FIG. 1. Massive slumps and earth flows *S* have occurred in deep glacial materials on the north side of Babine Lake in British Columbia. A nearby bluff of columnar basalt *B* shows no sign of instability. Deep glacial materials consist of glacial till and lakebed sediments. These materials were deposited against glacier ice which occupied Babine valley during melting of the glaciers. *Canadian Government Airphoto.*

HARVEY E. DISHAW*
R. C. Thurber & Assoc. Ltd.
Victoria, B. C., Canada

Massive Landslides

Difficult to detect on the ground, they are revealed by small-scale photos for construction engineers and geologists.

(*Abstract on next page*)

INTRODUCTION

LANDSLIDES DESCRIBED IN this paper are very large—usually exceeding a square mile in area. They are also deep and involve large volumes of material; hence the title "massive".

A massive landslide was seen several years ago during a study of small scale airphotos for the Columbia River dams[1]. But, the wide distribution of these slides in glaciated regions wasn't realized until the author had done several more preliminary engineering and resource studies using photographs having a scale of 1 inch equals 1 mile. These studies, covering thousands of square miles in British Columbia, revealed many massive slides in both soil and rock. A search of references yielded little to explain the origin of these slides. Two references[2,9] however seem to support the geologic origin suggested by the author in this paper.

* Presented at the Annual Meeting of the Columbia River-Puget Sound Regions of the American Society of Photogrammetry, Portland, Oregon, December 1966.

GEOLOGIC ORIGIN OF SLUMPS

During the Ice Age, glacier ice accumulated at many centers in British Columbia. Ice escaped westward to the sea by following preglacial valleys on the west side of the Coast Mountains. The moving ice greatly deepened and steepened these valleys; the deepest sounding in fiords along the west coast exceeds 2,500 feet[3]. Inland, the ice generally moved from the Coast Mountains east to the Rocky Mountains. In detail, however, the direction of ice movement was much more variable; for example, glacier ice flowed along such valleys as those of Babine and Takla Lakes[4] and many others. These valleys were deepened, widened and made more steep-sided by the movement of glaciers along their length.

ABSTRACT: *When glaciers moved across British Columbia during the Ice Age, their direction was guided by existing valleys. Passage of glacier ice deepened and widened many of these valleys, creating a U-shaped valley cross-section. Melting of the glaciers left steep-walled valleys, many of which were unstable because of over-steepened slopes and incompetent bedrock or soil materials. Massive landslides occurred immediately after glacial melting—bedrock and soil materials exceeding a cubic mile in volume slumped down at that time. The location of these massive landslides can usually be detected in small-scale aerial photographs. Their size can be delineated and broad engineering properties of the materials can be predicted. Engineers and geologists investigating construction sites should know the location, size and significance of these massive earth movements.*

Lateral support was removed from steep valley walls when the glaciers melted. In most places bedrock was competent and able to stand on near vertical cliffs without failure. However, where bedrock was strongly jointed or otherwise weakened, it was unable to stand on the steep slopes left by the retreating glaciers. Here massive failures in bedrock occurred—sometimes bringing down over a cubic mile of material from the valley walls.

In addition to failures in bedrock, massive landslides have been observed in soil materials (Figure 1). Because of its greater depth, glacier ice in deep valleys was the last to melt. Where a deep deposit of glacial sediments accumulated between the ice and upper valley banks, further melting caused progressive failure of the sediments—the volume of failed material depending on the depth of sediment at the point of failure.

Relative Size and Variety

Earth movements commonly described in engineering and geologic literature[5,6,7,8] range in size from small slumps in highway backslopes to slumps involving several million cubic yards of material. Earth movements described in this paper are massive by comparison—sometimes involving over a cubic mile of material (5×10^9 cubic yards).

Landslides seen in airphotos include Slump (Figures 2, 4, 5, 6, and 7), Rockslide and Debris Avalanche (Figure 3), Earthflow (Figure 1) and Block Glide (Figures 2 and 8).

Clues to Location of Massive Landslides

Because these slumps are so large, they are virtually impossible to detect on the ground or by using large scale airphotos (1 inch = 1,000 feet and 1 inch = 1,320 feet). However, massive landslides can be detected in small scale airphotos (1 inch = 4,000 feet to 1 inch = 6,000 feet) because the large area covered in each stereo-pair allows the investigator a regional view of the study area. The photo interpreter looks initially for anomalies in the valley cross-section which often point to sites of old earth movements. Here are some of the anomalies which can be clues to the location of large slumps:

HARVEY E. DISHAW

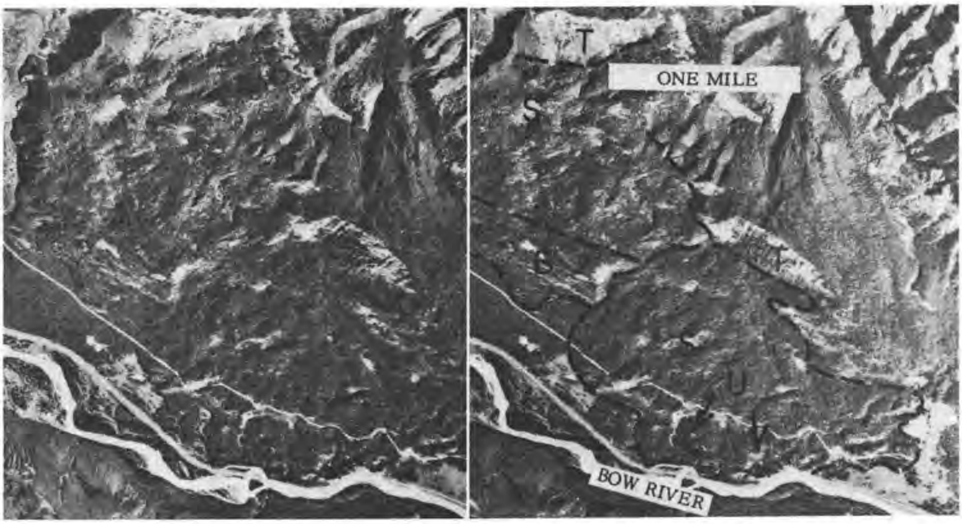

FIG. 2. The glacier that flowed down this section of the Bow River valley between Banff and Lake Louise was about two miles wide near its base. Bedrock slides *S* have almost closed the valley bottom at this point. Most of the slide material has a hummocky appearance with undrained depressions *U*. One slump block *B* is composed of relatively unbroken bedrock. Scarp faces of bedrock with talus banks *T* are further clues to the identification of these massive slides. *Canadian Government Airphoto.*

- *U*-shaped cross-section of glaciated valley is absent.
- Valley is usually narrower at the slide site—sometimes a canyon.
- Presence of a large block of material in the bottom of an otherwise unbroken valley section.
- Presence of bedrock islands in a river or lake occupying a former glaciated valley.
- Irregular shoreline of either lake or river.
- Presence of deep and extensive areas of broken bedrock.
- Slide material has a jagged or at least a hummocky appearance.
- Rapids in a stream or fiord.
- Bulging at the toe of slide.
- Presence of a scarp face on the valley side—usually with associated talus banks.
- Presence of ponds and undrained depressions on valley slopes.

The location of massive landslides is only the first step in the investigation. Areal extent of the landslide can be delineated and the

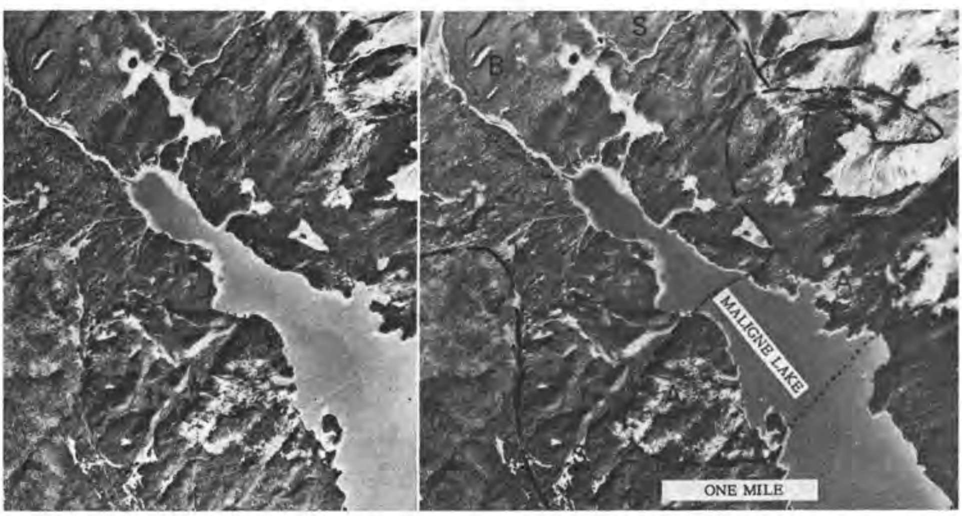

FIG. 3. A complex deposit of glacial materials and slide debris *KBS* blocked a glaciated valley near Jasper, Alberta, to form Maligne Lake. The rockslide and debris avalanche *A* came from right to left while some glacier ice remained in the lake depression. Extent of the avalanche is indicated by large boulders and irregular shoreline. *Canadian Government Airphoto.*

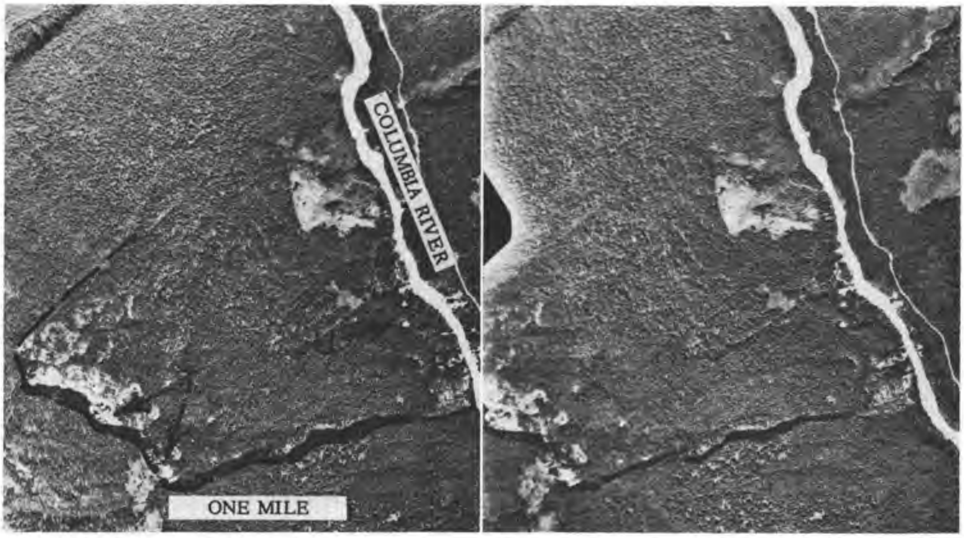

FIG. 4. The massive slump outlined by dashed lines is located north of Revelstoke, B. C. Valley sides, oversteepened by glacial erosion, were made unstable by post-glacial river downcutting. Clues to the presence of this slide are: scarp face with associated talus banks *T*; undrained depression *U* on the valley side; and bulging of slide debris *B* which narrows the river section. *Canadian Government Airphoto.*

character of the materials can be predicted after careful stereoscopic study of airphotos and reference to geologic literature.

SLIDE DEBRIS

Slumps in soil materials commonly occur in clay. Two or even more types of material (i.e. lacustrine clay and glacial till) may be present in the slide debris, but the original sequence of bedding is destroyed by slumping and normal seepage paths are blocked. Engineering soil properties vary from place to place on the deposit.

Slumps in bedrock are most common in sediments (shale, sandstone, etc.) and (in descending order) are less common in metasediments, intrusive rocks (granite) and extrusive rocks (basalt). Debris from bedrock slides can vary from thoroughly broken and fragmented material (Figure 2) to a large

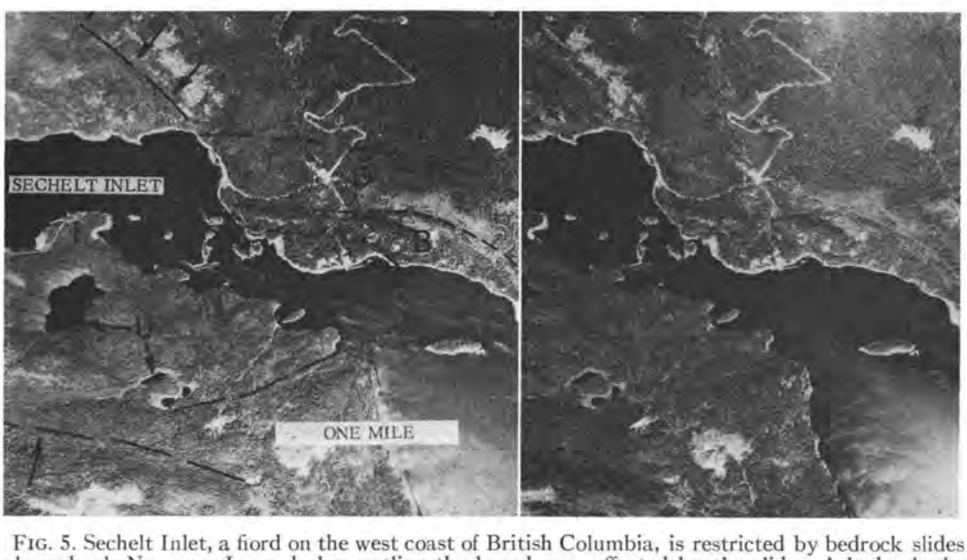

FIG. 5. Sechelt Inlet, a fiord on the west coast of British Columbia, is restricted by bedrock slides at Skookumchuck Narrows. Long dashes outline the broad area affected by the slides. A bedrock slump block *B* and bedrock knobs *K* have almost closed the once broad glaciated valley. Unconsolidated materials fill the depression *D* behind the slump block. Other features that help to identify this as a landslide area are irregular bedrock shorelines *I*, undrained ponds *U* and tidal rapids *R*. *B. C. Government Airphoto.*

FIG. 6. Mount Downton (7760 ft.), an extinct volcano in the interior of British Columbia was deeply eroded by glaciers during the last Ice Age. Bedrock slumps *S* occurred when glacier ice melted out of *U*-shaped valleys. Scarp faces with associated talus *T* and undrained ponds *U* help to identify sites of massive slides. Unfailed volcanic bedrock *V* has been well rounded by glacial erosion. *Canadian Government Airphoto.*

block of bedrock altered only by more extensive jointing (Figure 8). Slump debris is more permeable than unbroken rock. Foundation conditions for structures are less favourable on broken rock and stability of broken rock may be less than unfailed rock of the same type.

Engineering properties of slump debris will vary widely depending on type of failed material and type of failure mechanism. Slumps in bedrock can usually be distinguished from slumps in soil materials by examination of photos alone. While it is possible to predict broad engineering properties of slumped materials by photo interpretation, investigators must be prepared to do on-the-ground investigation and drilling of construction sites at an early stage. Complex engineering problems can be expected at sites selected on deposits of slump debris.

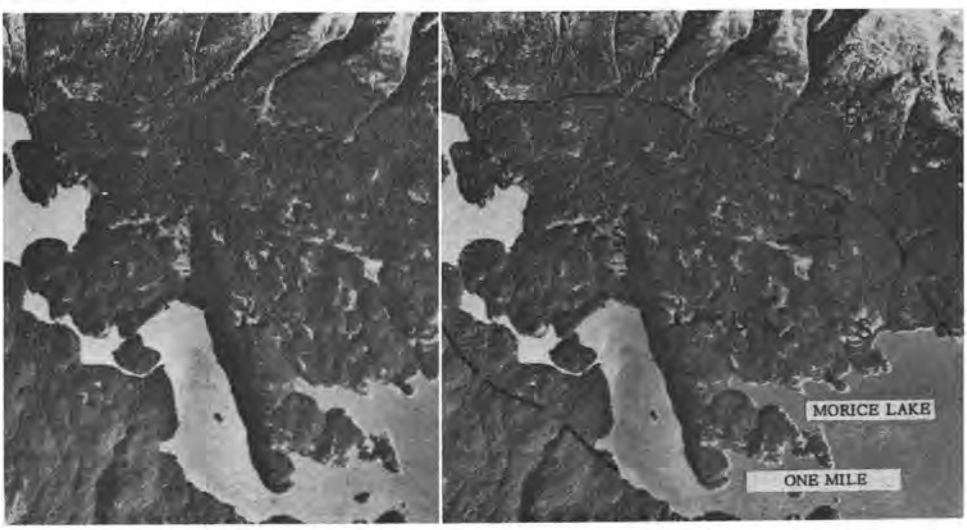

FIG. 7. This massive bedrock slump *S* closed the west arm of Morice Lake in British Columbia shortly after glacier ice melted from the valley. Steep unbroken bedrock slopes *B* are cut by post-glacial drainage. Slide material has a hummocky appearance with undrained depressions *U* and talus banks *T*. *Canadian Government Airphoto.*

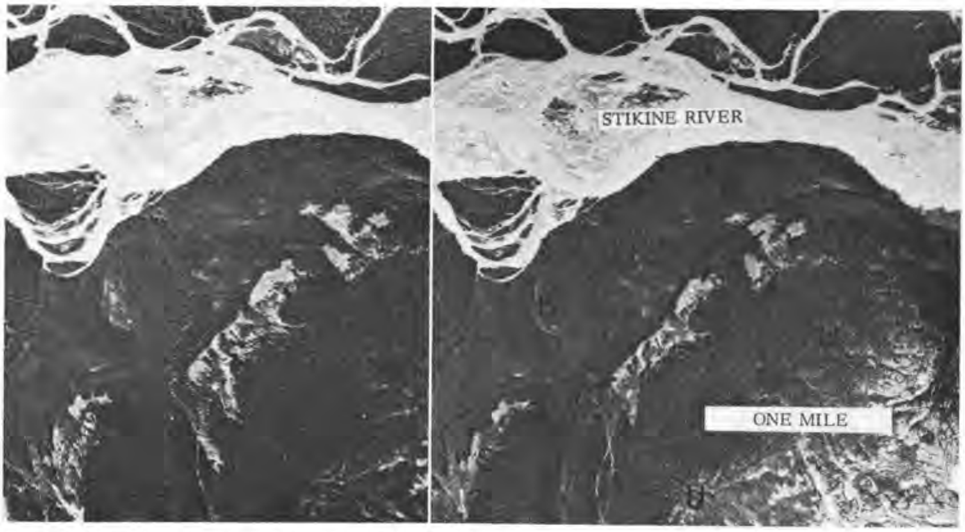

FIG. 8. The bedrock slump block *B* shown in this stereopair has a rounded unbroken appearance that is not normally associated with landslide material. However, the scarp face *S* and associated talus *T* from steep bedrock walls help to delineate the landslide area as separate from the unfailed mountain side *U*. *B. C. Government Airphoto.*

ENGINEERING APPLICATIONS

A narrow valley with steep rock walls and rapids in the stream often attracts engineers looking for a damsite for water storage. The photo interpreter's first task is to indicate whether the selected site is also the site of an ancient massive landslide. If it is, he can outline engineering problems and suggest a program of site investigation that will show the nature of design problems that must be dealt with.

Investigators of damsites must be wary of old landslides for these reasons:

- ★ Inactive slides may begin moving again.
- ★ Renewed activity of a slide may damage or destroy the dam and other structures including power lines.
- ★ Slide debris that drops into the reservoir could generate destructive waves.
- ★ Seepage through broken and fragmented bedrock forming the slide debris will be many times the seepage through unbroken rock.
- ★ Tunnelling in broken and jointed material is more difficult and costly than in sound rock.
- ★ It is impossible to drive unlined tunnels in broken rock.

A great range of size and quality of material is often available in slide debris ranging from semi-previous borrow to rip-rap material. Because engineering properties of slide debris vary widely, it is not considered to be good borrow material for road or dam construction. But it has been used successfully[8] and can be used for this purpose provided that careful materials control and inspection is enforced.

CONCLUSIONS

Massive landslides that are difficult to detect on the ground or by using large scale airphotos can usually be seen in small-scale airphotos. Their size can be delineated and broad engineering properties of the slide debris can be predicted. Engineers and geologists investigating construction sites should know the location, size and significance of these massive earth movements.

REFERENCES

1. Mollard, J. D. and Dishaw, H. E. (1966) Applications of Airphoto Interpretation in Hydro-Electric Power Investigations in Western Canada, *Engineering Journal*, Vol. 49, No. 4.
2. Fyles, J. G. (1963) Surficial Geology of Horne Lake and Parksville Map Areas, Vancouver Island, British Columbia, *G.S.C. Memoir 318*.
3. Holland S. S. (1964), Landforms of British Columbia, A Physiographic Outline, *Bulletin No. 48*, B. C. Department of Mines and Petroleum Resources.
4. Armstrong, J. E. (1965) Fort St. James Map Area, Cassiar and Coast Districts, British Columbia, *G.S.C. Memoir 252*.
5. Thornbury, Wm. D. (1954) Principles of Geomorphology, John Wiley & Sons Inc.
6. Eckel, Edwin B. et al (1958) Landslides and Engineering Practice, Highway Research Board, *Special Report 29*.
7. Nasmith, Hugh (1964) Landslides and Pleistocene Deposits in the Meikle River Valley of Northern Alberta, *Canadian Geotechnical Journal*, Vol. I, No. 3.
8. Terzaghi, Karl (1960) Storage Dam Founded on Landslide Debris, *Journal of the Boston Society of Civil Engineers*.
9. Terzaghi, Karl (1962) Stability of Steep Slopes on Hard Unweathered Rock, *Geotechnique*, Vol. XII, No. 4.