Dielectric Properties of Oil Shale

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Can RF energy be effectively utilized for in-situ heating of oil shales?

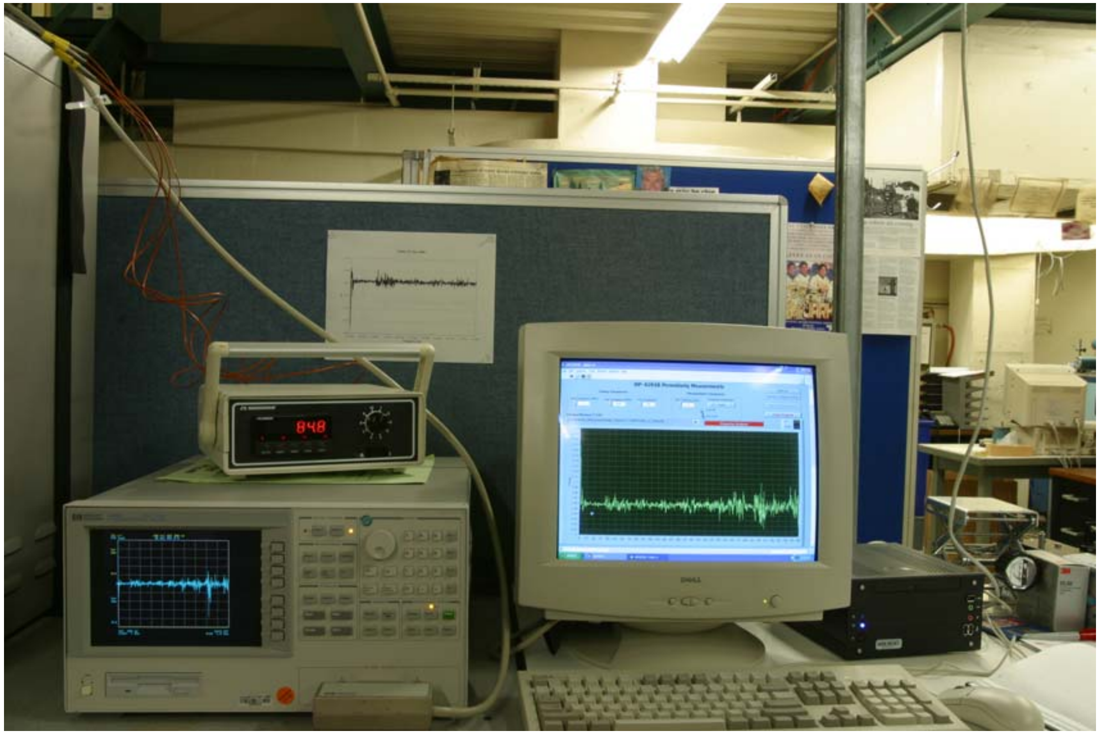
- Is there a dielectric loss mechanism in the kerogen between 1 MHz and 1 GHz?
- Can RF energy significantly penetrate and be deposited within the oil shales?
- What is the effect of fluids (and ions) on the dielectric properties of the oil shales?
- What is the effect of temperature on the dielectric properties of the oil shales?

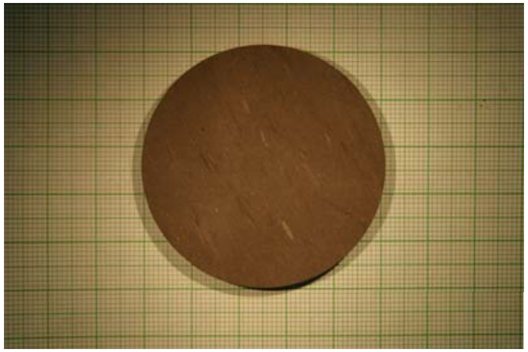
- measured complex dielectric constant on two sample suites from 1 MHz - 1.8 GHz

- measured complex dielectric constant at various water and brine saturations

- measured complex dielectric constant on dry samples up to ~ 150°C

Measurements Were Conducted Using an HP4291A Impedance/Material Analyzer and High Temperature Probe





Anadarko samples (10): SW Wyoming, Green River, 1.994 +/- 0.075 g/cc, 41.53 +/- 5.97 gal/ton*
Anvil Points samples (8): W Colorado, Green River, 1.947 +/- 0.057 g/cc, 45.28 +/- 4.83 gal/ton*

•J. Smith, *Theoretical Relationship Between Density and Oil Yield for Oil Shales*, U.S. Bureau of Mines Pub. 7248, 1969.

The complex dielectric constant was measured between 1 MHz and 1.8 GHz on all samples

Complex dielectric constant

$$\varepsilon^* = \varepsilon' - j\varepsilon''$$

ε' is the 'dielectric constant'

ε'' is the 'loss factor'

Power dissipated

$$P \sim \varepsilon'' f E^2$$

Skin depth

(Penetration depth For E to fall to 1/e)

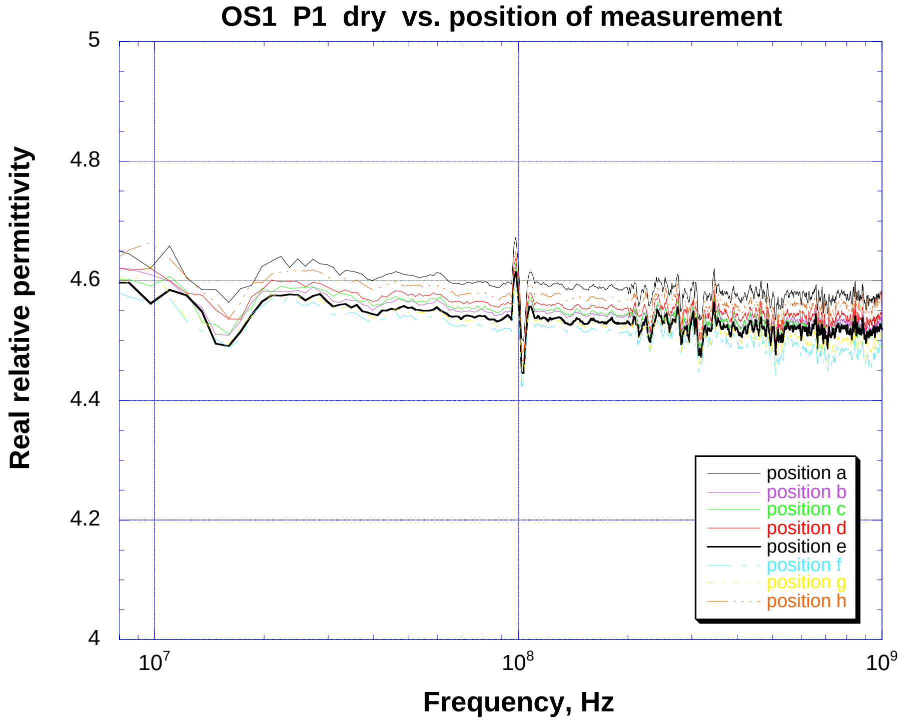
$$D_p \sim \varepsilon'^{1/2}/(\varepsilon'' f)$$

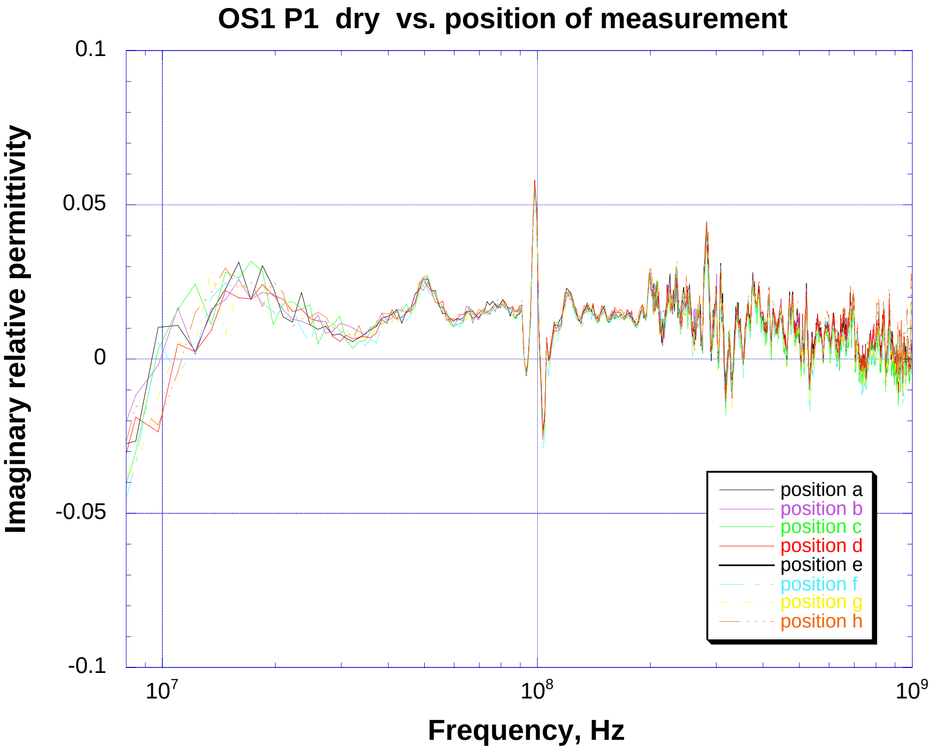
	ε'	ε''
Teflon (1&3 GHz)	2.1	.0003
Water (1 GHz)	77.5	1.2
Water (3 GHz)	76.6	12.0

Measurement variability within a sample was tested

P- face parallel to bedding
T - face perpendicular to bedding

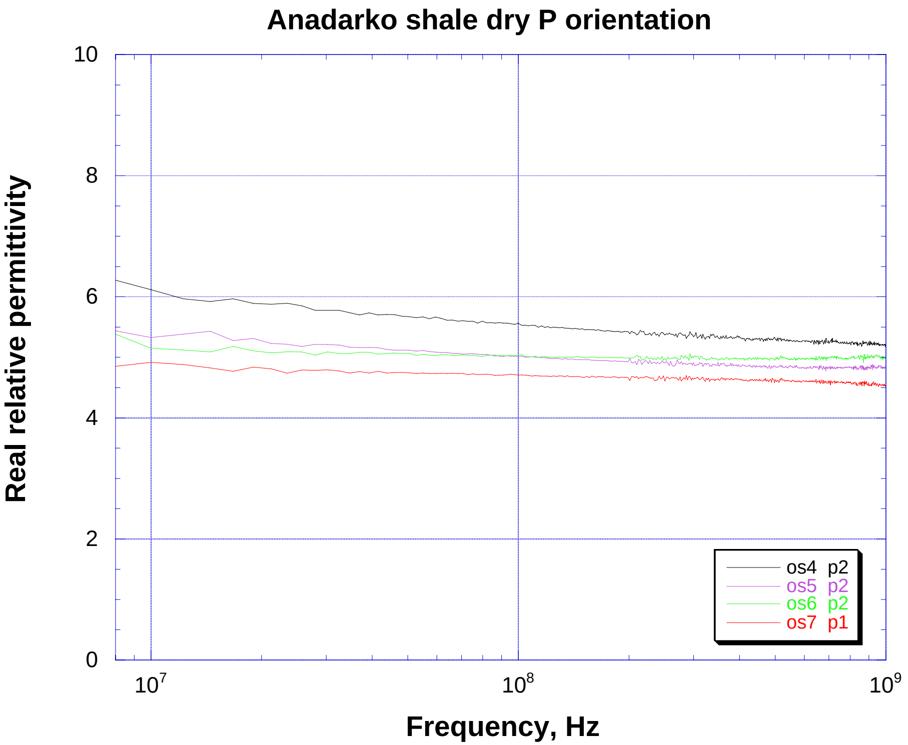
OS1 to OS3 - Anvil Points samples
OS4 to OS7 - Anadarko samples

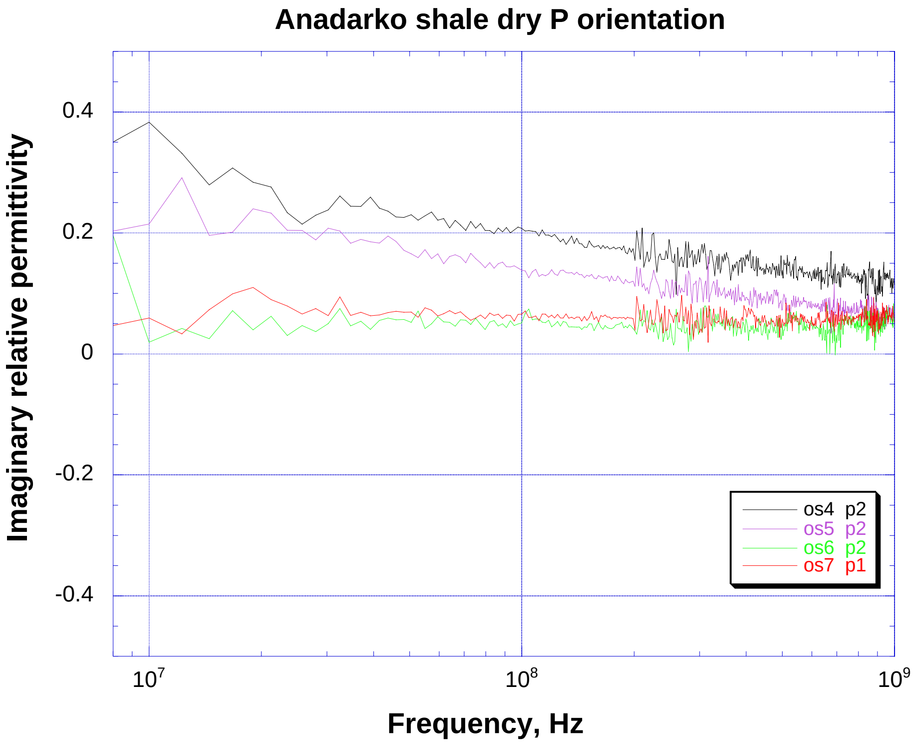




T (not shown) more variable than P, both relatively small

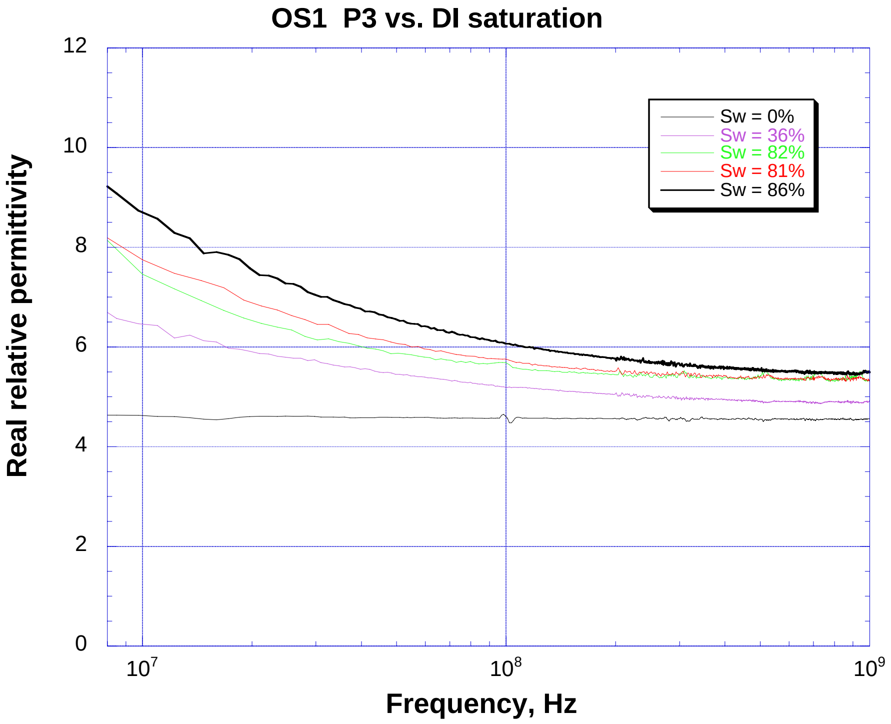
Dry, room temperature results for Anadarko samples

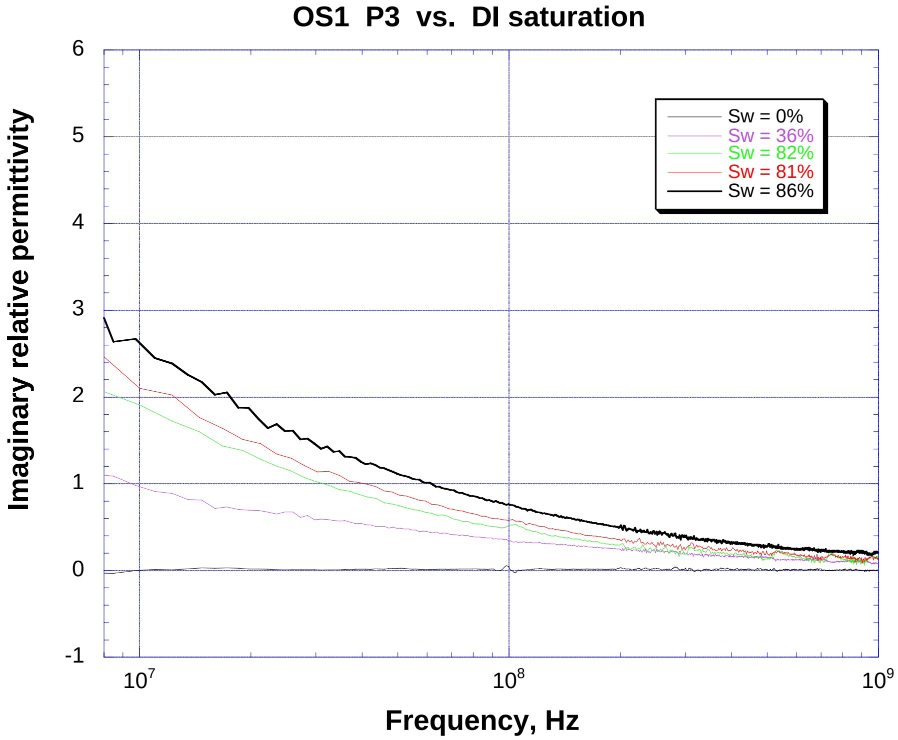




No kerogen-related loss mechanism in frequency band

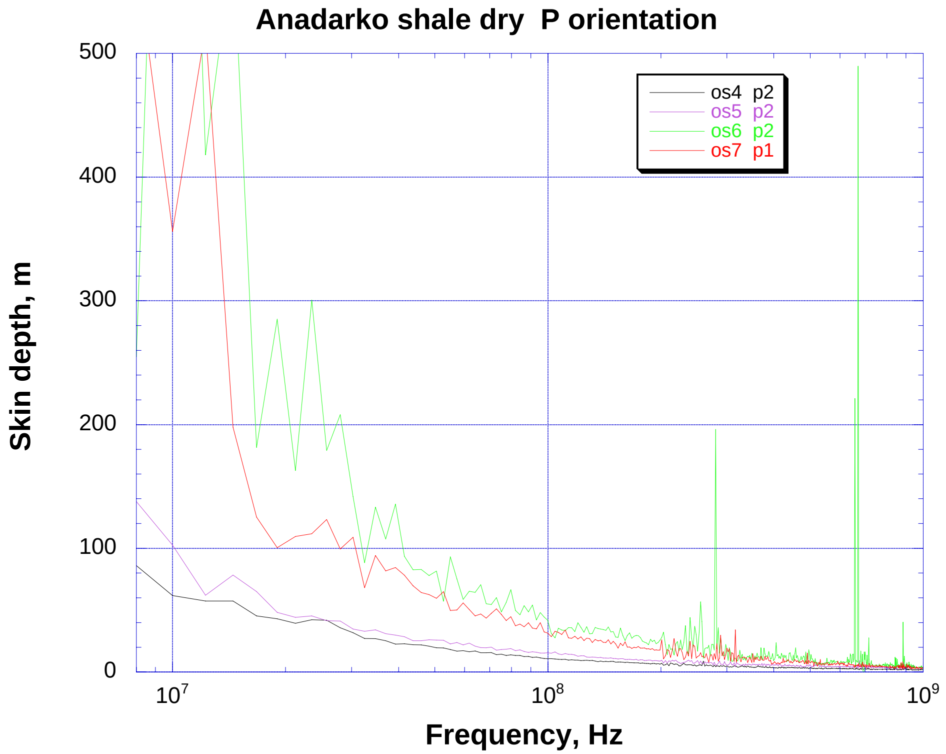
Complex dielectric constant at different de-ionized water saturations

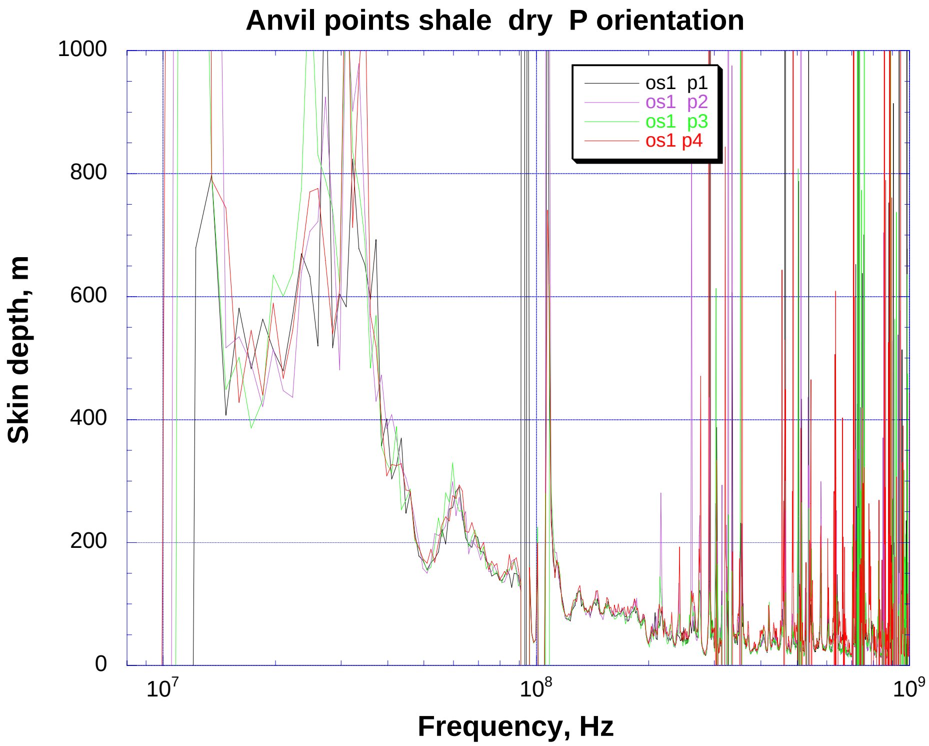




The loss factor is highly dependent on water saturation

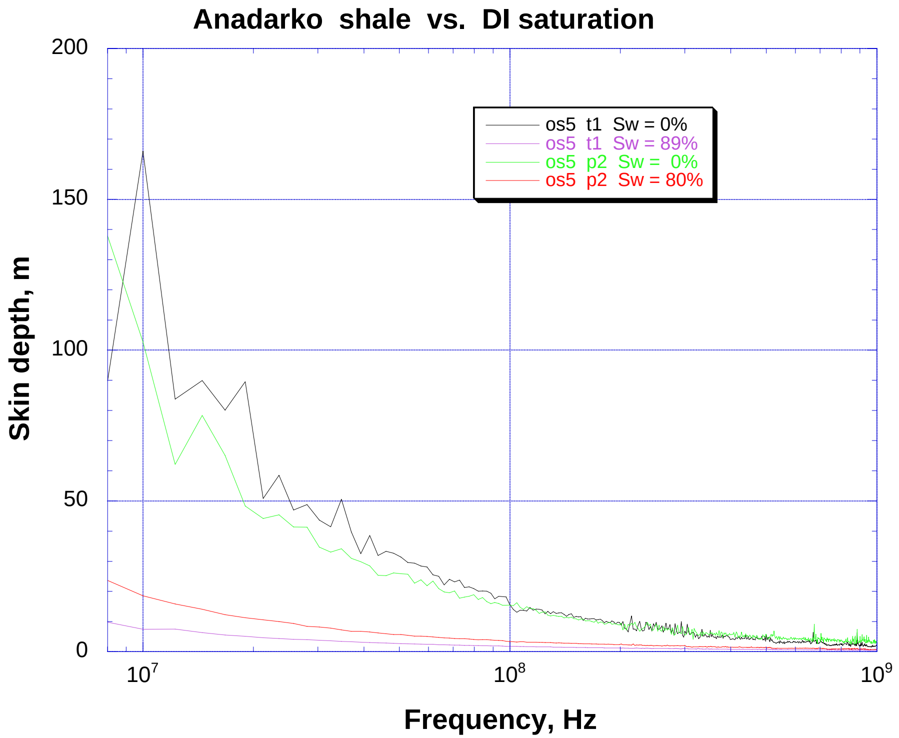
Large skin depths are measured in dry samples

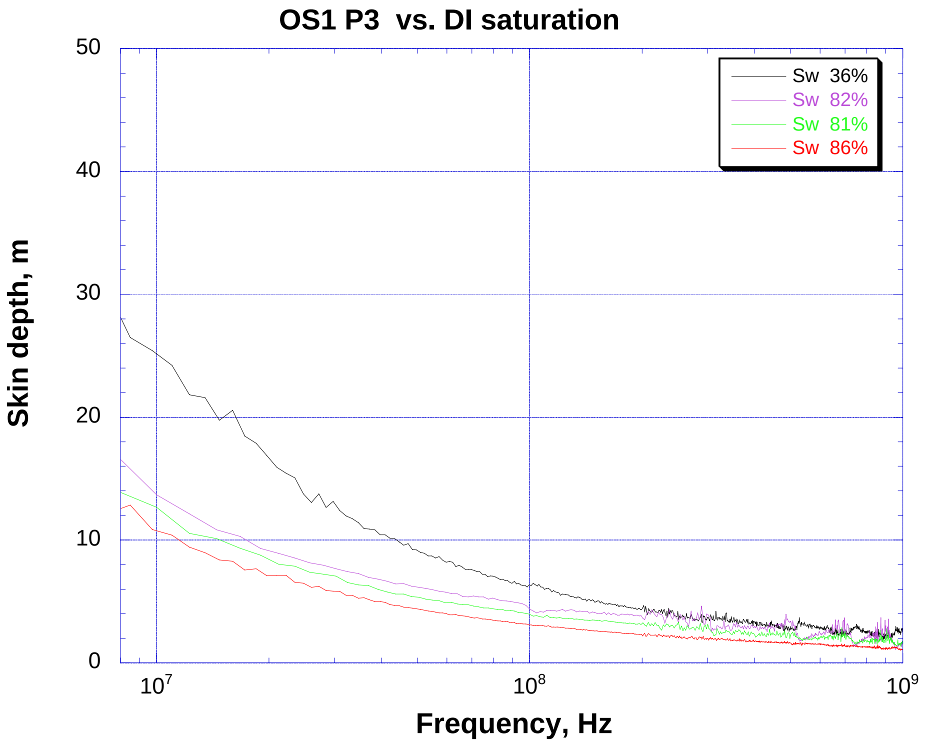




Heating rates are low in dry samples at lower frequencies.

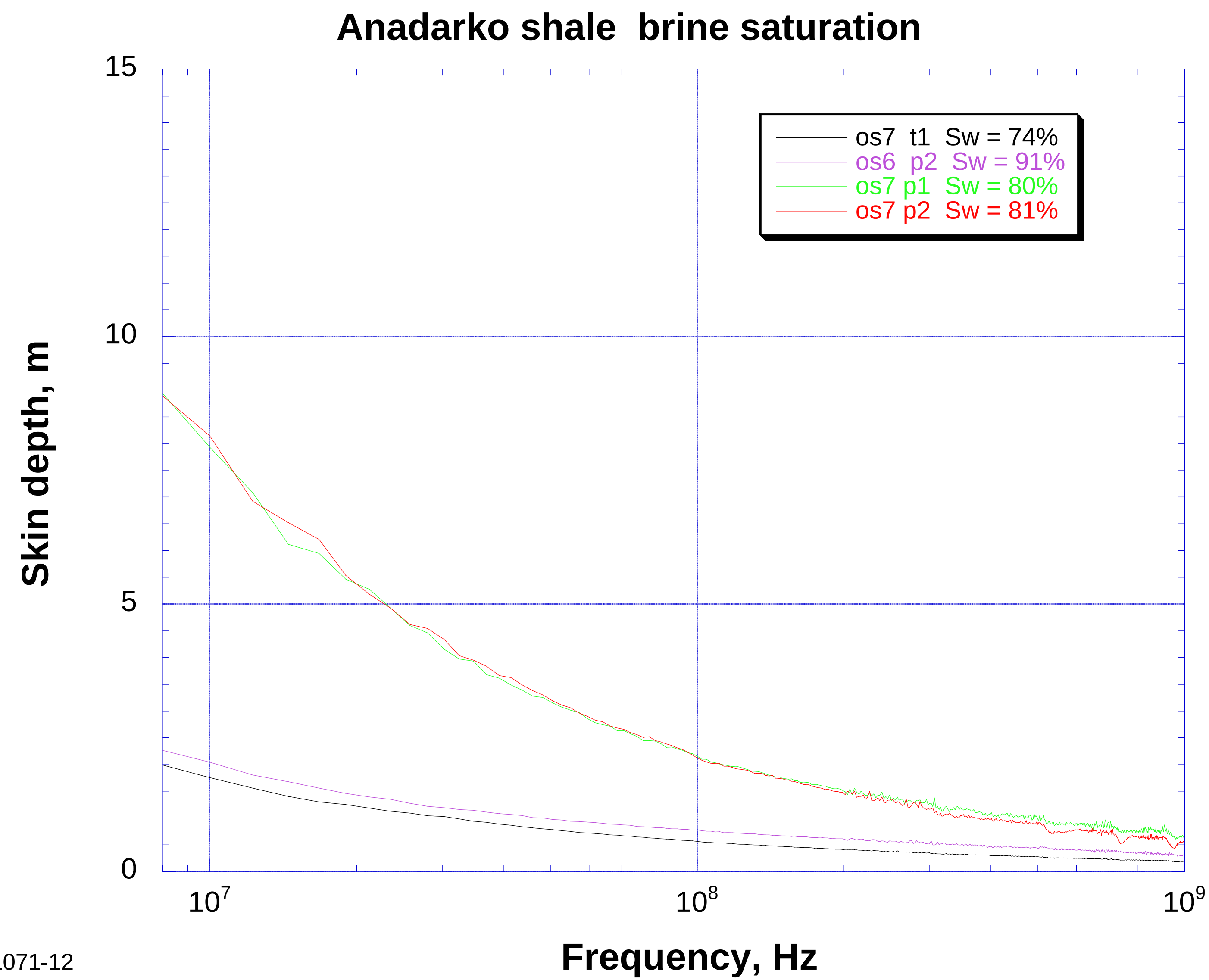
Saturation controls skin depth with de-ionized water





For skin depths of 10 meters, f < 20 MHz

Saline water further reduces the skin depth



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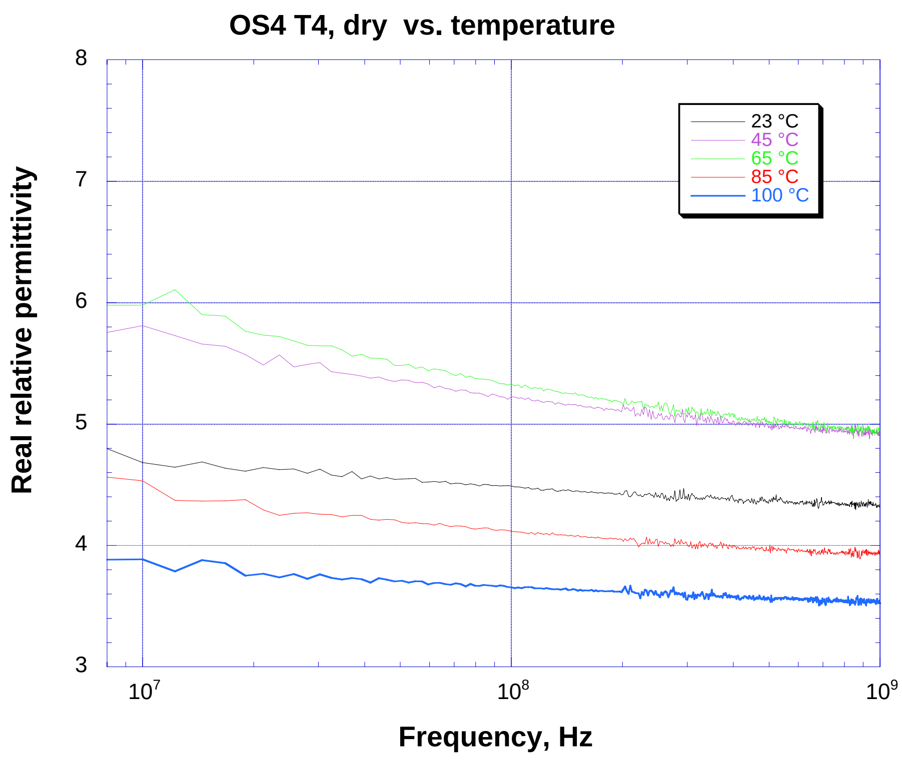
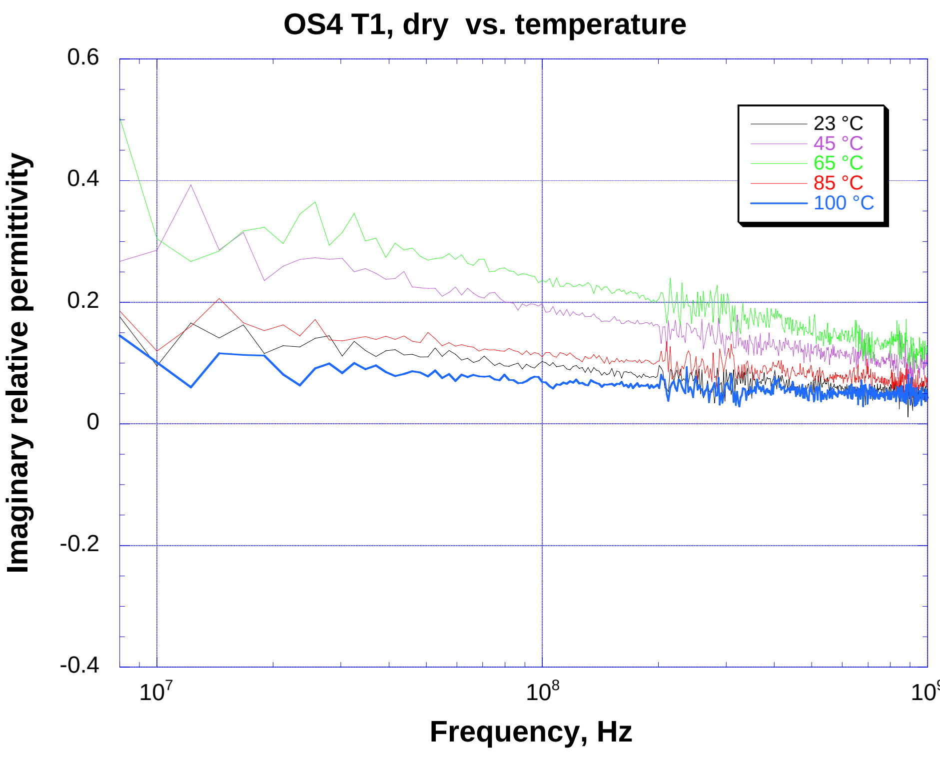
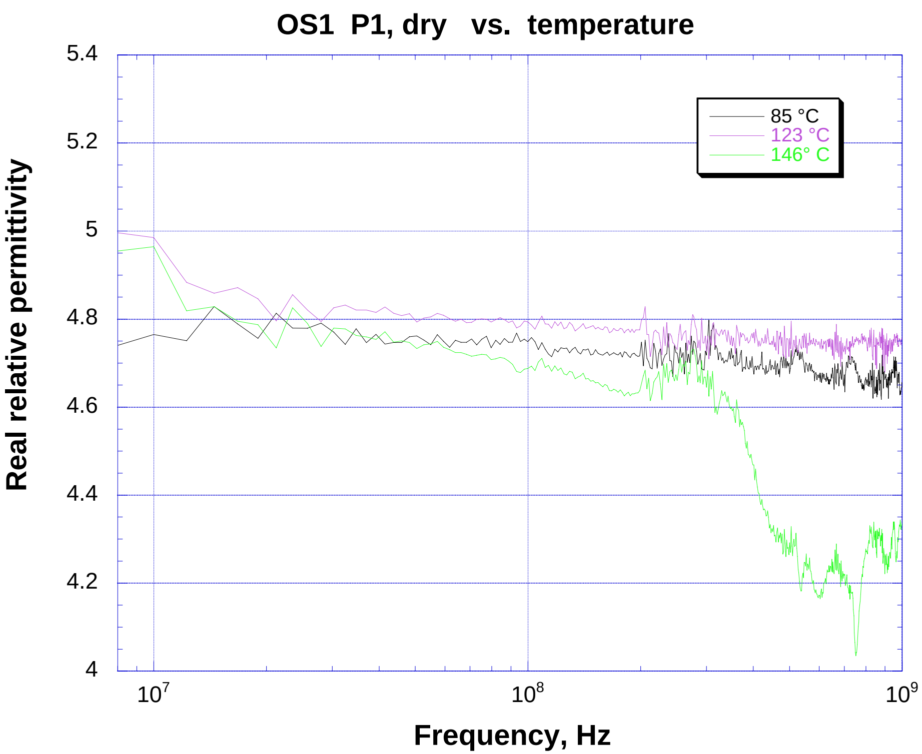
Anadarko dry sample measured at elevated temps

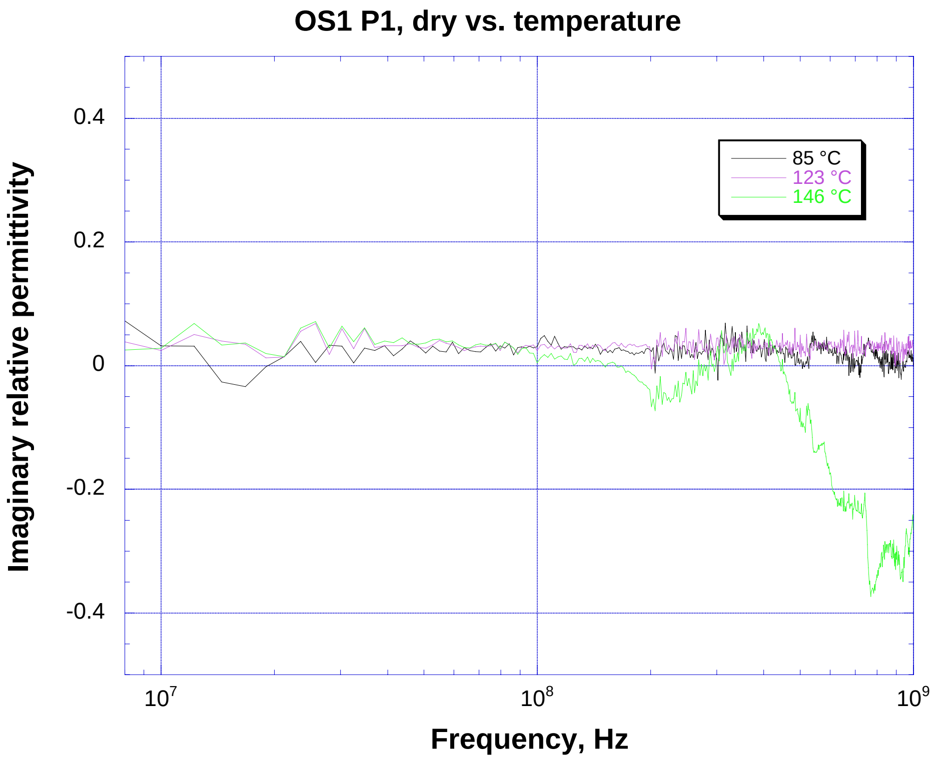




No temperature dependent loss mechanism was identified up to 100°C

Anvil Points dry sample measured at elevated temp





No temperature dependent loss mechanism was identified up to **146°C**

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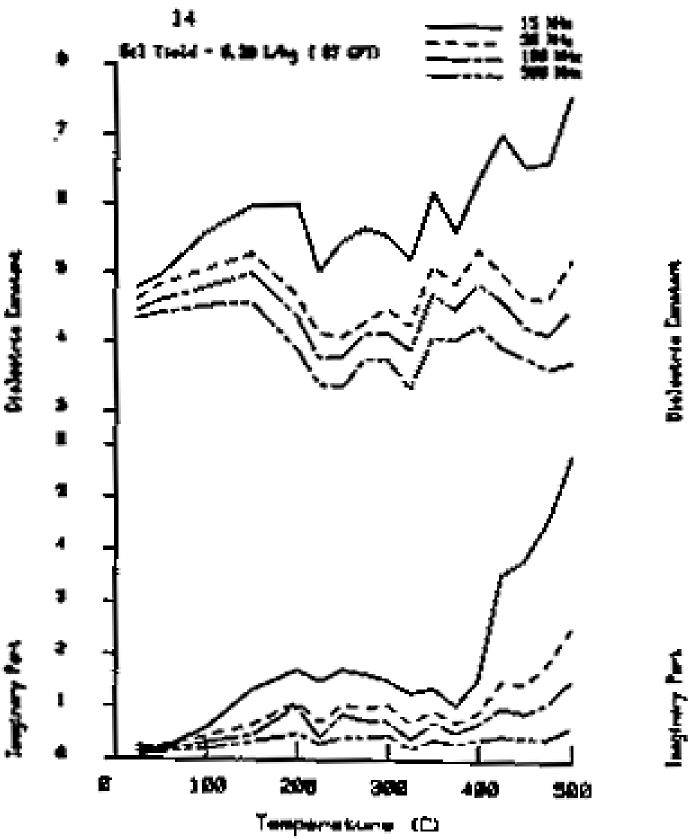
At higher temperatures there will be a kerogen related change in the loss factor



- Lower frequencies have a much larger loss factor above 400 C
- During a slow heating process the loss factor changes will occur at lower temperatures
- Near kerogen decomposition temperatures, an RF heating frequency should be utilized that avoids a runaway loss factor

Jesch, R.L. and R.H. McLaughlin, *Dielectric Measurements of Oil Shale as Functions of Temperature and Frequency*, IEEE Trans. Geoscience and Remote Sensing, Vol. GE-22, No. 2, March 1984

In-situ RF heating will be a complex dynamic process

- **Below 100°C, fluids control dielectric heating**
  - **Skin depth is controlled by saturation and brine concentration**
  - **Heating rate is controlled by skin depth**

- **Above 100°C, fluid migration will dynamically change skin depth and heating rate**
  - **Skin depth will increase**
  - **Heating rate will decrease**

- **At kerogen decomposition temperatures, skin depth and heating rate will dynamically change**
  - **Skin depth will decrease**
  - **Heating rate will increase**

In-situ RF heating experiments are essential to determine the regime of applicability (if any)

- Since pore fluids will control the early-phase heating process and limit RF penetration into the formation, early diffusive heating may be preferable on an economic basis

- If significant drying of the formation near the borehole occurs, RF heating will penetrate deeper into the formation and preferentially deposit energy there hence it may be preferable to diffusive heaters

- As kerogen breakdown temperatures are reached, previous studies indicate that the loss factor will significantly increase, reducing RF penetration. It is not clear if RF heating has any advantage over diffusive heating in this regime