From Magnetic Data to Basement Depth to IFR Model

(Magnetic Anomalies Caused by Basement and for IFR Model)

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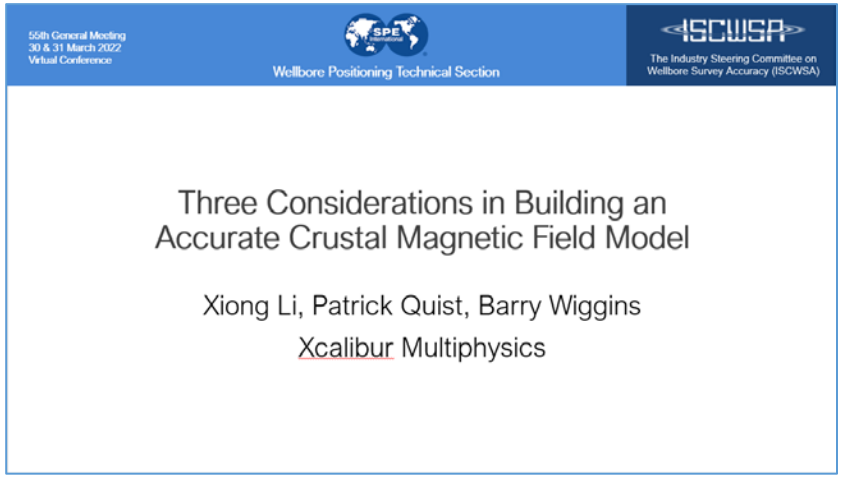
Xcalibur Multiphysics

Our Presentation at the 55th ISCWSA Meeting



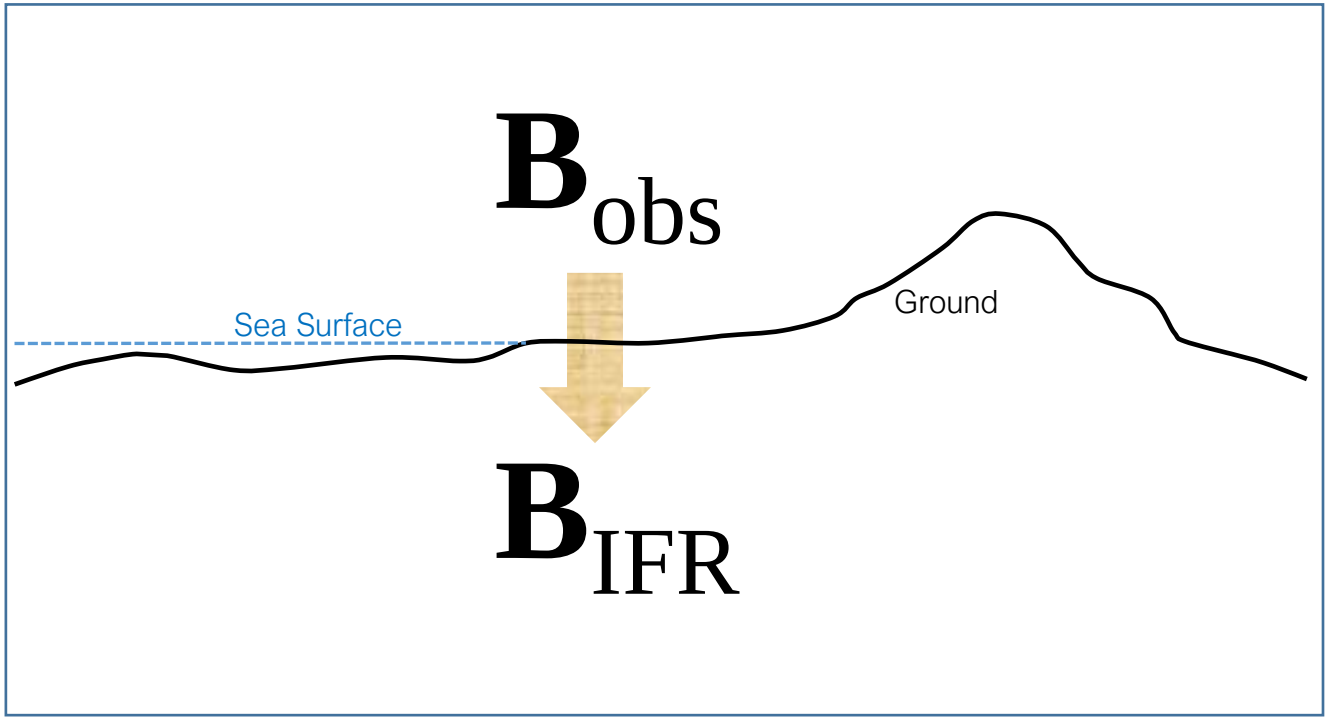
1. Basement depth as a constraint
2. Conversion considering variable DI directions
3. Use of high-resolution magnetic data

- Manoj Nair - How do you place equivalent sources when there is no basement depth information/virgin area?
- Jonathan Lightfoot - When wells are drilled extremely deep below the sedimentary basement, what can be used for declination, field strength and magnetic dip angle?
- Neil S. Bergstrom - Is the assumption of no magnetization from sediments sufficient?
- ……

This Talk

- Why does the basement matter?
- Where do I get the basement depth information?
- How can the basement depths be used in building an IFR model?
- How about basement depth uncertainties?

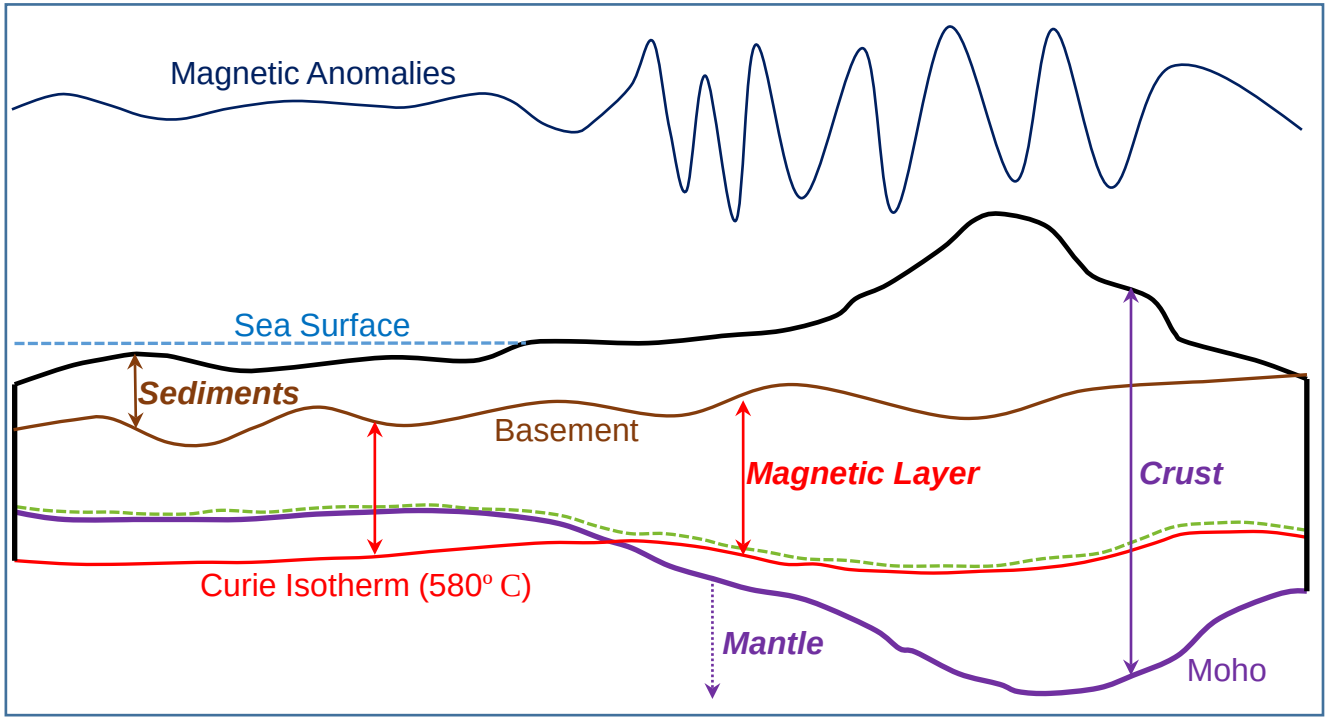
How Is an IFR Model Built?



An IFR Model Constrained by Basement

- Building an IFR model is to infer the magnetic field below the ground and ocean surface from the observed magnetic field above this surface.
- The key is to deduce the crustal magnetic field, not the main and disturbance fields.
- This is a geophysical problem.

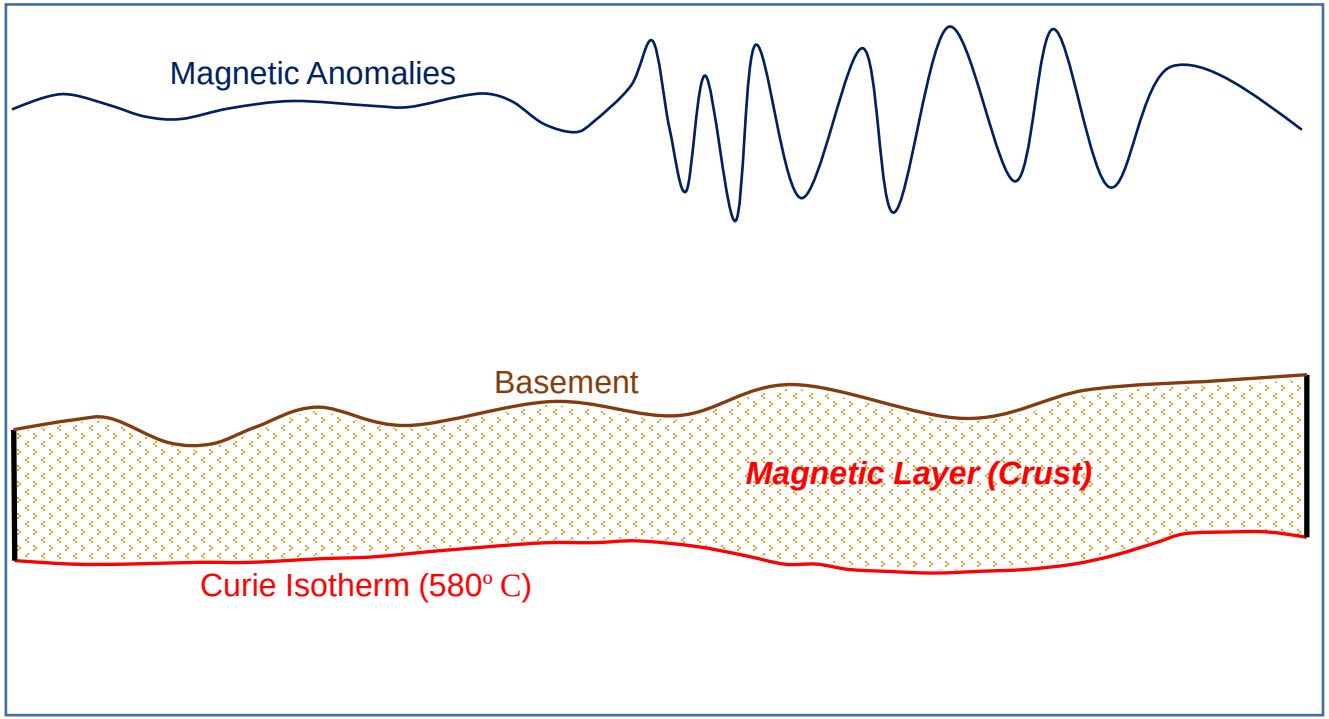
Geology (Horizons & Layers) and Crustal Magnetic Anomalies



SURFACES	LAYERS
Rock surface	
	Sediments
Basement	
	(Magnetic) crust
Curie isotherm	
Moho	
	Mantle

An IFR Model Constrained by Basement

From A Magnetic Layer to Crustal Magnetic Anomalies



- All materials lose magnetization when temperature reaches the Curie point (580º C).
- Sediments are often assumed no magnetization for our interest.
- Crustal magnetic anomalies are caused by the magnetic layer delimited by the (top surface of the) basement and the Curie depth.

An IFR Model Constrained by Basement

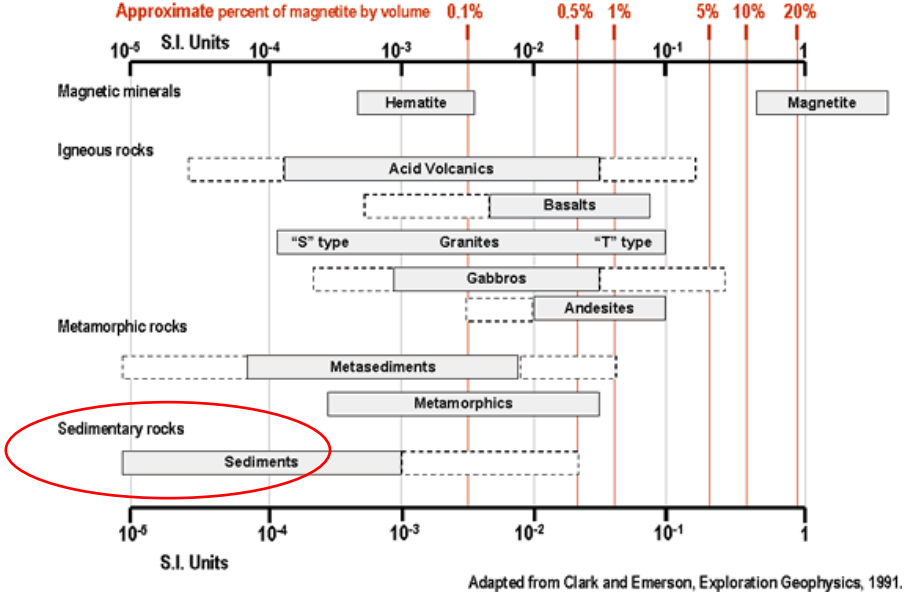
Basement

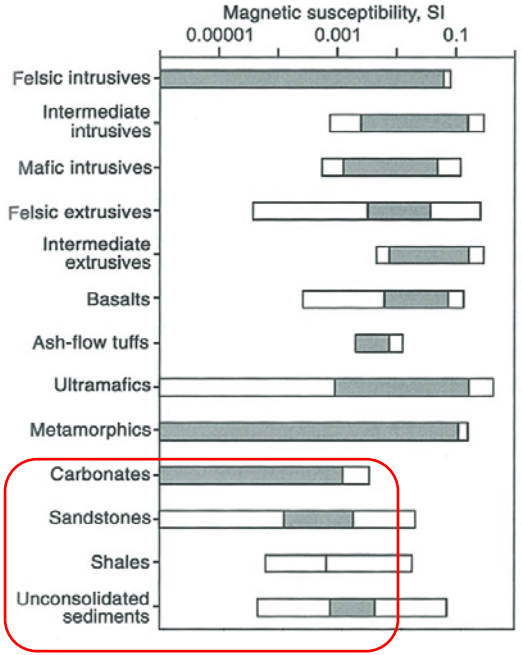
The level below which changes in rock properties do not affect observations significantly, or the lowest level of interest. Different types of basement may not coincide.

1. **Geologic basement** is the surface beneath which sedimentary rocks are not found; the igneous, metamorphic, granitized, or highly folded rock underlying sedimentary rocks.
2. **Petroleum economic basement** is the surface below which there is no current exploration interest, even though some sedimentary units may lie deeper.
3. **Magnetic basement** is the upper surface of igneous or metamorphic rocks whose magnetization is so much larger than that of sedimentary rocks that their effects get lost in the noise.
4. **Electrical basement** is the surface below which resistivity is very high so that variations below this surface do not affect electrical-survey results significantly.
5. **Acoustic basement** is the deepest more-or-less continuous reflection.
6. **Gravity** or **density basement** is where a very large density contrast exists so that anomalies resulting from deeper contrasts are lost in the noise.
7. **Hydrologic basement** is the deepest point where significant porosity exists.

https://wiki.seg.org/wiki/Dictionary:Basement

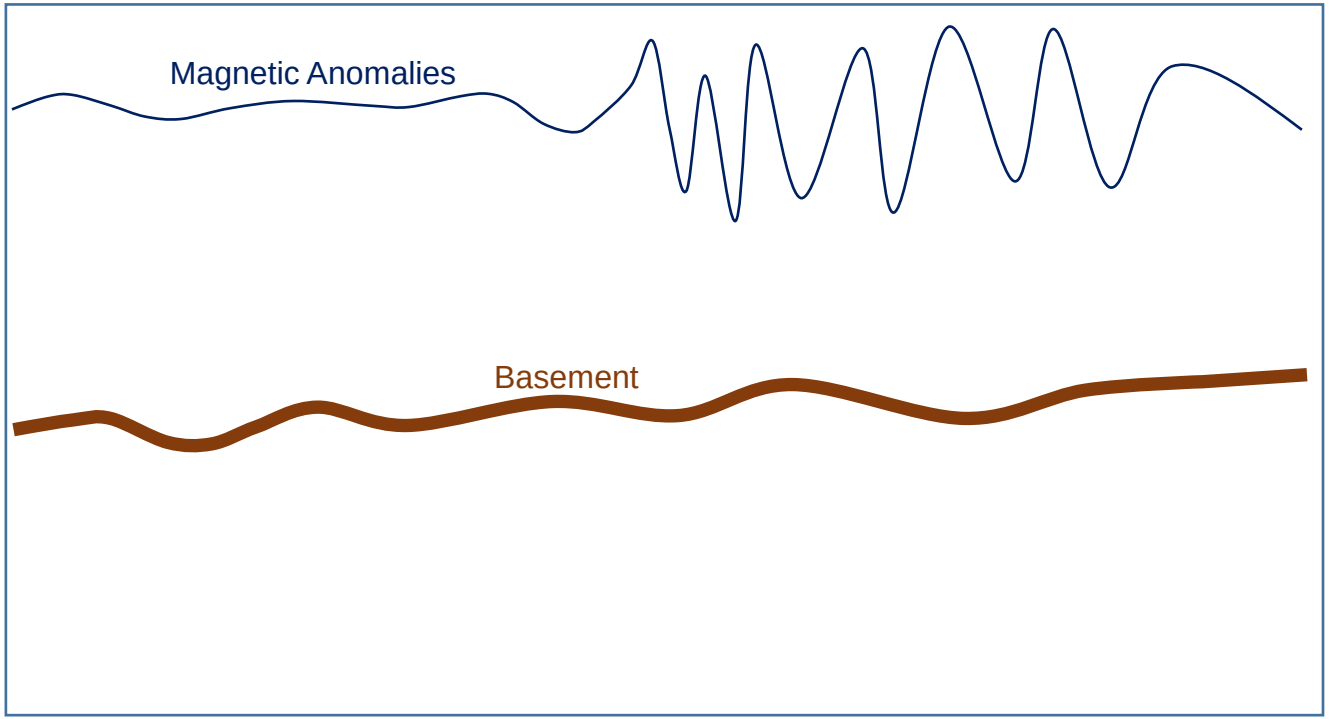
Magnetic Susceptibilities of Various Rock Types





D. A. Clark and D. W. Emerson, 1991, Notes on rock magnetization characterization in applied geophysical studies: Exploration Geophysics, p. 547-555.

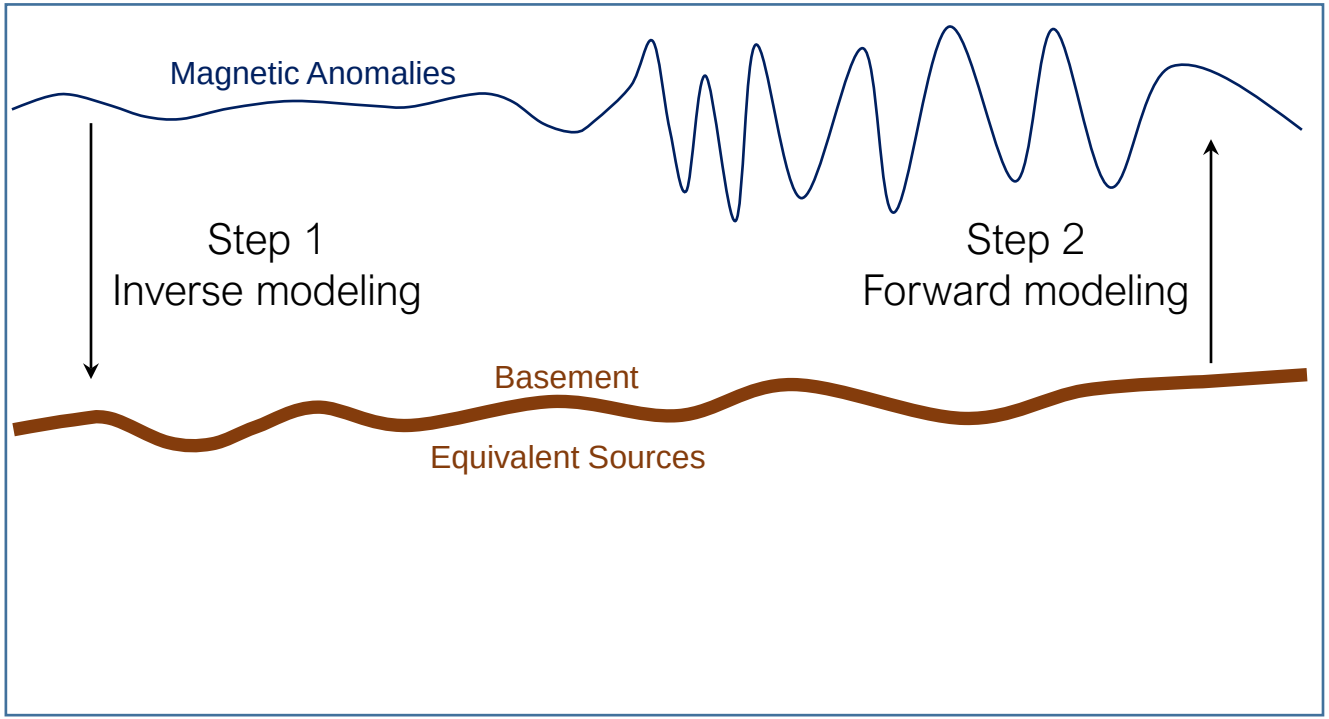
Theoretical Basis of the Equivalent Source Technique



An IFR Model Constrained by Basement

- The magnetic field is a potential field.
- Green's third identity states that the potential field outside a source domain can be equally described by sources on the domain boundary.
- The top surface of the basement is this boundary.
- Such fictitious sources are called equivalent sources.

The Equivalent Source Technique: From (Magnetic Data + Basement) to IFR



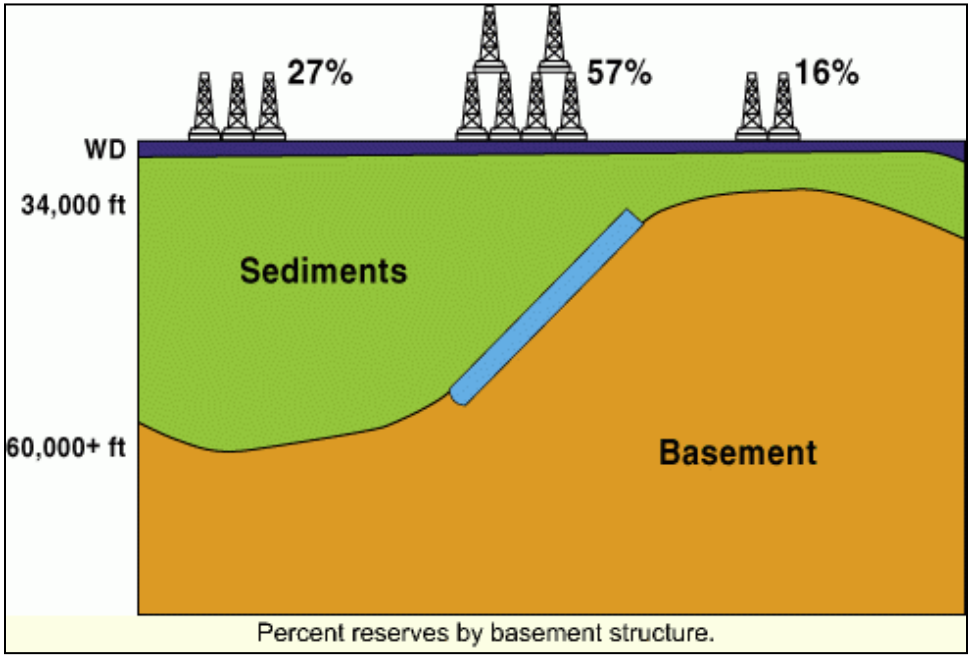
An IFR Model Constrained by Basement

- We can place equivalent source on the basement surface.
- We then determine the magnetization of equivalent sources via an inverse modeling.
- Finally, we calculate the vector magnetic field **anywhere** above the equivalent source surface (i.e., an **IFR model**) by a forward modeling.

Magnetic Anomalies due to Basement and for IFR

- Crustal magnetic anomalies are produced by magnetization variations in the basement.
- Magnetic anomalies and the basement depths **together** can be used to derive a distribution of equivalent sources and thus an IFR model.

Basement Structure and Oil Reserves in the Deepwater GoM (US Sector)



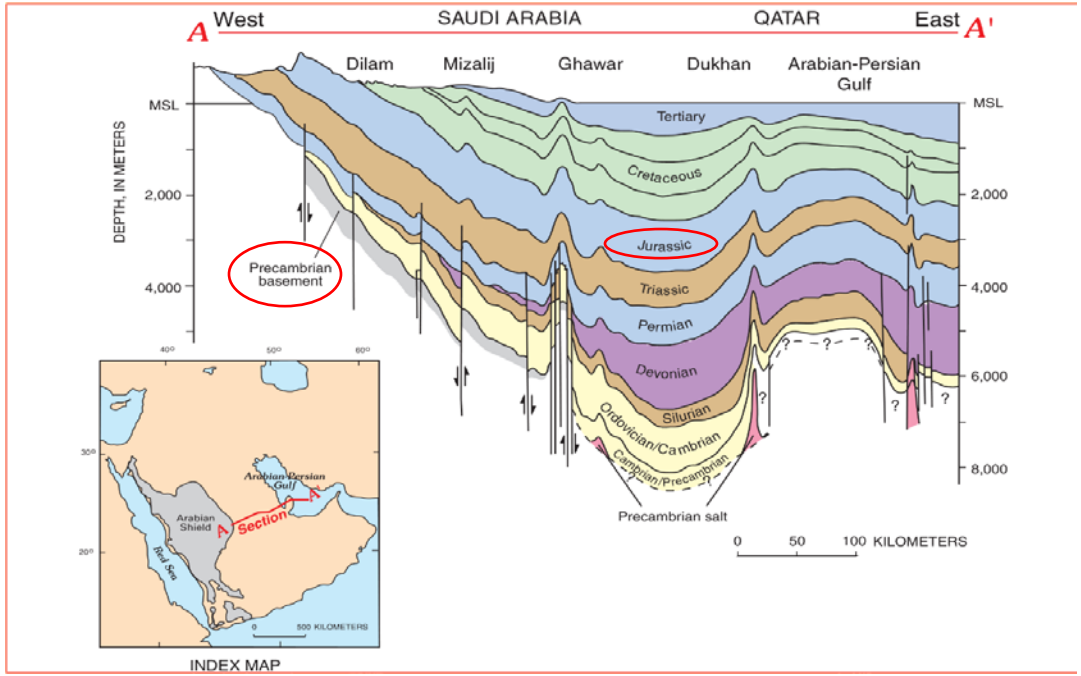
Percent reserves by basement structure.

C. Prieto and J. C. Pratsch, 2000, Offshore Magazine.

Importance of Basement Information

- In petroleum exploration, it is critical to understand basement depths and structures. Basement depth (or equivalently, sedimentary thickness) is a primary exploration risk parameter.
- Basin modelling (e.g., source rock volume estimation) and thermal maturity interpretation (e.g., source-rock burial-depth) need the basement depth information. Basement structure provides insight into the evolution of more recent sedimentary features (e.g., sub/mini-basin compartmentalization, salt structure distribution/kinesis, localization of reservoir-bearing structures) — for instance, in areas where the inherited basement fabric/architecture has affected (either continuously or episodically) basin evolution and development.
- The movement and flow of fluids within a basin, such as hydrocarbon migration along lateral and vertical carrier beds, can be facilitated by basement-involved sedimentary faults/fractures. Basin heat-flow patterns can also be moderated by fluid circulation along basement-involved fault systems.
- It is unimageable to drill a well when basement depths and structures are unknown.

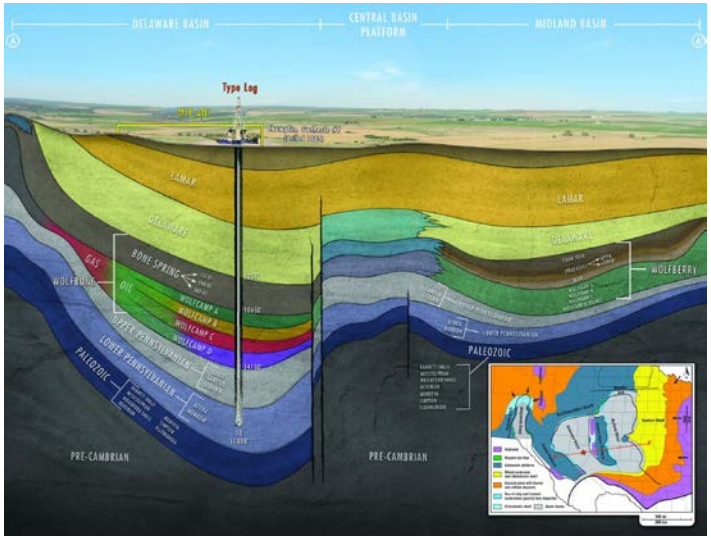
Regional Cross-Section of Ghawar

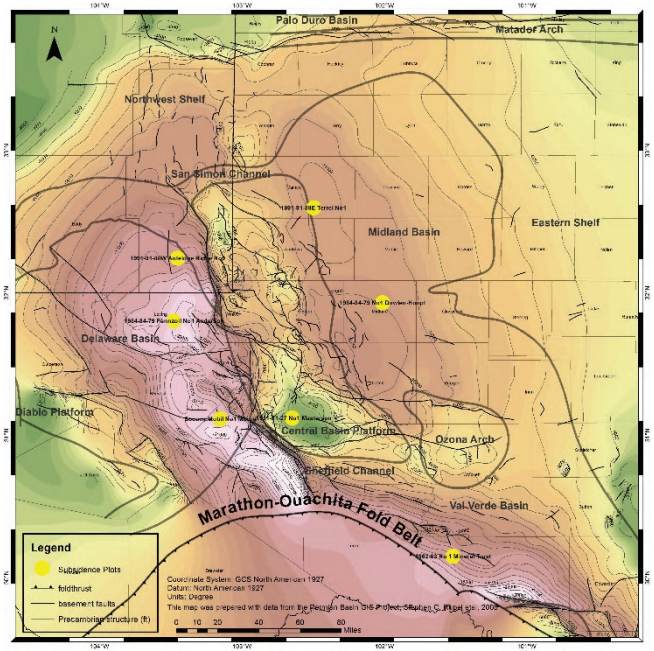


The main interval producing oil in Ghawar is the Arab D formation which sits in the Jurassic interval.

http://energy-cg.com/OPEC/SaudiArabia/OPEC_SaudiArabia_Ghawar.html

Precambrian Basement Depths of the Permian Basin

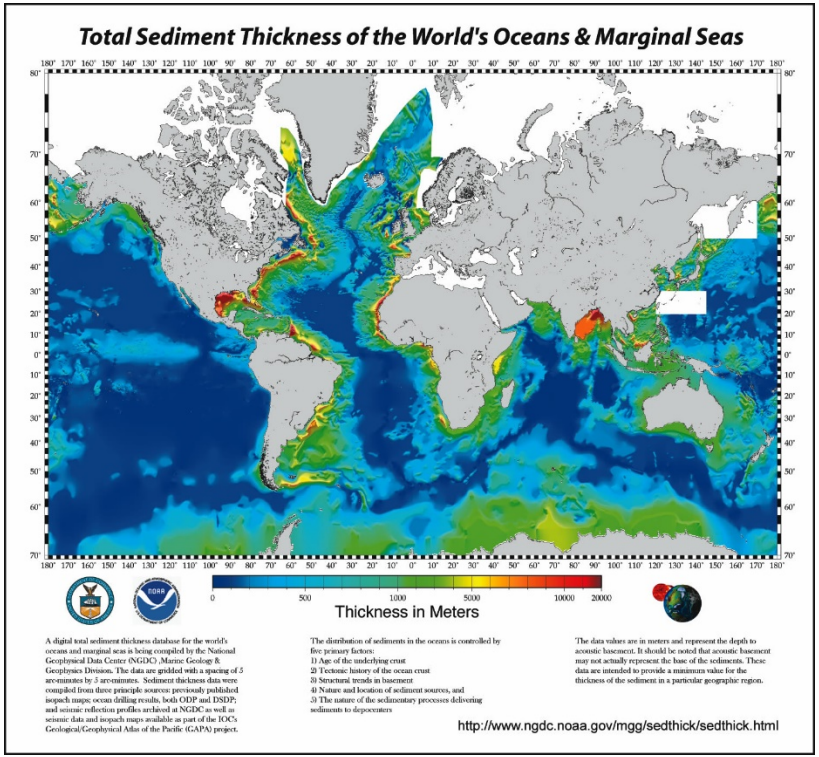




Ruppel, S. C., et al, 2008, Integrated synthesis of the Permian Basin: Data and models for recovering existing and undiscovered oil resources from the largest oil-bearing basin in the U.S., GIS Dataset.

An IFR Model Constrained by Basement

Sediment Thickness of the Oceans

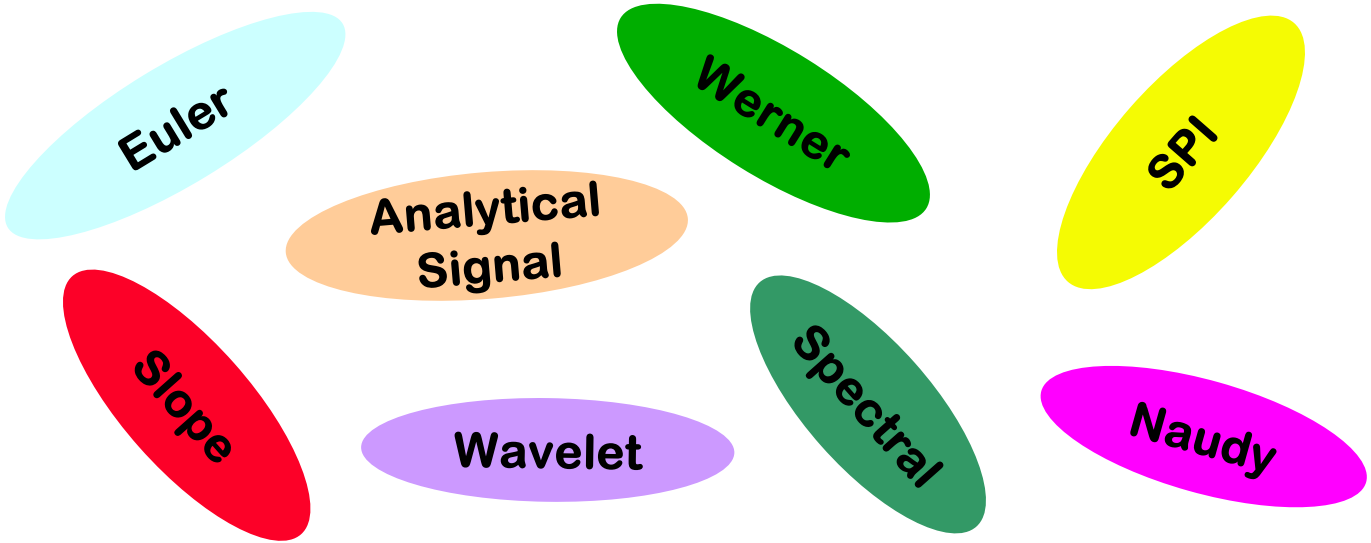


https://www.ngdc.noaa.gov/mgg/sedthick/sedthick.html

Magnetic Data for Basement Interpretation

- Magnetic data was used to interpret basement depths and structures in oil and gas exploration many decades before for wellbore surveying in directional drilling.
- The structural surface interpreted from magnetic depth estimates is often the best available approximation to the true crystalline (i.e., metamorphic/igneous) basement configuration.
- Different quick methods have been developed, over seventy years, to estimate the magnetic depth.

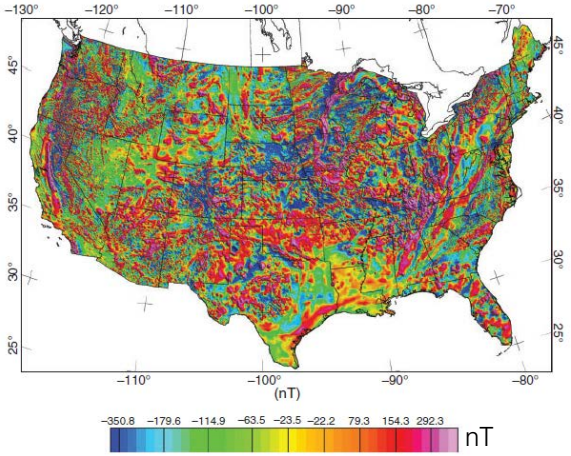
Methods for Magnetic Basement Depth Estimation



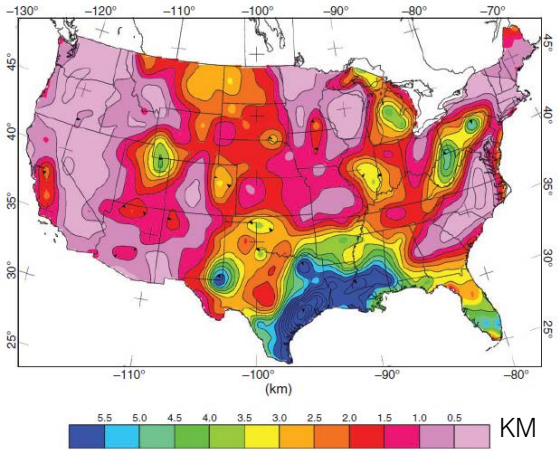
X. Li, 2003, On the use of different methods for estimating magnetic depth: The Leading Edge, p. 1090-1099.

Basement Depths Estimated from Magnetic Data

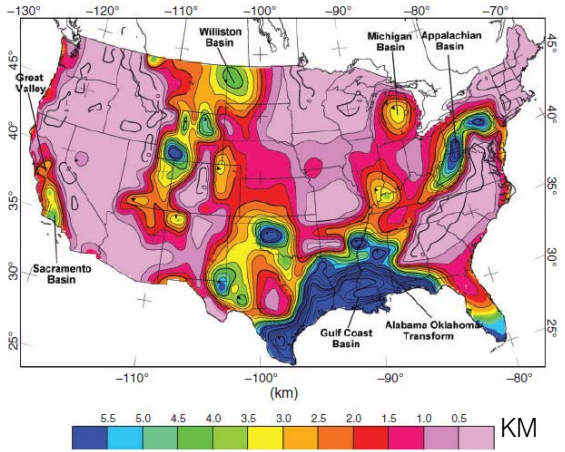
Magnetic RTP Anomaly



Magnetic Basement Depths

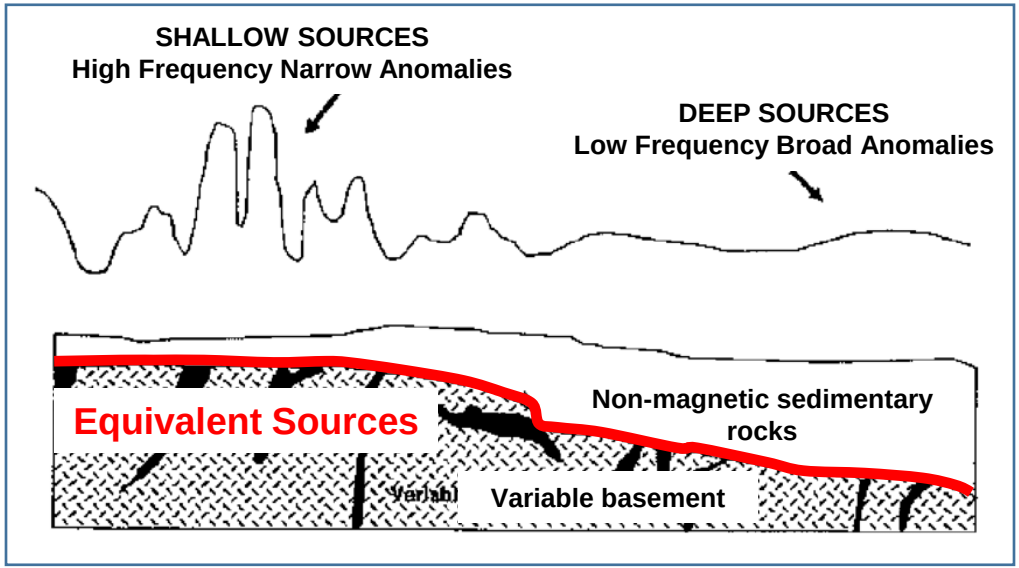


1° average sedimentary thickness map
(Laske and Masters, 1997)



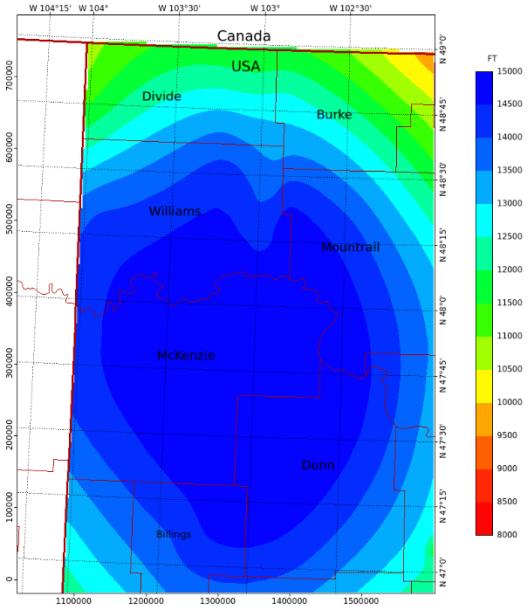
A. Salem et al, 2010, Sedimentary basins reconnaissance using the magnetic Tilt-Depth method: Exploration Geophysics, **41**, 198-209.

The Equivalent Source Technique and the Uncertainties in Basement Depths

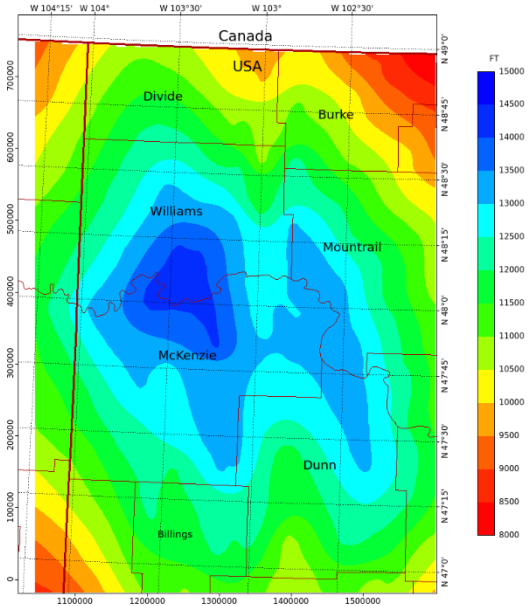


- Errors in magnetic data and the basement depths contribute to uncertainties in an IFR crustal field model.
- We can estimate this error to uncertainty propagation.

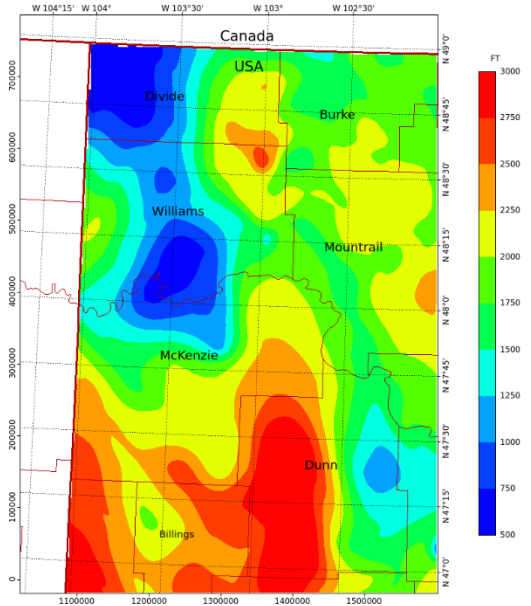
Two Basement Depth Models in the Bakken



Anderson, F. J., 2009, Depth to Precambrian basement rock in North Dakota: North Dakota Geological Survey.



Marshak, S., et al., 2017, The basement revealed: Tectonic insight from a digital elevation model of the Great Unconformity, USA, cratonic platform: Geology.

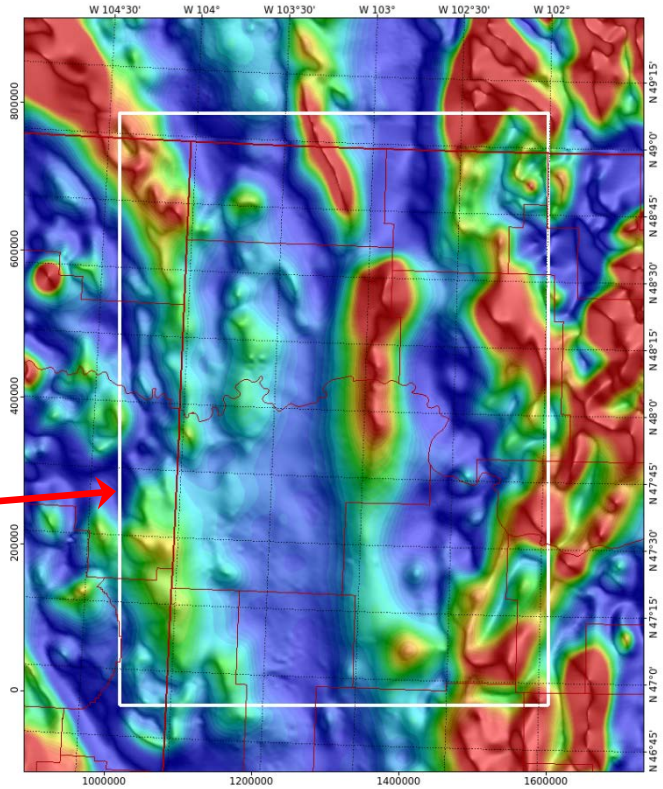


Differences

An IFR Model Constrained by Basement

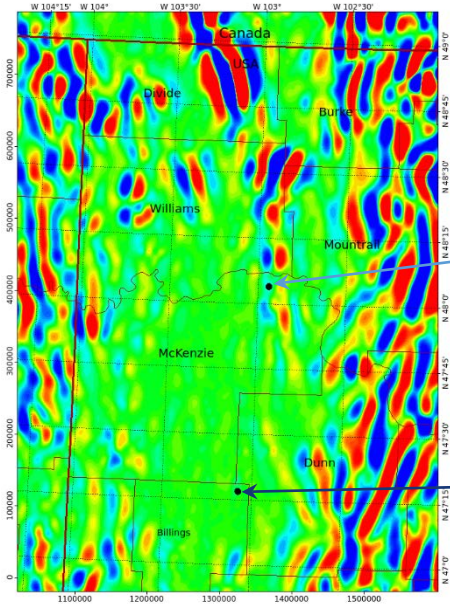
Magnetic Anomalies in the Bakken

An IFR model area



An IFR Model Constrained by Basement

Effects on IFR of Two Basement Depth Models in the Bakken



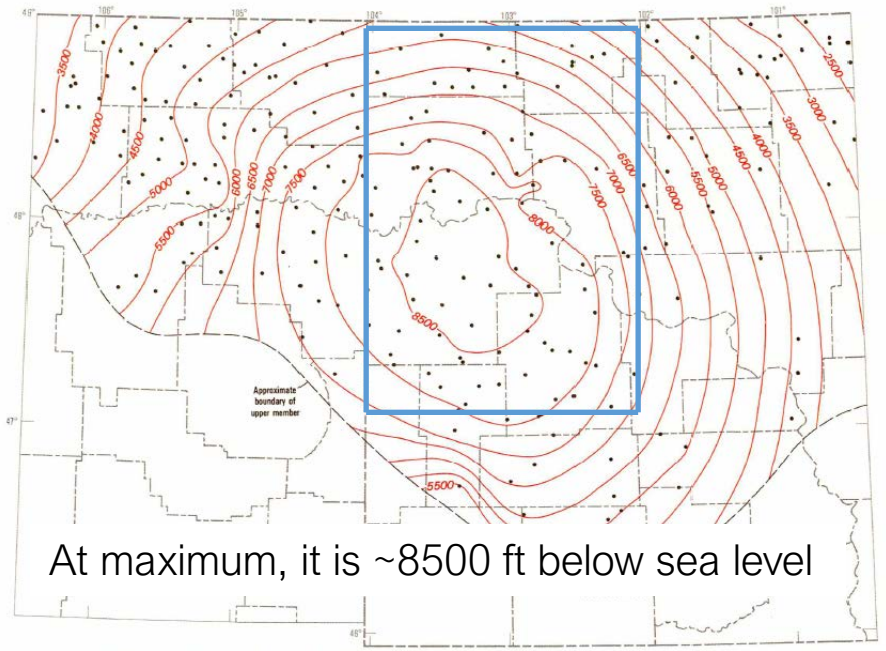
Declination differences at 8500 ft

Difference values

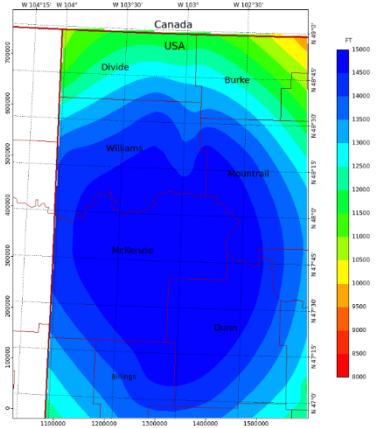
Basement depth	*2000 ft*
Declination	-0.010º
Inclination	0.001º
Total field	-2 nT

Basement depth	*2700 ft*
Declination	-0.003º
Inclination	0.000º
Total field	-0 nT

Top Depths of the Bakken Formation



At maximum, it is ~8500 ft below sea level

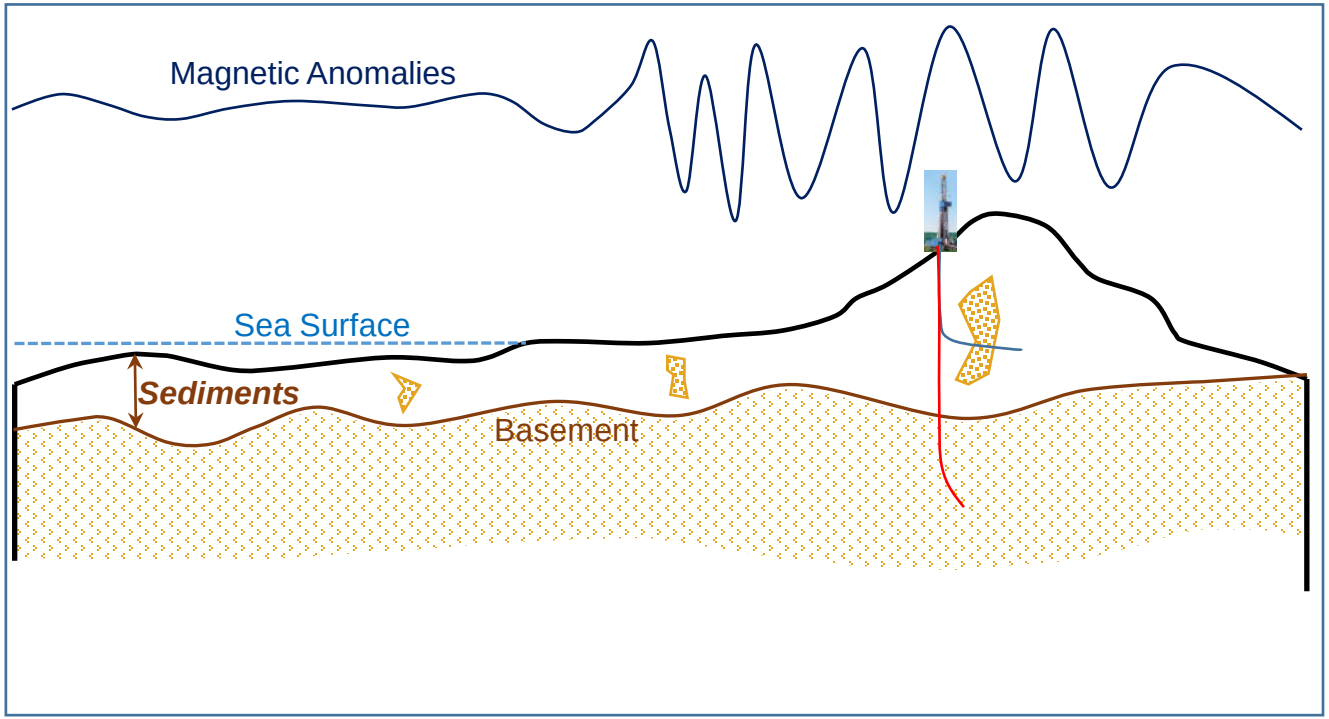


Basement depths are
>12 kft bsl under rigs

Rig location

https://store.usgs.gov/assets/mod/storefiles/PDF/OC-126_ND_MT_Selected_Physical_Properties_Bakken_Formation_1985.pdf

Strong Magnetic Sources above Basement, and Drilling into Basement



An IFR Model Constrained by Basement

- Theoretically and practically, IFR doesn't work.
- One better seeks alternatives.

Conclusions

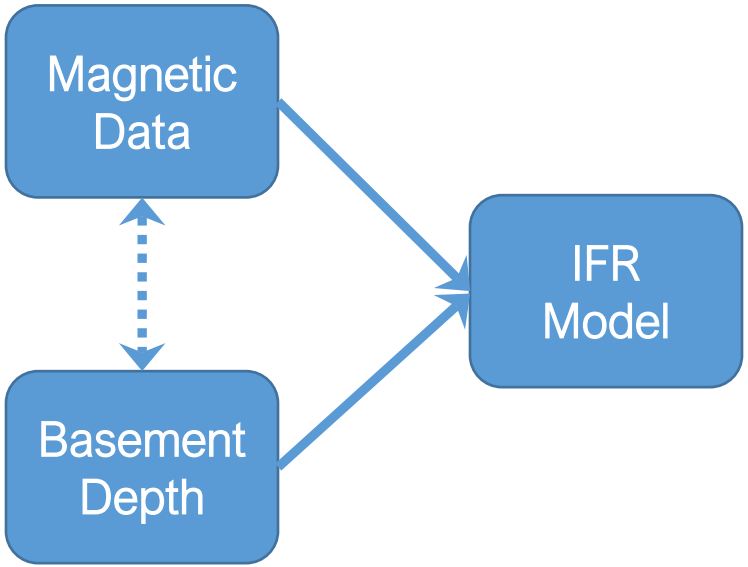
I. Building an IFR model requires magnetic data.

II. Building an accurate IFR model should use the basement depth information.

III. Magnetic data provides one way to estimate basement depths.

IV. Errors in both magnetic data and basement depths contribute to IFR model uncertainties, and these uncertainties can be estimated.

V. It is rare and unreasonable to drill when basement depths are unknown.



Thank you

Questions (bets@xcaliburmp.com)