Paper: Stresses in sprayed concrete tunnel linings at Heathrow Terminal 4

Additional materials

Acknowledgements

Organisations:

Mott MacDonald

Balfour Beatty

Heathrow Express

Universities of Surrey, Southampton, Warwick and EPFL

Individuals:

Alun Thomas

Pierre van der Berg

Guy Bridges

MMS I radial pressures

These are shown relative to in situ stress with $K_0 = 1.5$.

Stresses from the previous stage are shown faded.

Approximate position of top heading, bench and invert according to construction records shown in long section at the bottom of each page. These are approximate because progress was only recorded once per day.

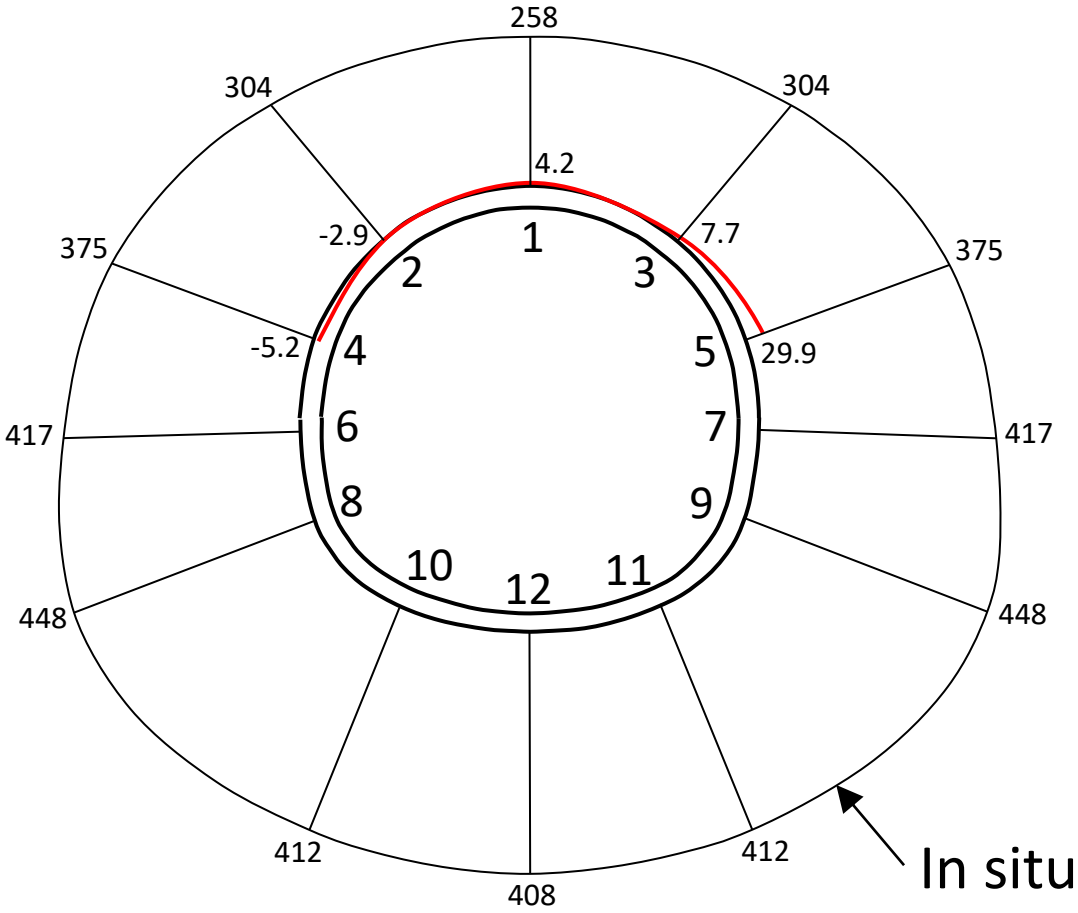
Average temperatures measured by thermistors attached to the radial pressure cells are shown for top heading, bench and invert on the right hand side.

MMS I radial pressures

Time from top heading excavation at MMS I:

0 hours

14/10/96 02:00



Temperature (°C):

Crown	19.8
Bench	-
Invert	-

In situ radial stress ($K_0 = 1.5$)

Location of array

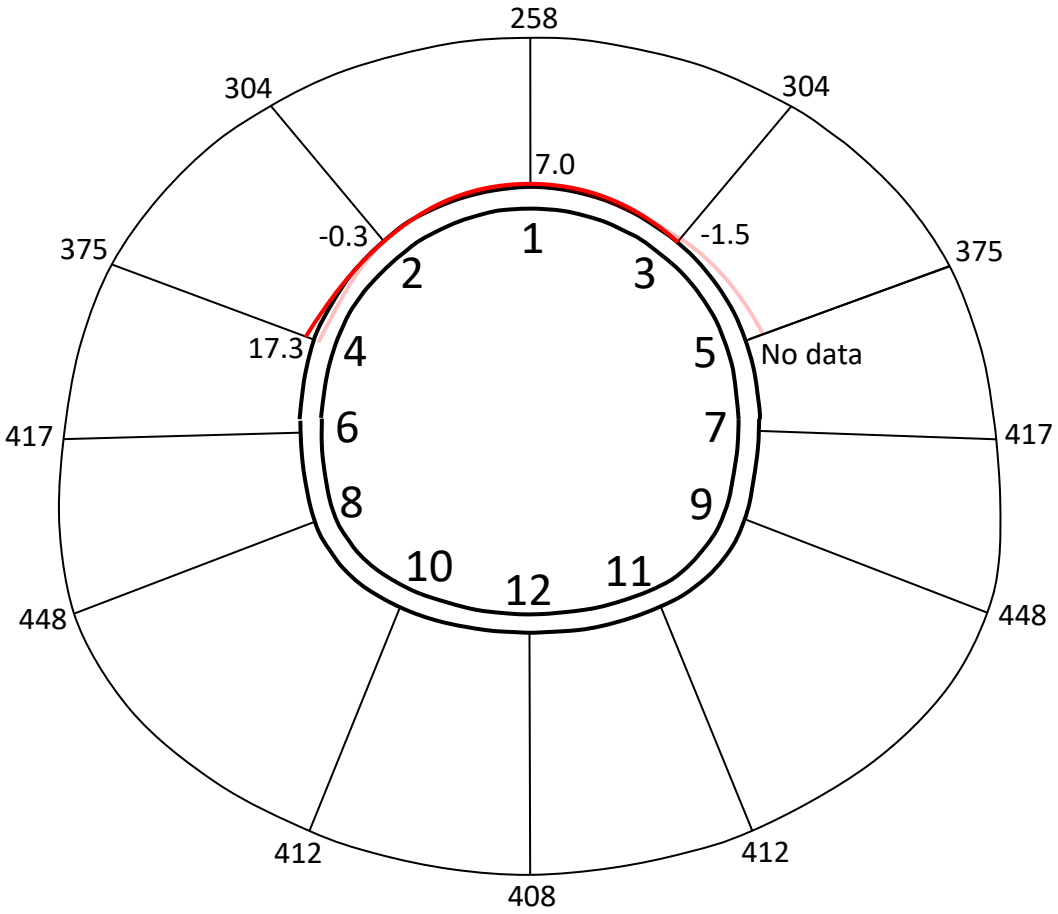
Long section

MMS I radial pressures

Time from top heading excavation at MMS I:

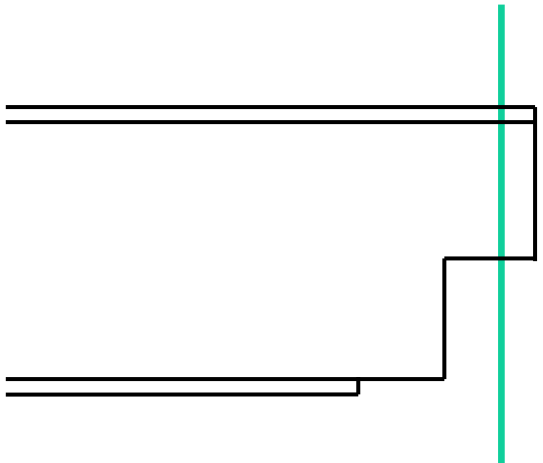
9 hours

14/10/96 11:00



Temperature °C

Crown	29.1
Bench	-
Invert	-

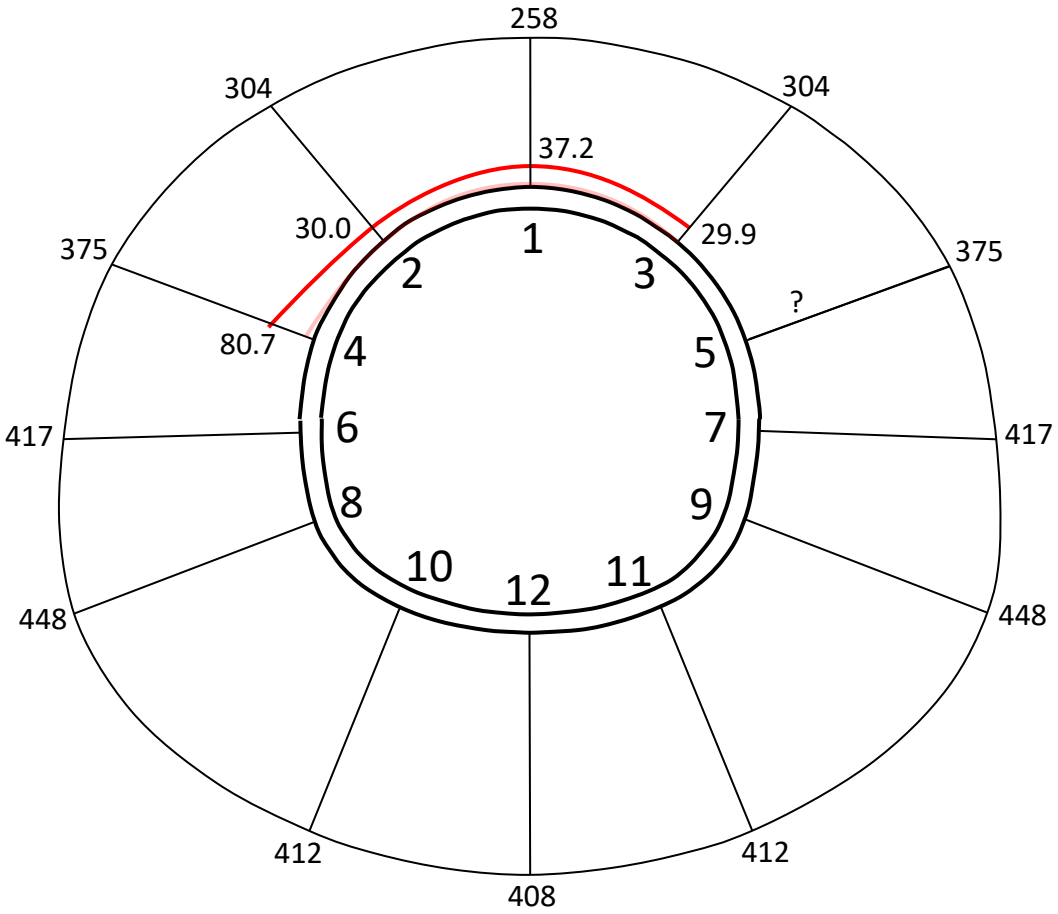


MMS I radial pressures

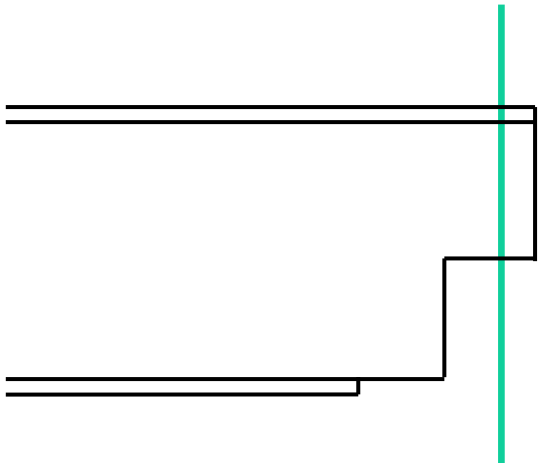
Time from top heading excavation at MMS I:

14 hours

14/10/96 16:00



Temperature °C	
Crown	39.2
Bench	-
Invert	-

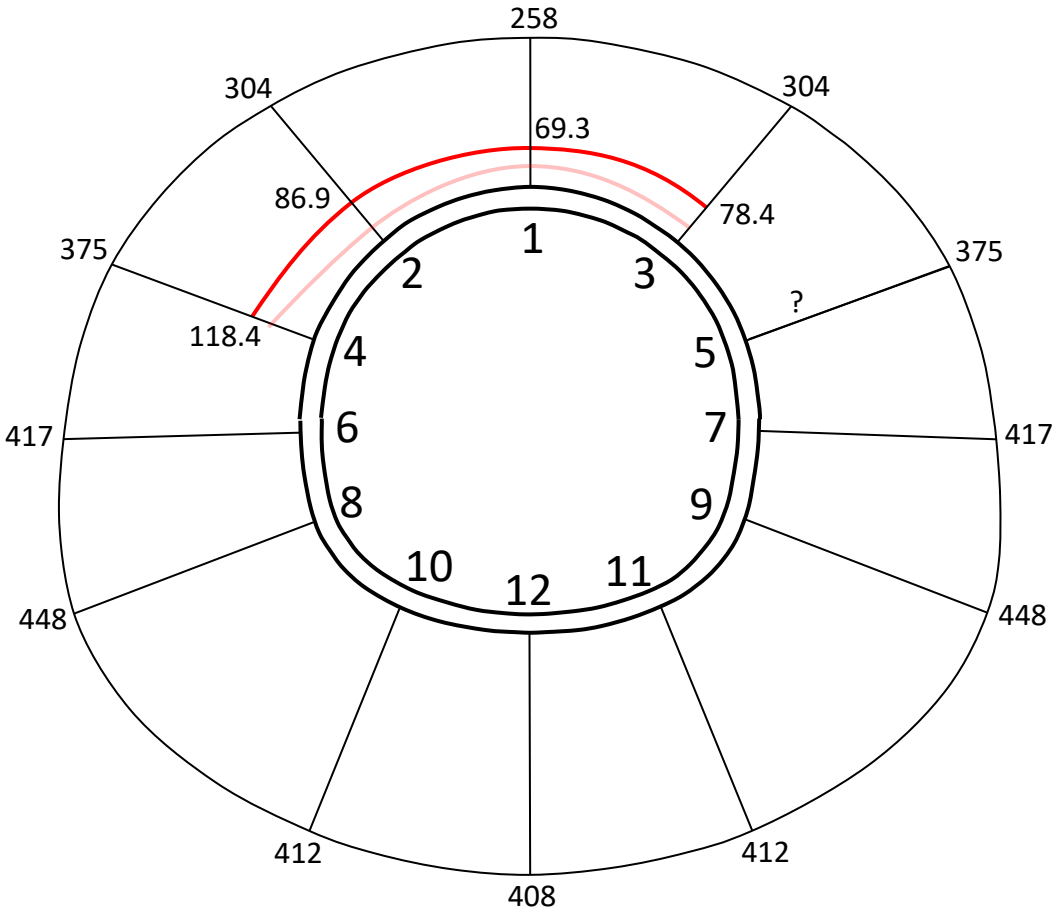


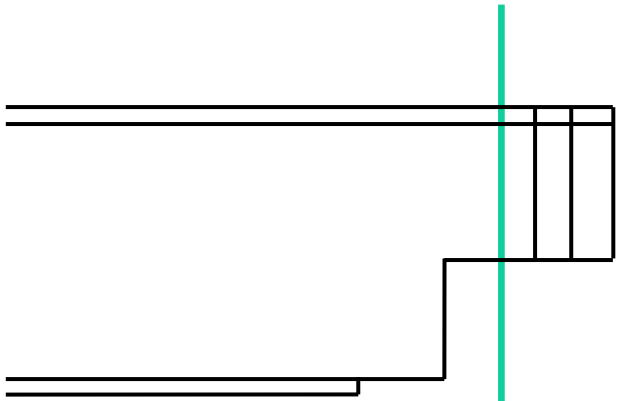
MMS I radial pressures

Time from top heading excavation at MMS I:

23 hours

15/10/96 01:00





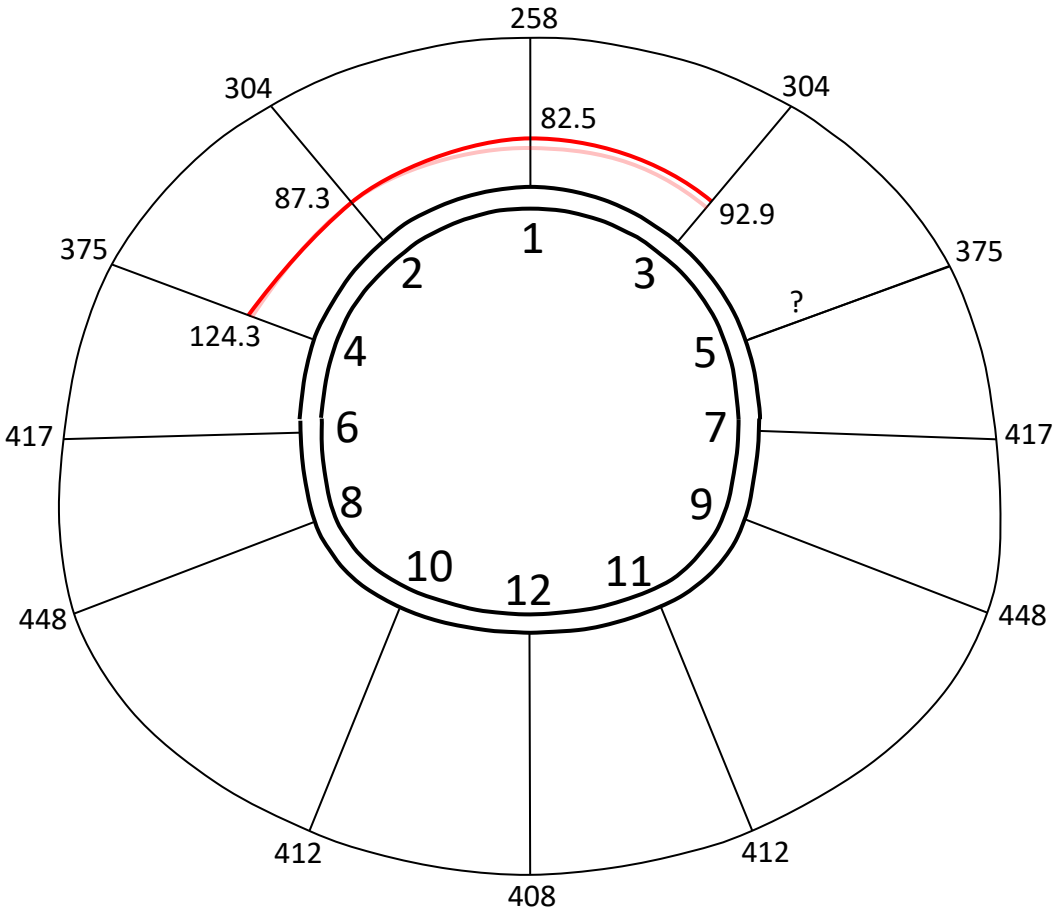
Temperature °C	
Crown	38.6
Bench	-
Invert	-

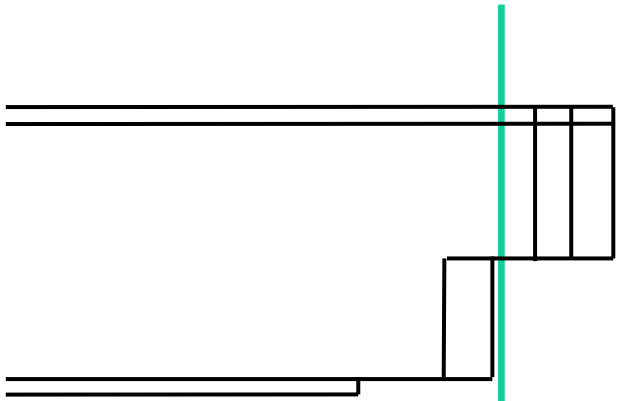
MMS I radial pressures

Time from top heading excavation at MMS I:

1 day 8 hours

15/10/96 10:00





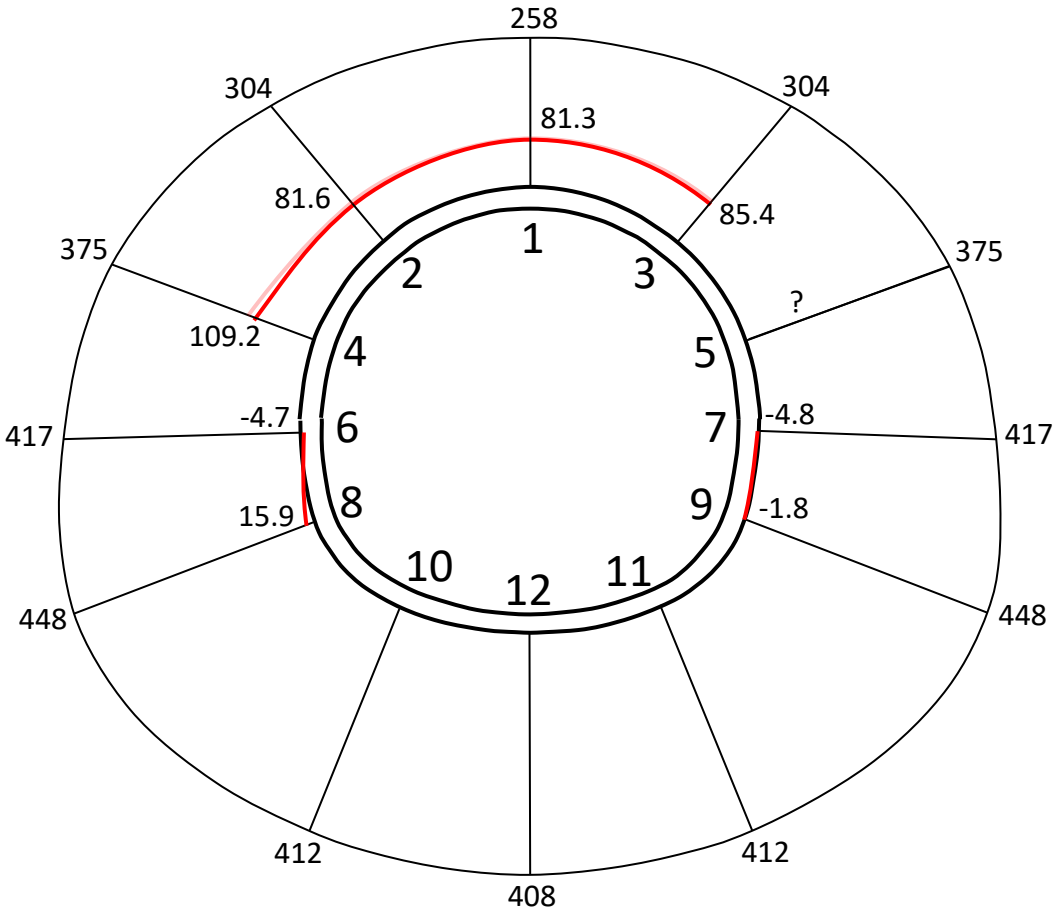
Temperature °C	
Crown	38.0
Bench	-
Invert	-

MMS I radial pressures

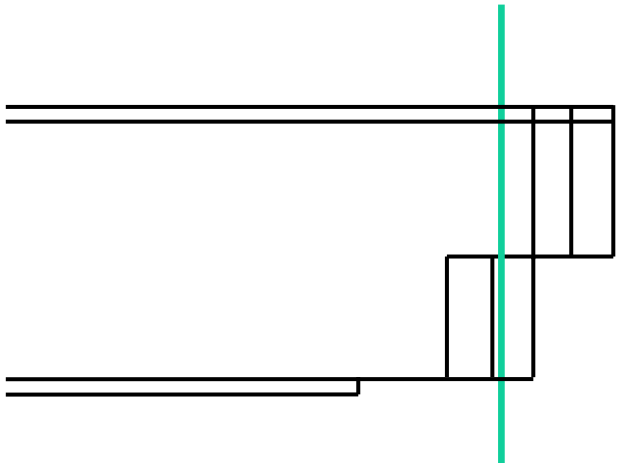
Time from top heading excavation at MMS I:

1 day 12 hours

15/10/96 14:00



Temperature °C	
Crown	36.4
Bench	17.6
Invert	-

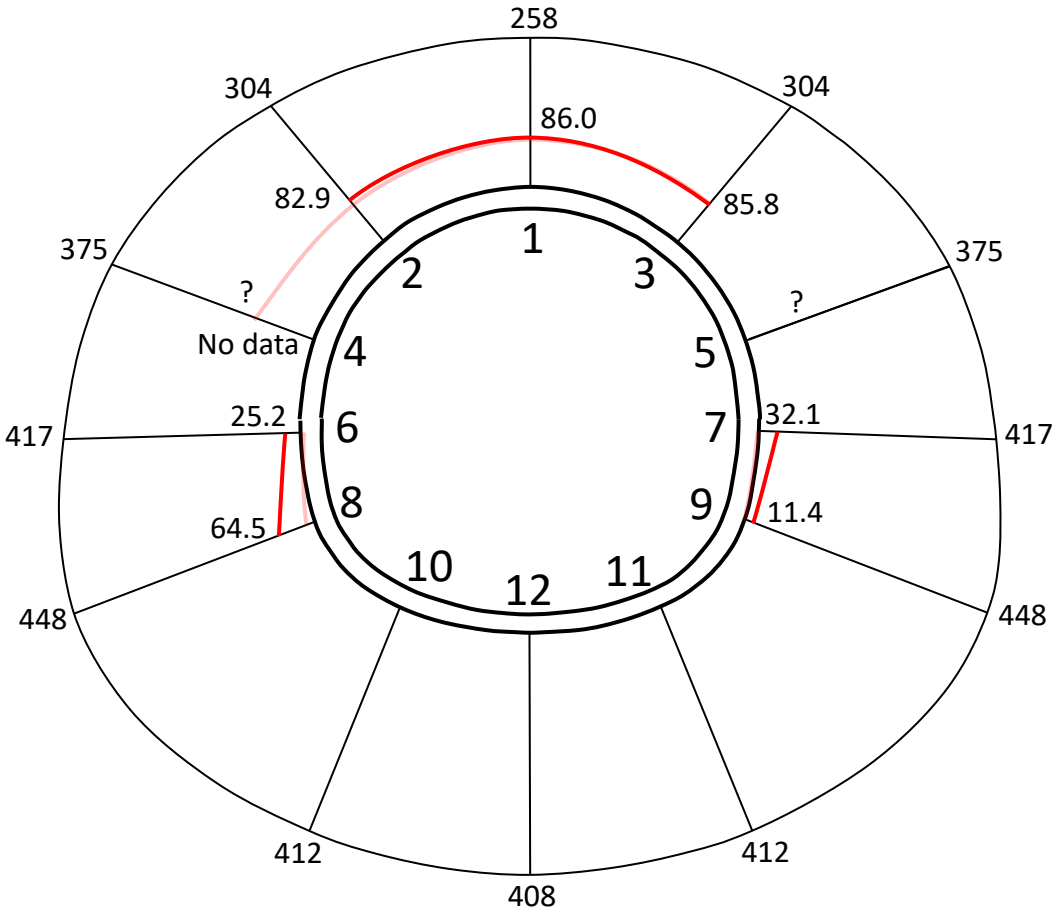


MMS I radial pressures

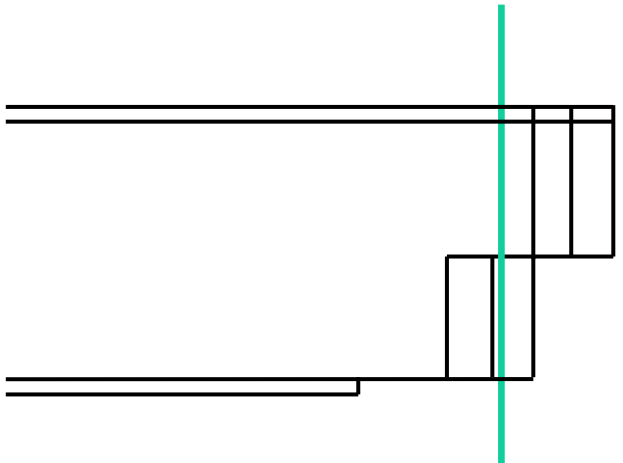
Time from top heading excavation at MMS I:

1 day 13 hours

15/10/96 15:00



Temperature °C	
Crown	34.7
Bench	18.4
Invert	-

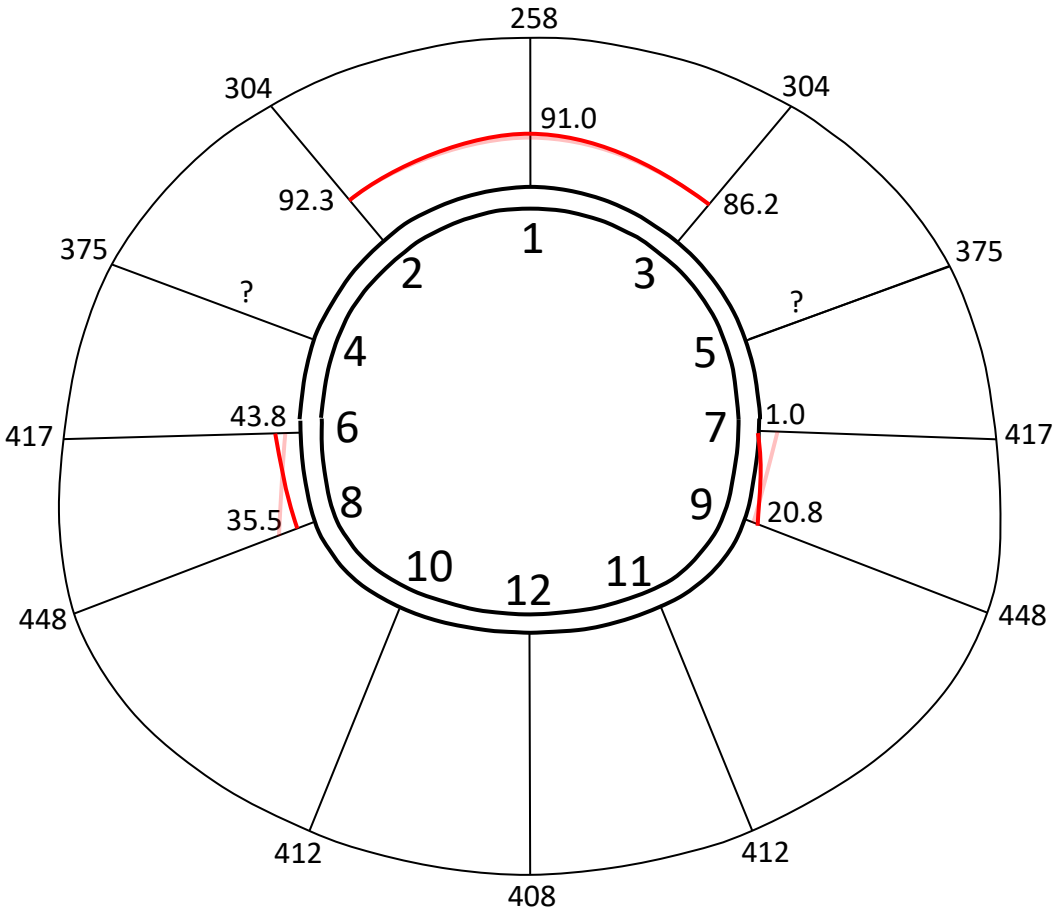


MMS I radial pressures

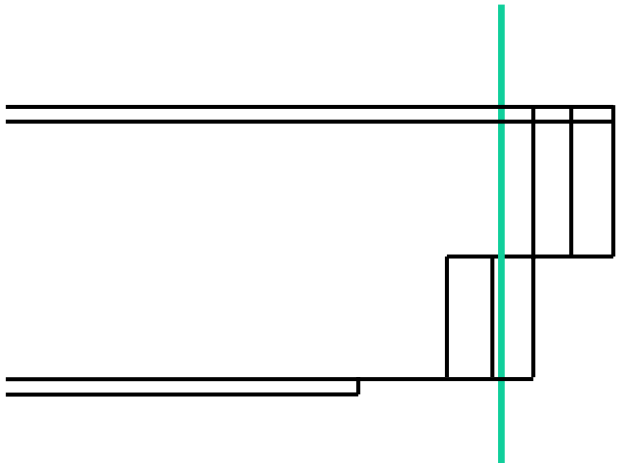
Time from top heading excavation at MMS I:

1 day 17 hours

15/10/96 19:00



Temperature °C	
Crown	33.5
Bench	24.9
Invert	-

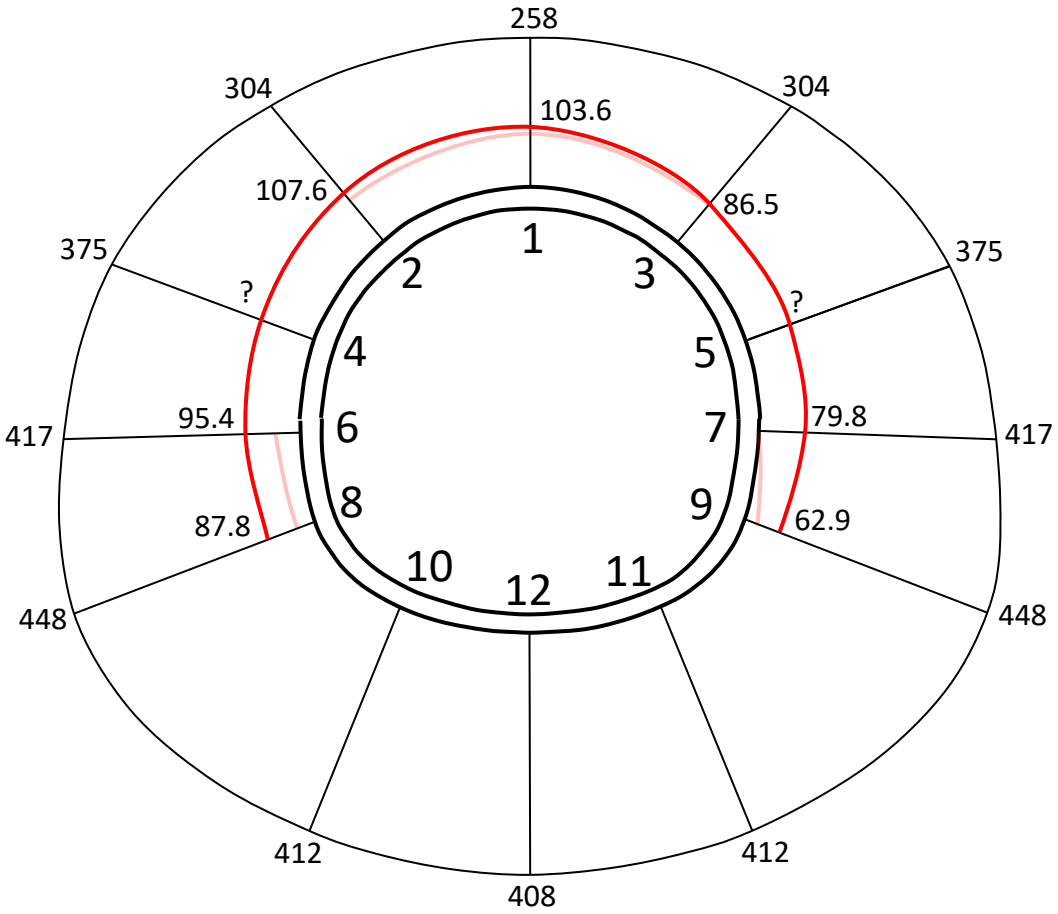


MMS I radial pressures

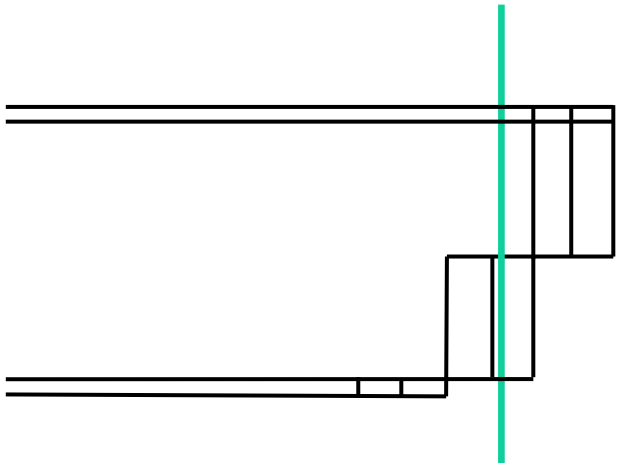
Time from top heading excavation at MMS I:

2 days 4 hours

16/10/96 06:00



Temperature °C	
Crown	32.3
Bench	29.2
Invert	-

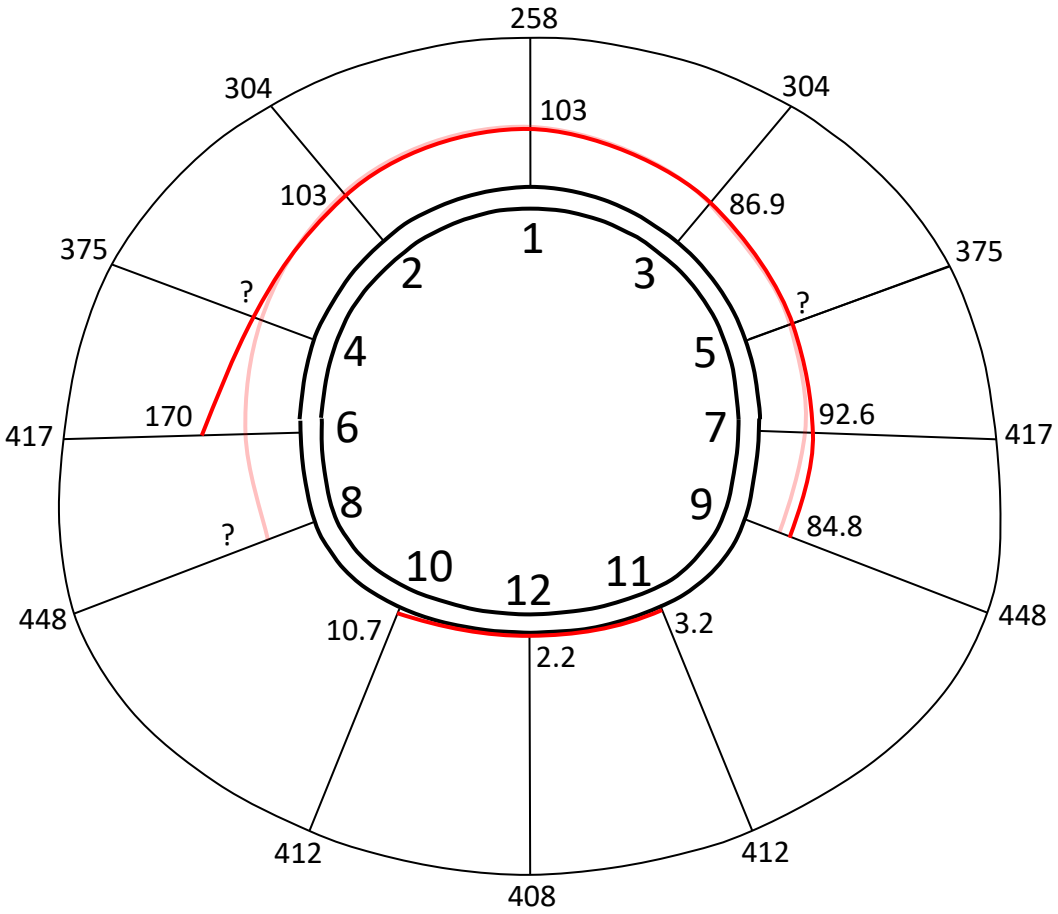


MMS I radial pressures

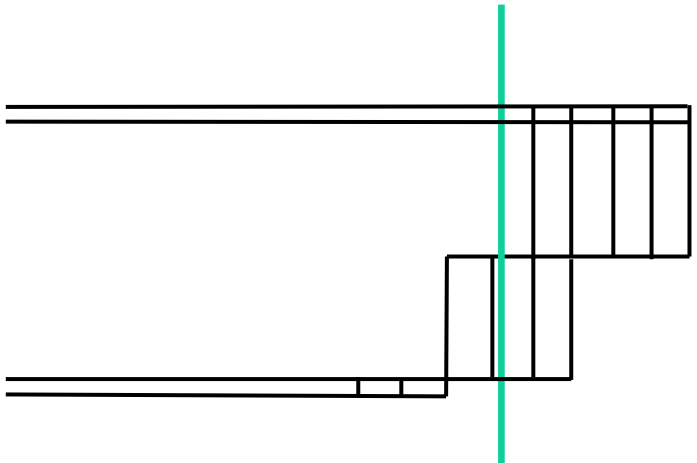
Time from top heading excavation at MMS I:

2 days 14 hours

16/10/96 16:00



Temperature °C	
Crown	30.8
Bench	34.9
Invert	19.3

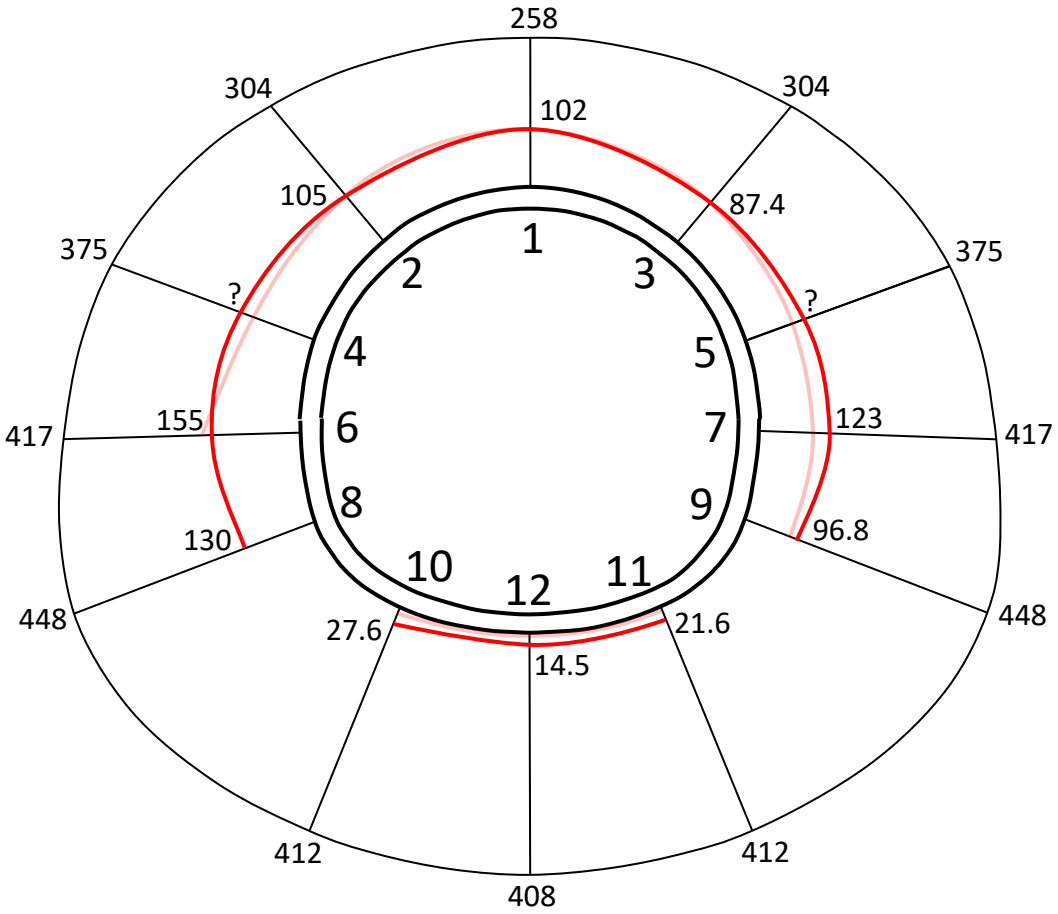


MMS I radial pressures

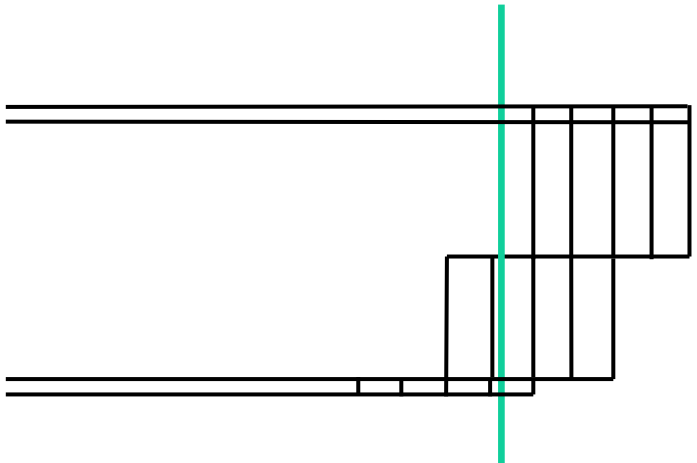
Time from top heading excavation at MMS I:

3 days 1 hour

17/10/96 03:00



Temperature °C	
Crown	29.2
Bench	31.8
Invert	34.4

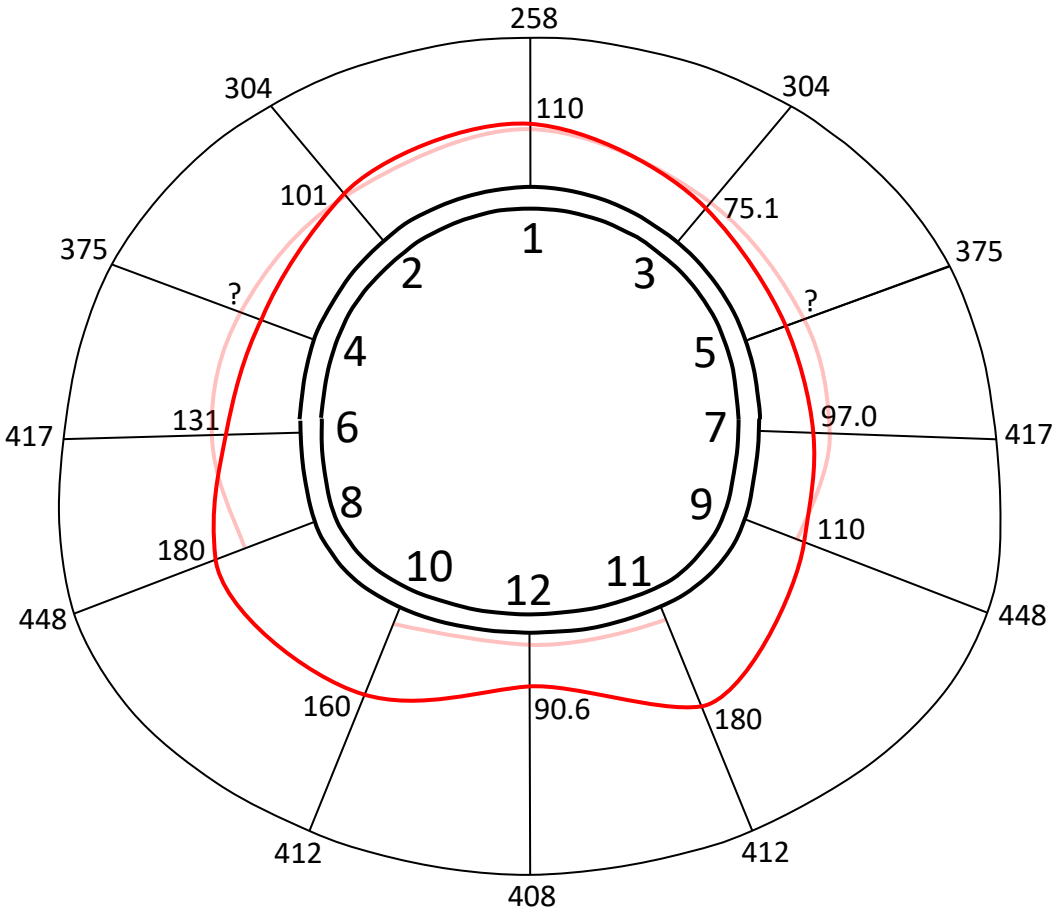


MMS I radial pressures

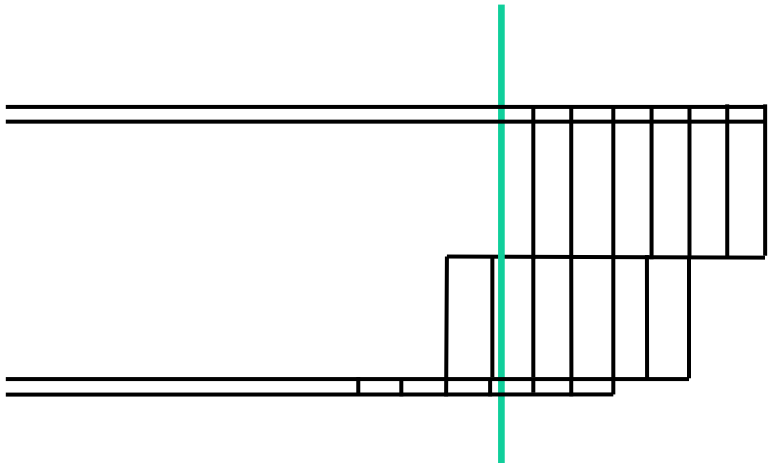
Time from top heading excavation at MMS I:

4 days 4 hours

18/10/96 06:00



Temperature °C	
Crown	26.3
Bench	27.7
Invert	35.7

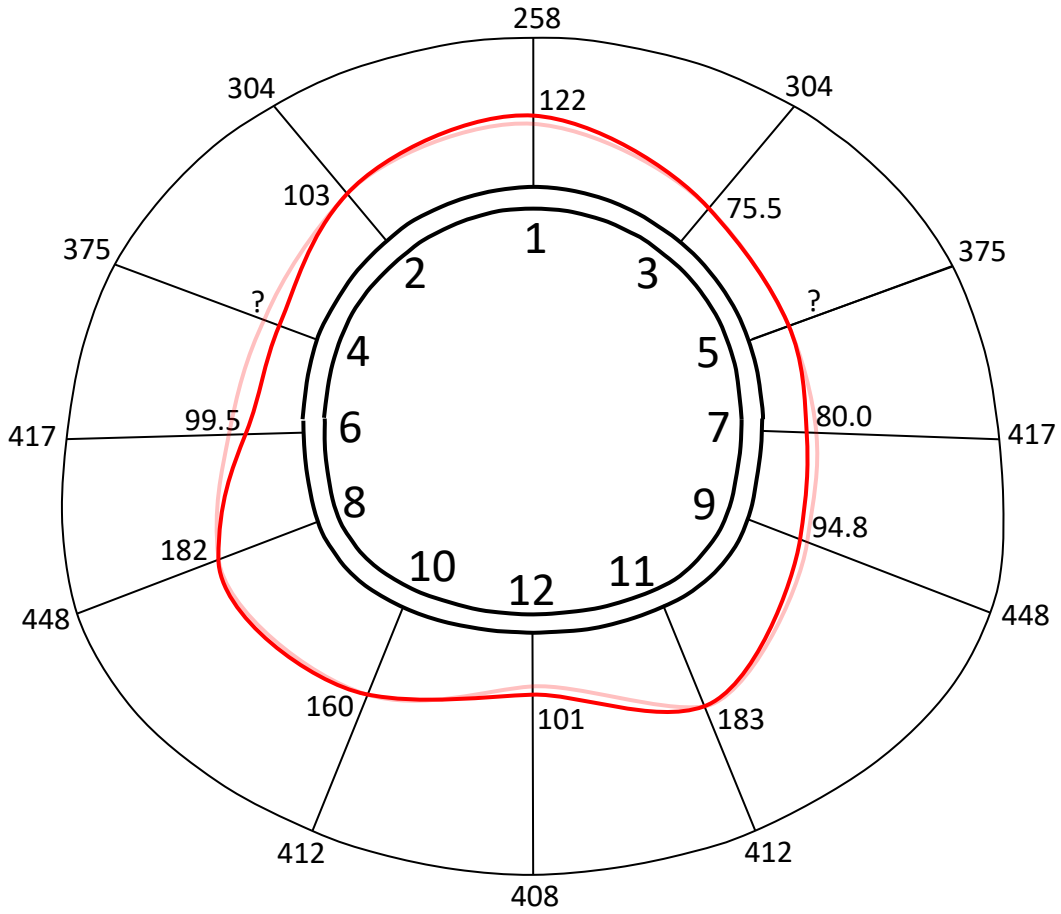


MMS I radial pressures

Time from top heading excavation at MMS I:

5 days 16 hours

19/10/96 18:00



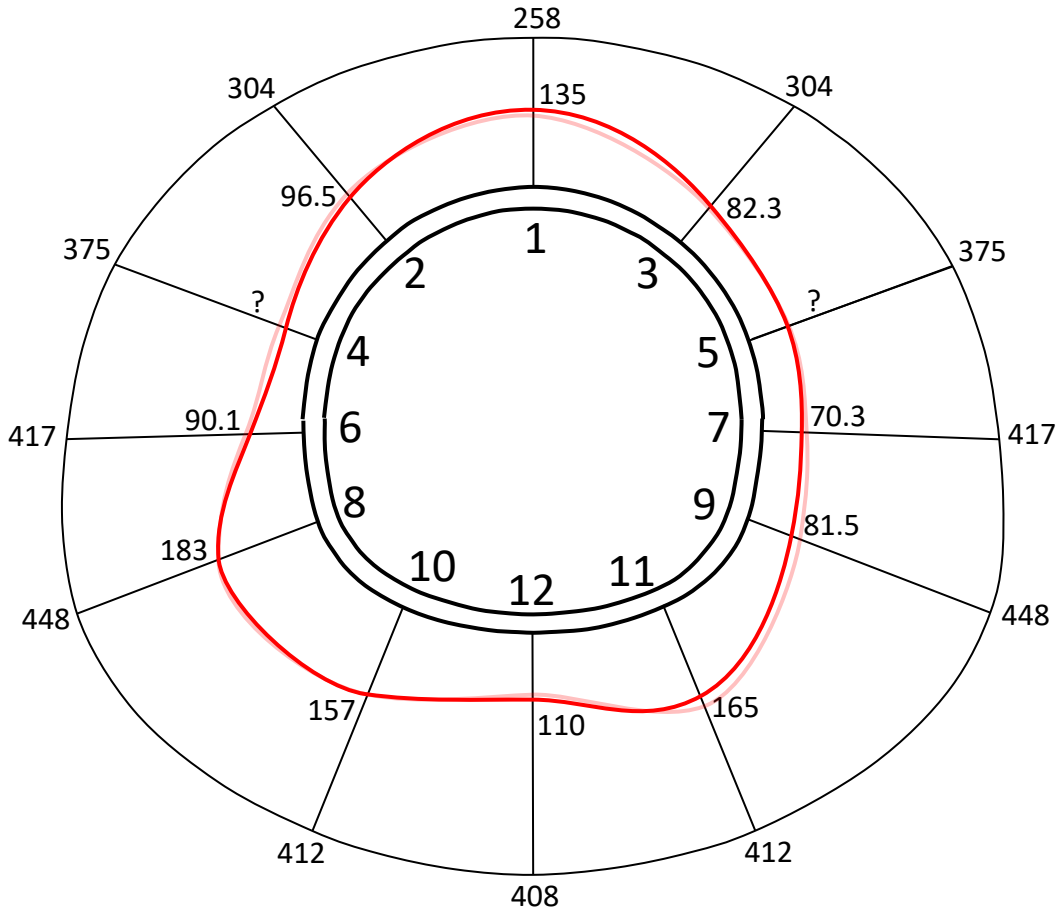
Temperature °C	
Crown	24.3
Bench	23.4
Invert	28.0

MMS I radial pressures

Time from top heading excavation at MMS I:

7 days 13 hours

21/10/96 15:00



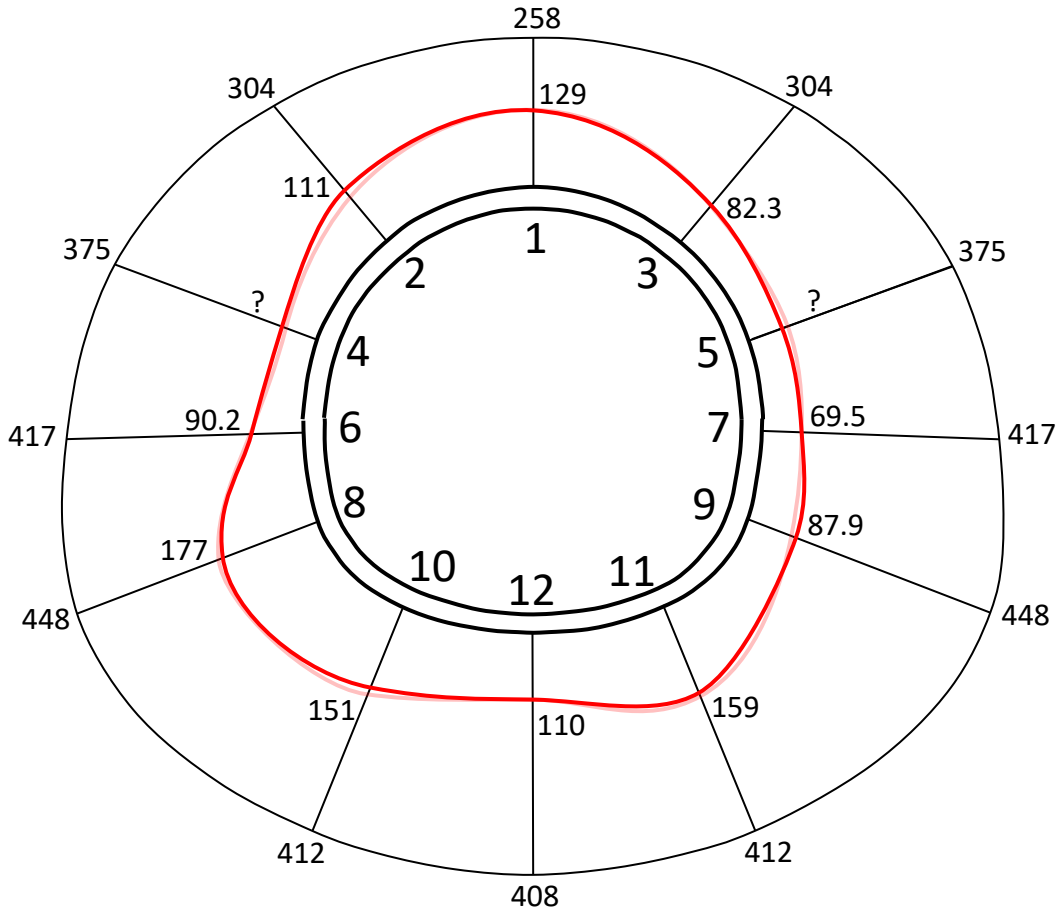
Temperature °C	
Crown	23.8
Bench	21.9
Invert	27.5

MMS I radial pressures

Time from top heading excavation at MMS I:

7 days 21 hours

21/10/96 23:00



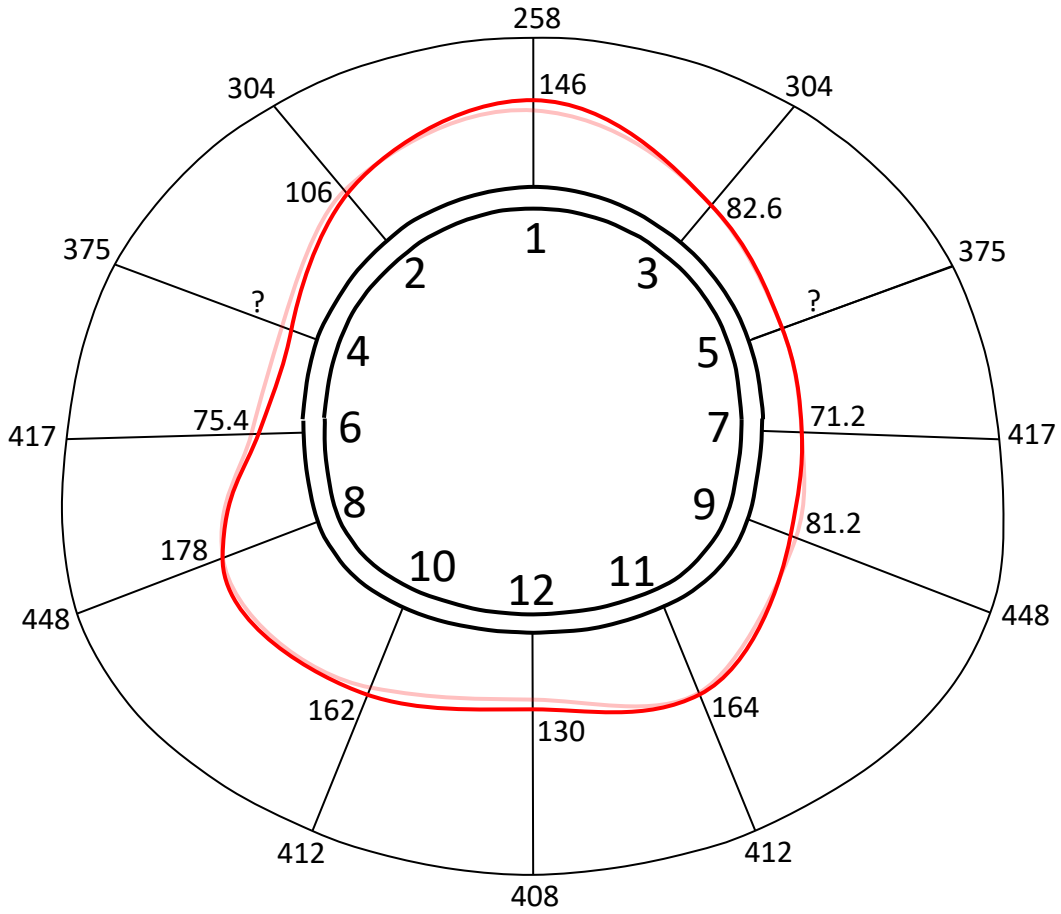
Temperature °C	
Crown	23.9
Bench	22.0
Invert	27.8

MMS I radial pressures

Time from top heading excavation at MMS I:

9 days 12 hours

23/10/96 14:00



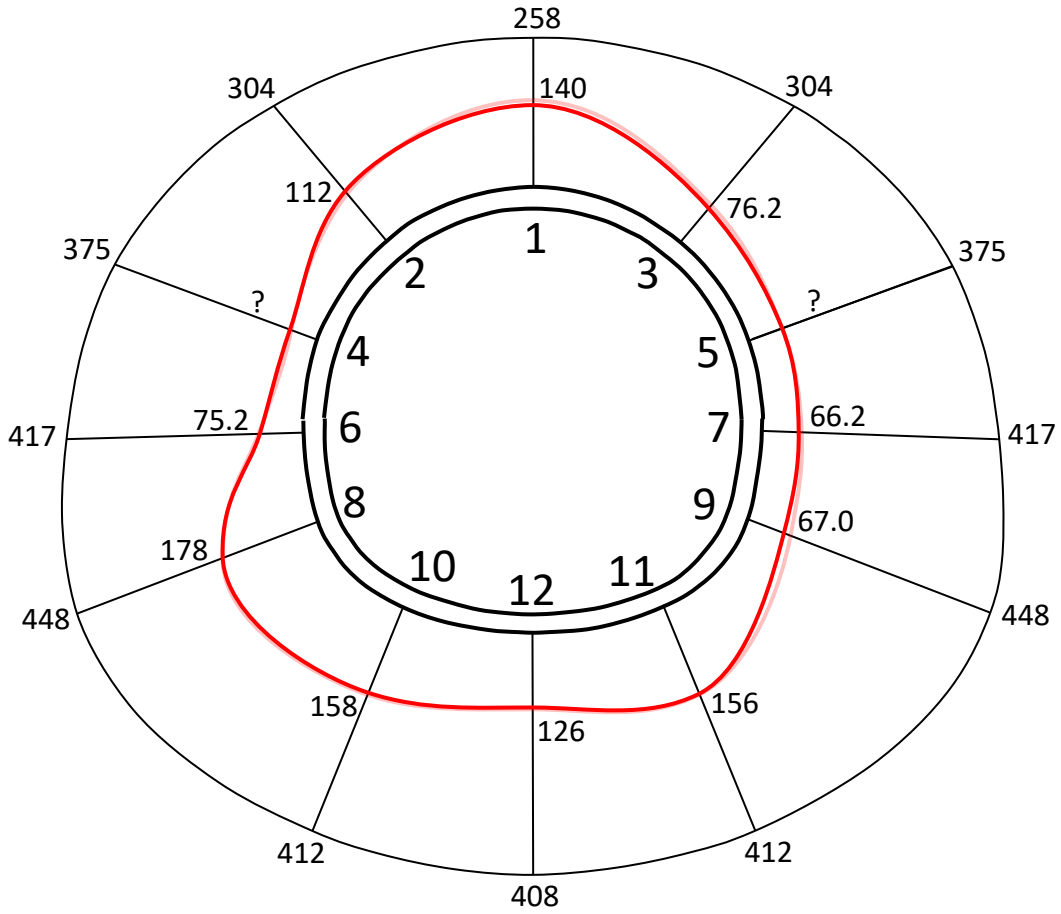
Temperature °C	
Crown	23.0
Bench	20.8
Invert	24.7

MMS I radial pressures

Time from top heading excavation at MMS I:

10 days 21 hours

24/10/96 23:00



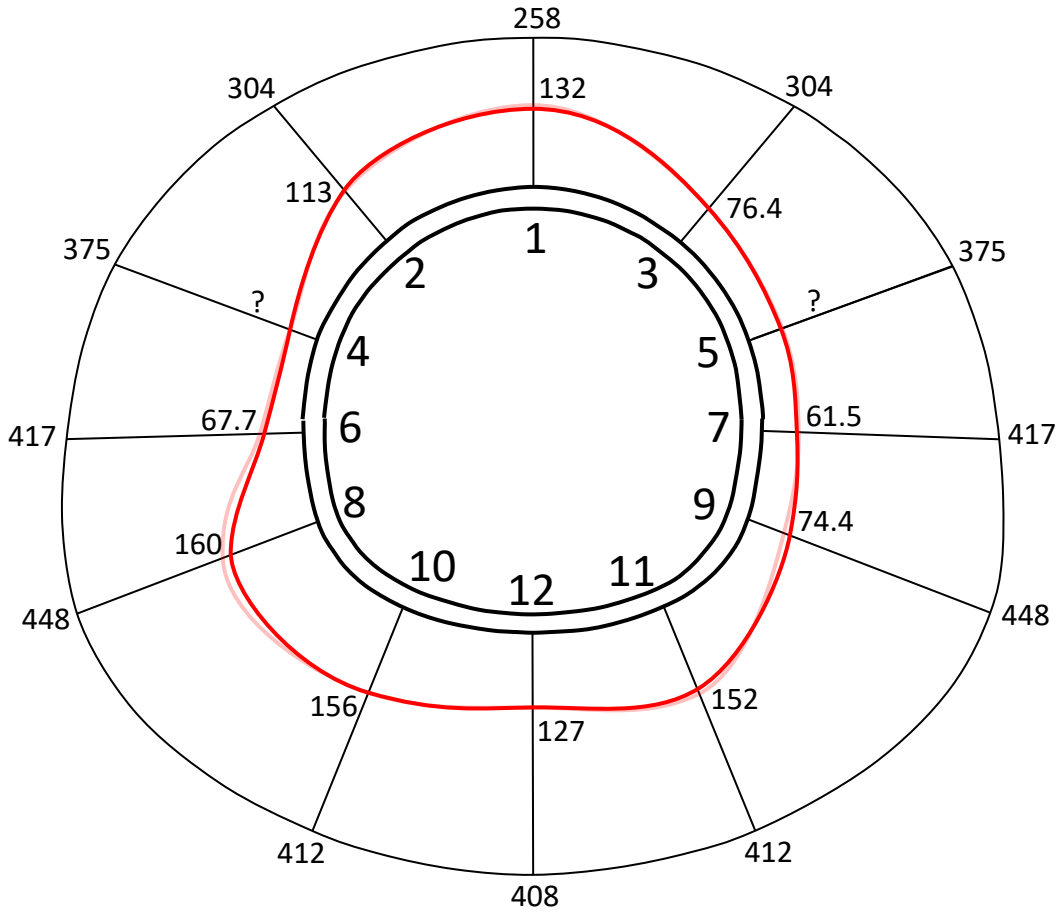
Temperature °C	
Crown	22.6
Bench	20.5
Invert	24.8

MMS I radial pressures

Time from top heading excavation at MMS I:

13 days 2 hours

27/10/96 04:30



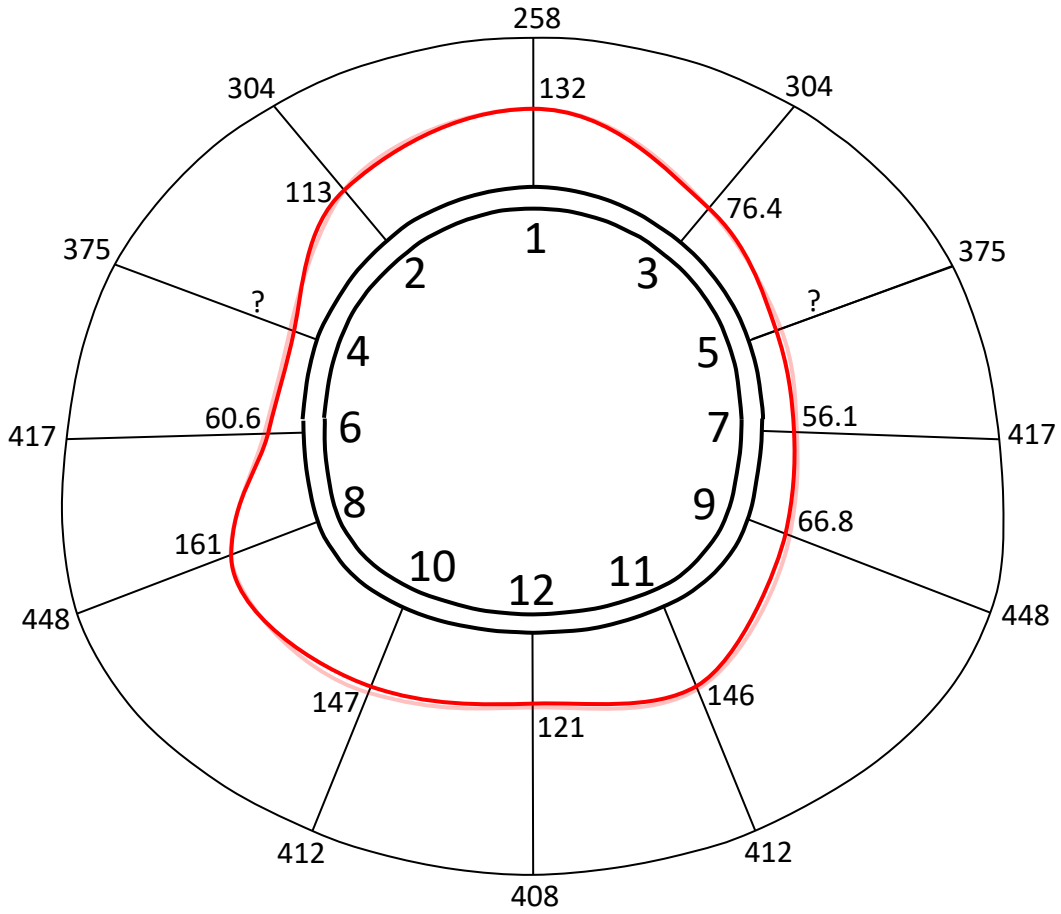
Temperature °C	
Crown	21.7
Bench	19.6
Invert	23.4

MMS I radial pressures

Time from top heading excavation at MMS I:

14 days 11 hours

28/10/96 13:20



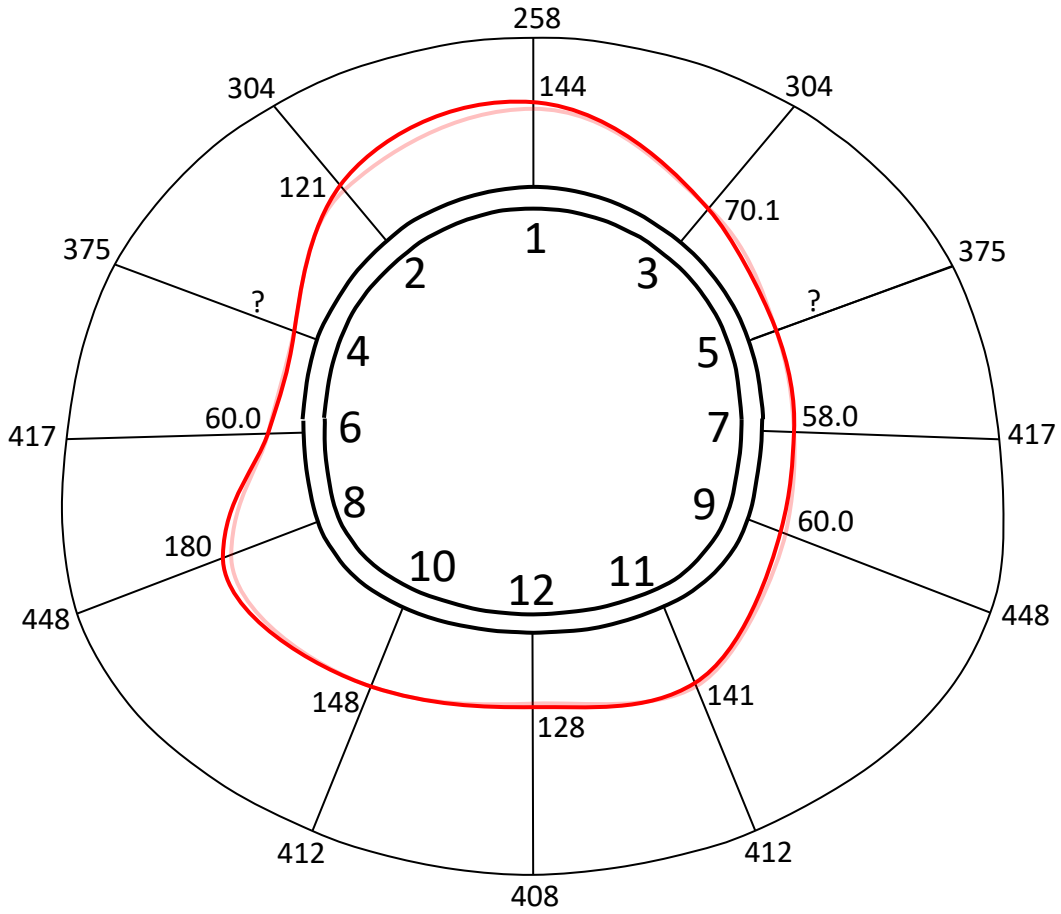
Temperature °C	
Crown	21.6
Bench	19.4
Invert	23.1

MMS I radial pressures

Time from top heading excavation at MMS I:

17 days 11 hours

31/10/96 12:45



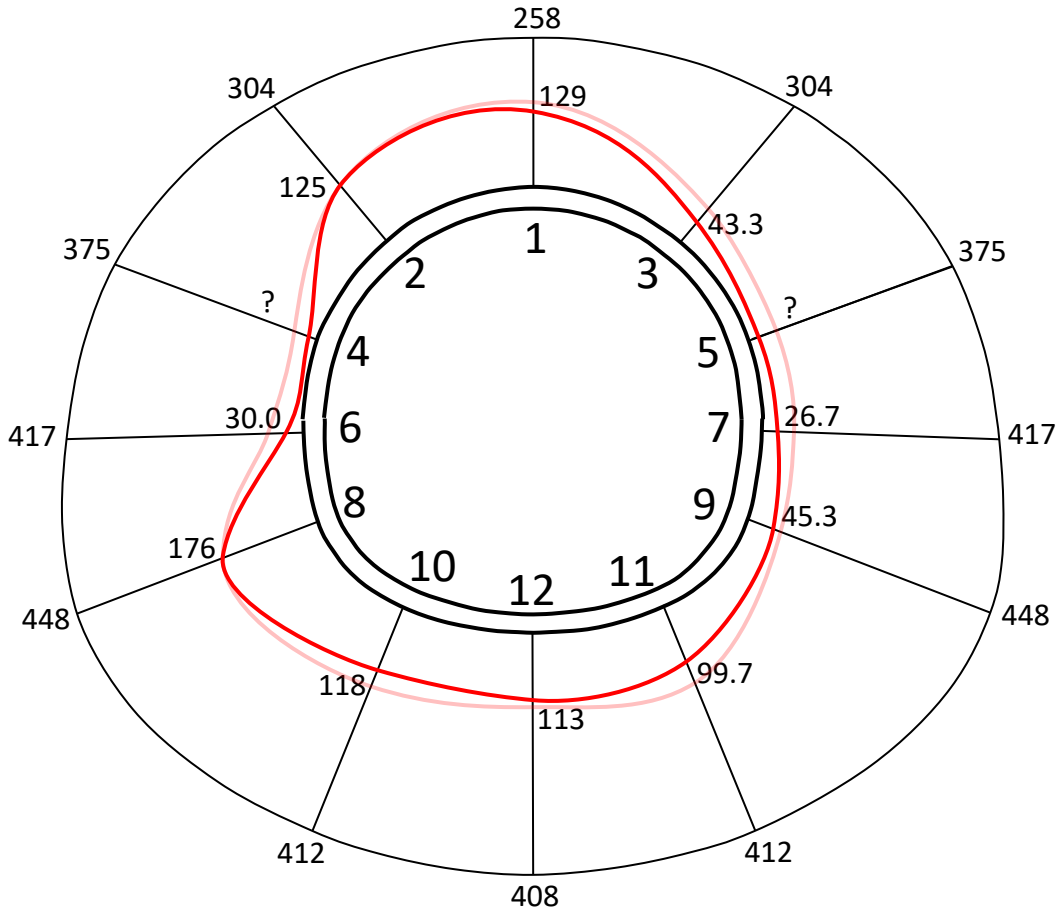
Temperature °C	
Crown	20.9
Bench	18.4
Invert	22.2

MMS I radial pressures

Time from top heading excavation at MMS I:

31 days

14/11/96 12:00



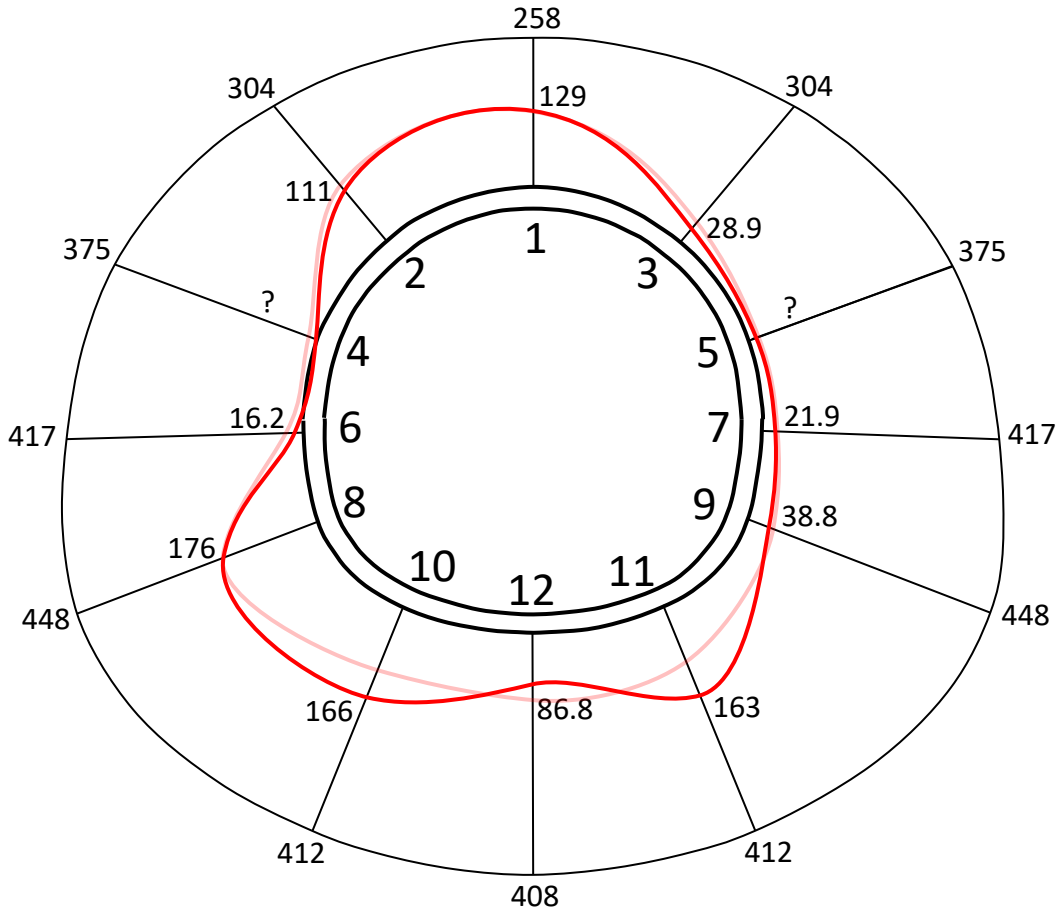
Temperature °C	
Crown	17.9
Bench	15.5
Invert	16.6

MMS I radial pressures

Time from top heading excavation at MMS I:

35 days

18/11/96 11:30



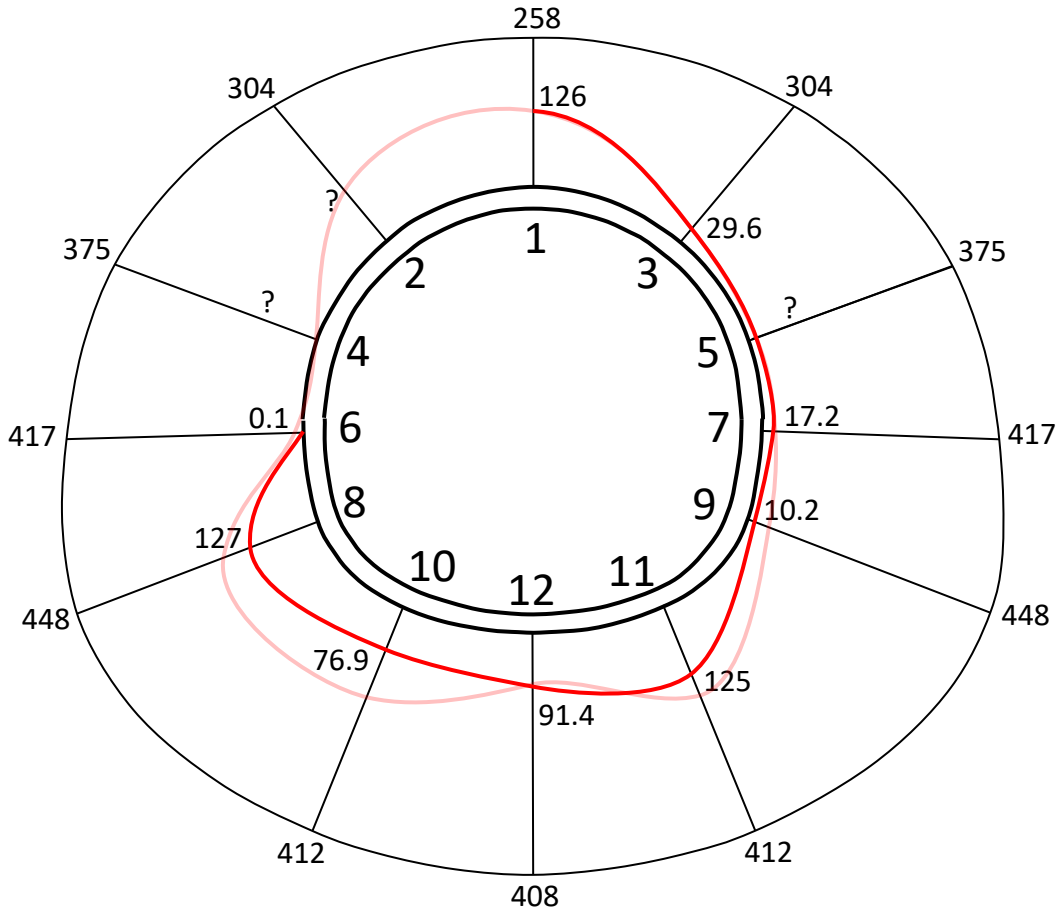
Temperature °C	
Crown	17.9
Bench	15.3
Invert	17.6

MMS I radial pressures

Time from top heading excavation at MMS I:

59 days

12/12/96 12:00



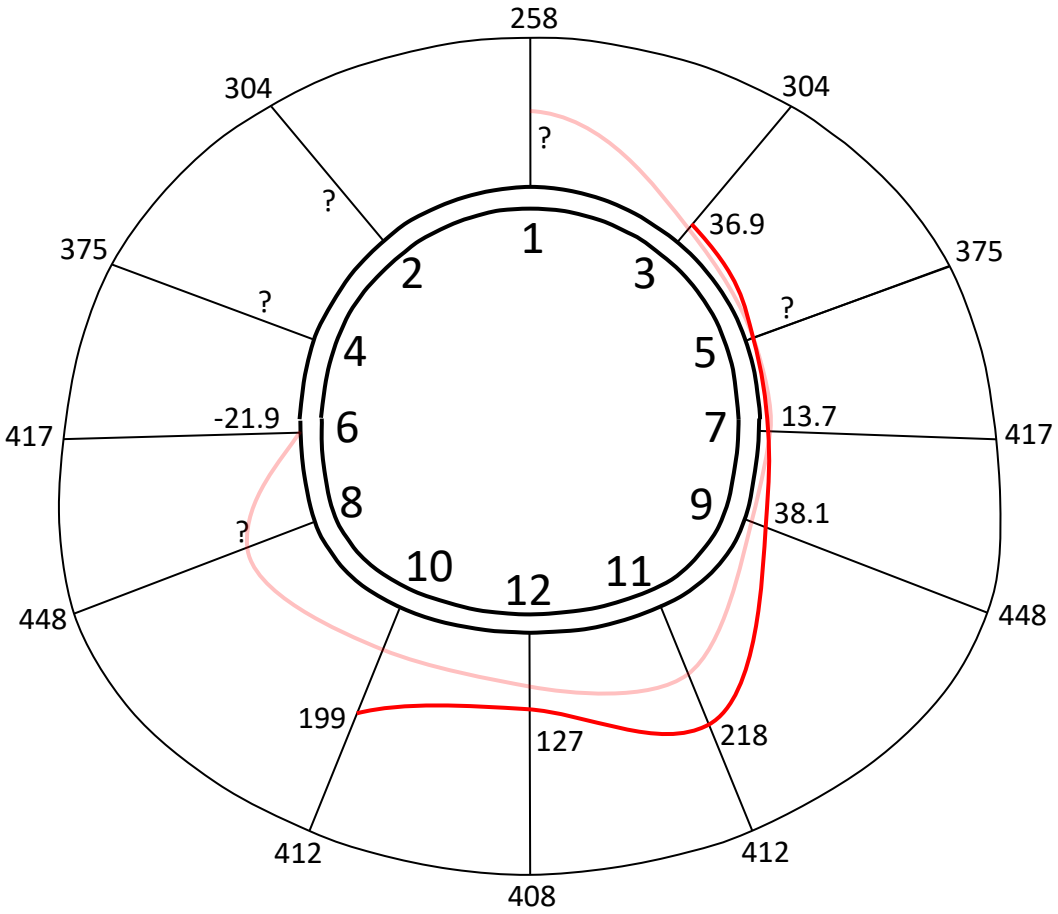
Temperature °C	
Crown	15.5
Bench	14.3
Invert	15.5

MMS I radial pressures

Time from top heading excavation at MMS I:

171 days

3/4/97 16:00



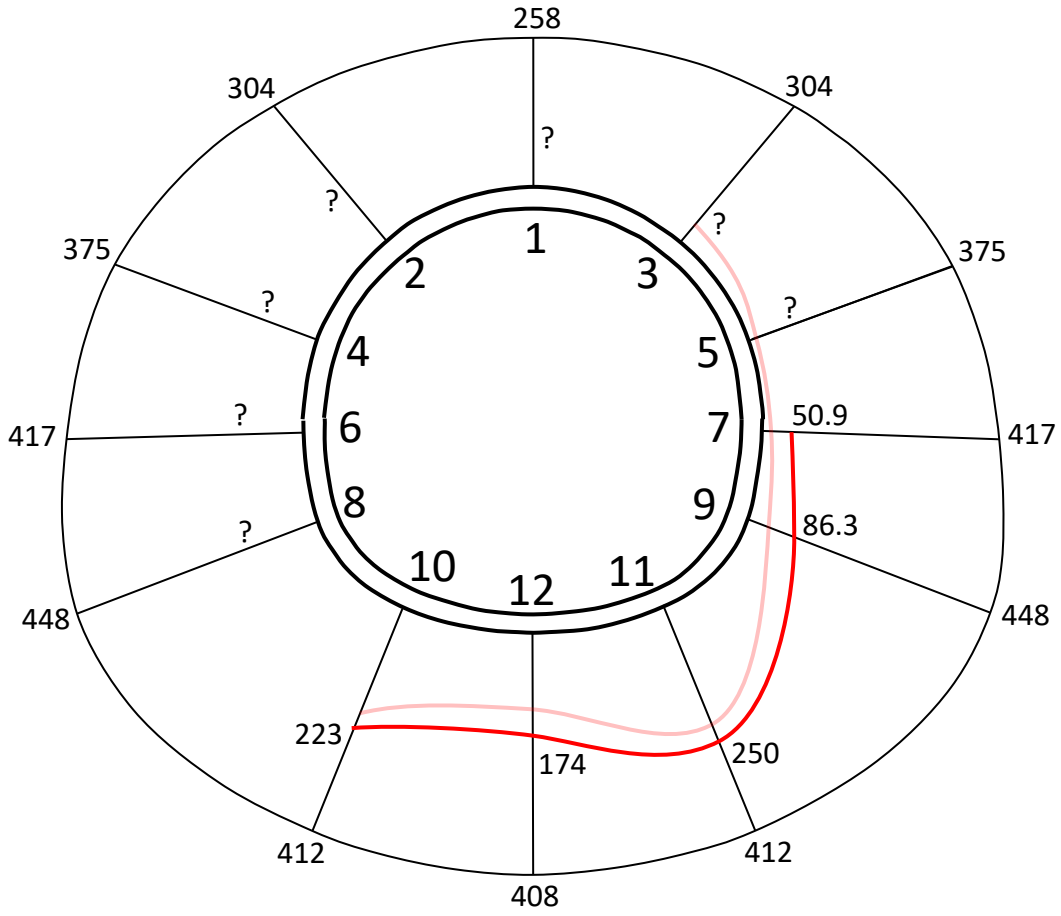
Temperature °C	
Crown	13.1
Bench	12.9
Invert	13.0

MMS I radial pressures

Time from top heading excavation at MMS I:

2.1 years

10/11/98 00:00



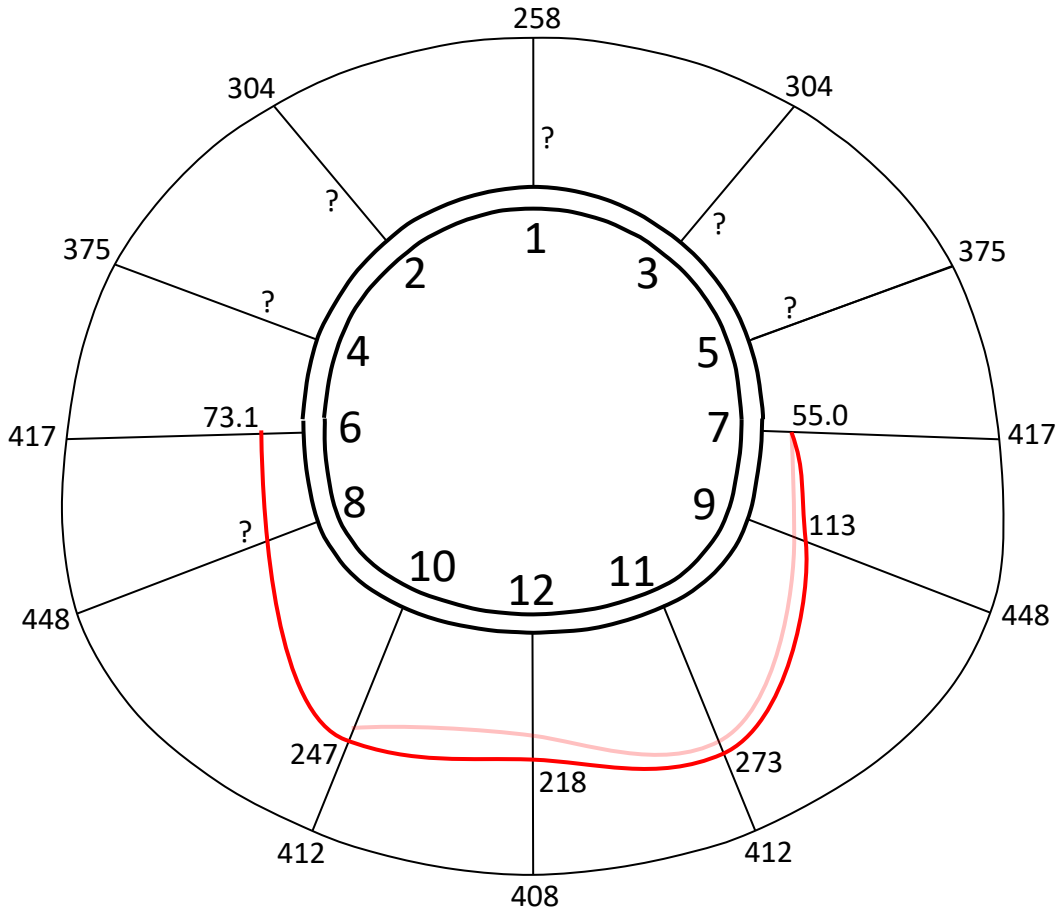
Temperature °C	
Crown	15.9
Bench	16.0
Invert	16.7

MMS I radial pressures

Time from top heading excavation at MMS I:

7.7 years

25/6/04 01:30



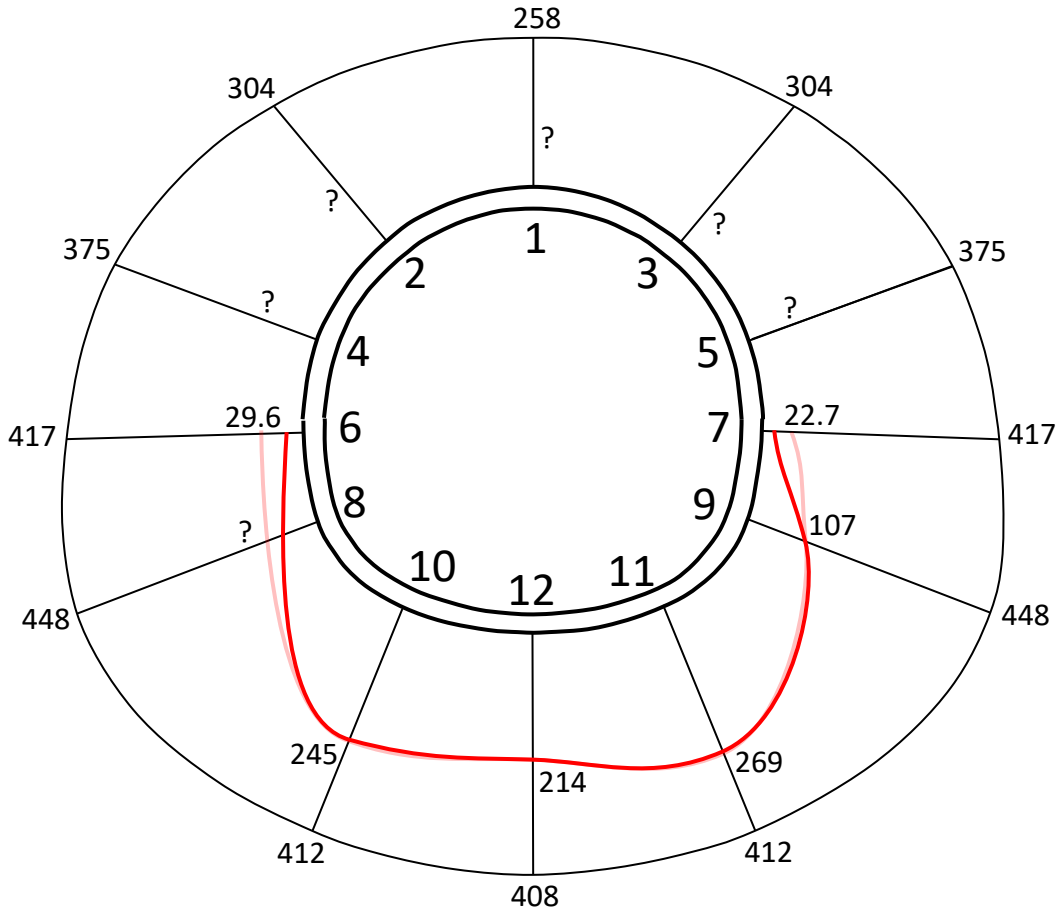
Temperature °C	
Crown	17.2
Bench	17.1
Invert	17.5

MMS I radial pressures

Time from top heading excavation at MMS I:

8.4 years

24/2/05 01:30



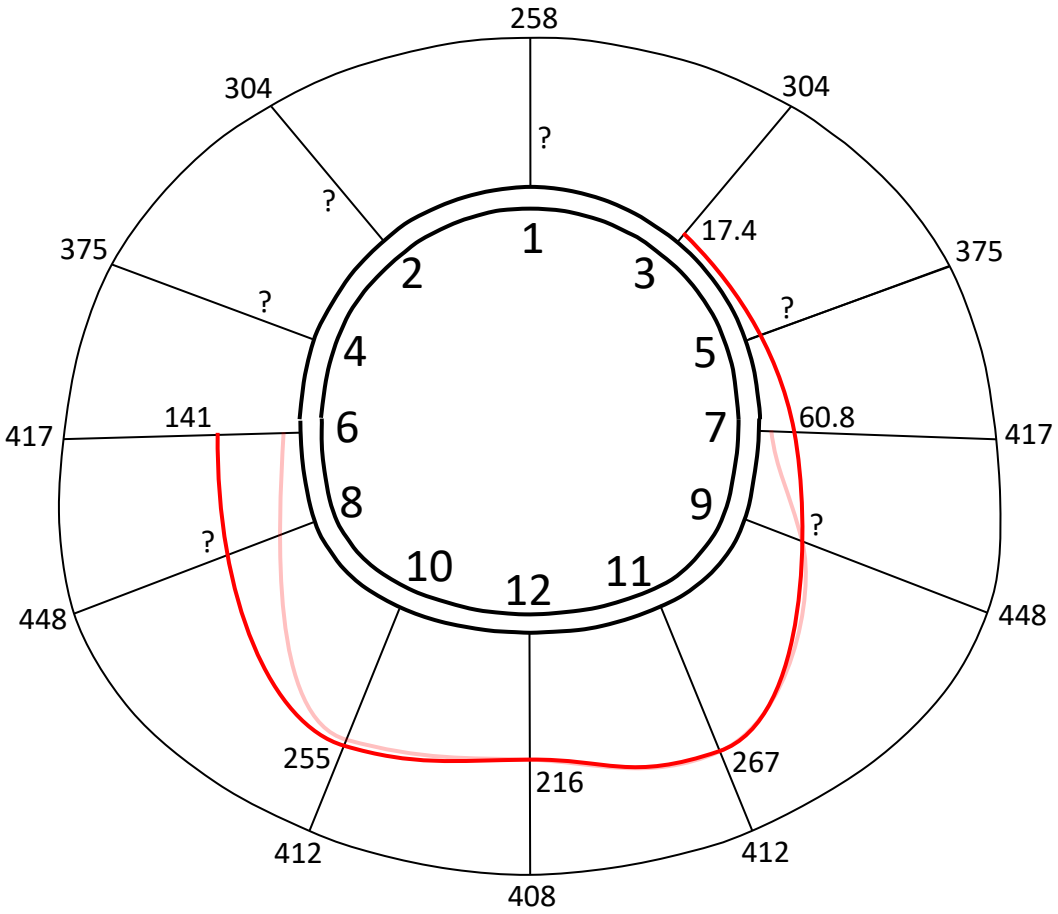
Temperature °C	
Crown	14.3
Bench	14.9
Invert	15.7

MMS I radial pressures

Time from top heading excavation at MMS I:

18.5 years

10/4/15 01:30



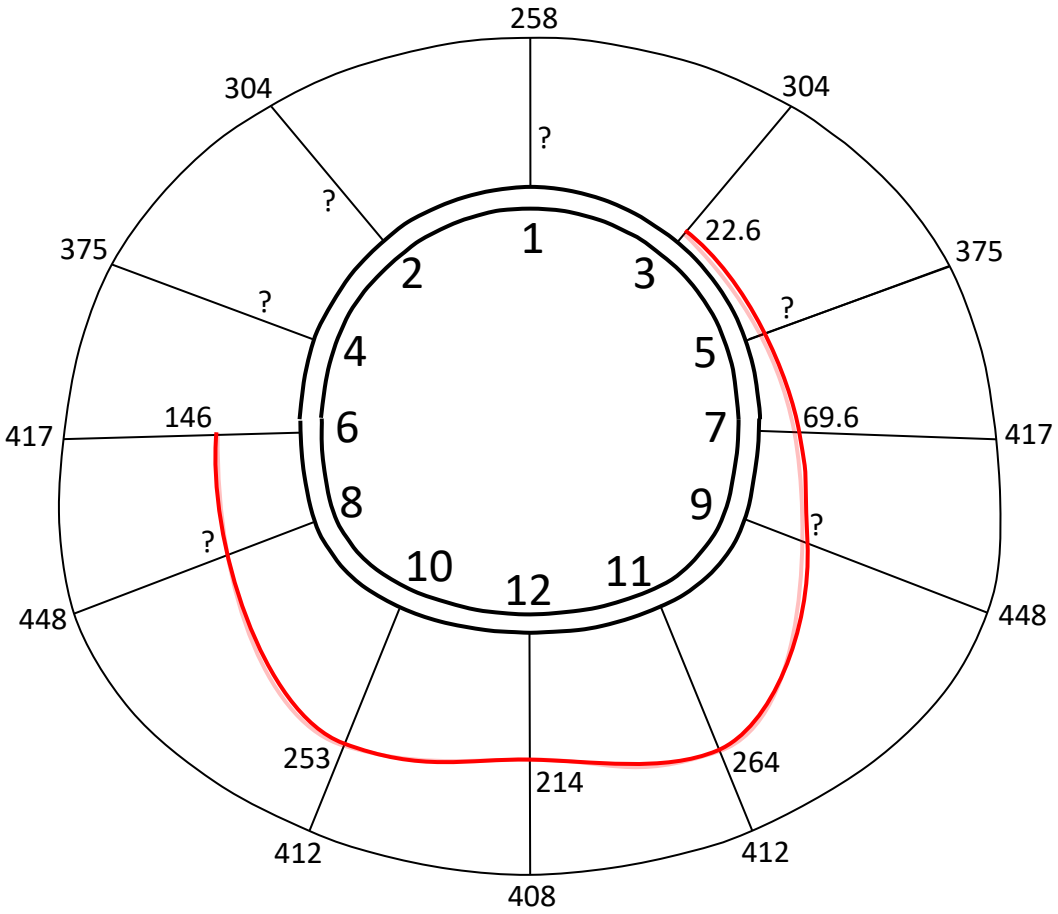
Temperature °C	
Crown	13.6
Bench	14.6
Invert	14.6

MMS I radial pressures

Time from top heading excavation at MMS I:

18.6 years

14/5/15 01:30



Temperature °C	
Crown	14.3
Bench	14.2
Invert	15.3

MMS VIII radial pressures

These are shown relative to in situ stress with $K_0 = 1.5$.

Stresses from the previous stage are shown faded.

Approximate position of top heading, bench and invert according to construction records shown in long section at the bottom of each page. These are approximate because progress was only recorded once per day.

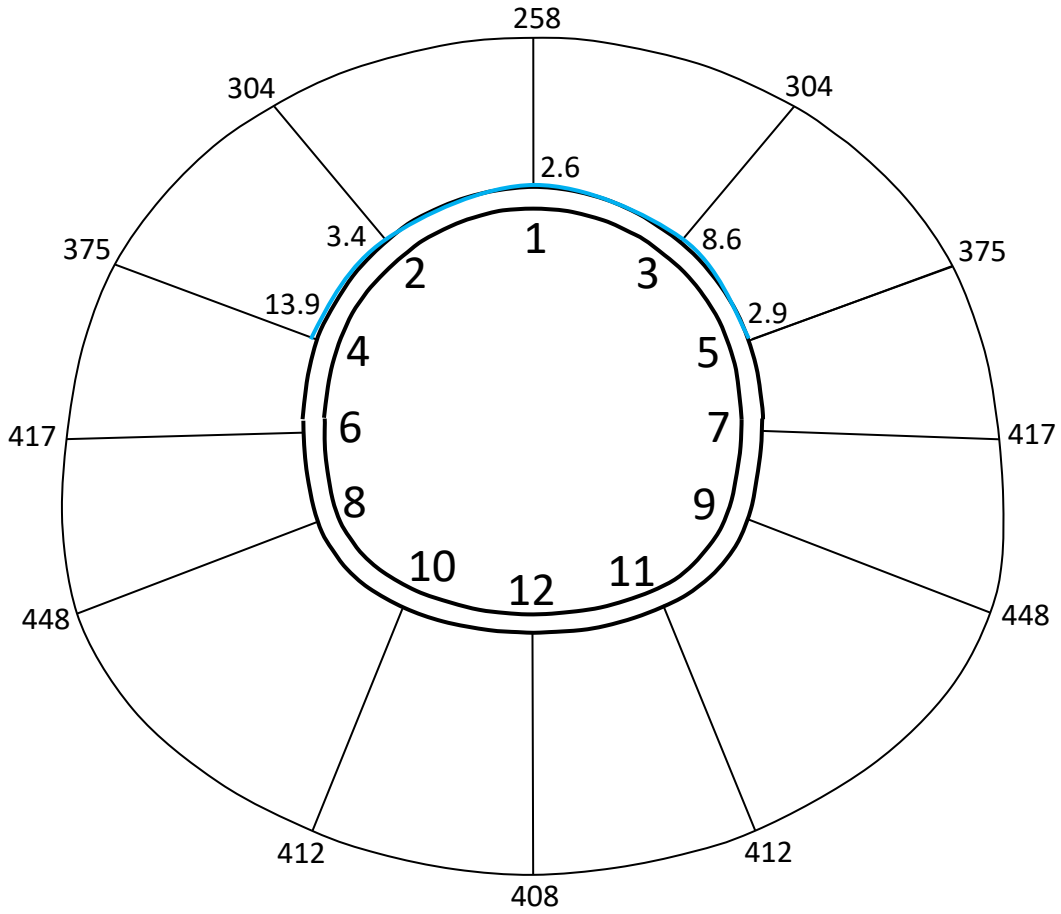
Average temperatures measured by thermistors attached to the radial pressure cells are shown for top heading, bench and invert on the right hand side.

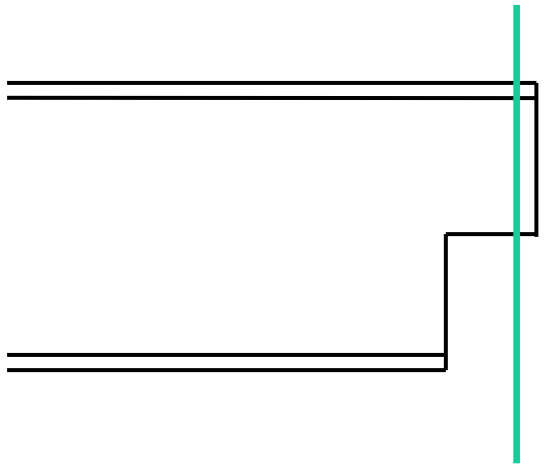
MMS VIII radial pressures

Time from top heading excavation at MMS VIII:

0 hours

26/10/96 12:00





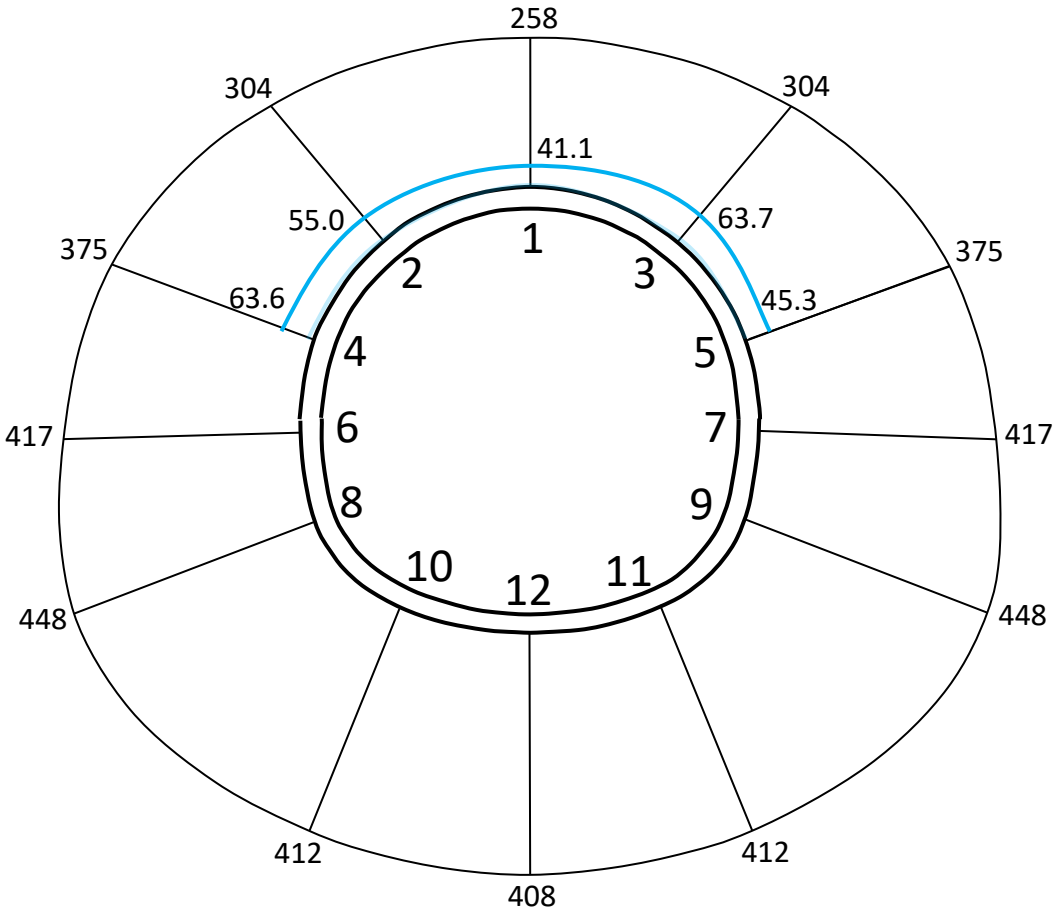
Temperature °C	
Crown	20.3
Bench	-
Invert	-

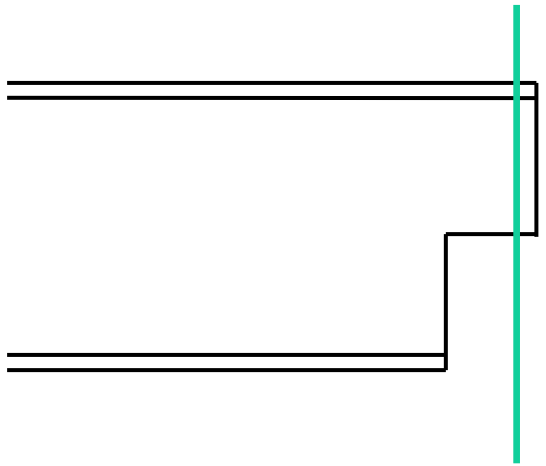
MMS VIII radial pressures

Time from top heading excavation at MMS VIII:

17.5 hours

27/10/96 05:30





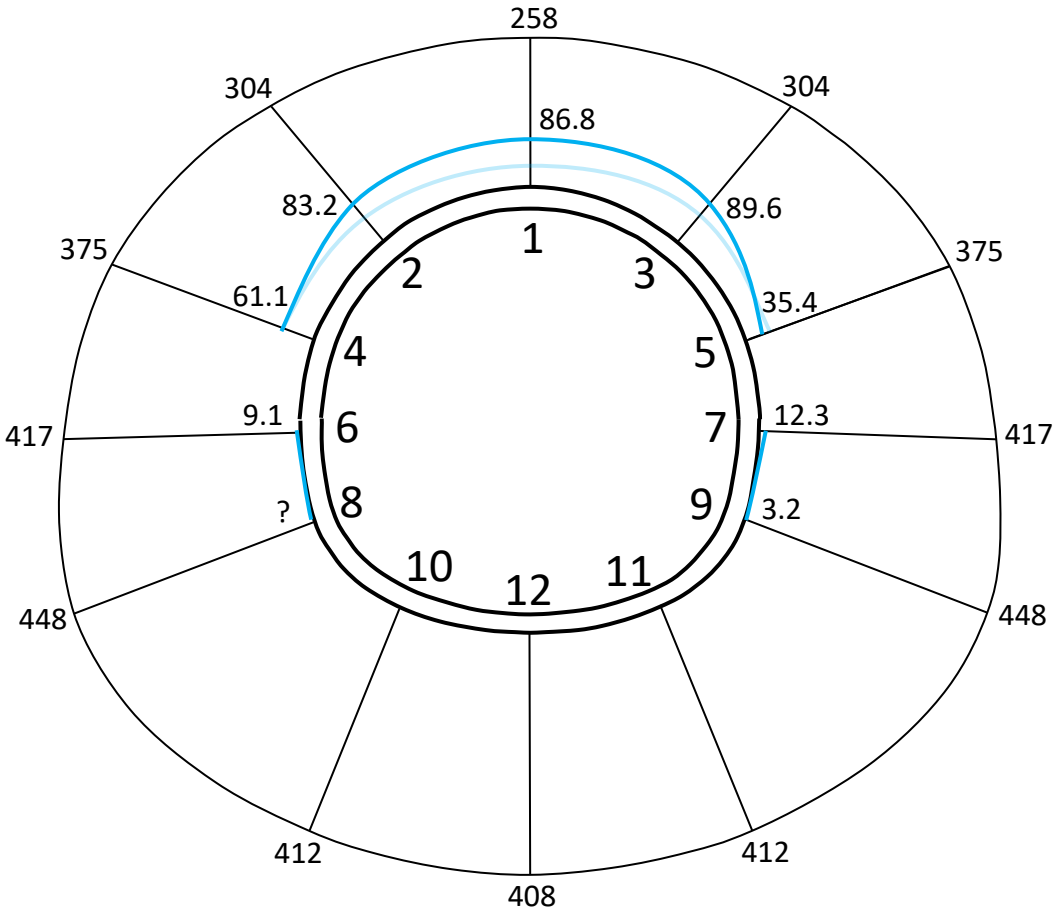
Temperature °C	
Crown	33.6
Bench	-
Invert	-

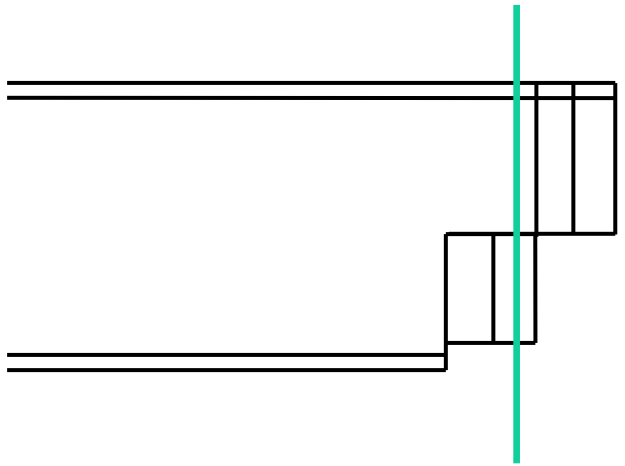
MMS VIII radial pressures

Time from top heading excavation at MMS VIII:

29 hours

27/10/96 17:00





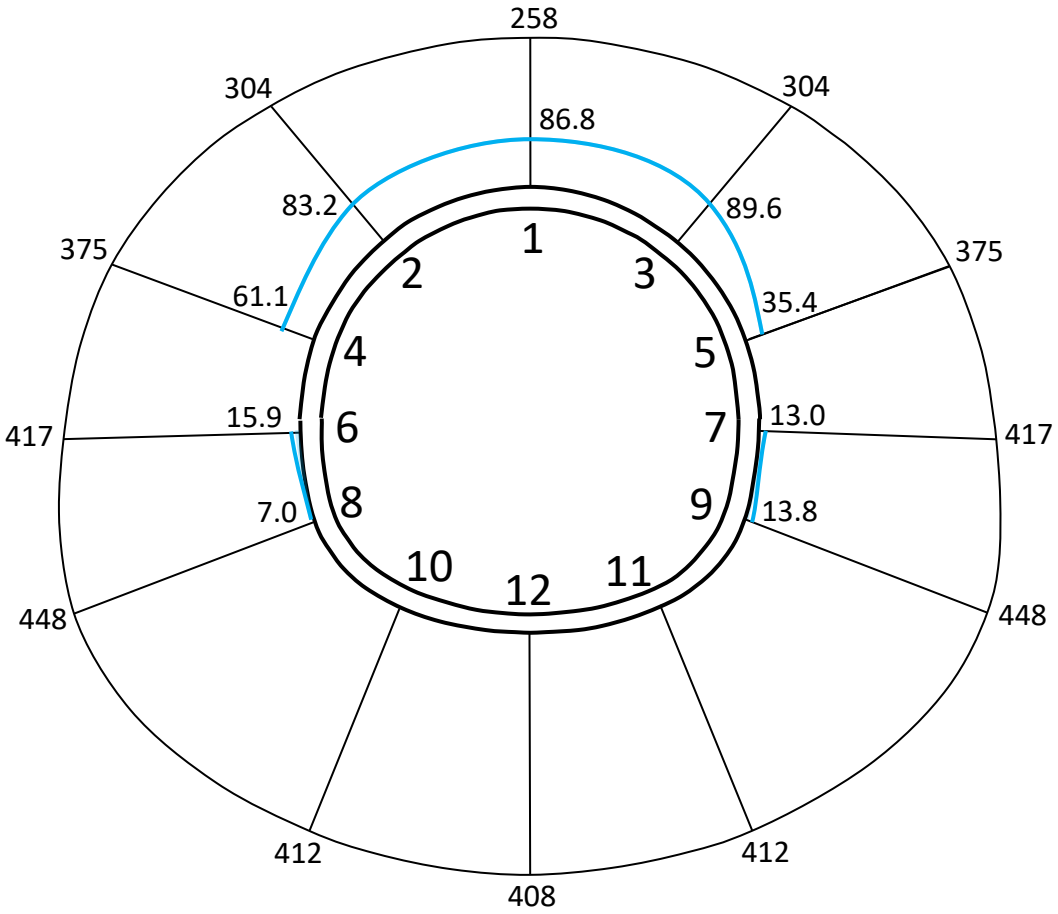
Temperature °C	
Crown	33.0
Bench	20.1
Invert	-

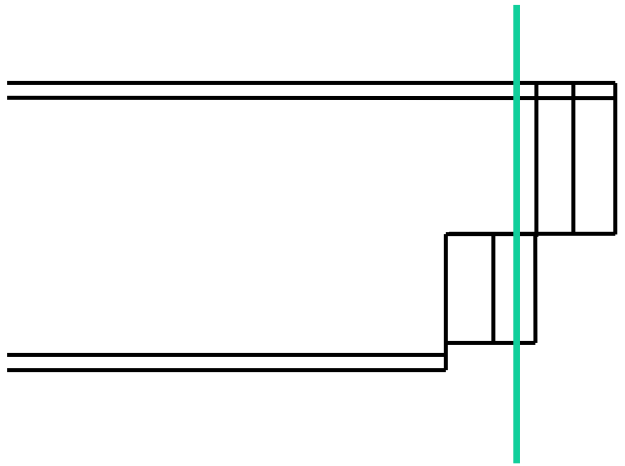
MMS VIII radial pressures

Time from top heading excavation at MMS VIII:

31 hours

27/10/96 19:00





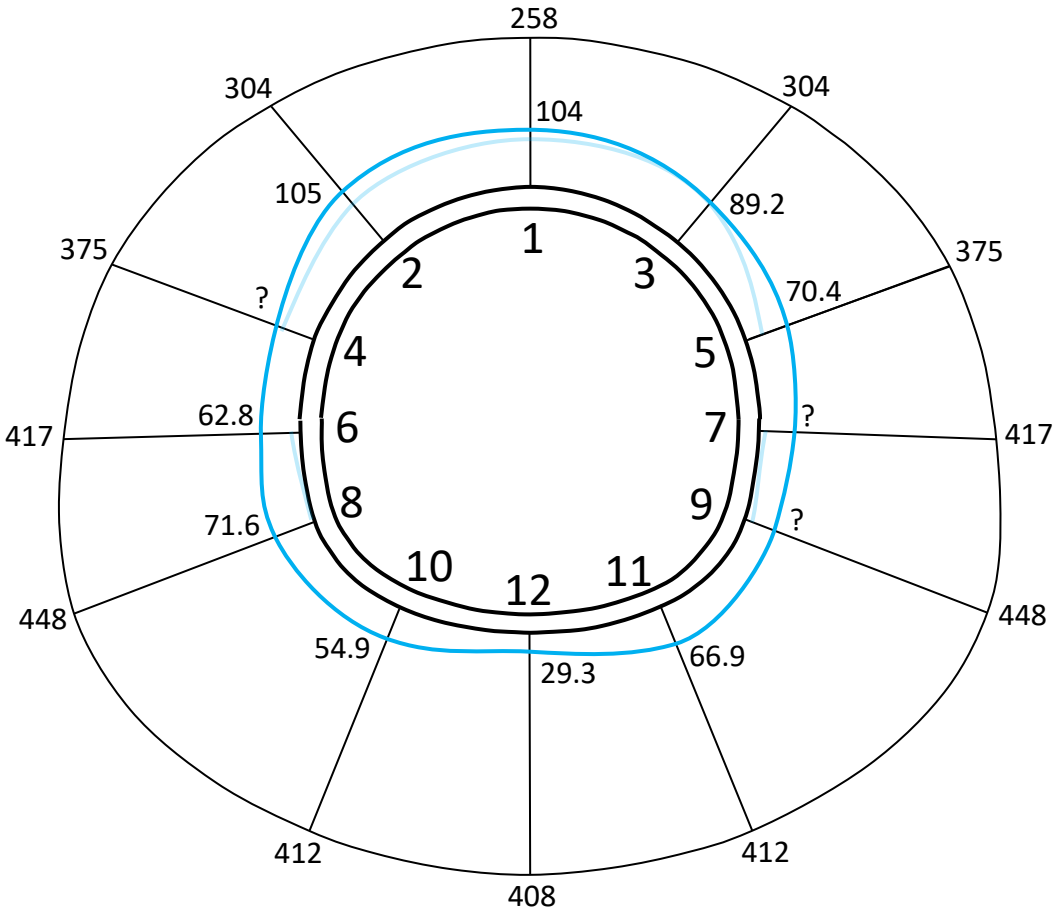
Temperature °C	
Crown	33.0
Bench	21.8
Invert	-

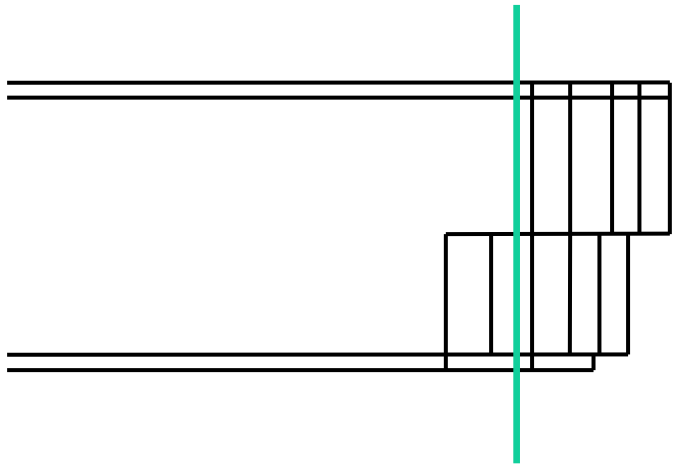
MMS VIII radial pressures

Time from top heading excavation at MMS VIII:

2 days 3.5 hours

28/10/96 15:30





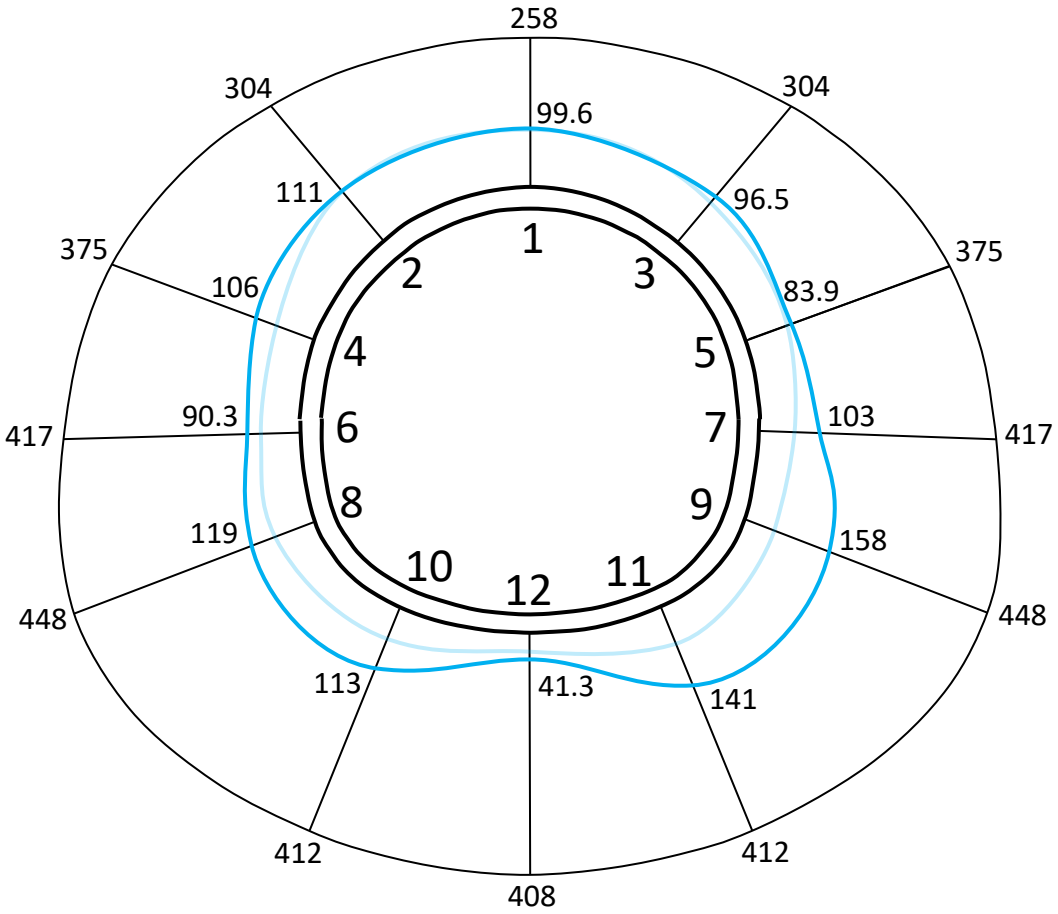
Temperature °C	
Crown	28.6
Bench	21.5
Invert	25.5

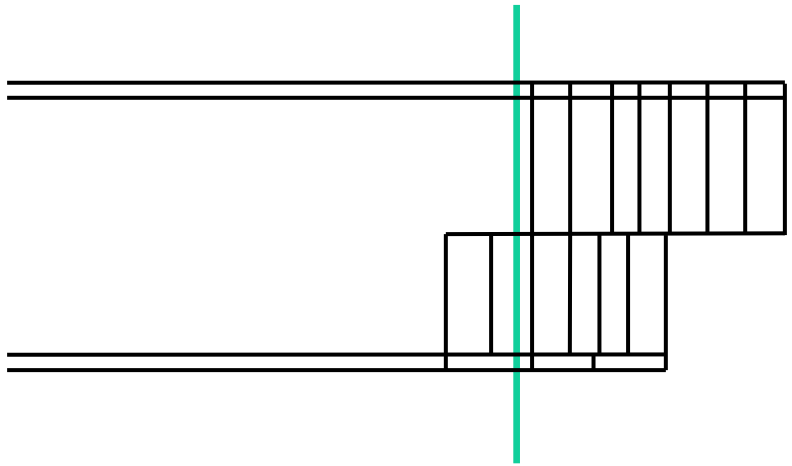
MMS VIII radial pressures

Time from top heading excavation at MMS VIII:

2 days 22 hours

29/10/96 10:00





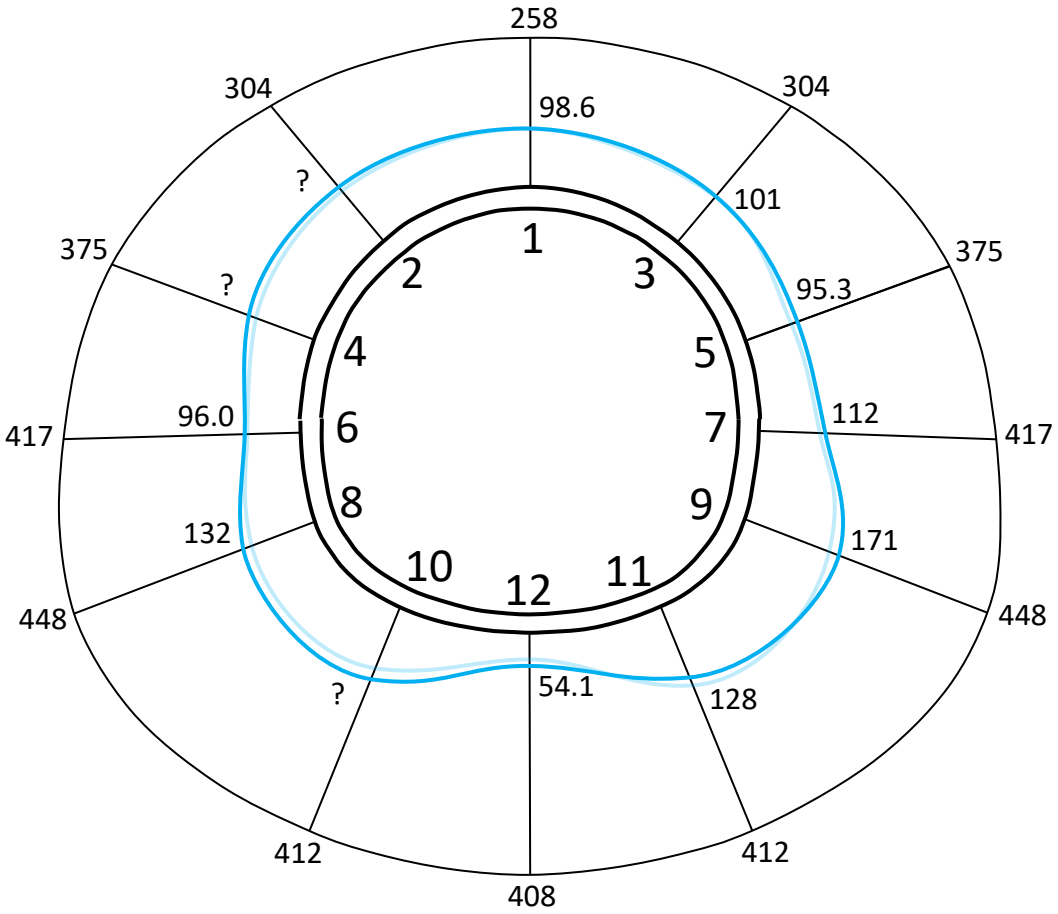
Temperature °C	
Crown	26.6
Bench	30.2
Invert	31.5

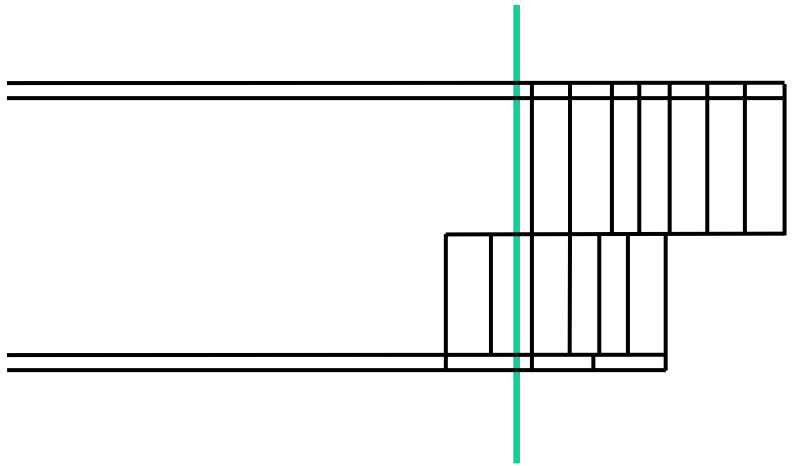
MMS VIII radial pressures

Time from top heading excavation at MMS VIII:

3 days 11 hours

29/10/96 23:00





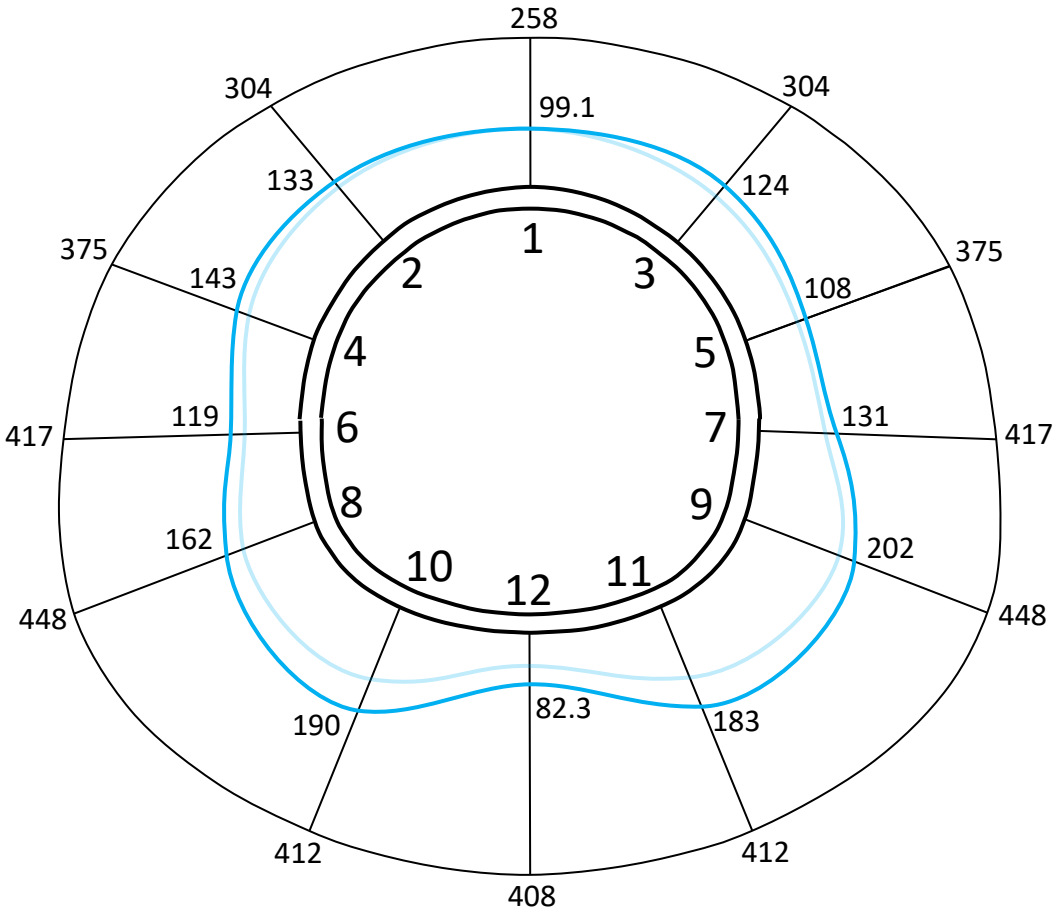
Temperature °C	
Crown	27.4
Bench	28.0
Invert	29.7

MMS VIII radial pressures

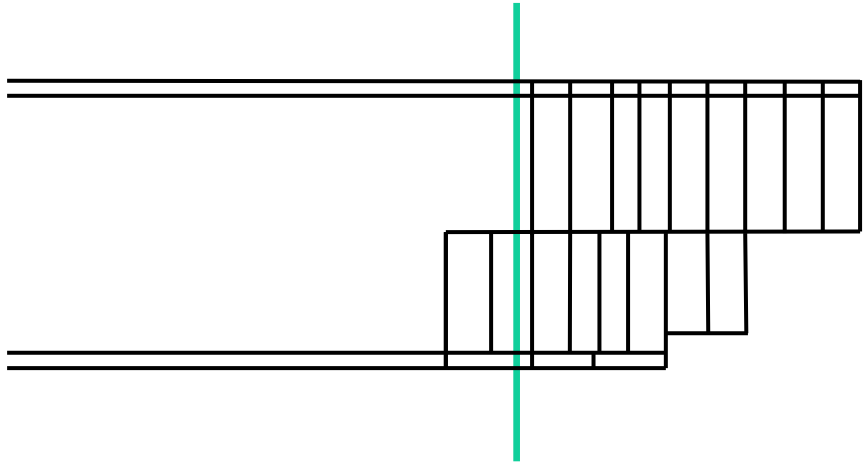
Time from top heading excavation at MMS VIII:

4 days 4 hours

30/10/96 16:00



Temperature °C	
Crown	27.8
Bench	28.0
Invert	30.5

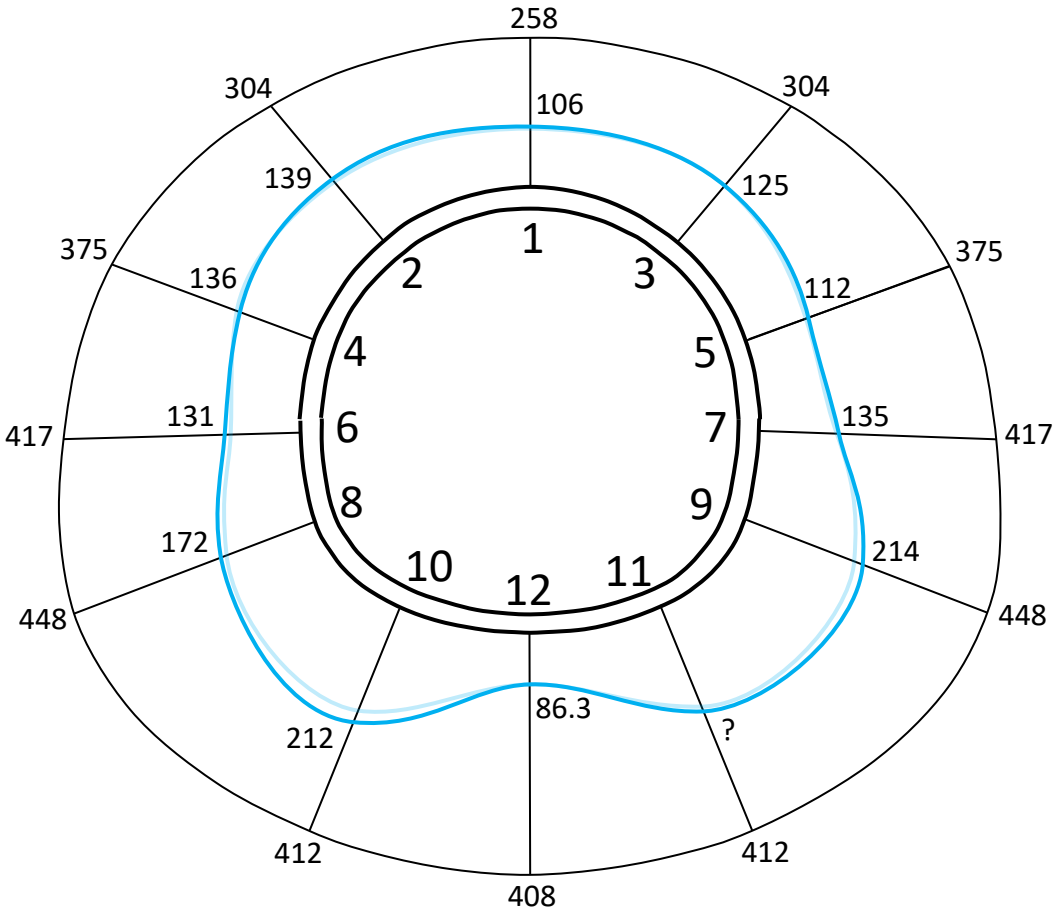


MMS VIII radial pressures

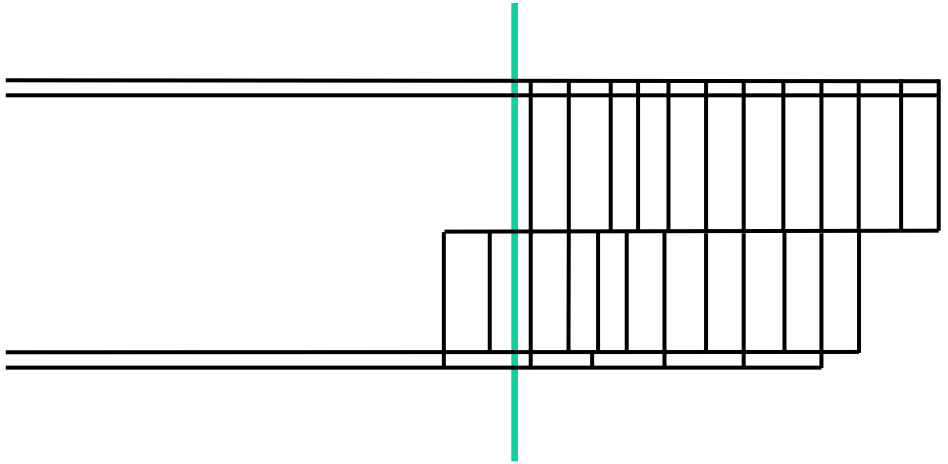
Time from top heading excavation at MMS VIII:

4 days 23 hours

31/10/96 11:00



Temperature °C	
Crown	26.2
Bench	26.3
Invert	29.6

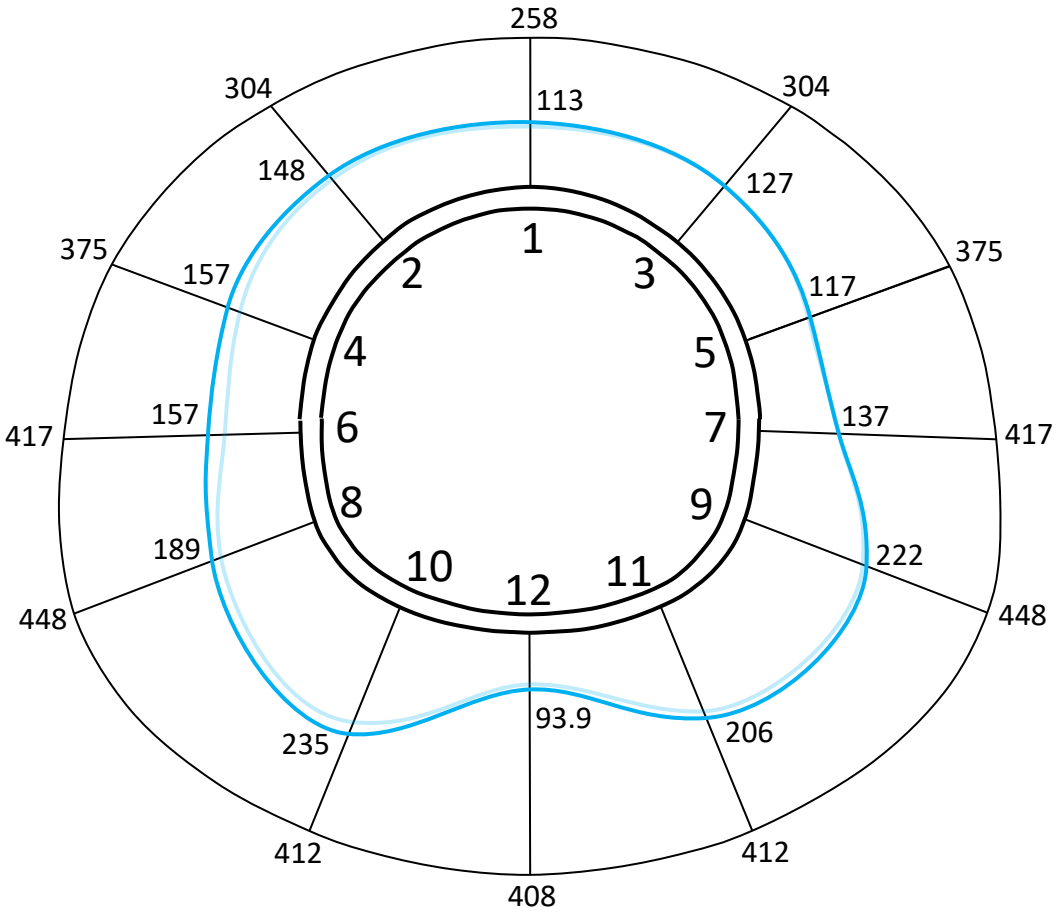


MMS VIII radial pressures

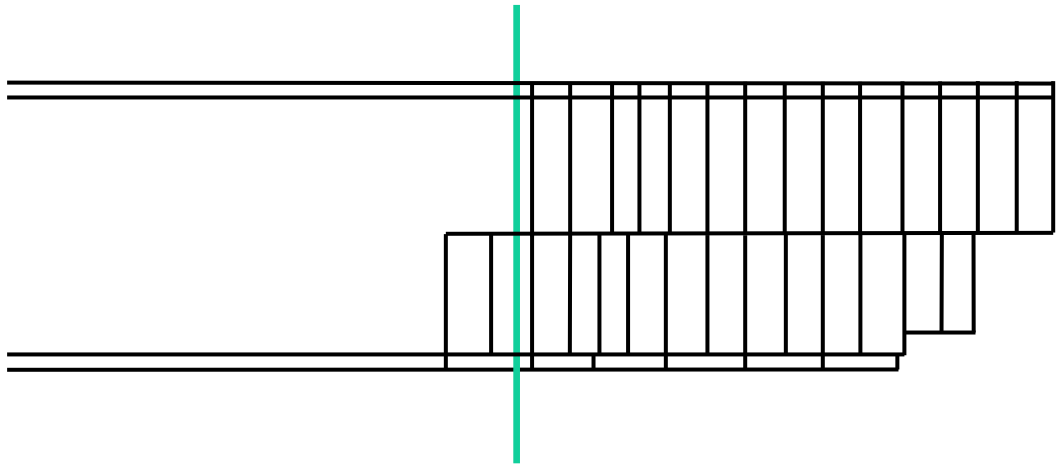
Time from top heading excavation at MMS VIII:

6 days

01/11/96 11:30



Temperature °C	
Crown	26.3
Bench	25.3
Invert	28.4

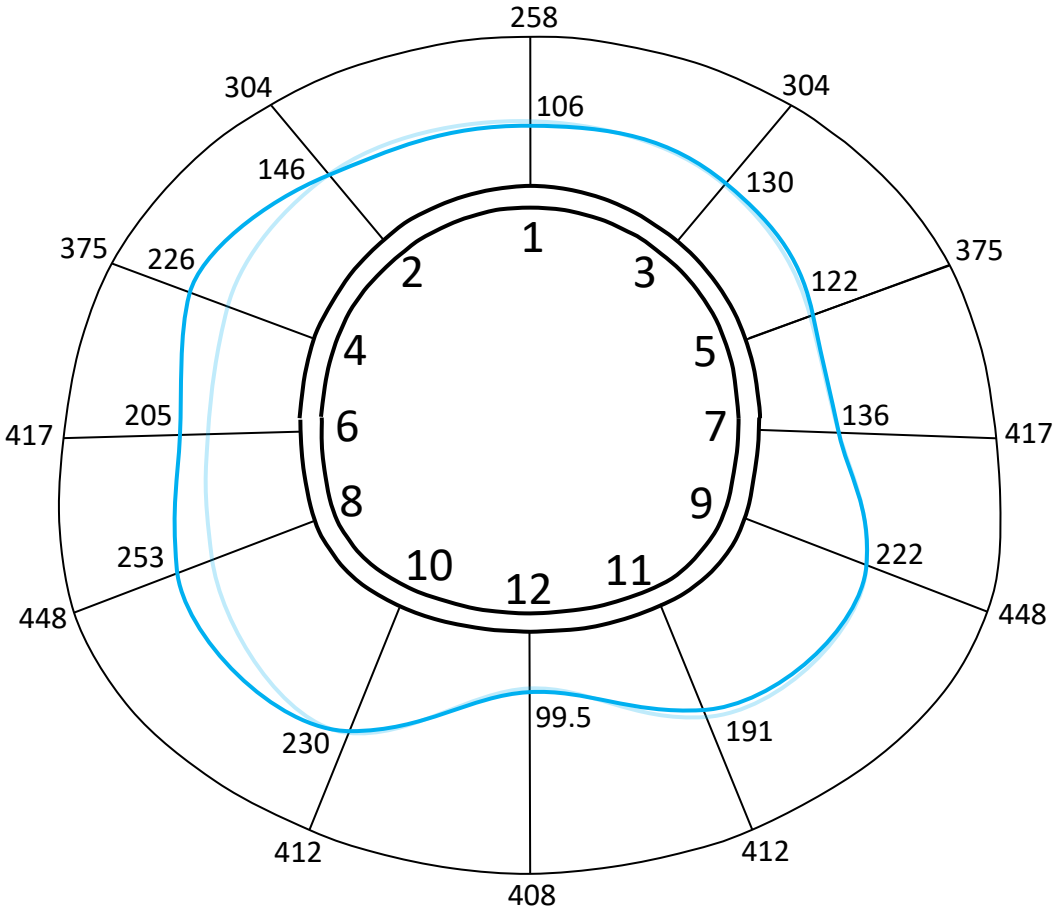


MMS VIII radial pressures

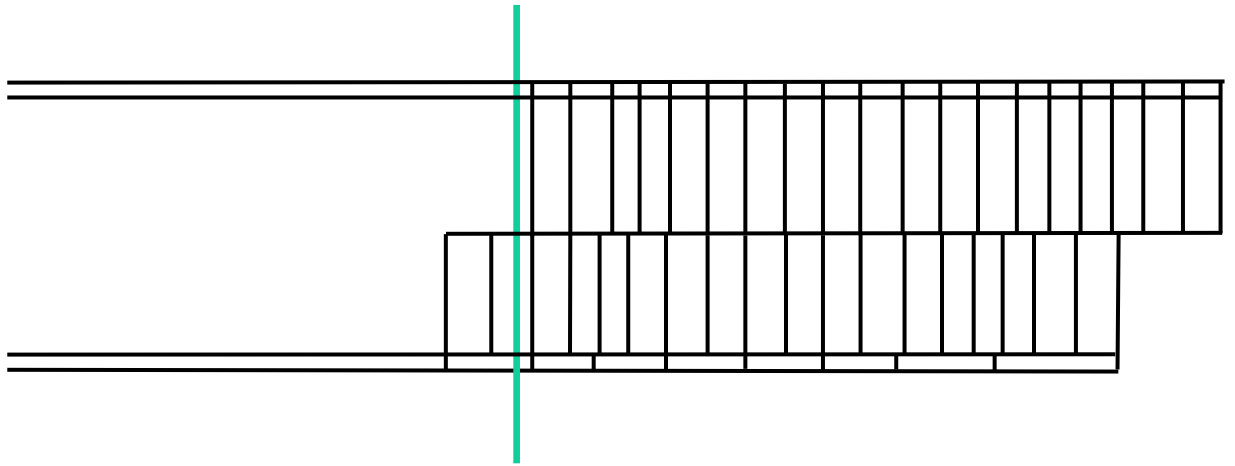
Time from top heading excavation at MMS VIII:

9 days

04/11/96 10:00



Temperature °C	
Crown	25.7
Bench	23.1
Invert	24.6

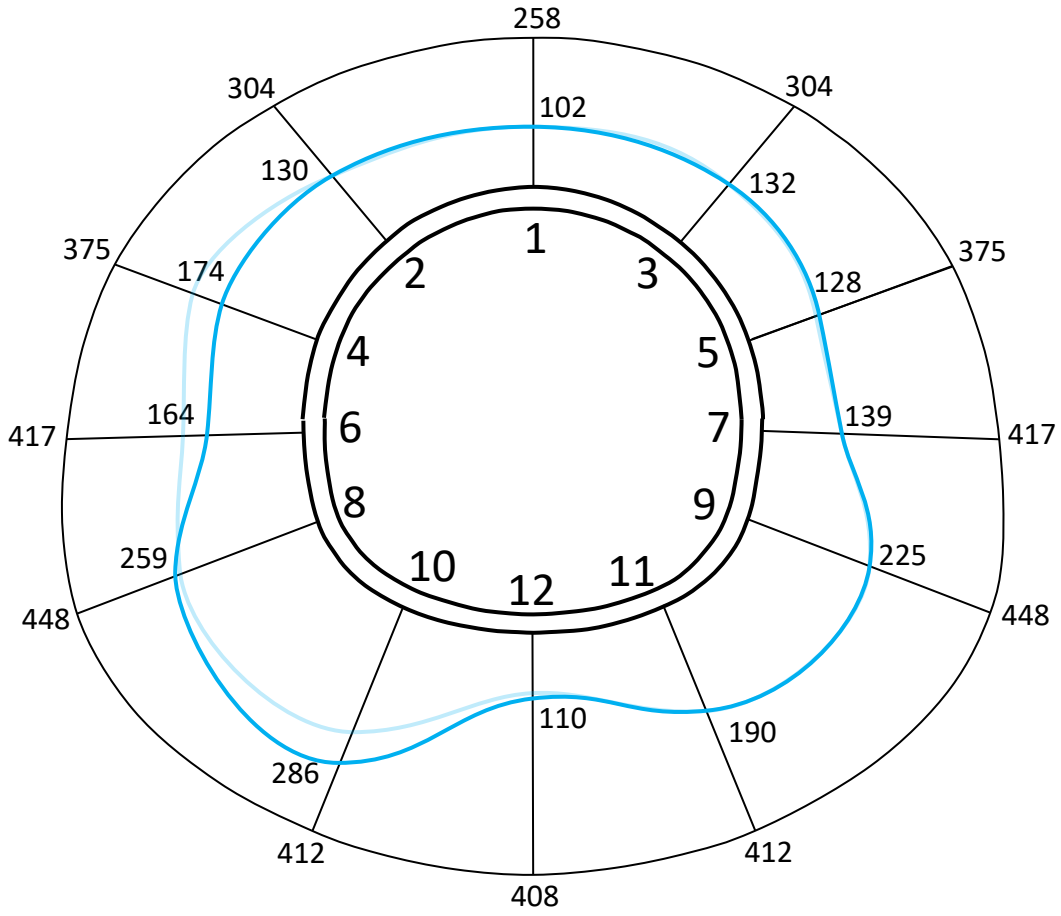


MMS VIII radial pressures

Time from top heading excavation at MMS VIII:

11 days

06/11/96 11:00



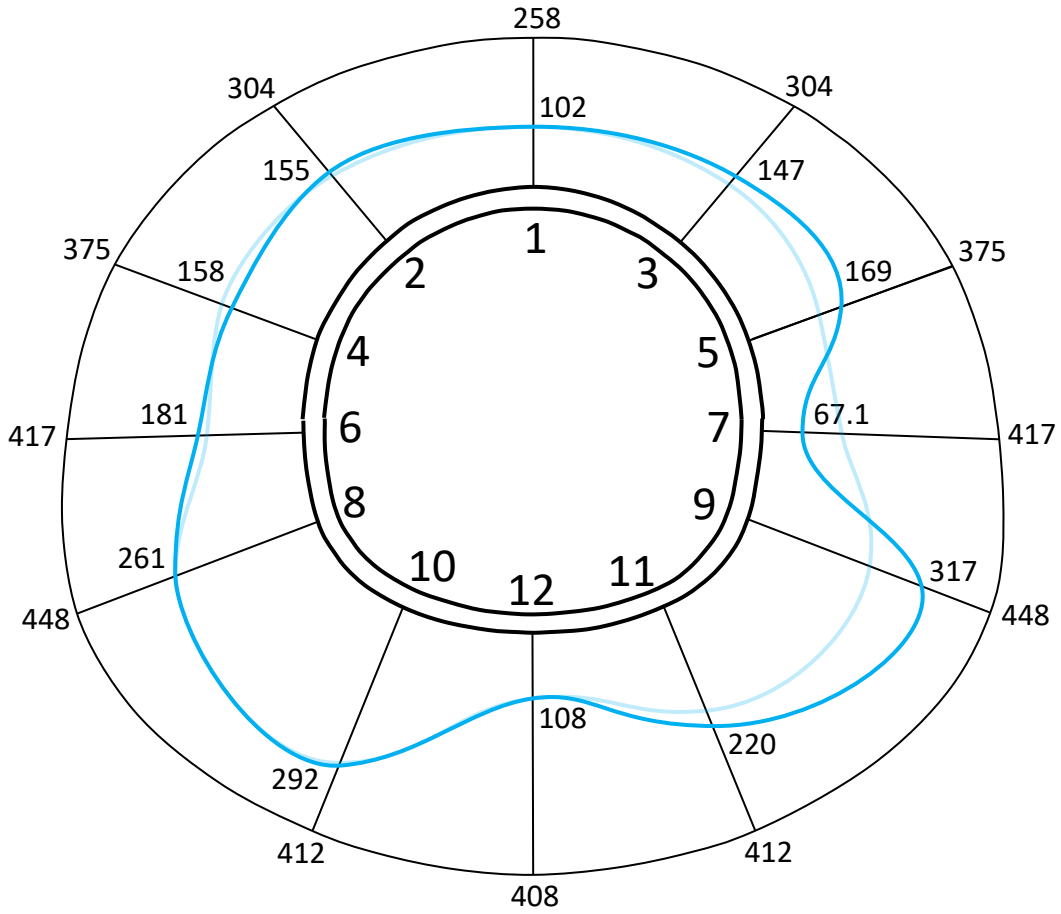
Temperature °C	
Crown	23.8
Bench	21.5
Invert	23.9

MMS VIII radial pressures

Time from top heading excavation at MMS VIII:

13 days

08/11/96 12:00



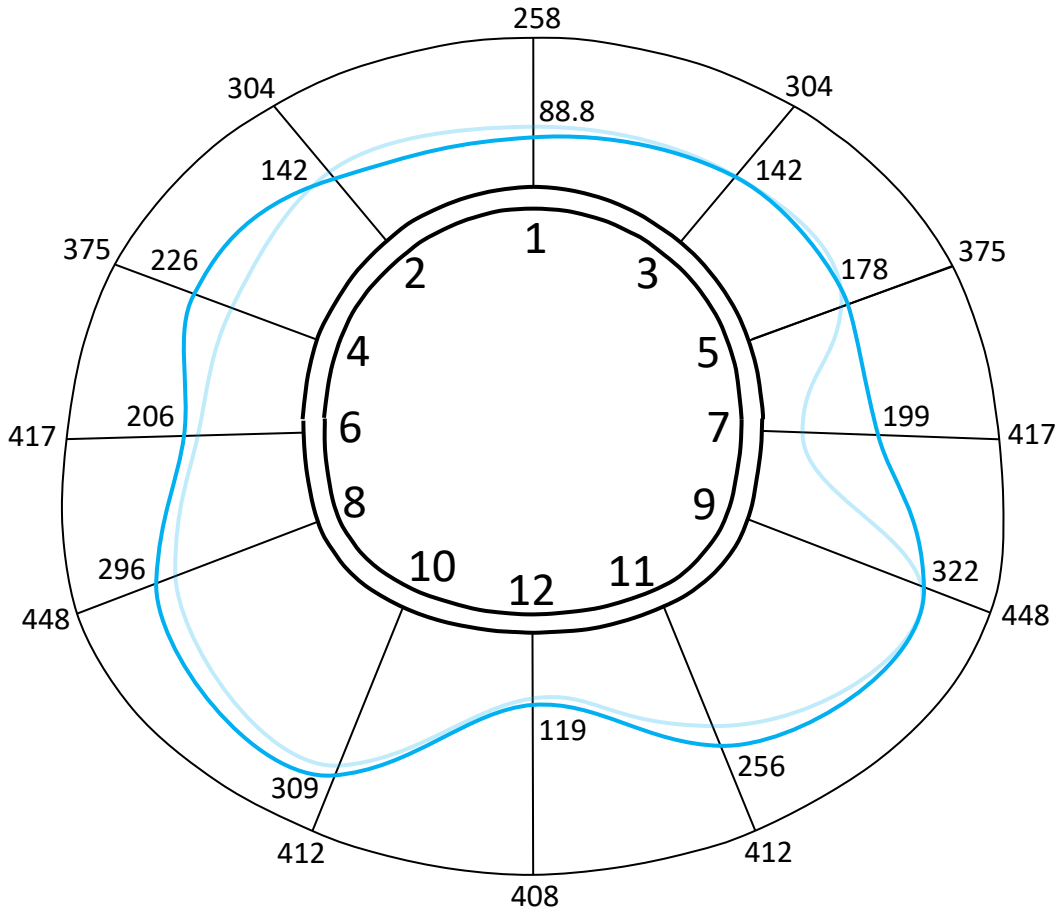
Temperature °C	
Crown	22.0
Bench	21.6
Invert	23.5

MMS VIII radial pressures

Time from top heading excavation at MMS VIII:

19 days

14/11/96 12:45



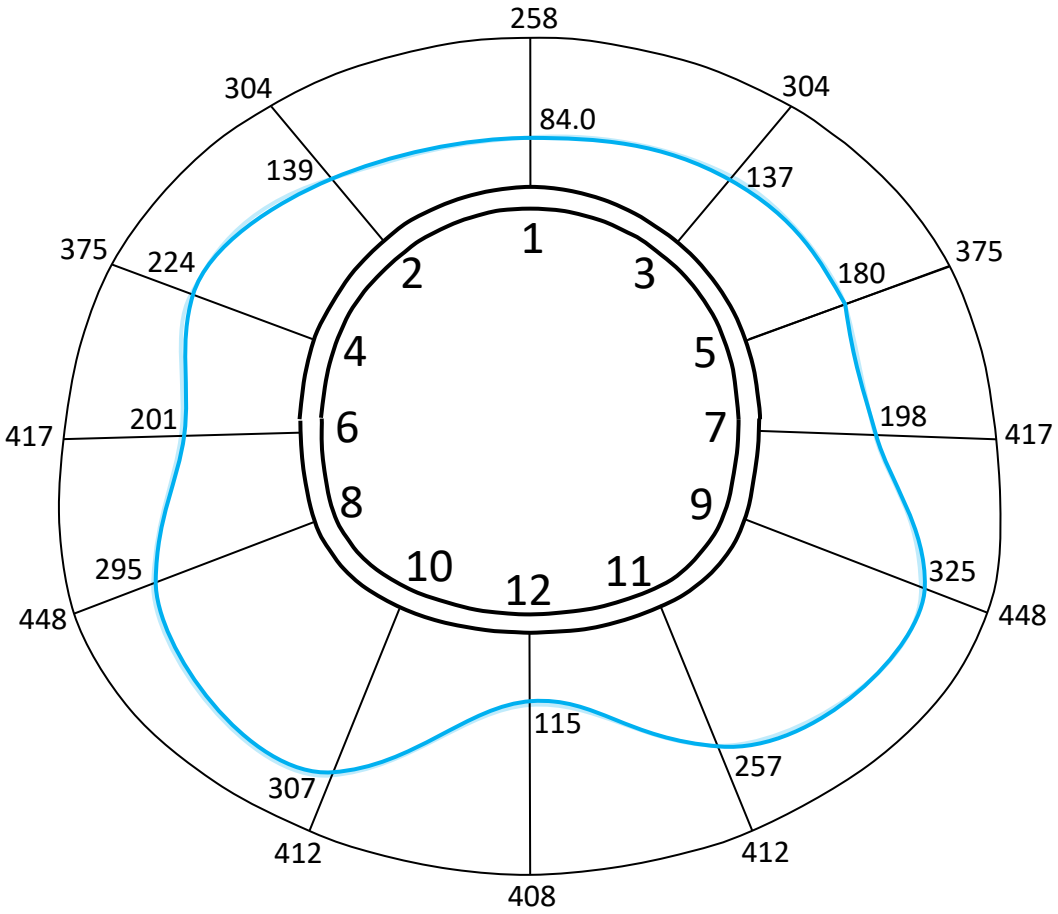
Temperature °C	
Crown	19.4
Bench	17.6
Invert	21.9

MMS VIII radial pressures

Time from top heading excavation at MMS VIII:

20 days

15/11/96 14:00



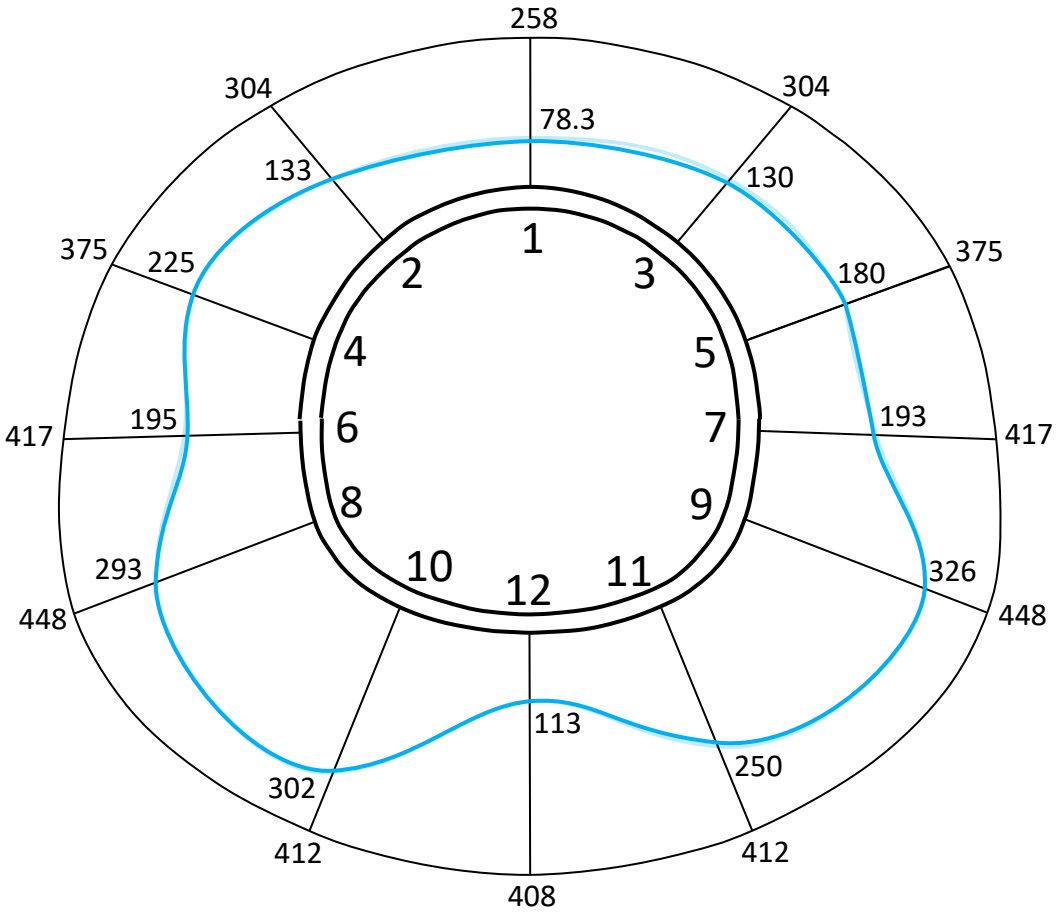
Temperature °C	
Crown	21.4
Bench	18.1
Invert	22.6

MMS VIII radial pressures

Time from top heading excavation at MMS VIII:

23 days

18/11/96 12:15



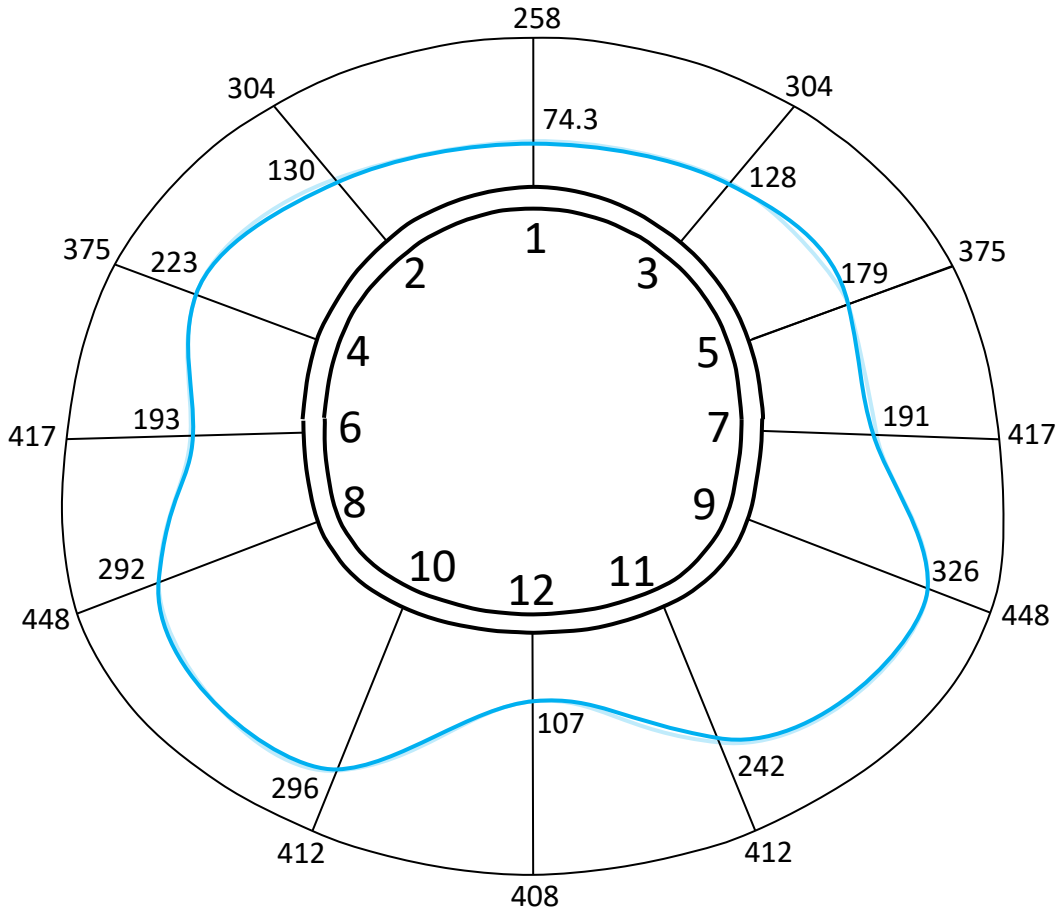
Temperature °C	
Crown	17.7
Bench	16.9
Invert	20.3

MMS VIII radial pressures

Time from top heading excavation at MMS VIII:

24 days

19/11/96 09:00



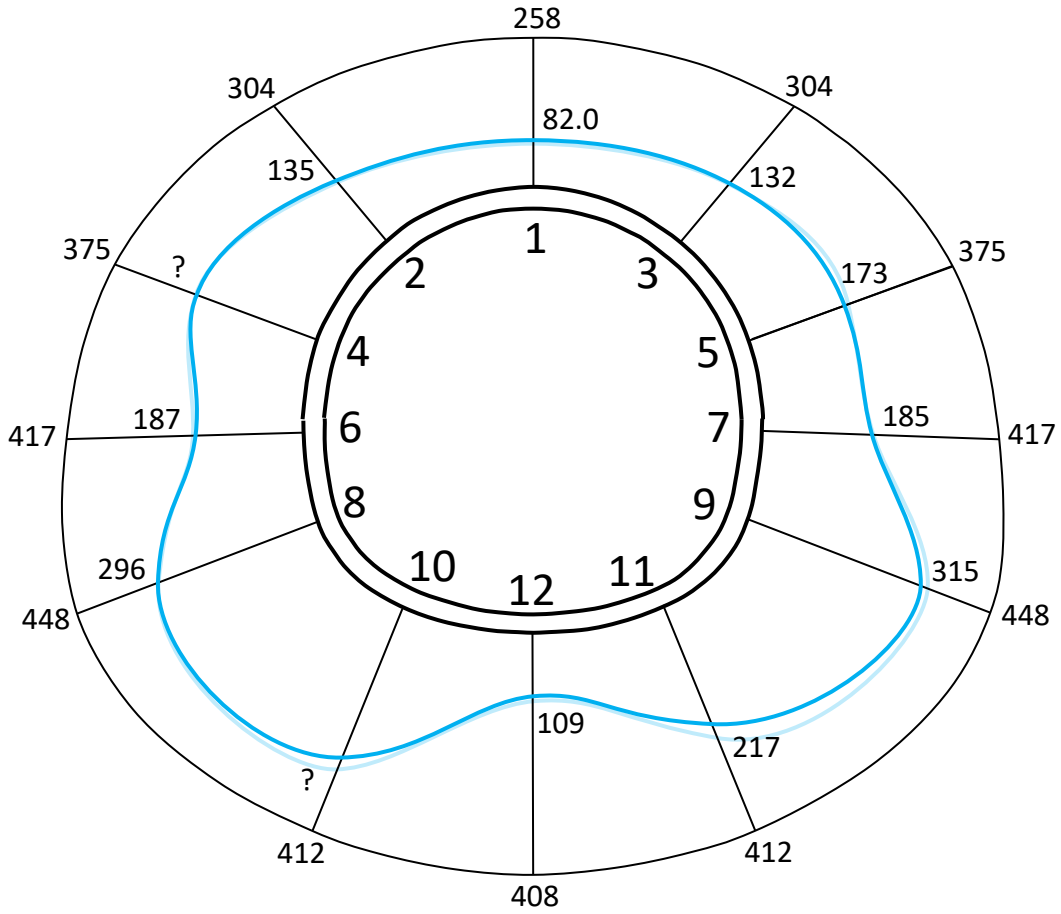
Temperature °C	
Crown	18.1
Bench	16.9
Invert	20.8

MMS VIII radial pressures

Time from top heading excavation at MMS VIII:

44 days

9/12/96 14:00



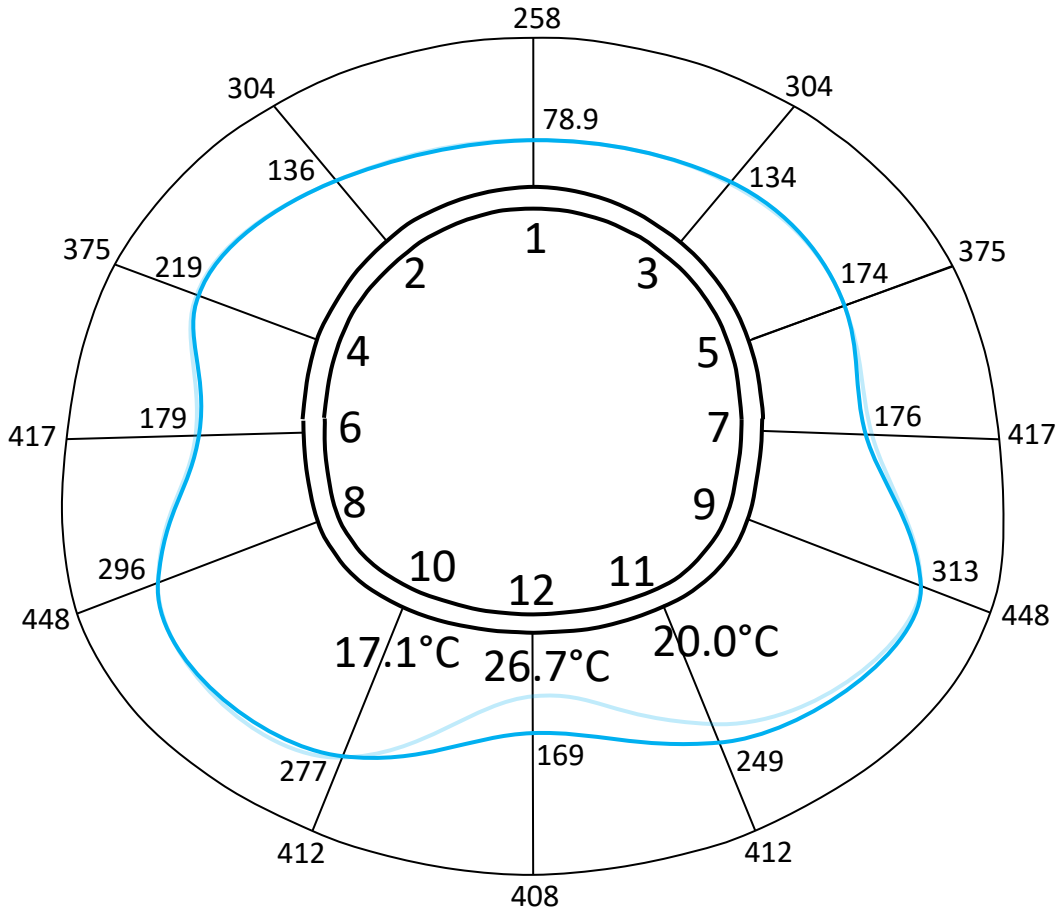
Temperature °C	
Crown	16.3
Bench	15.5
Invert	15.1

MMS VIII radial pressures

Time from top heading excavation at MMS VIII:

47 days

12/12/96 14:00



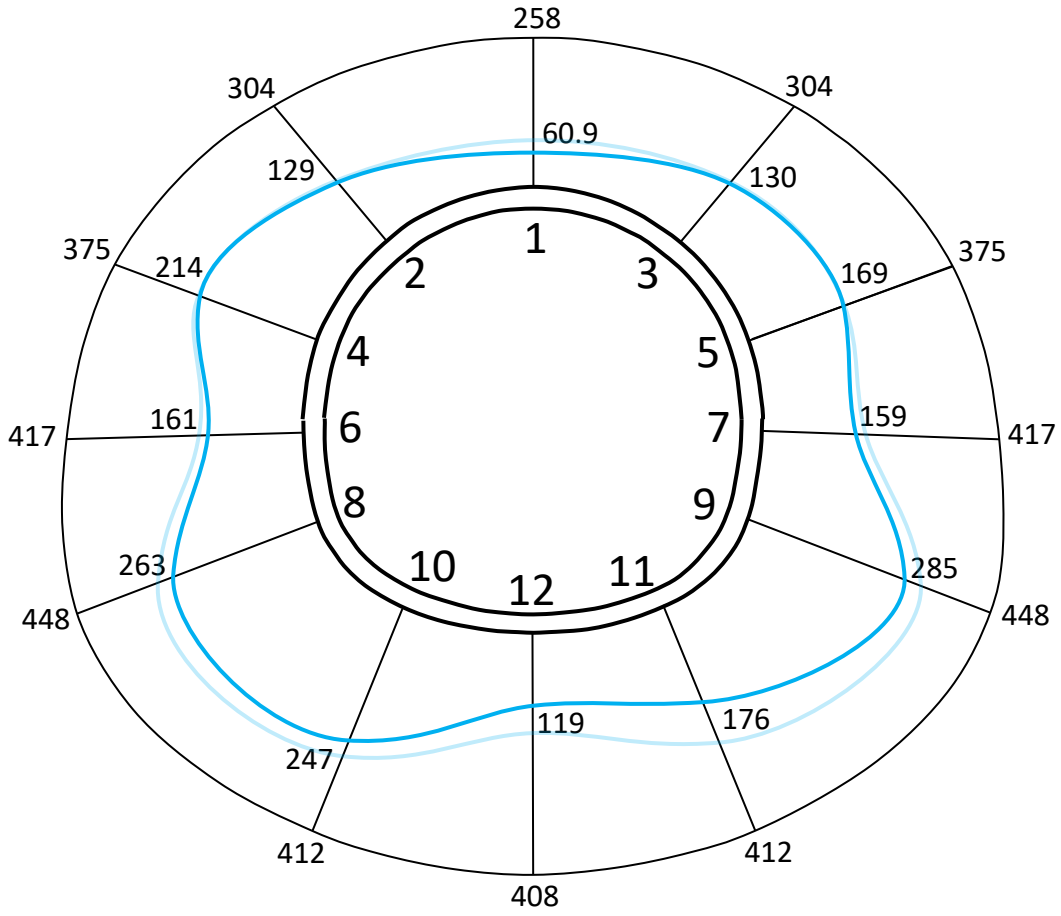
Temperature °C	
Crown	16.4
Bench	15.3
Invert	21.3

MMS VIII radial pressures

Time from top heading excavation at MMS VIII:

72 days

6/1/97 17:00



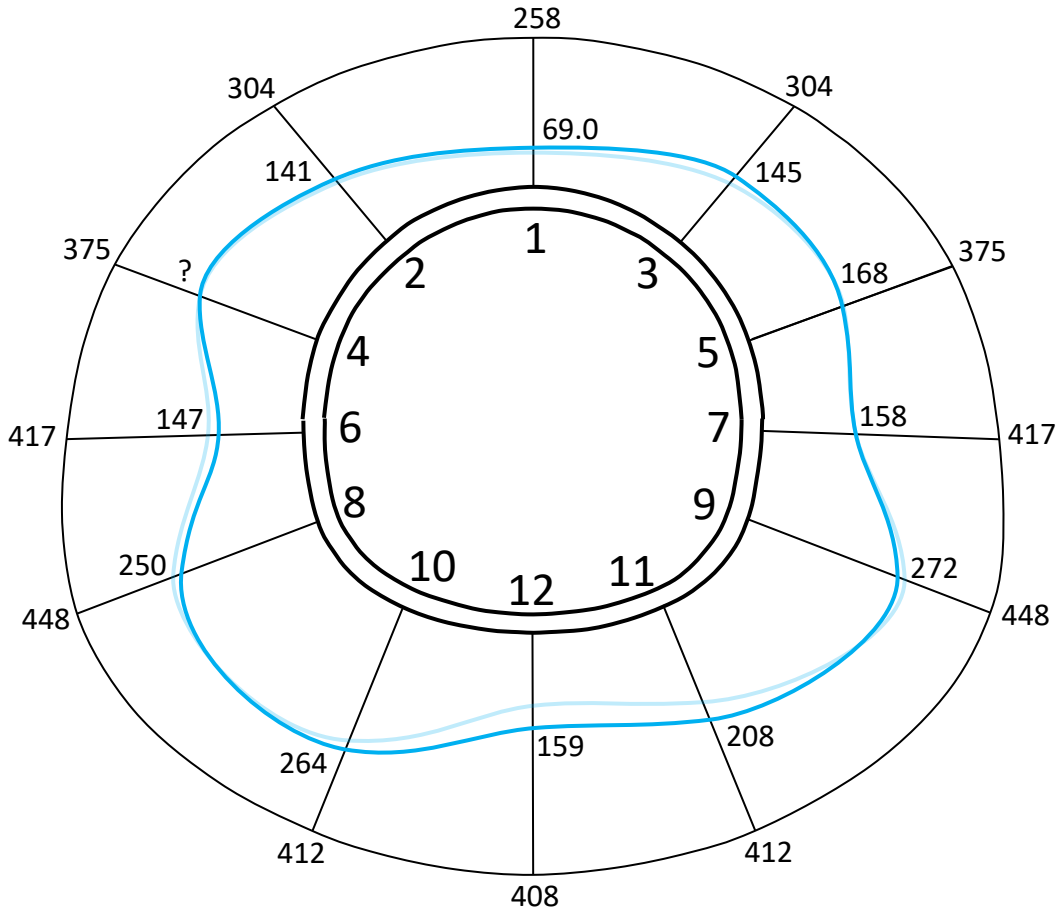
Temperature °C	
Crown	13.4
Bench	13.0
Invert	12.8

MMS VIII radial pressures

Time from top heading excavation at MMS VIII:

159 days

3/4/97 15:00



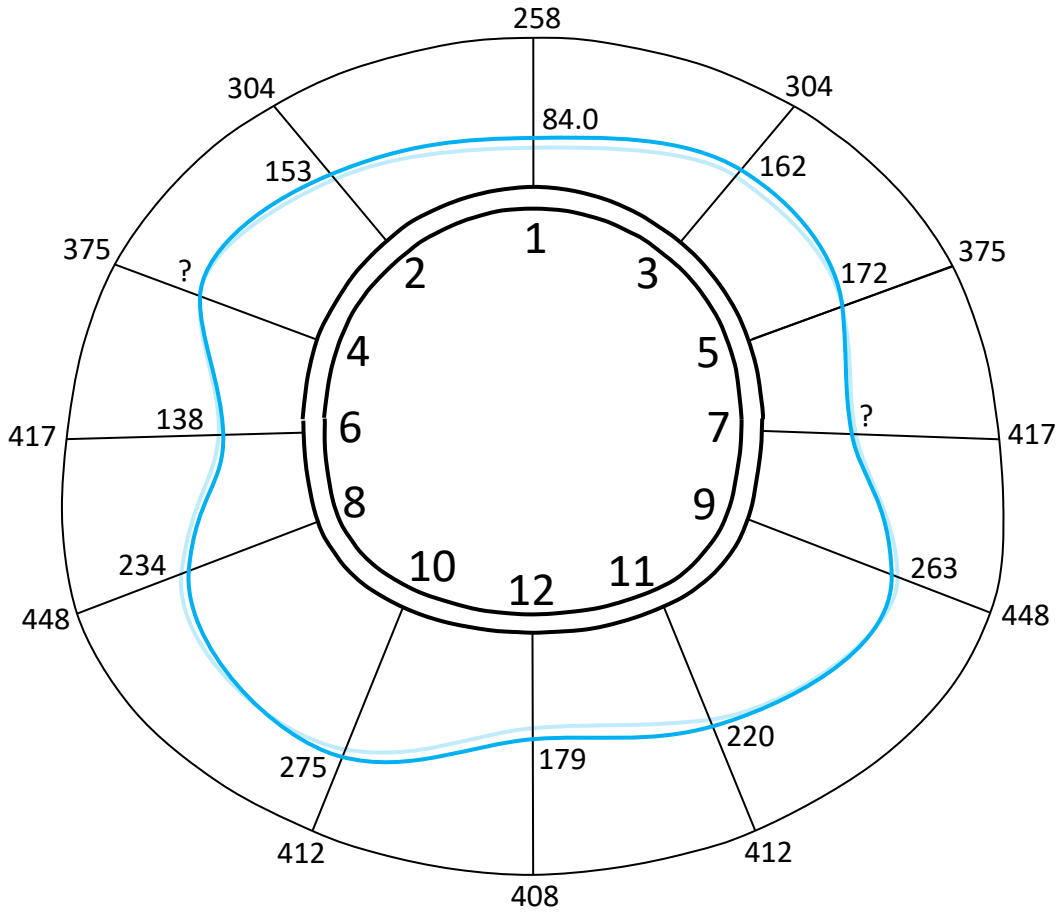
Temperature °C	
Crown	14.1
Bench	13.8
Invert	13.8

MMS VIII radial pressures

Time from top heading excavation at MMS VIII:

257 days

10/7/97 12:00



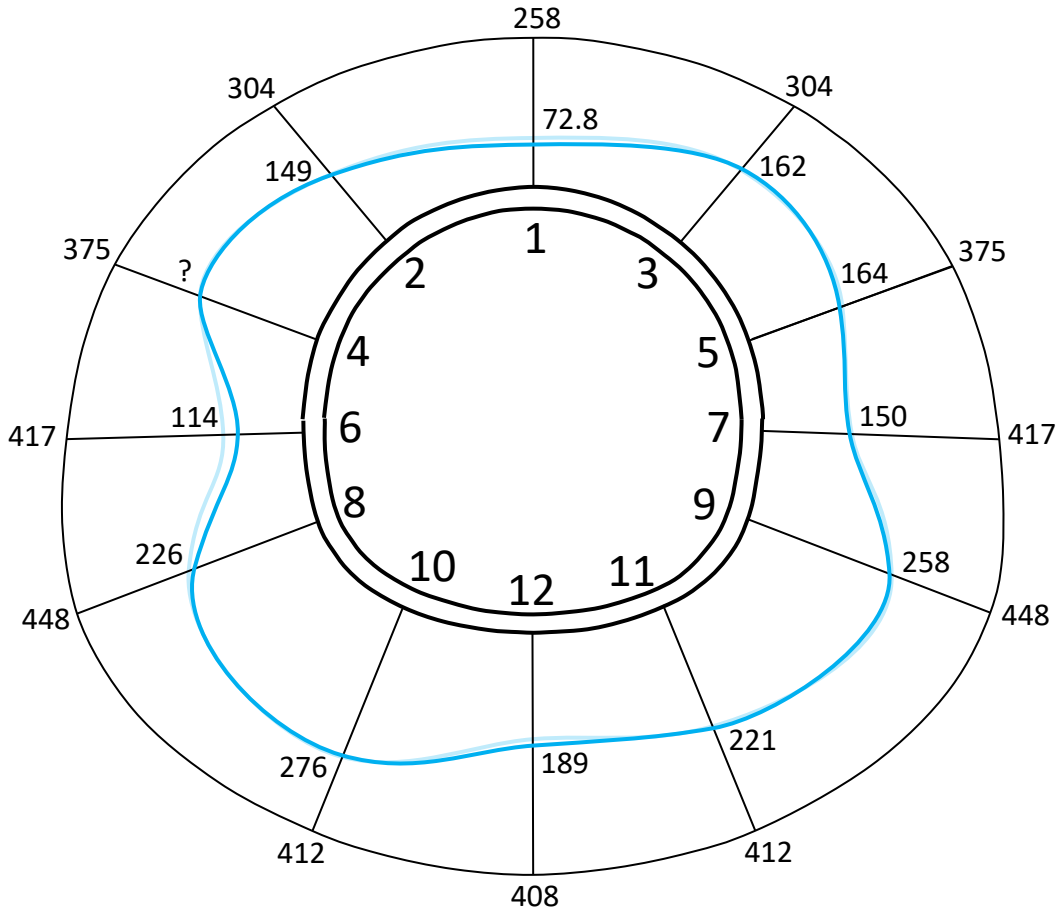
Temperature °C	
Crown	15.4
Bench	15.5
Invert	14.8

MMS VIII radial pressures

Time from top heading excavation at MMS VIII:

1.1 years

18/11/97 12:30



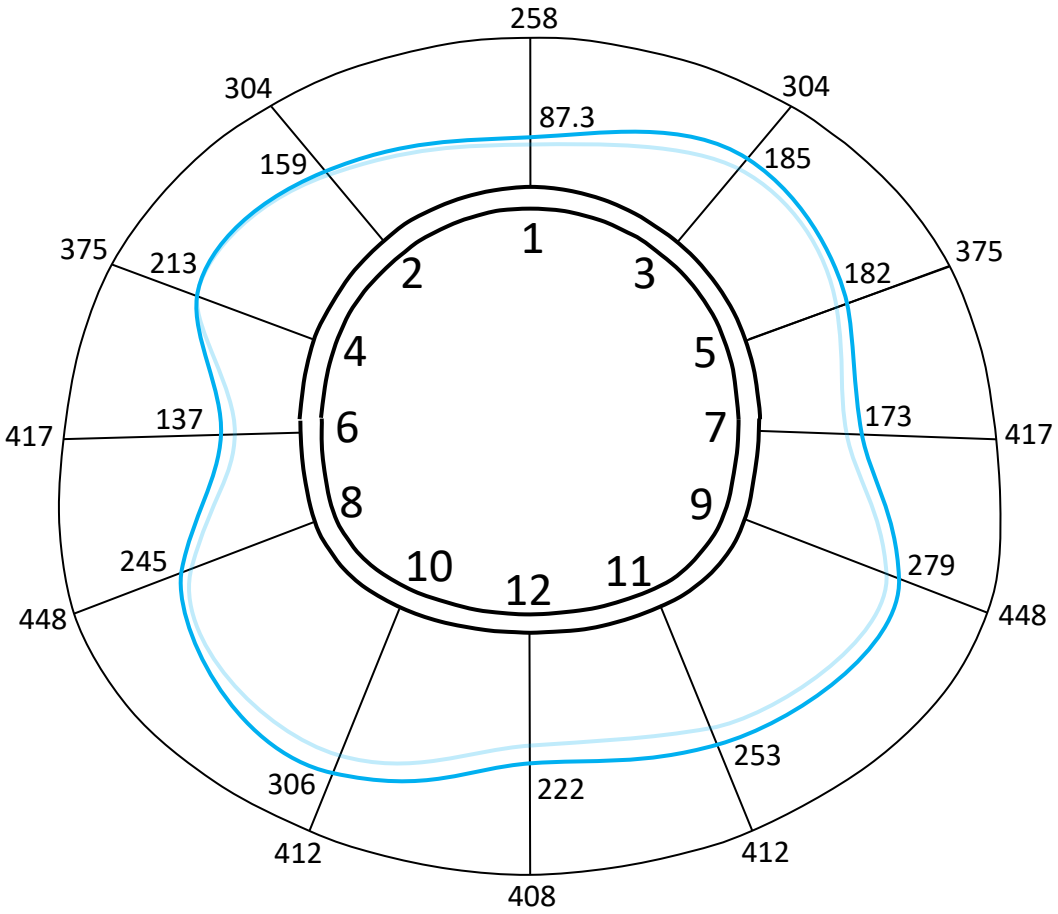
Temperature °C	
Crown	13.8
Bench	14.0
Invert	13.9

MMS VIII radial pressures

Time from top heading excavation at MMS VIII:

2.0 years

10/11/98 00:00



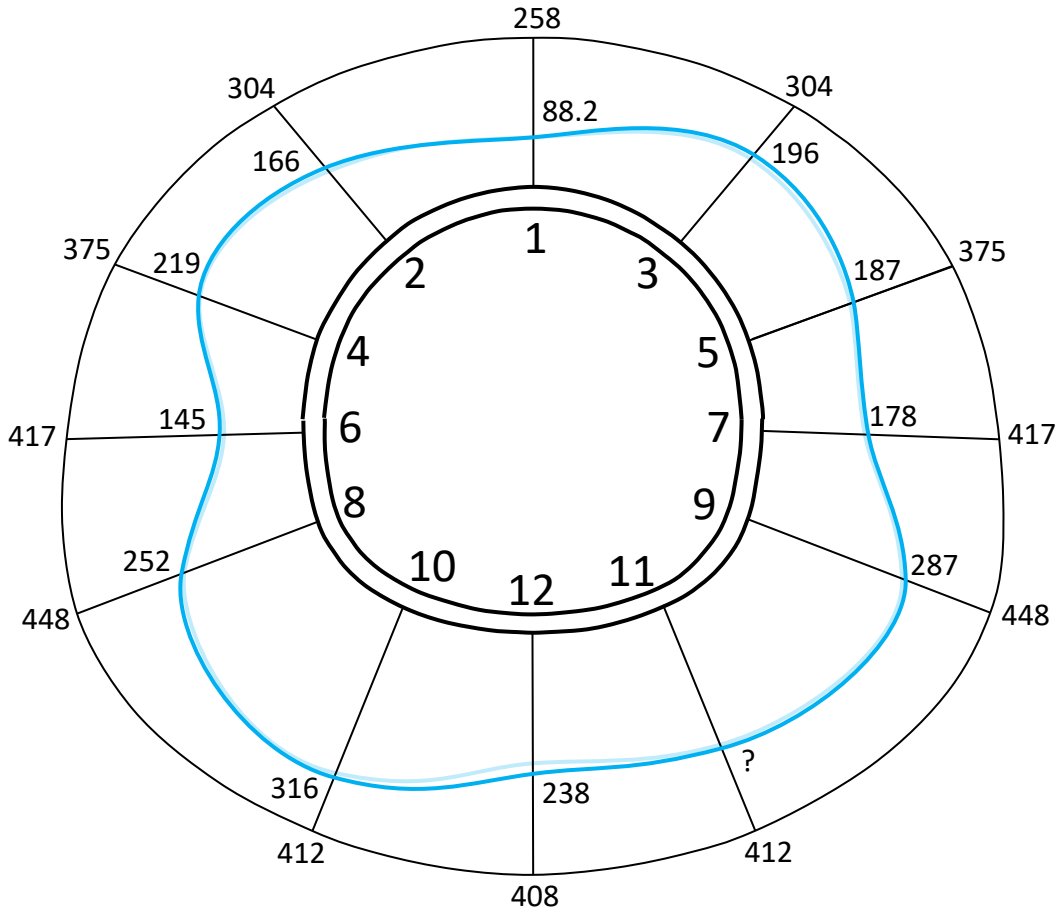
Temperature °C	
Crown	16.3
Bench	16.4
Invert	16.3

MMS VIII radial pressures

Time from top heading excavation at MMS VIII:

3.1 years

20/11/99 01:30



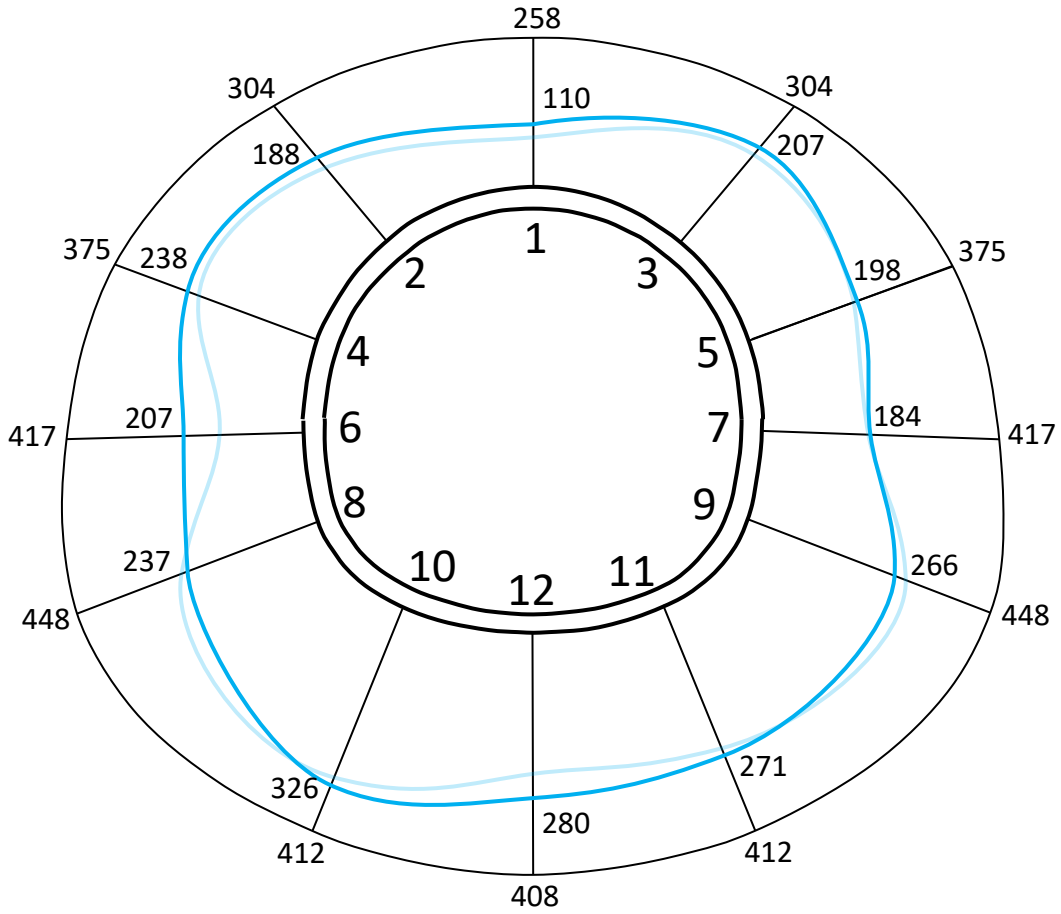
Temperature °C	
Crown	16.8
Bench	17.2
Invert	17.0

MMS VIII radial pressures

Time from top heading excavation at MMS VIII:

7.7 years

25/6/04 02:30



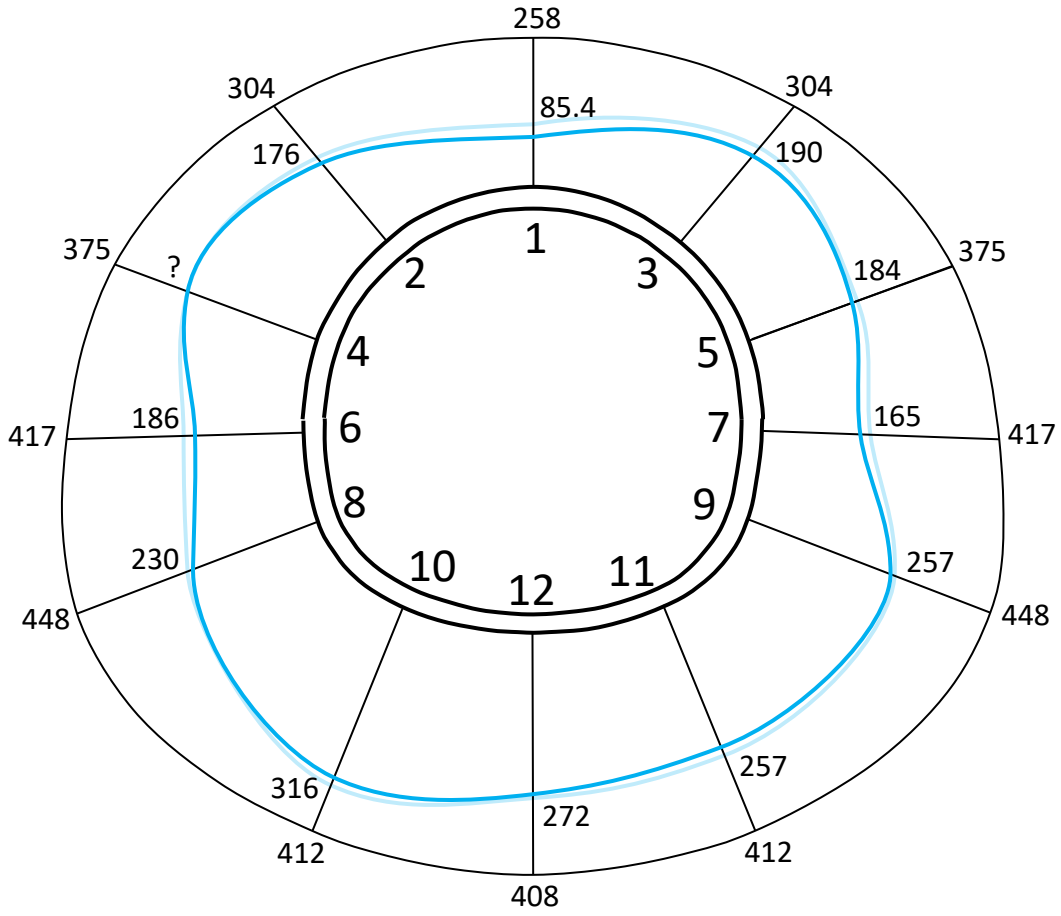
Temperature °C	
Crown	16.5
Bench	17.1
Invert	17.0

MMS VIII radial pressures

Time from top heading excavation at MMS VIII:

8.3 years

24/2/05 01:30



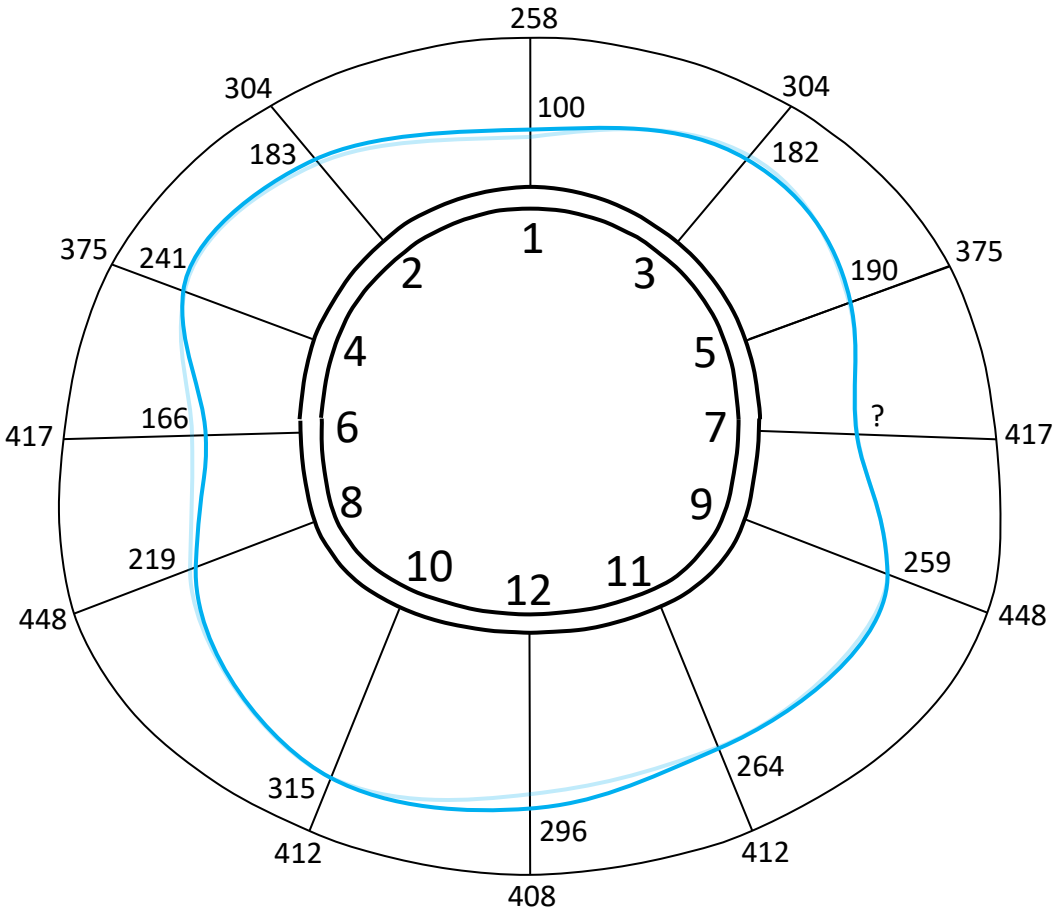
Temperature °C	
Crown	13.0
Bench	15.0
Invert	15.4

MMS VIII radial pressures

Time from top heading excavation at MMS VIII:

18.5 years

10/4/15 01:30



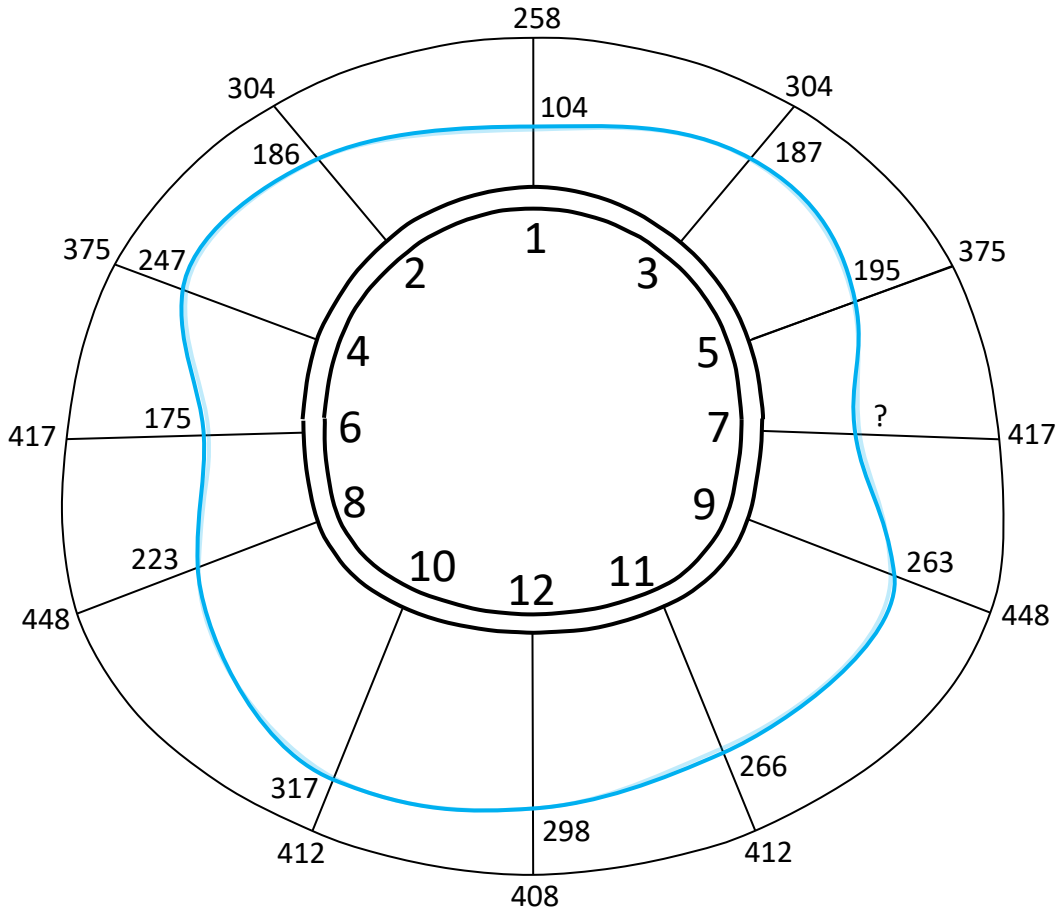
Temperature °C	
Crown	13.6
Bench	13.3
Invert	13.2

MMS VIII radial pressures

Time from top heading excavation at MMS VIII:

18.6 years

14/5/15 01:30



Temperature °C	
Crown	14.5
Bench	14.0
Invert	13.8

Additional figures

Pulling cables out of invert manhole to take readings

Note that cables exit the secondary lining at the Concourse Tunnel headwall.

Vibrating wire and thermistor cables