69-35

GEOLOGICAL SURVEY OF CANADA

DEPARTMENT OF ENERGY, MINES AND RESOURCES

PAPER 69-35

APPLICATION OF BOREHOLE STRATIGRAPHIC TECHNIQUES IN AREAS OF MOUNTAIN GLACIAL DRIFT IN ALBERTA, CANADA

(Report and 9 figures)

N. W. Rutter and J. E. Wyder

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ABSTRACT

Presented here are the results of an integrated program of drilling, side-wall sampling, and single-point electro-logging that has been successfully carried out in areas of mountain glacial drift near Canmore and Calgary, in Alberta. The purpose of this program was to obtain stratigraphic information that could not be acquired by conventional observational techniques. To date, reports from most test drilling programs using rotary hydraulic drills have consisted of descriptions of the chips carried to the surface by the drilling mud. Chip samples by themselves do not provide sufficient evidence for the determination of detailed stratigraphy in areas of rapid lateral and vertical changes in lithology, such as Calgary and Canmore. In these areas, side-wall sampling techniques and electro-logs proved to be valuable stratigraphic tools, readily eliminating ambiguities arising from the examination of chip samples alone.

The results of this program were useful in confirming stratigraphic relationships based on previous surface mapping, in extending geological boundaries, in determining the thickness of lithologic units, and in the discovery of new lithologic units.

APPLICATION OF BOREHOLE STRATIGRAPHIC TECHNIQUES IN AREAS OF MOUNTAIN GLACIAL DRIFT IN ALBERTA, CANADA

INTRODUCTION

The purpose of this report is two-fold: 1) to discuss the value and limitations of borehole stratigraphic techniques in areas of mountain glacial drift, and 2) to present practical examples of how stratigraphic problems may be resolved in areas where only surface geologic methods have previously been applied.

The borehole stratigraphic techniques used in this study enable the geologist to acquire chip samples, self-potential and resistivity electrologs, and side-wall samples from the strata penetrated. This combination of techniques was developed several years ago by Dr. E.A. Christiansen (Morrison, 1966) of the Saskatchewan Research Council for purposes of data gathering in the silty to clayey tills, stratified unconsolidated sediments, and shaly bedrock that are the most common near-surface materials in southern Saskatchewan. The method has been highly successful in the area for which it was developed and its use has been successfully extended into Manitoba and eastern Alberta where the deposits are similar. It was felt that its usefulness would be more limited in the many parts of Canada where tills are sandy or stony, where bedrock is more resistant than in Saskatchewan, and where gravels and sands must be tested.

The present study is the first attempt to apply the techniques used so successfully on the Prairies to areas underlain by the coarse sandy and stony sediments of the Pleistocene deposits. It was conducted within the city limits of Calgary, over an area covering about 155 square miles, and in a part of the Bow Valley near Canmore (Fig. 1). Calgary lies within the Interior Plains physiographic province, about 45 miles east of the Rocky Mountain Foothills, and is situated at the confluence of the eastward-flowing Bow and Elbow rivers. Rolling topography dominates the landscape, becoming hilly to the west and gently undulating to the east. The average elevation is 3,500 feet. The city is located in a region that has been influenced by repeated advances of both the Laurentide ice sheet from the east and Rocky Mountain glaciers from the west.

Canmore lies within the Cordilleran physiographic province and is situated in the Bow Valley, one of the major outlet valleys of the Rocky Mountains. The valley is bordered by northwest-trending mountains that rise

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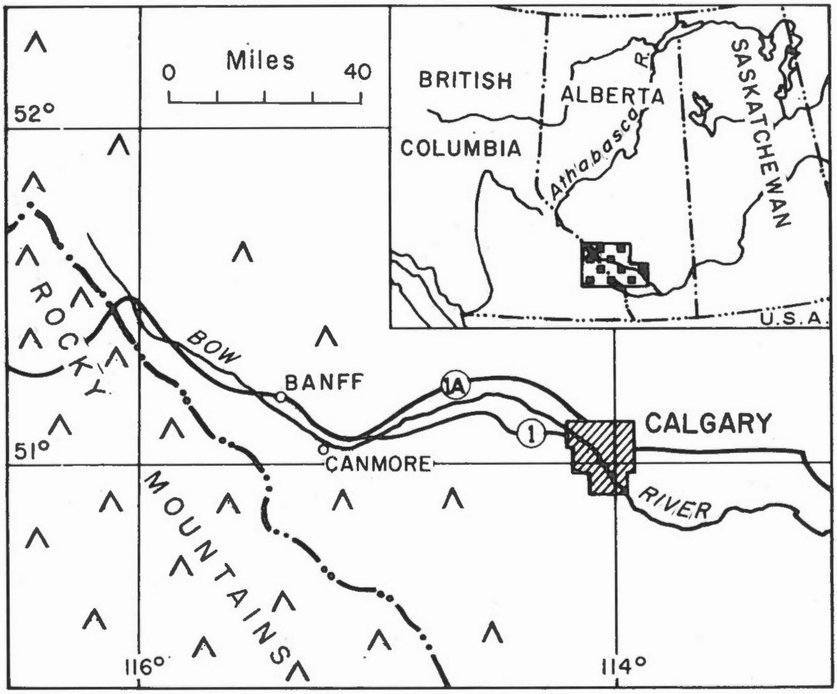

Figure 1. Area of experimental testing of borehole stratigraphic techniques.

to 10,000 feet or more, and local relief is about 4,000 feet. Several eastward-moving ice advances have been inferred from drift deposits exposed in the Bow Valley (Rutter, 1966a and b).

GENERAL GEOLOGY

Calgary Area

The Calgary area (Fig. 2) is underlain by the Paskapoo Formation (Tertiary) which consists of interbedded sandstone, siltstone, and shale. Quaternary deposits overlie these sediments except in scattered areas along river valleys. The only account of surficial geology of the Calgary region is that by Tharin (1960) whose work was the reference used in the selection of drilling sites and in the review that follows.

According to Tharin, glacial deposits present on the surface in the Calgary area include:

Spy Hill Till (Rocky Mountain) - This till is sandy, containing varying quantities of stones - limestone, dolomite and quartzite - derived from the west. It occurs as hummocky, disintegration moraine on Spy Hill, in the northwest corner of the study area, and as ground moraine south of the Bow River in the western part of the area. All deposits are found on the uplands.

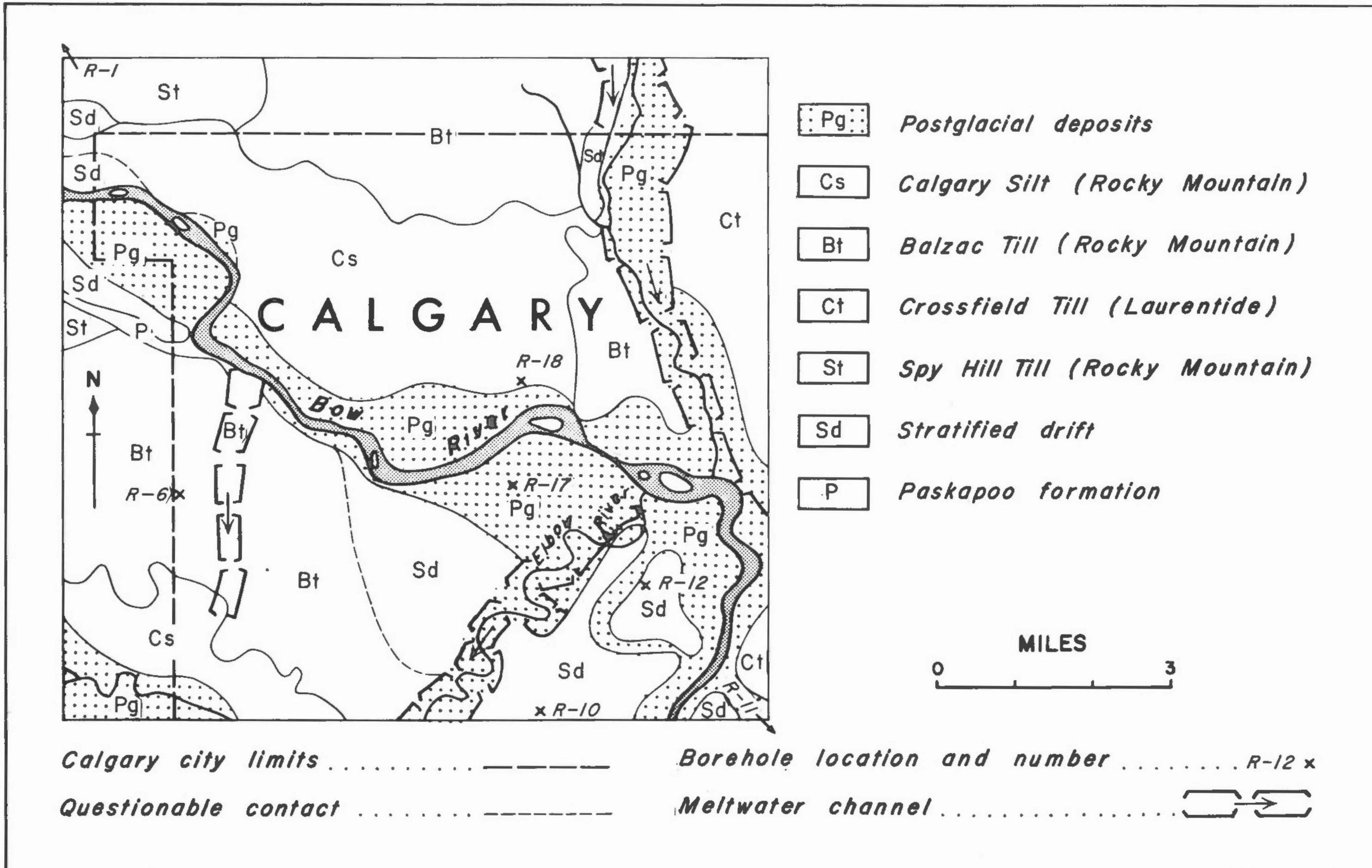

Figure 2. Surficial geology and borehole locations in the Calgary area, Alberta (modified after Tharin (1960)).

Crossfield Till (Laurentide) – On the eastern margins of the study area, Crossfield Till occurs in lowlands as ground moraine with flat, undulating topography. It is brown, calcareous, and sandy to silty. Pebbles of both eastern and western origin are abundant.

Balzac Till (Rocky Mountain) – Ground moraine consisting of Balzac Till is present mainly in the highest areas of the northern, western, southwestern and east-central part of the study area. It is light brown, very sandy and calcareous. Pebbles of limestone, dolomite and quartzite, western in origin, are common. Locally, some igneous and metamorphic pebbles, derived from the east, may be present.

Calgary Silt – Calgary Silt occurs mainly north of the Bow River where it forms a plain between the postglacial floodplain deposits and the uplands to the north. It is mainly a lacustrine silt, with varying amounts of sand and clay, deposited in glacial Lake Calgary. Pebbles, patches of till and till-like material are found within the unit. Much of the surface material has been reworked by wind.

Stratified drift and postglacial deposits – Fluvial and glaciofluvial gravel, sand and silt are abundant in the Calgary area. Postglacial gravels are mainly clean and well sorted, containing mostly limestone, dolomite and quartzite derived from the west, and minor amounts of igneous and metamorphic rocks derived from the east. Glaciofluvial sediments (stratified drift) are lithologically similar to the postglacial deposits but, generally, are not so well sorted.

Glaciers twice invaded the Calgary area from the Rocky Mountains to the west and from the Plains to the east (Tharin, 1960). During the early advance from the Rocky Mountains, the Spy Hill glacier flowed down the Bow River and over the Foothills, covering the entire area. At about the same time, Laurentide ice from the east, called by Tharin the 'Lochend glacier', also advanced into the area. As deglaciation took place, ground and hummocky disintegration moraine and stratified drift were deposited (Spy Hill Till).

During the next phase of glaciation, eastward-flowing ice in the Bow Valley did not reach the Calgary city limits, but glacier ice, from the Athabasca Valley to the northwest, was deflected southward into the vicinity of Calgary by re-advance of Laurentide ice. This re-advance of ice is represented in the study area by the Crossfield Till, and the southward flow of the glacier originating in the northwest, by the Balzac Till. Calgary Silt in the northwest and north-central districts was also deposited at this time in a glacial lake in Bow Valley, dammed by Laurentide ice to the east.

Canmore Area

In the Canmore section of Bow Valley (Fig. 3) there is some evidence of two and possibly three glacial advances (Rutter, 1966a and b). Early glacial activity is inferred from outwash gravel underlying till of the later Bow Valley advance and from the presence of 'black' basal till beneath both the gravel and the Bow Valley Till. Nonetheless, it is possible that the outwash gravels underlying the till are associated with the same glacier that

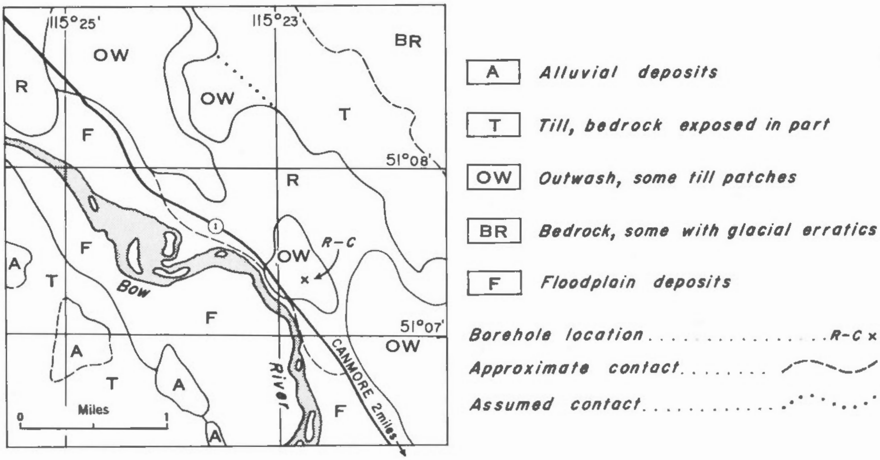

Figure 3. Surficial geology and borehole location, Canmore, Alberta.

deposited the Bow Valley Till, and further, that the 'black' basal till may not be equivalent in age with the underlying gravel but, rather, of similar age to the Bow Valley Till.

Evidence for the Bow Valley advance is based principally on thick, widespread Bow Valley Till deposits that indicate major glacier activity. Also, distinctive breaks-in-slope caused by glacial scouring and lateral, glacial-stream activity, and glacial erratics found at high elevations, are assumed to be equivalent in age to this advance. Near the Banff townsite, up-valley from the drilling site, Bow Valley Till grades laterally into outwash, indicating that the outwash was deposited during the retreat of the glacier that deposited the till.

The next advance, the Canmore* is evidenced by thin discontinuous patches of till overlying the outwash gravel that had been laid down during the retreat of the Bow Valley ice. Also, continuous ground moraine with erosional ridges found southeast of the confluence of the Bow and Cascade rivers is attributed to this advance although it must be stressed that this till could not be distinguished lithologically from till of the Bow Valley advance.

Because the above scheme had been built up from incomplete information derived only from surface 'exposures', the drilling and sampling reported in this paper were undertaken to test the inferred stratigraphic relationships.

FIELD TECHNIQUES

Drilling sites, located on the basis of known surface information, were selected to provide the maximum amount of Quaternary information.

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* Previously named the Bow Valley re-advance (Rutter, 1966a and b).

Nineteen boreholes were drilled in the Calgary area, seven of which are discussed in this paper. In the Canmore area, it was considered that one borehole would be sufficient to provide the necessary information and, accordingly, only one was drilled.

Drilling

All holes were drilled by a truck mounted, rotary hydraulic drill, with drilling mud being pumped down the centre of rotating drill rods to the bottom of the borehole to remove cuttings from the advancing drilling-bit. The mud is forced up between the drillhole walls and the drill rods to the surface, where it is collected in a portable mud pit. There the cuttings are allowed to settle before the mud is recirculated down the borehole. During the drilling of each borehole, the geologist collected chip samples and compiled a geologist's log. Following completion of the drilling, each borehole was electro-logged and sampled at selected levels with a side-wall sampler.

Chip Samples

Cuttings or chip samples were screened and collected from the drilling mud as it left the borehole. The samples were taken at ten-foot intervals, with allowance being made for the time it took the chips to travel up the hole. The samples were washed to remove mud. Chips representing the formation being drilled had then to be picked from the sample, as contamination by material above the working level of the bit is always present. Properly collected, chip samples can provide good lithologic records of boreholes in unconsolidated sediments. However, in the Calgary and Canmore areas, the complex stratigraphy cannot be determined from chip samples alone.

Geologist's Log

Descriptions of the chip samples formed the basis of the geologist's log. To these were added the depths and intervals where breaks in drilling speed occurred, and a description of materials encountered between chip samples. The log also provided a tally of the length of drill rod in a hole at any given time.

Electro-Log

The electro-log measures the self-potential and resistivity of formations. Self-potential is a natural phenomenon, believed to be caused mainly by electrical currents flowing between low permeability beds such as shale, and more permeable beds such as sand, wherever the two are in contact. The self-potential measured in a borehole depends mainly on the difference in conductivity between the formation fluid and the drilling mud. The most general use of self-potential logs is as an indicator of formational boundaries and, to a lesser extent, as an indicator of the quality of formational fluid.

Resistivity of a formation is defined as the resistance between opposite faces of a unit cube of the material. Major controlling factors are the resistivity of the formational fluid and the porosity of the rock. Other

Figure 4.

Side-wall sampler mounted on truck. (153177)

things being equal, a rock containing conductive formational fluid such as saline water, will be less resistive than one containing a less conductive fluid such as fresh water.

For the present project, a Widco 2-pen single point electrologger was used to obtain simultaneous self-potential and single point resistivity logs. Increasing resistivities were indicated by pen deflections, increasing to the right. The logs were interpreted in the conventional manner for conventional purposes, that is, low resistivities were associated with shales, clays, and silts; intermediate resistivities with till, sandy and pebbly clay and silt; and high resistivities with gravel, boulders, and bedrock sandstone. Simultaneous self-potential logs were used to indicate lithologic contacts.

Side-wall Sampler

The side-wall sampler, a development of the Saskatchewan Research Council, Saskatoon, Saskatchewan, is a wire-line device (Fig. 4), capable of extracting from the side of a borehole samples three-quarters of an inch in diameter and between one-half inch and five and one-half inches in length. Basically the sampler consists of a tool barrel, two and three-eighths inches in diameter, which holds the core tube. The tool barrel is suspended on 1, 000 feet of seven-sixteenths-inch single conductor, armoured cable, which is spooled on the drum of a hydraulic winch. The truck engine is used to provide electric and hydraulic power for operating the sampler.

Figure 5. Core tube in 'cocked' position (153178).

To obtain samples, the truck is backed over the borehole and levelled with hydraulic jacks. The core tube, whose length is determined by the diameter of the hole and the type of material to be sampled, is then cocked in an upright position (Fig. 5) and the tool barrel is lowered down the hole to the desired depth. An electric signal, sent down the cable to a solenoid, trips a spring, forcing the core tube against the side of the hole. By pulling on the cable, the core tube is forced into the material surrounding the sampler. As the tool barrel is pulled up, the core tube rotates through 180 degrees until it hangs downward inside the barrel. At the surface, it is removed, and the sample is extruded in a hydraulic press and placed in a plastic vial.

Sample horizons and core-tube lengths are selected on the basis of information available from the geologist's log and the electro-log, thus avoiding such hazards as boulders, gravel and hard sandstone layers. Sampling such hard materials frequently results in the loss of the core tube, either through the breaking of a shear pin or the collapsing of the tube. The side-wall sampler was used to sample all significant stratigraphic units in the boring program. By varying the length of the core tube, samples varying in length between one-quarter of an inch in sandstone and five and one-half inches in lake clays, were obtained. In all but two cases, where the hole collapsed, the side-wall samples allowed a detailed examination of the borehole stratigraphy.

RESULTS

Calgary Area

Of the nineteen boreholes drilled in the Calgary area, results of the seven most significant are discussed below.

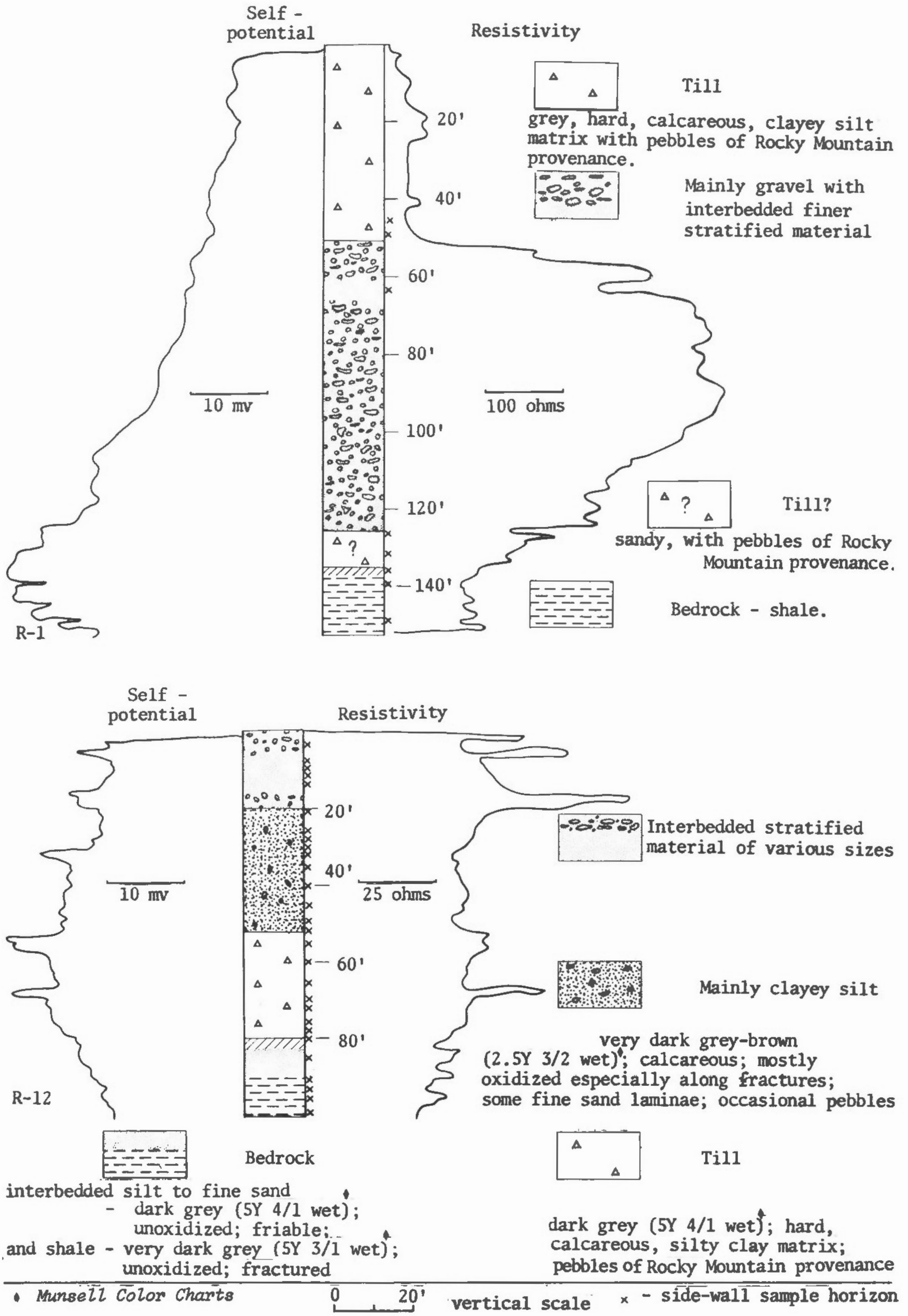

Figure 6. Electric log signatures and lithology for boreholes R-1 and R-12.

R-I (Northwest Calgary) (Fig. 6) - The drilling site is located on Spy Hill Till. Electro-logs, chip and side-wall samples indicate that the surface till unit is approximately 51 feet thick, about 20 feet thicker than previously reported (Tharin, 1960). Although only two side-wall samples were taken from this unit, the characteristic electro-log signatures are convincing enough to rule out any other interpretation.

Beginning at 51 feet the electro-log patterns change radically, indicating gravels interbedded with finer material. One side-wall sample was taken at 63 feet, where the resistivity signature suddenly decreases, suggesting a possible stringer of till; however, the sample proved to be fine gravel. The lower contact of the gravel unit is not sharply defined on the electro-log trace. Side-wall samples from the lower part of the hole, above bedrock, consist of pebbly, sandy silty clay, perhaps till. The base of the gravel unit was 'picked' at 126 feet and the top of the bedrock at 135 feet. This is the first report of thick gravel, probably glacial outwash, and till underlying the Spy Hill Till.

R-6 (west-central Calgary) (Fig. 7) - This borehole was selected for discussion primarily because of the ambiguity of the electro-log signatures. Without chip and side-wall samples for study, the electro-logs could be interpreted as indicating unconsolidated gravels and finer material. Chip samples indicated that perhaps bedrock is present for most of the zone penetrated; side-wall samples confirmed it. Samples from zones of low resistivity consisted of bedrock siltstone and shale. The resistivity peaks are, therefore, interpreted as representing sandstone or siltstone, commonly present in Paskapoo bedrock-outcrops in the area. In this borehole, 80 feet of bedrock were penetrated. An important geologic aspect of the bedrock brought out by side-wall sampling, is the depth to which oxidation and weathering were evident, oxidized zones being observed to 45 feet.

R-10 (south-central Calgary) (Fig. 7) - Samples and electro-logs from the upper 8 feet of the hole are difficult to interpret; the material is probably disturbed sediments and/or artificial fill, common in such a highly settled area.

Closely-spaced, side-wall samples and electro-log signature with distinct characteristics clearly distinguished four units. The most important unit recognized is a 17-foot bed, probably till derived from the Rocky Mountains, that is intercalated between two lacustrine units. If the upper lacustrine deposits are equivalent to Calgary Silt, glacial Lake Calgary must have been more extensive than previously believed. Neither Rocky Mountain Till underlying lacustrine deposits nor subtill lacustrine deposits have been previously reported in this area.

R-11 (southeast Calgary) (Fig. 7) - The surface material appears to be Laurentide Till, that is, till derived from the east. It has, therefore, been assumed that the upper part of the unit is all Laurentide Till, with the resistivity anomaly caused either by a large boulder or by a coarse gravel lens.

Borehole findings, especially the high density of the side-wall samples, indicate a thick section of Laurentide Till to 18 feet, than lacustrine deposits, equivalent perhaps to the lacustrine deposits located under Rocky Mountain Till in borehole R-10. Unoxidized bedrock was encountered at 24 feet.

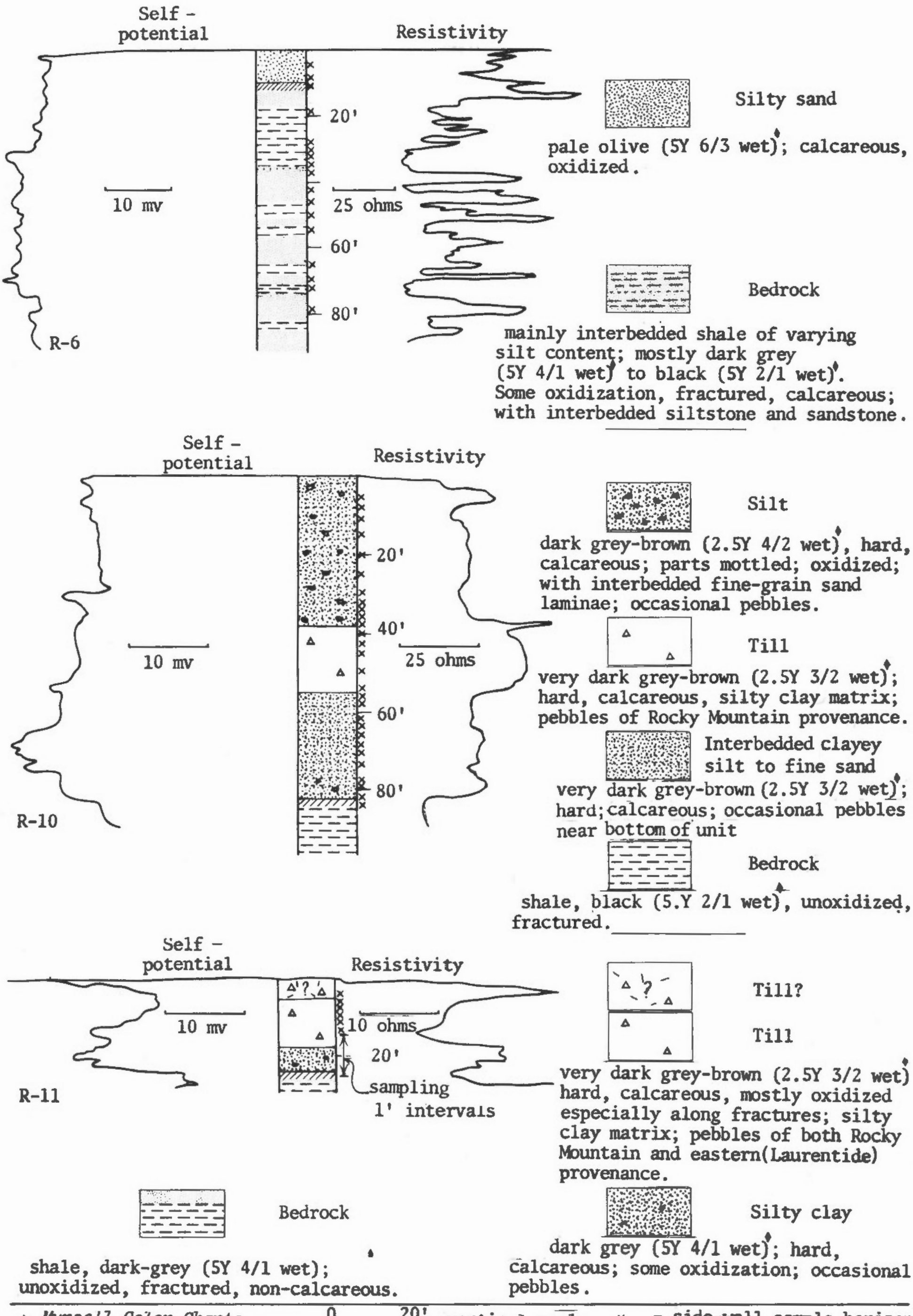

Figure 7. Electric log signatures and lithology for boreholes R-6, R-10 and R-11.

R-12 (east-central Calgary) (Fig. 6) - The resistivity trace indicates a single unit from the surface to a depth of 20 feet. Side-wall sampling of low-resistivity material in the upper 20 feet yielded sand and silt. The high-resistivity values are probably caused by gravel inclusions. The upper unit is, therefore, designated as interbedded gravel, sand and silt. Below 20 feet, it would be extremely difficult to distinguish units by means of electro-logs and chip samples. However, side-wall samples indicate pebbly, lacustrine deposits between 20 and 52 feet; till, most likely of Rocky Mountain origin, between 52 and 81 feet, and, at 81 feet, silty to fine, well-sorted sand that resembles the texture and lithology of bedrock sands. Although this might be a lacustrine deposit, it is probably weathered bedrock. Shale bedrock at 90 feet is unweathered. Once again, the lacustrine deposits overlying till may be Calgary Silt, further extending previously recognized boundaries of glacial Lake Calgary. Also, this is yet another occurrence of Rocky Mountain Till overlying lacustrine deposits.

R-17 (central Calgary) (Fig. 8) - The electro-log indicates three distinct units. Chip and side-wall samples show lacustrine deposits composed of sand, silt and clay, with occasional pebbles, to a depth of about 65 feet. Although the boundary is not determined exactly, samples indicate that till of Rocky Mountain origin is present below 65 feet. Because of the similarity of texture in the till and lacustrine units, no change is seen on the electro-logs. Gravel, most likely glacial outwash underlies the till and rests on bedrock. The bedrock is oxidized for about three feet. Again, as in other boreholes, lacustrine deposits overlie till probably derived from the Rocky Mountains.

R-18 (north-central Calgary) (Fig. 8) - Calgary Silt extends to a depth of 74 feet. Side-wall samples and electro-logs successfully differentiate the relatively thick units of sand, silty sand and silt. At 74 feet, till derived from the Rocky Mountains was discovered only by the use of the side-wall sampler. The electro-logs do not suggest any change until 84 feet where distinctive electro-log patterns indicate gravel and interbedded fine-grained material. Bedrock was encountered at 99 feet. Side-wall samples indicate an oxidized zone three or four feet thick.

Canmore Area

R-C (Canmore) (Fig. 9) - This hole was located to penetrate the outwash gravel underlying the Canmore Till. It was also hoped that the 'black till' underlying both this gravel and the Bow Valley Till would be encountered and could be confirmed as a separate stratigraphic unit. Outwash gravel was penetrated to a depth of about 64 feet. Below this outwash are 32 feet of till, and below this, about 54 feet of lacustrine silt overlie 20 feet of gravel and finer material. These, in turn, overlie 21 feet of 'black till'.

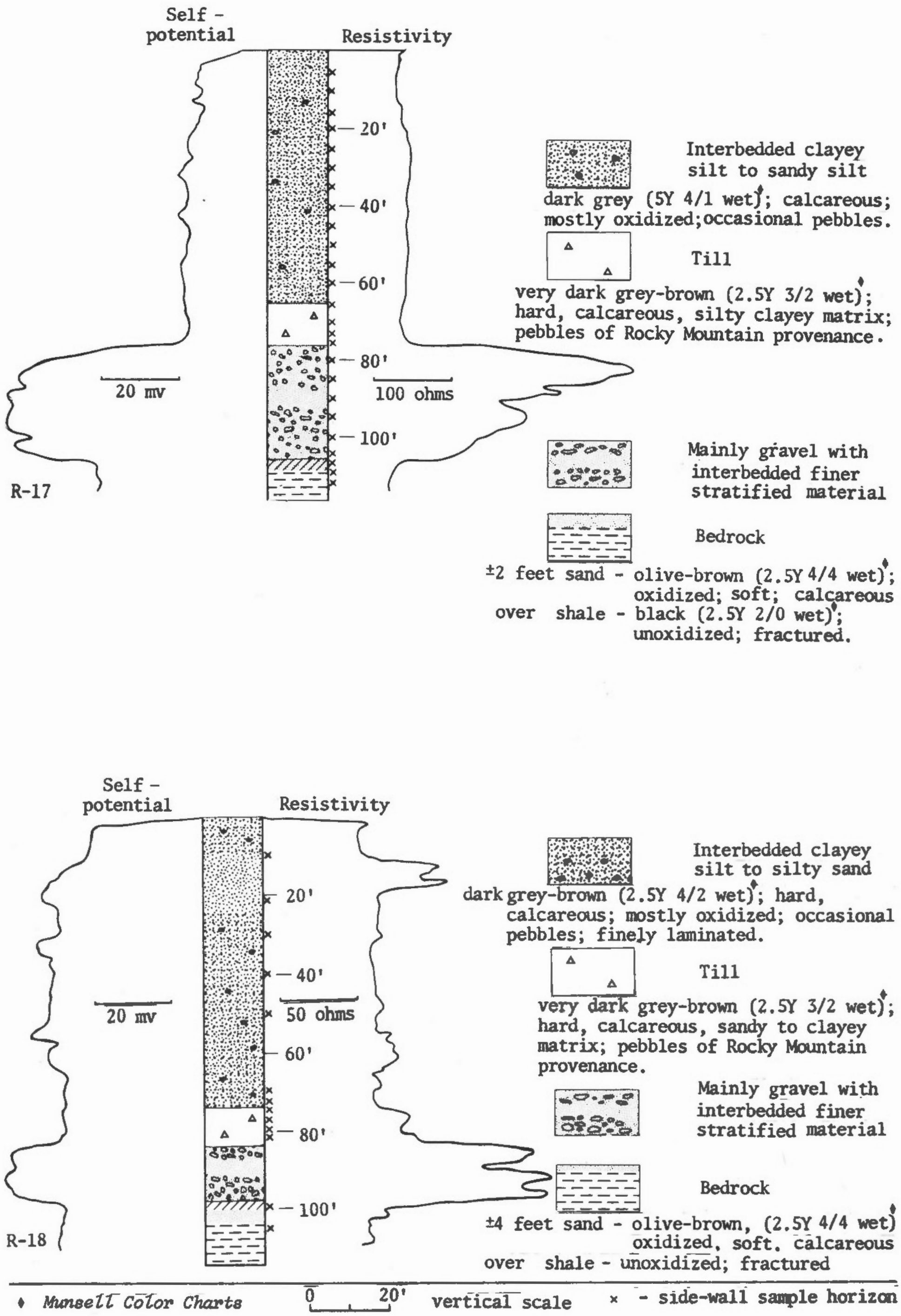

Figure 8. Electric log signatures and lithology for boreholes R-17 and R-18.

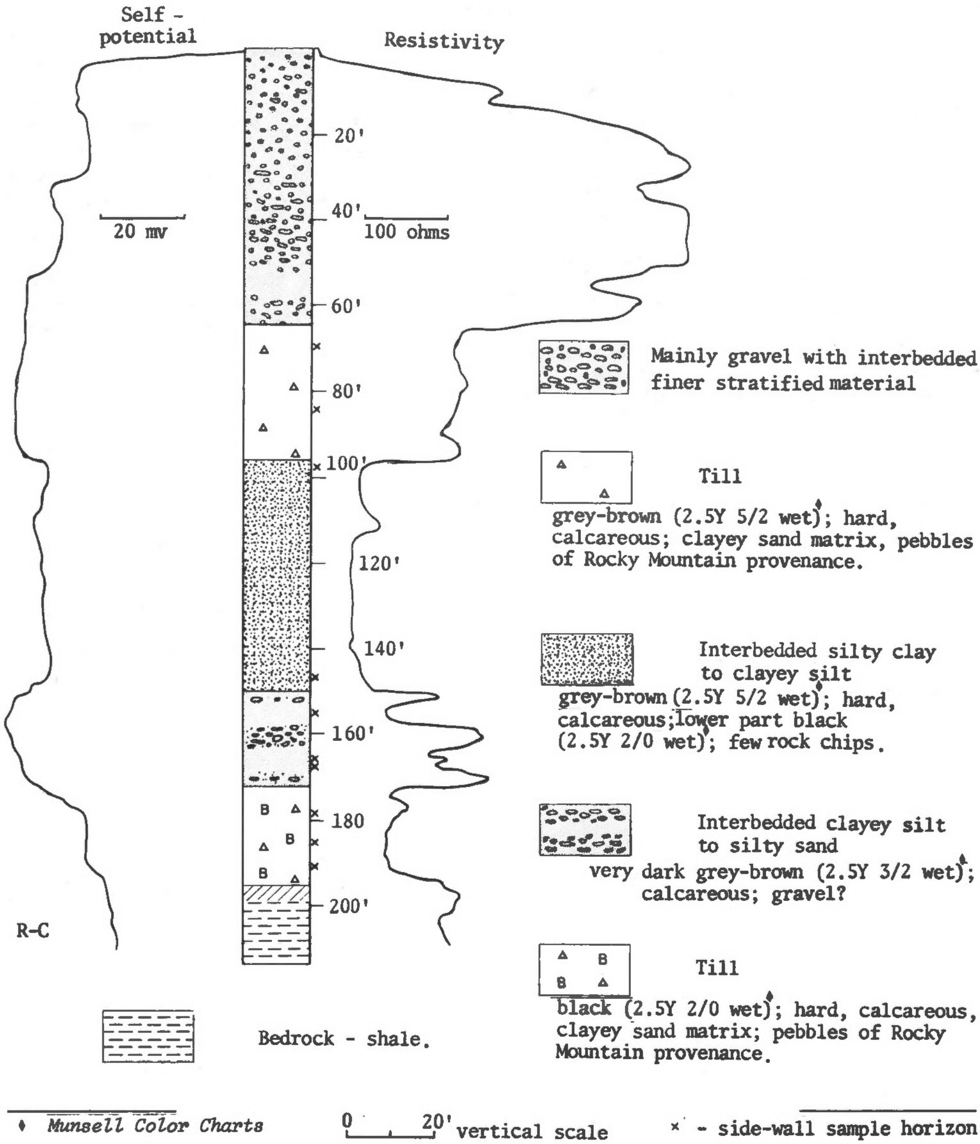

Figure 9. Electric log signature and lithology for borehole R-C.

DISCUSSION

Calgary Area

Interpretation of results from seven of the boreholes has greatly increased stratigraphic information available for the Calgary area. Important points include:

A glacier advance from the direction of the Rocky Mountains, earlier than that which deposited Spy Hill Till, is suggested by till underlying the Spy Hill Till and outwash in borehole R-1.

The boundaries of glacial Lake Calgary are shown by lacustrine deposits found in boreholes R-10, R-12, R-17 and R-18 to have extended farther east and south than had been generally believed.

As shown by boreholes R-10, R-12, R-17 and R-18, a distinct till unit of Rocky Mountain origin underlies the Calgary Silt. This may be equivalent to the till underlying the outwash in borehole R-1, and, if so, represents a glacial advance prior to the deposition of the Spy Hill Till.

A lake phase prior to the deposition of the lower pre-Spy Hill Till, derived probably from the Rocky Mountains and from the Crossfield Till, is indicated by lacustrine deposits in boreholes R-10 and R-11. These sediments may have been deposited during advances of both eastern and western glaciers which blocked normal drainage.

An extensive outwash unit underlies the Spy Hill Till.

Canmore Area

The outwash gravel of the top unit in borehole R-C is believed to have been deposited during the ice retreat that followed the Bow Valley advance. In all probability the 32 feet of underlying till was deposited at the actual time of the advance. The 'black till' represents a pre-Bow Valley advance. The succession encountered in this hole was the same as had been previously inferred, and the finding of 'black till' underlying the clayey silt and gravel unit, considerably strengthened earlier theories of a pre-Bow Valley advance. Therefore, the results of this borehole strongly suggest two phases of glacier activity prior to the Canmore advance, a hypothesis suggested earlier (Rutter, 1966a and b) but lacking, at that time, the convincing evidence now available.

CONCLUSIONS

The side-wall sampler can yield valuable information in areas of stony, bouldery till, and can usually penetrate a unit and recover enough sample to identify it. In gravelly deposits containing interbedded sand and silt, side-wall sampling can be carried out in the finer material whose locations can be determined from the electro-logs. The sampler has, however, one serious disadvantage. Each sample consists of material from an area only about one inch in diameter. It provides highly detailed information which, if not used in conjunction with other data such as electro-logs and geologist's logs, might give rise to gross errors of stratigraphic mapping. For example, if a twelve-inch sand lens occurring in 30 feet of till is sampled as being representative of the whole unit, a very serious misinterpretation would result unless other available data were also considered.

The results obtained from the boreholes described in this report provide evidence confirming aspects of glacial history of the region which, previously, were only inferred. They also provide new information, particularly regarding the extent of glacial Lake Calgary.

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