THE STATE ELECTRICITY AUTHORITY

TEMPERATURE MEASUREMENTS IN DRILLHOLES AT BÚRFELL

by

HAUKUR TÓMASSON, fil. cand.

geologist, S. E. A.

Reykjavík, Oct. 1963.

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1. Introduction

The geothermal department of the SEA made measurements of temperature in some drillholes which were drilled in the Búrfell area during the last two years. This was done at the request of Mr. C.K. Willey, vice president of Harza Engineering Company International. The geothermal department themselves were highly interested in these measurements, since they were made in holes not drilled for hot water or steam. They thus gave information about the normal temperature gradient in Iceland, outside the thermal areas.

The measurements were made on March 14th and 15th 1963 by the physicist Guðmundur Pálmason of the SEA geothermal department. The instrument used was a thermistor. Temperature readings were taken at 3-10 m intervals, and most of them at 3-5 m intervals. The calibration of the thermistor may have an error of $\pm$ 0,5°, but the relative accuracy is $\pm$ 0,1°.

2. The Geological setting

The geology of the Búrfell area has been described in several reports, most thoroughly in a report from Harza Engineering Company entitled "Búrfell Project" volume II, Appendix B.

The bedrock of the Búrfell area can be subdivided into the following series:

1) Hreppar series, which is of Pliocene to early Pleistocene age.
2) Móberg series, which is of late Pleistocene age.
3) Basalt flows and other volcanic products, of Postglacial age.

Temperature measurements were only made in holes in the Hreppar series as the other series are far too permeable to enable measurement of the temperature gradient.

The Hreppar series can be subdivided into various groups and formations through its relation to erosion unconformities. The oldest group is the Older Búrfell OB, which consists of clastic beds and flows of basaltic, andesitic and rhyolitic composition. A valley was eroded in the OB and was later filled with sand,talus and basalt beds. This valley filling is named the Sámsstaðamúli group (SM). This is because at present Sámsstaðamúli occupies the former site of the valley. The valley is called the SM unconformity. The two uppermost flows of the SM group have flowed over the whole of Búrfell.

The SM group in Búrfell and Skálarfell is covered by pillow lava and tuff breccia. These were formed by linear eruptions below a glacier and date from a glacial during the first half of the pleistocene. This formation is named the Búrfell pillow lava (BP).

Later a valley or canyon was eroded into the SM and OB groups and then filled by repeated basalt flows. This formation is named the Sámsstaðaklif Basalt (SB) as the typical outrop is around Sámsstaðaklif. The valley is called the SB unconformity.

The hole BH-8 is drilled in the OB group at the south end of Búrfell. The formation there consists of numerous basalt flows; this is the oldest part of Búrfell to outcrop.

The hole PT-2 is situated where the SB unconformity crosses the SM unconformity, in PT-2, therefore, the succession passes directly from the SB formation to the OB group.

The holes PT-14, PT-12, BH-14 and PT-21 are situated near a line from PT-2 perpendicular to the SM unconformity. PT-21 is situated well in the SM valley and goes through talus breccia and SM basalt beds. PT-14 is at the margin of the valley and this passes through talus breccia and reaches the OB group.

The hole T-6 is situated in the SM group. Its higher part goes through SM basalt beds, while the lower depths of the hole are in a thick layer of tuffaceous sandstone which fills the lowest part of the SM unconformity.

The basalt in Iceland as in many other places in the world shows that the earth has changed magnetic plarity several times and even that the magnetic polarity is cyclic with a cycle of approximately half a million years. The basalt in Búrfell shows the following magnetic polarity.

The OB in BH-8-normal magnetic polarity

The SM group and BP formation - reverse magnetic polarity

The SB formation - normal magnetic polarity

This shows that the Hreppar series in Búrfell and Sámsstaða-múli spans over three magnetic polarities.

On the assumption that the cycle of magnetic polarity is half a million years, the Hreppar series in this area should therefore cover one and a half million years. This indicates that the OB group is of very late Pliocene age, the SM and BP from the first half of the Pleistocene, and the SB of middle Pleistocene age.

3. The temperature measurements

The results of the temperature measurements are shown in figs 2-8 The temperature increase with depth is usually somewhat irregular. These irregularities seem to be caused by permeable areas in the holes, where water is leaking out of or flowing into the hole.

Table I shows the temperature gradient in the drillholes, both the total and with the holes divided into two layers. The boundaries between these layers are usually near formational boundaries or at a break in the temperature gradient.

TABLE I

	Measured interval			Temperature gradient °C/meter		
Holes	first layer	second layer	total	first layer	second layer	total
BH-8	8-50	50-92	8-92	0,135	0,047	0,090
PT-2	25-80	80-142	25-142	0,043	0,073	0,058
PT-14	24-76	-	24-76	0,034	-	0,034
PT-12	23-75	75-152	23-152	0,025	0,080	0,058
BH-14	12-90	90-156	12-156	0,054	0,052	0,053
PT-21	20-70	70-190	20-190	0,020	0,043	0,039
T-6	35-100	100-192	35-192	0,015	0,091	0,060
		average:		0,032[1]	0,064	0,056

[1] BH-8 excluded

The highest temperature gradient is in hole BH-8. In the vicinity of BH-8 another hole, BH- 7 was drilled at a 39 m higher elevation. This hole was abandoned as it met a bed of breccia, with plastic matrix, which caved in. The plasticity of the matrix was interpreted as a result of hydrothermal alteration. This hydrothermally altered breccia, not found in BH-8, is probably lying just above it. The rock in BH-8 is not substantially hydrothermally altered.

The high temperature gradient in the upper part of BH-8 rather supports the interpretation of the breccia in BH-7 as being hydrothermally altered, and even indicates that this hydrothermal activity is not very old and hardly extinct. BH-8 is the only hole measured which showed a much higher temperature gradient in the upper part than in the lower.

The holes PT-2; PT-12; PT-21 and T-6 have all much lower temperature gradients in the upper part than in the lower. In PT-14 the temperature gradient was only measured in the upper part and the result there corresponds well with the upper parts of the other holes. The hole BH-14 has the same gradient all the way through.

The upper or first layers of the holes are younger and more permeable than the lower or second layers. The influence of ground water flow is therefore more obvious there. The SM and SB unconformities are usually connected with permeable beds and the layer above has therefore a lower temperature gradient. (See holes PT-2 and PT-12).

The talus breccia is also highly permeable, thus causing lower temperature gradients in the overlying layers. This is quite obvious in holes T-6 and PT-21.

The upper layers in all the holes have small irregularities in the temperature curves. These are also due to variations in the permeability of the holes. With some exceptions, small irregularities are also found in the lower layers. Permeability tests and the temperature measurements agree fairly well, but the temperature measurements can in some cases give us a more precise picture of the permeability than we had before from permeability tests.

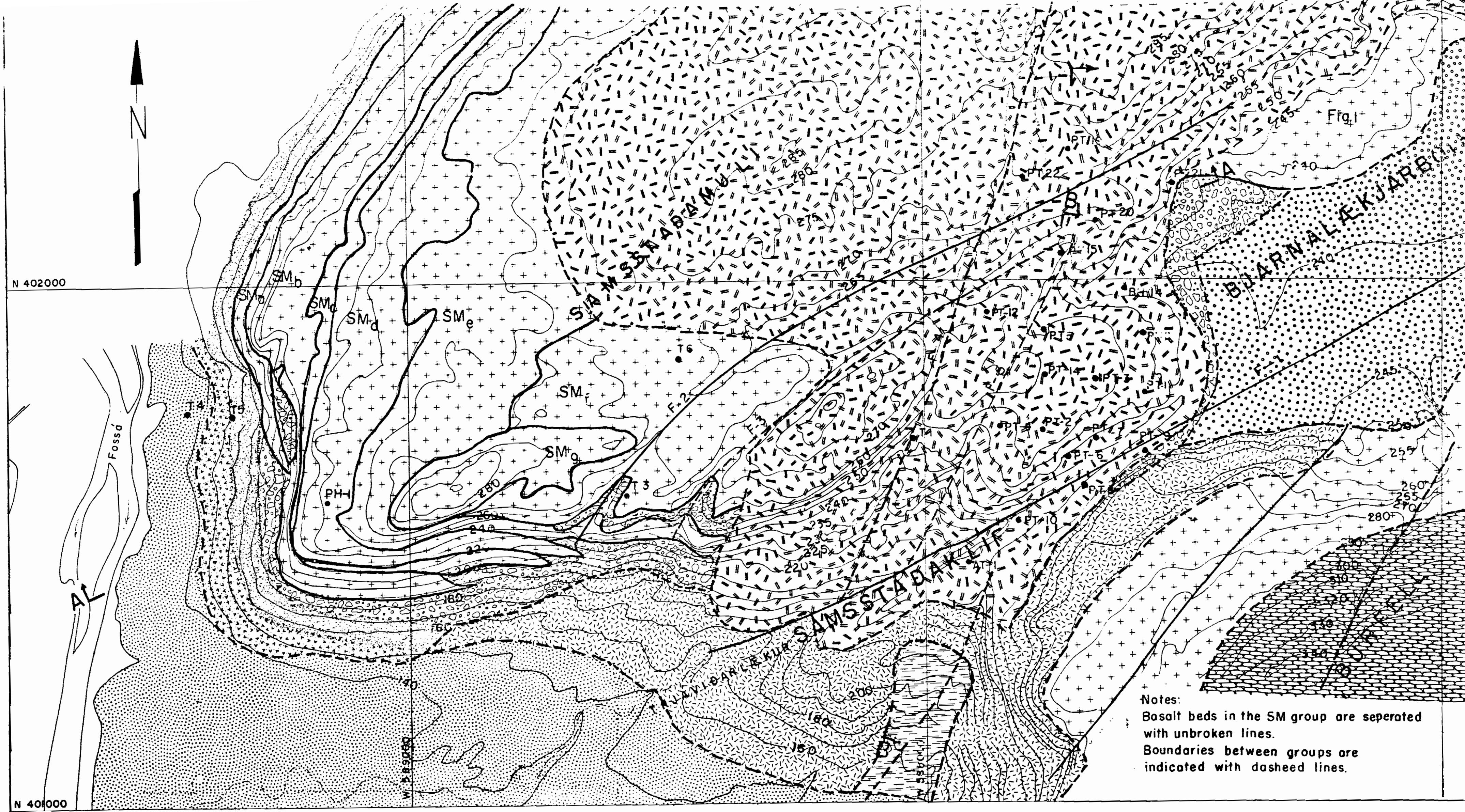
In hole T-6 long sections of the lower part were tested with a single packer. The total water take per meter was low. The temperature measurements indicate where this water take is mainly concentrated, i.e. in the Sedimentary breccia at a depth of 105 m and also some in the Tuffaceous sandstone at a depth of 155 m.

The exceptions to the small irregularities on the temperature curve are found only in the basalt bed SM_a and in the breccia above and below it, indicated as flow breccia on the drillhole profiles. This layer, which occurs in holes PT-12, PT-21 and BH-14, must be completely impermeable.

The origin of this bed has been a matter for some discussion. The present author interpreted it as an intrusive layer but the Harza geologist preferred to interpret it as an extrusive lava flow. The layer will be discussed in a seperate report.

In the lowest part of PT-2, in the OB group, there are small irregularities on the temperature curve. The rock is volcanic breccia and basalt beds, with a general slight hydrothermal alteration but a more intense alteration at the contacts. The permeability tests proved it quite tight.

The average temperature gradient in the upper part of the holes is $0,032^o$ c/m; BH-8 is excluded because of probable hydrothermal influence there. In the lower part the temperature gradient is 0.064^o c/m. The normal temperature gradient in this area is probably 0.05^o C/m, the value obtained in holes PT-21 and BH-14 which are least affected by horizontal ground water movement. This is slightly less than twice the normal temperature gradient for the earths crust but is probably close to what is the rule here in Iceland in non-thermal areas.



Notes:
Basalt beds in the SM group are seperated with unbroken lines.
Boundaries between groups are indicated with dasheed lines.

LEGEND:

- Overburden
- Finiglacial (FG) Sand and Gravel unconsolidated
- Glacial till (GT) Moraine (boulder clay)
- Sámsstaðaklif basalt (BS) Basalt and volcanic breccia
- Búrfell pillow lava (BP)

SÁMSSTAÐAMÚLI GROUP (SM)

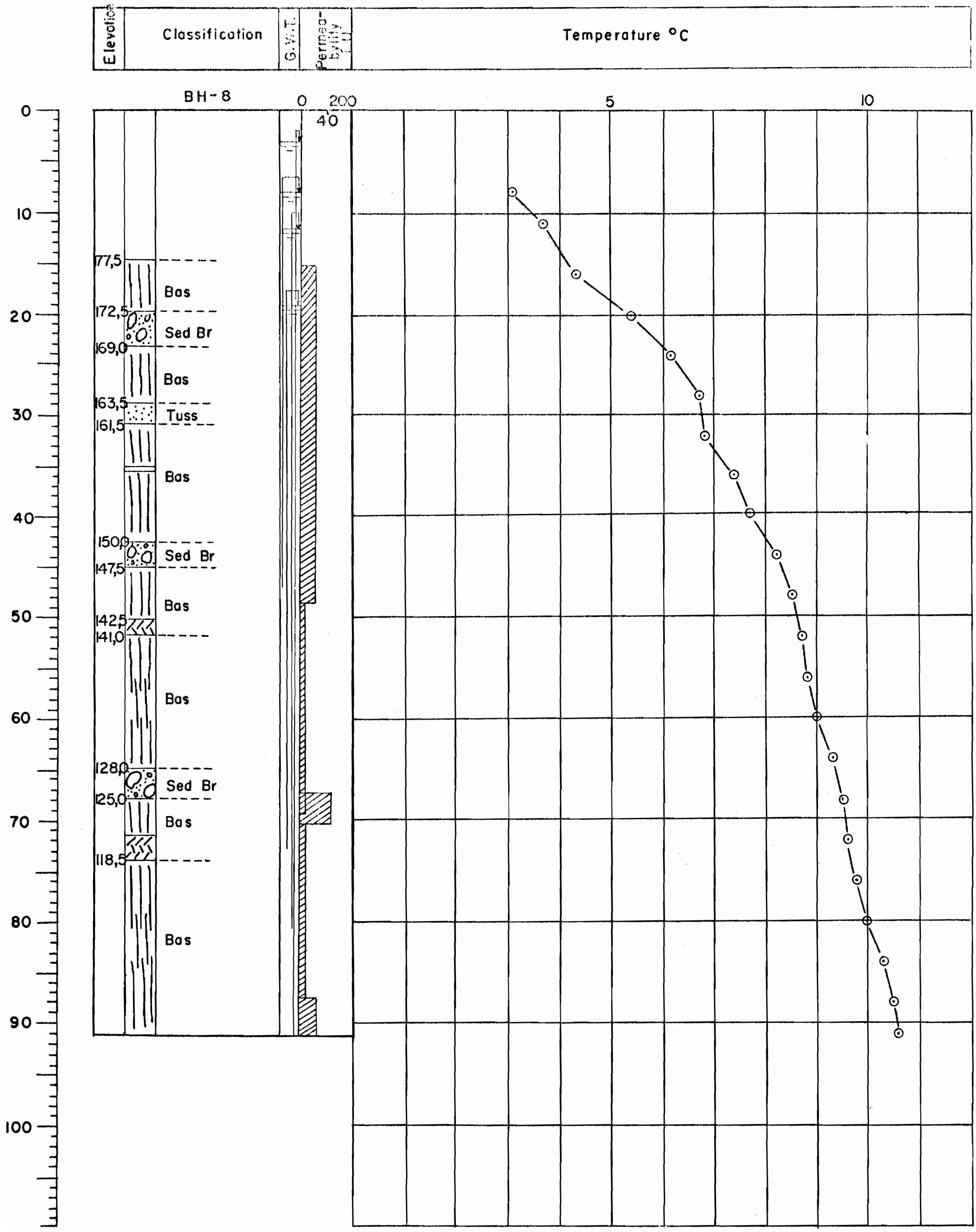
- Basalt flows (SM) interfingerin with
- Talus fanglomerate (TF) and
- Tuffacious Sandstone (TS) with tongues of
- Pillow lava (PL)

- Older Búrfell (OB) Basalt, andesite and rhyolite flows with clastic interbeds.
- Boreholes
- Fault or major fracture some are with numbers F-1 to F-5

Scale 0 100 200 300 Meters

RAFORKUMÁLASTJÓRI	
SÁMSSTAÐAMÚLI	20.9.63 HTA
	TNR. 451
Geologic Map.	B - 277
	FNR. 6435

Fig 2


Elevation
Classification
G.W.T.
Permea-bylity
Temperature °C
BH-8
0
200
40
5
10
0
10
20
30
40
50
60
70
80
90
100
177,5
Bas
172,5
Sed Br
169,0
Bas
163,5
Tuss
161,5
Bas
150,0
Sed Br
147,5
Bas
142,5
141,0
Bas
128,0
Sed Br
125,0
Bas
118,5
Bas

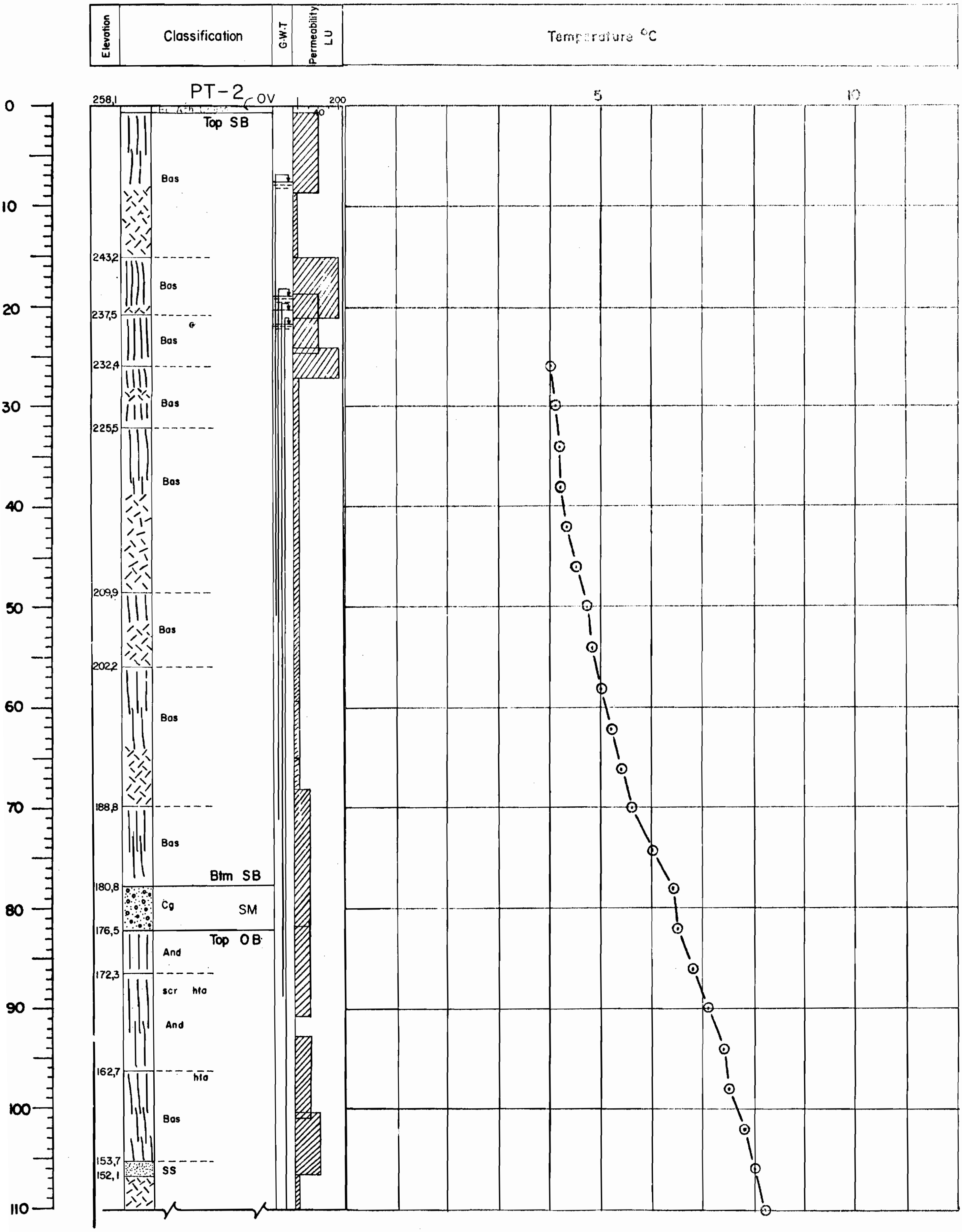

Elevation
Classification
G.W.T
Permeability LU
Temperature °C
PT-2
OV
258,1
Top SB
Bas
243,2
237,5
232,4
225,5
209,9
202,2
188,8
Btm SB
180,8
Cg
SM
176,5
Top OB
And
172,3
scr hta
162,7
hta
153,7
152,1
SS
200
40
5
10
0
10
20
30
40
50
60
70
80
90
100
110

Fig 3b

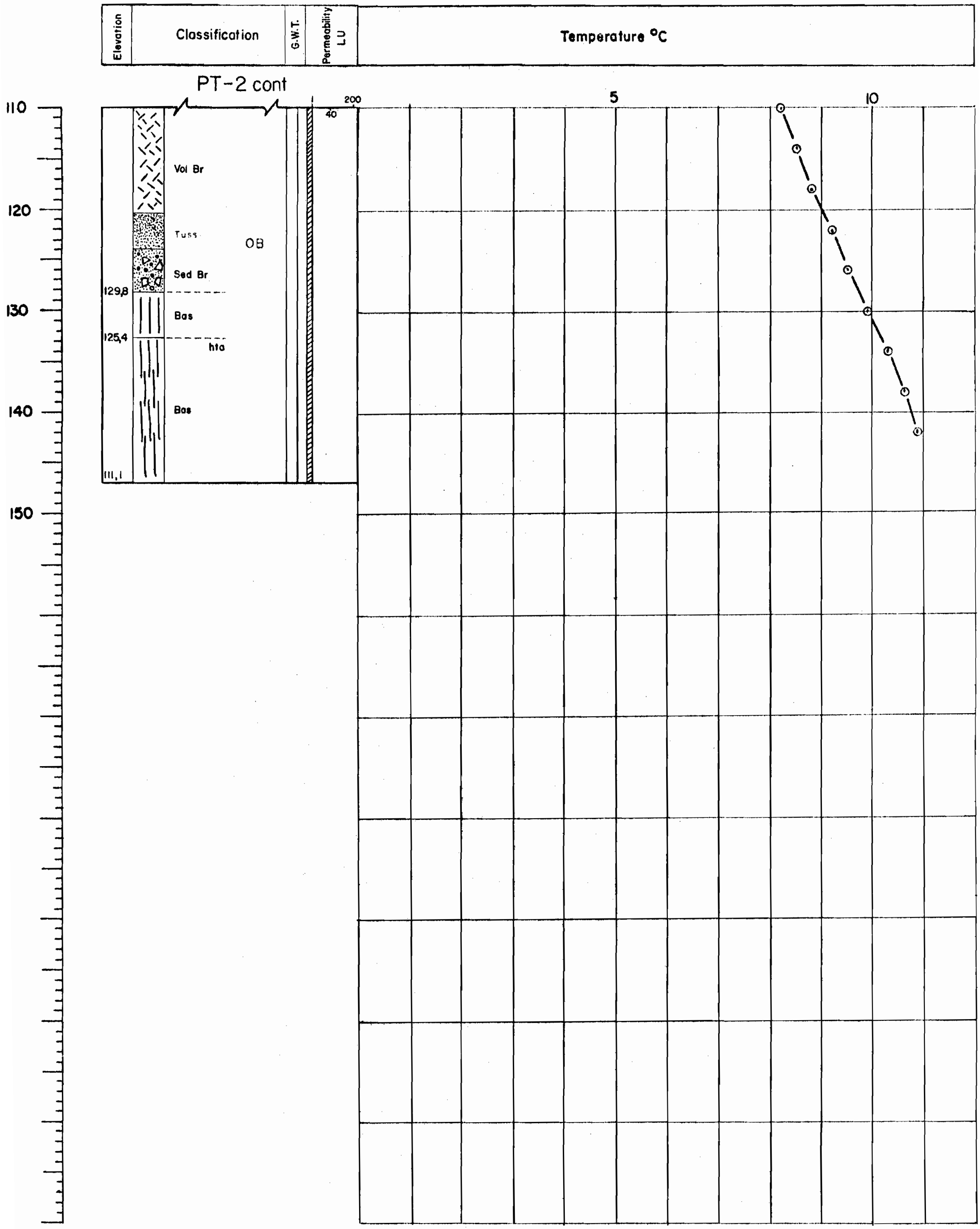
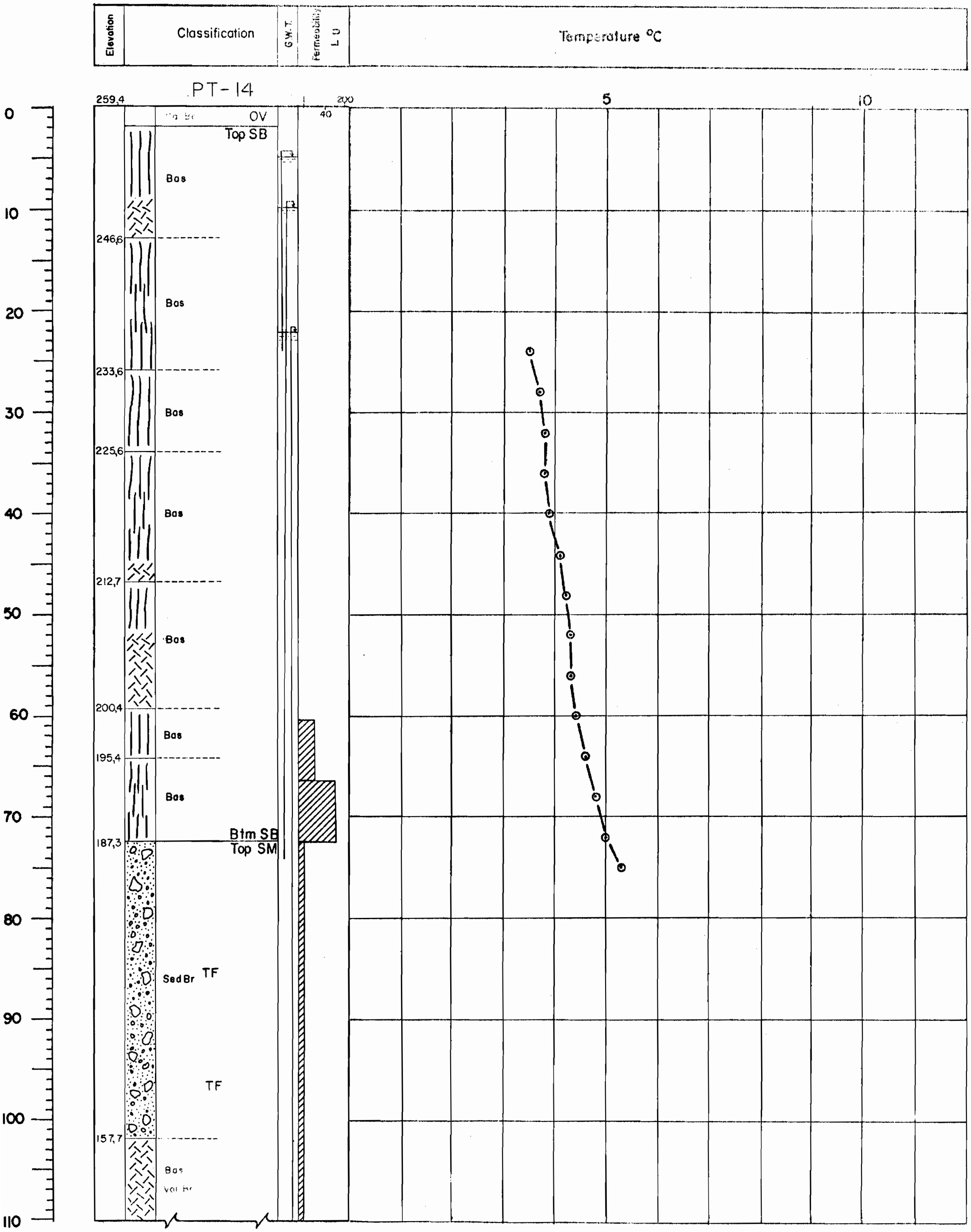
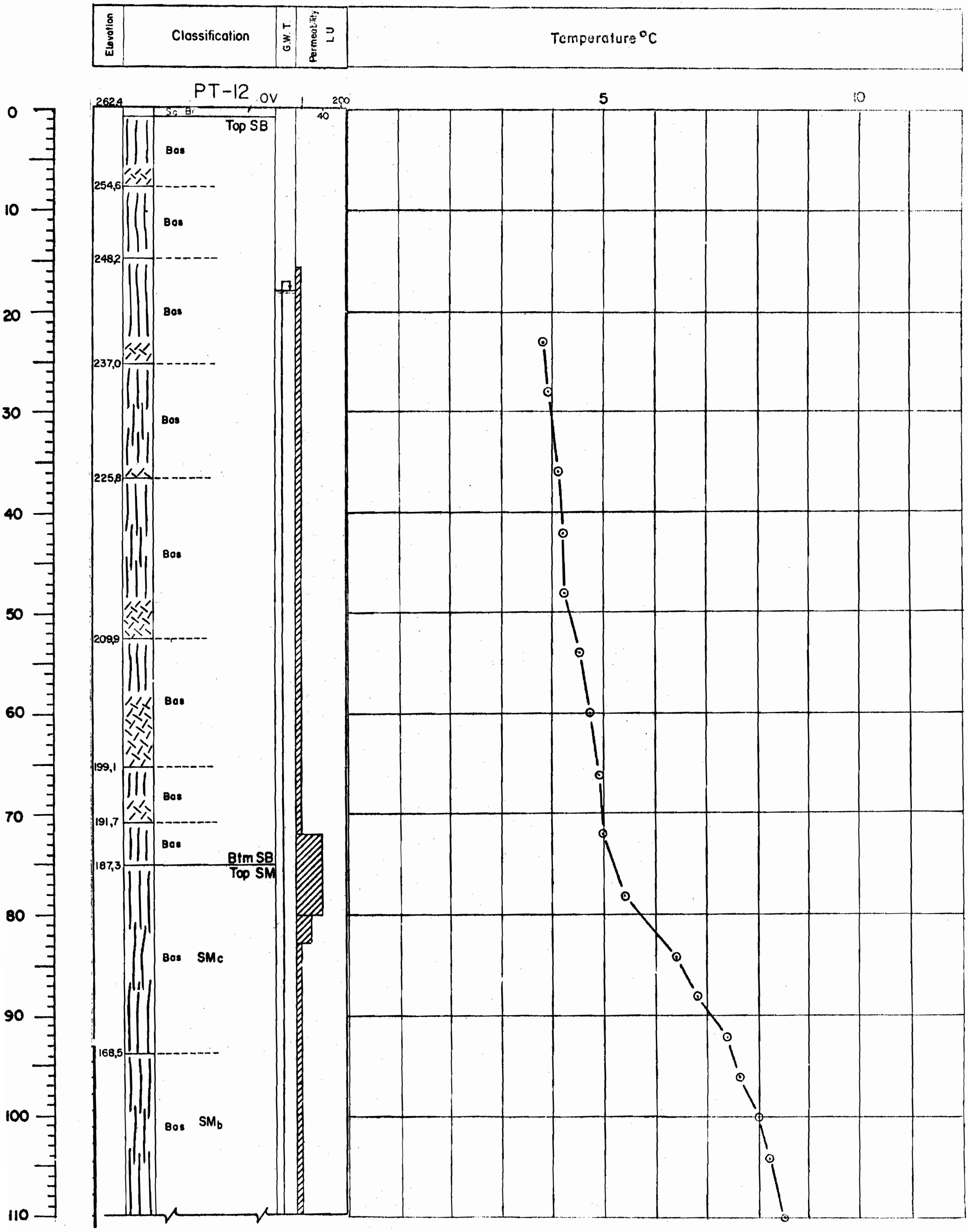

Elevation
Classification
G.W.T.
Permeability LU
Temperature °C
PT-2 cont
200
40
5
10
110
120
130
140
150
Vol Br
Tuss
OB
Sed Br
129,8
Bas
125,4
hta
Bas
111,1

Fig 4



Elevation
Classification
G.W.T.
Permeability
L U
Temperature °C
PT-14
259,4
200
40
5
10
OV
Top SB
Bas
246,6
Bas
233,6
Bas
225,6
Bas
212,7
Bas
200,4
Bas
195,4
Bas
187,3
Btm SB
Top SM
Sed Br TF
TF
157,7
Bas
0
10
20
30
40
50
60
70
80
90
100
110

Fig 5a



Elevation
Classification
G.W.T.
Permeability L.U
Temperature °C
PT-12
262,4
0V
200
40
5
10
Top SB
Bas
254,6
248,2
237,0
225,8
209,9
199,1
191,7
187,3
Btm SB
Top SM
SMc
168,5
SMb
0
10
20
30
40
50
60
70
80
90
100
110

Fig 5b

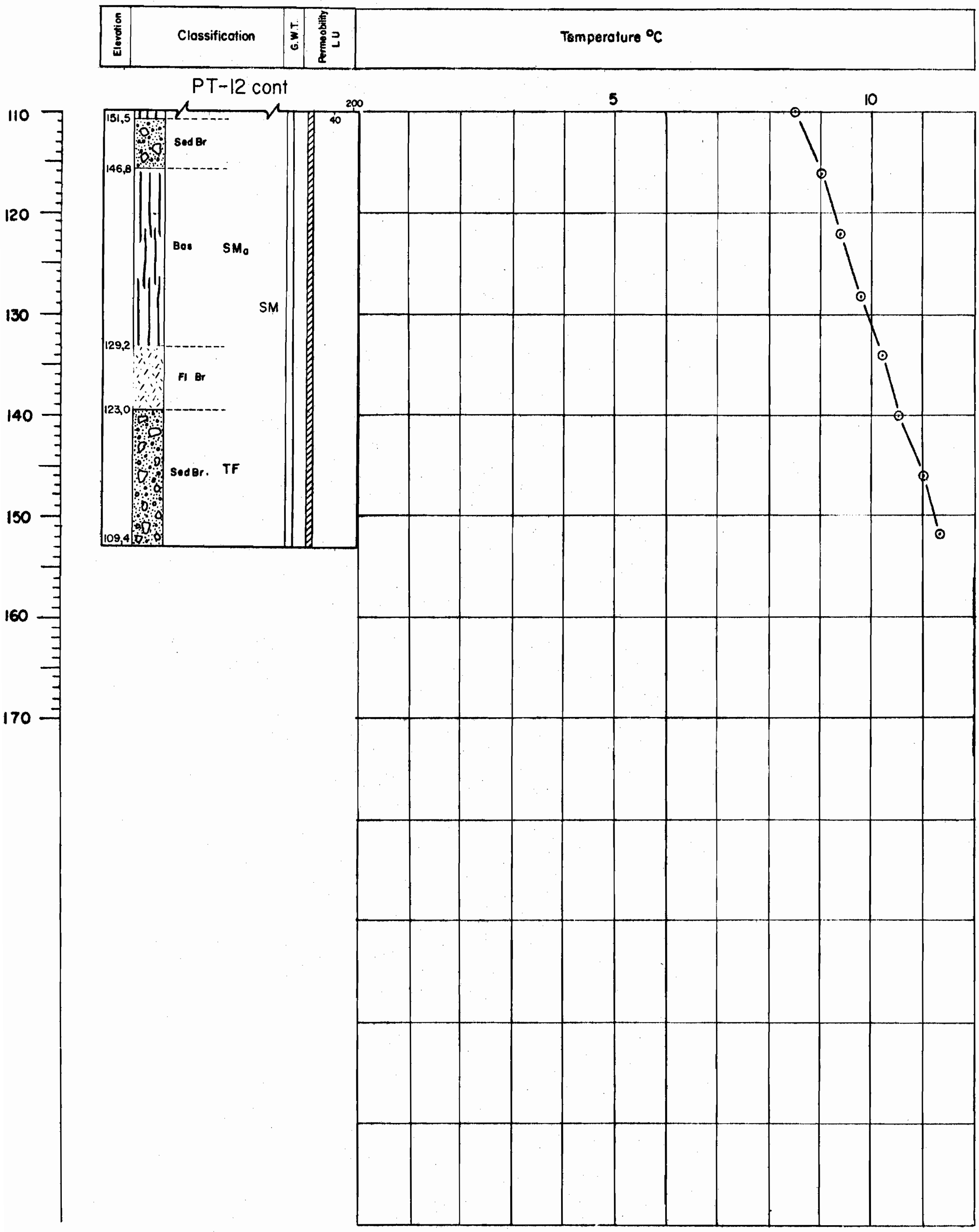
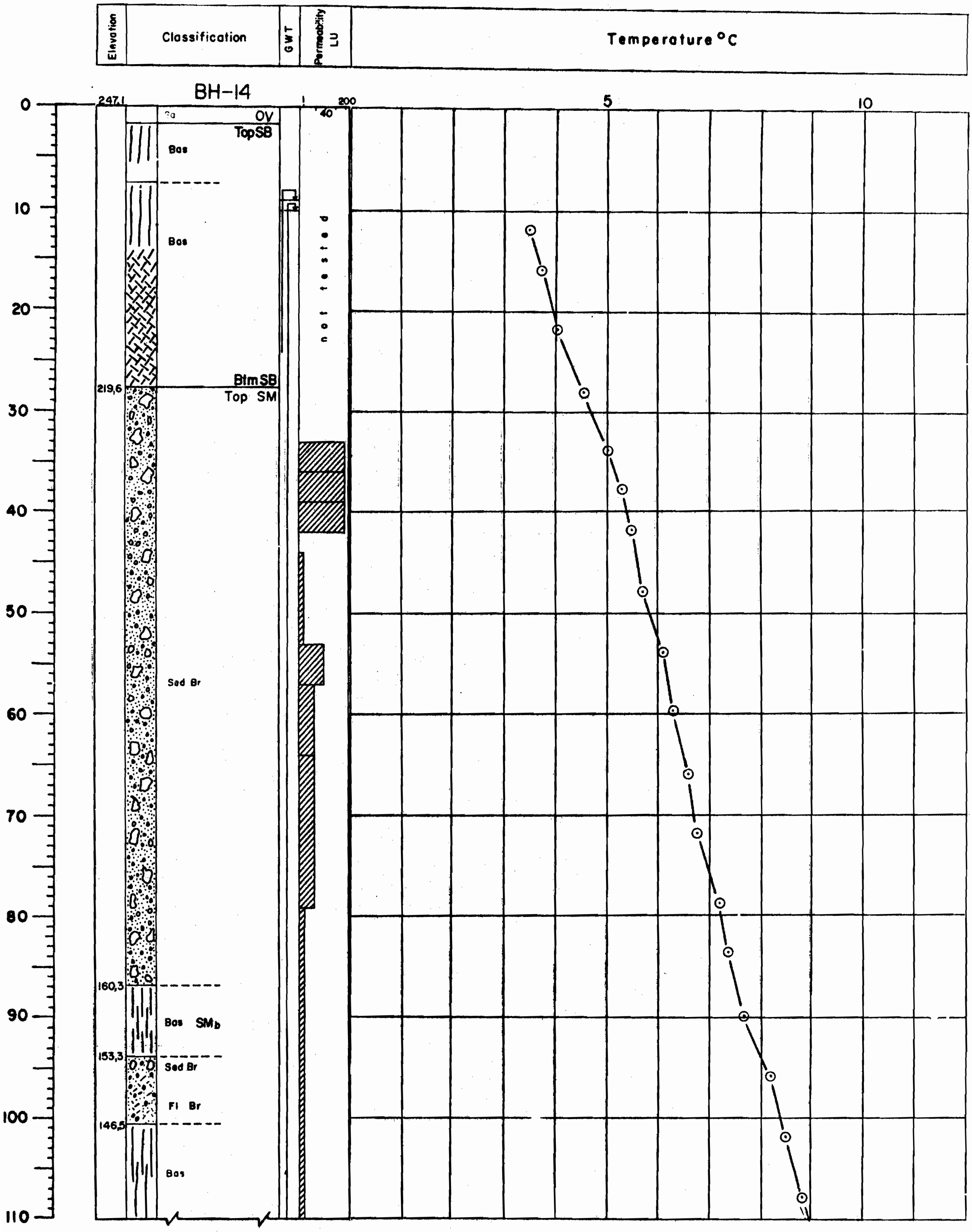
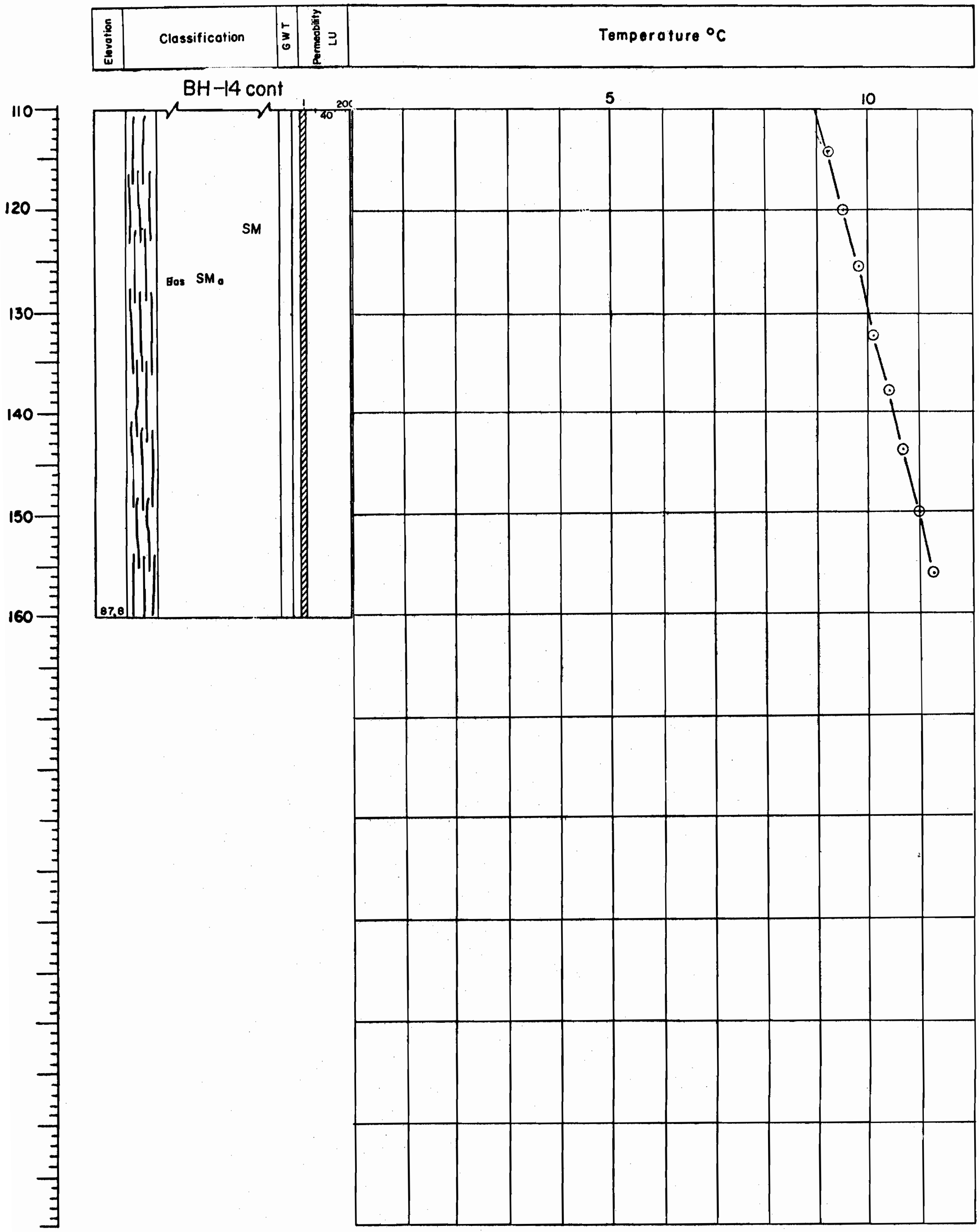

Elevation
Classification
G.W.T.
Permeability L.U
Temperature °C
PT-12 cont
200
40
5
10
110
120
130
140
150
160
170
151,5
Sed Br
146,8
Bas
SMa
SM
129,2
Fl Br
123,0
Sed Br.
TF
109,4

Fig 6a



Elevation
Classification
GWT
Permeability LU
Temperature °C
BH-14
247,1
1
200
40
5
10
OV
Top SB
Bas
Bas
not tested
Btm SB
Top SM
219,6
Sed Br
160,3
Bas
SM_b
153,3
Sed Br
Fl Br
146,5
Bas
0
10
20
30
40
50
60
70
80
90
100
110

Fig 6b



Elevation
Classification
G W T
Permeability LU
Temperature °C
BH-14 cont
110
120
130
140
150
160
1
200
40
5
10
SM
Bas SM a
87,8

Fig 7a

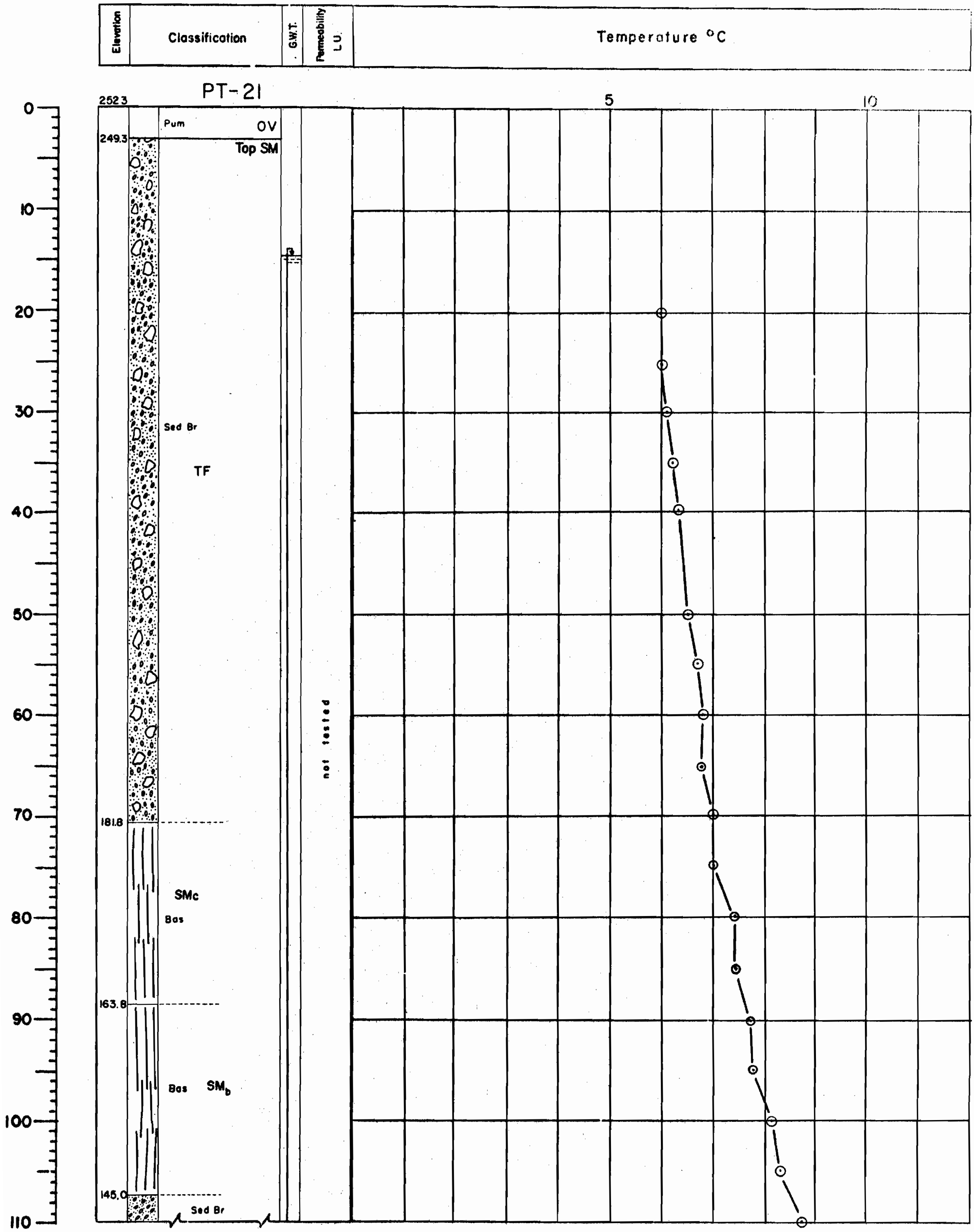

Elevation
Classification
G.W.T.
Permeability L.U.
Temperature °C
PT-21
252.3
249.3
Pum
OV
Top SM
Sed Br
TF
181.8
SMc
Bas
163.8
Bas
SM_b
145.0
Sed Br
not tested
0
10
20
30
40
50
60
70
80
90
100
110
5
10

Fig 7b

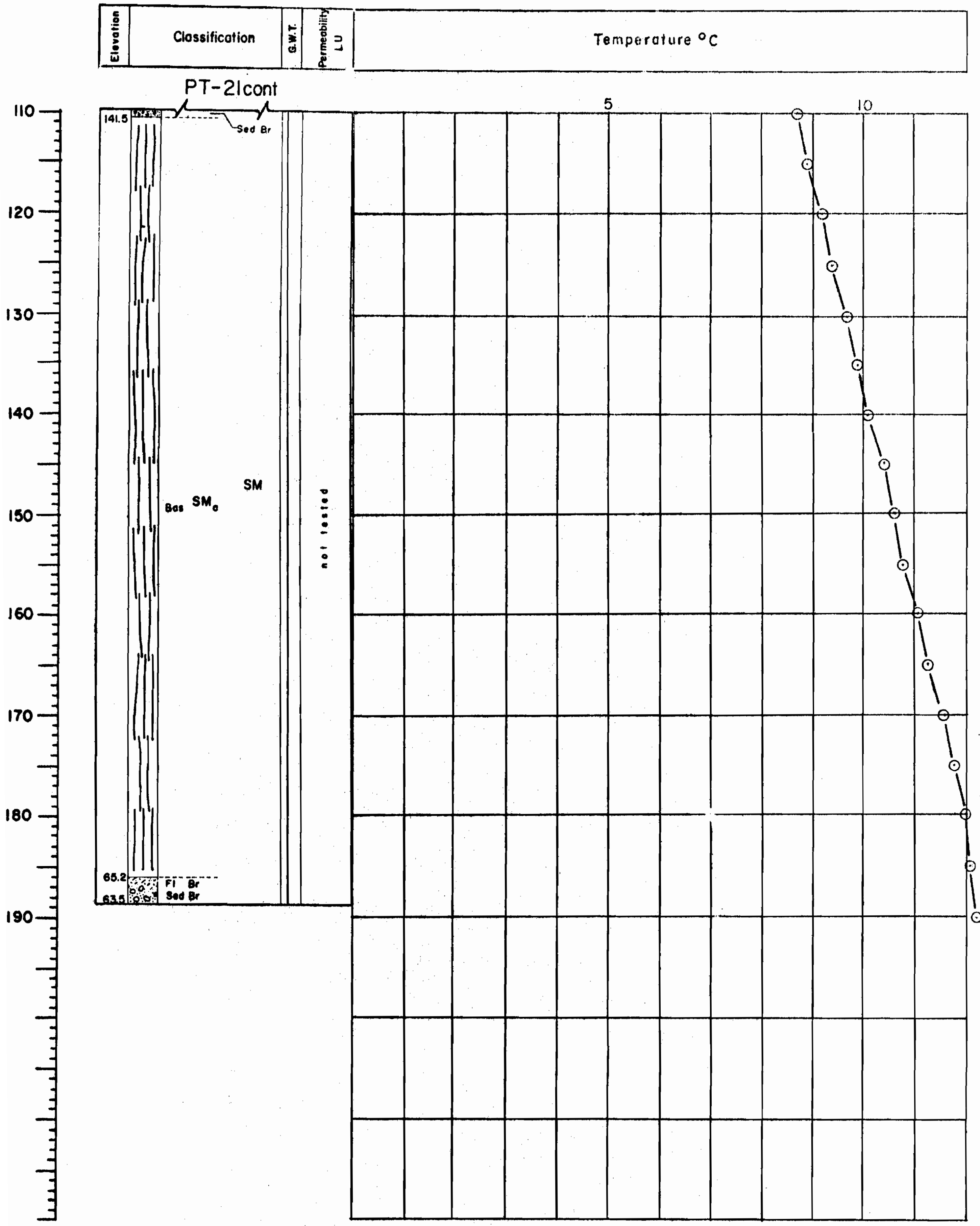
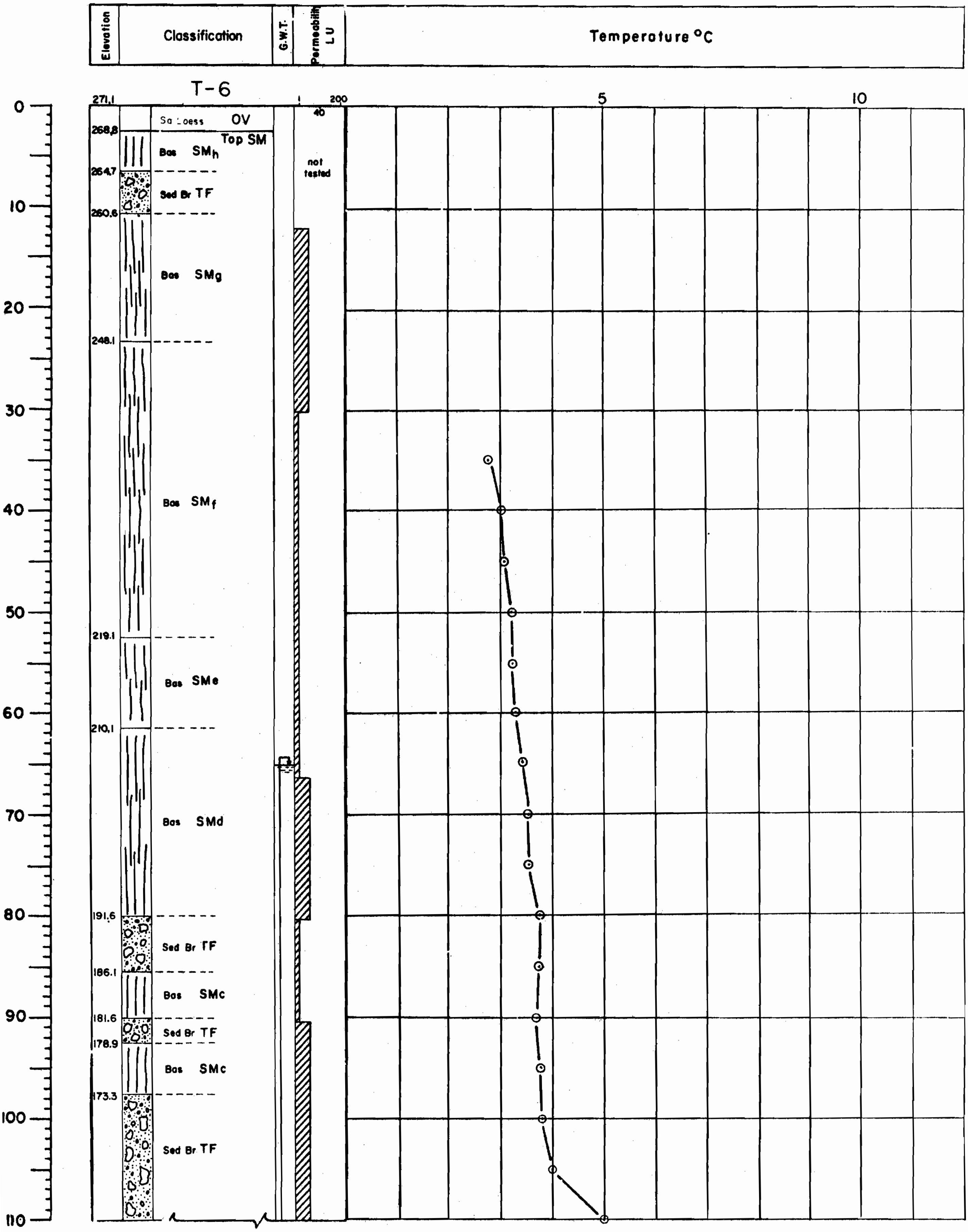
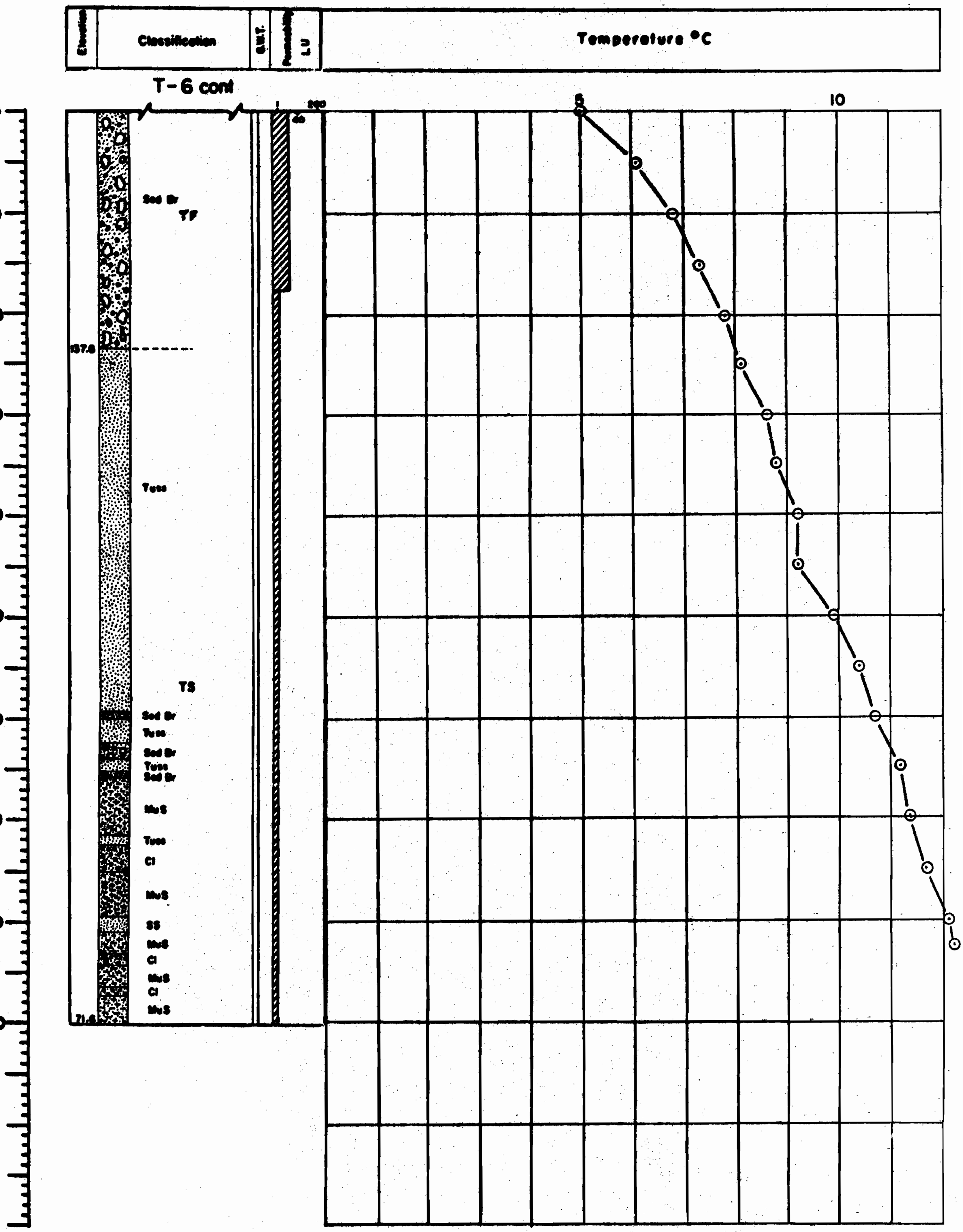

Elevation
Classification
G.W.T.
Permeability L.U
Temperature °C
PT-21cont
5
10
110
120
130
140
150
160
170
180
190
141.5
Sed Br
Bas
SM
SM
not tested
65.2
Fl Br
63.5
Sed Br

Fig 8a



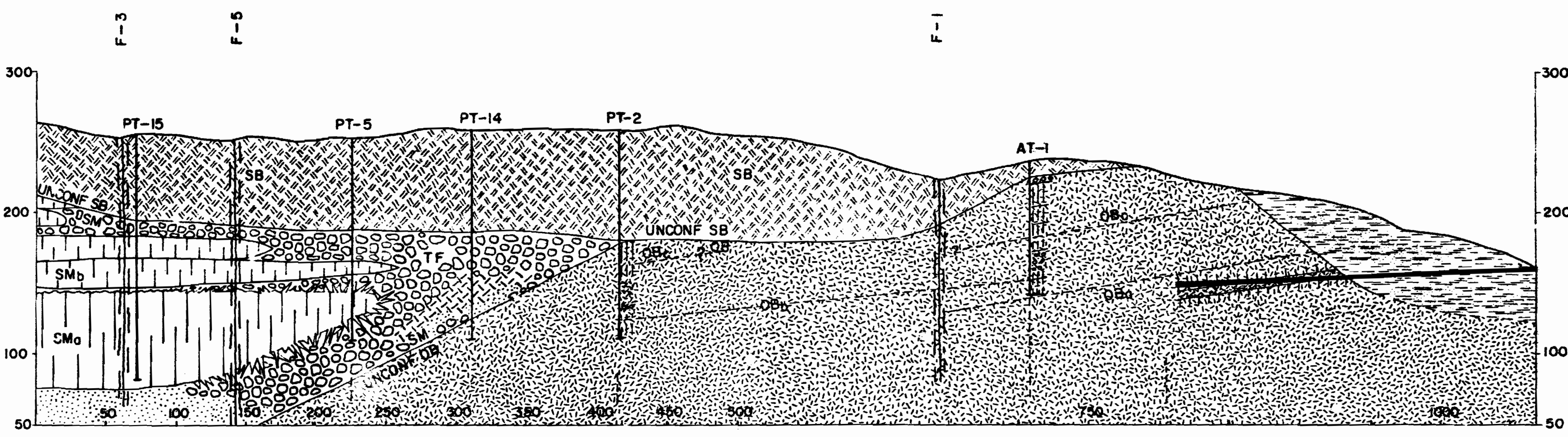
Elevation
Classification
G.W.T.
Permeability L U
Temperature °C
T-6
0
10
20
30
40
50
60
70
80
90
100
110
271,1
268,8
264,7
260,6
248,1
219,1
210,1
191,6
186,1
181,6
178,9
173,3
Sa Loess
OV
Top SM
Bas SMh
Sed Br TF
Bas SMg
Bas SMf
Bas SMe
Bas SMd
Sed Br TF
Bas SMc
Sed Br TF
Bas SMc
Sed Br TF
1
200
40
not tested
5
10

Fig 8 b



Classification
G.W.T.
L.U
Temperature °C
T - 6 cont
5
10
110
120
130
140
150
160
170
180
190
200
Sed Br
TF
137.8
Tuss
TS
Sed Br
Tuss
Sed Br
Tuss
Sed Br
MuS
Tuss
Cl
MuS
SS
MuS
Cl
MuS
Cl
MuS
71.6

Fig. 9



B–B

LEGEND

Glacial Till formation moraine GT

Sámsstaðaklif Basalt formation SB

Sámsstaðamúli formation, basalt SMa–g

—"—"—"—"— talusbreccia and fanglomerate TF

—"—"—"—"— tuffacioas sandstone TS

—"—"—"—"— breccia and sandstone inside TF

Sámsstaðamúli formation, intrusive breccía, schematic

Older Búrfell formation, (OB) drillholes and exploration tunnel are shown and dashed lines showing conections of strata

Fault or major fracture

Centerline drillholes

RAFORKUMÁLASTJÓRI		
SÁMSSTAÐAMÚLI		Tnr. 452
Geologic section		B–277
	Fnr. 6436	