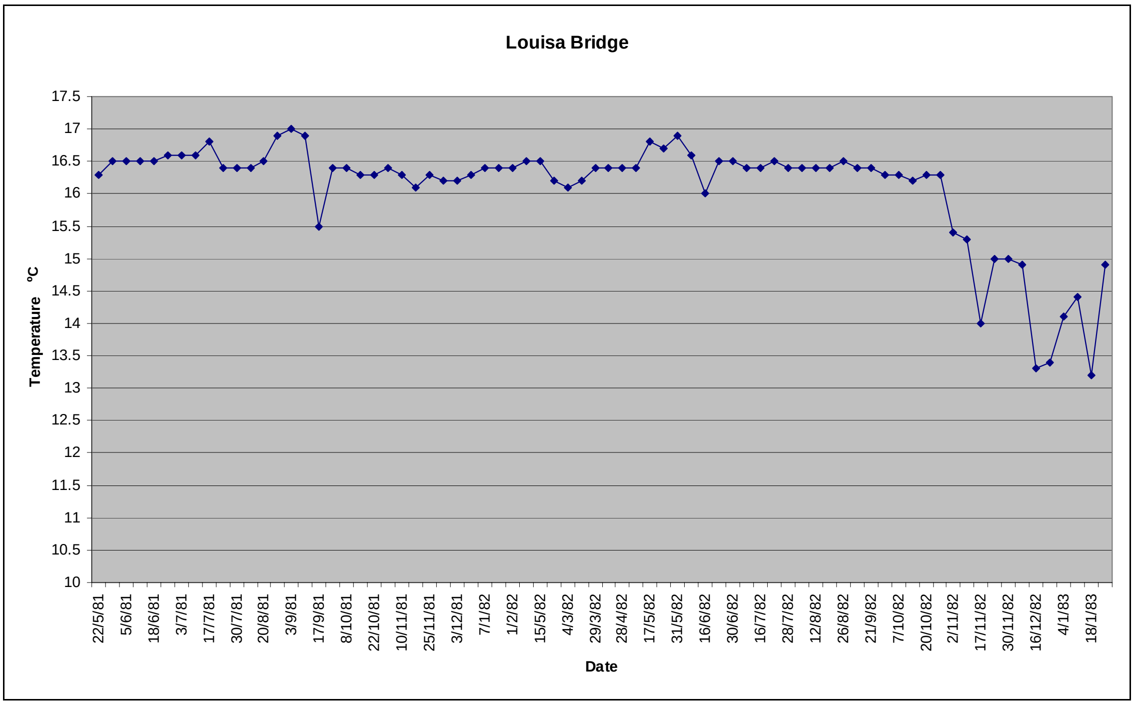
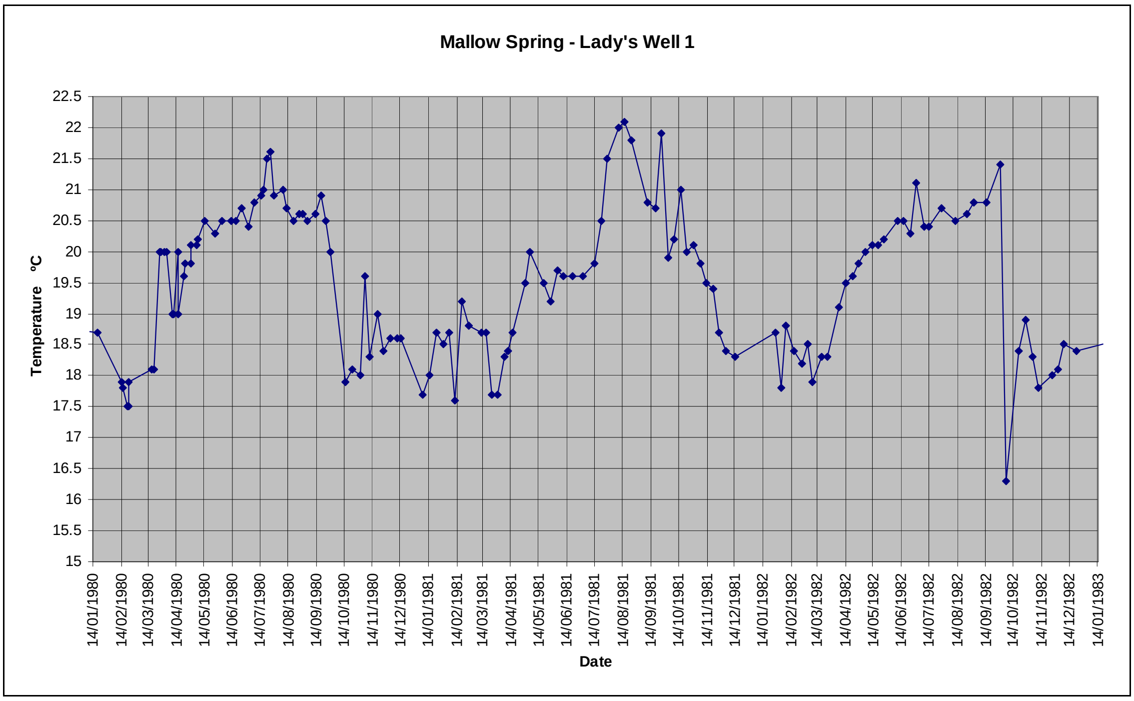
Appendix I:

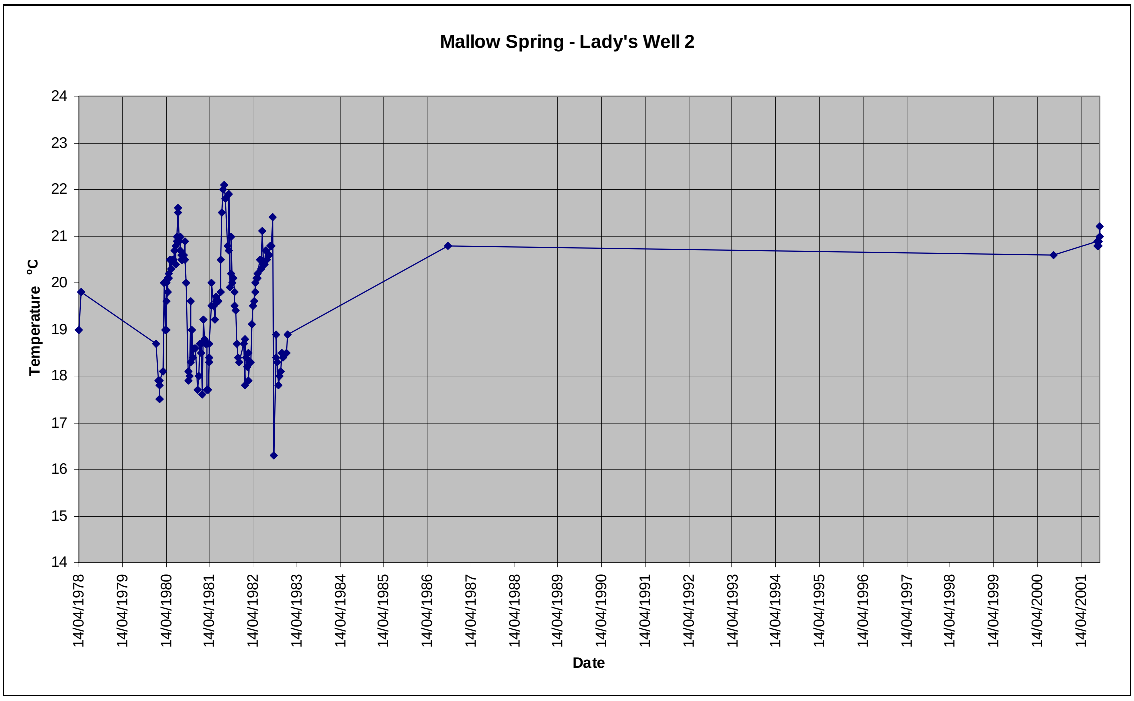
Warm Spring Temperature Monitoring Data

Appendix II:

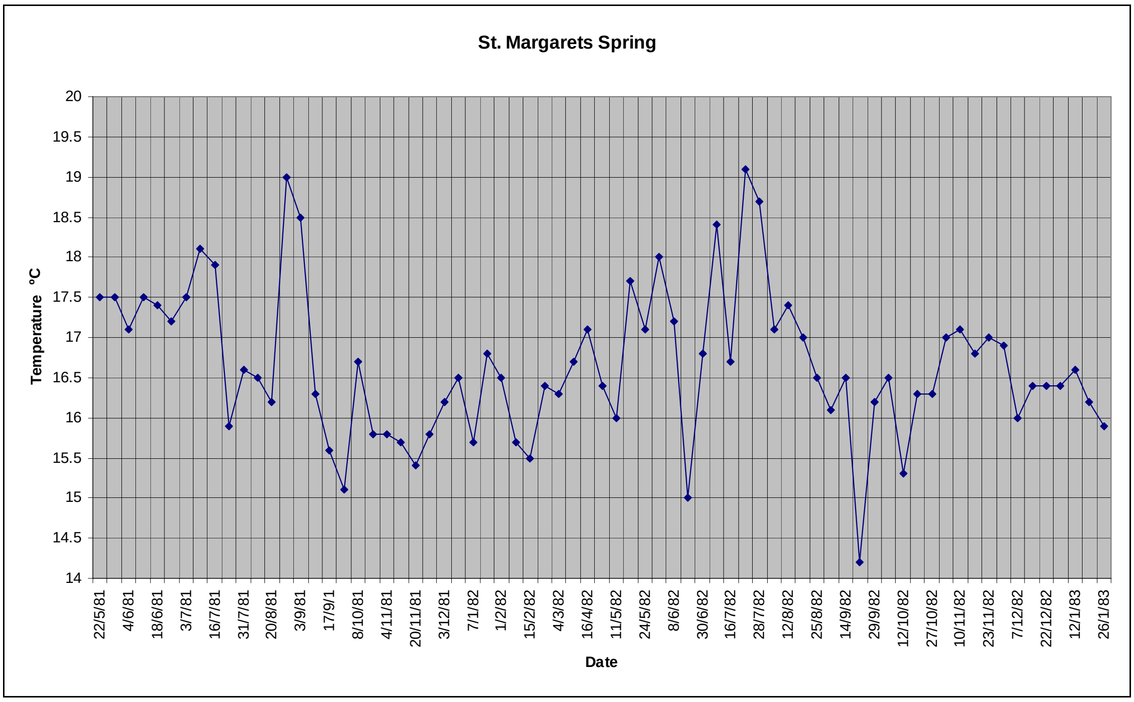
Warm Springs Temperature Monitoring Charts

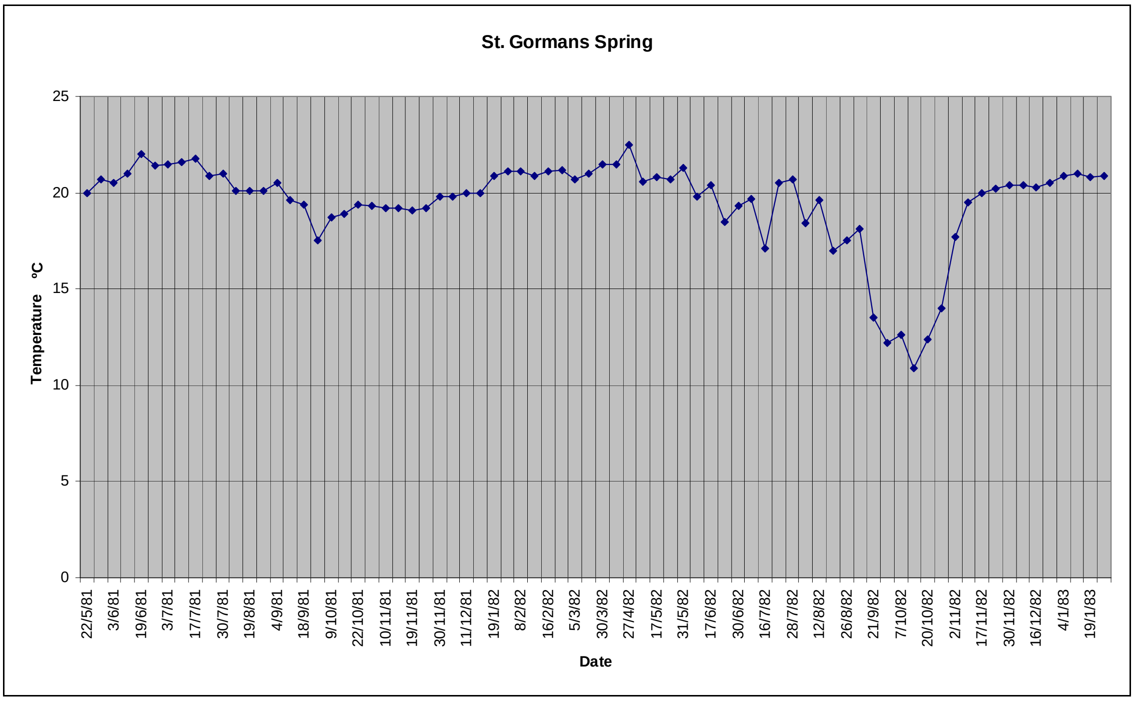

Louisa Bridge
Temperature °C
Date
17.5
17
16.5
16
15.5
15
14.5
14
13.5
13
12.5
12
11.5
11
10.5
10
22/5/81
5/6/81
18/6/81
3/7/81
17/7/81
30/7/81
20/8/81
3/9/81
17/9/81
8/10/81
22/10/81
10/11/81
25/11/81
3/12/81
7/1/82
1/2/82
15/2/82
4/3/82
29/3/82
28/4/82
17/5/82
31/5/82
16/6/82
30/6/82
16/7/82
28/7/82
12/8/82
26/8/82
21/9/82
7/10/82
20/10/82
2/11/82
17/11/82
30/11/82
16/12/82
4/1/83
18/1/83

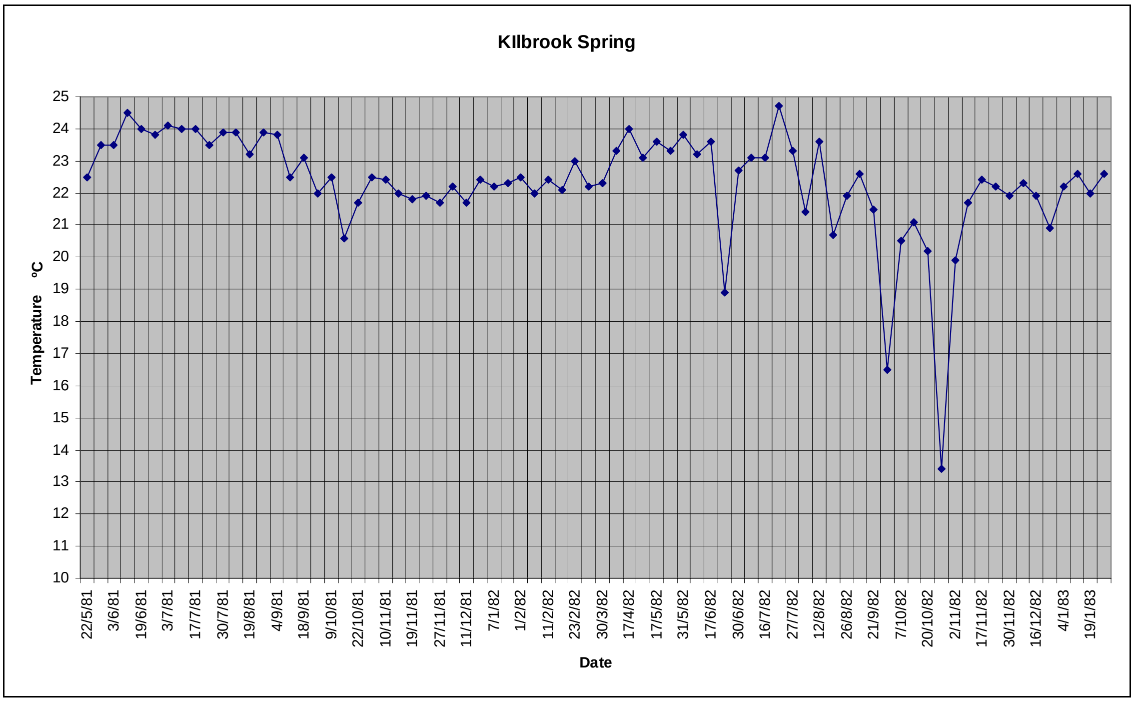

Mallow Spring - Lady's Well 1
Temperature °C
Date
22.5
22
21.5
21
20.5
20
19.5
19
18.5
18
17.5
17
16.5
16
15.5
15
14/01/1980
14/02/1980
14/03/1980
14/04/1980
14/05/1980
14/06/1980
14/07/1980
14/08/1980
14/09/1980
14/10/1980
14/11/1980
14/12/1980
14/01/1981
14/02/1981
14/03/1981
14/04/1981
14/05/1981
14/06/1981
14/07/1981
14/08/1981
14/09/1981
14/10/1981
14/11/1981
14/12/1981
14/01/1982
14/02/1982
14/03/1982
14/04/1982
14/05/1982
14/06/1982
14/07/1982
14/08/1982
14/09/1982
14/10/1982
14/11/1982
14/12/1982
14/01/1983

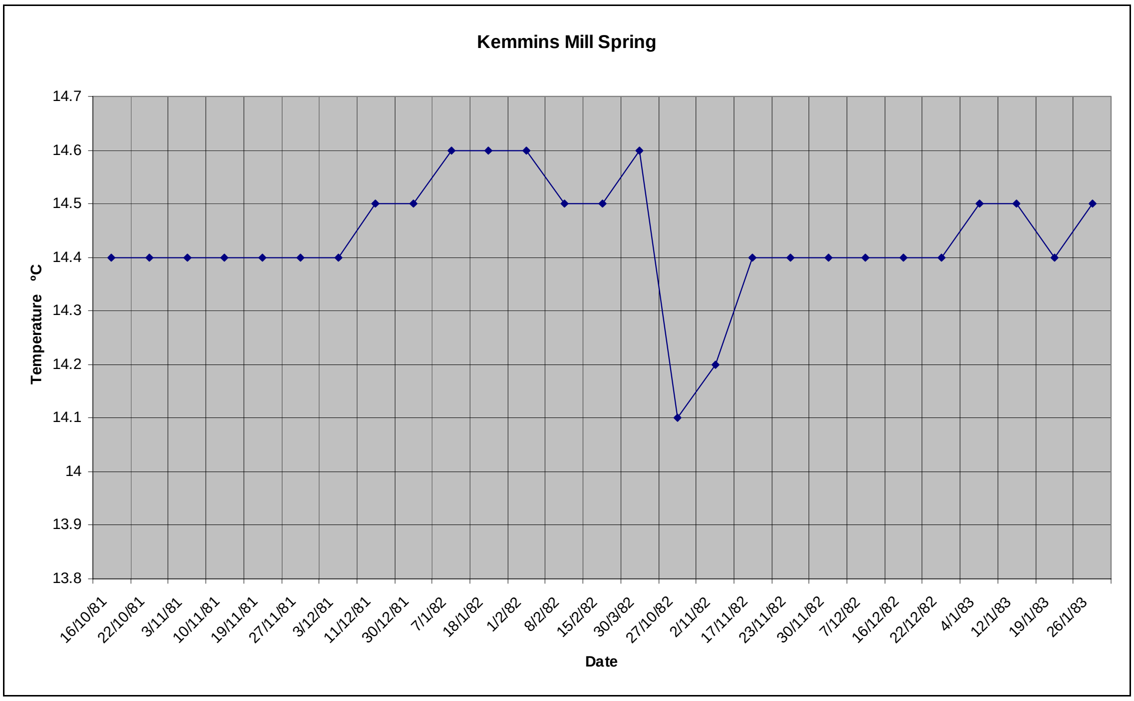


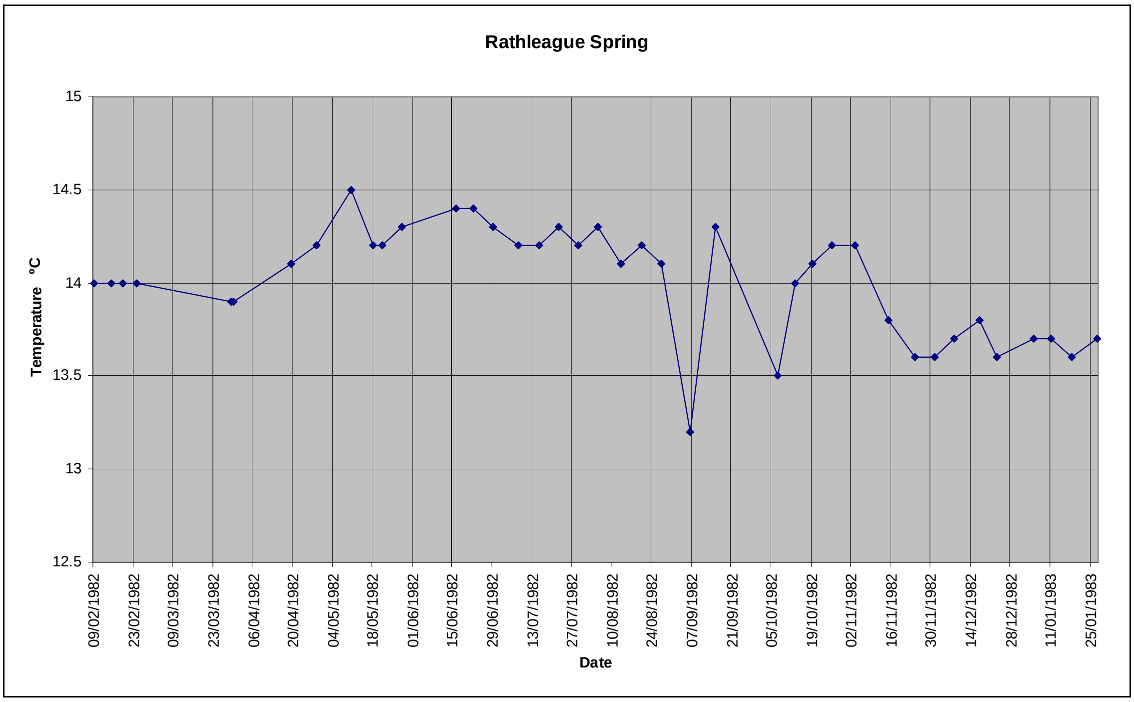
The previous chart shows the detail from 1980 to 1983 from the left portion of this chart

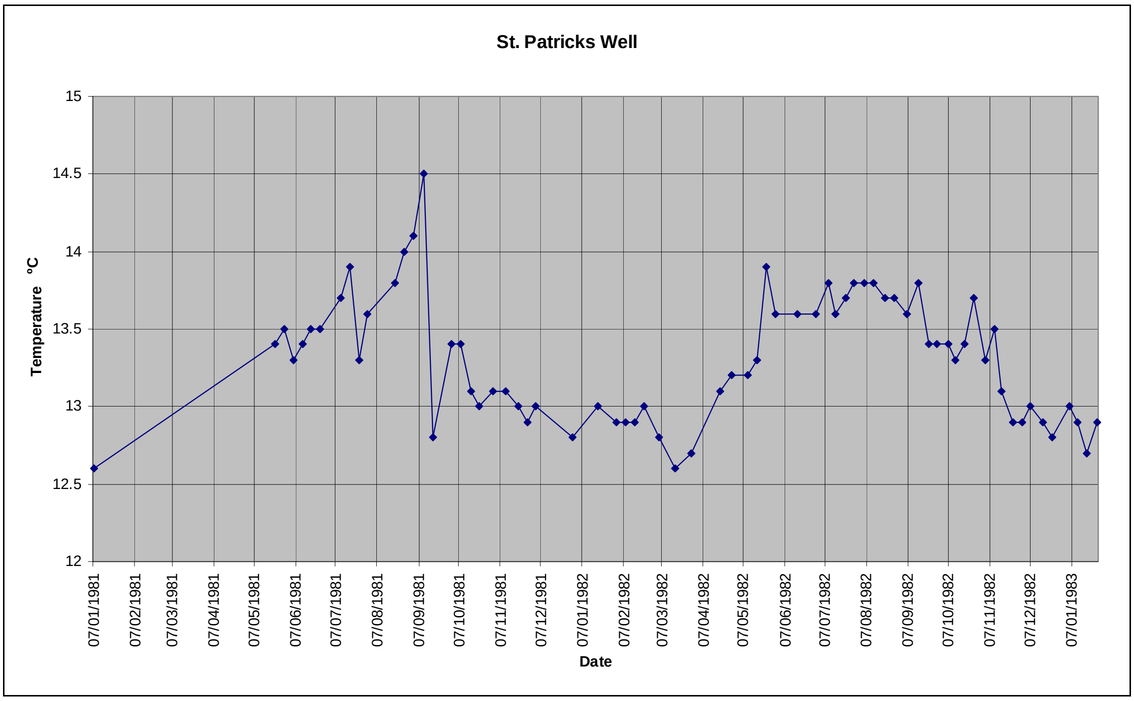


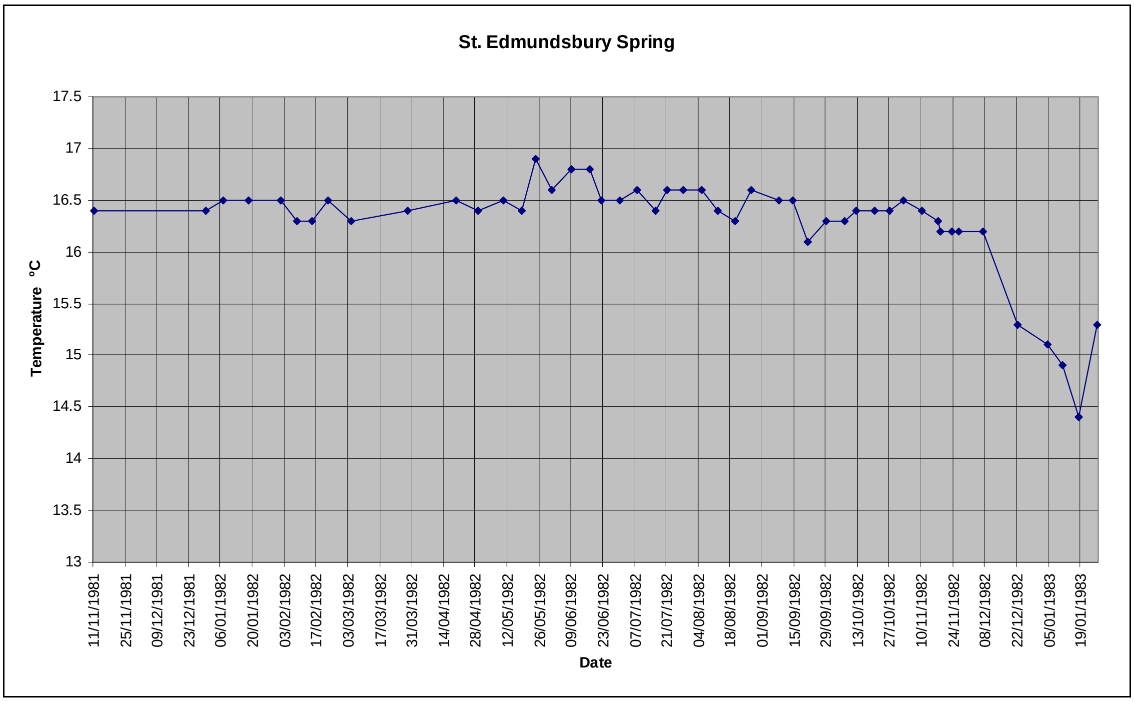

St. Gormans Spring
Temperature °C
25
20
15
10
5
0
22/5/81
3/6/81
19/6/81
3/7/81
17/7/81
30/7/81
19/8/81
4/9/81
18/9/81
9/10/81
22/10/81
10/11/81
19/11/81
30/11/81
11/12/81
19/1/82
8/2/82
16/2/82
5/3/82
30/3/82
27/4/82
17/5/82
31/5/82
17/6/82
30/6/82
16/7/82
28/7/82
12/8/82
26/8/82
21/9/82
7/10/82
20/10/82
2/11/82
17/11/82
30/11/82
16/12/82
4/1/83
19/1/83
Date

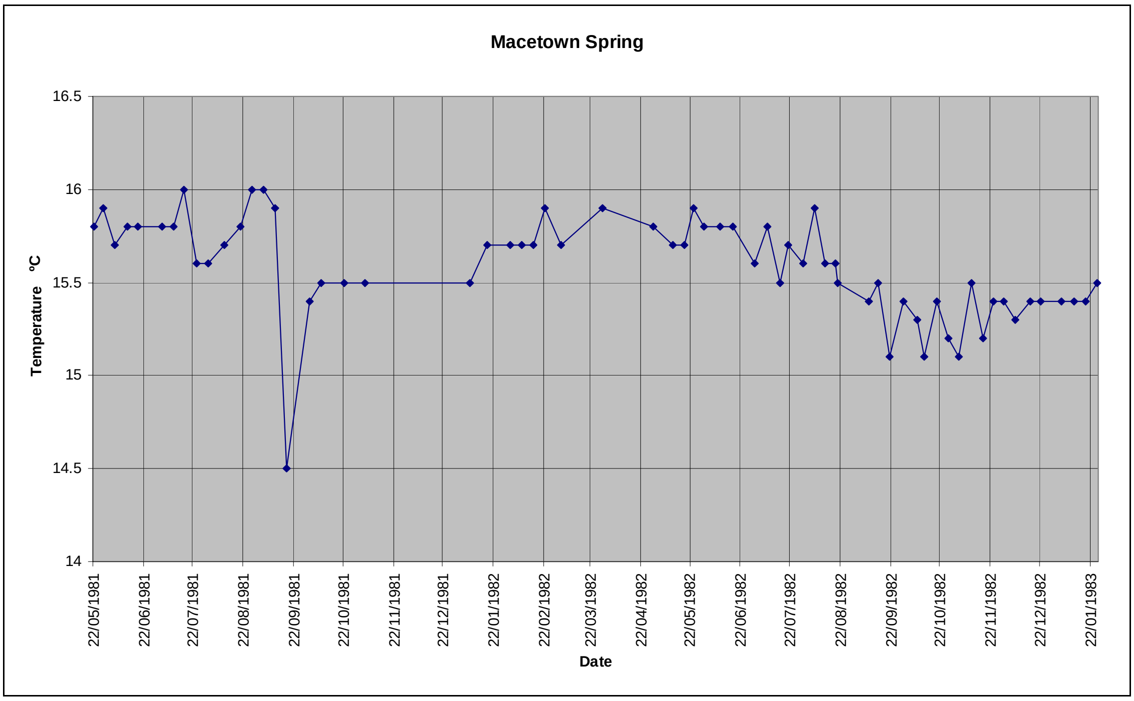

KIlbrook Spring
Temperature °C
25
24
23
22
21
20
19
18
17
16
15
14
13
12
11
10
22/5/81
3/6/81
19/6/81
3/7/81
17/7/81
30/7/81
19/8/81
4/9/81
18/9/81
9/10/81
22/10/81
10/11/81
19/11/81
27/11/81
11/12/81
7/1/82
1/2/82
11/2/82
23/2/82
30/3/82
17/4/82
17/5/82
31/5/82
17/6/82
30/6/82
16/7/82
27/7/82
12/8/82
26/8/82
21/9/82
7/10/82
20/10/82
2/11/82
17/11/82
30/11/82
16/12/82
4/1/83
19/1/83
Date


Kemmins Mill Spring
Temperature °C
14.7
14.6
14.5
14.4
14.3
14.2
14.1
14
13.9
13.8
16/10/81
22/10/81
3/11/81
10/11/81
19/11/81
27/11/81
3/12/81
11/12/81
30/12/81
7/1/82
18/1/82
1/2/82
8/2/82
15/2/82
30/3/82
27/10/82
2/11/82
17/11/82
23/11/82
30/11/82
7/12/82
16/12/82
22/12/82
4/1/83
12/1/83
19/1/83
26/1/83
Date


Rathleague Spring
Temperature °C
15
14.5
14
13.5
13
12.5
09/02/1982
23/02/1982
09/03/1982
23/03/1982
06/04/1982
20/04/1982
04/05/1982
18/05/1982
01/06/1982
15/06/1982
29/06/1982
13/07/1982
27/07/1982
10/08/1982
24/08/1982
07/09/1982
21/09/1982
05/10/1982
19/10/1982
02/11/1982
16/11/1982
30/11/1982
14/12/1982
28/12/1982
11/01/1983
25/01/1983
Date


St. Patricks Well
Temperature °C
Date
15
14.5
14
13.5
13
12.5
12
07/01/1981
07/02/1981
07/03/1981
07/04/1981
07/05/1981
07/06/1981
07/07/1981
07/08/1981
07/09/1981
07/10/1981
07/11/1981
07/12/1981
07/01/1982
07/02/1982
07/03/1982
07/04/1982
07/05/1982
07/06/1982
07/07/1982
07/08/1982
07/09/1982
07/10/1982
07/11/1982
07/12/1982
07/01/1983


St. Edmundsbury Spring
Temperature °C
Date
17.5
17
16.5
16
15.5
15
14.5
14
13.5
13
11/11/1981
25/11/1981
09/12/1981
23/12/1981
06/01/1982
20/01/1982
03/02/1982
17/02/1982
03/03/1982
17/03/1982
31/03/1982
14/04/1982
28/04/1982
12/05/1982
26/05/1982
09/06/1982
23/06/1982
07/07/1982
21/07/1982
04/08/1982
18/08/1982
01/09/1982
15/09/1982
29/09/1982
13/10/1982
27/10/1982
10/11/1982
24/11/1982
08/12/1982
22/12/1982
05/01/1983
19/01/1983

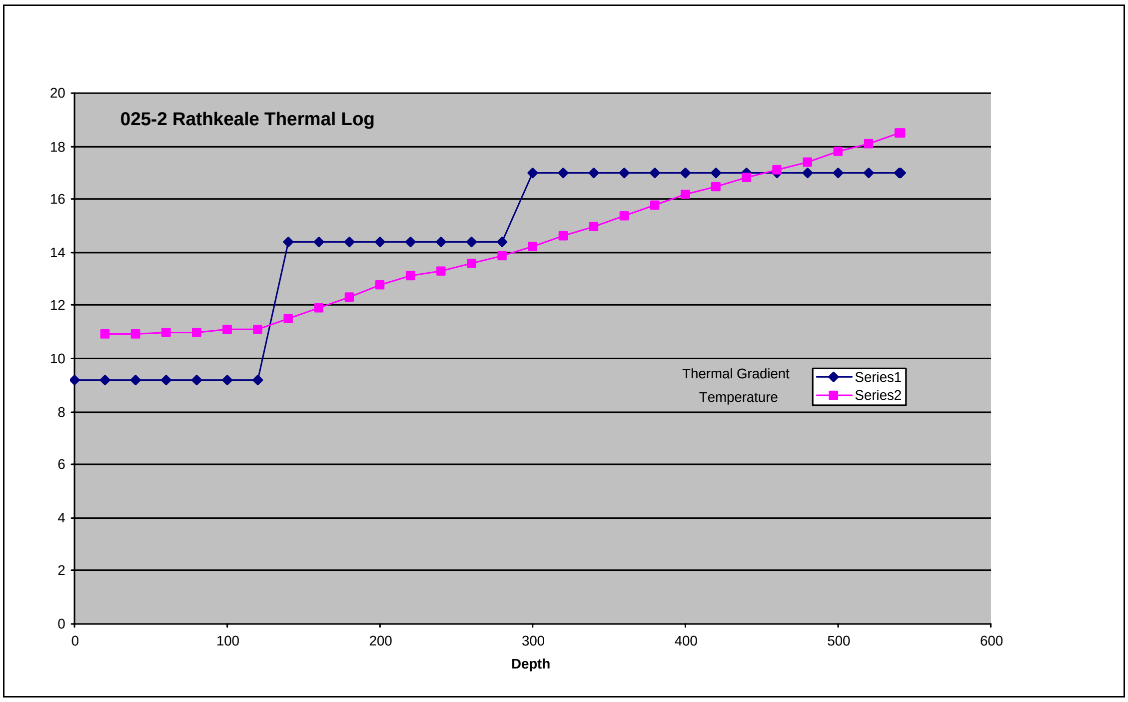

Macetown Spring
16.5
16
15.5
15
14.5
14
Temperature °C
22/05/1981
22/06/1981
22/07/1981
22/08/1981
22/09/1981
22/10/1981
22/11/1981
22/12/1981
22/01/1982
22/02/1982
22/03/1982
22/04/1982
22/05/1982
22/06/1982
22/07/1982
22/08/1982
22/09/1982
22/10/1982
22/11/1982
22/12/1982
22/01/1983
Date

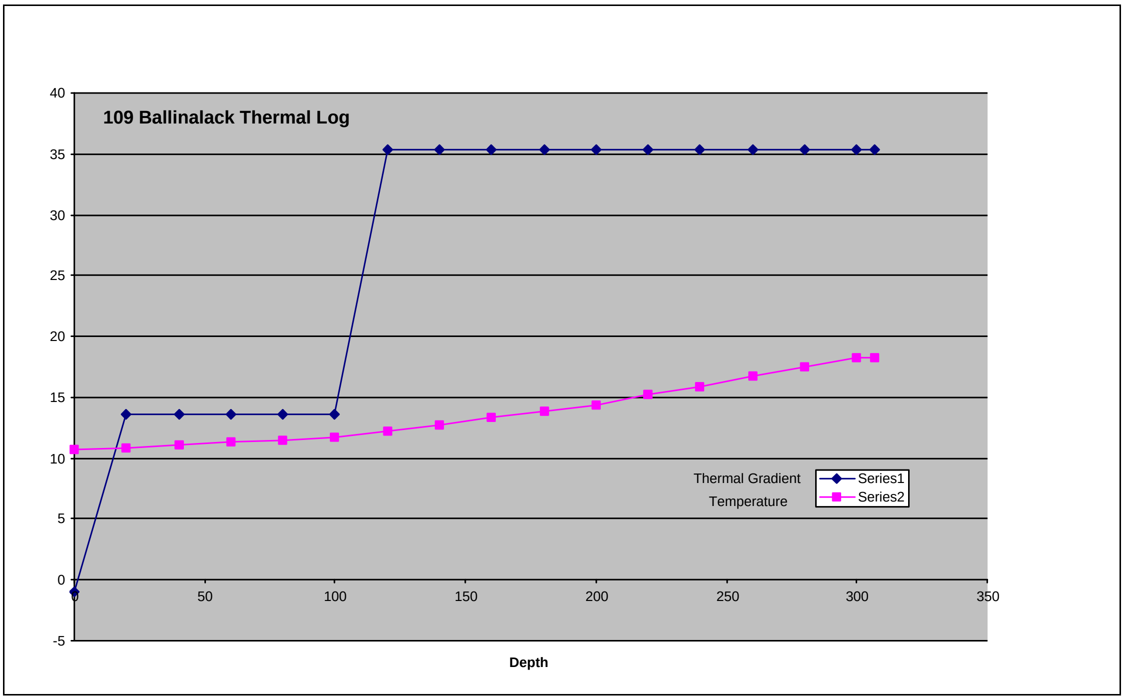
Appendix III:

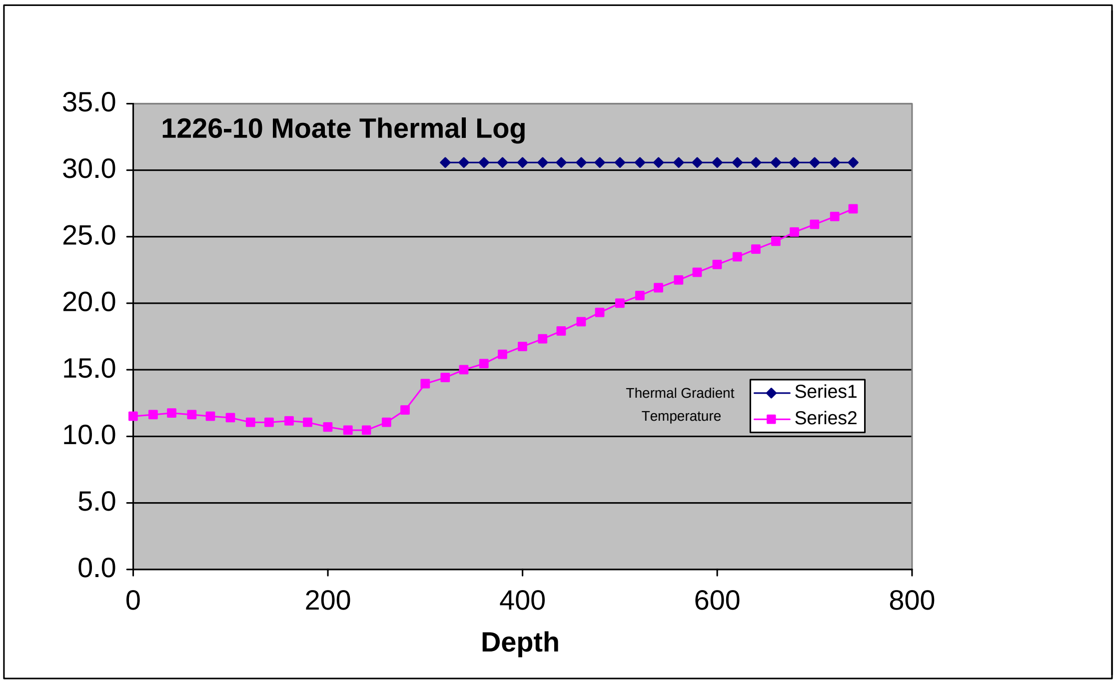
Borehole Temperature and Geothermal Gradient Data

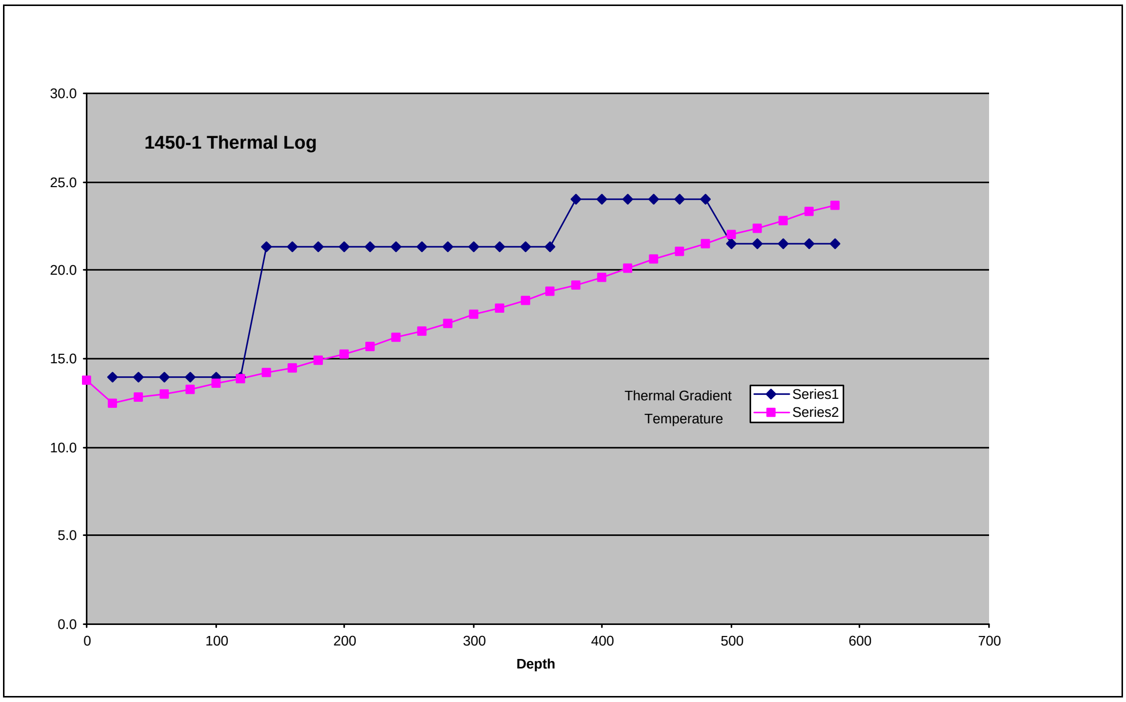
Appendix IV:

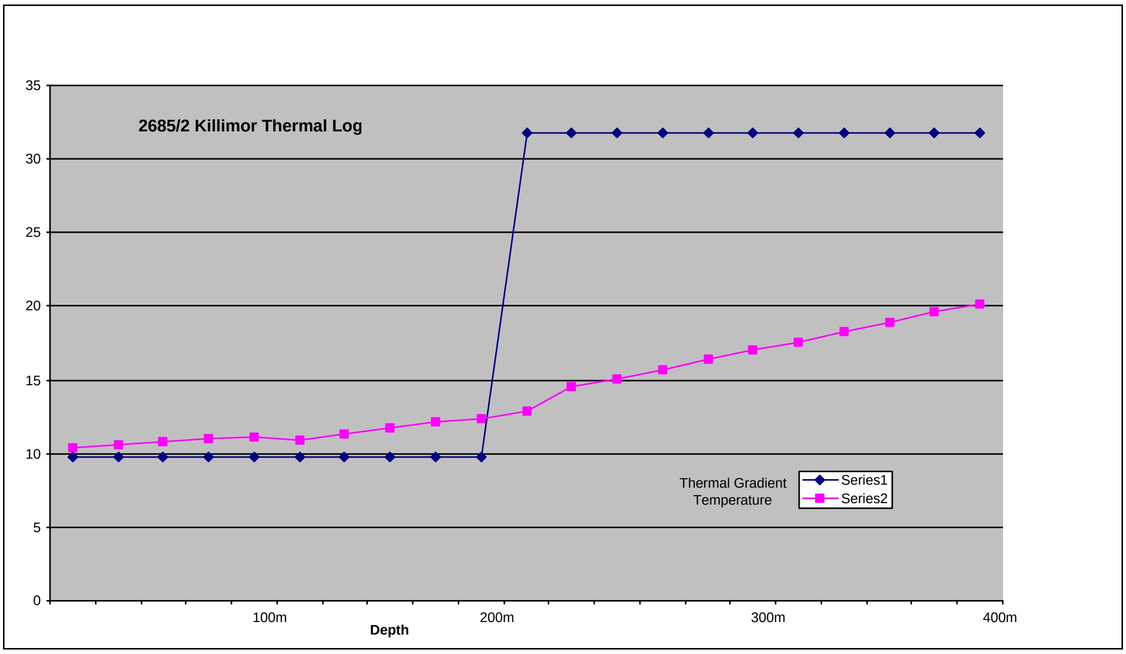
Borehole Temperature and Geothermal Gradient Logs

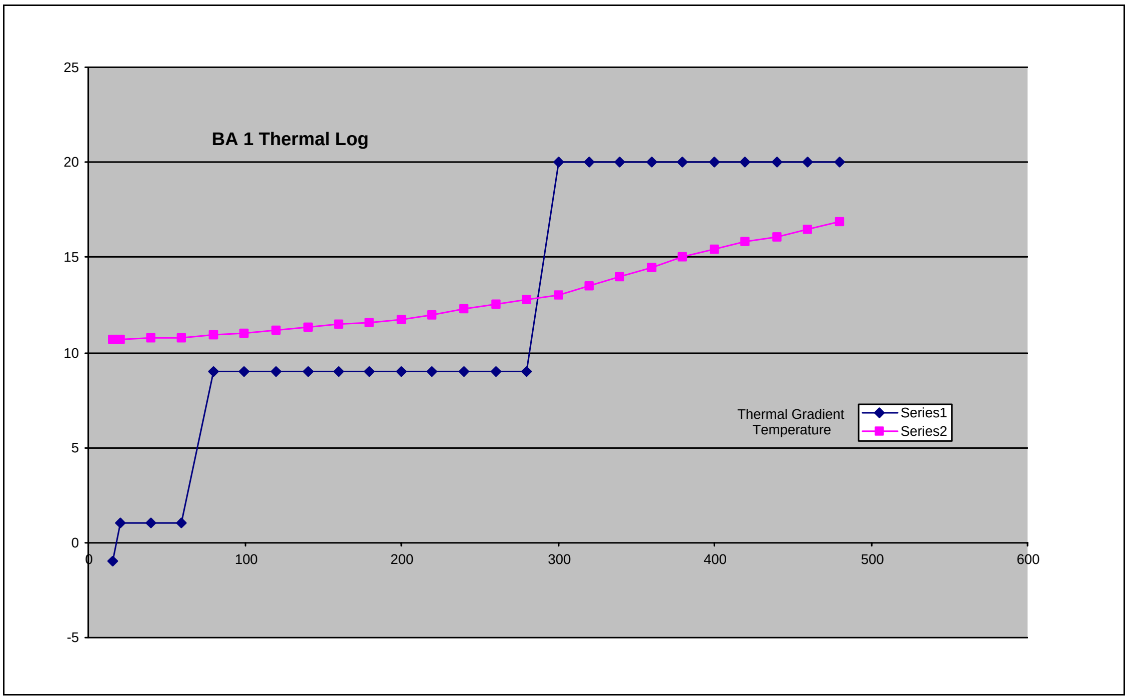

025-2 Rathkeale Thermal Log
20
18
16
14
12
10
8
6
4
2
0
0
100
200
300
400
500
600
Depth
Thermal Gradient
Temperature
Series1
Series2

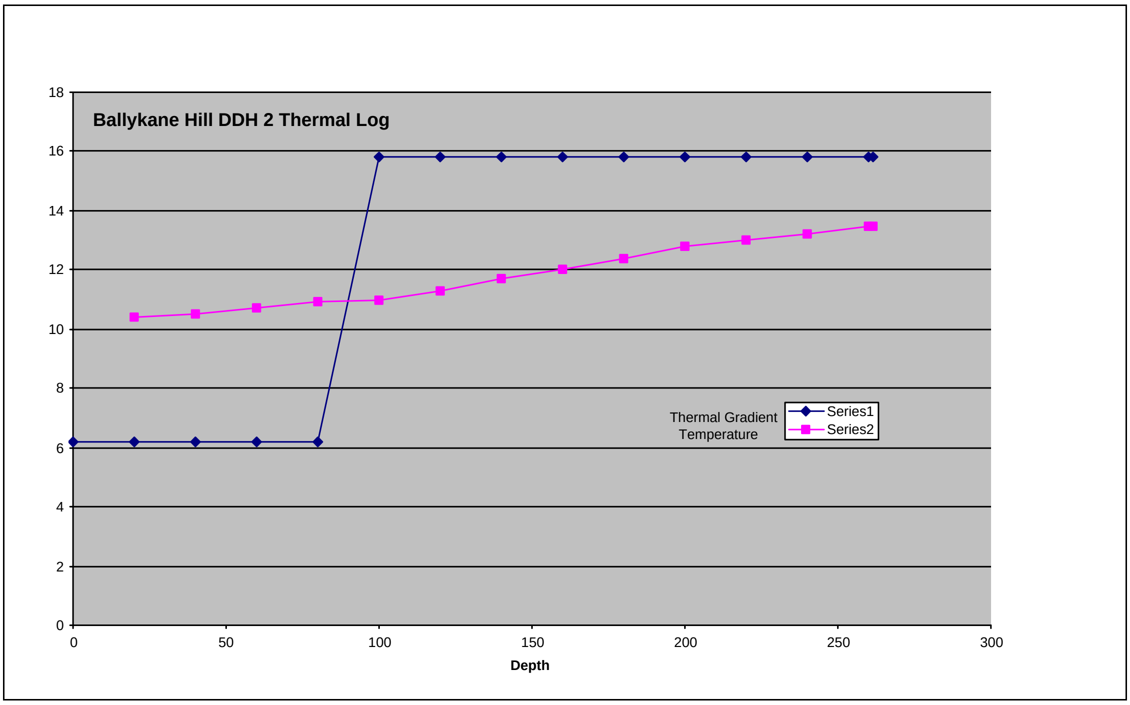

109 Ballinalack Thermal Log
40
35
30
25
20
15
10
5
0
-5
0
50
100
150
200
250
300
350
Depth
Thermal Gradient
Temperature
Series1
Series2

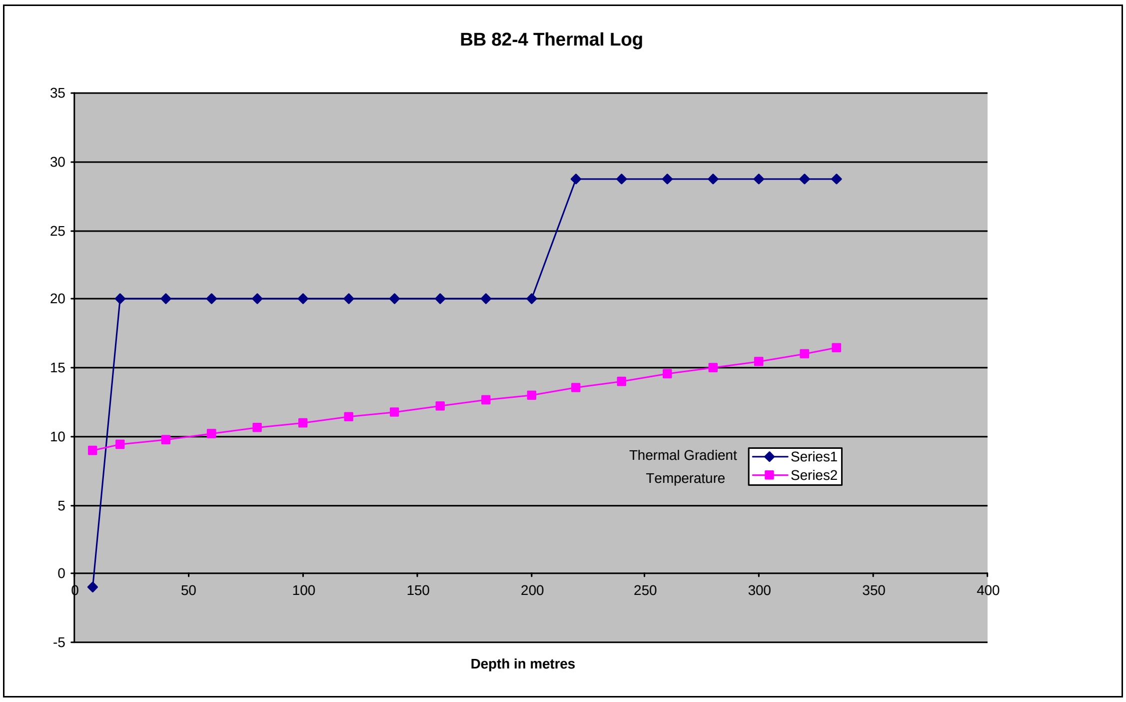

1226-10 Moate Thermal Log
35.0
30.0
25.0
20.0
15.0
10.0
5.0
0.0
0
200
400
600
800
Depth
Thermal Gradient
Temperature
Series1
Series2

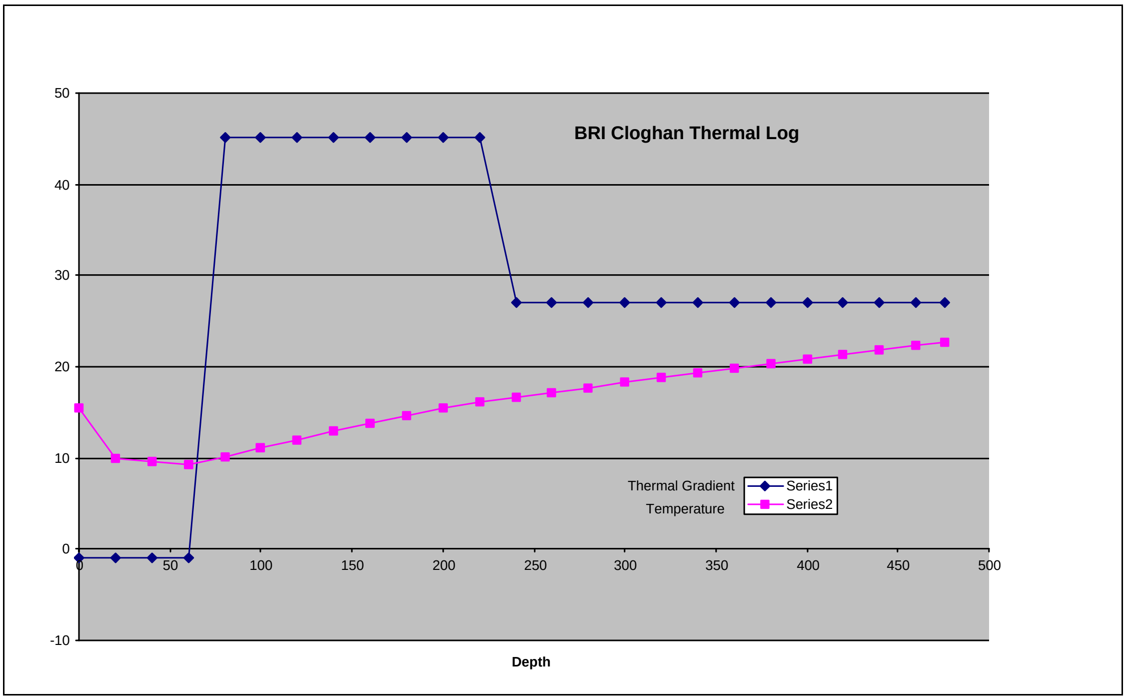

1450-1 Thermal Log
30.0
25.0
20.0
15.0
10.0
5.0
0.0
0
100
200
300
400
500
600
700
Depth
Thermal Gradient
Temperature
Series1
Series2

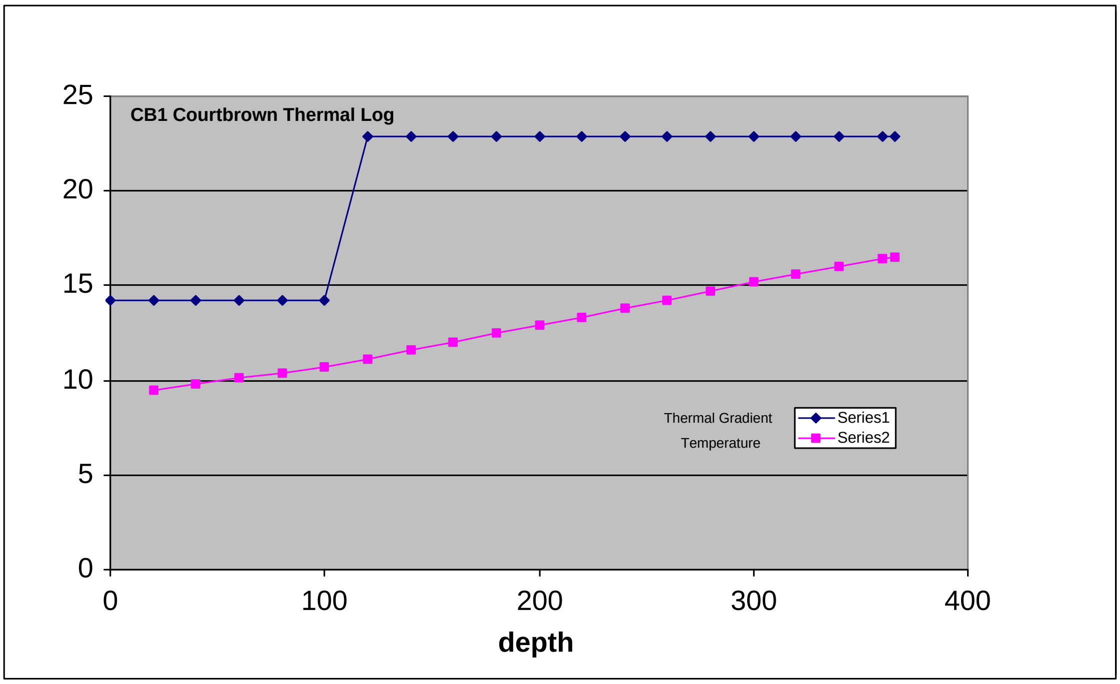

2685/2 Killimor Thermal Log
35
30
25
20
15
10
5
0
100m
200m
300m
400m
Depth
Thermal Gradient
Temperature
Series1
Series2

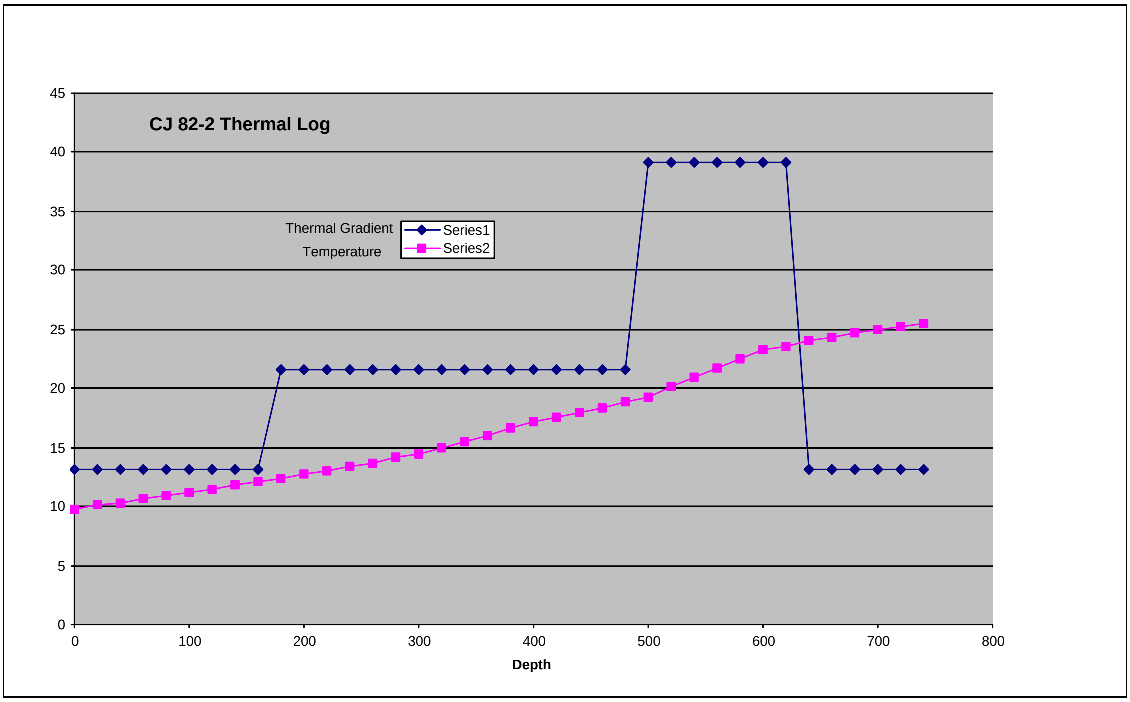

BA 1 Thermal Log
25
20
15
10
5
0
-5
0
100
200
300
400
500
600
Thermal Gradient
Temperature
Series1
Series2

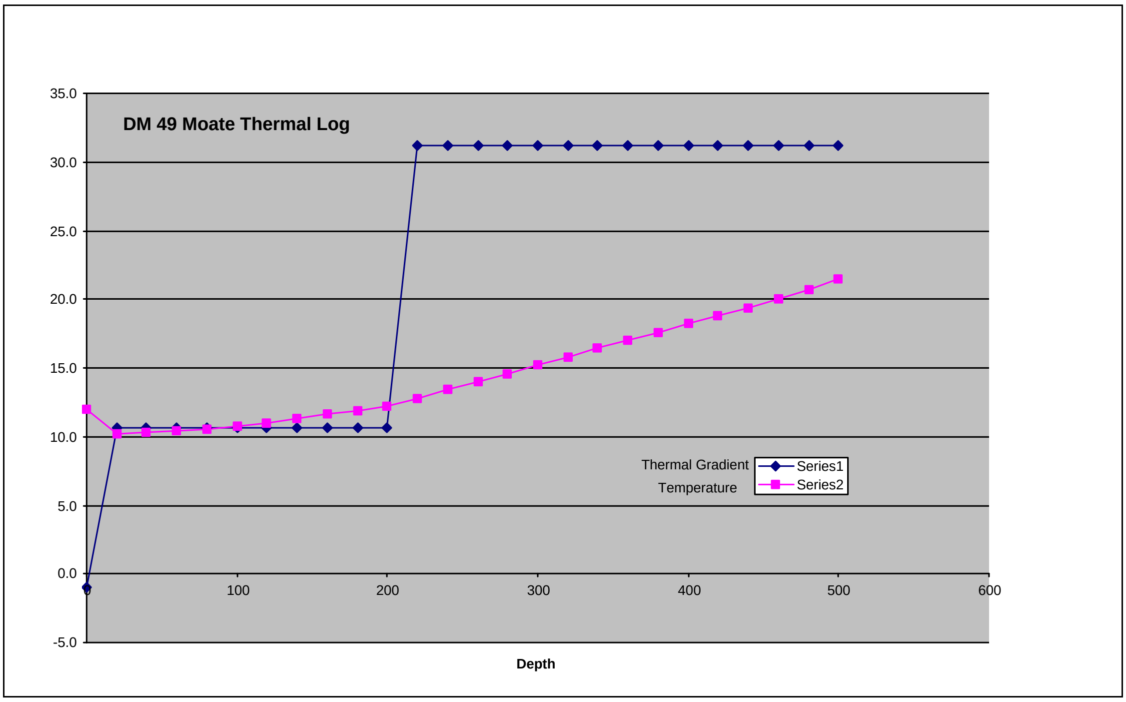

Ballykane Hill DDH 2 Thermal Log
18
16
14
12
10
8
6
4
2
0
0
50
100
150
200
250
300
Depth
Thermal Gradient
Temperature
Series1
Series2

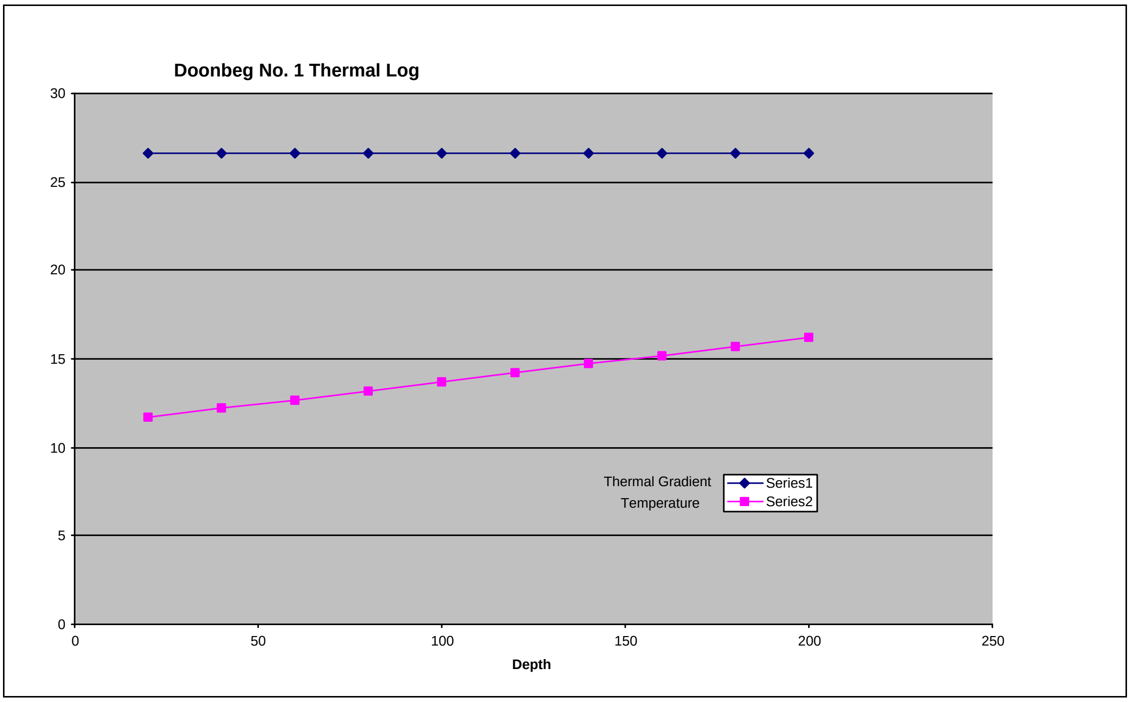

BB 82-4 Thermal Log
35
30
25
20
15
10
5
0
-5
0
50
100
150
200
250
300
350
400
Depth in metres
Thermal Gradient
Temperature
Series1
Series2

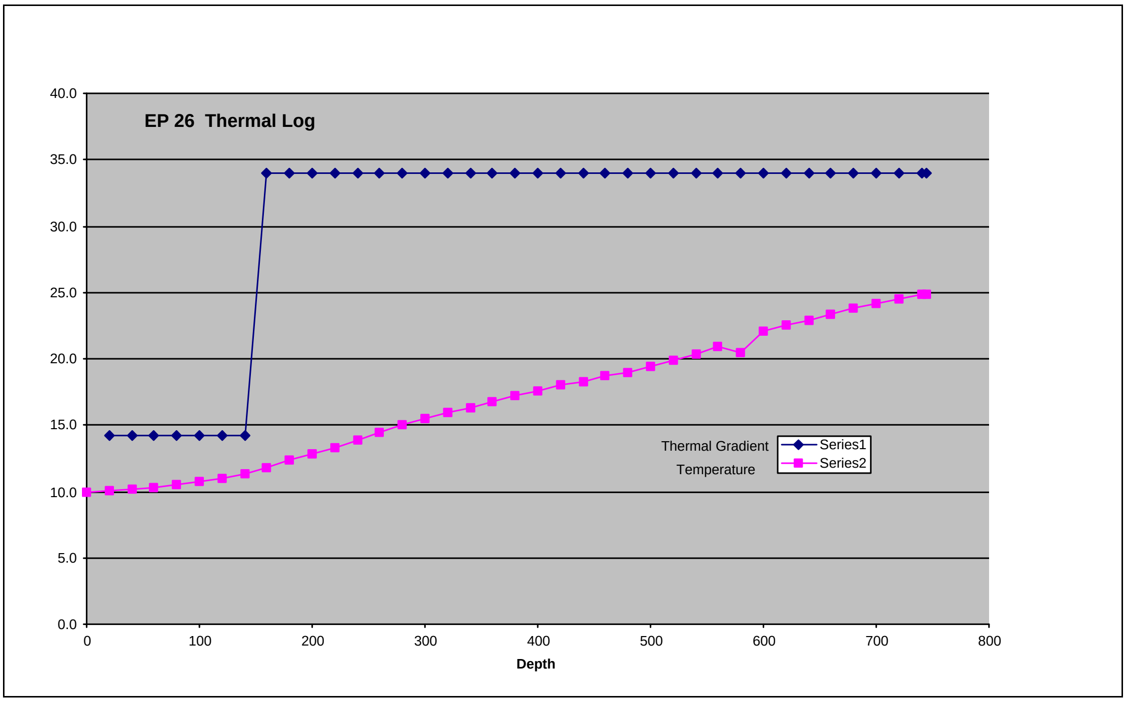

BRI Cloghan Thermal Log
50
40
30
20
10
0
-10
0
50
100
150
200
250
300
350
400
450
500
Depth
Thermal Gradient
Temperature
Series1
Series2

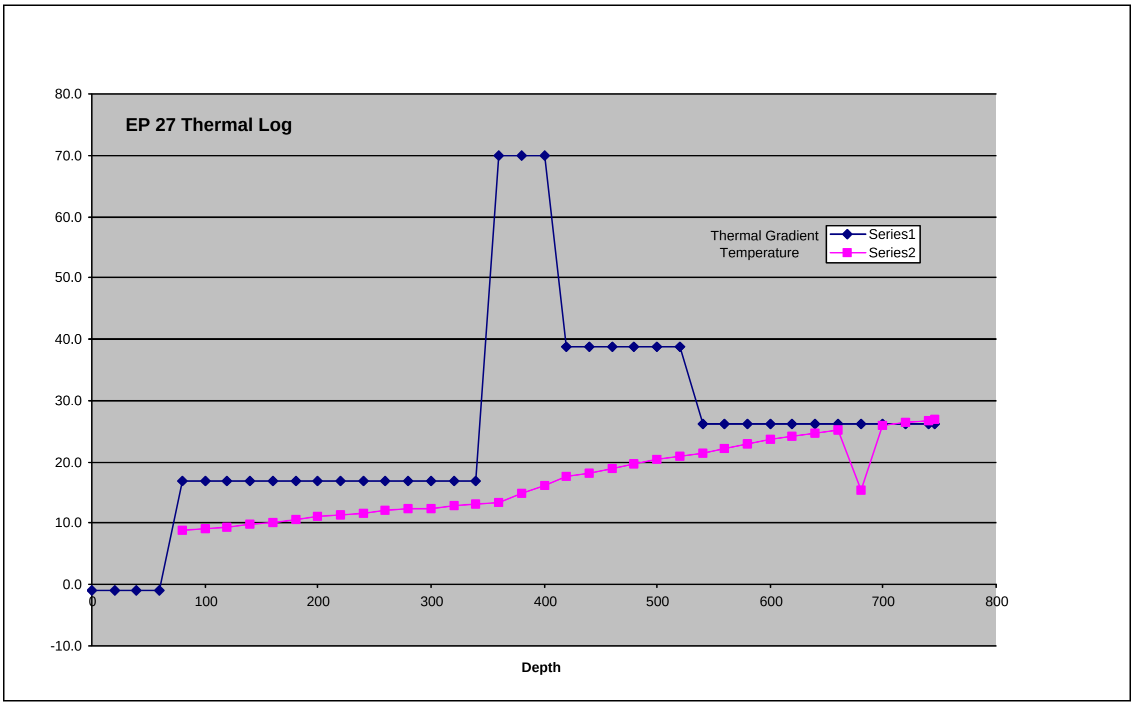

CB1 Courtbrown Thermal Log
25
20
15
10
5
0
0
100
200
300
400
depth
Thermal Gradient
Temperature
Series1
Series2

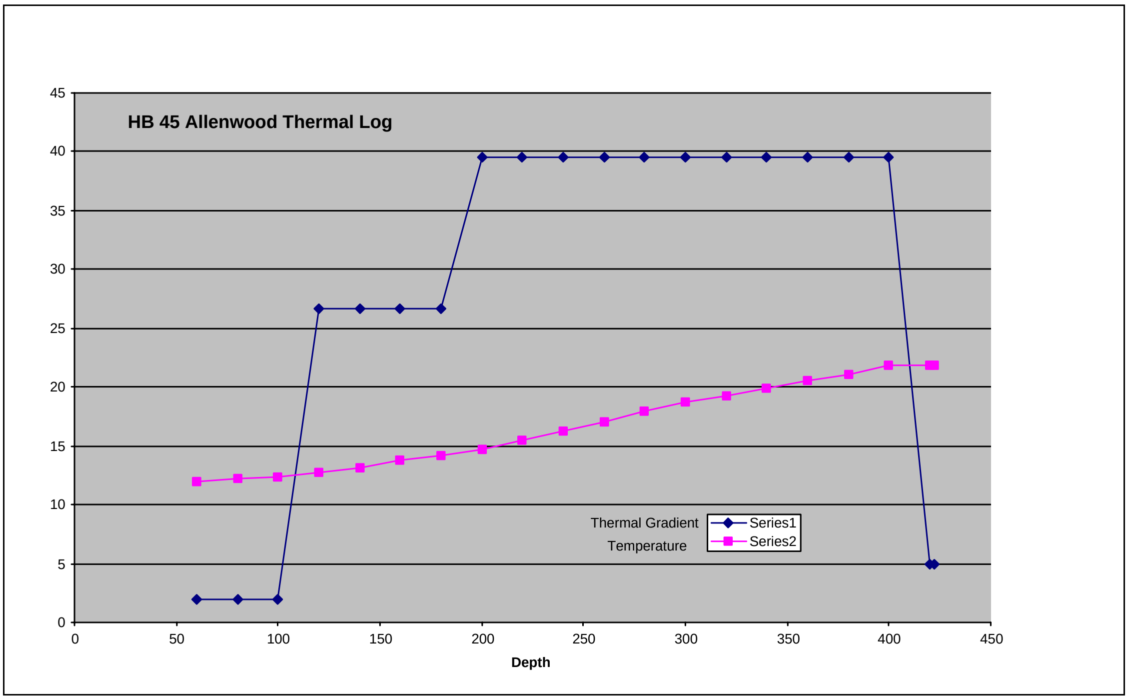

CJ 82-2 Thermal Log
Thermal Gradient
Temperature
Series1
Series2
45
40
35
30
25
20
15
10
5
0
0
100
200
300
400
500
600
700
800
Depth

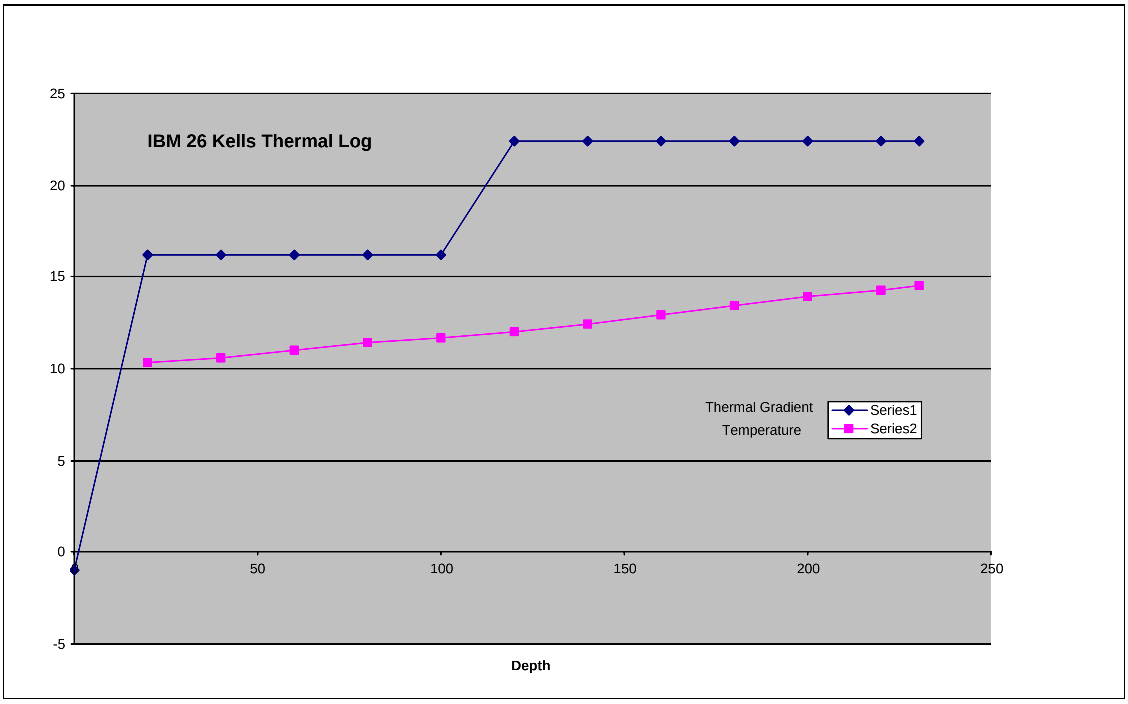

DM 49 Moate Thermal Log
Thermal Gradient
Temperature
Series1
Series2
35.0
30.0
25.0
20.0
15.0
10.0
5.0
0.0
-5.0
0
100
200
300
400
500
600
Depth

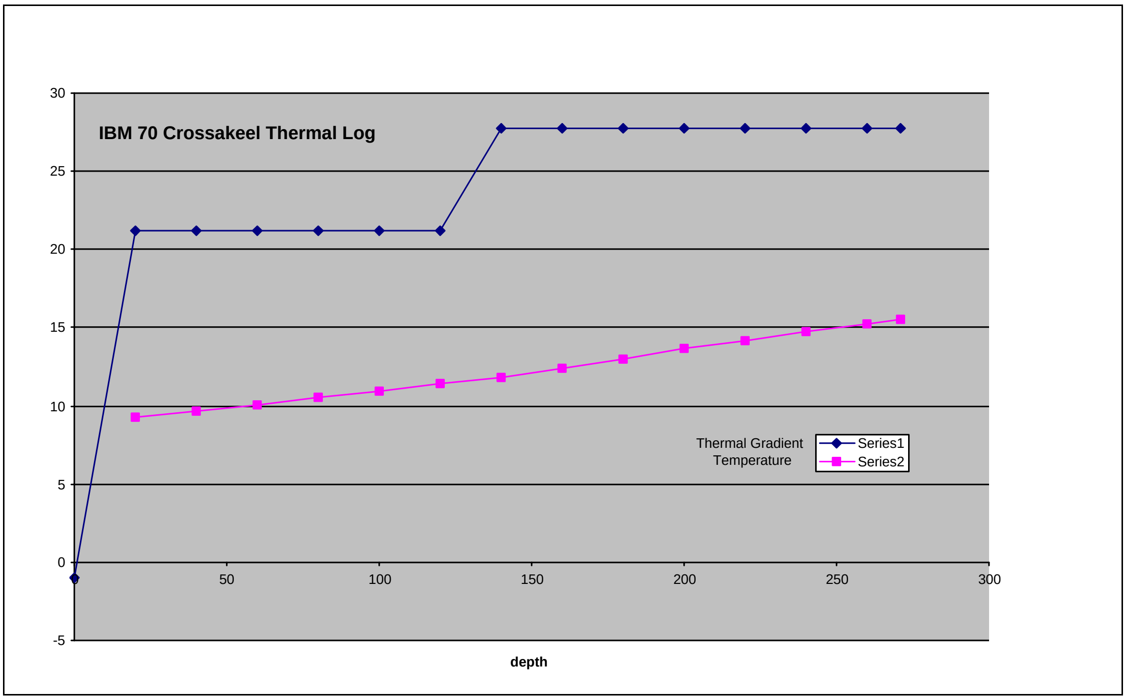

Doonbeg No. 1 Thermal Log
30
25
20
15
10
5
0
0
50
100
150
200
250
Depth
Thermal Gradient
Temperature
Series1
Series2

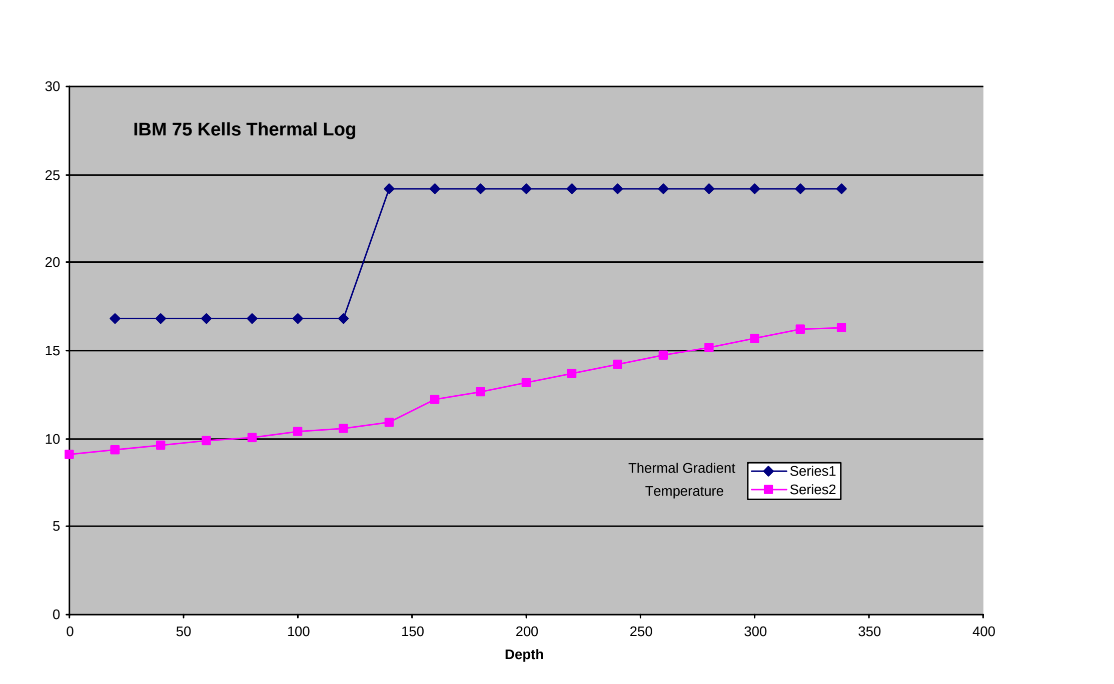

EP 26 Thermal Log
40.0
35.0
30.0
25.0
20.0
15.0
10.0
5.0
0.0
0
100
200
300
400
500
600
700
800
Depth
Thermal Gradient
Temperature
Series1
Series2

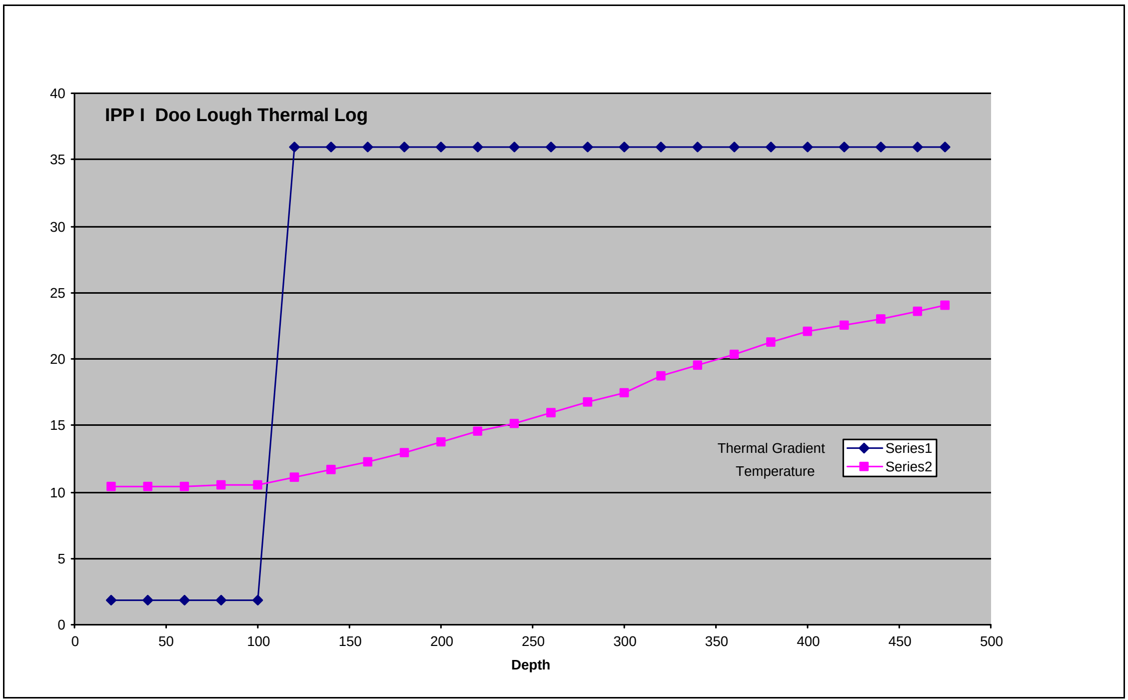

EP 27 Thermal Log
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
-10.0
0
100
200
300
400
500
600
700
800
Depth
Thermal Gradient
Temperature
Series1
Series2

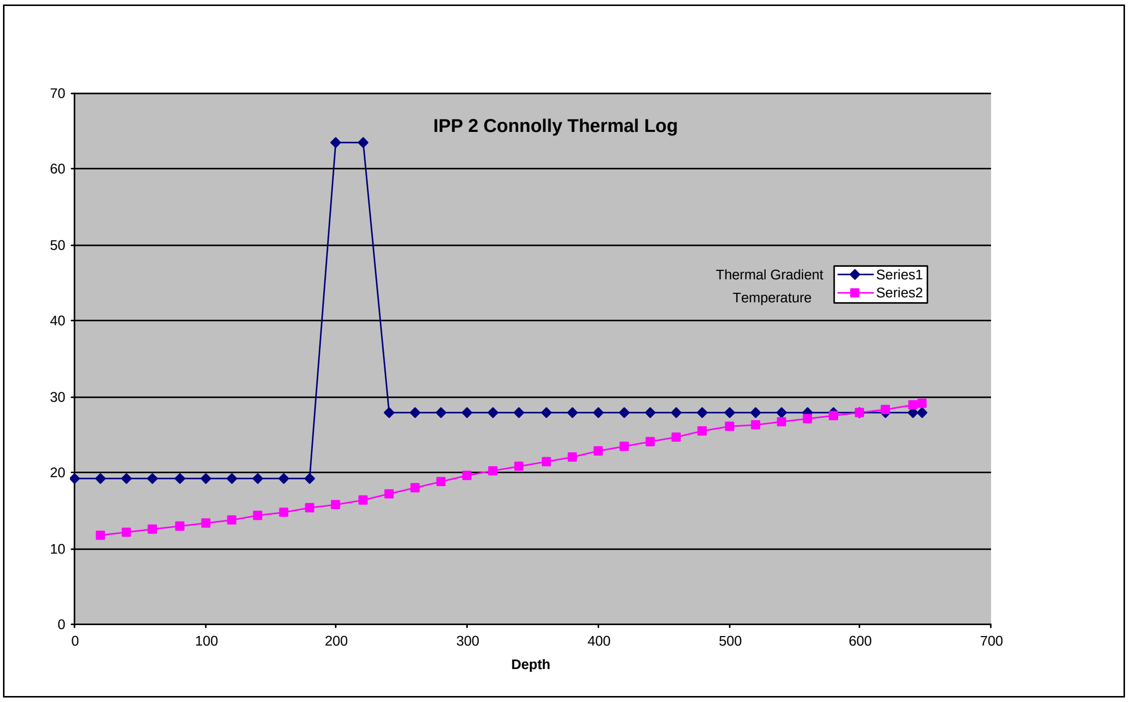

HB 45 Allenwood Thermal Log
45
40
35
30
25
20
15
10
5
0
0
50
100
150
200
250
300
350
400
450
Depth
Thermal Gradient
Temperature
Series1
Series2

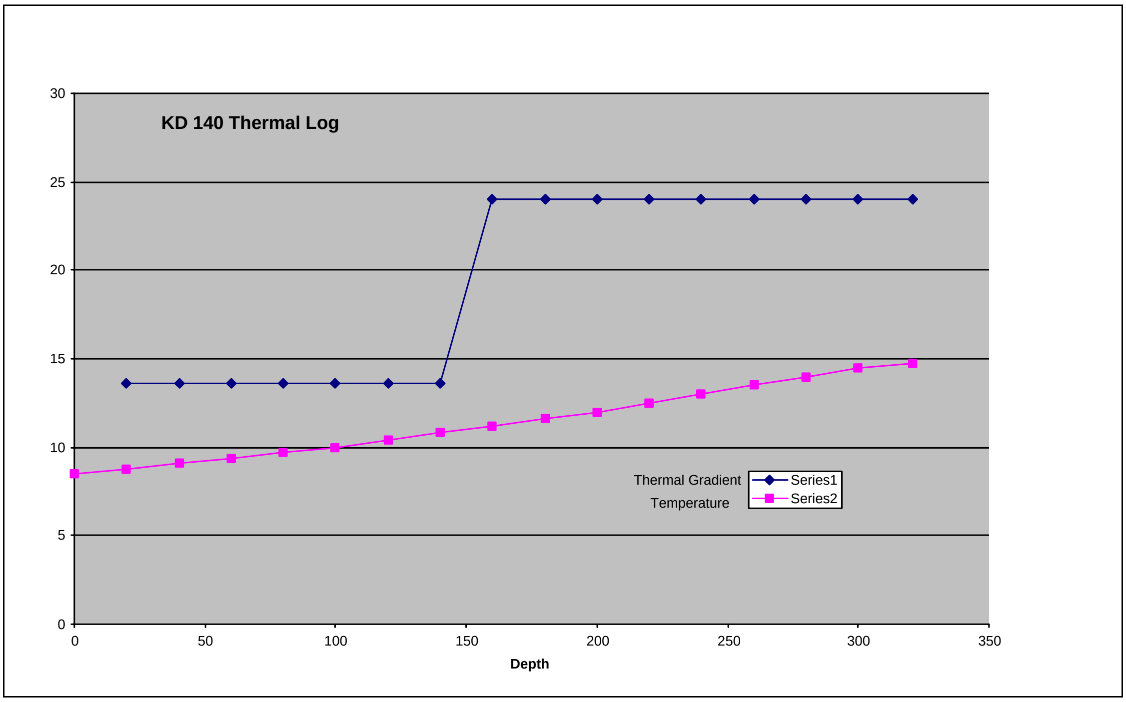

IBM 26 Kells Thermal Log
25
20
15
10
5
0
-5
50
100
150
200
250
Thermal Gradient
Temperature
Series1
Series2
Depth

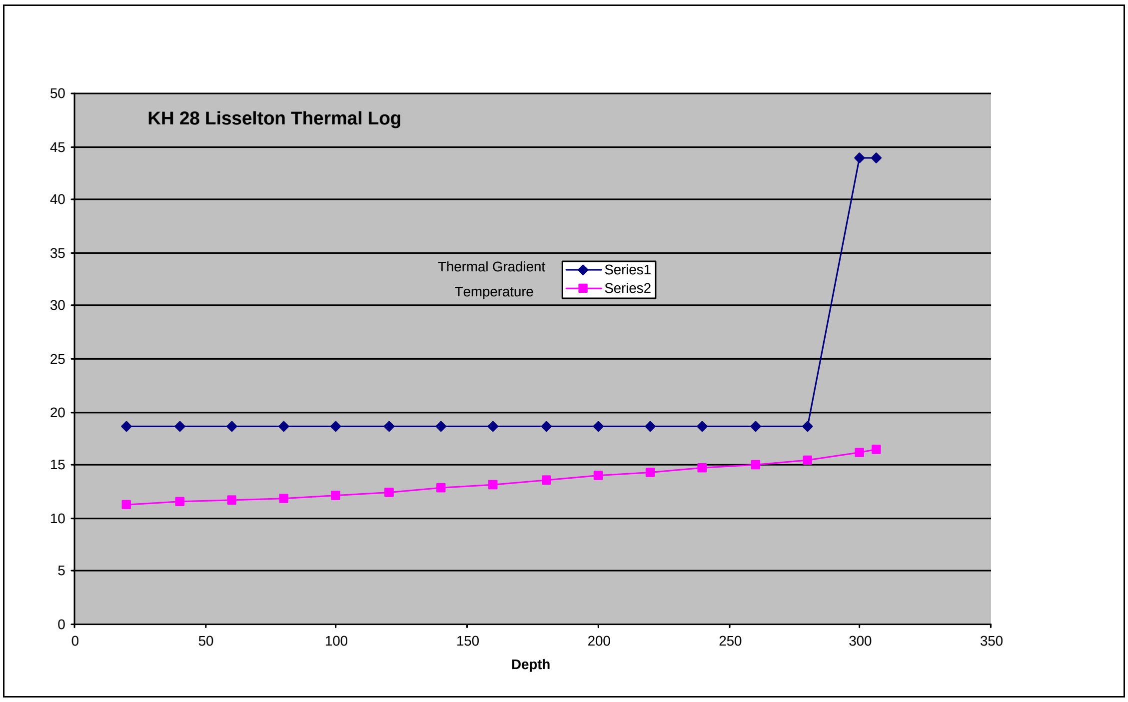

IBM 70 Crossakeel Thermal Log
30
25
20
15
10
5
0
-5
50
100
150
200
250
300
Thermal Gradient
Temperature
Series1
Series2
depth

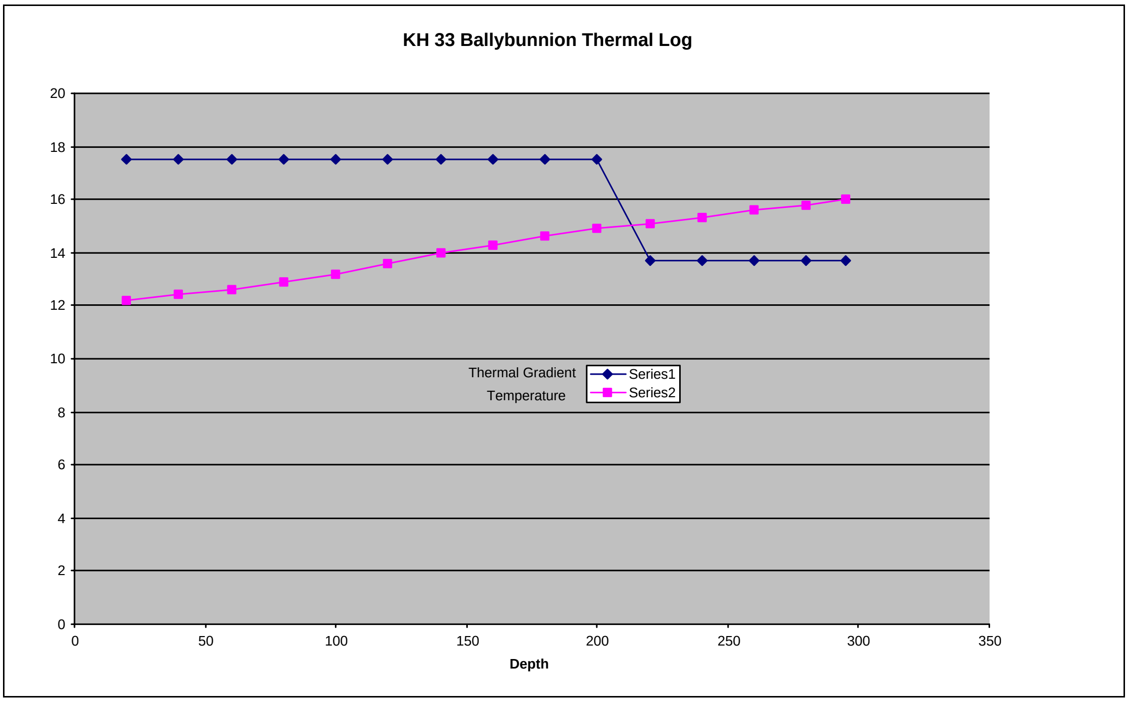

IBM 75 Kells Thermal Log
Thermal Gradient
Temperature
Series1
Series2
Depth
0
5
10
15
20
25
30
0
50
100
150
200
250
300
350
400

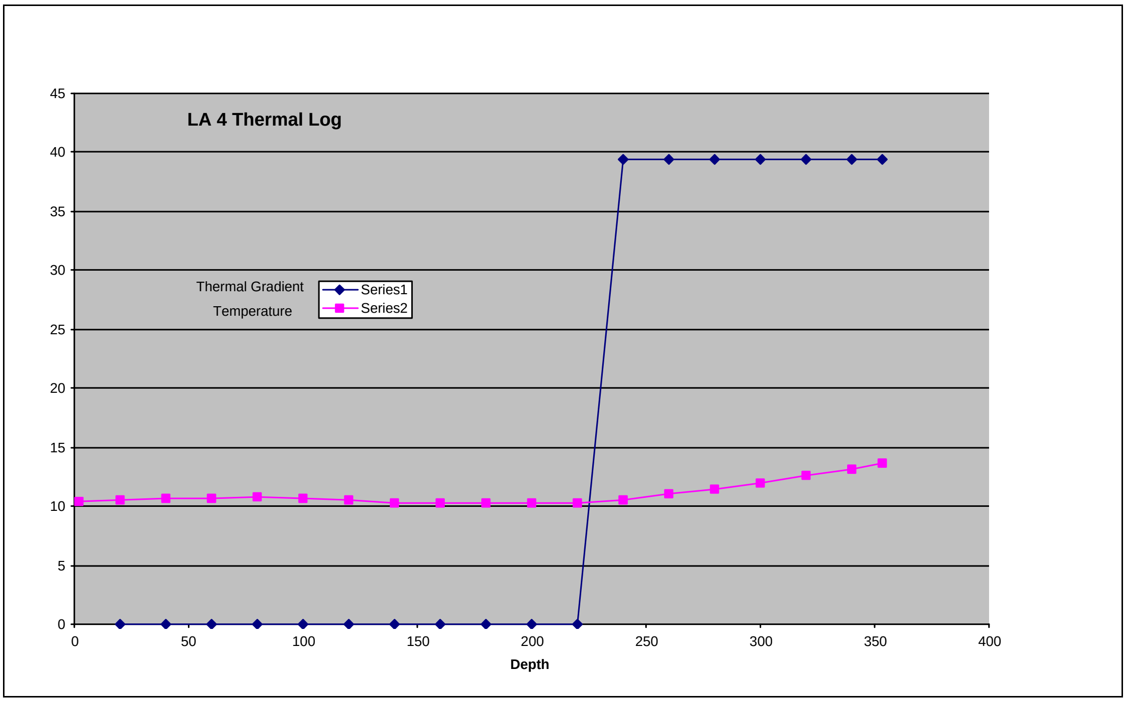

IPP I Doo Lough Thermal Log
Thermal Gradient
Temperature
Series1
Series2
Depth
0
5
10
15
20
25
30
35
40
0
50
100
150
200
250
300
350
400
450
500


IPP 2 Connolly Thermal Log
70
60
50
40
30
20
10
0
0
100
200
300
400
500
600
700
Depth
Thermal Gradient
Temperature
Series1
Series2

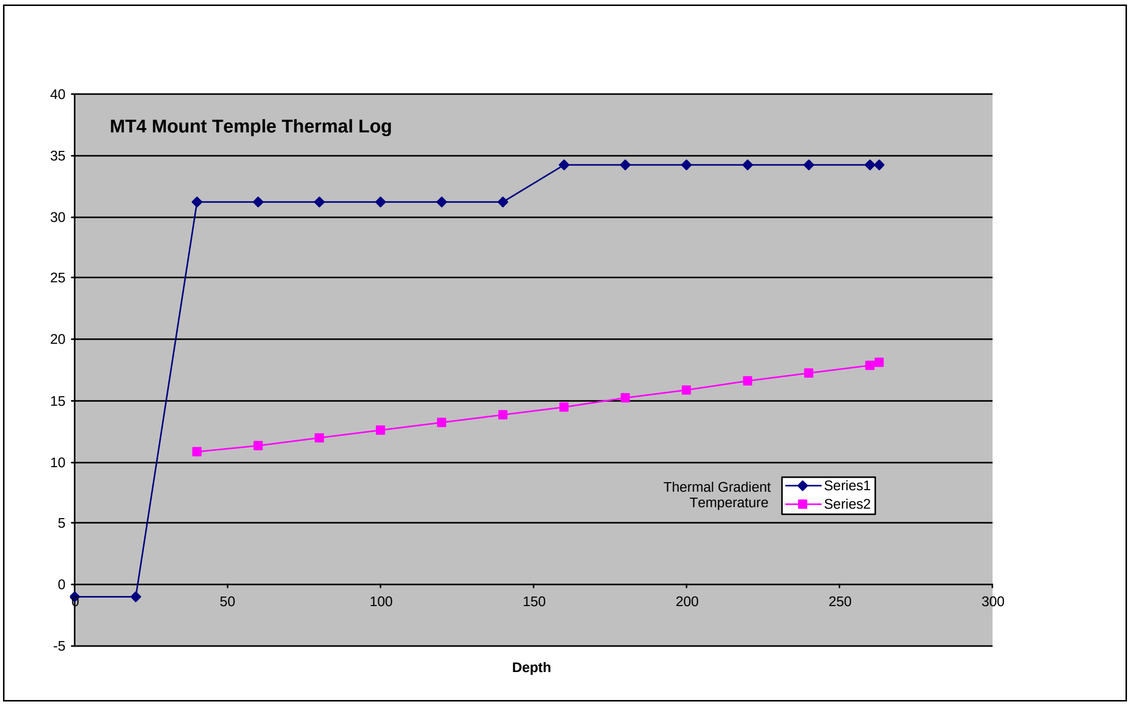

KD 140 Thermal Log
30
25
20
15
10
5
0
0
50
100
150
200
250
300
350
Depth
Thermal Gradient
Temperature
Series1
Series2


KH 28 Lisselton Thermal Log
Thermal Gradient
Temperature
Series1
Series2
Depth
0
5
10
15
20
25
30
35
40
45
50
0
50
100
150
200
250
300
350


KH 33 Ballybunnion Thermal Log
Thermal Gradient
Temperature
Series1
Series2
Depth
0
2
4
6
8
10
12
14
16
18
20
0
50
100
150
200
250
300
350



LA 4 Thermal Log
Thermal Gradient
Temperature
Series1
Series2
45
40
35
30
25
20
15
10
5
0
0
50
100
150
200
250
300
350
400
Depth



MT4 Mount Temple Thermal Log
Thermal Gradient
Temperature
Series1
Series2
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25
20
15
10
5
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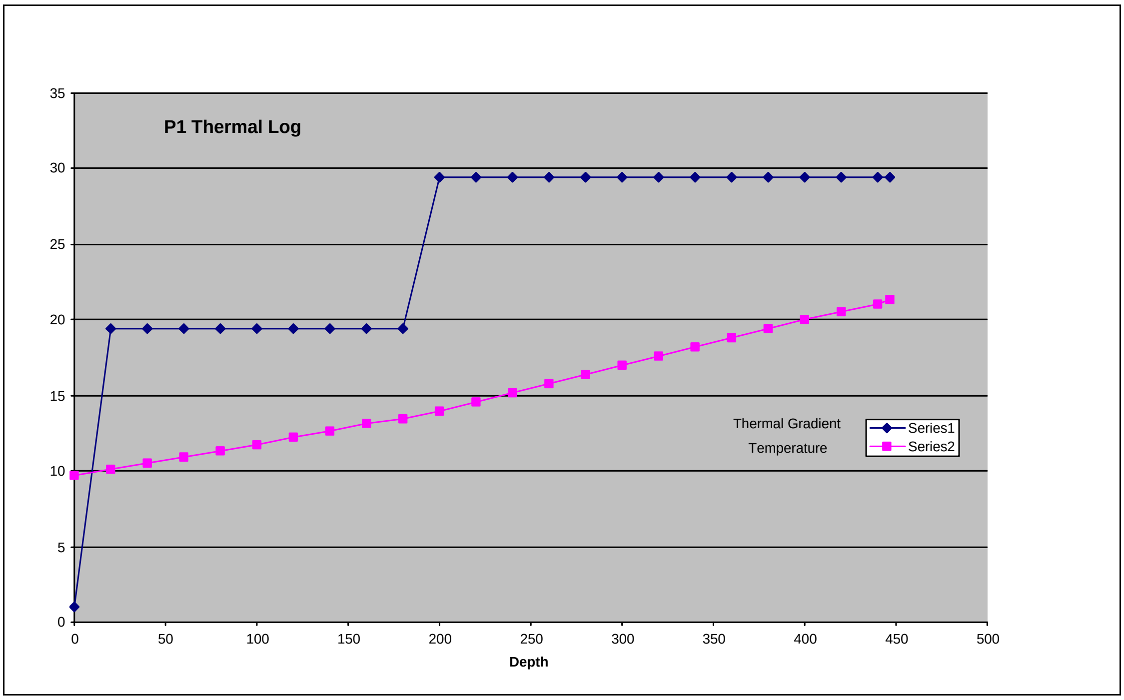
-5
0
50
100
150
200
250
300
Depth


P1 Thermal Log
Thermal Gradient
Temperature
Series1
Series2
Depth
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30
25
20
15
10
5
0
50
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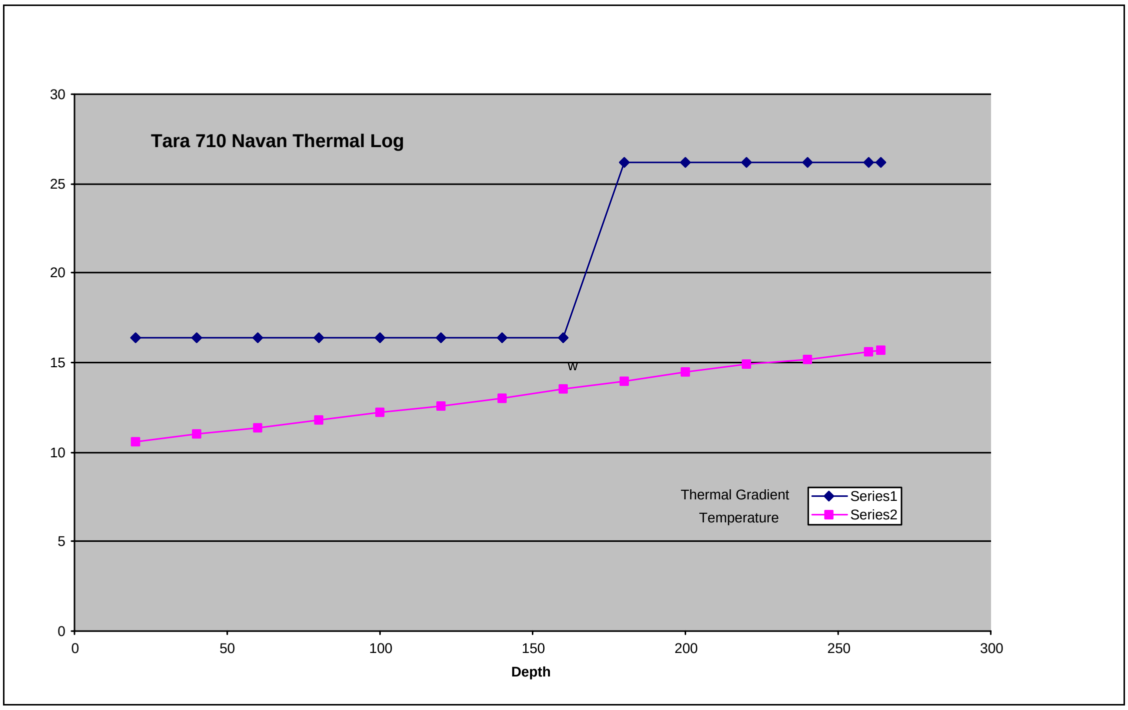
150
200
250
300
350
400
450
500


Tara 710 Navan Thermal Log
w
Thermal Gradient
Temperature
Series1
Series2
Depth
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25
20
15
10
5
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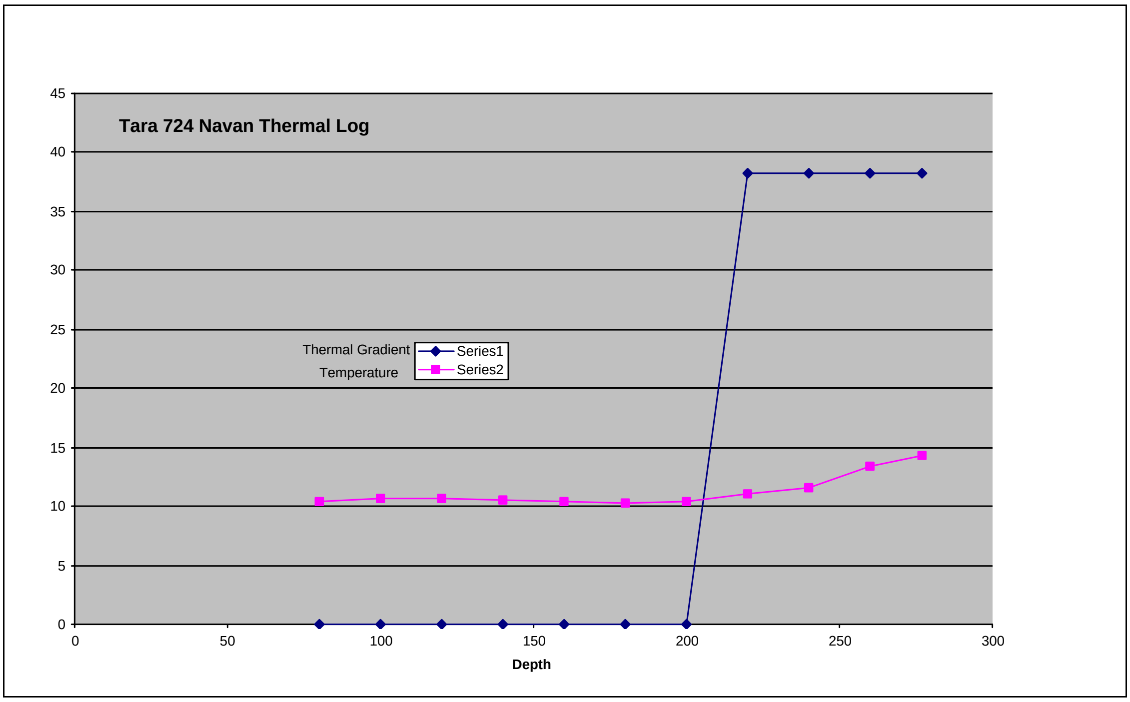
50
100
150
200
250
300

Appendix IV


Tara 724 Navan Thermal Log
Thermal Gradient
Temperature
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Series2
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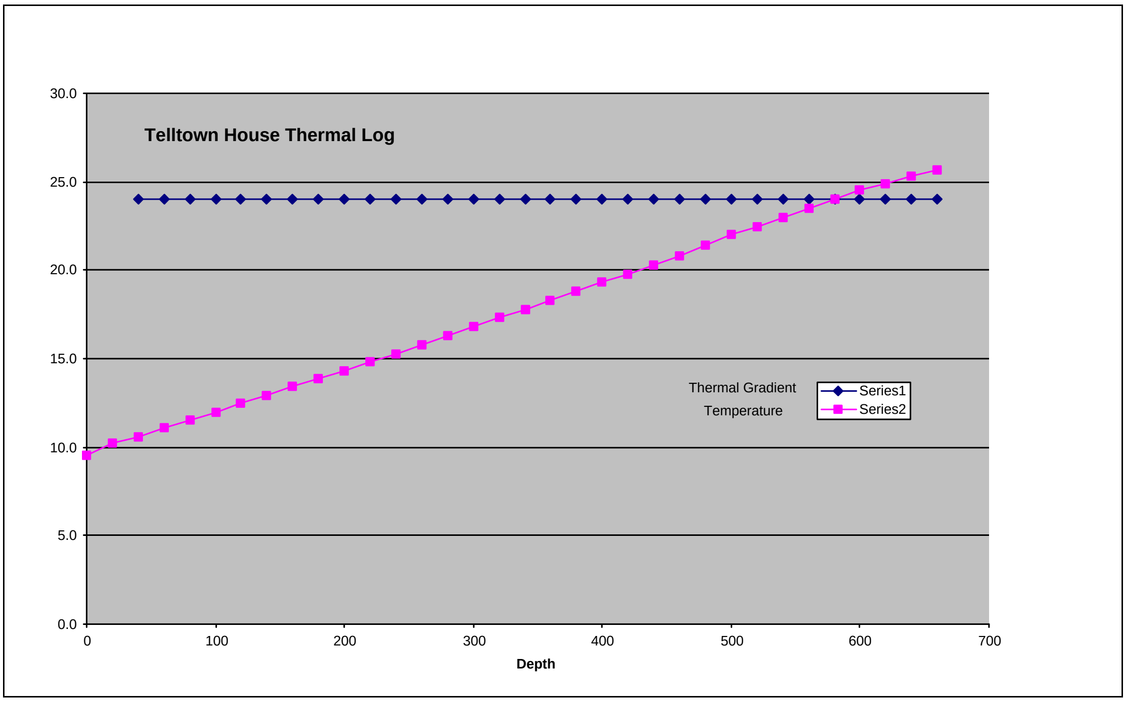
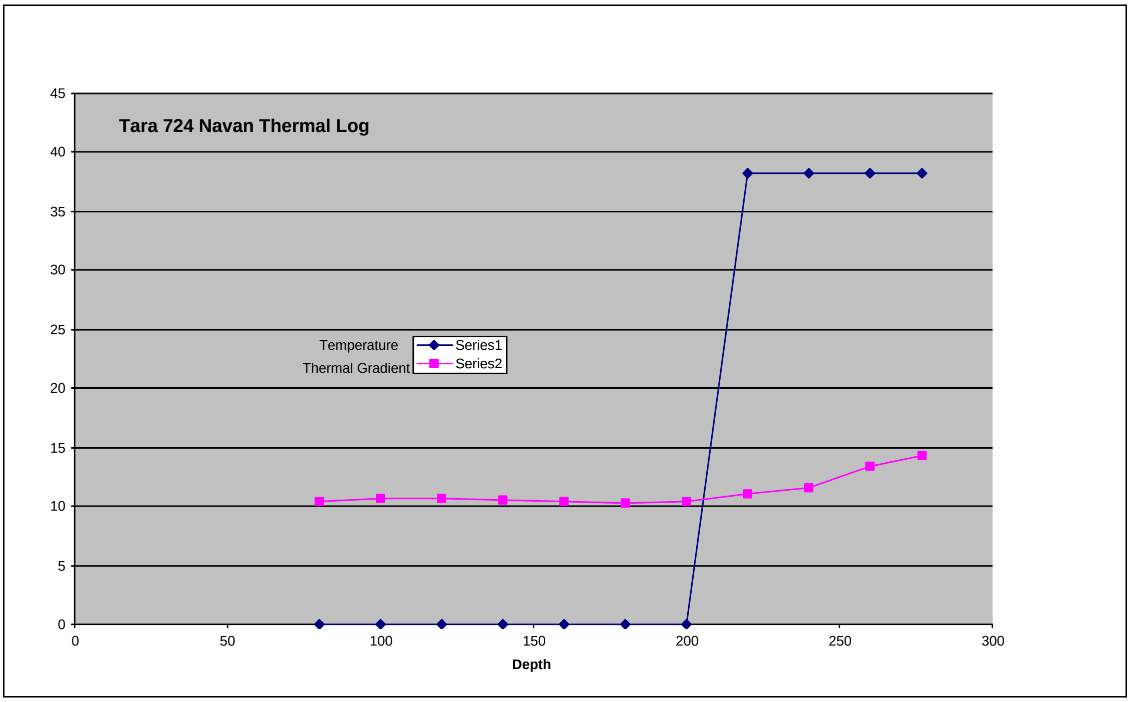
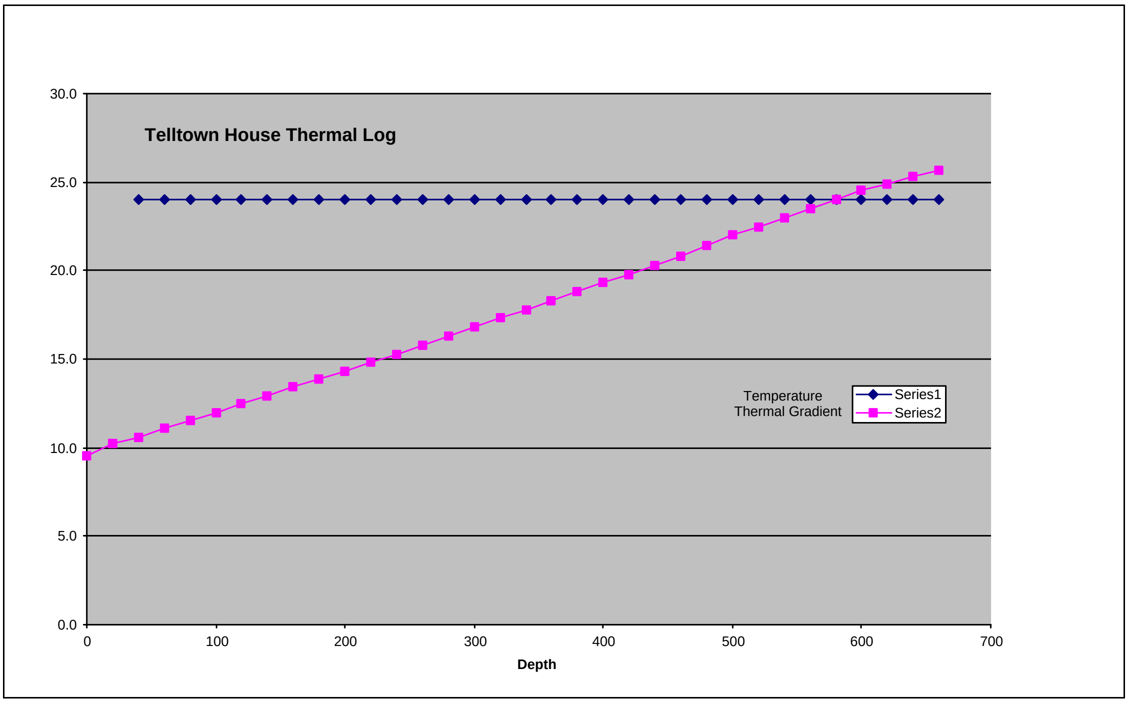
35
30
25
20
15
10
5
0
0
50
100
150
200
250
300
Depth


Telltown House Thermal Log
Thermal Gradient
Temperature
Series1
Series2
30.0
25.0
20.0
15.0
10.0
5.0
0.0
0
100
200
300
400
500
600
700
Depth


Tara 724 Navan Thermal Log
45
40
35
30
25
20
15
10
5
0
0
50
100
150
200
250
300
Depth
Temperature
Thermal Gradient
Series1
Series2


Telltown House Thermal Log
30.0
25.0
20.0
15.0
10.0
5.0
0.0
0
100
200
300
400
500
600
700
Depth
Temperature
Thermal Gradient
Series1
Series2

Appendix V:

Detailed Analysis of temperature monitoring results

Detailed analysis of temperature monitoring results

Boreholes monitored by CSA Group and used in deep (500m and deeper) modelling

The following contractions are used: EOH = end of hole, BHT = bottom hole temperature

00-468-5
Situated in southwest Co. Tipperary this borehole was monitored to a depth of 455m. The gradient is consistently low at 12.63ºC/km, which is interpreted to be the result of the combination of the thick development of partially dolomitized, and fractured Waulsortian together with the low regional geothermal gradients recorded in other boreholes in the southern midlands.

01-541-03
Monitored to a depth of 810m in southeast Co. Galway this borehole shows moderate geothermal gradients with a maximum gradient of 22.7ºC/km between 260m and 740m. The top of the borehole intersects Waulsortian from 153m to 310m and records low gradients interpreted to be the result of influx of surface water deep into the groundwater. The gradient drops off again to 12ºC/km for the basal 70m of the borehole within shales and sandstones at the base of the Carboniferous. This sudden drop in geothermal gradient is surprising considering the presence of sandstone but indicates that porosity and permeability in the area is not primary and is, in fact, fracture controlled. The fracture density is interpreted to be decreasing in the sandstones thereby resulting in decreased circulation. The basal gradient in this borehole has not been used in deeper estimates of geothermal gradient and temperature as it is very unusual for the area and may be localised.

02-1453-10
Monitored to a depth of 665m this borehole shows a surprisingly low geothermal gradient of 12.5ºC/km between 220 and 340m and a gradient of 22.9ºC/km from 340m to EOH. The geology here consists of relatively unfractured and uniform shaley limestone and therefore has a lower than expected geothermal gradient as there is no mechanism of circulation of deeper warm waters upward to continually warm these rocks. However it is postulated that below this unit there may be a sudden increase in gradient where heat has built up and not been transferred to the surface. This is based on a comparison with the well known phenomenon in oil-well drilling where non-conductive salt horizons exhibit anomalously low temperatures but below those units there is a sudden rise in recorded temperatures due to the build up of heat.

1226-28
Monitored to a depth of 329m this borehole records a maximum geothermal gradient of 17.9ºC/km. Predominantly in Waulsortian, such low geothermal gradients are again thought to indicate the effect of the influx of surface water along fractures or secondary porosity.

1439-3
Monitored to a depth of 525m in the North Meath area this borehole showed a geothermal gradient of 18.6ºC/km to a depth of 240m where it increased to 22.5ºC/km to a depth of 420m and then dropped back again to 16.3ºC/km to the base of the borehole. The geology is essentially constant throughout the borehole (Calp) and the reason for the drop in geothermal gradient is not clear. It may be the case that, as in the east Clare and southeast Co. Galway area, there is a levelling off of the geothermal gradient close to large Lower Palaeozoic buried

inliers (where there are no deep penetrating faults) and as we move north from the Navan area towards the Longford-Down, Lower Palaeozoic area the effects of this are being detected.

1450-1
Located in the Navan Mine area of Co. Meath this borehole was monitored to a depth of 580m. The gradient gradually increases to 24.5°C/km to 440m before dropping off to 21.5°C/km for the basal part of the borehole. The borehole intersects the same geological unit throughout. This decrease in gradient was considered sufficiently sustained to be real though the explanation is uncertain. It is considered possible that the sudden change from 440m downward is the result of fracturing increasing the influx of cold water from surface.

HB-63
Monitored to a depth of 457m the maximum gradient here is 18°C/km. Drilled mostly in Waulsortian and Waulsortian Equivalent lithologies it is considered that this borehole is showing colder temperatures than normal for the area and probably reflects cold surface water penetrating deep into the Waulsortian along fractures and dolomite related porosity and permeability. An adjacent borehole (HB-45 Allenwood) of similar depth shows geothermal gradients up to 39.6°C/km but was removed from the database because of uncertainty in extrapolation of these gradients.

PA-98-01
Monitored to a depth of 332.1m this borehole, located in east Co. Offaly, recorded temperature values indicating a gradient of 20.7°C/km between 120m and 240m and a gradient of 25.7°C/km between 260m and EOH. The comparatively high geothermal gradient at shallow depths may indicate some warm spring development. Located close to the Iapetus Sutur, connecting the warm springs of the Mallow/Glanworth area with the warm springs of the Meath/Dublin area, this borehole indicates there may be some continuity between these two areas parallel to the postulated position of the Iapetus Suture but offset to the east. Data from this borehole has been only used in extrapolation of temperatures and geothermal gradients to 1,000m as the higher gradient in the borehole was not considered sufficiently tested to extrapolate deeper. The geology of the borehole is shaley limestone (ABL) throughout and fracturing is thought to be a significant factor in water movement in the borehole.

RND-1
Located in northeast Co. Kildare this borehole was monitored to a depth of 537.8m from surface and shows lower than average geothermal gradients for the area. The geology of the area records the presence of Waulsortian lithologies at a depth of between 370m and 470m in the borehole. It is interpreted that this unit is fractured and/or dolomitized, resulting in increased permeability in the unit and therefore this is acting as a conduit for relatively cold surface water deep into the groundwater. This results in local reduction of the geothermal gradient and for this reason data from this borehole are only used in modelling of the less deep geothermal gradients and temperatures in the area.

Boreholes monitored by CSA and used in shallow (100m) modelling only

1629-66
Monitored only to 156m the geothermal gradient in this borehole decreases from 15°C/km between 20m and 159m to 13.75°C/km to EOH. Surface water penetrating along fractures is considered to affect the results here.

1439-2
Monitored to a depth of 244m this borehole shows a significant decrease from a geothermal gradient of 16.6°C/km between 60m and 120m to a geothermal gradient of 2.2°C/km for the base of the borehole. This data shows influence from cold surface water and is not consider reliable for deep extrapolation.

2872-1
Monitored only to a depth of 128m this borehole is not included in geothermal calculations at depth. However the geothermal gradient of 22.5°C/km between 100m and 128m is considered typical for this area.

3245-113
Monitored to a depth of 108.4m in the Galmoy Mine area of Co. Kilkenny, courtesy of Arcon Mines Ltd., this borehole shows a very low geothermal gradient of 7.5°C/km. Dewatering in the mine area is interpreted as causing increased flow of water towards the mine area and therefore more rapid movement of surface water to depth in the mine thereby decreasing groundwater temperatures and the geothermal gradient there.

3245-128
Monitored to a depth of 163m in the Galmoy Mine area and similar to borehole 3245-113 the low geothermal gradient here of 9°C/km is also interpreted as resulting from de-watering at the mine.

3248-1
Monitored to a depth of 342m and located in south County Roscommon this borehole shows a significantly lower than average geothermal gradient for this area of the north midlands throughout the section. The geology shows a succession through the limestones including the Oakport Formation which is typical of the area. The gradient increases slowly downward in a series of steps which is interpreted as resulting from the influx of surface (meteoric) water along fractures causing local distortion of the overall gradient. There may also be karst present, which is a common feature of the Oakport Formation and the associated lithologies in the area. The data from this borehole were not used in deep geothermal gradient estimates. It is also possible that the low geothermal gradients here may partly result from the lack of deep geothermal heat recharge due to the absence of deep penetrating faults as seen on the west side of the inlier where gradients are higher (ex. BB 82-4 Strokestown).

Ballinageragh/Charleville 2
Monitored to a depth of 30m this borehole records a geothermal gradient of 10°C/km which is not unusual for the area. The borehole is too shallow and the data are not used to extrapolate to depth.

BCDR-1
Monitored to a depth of 269m in Co. Offaly this borehole shows very low to moderate geothermal gradients, peaking at 17.4°C/km between 160m and 269m. This value has not been used in calculating temperatures and geothermal gradients at depth but is not unusual for the area.

CW-DOB-1
Monitored to a depth of 234.1m in the Galmoy Mine area, a maximum geothermal gradient of 22.9°C/km is considered a reasonable figure in an area where de-watering is taking place.

Though the value is somewhat low when compared with modelled values for the area and the data has not been used to extrapolate to depth.

DG-4
Only monitored to 54.6m, this borehole recorded a high geothermal gradient of 28.4°C/km. The borehole is too shallow and the data are not used to extrapolate to depth.

Johnstown/Mitchelstown test 1 & 2
This shallow borehole in north Co. Cork monitored to a depth of 42.25m records geothermal gradients between 58.8°C/km and 63°C/km. Though locally indicative of warm spring occurrence, they are considered as not representing the situation at depth. This is especially true when compared to drill tests in warm springs in the Mallow area where geothermal gradient decreases rapidly with depth.

LK-1389
Monitored from 129.5m to a depth of 225m, geothermal gradients in this borehole reach a maximum of 16°C/km but are not considered valid due to the location of the borehole in the de-watered zone of the Lisheen Mine.

LK-1411
Monitored from 160m to 270m all data in this borehole is considered an invalid due to de-watering at the Lisheen Mine.

LK-1429
Monitored from 117.8m to 221.7m this borehole records a basal geothermal gradient of 18°C/km which is considered reasonable for the area but is considered unreliable for deeper calculations of geothermal gradients. De-watering in the area of the mine has lowered the groundwater level to 117.8m.

NC-10
Monitored to a depth of 116m this borehole records low geothermal gradients of 15°C/km between 20m and 100m which are not unusual for this area but indicate influx of surface water along fractures.

P.Butler Clare
Monitored to a depth of 100m a very low geothermal gradient of 10°C/km is recorded here and is probably a reasonable value, however the data is not extrapolated to depth due to the shallow depth of the borehole.

SG-4
This borehole, located close to Hotwell House was monitored to a depth of 41m and records a very high geothermal gradient of 45°C/km. The geothermal gradient here is a localised effect of the warm spring and cannot be extrapolated to depth, as with the Glanworth and Mallow examples.

SG-7
Also located close to Hotwell House and monitored to a depth of 180m and geothermal gradient of 88°C/km is recorded in the top 20m but drops off to 10°C/km between 40m and 80m and to a 0°C/km from 80m to EOH.

Silvermines K Well 2
Located in Waulsortian and monitored to a depth of 45.5m, this borehole recorded a geothermal gradient of 8°C/km. The borehole is too shallow to be used for depth extrapolation.

TW-10
Monitored to a depth of 76.3m in the vicinity of Galmoy Mine this borehole records a low geothermal gradient of 6°C/km which is interpreted to be a result of the de-watering in the area.

Waterwell Louth 1
Monitored to a depth of 100m, this borehole records a geothermal gradient of 20°C/km. This is not particularly low for the area but it would be expected to increase at depth. For this reason and the fact that the borehole is relatively shallow the data are not used to extrapolate to depth.

Boreholes monitored by mineral exploration companies

Some of the companies involved in mineral exploration in Ireland have collected temperature data in drill-holes in Ireland as part of other down-hole surveys in boreholes particularly in surveys to measure the angle of dip and the azimuth of a borehole. Some of this data has been accessed through mining companies such as Outokumpu (now-Boliden) based in Navan, Co. Meath and other data from Arcon, Galmoy, Co. Kilkenny. This data has been incorporated into the database and has provided valuable additional temperature data.

Boliden (Outokumpu) data

Data from 13 boreholes was received from Outokumpu. A final list of 8 boreholes were used in the data modelling. Borehole dip deviations of up to 20° from vertical were recorded in some of the following boreholes. This amounts to a maximum elevation error of 30m for every 500m recorded. The lack of dip information for most of the other boreholes in the study meant that correction for this error would not be consistent and therefore no correction was applied.

134-02
Located in the east Co. Galway area and monitored to a depth of 658m by Tara Exploration, this borehole shows a consistent geothermal gradient of 11.6°C/km from 70m to 322m and a geothermal gradient of 19°C/km from 322m to 526m where it drops to 17.5°C/km to the EOH. Gradients are quite variable in this part of the country due to extensive development of karst related to aquifers near surface (ref. aquifer map) causing local reduction in geothermal gradients.

3488-13
Monitored to a depth of 774m by Tara Exploration this borehole shows a slowly increasing gradient from 13.1°C/km at surface to a max of 16.6°C/km from 408m depth to the EOH. The borehole cuts through Waulsortian from collar to a depth of 767m and this is considered to result in the low geothermal gradients as the Waulsortian is providing a direct conduit for cold surface recharge and is dampening the effect of the geothermal gradient.[1]

[1] Waulsortian in a confined aquifer situation can allows the percolation of water from warmer depths upward, thereby increasing the apparent geothermal gradient.

580-6
Monitored to a depth of 391m by Tara Exploration the geothermal gradients in this borehole are low, starting at 6.4ºC/km to a depth of 223m where they increase to 15.6ºC/km to EOH. From data collected from other boreholes throughout the mid-lands the presence of Pale Beds from 141m to 362m is likely to cause a local decrease of values in the area.

NO1256
Monitored from 875m to a depth of 1550m in the Navan area of Co. Meath by Tara Exploration, this borehole shows a consistently high gradient of 28.4ºC/km from 884m to 1541. The geology of the borehole is mostly Upper Dark Limestones and, as for borehole NO1588, it also recorded high geothermal gradients in this unit which seem to be directly related to the location of the boreholes in this area, close to and intimately connected to major faulting, at the southern side of the Longford-Down Lower Palaeozoic Inlier.[2]

NO1588
Located in the Navan area, this borehole was monitored to a depth of 1068m by Tara Exploration. Data is only available from 379m to the base of the borehole and a high geothermal gradient of 32ºC/km is recorded at the top (379-478m) of the monitored zone. This gradient rapidly decreases to 22.2ºC/km between 487m and 703m, from 478m - 811m it increases to 25.25ºC/km but drops off again to 18.5ºC/km at 811m to the base of the borehole. As with borehole NO1617, the basal low geothermal gradient coincides with the position of the Pale Beds unit and reflects some increase of the influx of surface waters there[3],[4].

NO1595
Monitored to a depth of 1241m by Tara Exploration from the same collar as borehole NO 1630, this borehole shows a consistent geothermal gradient of 21ºC/km from 100m to 827m where it increases to 32ºC/km but drops back again to 21.6ºC/km at 1070m to the base of the borehole. The 250m of high gradient in the borehole coincides with the presence of Waulsortian between 919m and 997m and also Shaley Pales between 1035m and 1042m. Pale Beds are present between 1042 and 1239m. This pattern of geothermal gradient again reflects the previously observed effect of the Waulsortian and the Shaley Pales causing a local increase in the geothermal gradient and the Pale Beds causing a decrease. Higher porosity and permeability in the former units may be the result of dolomitization or fracturing. As seen before close to the surface, this increased fracturing and/or porosity and permeability can result in a local decrease in the geothermal gradient due to infiltration of cold surface water into the groundwater.

NO1617
Located in the Navan area of Co. Meath, this borehole was monitored to a depth of 981m by Tara Exploration. Data in this borehole show a gradient of 18.5ºC/km to 306m, where it

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[2] Data monitored by Tara Exploration gives consistently higher values than recorded by CSA in adjacent bore-holes. This is partly the result of the different thermometers used. An attempt to calibrate one of the thermometers used by Tara was only partly successfully (as the bore-hole was blocked) but showed a higher value for the Tara instrument by 0.8 – 1.0ºC. No correction is applied as 1ºC is within the error of the data.
[3] Silica rich rocks are more conductive than limestones but apparent conductivity, measured as water temperature, can be primarily controlled by fracture density, porosity and permeability of the rocks rather than the inherent conductivity of the lithology.
[4] Data from Tara Exploration indicates that two dip meters with different thermometers recorded the same drop off in temperature in the Pale Beds unit in bore-hole NO1588.

increases to 24.5°C/km and continues to 855m. The gradient then drops back to 18.5°C/km for the base of the borehole. This indicates that the presence of Pale Beds lithologies result in a reduced geothermal gradient, possibly as a result of decreased water flow, resulting in decreased conductivity and therefore a localised cooling in the area.

NO1630
Monitored to a depth of 1263m by Tara Exploration in the Navan Mine area from the same site as NO1595 but deviated slightly, this borehole shows a consistent geothermal gradient of 22.6°C/km from the top of the borehole to 957m where it temporarily jumps to 44°C/km for 40m before returning to 22.6°C/km to EOH. Waulsortian is present from 922m to 974m and is thought to account for the sudden increase in geothermal gradient.[5] Below the Waulsortian the geothermal gradient values are constant despite the presence of Pale Beds from 1032m to EOH which normally results in lower geothermal gradient values, as in boreholes 580-6, NO1617, NO1588 and NO1595.

Additional new data from other sources

BG4
Monitored to a depth of 500m by F.X. Murphy and UCC (Murphy and Brück 1989) to investigate the deeper parts of the warm springs at Ballynagoul. The low geothermal gradient of 10°C/km from 300m to EOH is a typical geothermal gradient for the area.

Camus No. 1
Monitored to a depth of 125m during studies for heat-flow density by the Applied Geophysics Unit of UCG, this borehole records a geothermal gradient of 26°C/km from 10m to 125m. This indicates an encouragingly high temperature for the Galway Granite and reflects the heat flow values interpreted for parts of the Galway granite in work carried out by Brock and Barton (1988b).

Glangevlin GW3
Monitored to a depth of 56.1m by Minerex, a maximum geothermal gradient of 22°C/km is recorded for this borehole. This is not an unusual gradient for this area but is not extrapolated at depth due to the shallow depth of the borehole.

Mallow Mart Borehole
Monitored to a depth of 500m by F.X. Murphy and UCC (Murphy and Brück 1989) to investigate the deeper potential of the warm springs at Mallow, this borehole recorded a geothermal gradient of 5°C/km from 140m to 500m. This is an even lower than average geothermal gradient for the area, which is more commonly 10 – 12°C/km. The low value recorded here is the result of the higher than normal surface temperatures masking the real increase in temperature with depth.

Quinagh Borehole
Monitored to a depth of 216m by the GSI, this borehole records an overall geothermal gradient of 10°C/km. This value is average for the area and helps define the southern limit of the higher geothermal gradients to the north but is not used directly to model geothermal gradients at depth, because the borehole is too shallow.

[5] Waulsortian located at depth can increase the temperature and apparent gradient, whereas near surface it can cause local cooling.

Boreholes monitored in the previous study by Minerex Ltd.

025-2 Rathkeale
Drilled to a depth of 541m this borehole in Co. Limerick has a moderate geothermal gradient with a gradual increase to a maximum of 17°C/km. This is not untypical of the south of Ireland where gradients are generally lower than further north.

109 Ballinalack
Monitored to a depth of 307m, this borehole shows a very high geothermal gradient of 35.4°C/km from 120m to EOH. This represents a localised 'hot spot' for the area, where values are normally in the range of 20 -25°C/km.

1226-10-Moate
Monitored to a depth of 740m, this borehole shows a high gradient of 30.6°C/km between 320m and 740m. This high value is relatively consistent with values to the east in borehole 109 Ballinalack and to the southwest in borehole P1 Shannonbridge. The northeast-southwest Caledonian trend indicated here seems real despite the bias in the data resulting from temperatures only being available in boreholes in the northeast-southwest trending Carboniferous basins.

2685-2 Killimor
Monitored to a depth of 395m, this borehole shows an increase from a low geothermal gradient of 9.8°C/km between 20m and 200m to 31.8°C/km in the lower part of the borehole. The high gradient is consistent with values seen in other boreholes in this area (P1 Shannonbridge etc.) and is therefore considered reliable.

Ballina BA1
Monitored to a depth of 480m and the only borehole in the Co. Mayo area, this borehole is therefore extremely important in the prediction of the geothermal gradients for the region. However the values here are disappointing with a gradient of 9°C/km between 80m and 280m increasing to 20°C/km from 300m to EOH. The increased lower geothermal gradient is somewhat encouraging, but because of the scarcity of data in the west and northwest, this geothermal value strongly influences the predicted values for the whole region.

Ballykane Hill DDH 2
Monitored to a depth of 261m, the low geothermal gradients (maximum 15.8°C/km between 100m and 261m) is considered to be the result of the influx of surface water through porosity/fractures into the ground water, especially when compared with some of the higher values in the area. For this reason and the shallow depth of the borehole the data have not been used in calculations of deeper geothermal gradients in the area.

BB 82-4 Strokestown
Monitored to a depth of 334m this borehole records a geothermal gradient of 20°C/km between 20m and 200m, below which it increases to 26.7°C/km to EOH. Situated on the west side of the Strokestown Inlier and adjacent to the inlier boundary fault, it is considered that this is a valid high geothermal value for the area and indicates continuation of these faults deep into the crust.

BR1 Cloghan
Monitored to a depth of 475m, this borehole records an extremely high geothermal gradient of 45.2°C/km between 80m and 220m. The lower value of 27°C/km between 240m and 475m in the borehole is a very encouraging geothermal gradient for the area and confirms the region as being highly prospective in terms of geothermal potential.

CB1 Courtbrown
Monitored to a depth of 366m, the maximum geothermal gradient in this borehole of 22.9°C/km between 140m and 366m is typical of the area and marks the zone of transition from very low geothermal gradients in the south and the warmer areas of west Co. Clare.

CL82-2
Monitored to a depth of 736m, the variable geothermal gradients in this borehole show a high gradient of 39.2°C/km between 500m and 620m decreasing suddenly to 13.1°C/km to EOH. An average geothermal gradient value of 21.6°C/km is possibly more accurate for the borehole. However in the interests of consistency the lower geothermal gradient of 13.1°C/km has been used to extrapolate to depth.

DM-49 Moate
Monitored to a depth of 500m, the geothermal gradient in this borehole increases from 10.6°C/km between 20m and 200m to 31.2°C/km from 200m to EOH. The high geothermal gradient towards the base of the hole is consistent with the northeast trend seen in the area from other measurements.

EP26 Tara
Monitored to a depth of 744m, the low geothermal gradient of 14.2°C/km recorded from 20m to 140m depth increases to 34°C/km at 160m and continues to EOH. This is a very high value but is not considered un-typical of the Navan area.

EP 27 Tara
Monitored to a depth of 745m, the very varied geothermal gradient values in this borehole are considered to be locally anomalous (i.e. geothermal gradient values of 38 – 70°C/km). The more stable geothermal gradient of 26.1°C/km from 540m to EOH is used as a conservative value to extrapolate to deeper levels, as it is lower than many of the values in surrounding boreholes.

HB-45 Allenwood
Monitored to a depth of 423m, a very high geothermal gradient value of 39.6°C/km is recorded from 200m to 400m followed by a sudden drop to 5°C/km from 400m to 422m. The area generally has a high gradient but this value is not considered to continue to depth and is not used for deeper extrapolation.

IBM 26 Kells
Monitored to a depth 230m, the moderate geothermal gradient of 22.4°C/km recorded in the borehole is considered close to what is expected for the area but is not used for deeper extrapolation due to the shallow depth of monitoring here.

IBM 70 Crossakeel
Monitored to a depth of 271m, the geothermal gradient in this borehole slowly increases from 21.2°C/km between 20m and 120m to 27.8°C/km between 140m and 271m. The geothermal gradient values here have not been used for deeper extrapolation due to the shallow depth of

the borehole. If this is a real geothermal gradient it would result in an increase in the area of high geothermal gradients between Navan and Ballinalack along the south side of the Longford-Down, Lower Palaeozoic Inlier. This may be a possibility and may indicate the extension of some of the inlier controlling faults into this area.

IBM 75 Kells
Monitored to a depth of 338m, this borehole records a maximum geothermal gradient of 24.2ºC/km between 160m and 337.7m. This confirms the values generally found in this part of the north midlands, south of the Lower Palaeozoic Inlier.

Keel KD 140
Monitored to a depth of 321m, geothermal gradients in this borehole increase from 13.6 to 24ºC/km at 160m, the lower of which is considered moderate for the area. The position of the Keel area adjacent to the Lower Palaeozoic and close to major faults indicates that high geothermal gradients would be expected to continue at depth in this area.

KH 28 Lisselton
Monitored to a depth of 306m, a geothermal gradient of 18.6ºC/km is present from 20m to 280m followed by a sudden increase to 44ºC/km at 300m to EOH. The low geothermal gradient value of 18.6ºC/km is not unusual for the area and is considered more indicative than the higher value.

KH 33 Ballybunnion
Monitored to a depth of 295m, the geothermal gradient in this borehole decreases from 17.5ºC/km between 20m and 200m to 13.7ºC/km between 200m and 295m. This may be the result of fracturing / porosity in the limestones or may in fact be real, but the data is not considered reliable for extrapolation to depth due to the shallow depth of the borehole.

LA4 Loughrea
Monitored to a depth of 353m, this borehole records a very high geothermal gradient of 39.4ºC/km between 240m and 353m which is considered to be a factor, of the abnormally low temperatures encountered at the top of the borehole, causing an apparent sudden increase deeper in the borehole. This may be the result of karst at the top of the borehole and therefore the data is not considered reliable for extrapolation to depth.

MT4 Mount Temple
Monitored to a depth of 263m, this borehole records a geothermal gradient of 31.2ºC/km from 40m to 140m and a geothermal gradient of 34.2ºC/km from 160m to 263.2m. These geothermal values are very similar to those seen in P1 Shannonbridge to the south and seem to be accurate. However the data has not been used in deeper extrapolations of geothermal values due to the shallow borehole depth.

P1 Shannonbridge
Monitored to a depth of 447m, this borehole shows a strong increase from a geothermal gradient of 19.4ºC/km between 20m and 180m to 29.4ºC/km between 200m and 446.5m. The occurrence of high geothermal gradients along a northeast trend in the area allows the interpretation that they are valid and therefore a good guide to geothermal gradients at depth.

Tara 710 Navan

Monitored to a depth of 264m, this borehole records an increasing geothermal gradient from 16.4°C/km down to 160m to 26.2°C/km between 180m and EOH. This is typical for the area around Navan, but is not used at depth as it is shallow and there are plenty of other boreholes in the area for modelling at depth.

Tara 724 Navan
Monitored to a depth of 277m, this borehole records a 0°C/km gradient down to 200m and suddenly jumps to 38.2°C/km to EOH. The depressed upper geothermal gradient results in the sudden increase recorded at depth and, coupled with the relatively shallow depth of the borehole, the data are considered suspect and not used to extrapolate to depth.

Telltown House
Monitored to a depth of 660m, a consistent geothermal gradient of 24°C/km in this borehole is considered a reliable indication of the geothermal gradient in this area.

Appendix VI:

Geology and Location maps

CONTENTS:

It should be noted that all maps produced for this study are potential maps only and cannot be used as definitive measurements of temperature and gradient except at the point where readings are taken.

Appendix VII: Modelled Temperature Maps

CONTENTS:

It should be noted that all maps produced for this study are potential maps only and cannot be used as definitive measurements of temperature and gradient except at the point where readings are taken.

Erratum: In using the information tool in Mapinfo with the following maps please note that the borehole base temperature for borehole Drumkeeran 1 should be 72.35°C, for borehole Johnstown Mitchelstown test 2 it should be 23.5°C, for NO1588 it should be 30.5°C, for Glenoo No. 1 it should be 54.4°C and for Owengar No. 1 it should be 52.78°C.

Appendix VIII:

Modelled Geothermal Gradient Maps

CONTENTS:

It should be noted that all maps produced for this study are potential maps only and cannot be used as definitive measurements of temperature and gradient except at the point where readings are taken.

Erratum: In using the information tool in Mapinfo with the following maps please note that the borehole base temperature for borehole Drumkeeran 1 should be 72.35°C, for borehole Johnstown Mitchelstown test 2 it should be 23.5°C, for NO1588 it should be 30.5°C, for Glenoo No. 1 it should be 54.4°C and for Owengar No. 1 it should be 52.78°C.

Appendix VIII

Appendix IX:

Modelled Temperature and Geothermal Gradient Maps - Measured Data

CONTENTS:

It should be noted that all maps produced for this study are potential maps only and cannot be used as definitive measurements of temperature and gradient except at the point where readings are taken.

Erratum: In using the information tool in Mapinfo with the following maps please note that the borehole base temperature for borehole Drumkeeran 1 should be 72.35°C, for borehole Johnstown Mitchelstown test 2 it should be 23.5°C, for NO1588 it should be 30.5°C, for Glenoo No. 1 it should be 54.4°C and for Owengar No. 1 it should be 52.78°C.

Appendix X:

Modelled Heat Flow Density Map - Measured Data

CONTENTS:

It should be noted that all maps produced for this study are potential maps only and cannot be used as definitive measurements of temperature and gradient except at the point where readings are taken.

Appendix XI:

Glossary of Technical Terms

Glossary of Technical terms

Aquifer	Water-bearing strata with porosity and transmissivity / permeability.
Asbian Reef	Similar massive limestones to the Waulsortian, but younger in age.
Basinal limestones	Limestones formed id deep water, usually by shallow shelf sediments which have "avalanched" down. Usually have a coarse fossiliferous base to the bed grading up to a muddy barren top.
Carboniferous	The time period extending from 345 to 280 million years ago and represented by thick limestone and carbonaceous shale deposits in the Irish midlands.
COP	Co-efficient of Power. Kilowatts of heat out / Kilowatts of electricity in.
Dalradian	The youngest stratigraphic division of the Precambrian in Ireland represented by metamorphosed sediments in the northwest of Ireland.
Devonian	The time period extending from 395 to 354 million years old and part represented by the Old Red Sandstone mostly in the south of Ireland.
Dolomite	Limestone rocks with >15% magnesian limestone. The introduction of magnesium into limestone results in creation of porosity and can therefore be an indicator of aquifer potential.
Drill Stem Test (DST)	A production test carried out during oil well exploration drilling to test for the presence of oil or gas.
Earths Crust	The upper layer of the earth (25 – 32km thick) which forms the mountains and underlies the oceans.
Evaporites	A sediment resulting from the evaporation of saline water. It consists of such minerals as kainite, carnallite, sylvite, halite, gypsum, anhydrite, calcite, dolomite.
Fault	A fracture in rock with an observable amount of displacement.
Fracture	A break in rock generally without displacement.
Geothermal gradient	Also referred to as 'heat gradient'. Rate of increase of temperature in the earths crust with depth. Average gradient in the earth is 30°C/km.
Geothermal	Heat produced within the earths crust by convection from the deeper high temperature areas and through radioactive decay.
Granite	A coarse grained igneous rock consisting of quartz (20 – 40%) and other minerals (Feldspar, Mica, Apatite, Zircon, Magnetite).
Ground-water	Water occupying openings, cavities and spaces in rocks. The upper surface in the rock and/or sediment is known as the Water Table.

Heat Flow	The rate at which heat is lost from the inner zones of the Earth to the atmosphere.
'Hot spot'	Defined for this study as any area with regionally anomalous temperatures – actual temperature is not relevant.
Hydrogeology	The study of the geological factors relating to ground-water.
Iapetus Suture	The name given to the position of the rifting that opened and created the Iapetus Ocean. This was a relatively short lived ocean which closed again along a line, crossing Ireland with a northeast southwest trend extending between Dundalk and Limerick.
Igneous	Rocks derived from a molten source, they are either Extrusive Volcanic or Intrusive rocks.
Inlier	Older rock outcropping in an area surrounded by younger rock.
Intrusive	Molten rock which has been forced into pre-existing rocks and which does not reach the surface.
Karst	Distinctive landforms of dry valleys, caves and underground channels that develop in limestones which are readily dissolved by water and thus result in open fractures with rapid water conductivity.
Kiltorcan Formation	Coarse-grained white-yellow sandstone, mud-flake conglomerate, red-yellow flaggy sandstone, green silty mudstone and green mudstone, up to 400m thick. It is of uppermost Devonian age, about 355 million years old.
Limestone	Rocks composed primarily of calcium carbonate($CaCO_3$) and and/or dolomite.
Lithology	Technical term for the phrase 'rock type' which refers to the general characteristics of the rocks. The term is usually but not exclusively used for sedimentary rocks.
Lower Palaeozoic	The time period extending from 600 to 345 million years old and present in Ireland mostly in the Wicklow/Wexford, Longford/Down and Mayo areas.
Matrix	When a rock is composed of large grains (of any size), the smaller material that fills in the spaces is known as the matrix.
Metamorphism	The process of heat and/or pressure which alters pre-existing rocks.
Meteoric water	Water which penetrates rocks and sediments from above, i.e. from rain, hail, sleet, snow and the water in streams and rivers.
Namurian	A stratigraphic stage name for the base of the European Upper Carboniferous, rocks about 325 to 310 million years old.

Oakport Limestone	The O. L. Formation is a massive pale grey peloidal wackestone and grainstone limestone, generally shale-free, except for minor intervals of calcilutite and dark shale.
Palaeo-	A prefix to denote events or rocks that are ancient or of past times.
Pale Beds	Sandy, skeletal, oolitic and intraclastic calcarenites, micrite and shales, some 200m thick in the north Midlands. Informal name for the Courceyan Meath Formation.
Permeability	A term applied to rock when it possesses small cavities along which water can pass (often denoted as 'k' and measured in milledarcies).
Porosity	A term applied to rock when it possesses cavities between the mineral grains which can contain water. Fracturing of rock can cause secondary porosity.
Sandstone	A sedimentary rock composed of particles between 0.06mm and 2mm diameter and usually >75% quartz. The term sandy is also applied to limestones with grains within the range of sandstone grain size.
Sedimentary basin	Regional depression in which sedimentary strata are deposited. A modern example is the Mediterranean Sea basin. An ancient example is the Carboniferous limestone basin of the Irish midlands.
Sediments	Material which accumulates at the bottom of water in oceans, lakes, rivers, etc. Also material which accumulates in many other ways such as in deserts and mountains, also from volcanoes and glaciers.
Seismic waves	An earthquake or explosion or impact produces shock waves which travel through the ground. These can be measured and lead to an understanding of the nature of the ground.
Shale	Fine grained clay rich rock with well defined bedding planes and generally has no porosity and is impermeable.
Shaley Pales	A sequence of shale, sandstone and limestone beds, some 110m thick. Informal name for the Courceyan Moathill Formation.
Shelf Limestones	Fossiliferous well-bedded limestones formed in shallow, often warm, seas.
Sherwood Sandstone	A 300m to 650m thick sequence of Triassic, pink to reddish-brown sandstones, with silty sandstone and brown mudstone, occuring in the north-east of the island, about 250 to 235 million years old.
Siltstones:	A sedimentary rock composed of fine particles, 0.002 to 0.06mm in size, between a mudstone and sandstone
Soil	This is the accumulation of loose weathered material overlying bedrock or older partly consolidated material. It consists of three layers: two horizons of the soil proper and the subsoil. The top A horizon of the soil proper is

	strongly leached and contains much organic matter in its upper part. The bottom B horizon consists of clay and silt where the leached Ca, Fe and other minerals are deposited. The underlying C horizon or subsoil consists of partly weathered and/or shattered rock.
Stratigraphy	The study of stratified rocks, especially their sequence in time, the character of the rocks and the correlation of beds in different localities.
Thermal Conductivity	The ability of heat to pass through rocks, measured in $Wm^{-1}K^{-1}$ or Watts per metre per degree Kelvin
Triassic	The time period extending from 225 to 190 million years ago and part represented by the Sherwood Sandstone in Northern Ireland.
Upper Limestone	An old term for the younger Viséan limestones above the Waulsortian limestones
Variscan	A mountain building event 300 million years ago affected Europe, Britain, Ireland and North America. It's effects are especially seen in the folded and faulted rocks of Munster. Also known as the Hercynian).
Viséan	A stratigraphic stage name for the top of the European Lower Carboniferous, from 345 to 325 million years in age.
Volcanic	To do with molten rock extruded onto the surface
Vug	A cavity in a rock usually with a lining of crystalline minerals, a term especially of cavities in mineral veins
Vugular porosity	Porosity in a rock caused by the connectivity of the contained vugs.
Water Table	The upper surface in the rock and/or sediment of the groundwater saturation.
Waulsortian	Term used for Carboniferous aged limestone mud mounds which have little stratification and internal structure and when karstified or dolomitised form significant aquifers.
Wireline	During drilling procedures, a wireline is used to recover the material drilled from the bottom of the hole, without having to withdraw the whole drilling set-up each time.

Appendix XII:

Recent Source Data

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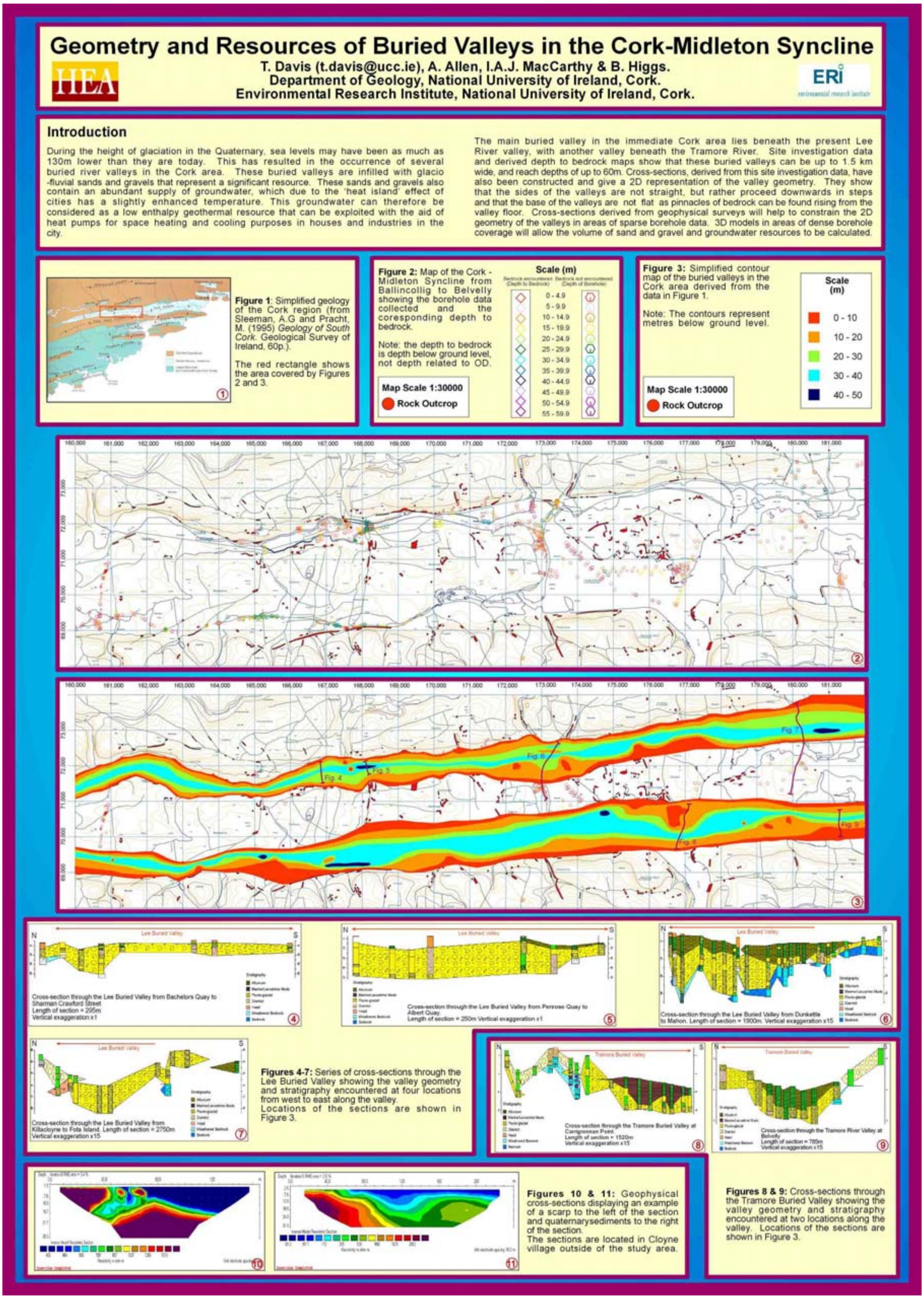
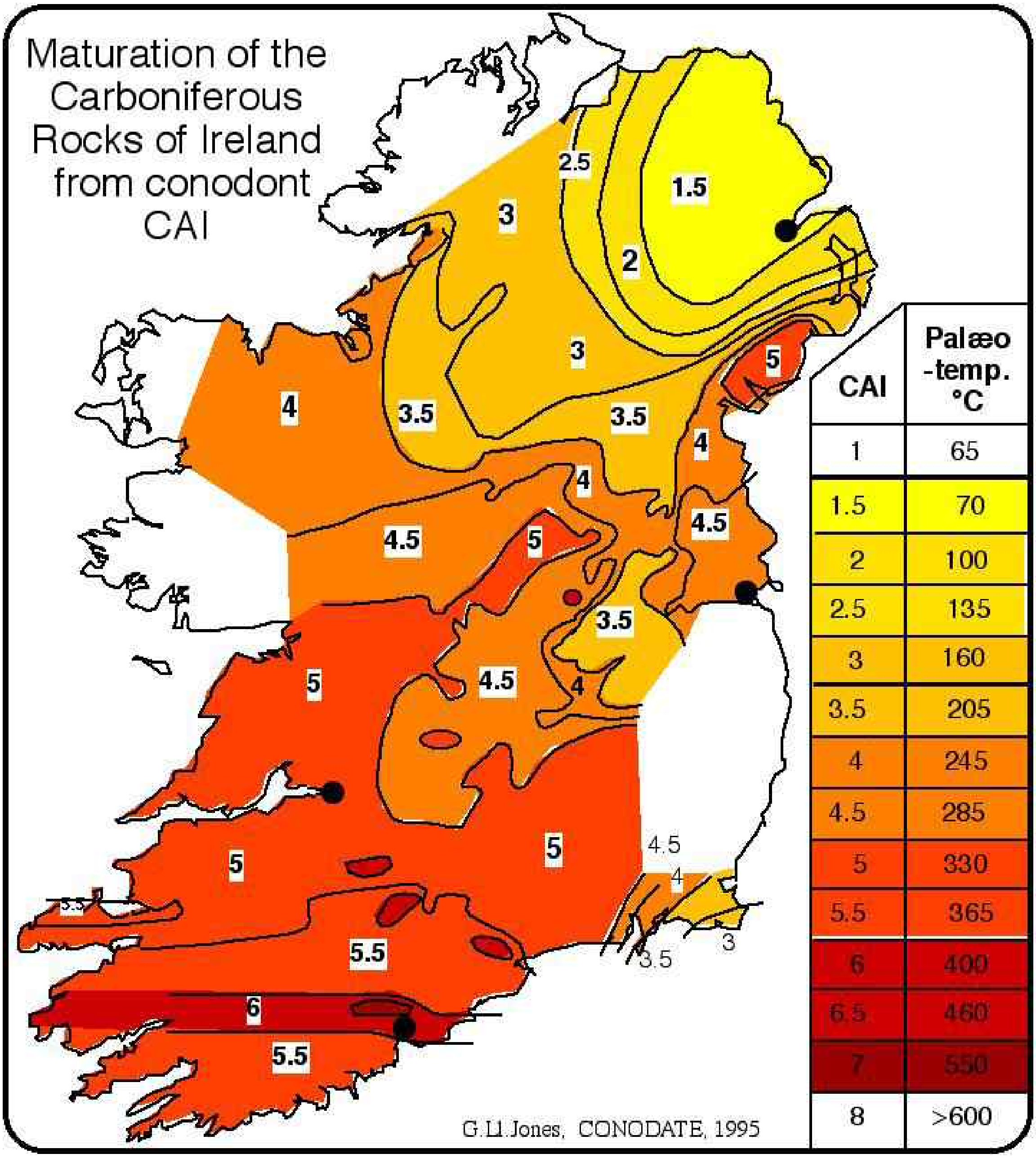


Geometry and Resources of Buried Valleys in the Cork-Midleton Syncline
T. Davis (t.davis@ucc.ie), A. Allen, I.A.J. MacCarthy & B. Higgs.
Department of Geology, National University of Ireland, Cork.
Environmental Research Institute, National University of Ireland, Cork.
HEA
ERI
Introduction
During the height of glaciation in the Quaternary, sea levels may have been as much as 130m lower than they are today. This has resulted in the occurrence of several buried river valleys in the Cork area. These buried valleys are infilled with glacio -fluvial sands and gravels that represent a significant resource. These sands and gravels also contain an abundant supply of groundwater, which due to the 'heat island' effect of cities has a slightly enhanced temperature. This groundwater can therefore be considered as a low enthalpy geothermal resource that can be exploited with the aid of heat pumps for space heating and cooling purposes in houses and industries in the city.
The main buried valley in the immediate Cork area lies beneath the present Lee River valley, with another valley beneath the Tramore River. Site investigation data and derived depth to bedrock maps show that these buried valleys can be up to 1.5 km wide, and reach depths of up to 60m. Cross-sections, derived from this site investigation data, have also been constructed and give a 2D representation of the valley geometry. They show that the sides of the valleys are not straight, but rather proceed downwards in steps and that the base of the valleys are not flat as pinnacles of bedrock can be found rising from the valley floor. Cross-sections derived from geophysical surveys will help to constrain the 2D geometry of the valleys in areas of sparse borehole data. 3D models in areas of dense borehole coverage will allow the volume of sand and gravel and groundwater resources to be calculated.
Figure 1: Simplified geology of the Cork region (from Sleeman, A.G and Pracht, M. (1995) Geology of South Cork. Geological Survey of Ireland, 60p.).
The red rectangle shows the area covered by Figures 2 and 3.
Figure 2: Map of the Cork - Midleton Syncline from Ballincollig to Belvelly showing the borehole data collected and the coresponding depth to bedrock.
Note: the depth to bedrock is depth below ground level, not depth related to OD.
Map Scale 1:30000
Rock Outcrop
Scale (m)
0 - 4.9
5 - 9.9
10 - 14.9
15 - 19.9
20 - 24.9
25 - 29.9
30 - 34.9
35 - 39.9
40 - 44.9
45 - 49.9
50 - 54.9
55 - 59.9
Figure 3: Simplified contour map of the buried valleys in the Cork area derived from the data in Figure 1.
Note: The contours represent metres below ground level.
Map Scale 1:30000
Rock Outcrop
Scale (m)
0 - 10
10 - 20
20 - 30
30 - 40
40 - 50
Fig. 4
Fig. 5
Fig. 6
Fig. 7
Fig. 8
Fig. 9
Figures 4-7: Series of cross-sections through the Lee Buried Valley showing the valley geometry and stratigraphy encountered at four locations from west to east along the valley. Locations of the sections are shown in Figure 3.
Figures 8 & 9: Cross-sections through the Tramore Buried Valley showing the valley geometry and stratigraphy encountered at two locations along the valley. Locations of the sections are shown in Figure 3.
Figures 10 & 11: Geophysical cross-sections displaying an example of a scarp to the left of the section and quaternarysediments to the right of the section.
The sections are located in Cloyne village outside of the study area.



Palaeotemperature distribution map of Ireland, showing the heat distribution in the distant past, from Jones (1995)

Recent Large Scale Ground-Source Heat Pump Installations in Ireland

Sarah O'Connell and Stephen F. Cassidy[6]
Mechanical & Manufacturing Engineering Dept, CIT, Cork, Ireland
Email: sarahoconnell@cit.ie, scassidy@cit.ie

Abstract

This paper examines the effectiveness and suitability of Ground Source Heat Pump technology for the Irish climate. The success of the installations to date is evaluated in the areas of operation of overall system, environmental benefits and financial benefits accrued. Geothermal resources in Ireland are mainly low temperature. As a result of this, geothermal energy is used for heating and cooling of buildings as there is insufficient resources for electricity generation. Ground Source Heat Pumps are mainly used for heating, as there is little need for summer cooling. While there are over 500 domestic installations in the country it is only recently that large-scale projects have been introduced. Buildings in both urban and rural settings are looked at. Building types range from swimming pools to office buildings. The performance of ground source heat pumps in large-scale applications has been excellent. There are significant reductions in CO_2 emissions. Payback periods are 4 - 6 years despite installation costs being high. More installers and a reduction in heat pump costs could reduce installation costs.

Keywords: *Ground-Source heat pumps, Ireland, case studies.*

1. Introduction

Thermal energy consumption in Ireland is 1.032 Mtoe (155.67 TWh) for domestic heating. For the tertiary sector it is 0.421 Mtoe(63.50 TWh) (Dubuisson 2002). Less than 1% of Irish households are heated using a heat pump. This contrasts sharply with Switzerland, one of the world leaders in heat pump technology, in which 67% of homes are equipped with a heat pump (Rybach and Sanner 2000). The reasons for such a low number of installations in Ireland is due to a) low public awareness of heat pump technology and its advantages over conventional heating systems, b) air conditioning, which drove the heat pump market, especially in the US, is not required in Ireland, c) a lack of hot springs, a feature which usually promotes the use of ground source heat pumps (GSHP) and d) few installers to promote and install heat pump systems.

There are between 500 to 600 domestic ground source heat pump installations in Ireland, typically in the range between 10 and 14 kW. Presently, there are approximately 18 large-scale commercial systems installed (Sikora 2002). The installed thermal capacity in Ireland is 7 – 8 MWt. This paper deals with these large-scale commercial installations that have an output larger than 12kW. This figure was chosen so direct comparisons with other countries could be made using the data compiled by Lund and Freeston (2000) in their assessment of global geothermal energy.

While the number of GSHP systems currently installed in Ireland is low, there appears to be a large potential for growth in the area due to the prevailing climatic and soil conditions. Ireland has a mild climate due to the proximity of Gulf Stream currents in the Atlantic Ocean. The average annual air temperature is 9°C. The lowest mean daily minimum temperature in winter is 2.5°C. The country has both a high rainfall rate, 800 to 2,800mm per annum, and high relative humidity values are between 71% and 91% (Met Eireann 2002). These factors combine to ensure a large moisture content in the soil thereby increasing its thermal conductivity. Saturated soil has a thermal conductivity

[6] Corresponding author.

value up to four times greater than dry soil. The overall geological composition in Ireland, 40% of parent soil composition at depths of 1m and greater consists of either Sandstone or Limestone (Gardiner and Radford 1980). Sandstone has a thermal conductivity of between 1.28 W/mK and 5.10 W/mK. Limestone has thermal conductivity between 1.96 W/mK and 3.93 W/mK. Average ground temperatures at depths of 1m and greater are between 9°C to 13°C (Connor 1998). Horizontal collector ground loops may thus be used in Ireland, as the collector will not encounter external frost since diurnal damping depths are 0.2m for sandstone, and 0.1m for damp soil consisting of organic matter. This, together with the easy availability of land and the cheaper installation cost over conventional vertical borehole collectors, means than horizontal collectors are the most common form of collector type used.

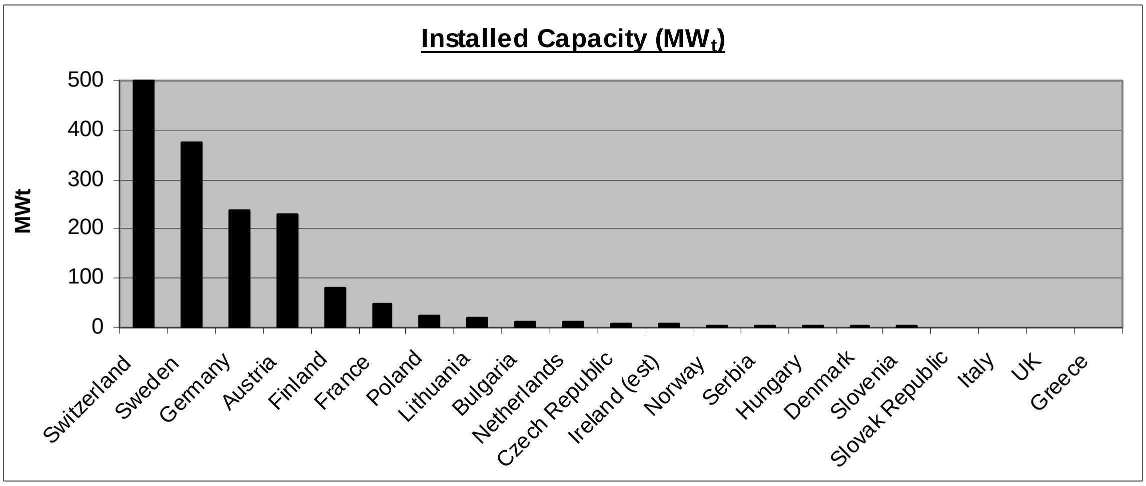


Figure 1: Installed Ground-source Heat Pump capacity in Europe. (Lund and Freeston 2000)

Installed ground-source heat pump capacity for Europe is shown in Figure 1. Total European installed capacity is 1,577 MW of which the estimated installed capacity for Ireland is 3.7 MW. The European annual growth rate is 15% (Rivoalen 2001). Geothermal heat pump installations in the US have total capacity of 1,356 MW, comparable to the whole of Europe and are expected to increase at a rate of 10% annually (Lund and Freeston 2000). The estimated Irish annual growth rate is 30%. The high Irish growth rate is due to the lack of maturity in the heat pump market.

2 Recent Large Scale GSHP Installations in Ireland

The following is an analysis of installations that have been recently installed in Ireland. Most have been extremely successful and indicate that ground-source heat pumps are well suited to the Irish climate. The majority of these large scale installations have been in showcase buildings which feature a range of renewable energy technologies such as solar panels for hot water heating, sustainable building design and layout and natural ventilation. Table 1 gives a summary of these installations.

Horizontal collectors are the preferred option as vertical boreholes are 4 – 5 times more expensive to install in Ireland than horizontal systems (O'Brien 2002). The horizontal collectors have all been installed at a depth of 1m with the exception of the Churchfield installation, which was installed at 0.5m depth. Ireland is not a densely populated country with only 52 persons per square kilometre thus accounting for the availability of land to install horizontal collectors. Typically ¾ inch diameter pipe is laid in parallel and manifolded together.

1 Table 1: Commercial GSHP Installations in Ireland

Building Location	Building Type	Inst-alled	Collector Type	Collector Length (m)	Heat Pump (k W)	COP	Pay-back period (years)	Estimated % CO2 Emissions Reduction
Trinity College, Dublin (out of commission)	4 University buildings		Aquifer Boreholes (solar add-on)	4 x 12	6 Heat Pumps 450 kW	~ 4	1.5 - 4	60
Motor Tax Office, Tralee, Co. Kerry	Office	1999	Horizontal Closed Loop	5100	130 kW	3.7	4	52 (B.& E.M. 2001)
Share Hostel, Cork.	Residential	2002	Shallow Aquifer Borehole	20	100 kW	3.5		30
Mallow Swimming Pool, Co. Cork	Swimming Pool	1987	Geothermal Aquifer Borehole	75	100 kW	4	11.5	
Carbery GAA, Co. Kildare	Sports Hall	2003	Direct Expansion Horizontal	440	46 kW	6 (max)		
Dolmen Centre, Co. Donegal	Sports Complex	2000	Horizontal Closed Loop	1800	45 kW	~ 3		45
Marlton House, Wicklow Town	Residential with Swimming Pool		Horizontal Closed Loop	2800	40 kW	3.5	6 - 8	45
Sports Centre Churchfield, Cork	Sports Complex	1997	Horizontal & Vertical	600 Horiz 120 Vert	34 kW	2.37		
Camp Hill Community, Callan, Co. Kilkenny	Residential Care Facility	1996	Artesian Well & Tubing on Roof		30 kW	3.5	6 - 8	45
Spiddal, Co. Galway	Private dwelling &swimming pool	2001	Horizontal Closed Loop	1500	30 kW	3.5	6 - 8	45
An Seanscoill, Co. Galway	Old School House		Horizontal Closed Loop	1500	30 kW	3.5	6 - 8	45
Caheroye House, Athenry, Co. Galway	Country Hotel	2002	Horizontal Closed Loop	1500	30 kW	3.5	6 - 8	45
Navan, Co. Meath	Private dwelling & Offices	2000	Pipe in stream Closed Loop	1500	30 kW	3.5	6 - 8	45
Briar Hill	Large Private Dwelling			1500	30kW	3.5	6 - 8	
Landfill Site Office, Kinsale Road, Cork.	Office	2000	Horizontal Closed Loop	2400	28 kW	3.5	4.5 - 6	30
Pairc Gno an Daingan, Co.Kerry.	Technology Park Offices	2002	Horizontal Closed Loop	960	26 kW			
Green Building, Temple Bar, Dublin	Apartments / Office / Retail	1994	Vertical Borehole	150	23 kW	4.87	2.5	86 (Cooper 1995)
Heritage House Ballyhooley, Co.Cork	Residential Listed building	1995	Air & Horizontal in compost	1050	19 kW	3.3 – 3.6	6	45

The borehole collector at Mallow Swimming pool uses the Mallow geothermal aquifer as its source. The water from this aquifer has an average recorded temperature of 19ºC. The borehole at Churchfield was installed to compare its performance with that of the horizontal collector. The horizontal loop proved to be more efficient. A vertical borehole was chosen for the Green Building in Temple Bar due to space restrictions. Some seepage from the bedrock also increases the heat pump COP. The decomposing waste at the Kinsale Road Landfill site is used as the heat source for the Administration building. The Share Hostel in Cork uses the Lee Valley aquifer, which, due to the heat island effect, has a water temperature of 12 –13ºC. The collector installed in Navan was placed on a stream bed and consists of stainless steel piping. Where possible, favourable geophysical features have been used for the collector, for example, the artesian well in Callan, Co. Kilkenny. In theory this should improve the system performance, however, the systems have not been monitored so the reduction in energy consumption has not been quantified.

The 6 heat pumps installed in Trinity College, Dublin range in size from 50 kW to 150 kW. The 30 kW systems are a standard size and the associated horizontal collectors are 1500m in length. Tralee Motor Tax office is the largest installation serving a single building. Mallow Swimming pool payback period is significantly higher because the project was the first of its kind in the country and encountered much higher exploration costs to determine the heating potential of the aquifer. For the Green Building in Temple Bar, the payback period for the entire building is estimated to be 18 years. As ground source heat pumps are a much more commercially attractive solution than other forms of renewable energy, they have a significantly shorter payback period than the building as a whole. For the Tralee Motor Tax office, the payback period was good due to its use for both heating and cooling. This can be accounted for by the very low running costs for the GSHP system. For example, in February 2001, heating costs amounted to approximately 15 euros per week.

For the Tralee Motor Tax office, CO_2 emissions were reduced by 52% as compared with a BRESCU type-3 office building. For the entire Green Building in Temple Bar, the reduction was 86%. This reduction was enhanced by the inclusion of foliant species as well as other renewable energies. The heat pumps in Trinity reduced CO_2 emissions by 920,000 $kgCO_2/kWh$ annually. In Churchfield, a natural gas fired boiler is running continuously so there is a neglible reduction in emissions. CO_2 emissions for the other buildings have been estimated based on heat pump annual energy consumption and using BRECSU CO_2 emissions indicators (BRECSU 2000). The 45% reduction is based on a comparison with an oil-fired boiler while the 30% reduction is based on comparison with Natural Gas where it is available.

Future projects include geothermal heating systems for Nursing home and health care projects with floor areas between 1200 – 1800m^2 in planning or progress. The Ballymun regeneration project in Dublin plans to install ground-source heat pumps in five houses to evaluate their practicality in high-density urban dwellings (Sikora 2002). Macroom Environmental Industrial Estate is a project initiated by Cork County Council. The pilot building will use an open loop water source heat pump to provide heating for the building. A 200kW system is under construction for University College Cork utilising boreholes in a gravel aquifer. Inniscarra Environmental offices will have a buried horizontal loop installation with a proposed total heat output of 42kW, due to start on site in Sept 2003.

Discussion

Running costs for GSHP systems in Ireland are significantly lower than other forms of heating. For example, a domestic oil boiler has running costs 66% greater than a ground-source heat pump. However, the high initial investment may be a deterrent to prospective users. Installation costs are 40% greater than oil or gas fired boilers, the most common forms of residential space heating, and 50% greater than electric storage heaters (O'Brien

2000). This is largely due to the lack of competition installing ground-source heat pump systems and the high cost of heat pump units. As the environmental and cost saving benefits of ground-source heat pumps becomes more widely known, this should encourage growth in the market and so reduce the initial installation costs. Organisations such as The Geothermal Association of Ireland, Sustainable Energy Ireland, and government funded Energy Offices at both national and local level are raising the profile of ground-source heat pumps in Ireland.

The increasing urbanisation of Ireland will require GSHP installations to become more compact. An alternative to borehole heat exchangers is to install the collector under or in building foundations. This technology has never been applied in Ireland although it has been developed extensively in Austria mainly using foundation piles containing HDPE piping with brine as the heat transfer fluid. Collector piping has also been installed in raft foundations and diaphragm walls (Brandl 1998). This technology has also been implemented in Canada for a 211 kW heat pump capacity system under an office building (Caneta 1999) and in the US for a 6-ton (21kW) sub-slab heat pump installation (Drown et al. 1992). A project is currently underway at Cork Institute of Technology to install a collector under the footprint of a building (O'Connell in prep.). The aim of this project is to demonstrate the technical and economic feasibility of locating collectors in the foundations of buildings in Ireland. This, it is hoped, will make the use of GSHP in the urban environment more widespread in Ireland.

Ireland exceeded the maximum permissible greenhouse gas emission target set by the Kyoto protocol at 13% over 1990 levels in 1999. To limit energy related CO_2 gas emissions, renewable energy may be used to reduce emissions of CO_2 by over 4.25 million tonnes which is over 35% of Ireland's target (Kellett 2002). Ground-source heat pumps may contribute greatly to this reduction as they reduce CO_2 emissions by between 30 % and 100% as compared with conventional heating systems (Dubuisson 2002).

Conclusions and Recommendations

The majority of the projects detailed in this paper have received funding incentives from local, national or EU level. It is hoped that these buildings will demonstrate the commercial viability of ground source heat pumps to the wider public and so increase the take up of this technology. The potential for ground source heat pumps in Ireland is extensive. At present the percentage of heating requirements met by heat pumps is insignificant. The potential primary energy savings for residential and tertiary sectors is 2.426 TWh/year equivalent to 80,000 units as estimated by Sustainable Energy Ireland. These would reduce CO_2 emissions by 617000 tonnesCO_2/year and the primary energy requirement for heating would be cut by 5%. The extra investment required would be 602.6 million euros (Dubuisson 2002).

The barriers preventing this potential from being realised include: higher capital cost of GSHP systems; higher perceived risk; price distortions (external cost of fossil fuels, subsidies for infrastructures); unfavourable market characteristics; lack of installation experience; absence of quality standards and, finally, low level of awareness among the general public and decision makers in government and county councils.

To encourage greater use of GSHP systems, the following measures should be undertaken:

- Subsidies for installation of domestic heat pumps as well as the existing subsidies for developers.
- Certified installers.
- Standards for new building codes with regard to technical/economic considerations for heat-pump installation.
- Standards for use of heating and cooling systems in buildings with air conditioning.
- Restrictions on use of fossil fuel and direct electricity heating.
- Carbon fuel tax.
- Continual research and development of heat-pump systems specially designed for conditions in Ireland.

Acknowledgements

Funding received from the HEA under PRTL Cycle II Environmental Research Institute – New Energy Systems in Buildings. The author would also like to thank Dunstar Ltd (Clonakilty, Co. Cork) for technical expertise and information shared.

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Appendix XII