a number of

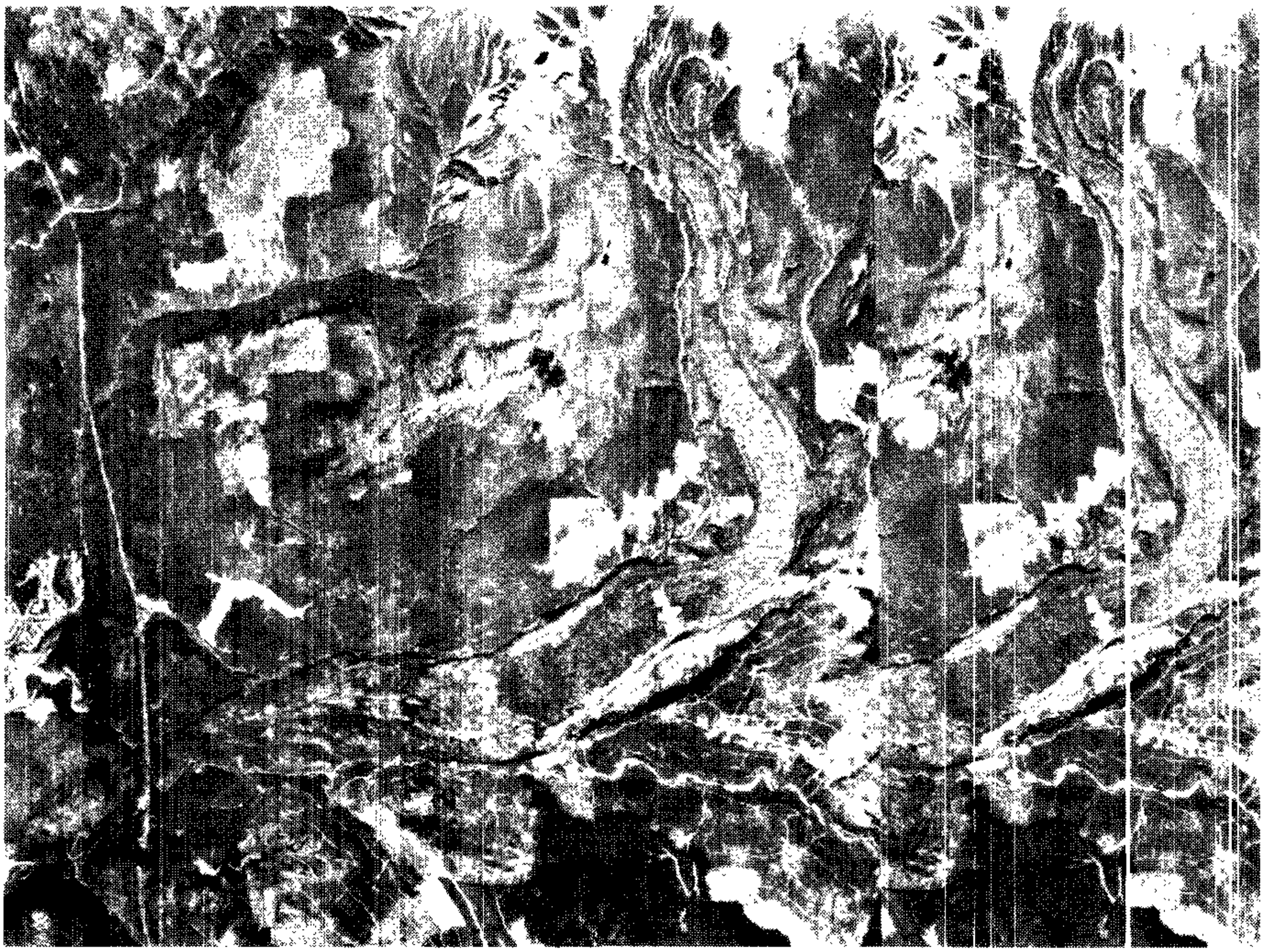

Plate 4-3-1. Postglacial lava flow deposits south of Mount Garibaldi in the Ring Creek area. Note the excellent preservation of morphologic features such as transverse flow ridges and lateral levees. The communities of Squamish, Garibaldi Estates and Brackendale occur directly west of toe of the lava flow. The largest sand and gravel operation in the area can be seen in the southwest corner of the photo.

Plate 4-3-2. Bouldery debris-flood deposits from the August, 1991 event on Furry Creek. Note the large size of the boulders (up to a few metres in diameter) in this abandoned channel that is now entirely above present discharge levels. The upper level of the boulder levees indicates that flow levels almost reached the top of the buttresses of the railroad bridge in the distance and the highway bridge from which the photo was taken.

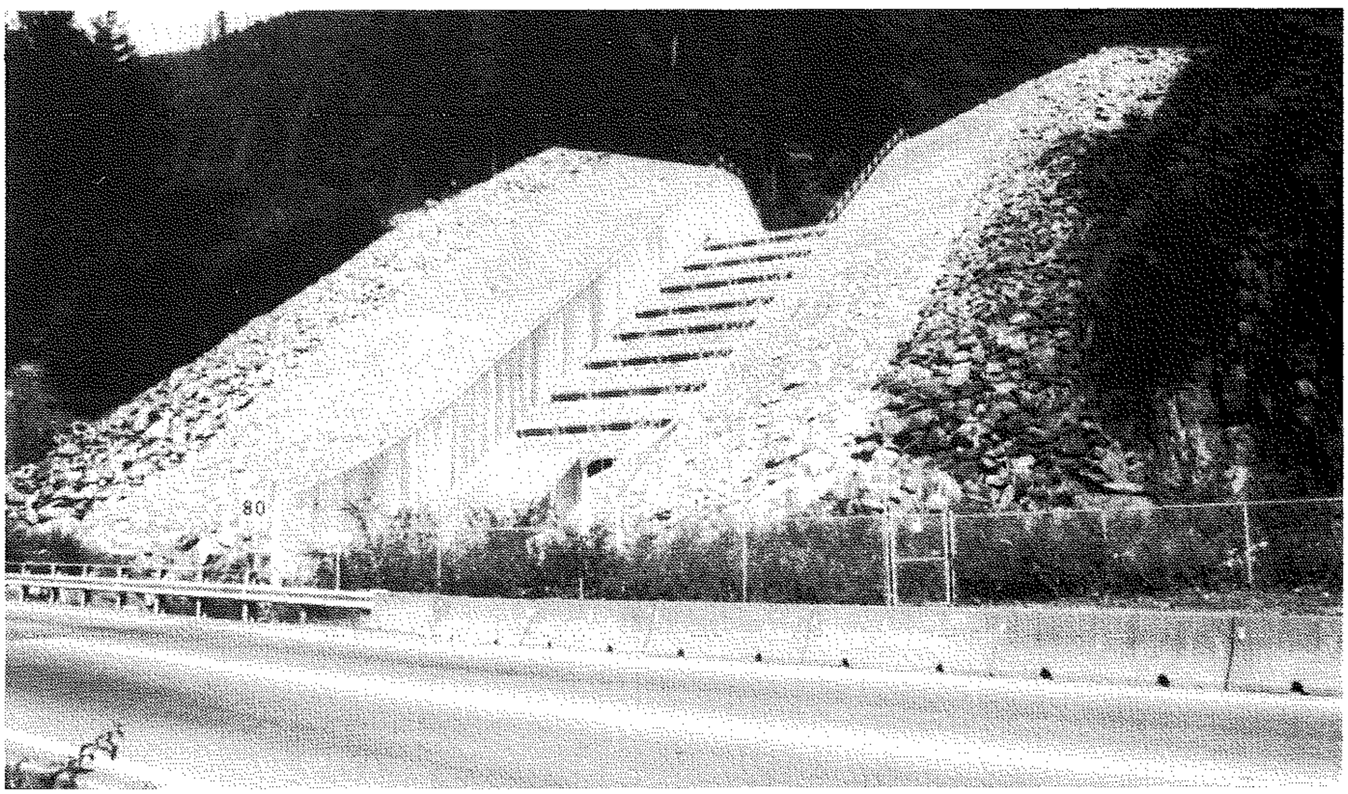

Plate 4-3-3. One of several engineering structures built along the Sea to Sky Highway (#99) to control debris torrents in high-gradient streams flowing off the Coast Mountains into Howe Sound.

well preserved lava flow deposits in the Mount Garibaldi and Garibaldi Lake areas such as the Ring Creek lava (Plate 4-3-1) which issued from a volcanic cone on the southeast slope of Mount Garibaldi and flowed more than 15 kilometres around the east and south sides of Paul Ridge (Mathews, 1958; Green, 1990).

The southern Coast Mountains were subjected to at least three phases of glaciation during the Holocene including: an early Neoglacial advance known as the Garibaldi phase that occurred between about 6000 and 5000 ^{14}C years BP; a middle Neoglacial phase (Tiedemann advance) that began about 3300 ^{14}C years BP and ended some time after 1900 ^{14}C years BP; and a late Neoglacial phase (Little Ice Age advance) that began before 900 ^{14}C years BP and reached a maximum between 1800 and 1900 A.D. (Ryder and Thomson, 1986). Moraines, trim lines and other glacial features from this latter advance are well preserved in areas near modern glaciers throughout the region.

GEOLOGIC HAZARDS

The study area has been the focus of numerous investigations of geologic hazards including published studies on debris torrents along Howe Sound (Hungr *et al.*, 1984, 1987), landslides in the Rubble Creek area (Moore and Mathews, 1978) and volcanism in the Mount Garibaldi area (Mathews, 1952a, b; Green, 1990). Numerous other unpublished studies have also been conducted including recent investigations of debris torrents, floods and other geologic hazards along proposed and existing highway corridors (Thurber Engineering Ltd., 1983; Buchanan, 1990, 1991) and an ongoing study of the Cheekye River alluvial fan (Thurber Engineering Ltd. and Golder Associates Ltd., 1992). A summary discussion of geologic hazards in the Howe Sound, Squamish and Whistler areas was recently presented by Hungr and Skermer (1992).

The climate of the region is characterized by high and episodic precipitation as well as sudden large-magnitude snowmelt events; glaciers cover a large part of high-elevation areas (Figure 4-3-1). The combined effects of these climatic factors, as well as the abundance of relatively unstable surficial materials, makes the study area particularly susceptible to slope hazards such as debris flows, debris torrents, rock avalanches and rockfalls. Poorly consolidated volcanic rocks of the Garibaldi Group are especially prone to mass movements.

Evidence of the current susceptibility of the Squamish area to flooding and slope hazards was observed at a number of sites during the course of this study as a result of an unusually high summer rainfall event in 1991 (Hungr and Skermer, 1992). Debris flows and floods during that time occurred on a number of streams in the area including Britannia Creek, Mamquam River, Cheekye River and Furry Creek (Plate 4-3-2). Extensive channel clearing and stabilizing activities were observed at these and other sites in the region as a result of debris deposition in and along stream and alluvial-fan channels at some sites and lateral channel shifting and erosion at other sites during the 1991 event.

Debris torrents are particularly common in the Howe Sound area. They typically have volumes of about 20 000 cubic metres and can attain discharges more than an order of magnitude greater than those of the largest floods (Hungr and Skermer, 1992). Approximately $35 million was spent on engineering structures along Howe Sound (Plate 4-3-3) in response to three debris torrent disasters in the early 1980s.

A well known example of a rock avalanche occurred on Rubble Creek in the Mount Garibaldi area. The slide involved about 25 million cubic metres of rock derived from the steep, unstable margin of a lava flow that formed by ponding against glacial ice at the end of the Late Wisconsinan (Moore and Mathews, 1978).

The Porteau Cove bluffs provide an excellent example of an area susceptible to rockfall hazards. The likelihood of rockfalls in this region is increased by steeply dipping sheet joints in the plutonic rocks (Plate 4-3-4). Several people have been killed by rockfalls at this site, the most recent fatality occurring in the spring of 1991. Approximately 3000 metres of steel anchors were installed in the steep rock slopes at this site in 1991 by the Ministry of Transportation and Highways (Hungr and Skermer, 1992).

1992 PROGRAM – AGGREGATE RESOURCES

The initial component of this study involves the development of techniques for deriving aggregate resource maps from existing terrain maps. Sand and gravel resources generate between $130 and $150 million per year within the province (B.C. Ministry of Energy, Mines and Petroleum Resources, 1990). Although the Ministry of Transportation and Highways currently supports a sand and gravel inventory suitable for provincial government needs, local and regional needs are not currently examined. Rapidly expanding urban development and future transportation corridors require an accessible sand and gravel database.

METHODS

Terrain units with varying levels of sand and gravel resource potential were identified on existing surficial geology maps (Thomson, 1980a, b) of the Squamish area (NTS sheets 92 G/11 and G/14) by an evaluation of the following geologic characteristics: genesis of the surficial material, grain-size distribution (if available), geomorphologic expression, stratigraphic position, unit thickness and deposit size. This information was supplemented with water-well data for several 1: 50 000 NTS sheets (92G 5, 11 and 14), obtained from the Ministry of Environment, Lands and Parks. The well logs were summarized and entered into a computer database. Well locations on 92G/11 were identified in the field where possible.

Reconnaissance geomorphologic, sedimentologic and stratigraphic field investigations were conducted to test the validity of the aggregate potential designations (*see* below) and the utility of the compiled borehole data. Sand and gravel deposits were investigated at about 2[illegible] different sites including several active pits and a number of abandoned operations. Sediment samples were collected in order to determine the lithological and textural characteristics of the deposits and assess aggregate potential. Associated wood

Plate 4-3-4. Sheet joints in quartz diorite bluffs at Porteau Cove along Highway 99, the site of a number of rockfall disasters. An ambitious slope-stabilization program was conducted at this site in 1991 by the Ministry of Transportation and Highways.

and shell materials were obtained from critical horizons for radiocarbon dating to aid in interpretations of deposit genesis. Physical properties of the deposits, important for determining aggregate quality (such as particle shape, maximum clast-size, grain-size distribution and the presence of deleterious substances including structurally weak particles, clay, organics, chert and chemically reactive particles), were also described. Qualitative determinations of aggregate quality used in this study are based on these physical properties. Although the relative importance of each property varies with different construction applications (Barksdale, 1991), good quality aggregates generally are well graded and contain few large clasts, little silt or clay and few deleterious substances. Detailed laboratory tests, including specific gravity, adsorption, degradation, abrasion, sulphate soundness, sand equivalent and freeze-thaw tests, used to examine aggregate suitability for specific applications (Barksdale, 1991) are beyond the scope of this study.

RESULTS

DESCRIPTION OF AGGREGATE DEPOSITS

The results of field investigations in the area indicate that the most common sources of aggregate presently or previously exploited in the region are glaciofluvial sediments deposited in braided stream, delta and fan-delta environments. Terrain units consisting of glaciofluvial deposits are relatively easily identified and accurate mapping of these units appears to be more consistent than other terrain units. These sand and gravel deposits provide good quality aggregates as they generally are well graded and contain few fines or deleterious substances. Deltaic deposits are characterized by thick sequences of moderately to well sorted gravels with well developed foreset bedding (Plate 4-3-5). Beds of sandy matrix-filled gravels typically alternate with open-work gravels; silts and clays are rare. Fan-delta deposits are similar but tend to have a greater range in clast sizes with a larger number of cobbles and boulders (Plate 4-3-6). Fan-delta deposits in the area are typically smaller than glaciofluvial deltaic deposits and they are mainly restricted to areas along the lower slopes of mountains bordering Howe Sound. Braided stream deposits are generally dominated by pebble to cobble gravels with horizontal bedding and cut-and-fill channel structures on all scales (Plate 4-3-7). Braided stream deposits occur as progradational sequences overlying glaciofluvial delta deposits at several sites (Plate 4-3-8).

Alluvial fan deposits are the second most abundant aggregate source in the region, comprising nearly 25 per cent of the gravel pits visited. These deposits are generally lower quality aggregates than glaciofluvial deposits because they tend to have an overall wider range in clast size and more variability in grain-size distribution from bed to bed. For example, they often contain diamicton units with relatively high proportions of silt and/or clay interbedded with the sand and gravel. The proportion of large boulders in these deposits is also generally higher than in most of the productive glaciofluvial sequences in the area.

Talus deposits have been worked at a number of sites in the area and are an unexpectedly common source of sand and gravel. These deposits are characterized by crudely bedded, angular, pebble to cobble-sized gravels (Plate 4-3-9). They are typically monolithologic, consisting of fragments of basalt or other volcanic rocks. They are derived mainly from steep exposures of Garibaldi Group volcanics. Closely spaced columnar jointing (in some cases on the order of a few centimetres) in these young volcanic rocks has allowed for the development of relatively thick talus accumulations of pebble to small cobble-sized material. At some sites the deposits are relatively uniform in size and they are a potential source of aggregate as they contain virtually no fine-grained matrix materials.

SUBSURFACE (WATER-WELL) DATA

The British Columbia water-well database, housed with the Ministry of Environment, Lands and Parks, is an excellent source of subsurface surficial geology data but a preliminary evaluation of the utility of the data for the purpose of producing aggregate potential maps indicates a number of problems. First, the database is incomplete as there is no provincial legislation requiring submission of well logs. Data are supplied gratuitously to the province, mainly by companies and drilling contractors. In addition, the data provided are not independently confirmed by the province and consequently all data released to users by the Ministry is qualified with a cautioning disclaimer. The database includes a computerized listing of well logs and a manually plotted series of maps showing well locations. The well owner, date and method of construction and well depth are recorded for all sites in the computerized listing. However, detailed location data, well yield information, water table depth and water quality data are only available for some wells. Well locations have been plotted using the British Columbia Geographic System (BCGS) of mapping at scales ranging from about 1:12 000 to 1:16 000 in the study area. Unfortunately plotted locations have not been verified and field checking of these maps in the Squamish area revealed a number of misplotted wells. In addition, cross-referencing of well locations in the computer database with locations on the maps is problematic as, in some cases, one or more sites with the same well number have been plotted in the same BCGS map unit and in a few cases not all well locations have been plotted.

In spite of these difficulties, the provincial water-well database can be used at sites where there are no discrepancies between recorded and plotted locations or where detailed location data are available and can be verified. Similarly, although the quality of the well logs in the database generally has not been independently verified, many of the logs have been provided by professional groundwater geologists, as in the example provided in Figure 4-3-2. Although there are obvious problems with using unverified data, the database is nevertheless considered to be a valuable source of subsurface data because of the good quality of many of the logs and the possibility of verification of the data by field studies and by stratigraphic comparisons of independent logs with published data.

AGGREGATE POTENTIAL

Terrain units in the study area having high, medium and low potential for aggregate deposits were identified on the basis of the geologic criteria outlined above from existing data. The relative terms high, medium and low are used because this type of classification can easily be used by land-use planners. Regional variations in factors controlling aggregate potential, such as natural abundance, quality, accessibility and degree of man-induced alienation, can also be accommodated. In addition, although the classification is qualitative, it can be derived by quantitative methods, with a degree of sophistication that varies with the level of data available.

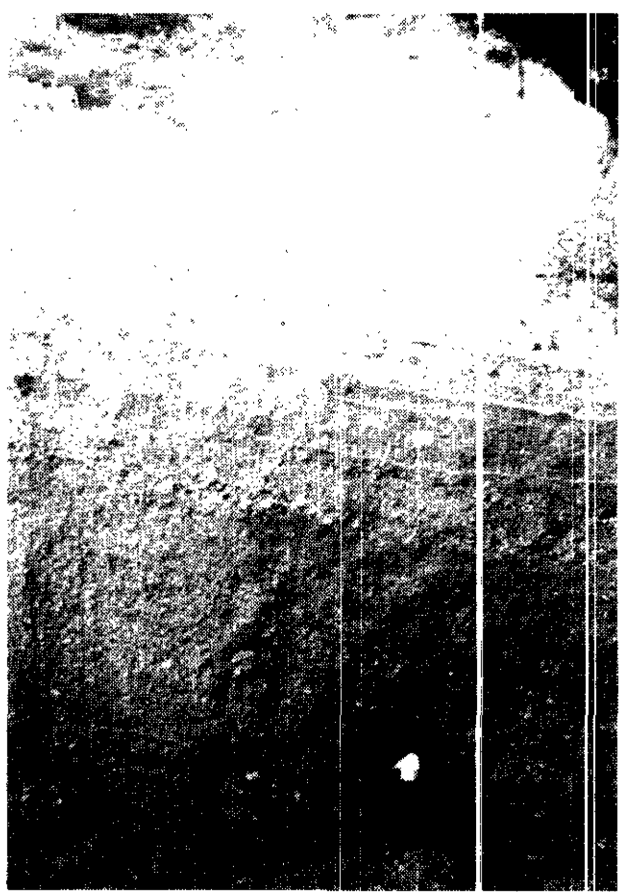

Plate 4-3-5. Well sorted deltaic gravels at the Coast Aggregate Ltd. pit east of Squamish. Foreset bedding is defined by alternating strata of sandy matrix-filled gravels and open-work gravels.

Plate 4-3-6. Glaciofluvial fan-delta deposit at a small gravel pit approximately 500 metres north of Shannon Falls. The boulder at the base of the exposure is 1.1 metres in diameter. Note the high degree of clast rounding.

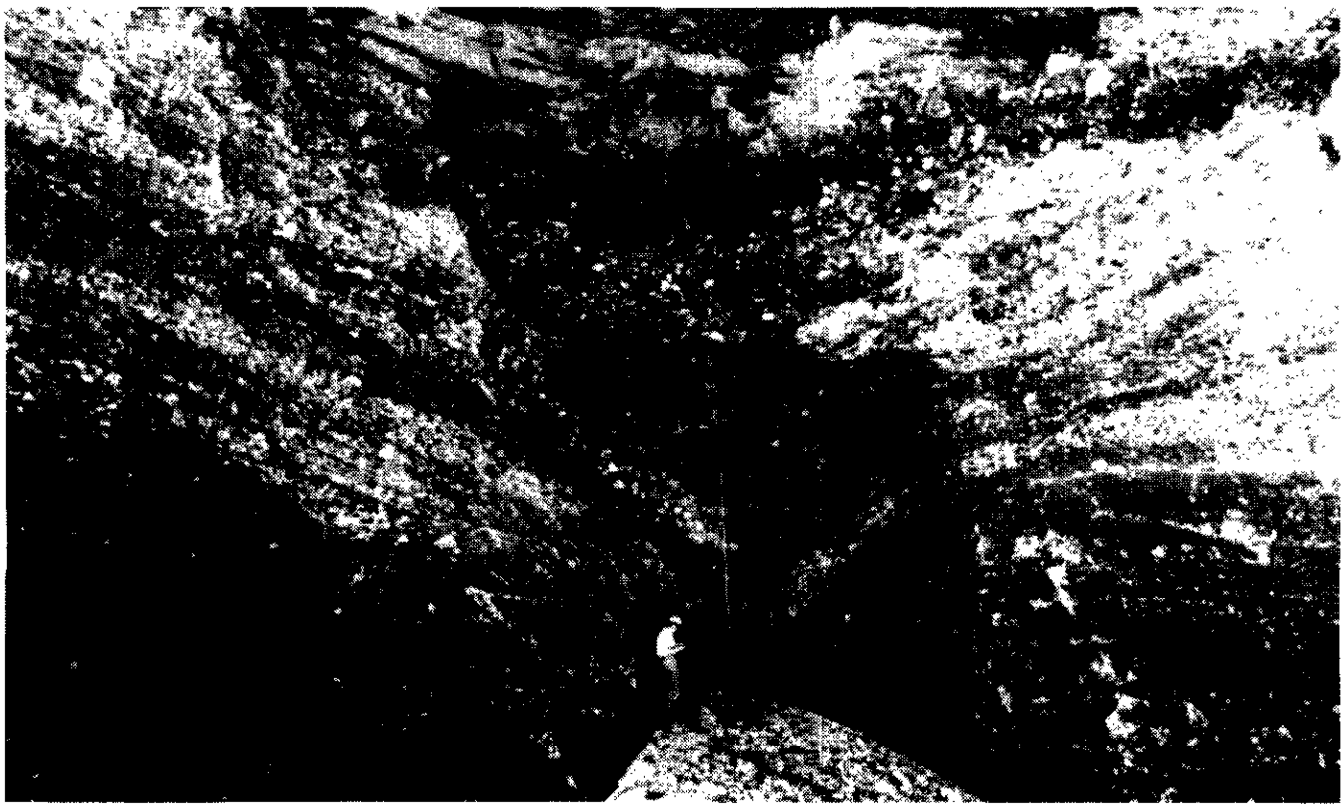

Plate 4-3-7. Well developed channel structures in braided stream deposits. Dark layers are open-work gravels stained with manganese oxides. The photo is taken at the same site as Plate 4-3-5 but at a higher stratigraphic level.

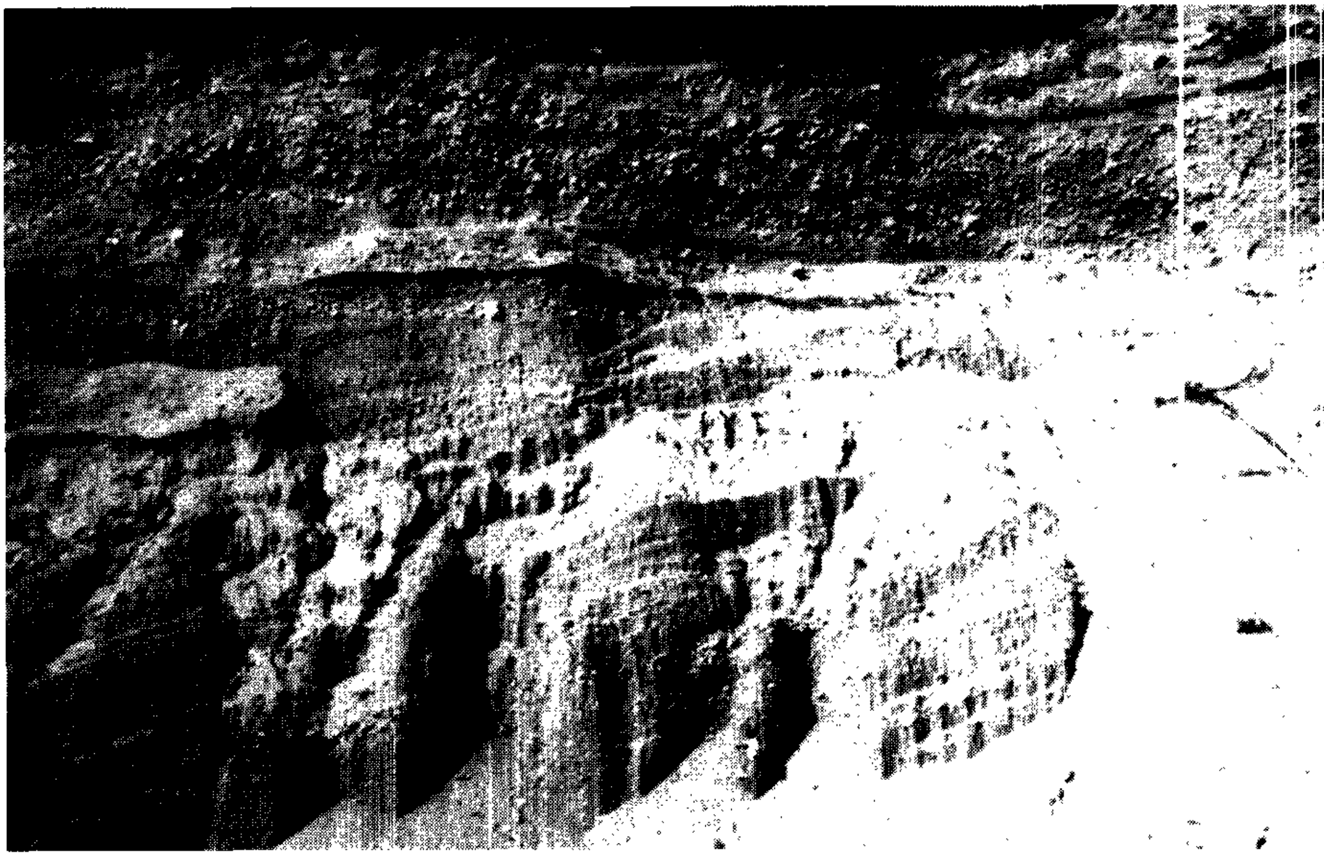

Plate 4-3-8. Glaciofluvial deltaic gravels with steep foreset bedding overlain by braided stream deposits with horizontal bedding and large-scale, low-angle, trough crossbedding along the north side of the Mamquam River about 4 kilometres upstream of its confluence with the Squamish River.

Terrain units identified as having high potential for aggregate deposits include glaciofluvial terrace and deltaic deposits (F^G). Fluvial low-terrace deposits (Ft) and alluvial fan deposits (Ff) identified with sand, pebble and/or general gravel textural modifiers or those known to be composed mainly of sand and/or gravel on the basis of drill logs were classified as moderate potential aggregate deposits. Floodplain deposits (F^Al) were identified as low potential sand and gravel deposits because of the shallow water table. The latter can be inferred from terrain maps by the presence of a qualifying descriptor (identified with the ^ superscript) indicating active modifying processes such as flooding, or from subsurface data such as water-well records (*e.g.*, Figure 4-3-2). Other map units with low aggregate potential include alluvial fans dominated by muddy debris-flow deposits, colluvial deposits including gravelly landslide and talus deposits (Cf), and gravelly or sandy morainal deposits. Terrain units with moderate or high potential occurring as secondary or tertiary units within a map polygon, those occurring as veneers over bedrock or morainal deposits and those with thick overburden were classified as low potential units. There are several other types of surficial materials that have potential mainly as sandy aggregates but that were not mapped in the study area. These include: thick sandy eolian deposits (*e.g.*, sand dunes), sandy lacustrine beach deposits, proximal glaciolacustrine sediments, marine spits, bars and beaches, and glaciomarine raised-beach and nearshore deposits.

CONCLUSIONS

Uses of surficial geology data briefly outlined in this paper include applications in the fields of mineral exploration and development, forestry, environmental studies (including fisheries, wildlife, recreation, parks and groundwater applications), engineering, geologic hazard studies and land-use planning. Surficial geology data in the form of maps and drill logs currently exist for much of British Columbia but the information is complicated and commonly must be scientifically evaluated, synthesized and in some cases supplemented with new data before it can be readily utilized in these applied fields.

From descriptions of existing and potential aggregate deposits in the study area, it is concluded that glaciofluvial braided stream and deltaic deposits are the highest potential aggregates because they are extensive, well sorted and contain little silt or clay. Low-terrace fluvial deposits and gravelly alluvial fan sediments are considered to be moderate potential aggregates as they tend to be more poorly sorted than glaciofluvial deposits. Gravelly colluvial and morainal

Plate 4-3-9. Angular, monolithologic talus deposits exposed along the shoreline of Howe Sound near Watts Point. These deposits are derived from steep cliffs of strongly jointed basalt and have been quarried at several sites in the area. Note the wood fragment directly below the rock hammer.

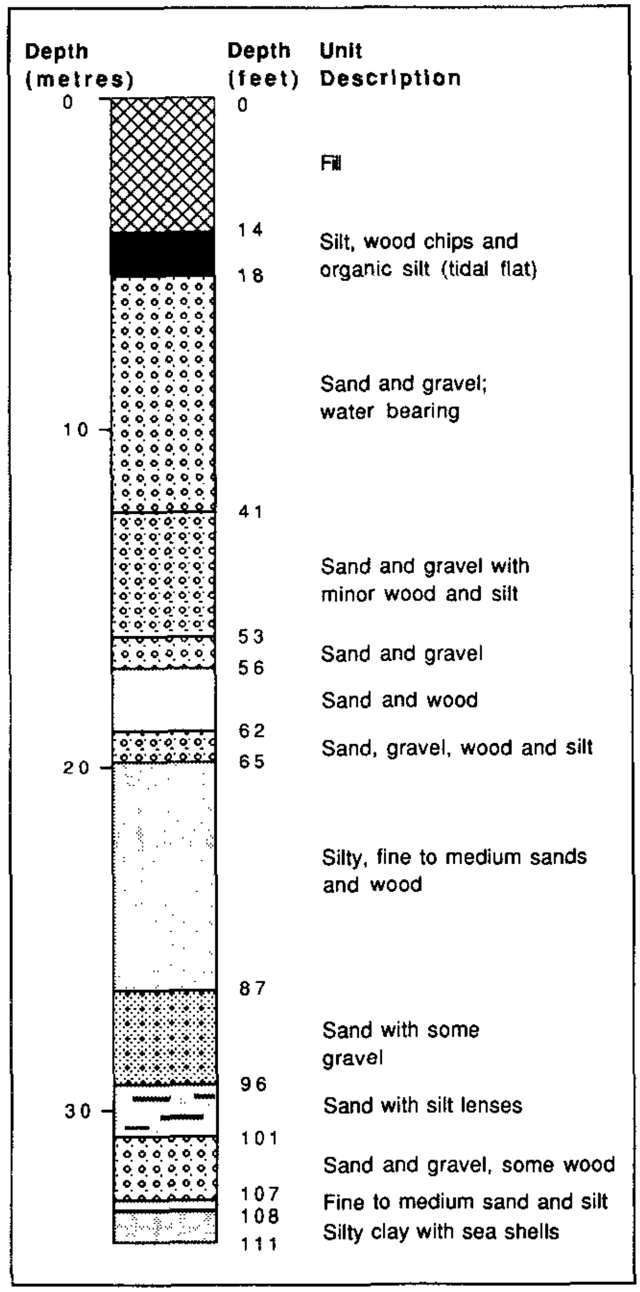

Figure 4-3-2. Sample well log from the British Columbia water-well database maintained by the Ministry of Environment, Lands and Parks. The shallow water table, indicated by the presence of water-bearing sand and gravel near the surface, limits the potential of these deposits for aggregate purposes.

deposits are low potential units as are moderate or high potential sand and gravel deposits that occur as thin veneers or with thick overburden.

Preliminary results of field evaluations of aggregate potential maps prepared in the office indicate that, in general, potential sand and gravel areas identified from existing data were much larger than those identifiable in the field. The main reason for this is that sand and gravel deposits typically comprise small areas within larger, more generalized terrain units. In addition, many large map units with good potential for sand and gravel are not exploitable because of shallow groundwater tables. These map units include intermittently active fluvial channels and bars, and low terraces and floodplains. Classification of sand and gravel potential from mapped surficial geology data will have to take these factors into account. For example, map units containing relatively small areas with high potential for aggregate that occur within a larger region of lower potential will have to be distinguished from map units dominated by areas with high potential for sand and gravel deposits. Similarly, map units with near-surface water should be distinguished from those with deep groundwater tables. Information on high groundwater table levels may have to be derived from sources other than surficial geology maps, such as water-well records. Additional data on slope, topography and depth to bedrock should also be incorporated into the classification. Other regional factors, such as the abundance of gravelly talus deposits derived from recent volcanics in this region, will also have to be considered.

FUTURE WORK

Methodologies for the production of derivative products such as 1:50 000 aggregate distribution maps which include volume and shape estimates are currently being developed. Further research in the aggregate component of this program will include:

- Testing the accuracy of these methodologies for producing aggregate potential maps and their applicability to different areas of the province.
- An evaluation of the utility of using existing subsurface data for three-dimensional reconstructions.
- An investigation of techniques for capturing surficial geology data in digital format and producing derivative algorithms.

In addition to providing information on aggregate deposits, data collected during this study will be used to elucidate the Quaternary history of the area and to investigate the frequency and nature of geologic hazards in the region. Studies to develop methodologies for combining surface and subsurface data to produce other applied products such as geologic hazard potential maps will be conducted in a subsequent phase of this project.

ACKNOWLEDGMENTS

Colleen Bauer provided outstanding assistance in the field. Diagrams were capably drafted by Scott Henthorn. The manuscript was reviewed by John Newell, Peter Bobrowsky, Brian Grant and Paul Matysek. This study was initiated on the basis of a recommendation of an independent advisory panel to the Surficial Geology Unit. Panel members are Rob Buchanan, John Clague, Kay Fletcher, Bob Gerath, Nat Rutter, June Ryder, Ian Thompson and Doug VanDine. Their contributions to this and related projects is gratefully acknowledged as is the assistance of Peter Bobrowsky, Tim Giles, Dan Kerr and Paul Matysek in the development of the program.

REFERENCES

Barksdale, R.D. (Editor) (1991): The Aggregate Handbook; *National Stone Association*, Washington, D.C.

Bobrowsky, P.T., Giles, T. and Jackaman, W. (1992): Surficial Geology Map Index of British Columbia; *B.C. Ministry of Energy, Mines and Petroleum Resources*, Open File 1992-13.

B.C. Ministry of Energy, Mines and Petroleum Resources (1990): British Columbia Mineral Statistics, Annual Summary Tables, Historical Mineral Production to 1990; prepared by the Mineral Statistics Section, 86 pages.

Boydell, A.N. (1992): Surficial Geology and Land Use; unpublished report prepared for the Surficial Geology Task Group, Resource Inventory Committee, Victoria, 15 pages.

Buchanan, R.G. (1990): Preliminary Geotechnical Investigation, Indian Arm Corridor (East Alternative), Sea to Sky Highway Project; unpublished report, *B.C. Ministry of Transportation and Highways*, 22 pages.

Buchanan, R.G. (1991): Geotechnical Investigation, Squamish to Whistler Village, Preliminary Planning and Design; unpublished report, *B.C. Ministry of Transportation and Highways*, 33 pages.

Clague, J.J. (1989): Quaternary Sea Levels (Canadian Cordillera); *in* Quaternary Geology of Canada and Greenland, Fulton, R.J., Editor, *Geological Survey of Canada*, Geology of Canada, Number 1, pages 43-47.

Ferguson, A. and McPhee, M. (1992): Howe Sound Watershed Environmental Science Workshops and Public Meetings, Summary of Proceedings; unpublished report, *Environment Canada*, 107 pages.

Green, N.L. (1990): Late Cenozoic Volcanism in the Mount Garibaldi and Garibaldi Lake Volcanic Fields, Garibaldi Volcanic Belt, Southwestern British Columbia; *Geoscience Canada*, Volume 17, pages 171-175.

Hungr, O. and Skermer, N.A. (1992): Debris Torrents and Rockslides, Howe Sound to Whistler Corridor; *in* Geotechnique and Natural Hazards, Technical Tours Guidebook, *BiTech Publishers Ltd.*, pages 4-46.

Hungr, O., Morgan, G.C. and Kellerhals, R. (1984): Quantitative Analysis of Debris Torrent Hazards for Design of Remedial Measures; *Canadian Geotechnical Journal*, Volume 21, pages 663-667.

Hungr, O., Morgan, G.C., VanDine, D.F. and Lister, D.R. (1987) Debris Flow Defenses in British Columbia; *Reviews in Engineering Geology*, Volume 7, pages 201-223.

Mathews, W.H. (1951): The Table, a Flat-topped Volcano in Southwestern British Columbia; *American Journal of Science* Volume 249, pages 830-841.

Mathews, W.H. (1952a): Mount Garibaldi, a Supra-glacial Volcano in South-western British Columbia; *American Journal of Science*, Volume 250, pages 81-103.

Mathews, W.H. (1952b): Ice-dammed Lavas from Clinker Mountain, South-western British Columbia; *American Journal of Science*, Volume 250, pages 553-565.

Mathews, W.H. (1958): Geology of the Mount Garibaldi Map Area, South-western British Columbia – II, Geomorphology and Quaternary Volcanic Rocks; *Geological Society of America*, Bulletin, Volume 69, pages 179-198.

McCammon, J.W. (1977): Surficial Geology and Sand and Gravel Deposits of Sunshine Coast, Powell River and Campbell River Areas; *B.C. Ministry of Energy, Mines and Petroleum Resources*, Bulletin 65, 36 pages.

Monger, J.W.H. (1990): Georgia Basin: Regional Setting and Adjacent Coast Mountains Geology, British Columbia; *in* Current Research, *Geological Survey of Canada*, Paper 90-1F, pages 95-107.

Moore, D.P. and Mathews, W.H. (1978): The Rubble Creek Landslide, British Columbia; *Canadian Journal of Earth Sciences*, Volume 15, pages 1039-1052.

Roddick, J.A. and Woodsworth, G.J. (1979): Geology of Vancouver, West Half, and Mainland Part of Alberni; *Geological Survey of Canada*, Open File 611.

Ryder, J.M. (1980): Terrain Map of Sechelt, 92G/5; unpublished map, *B.C. Ministry of Environment, Lands and Parks*, 1:50 000-scale.

Ryder, J.M. and Thomson, B. (1986): Neoglaciation in the Southern Coast Mountains of British Columbia: Chronology Prior to the Late Neoglacial Maximum; *Canadian Journal of Earth Sciences*, Volume 23, pages 273-287.

Thomson, B. (1980a): Terrain Map of Squamish, 92G/11; unpublished map, *B.C. Ministry of Environment, Lands and Parks*, 1:50 000-scale.

Thomson, B. (1980b): Terrain Map of Cheakamus River, 92G/14; unpublished map, *B.C. Ministry of Environment, Lands and Parks*, 1:50 000-scale.

Thomson, B. (1980c): Terrain Map of Sechelt Inlet, 92G/12; unpublished map. *B.C. Ministry of Environment, Lands and Parks*, 1:50 000-scale.

Thurber Engineering Ltd. (1983): Debris Torrent and Flooding Hazards Along Highway 99; unpublished report for *B.C. Ministry of Transportation and Highways*.

Thurber Engineering Ltd. and Golder Associates Ltd. (1992): Cheekye River Terrain Study; unpublished report for *B.C. Ministry of Lands, Parks and Housing*.

Walmsley, M.E. (1992): Report of the Soils, Geology and Archaeology Task Force; unpublished report prepared for the Resource Inventory Committee by *Westland Resource Group*, Victoria, 24 pages.