Effects of Stratigraphy on Geothermal Reservoir Performance*

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Abstract

Geothermal reservoir performance is critical to successful production of energy from geothermal resources. It is highly dependent upon a variety of factors, including reservoir types, fluid properties, rock properties, temperature, structural geology, stratigraphy, and others. Drilling of the well field and construction of the associated fluid collection and processing system is one of the largest costs of developing a geothermal resource. Proper conceptual modeling of the geothermal resource is necessary to optimize the design of the subsurface and surface geothermal energy production system. When done correctly, we can maximize the return on investment of our development dollars. Furthermore, we can use this information to better maintain the 'health' of our reservoirs and wells. We can also improve and optimize well and reservoir productivity, providing additional return on our geothermal investments. This paper outlines some of the interactions between geothermal reservoirs and their associated stratigraphies. The resultant effects upon reservoir performance as seen at the wellhead are discussed in detail.

References

Grant, M., I. Donaldson, and P. Bixley, 1982. “Geothermal Reservoir Engineering”, Academic Press, New York, NY.

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Timlin, M., 2008. “SuperWell – A Simple Well Bore Flow Simulator in Spreadsheet Format”, Proceedings, Thirty-Third Workshop on Geothermal Reservoir Engineering, Stanford, CA.

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Factors

Many factors influence geothermal reservoir performance:

- Reservoir type
- Fluid properties
- Rock properties
- Temperature
- Structural geology
- Stratigraphy
- Others

This paper focuses on stratigraphy, specifically cap rock.

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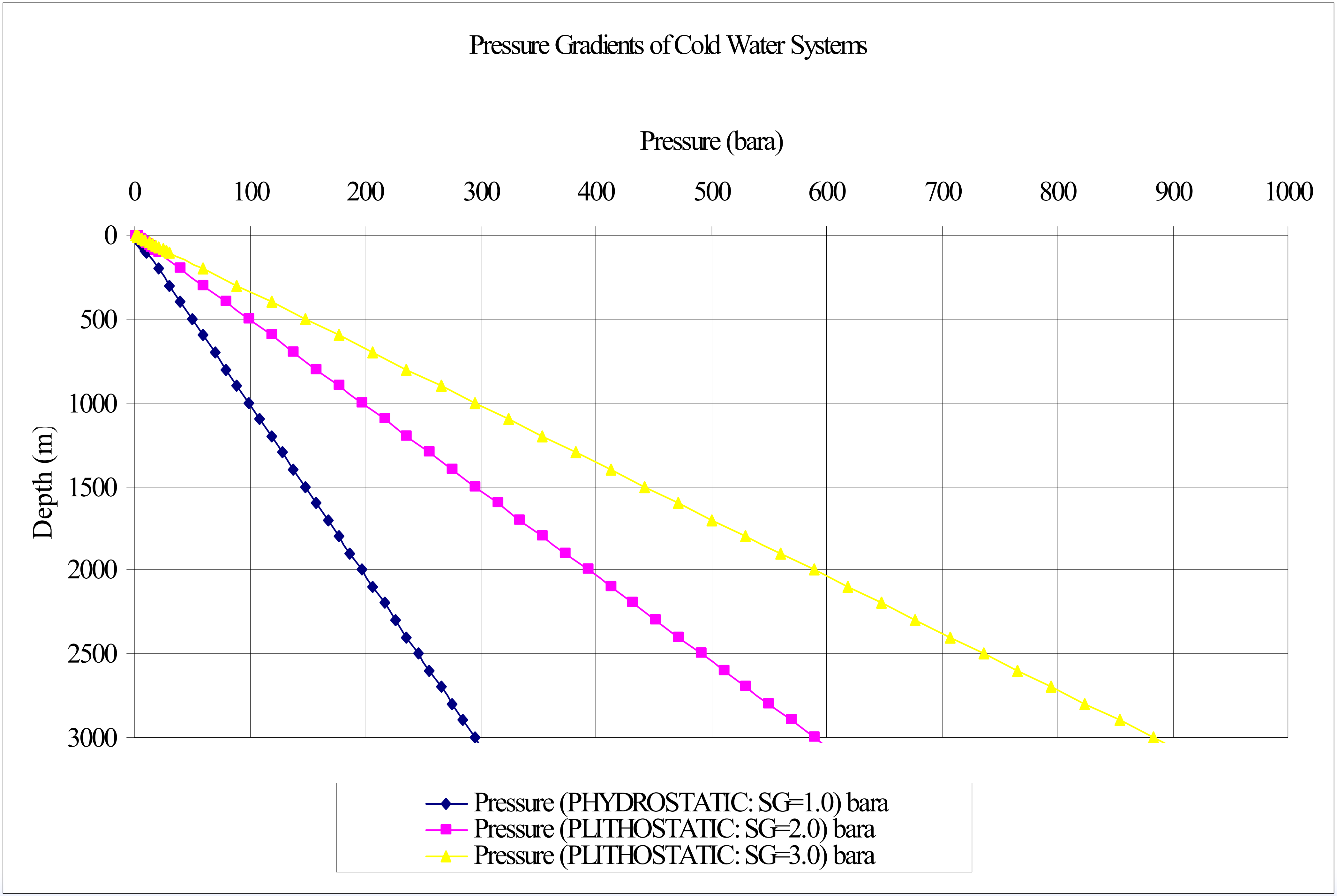
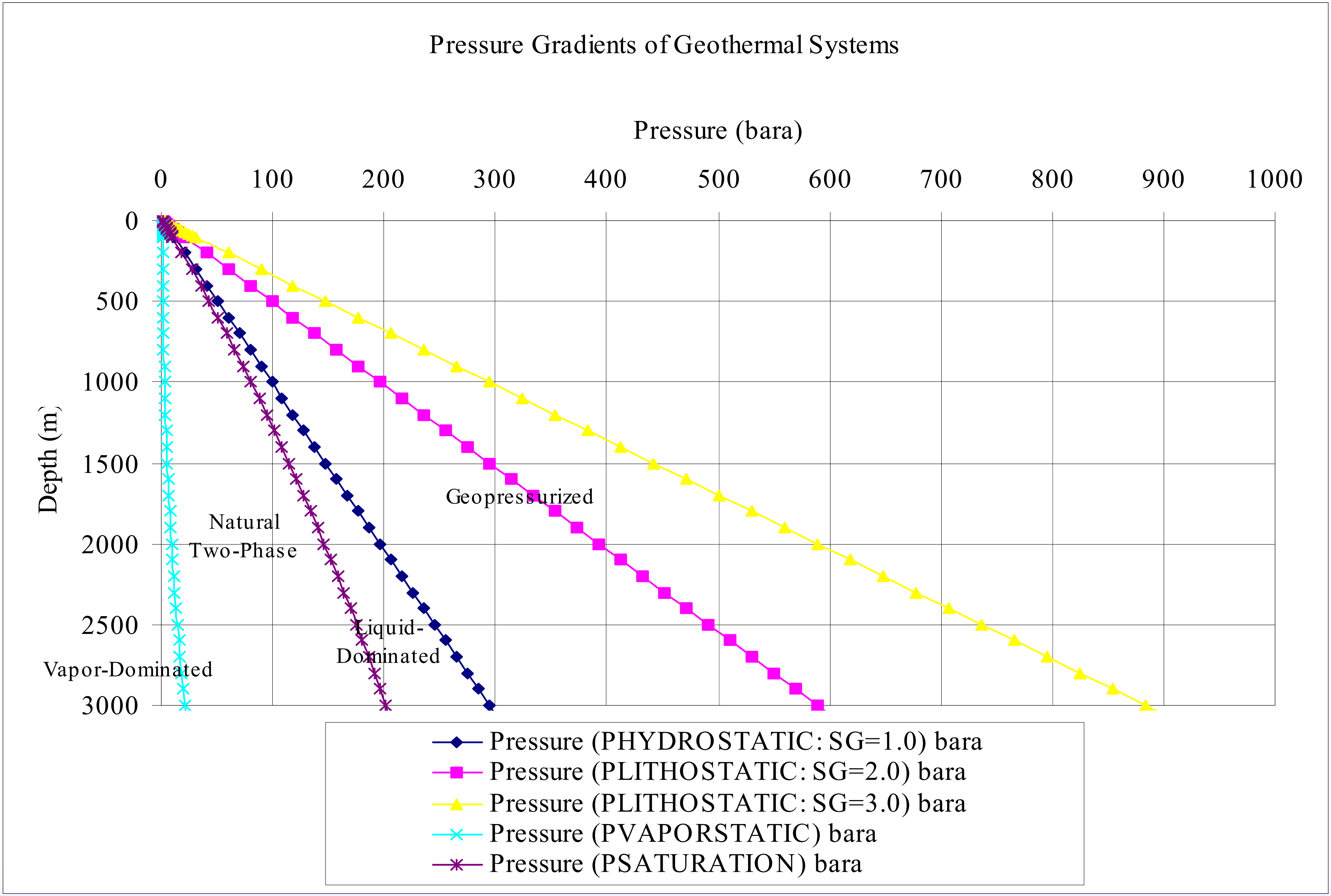
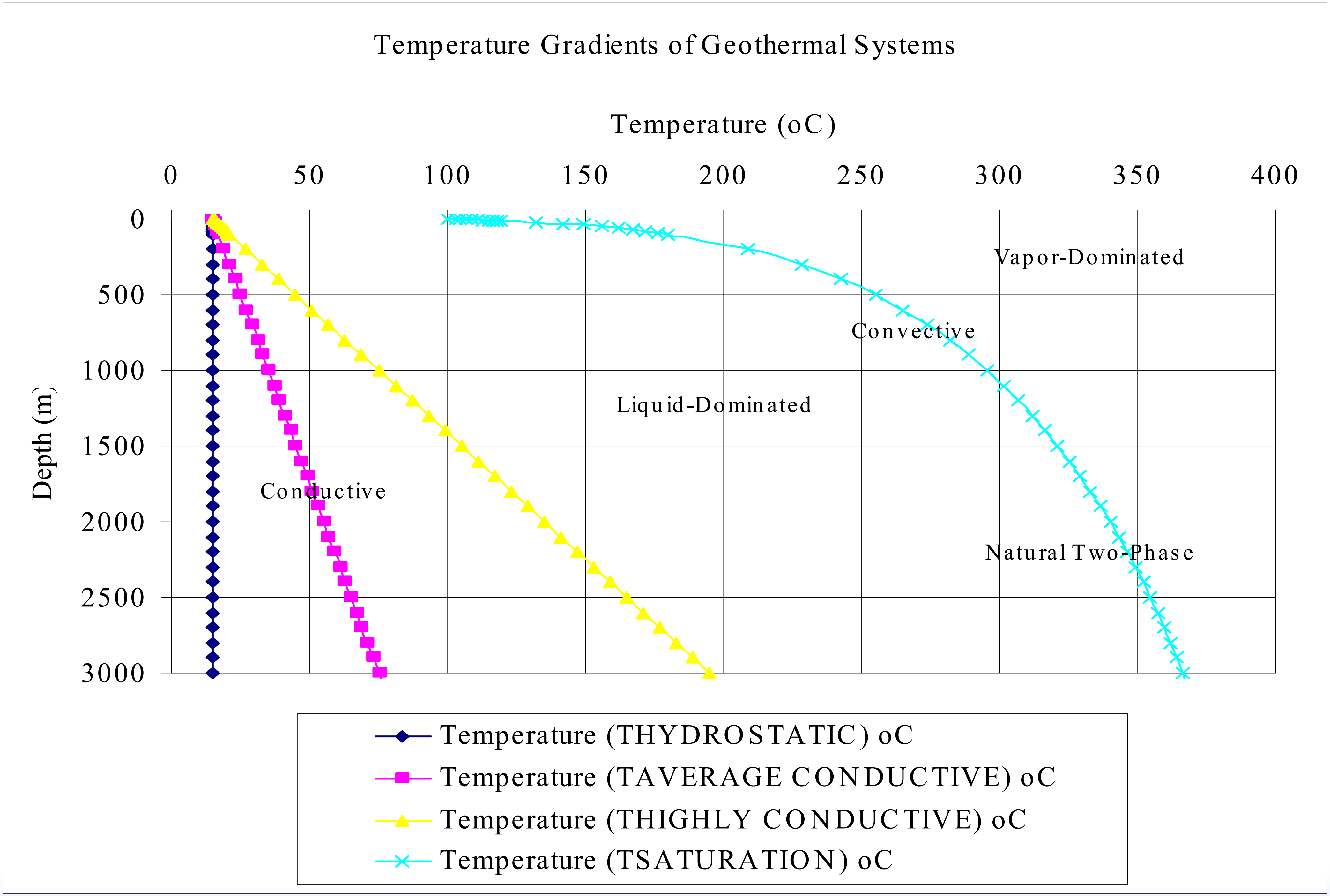
An Idealized Geothermal System

For the investigations described in this paper, a model comprising a 4-layer stratigraphic column was used:

- Atmosphere (cool, partially-saturated, heat sink)
- Cap rock (warm, porous, saturated, insulator)
- Reservoir rock (hot, porous, saturated fluid source)
- Basement rock (hot, porous, saturated heat source)

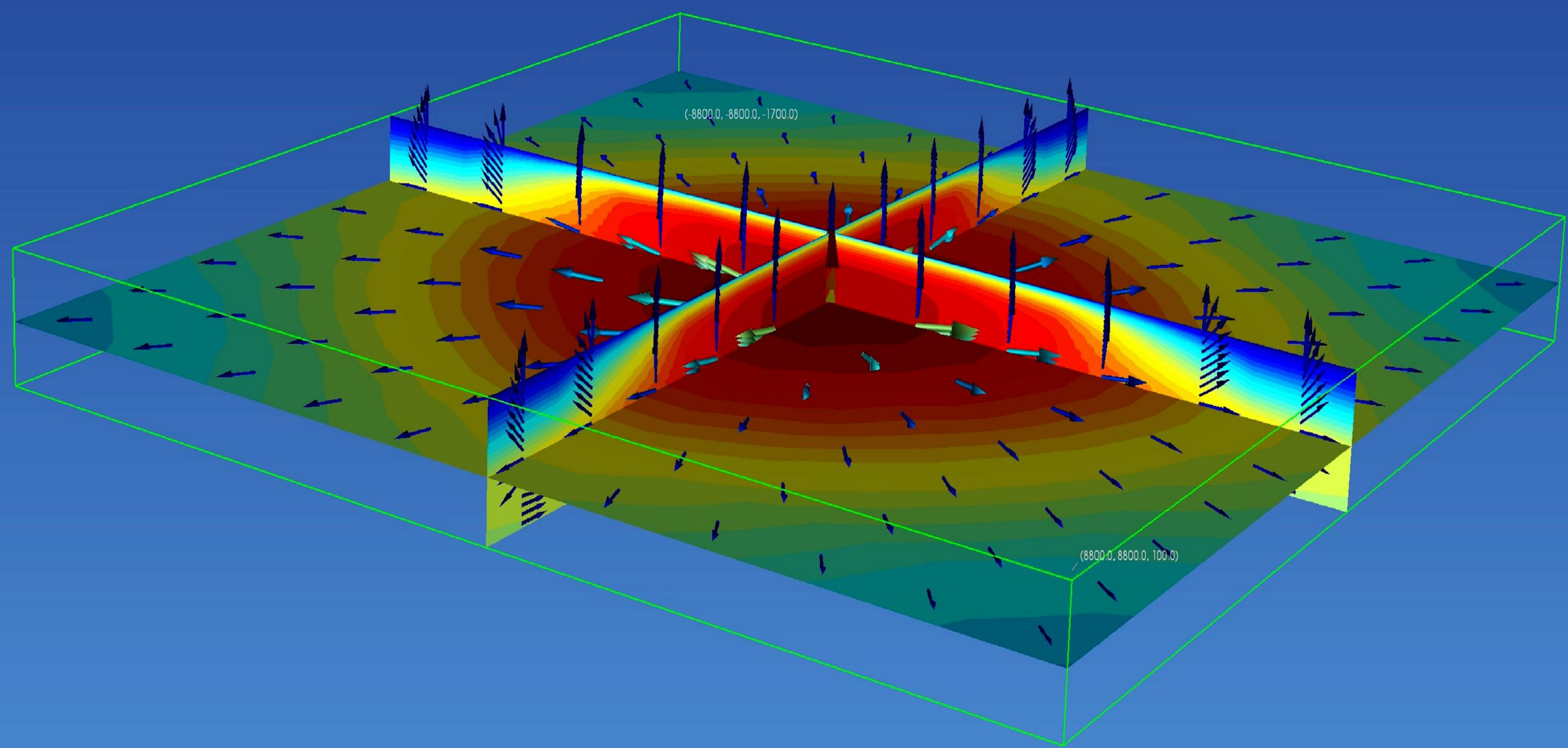

Pressure Gradients of Cold Water Systems
Pressure (bara)
0
100
200
300
400
500
600
700
800
900
1000
Depth (m)
0
500
1000
1500
2000
2500
3000
Pressure (PHYDROSTATIC: SG=1.0) bara
Pressure (PLITHOSTATIC: SG=2.0) bara
Pressure (PLITHOSTATIC: SG=3.0) bara

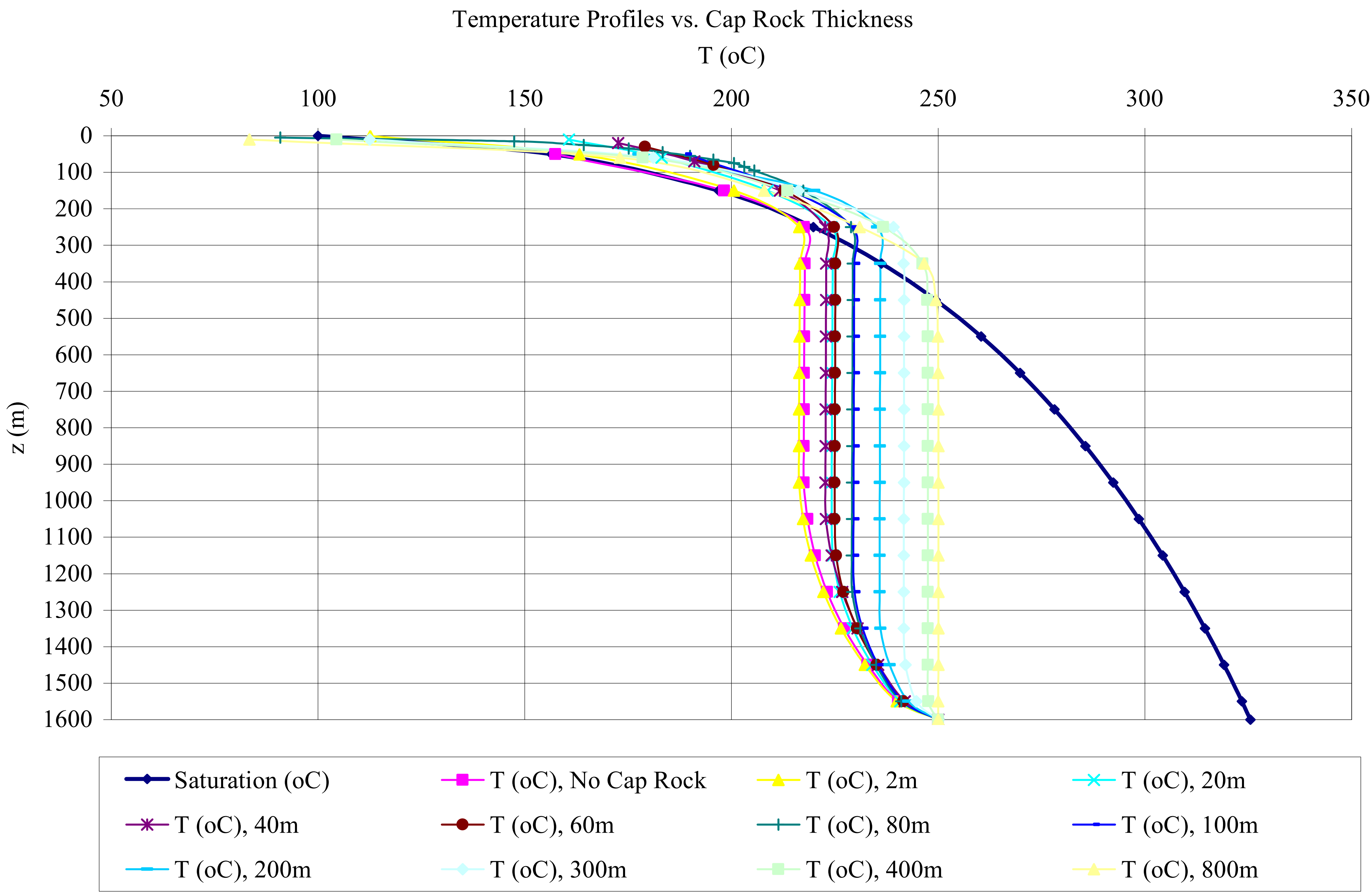

Pressure Gradients of Geothermal Systems
Pressure (bara)
0
100
200
300
400
500
600
700
800
900
1000
Depth (m)
0
500
1000
1500
2000
2500
3000
Geopressurized
Natural
Two-Phase
Liquid-
Dominated
Vapor-Dominated
Pressure (PHYDROSTATIC: SG=1.0) bara
Pressure (PLITHOSTATIC: SG=2.0) bara
Pressure (PLITHOSTATIC: SG=3.0) bara
Pressure (PVAPORSTATIC) bara
Pressure (PSATURATION) bara

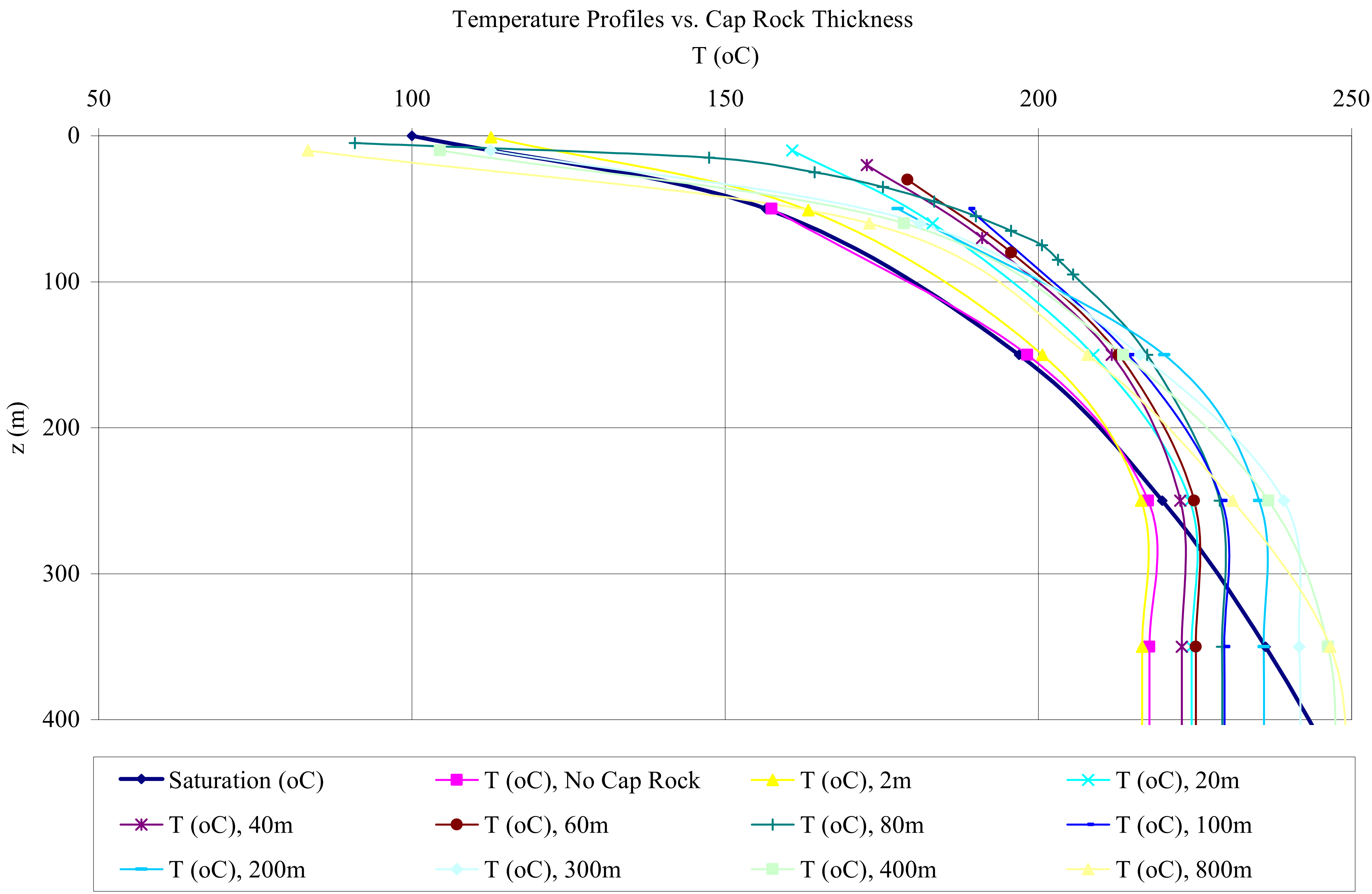


Temperature Gradients of Geothermal Systems
Temperature (oC)
0
50
100
150
200
250
300
350
400
0
500
1000
1500
2000
2500
3000
Depth (m)
Vapor-Dominated
Convective
Liquid-Dominated
Conductive
Natural Two-Phase
Temperature (THYDROSTATIC) oC
Temperature (TAVERAGE CONDUCTIVE) oC
Temperature (THIGHLY CONDUCTIVE) oC
Temperature (TSATURATION) oC

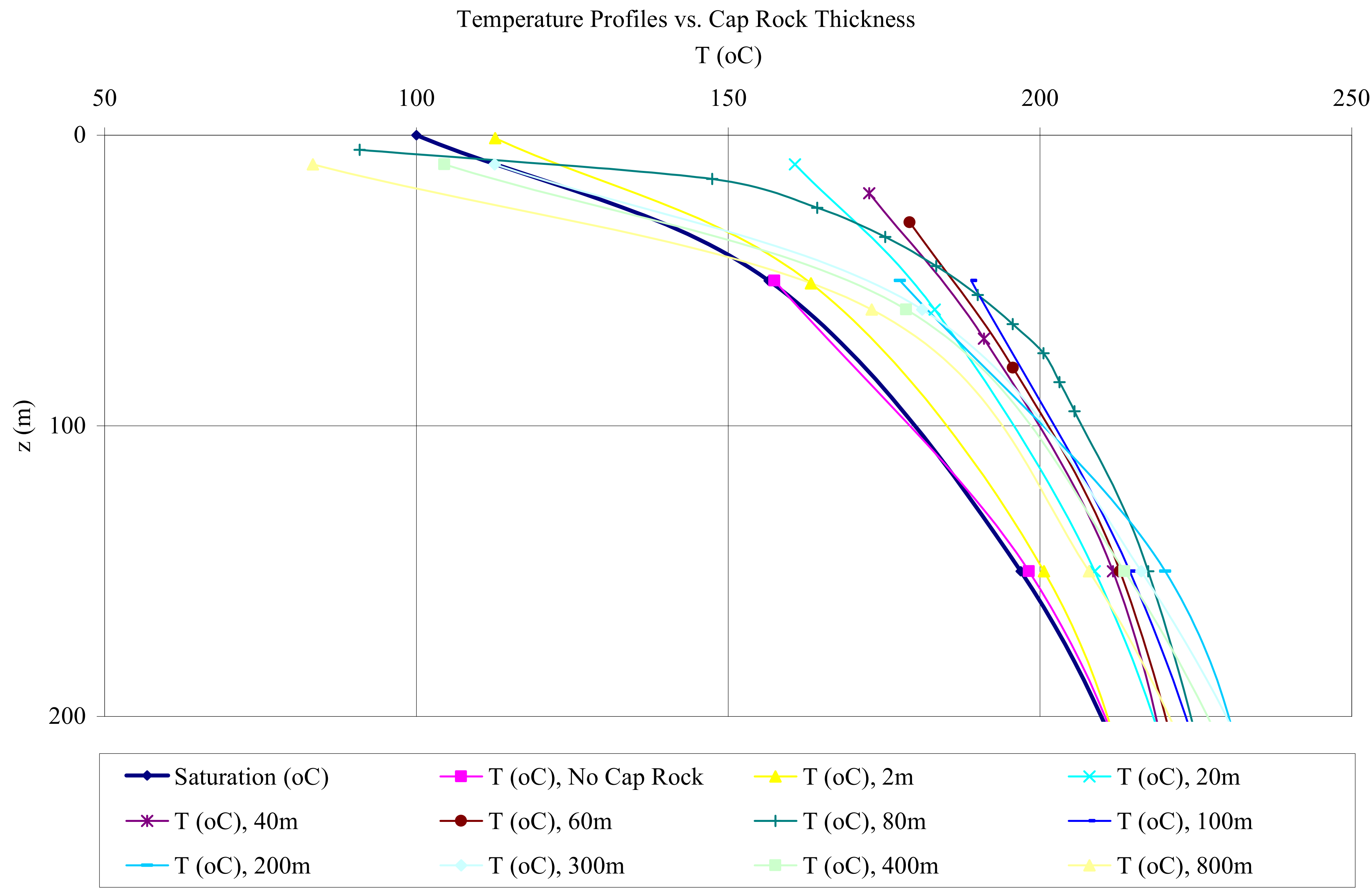
Natural State Modeling



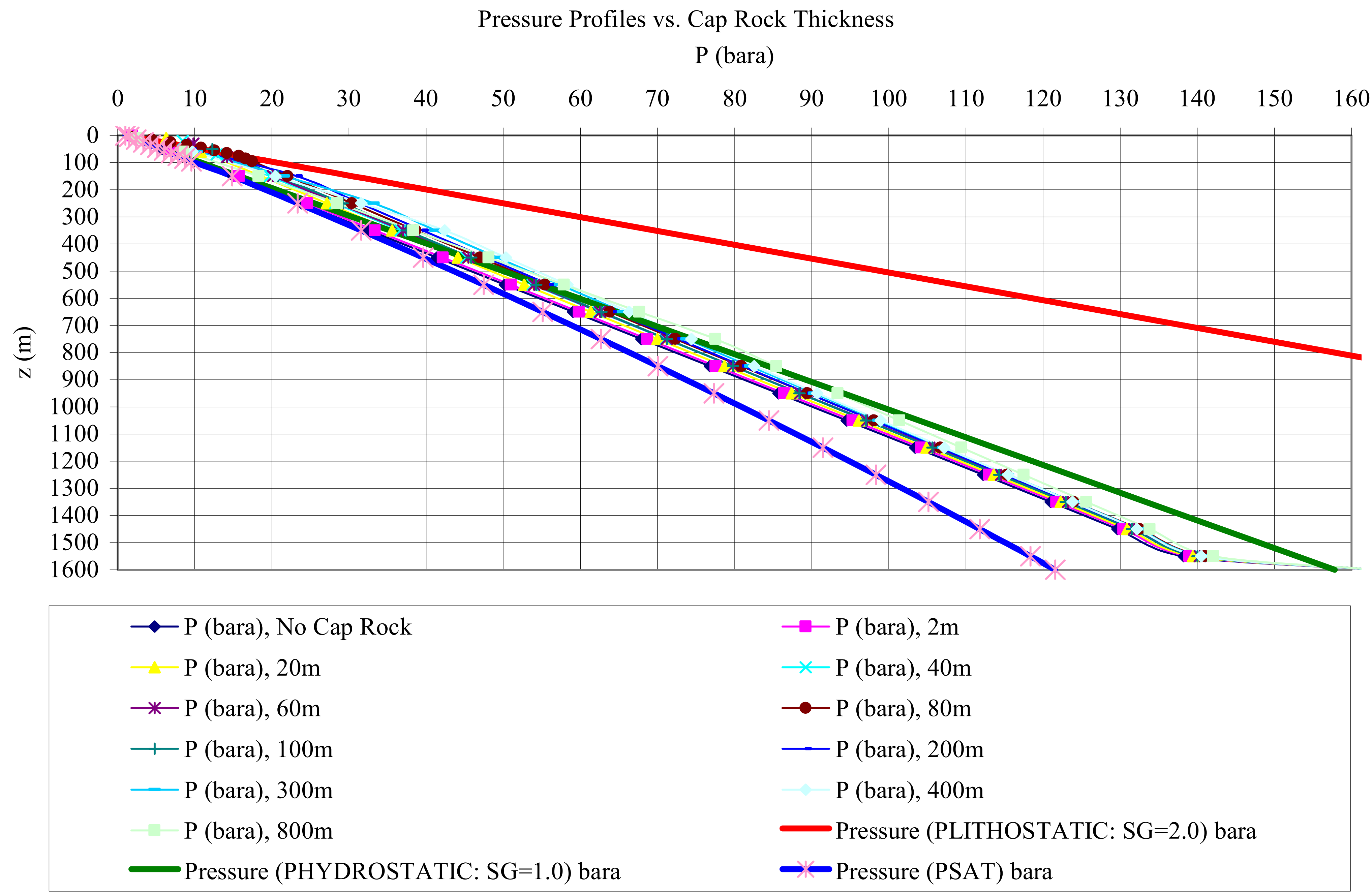

Temperature Profiles vs. Cap Rock Thickness
T (oC)
50
100
150
200
250
300
350
z (m)
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500
1600
Saturation (oC)
T (oC), No Cap Rock
T (oC), 2m
T (oC), 20m
T (oC), 40m
T (oC), 60m
T (oC), 80m
T (oC), 100m
T (oC), 200m
T (oC), 300m
T (oC), 400m
T (oC), 800m



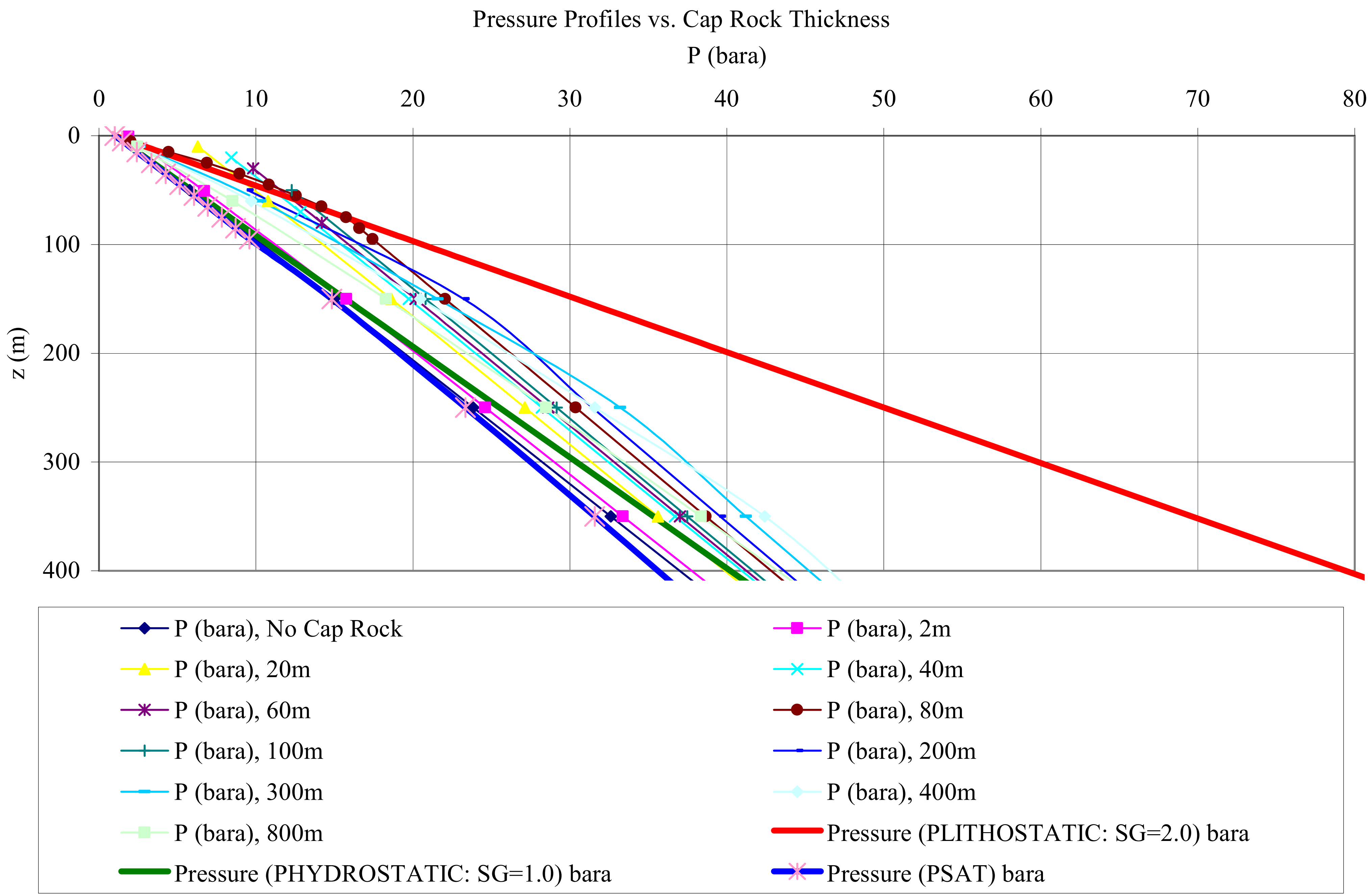
Temperature Profiles vs. Cap Rock Thickness
T (oC)
50
100
150
200
250
0
100
200
300
400
z (m)
Saturation (oC)
T (oC), No Cap Rock
T (oC), 2m
T (oC), 20m
T (oC), 40m
T (oC), 60m
T (oC), 80m
T (oC), 100m
T (oC), 200m
T (oC), 300m
T (oC), 400m
T (oC), 800m

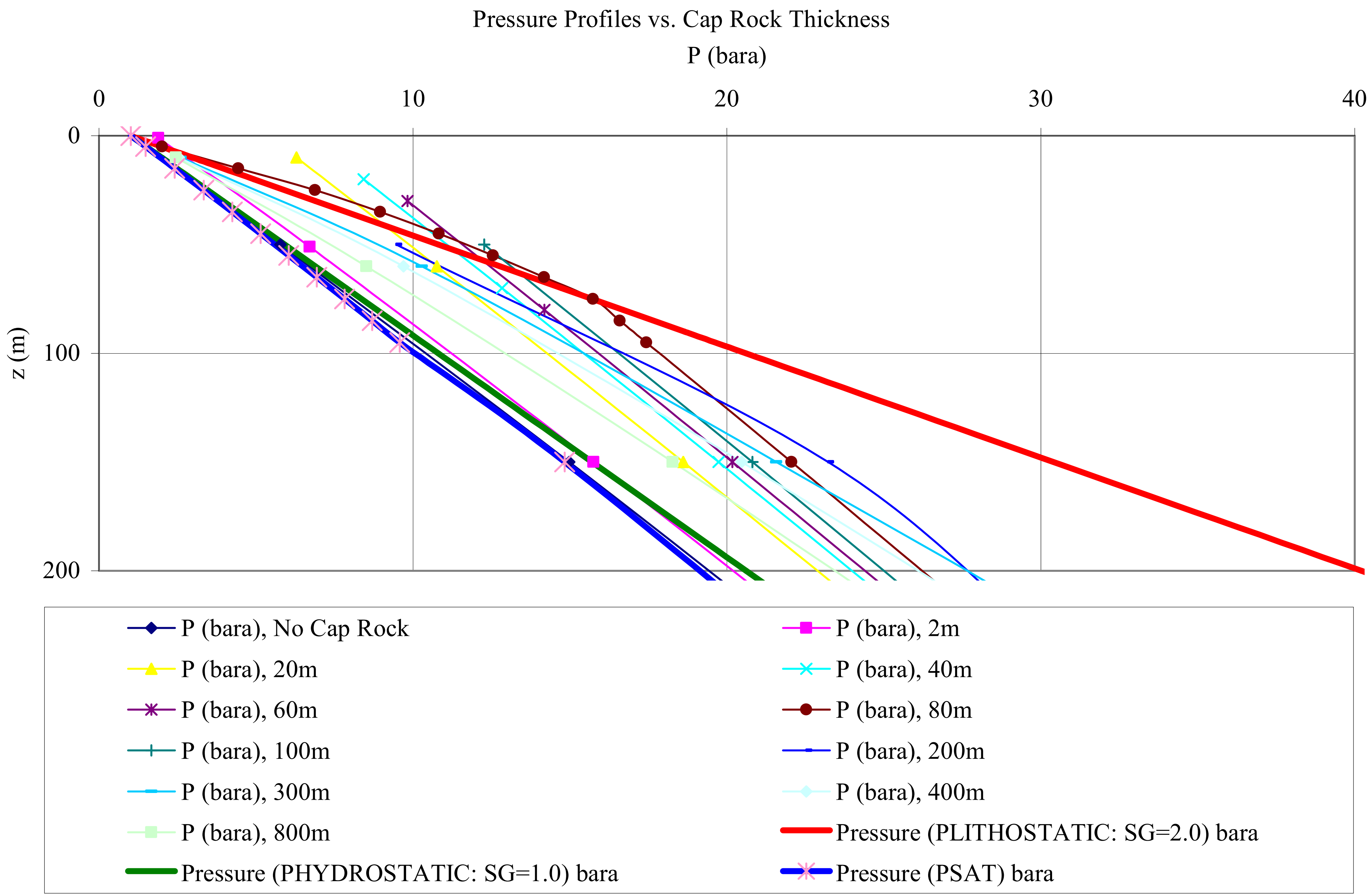


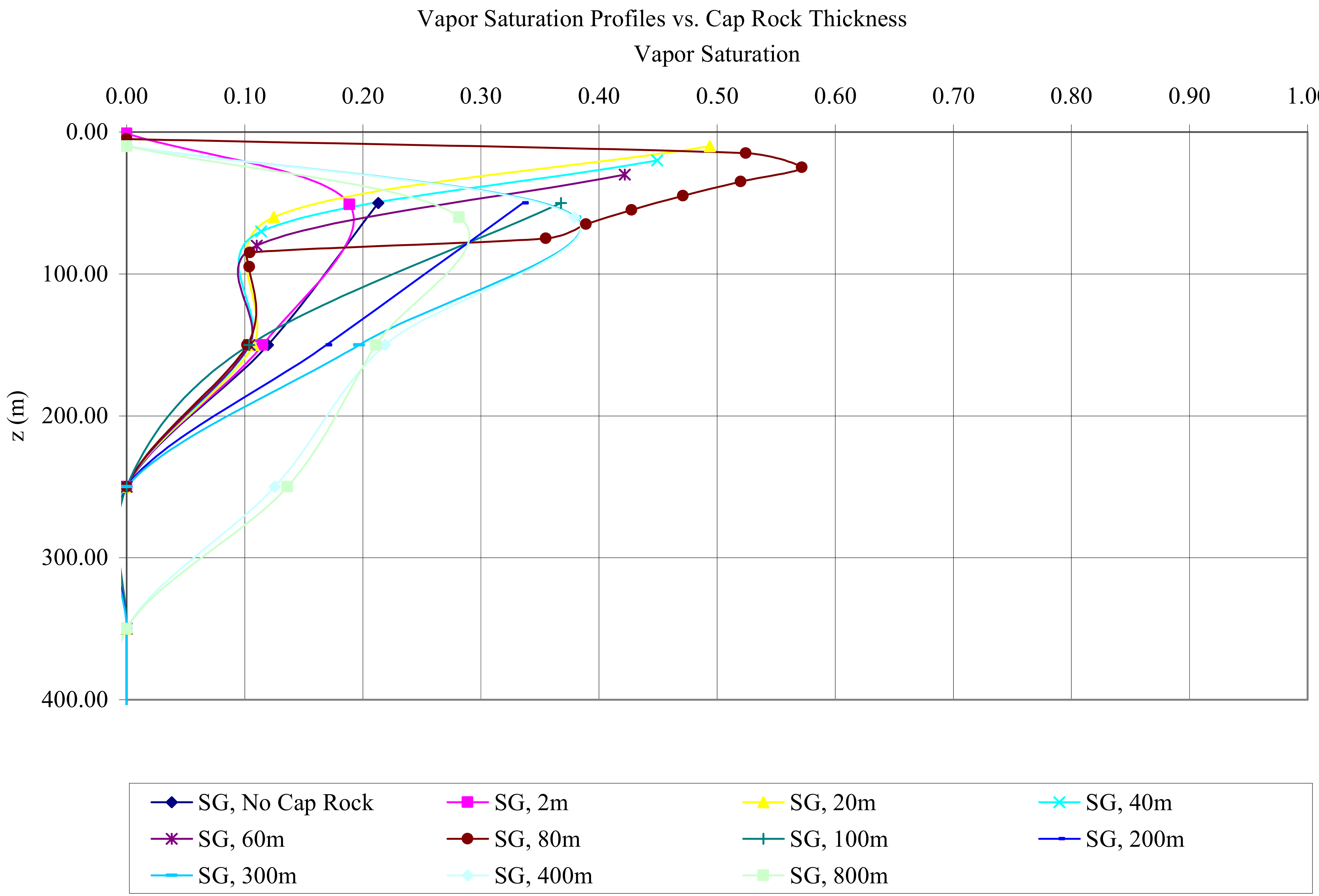
Temperature Profiles vs. Cap Rock Thickness
T (oC)
50
100
150
200
250
0
100
200
z (m)
Saturation (oC)
T (oC), No Cap Rock
T (oC), 2m
T (oC), 20m
T (oC), 40m
T (oC), 60m
T (oC), 80m
T (oC), 100m
T (oC), 200m
T (oC), 300m
T (oC), 400m
T (oC), 800m

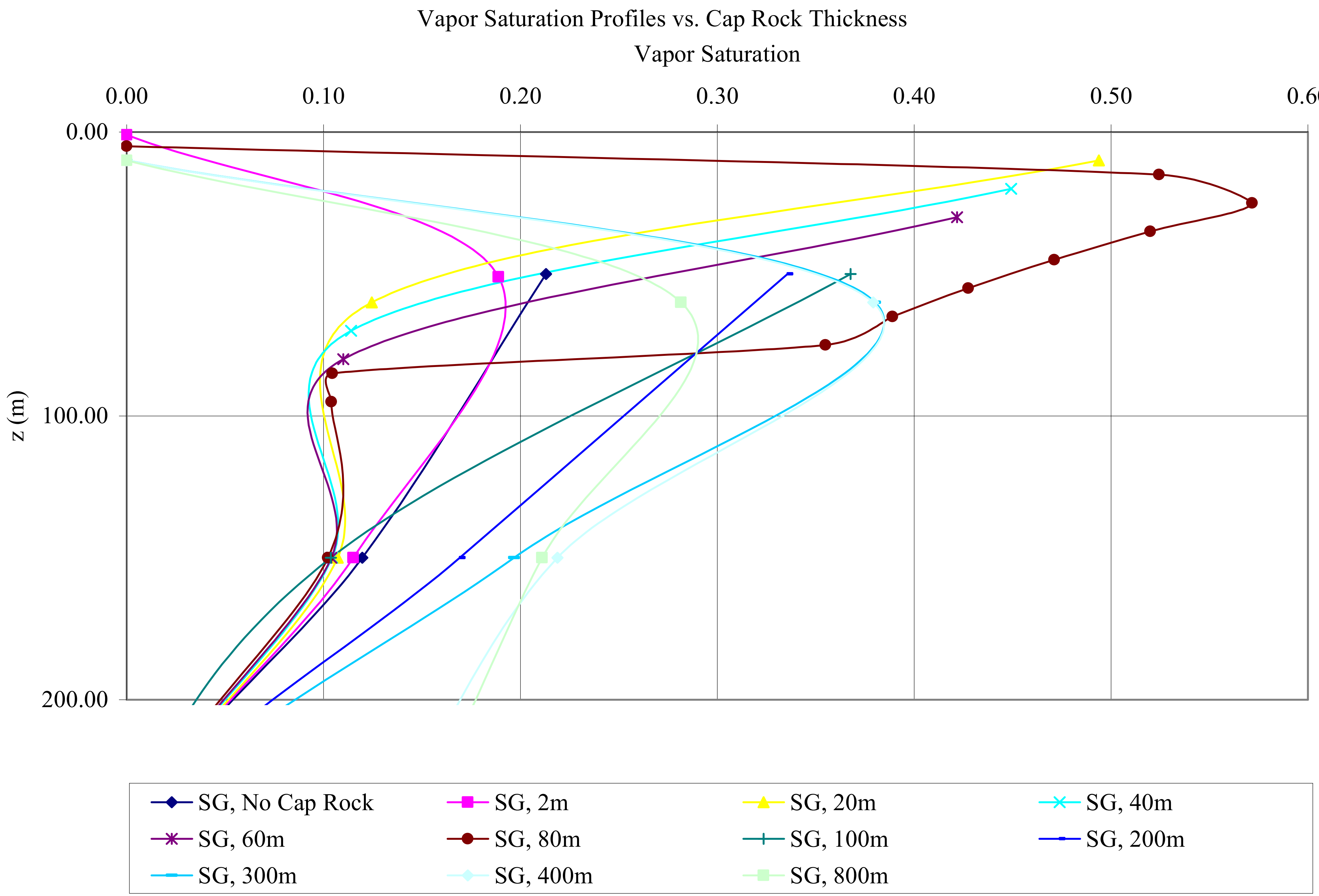


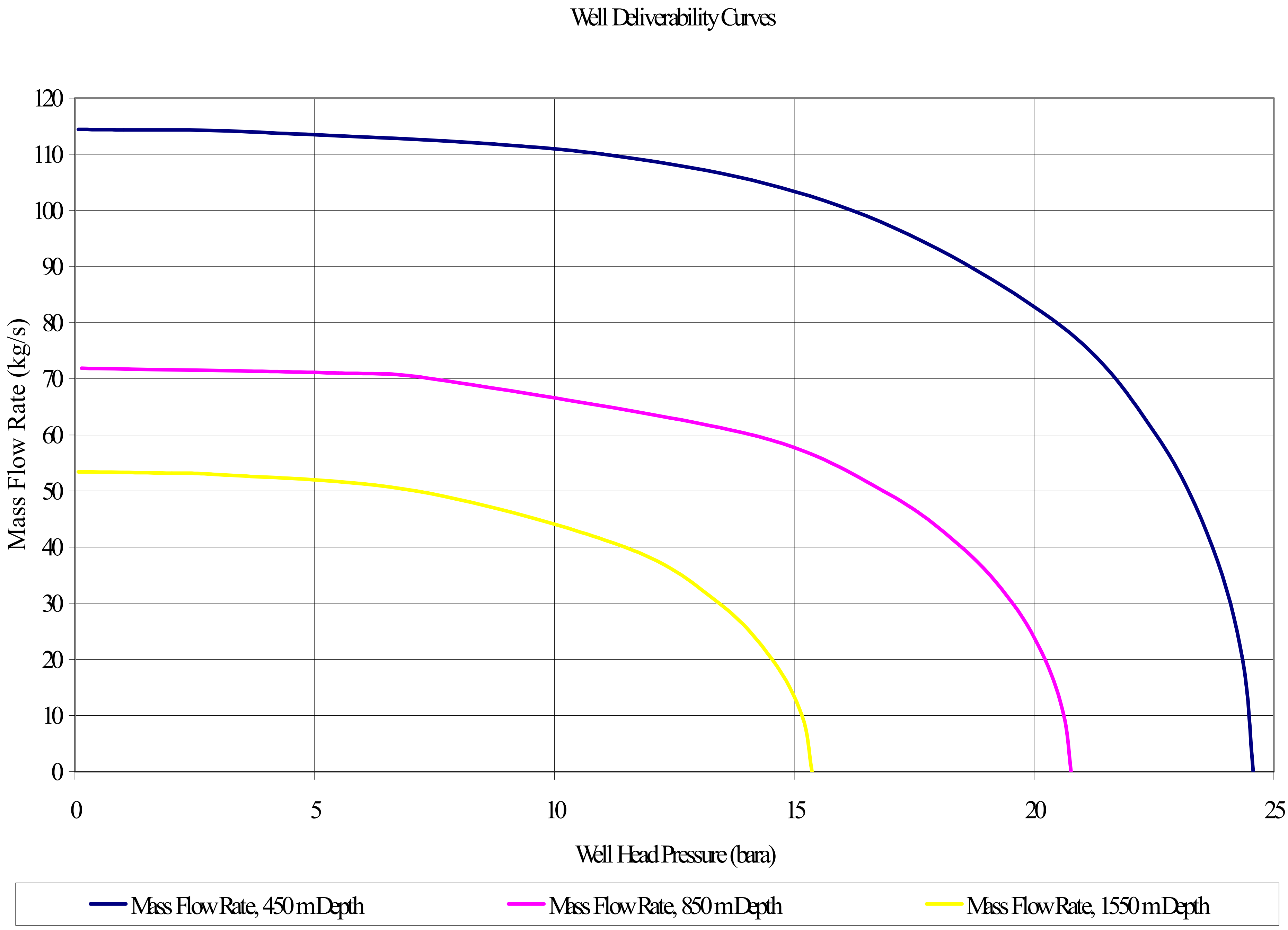
Pressure Profiles vs. Cap Rock Thickness
P (bara)
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
z (m)
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500
1600
P (bara), No Cap Rock
P (bara), 2m
P (bara), 20m
P (bara), 40m
P (bara), 60m
P (bara), 80m
P (bara), 100m
P (bara), 200m
P (bara), 300m
P (bara), 400m
P (bara), 800m
Pressure (PLITHOSTATIC: SG=2.0) bara
Pressure (PHYDROSTATIC: SG=1.0) bara
Pressure (PSAT) bara

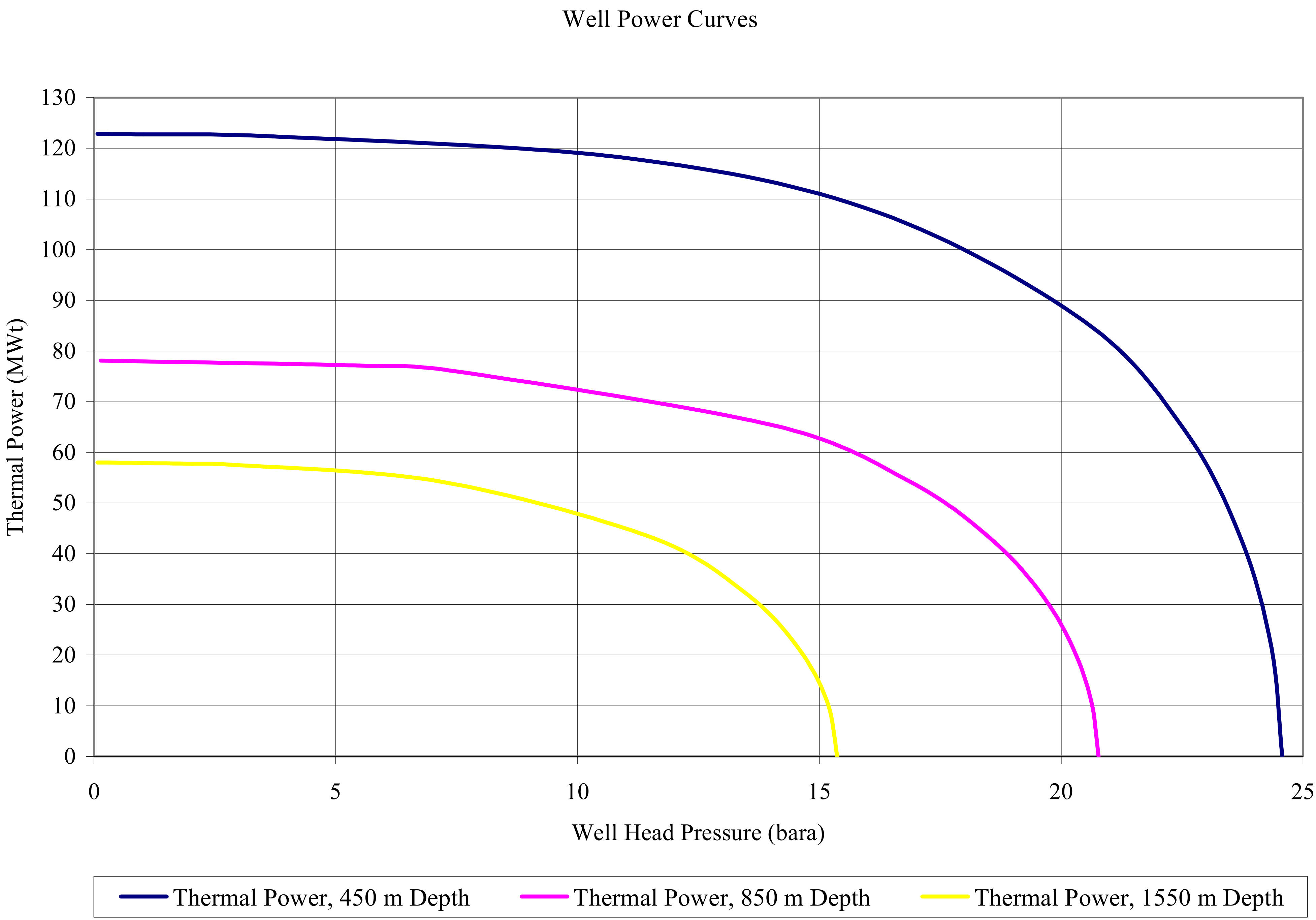

Pressure Profiles vs. Cap Rock Thickness
P (bara)
0
10
20
30
40
50
60
70
80
0
100
200
300
400
z (m)
P (bara), No Cap Rock
P (bara), 2m
P (bara), 20m
P (bara), 40m
P (bara), 60m
P (bara), 80m
P (bara), 100m
P (bara), 200m
P (bara), 300m
P (bara), 400m
P (bara), 800m
Pressure (PLITHOSTATIC: SG=2.0) bara
Pressure (PHYDROSTATIC: SG=1.0) bara
Pressure (PSAT) bara


Pressure Profiles vs. Cap Rock Thickness
P (bara)
0
10
20
30
40
z (m)
0
100
200
P (bara), No Cap Rock
P (bara), 2m
P (bara), 20m
P (bara), 40m
P (bara), 60m
P (bara), 80m
P (bara), 100m
P (bara), 200m
P (bara), 300m
P (bara), 400m
P (bara), 800m
Pressure (PLITHOSTATIC: SG=2.0) bara
Pressure (PHYDROSTATIC: SG=1.0) bara
Pressure (PSAT) bara


Vapor Saturation Profiles vs. Cap Rock Thickness
Vapor Saturation
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
0.90
1.00
z (m)
0.00
100.00
200.00
300.00
400.00
SG, No Cap Rock
SG, 2m
SG, 20m
SG, 40m
SG, 60m
SG, 80m
SG, 100m
SG, 200m
SG, 300m
SG, 400m
SG, 800m


Vapor Saturation Profiles vs. Cap Rock Thickness
Vapor Saturation
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.00
100.00
200.00
z (m)
SG, No Cap Rock
SG, 2m
SG, 20m
SG, 40m
SG, 60m
SG, 80m
SG, 100m
SG, 200m
SG, 300m
SG, 400m
SG, 800m


Well Deliverability Curves
120
110
100
90
80
70
60
50
40
30
20
10
0
0
5
10
15
20
25
Mass Flow Rate (kg/s)
Well Head Pressure (bara)
Mass Flow Rate, 450 m Depth
Mass Flow Rate, 850 m Depth
Mass Flow Rate, 1550 m Depth



Well Power Curves
Thermal Power (MWt)
130
120
110
100
90
80
70
60
50
40
30
20
10
0
0
5
10
15
20
25
Well Head Pressure (bara)
Thermal Power, 450 m Depth
Thermal Power, 850 m Depth
Thermal Power, 1550 m Depth

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Conclusions

Cap rock thickness is a key factor in the formation and performance of geothermal reservoirs.

While geothermal reservoirs can form without the presence of a cap rock layer, these will tend to be cool, small, and unstable.

Geothermal reservoirs with thin cap rock layers will tend to be hotter, larger, and less stable than those without any cap rock.

There seems to be a 'critical thickness' above which the reservoir becomes progressively more stable.

With cap rock layers of sufficient thickness and integrity, we will probably see little or no surface temperature elevation and few or no surface expressions; theoretically, this proves the probable existence of many 'hidden reservoirs'.

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Acknowledgements

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References

Grant, M., I. Donaldson, and P. Bixley, 1982. "Geothermal Reservoir Engineering", Academic Press, New York, NY.

Newson, J., 2008. Private communications, Geothermal Institute, University of Auckland, Auckland, New Zealand.

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