Oil Shales: Their Shear Story*

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Search and Discovery Article #40379 (2009)
Posted March 15, 2009

*Adapted from oral presentation at AAPG Annual Convention, San Antonio, TX, April 20-23, 2008

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Abstract

Organic-rich shales house large untapped amounts of hydrocarbons. In-situ recovery of these hydrocarbons involves thermal cracking and steamflooding of these reservoirs which changes its physical properties, and shear properties in particular. We measure, within the seismic band, the complex shear modulus (and thus also the attenuation) of two oil shale samples, one rich in organic content and the other low in organic content.

Both the kerogen-rich and the lean shale show a weak dependence of modulus and Q on frequency. Their properties can be effectively considered frequency independent within the seismic band. These shales, however, show a dramatic change in shear-wave velocity and attenuation with temperature. Their shear moduli and Q decrease with melting of the kerogen, but with the subsequent loss of some of the kerogen, both shear moduli and Q increase. The magnitudes of these changes along the direction of the bedding and perpendicular to the bedding differ, which makes velocity anisotropy and attenuation anisotropy potentially valuable attributes. The velocity anisotropy and attenuation anisotropy of the shales can change significantly with temperature, in some cases by more than an order of magnitude. The amount of kerogen content in a shale also influences the velocity and attenuation. The more the organic content, the lower is the shear modulus and the higher is the attenuation.

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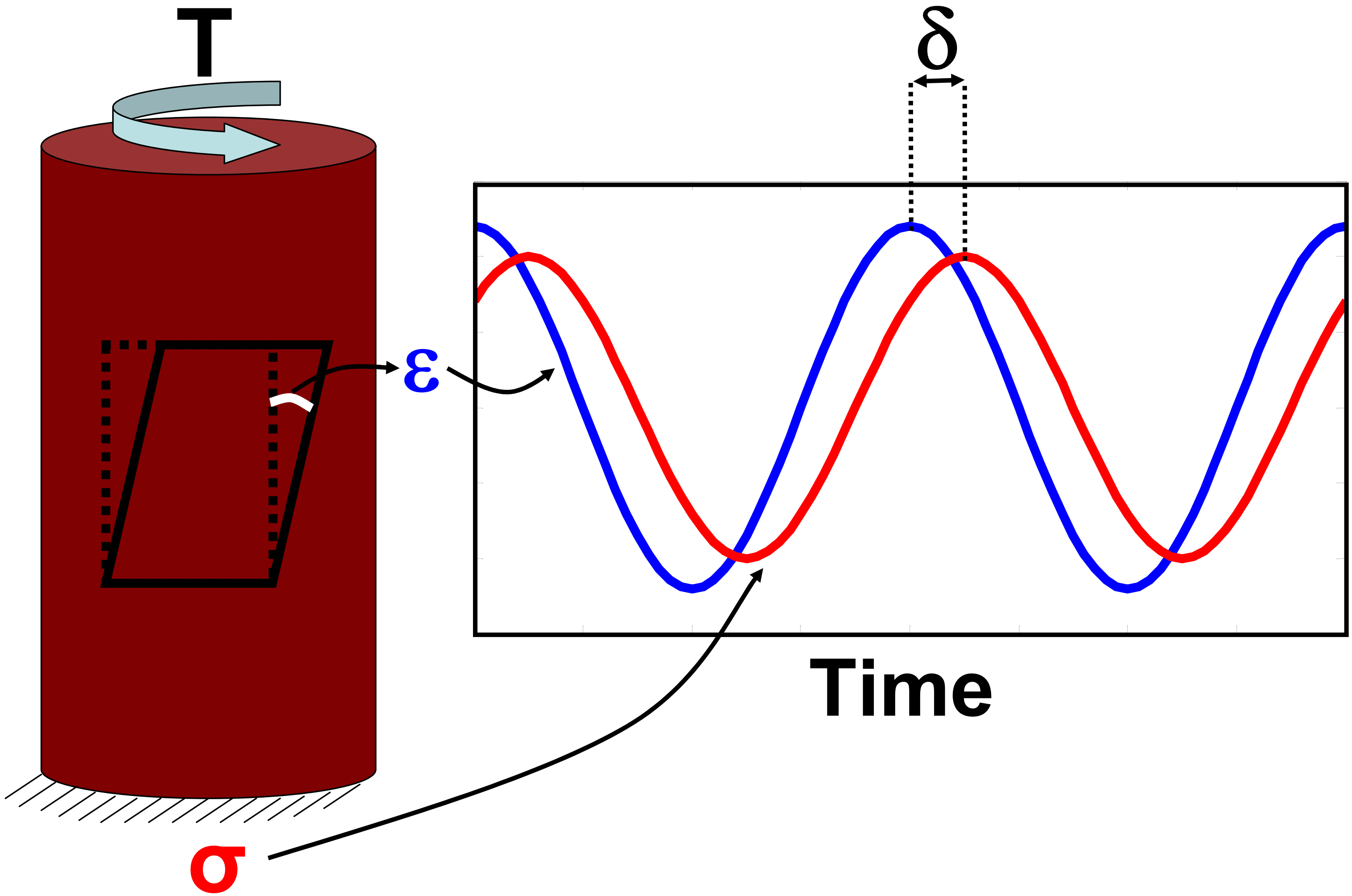
Facts

- Huge reserves
- Environmental issues
- In-situ recovery

Why shear properties?

Experiment



Dynamic Properties

$$\epsilon = \epsilon_0 e^{-i\omega t}$$

$$\sigma = \sigma_0 e^{-i(\omega t - \delta)}$$

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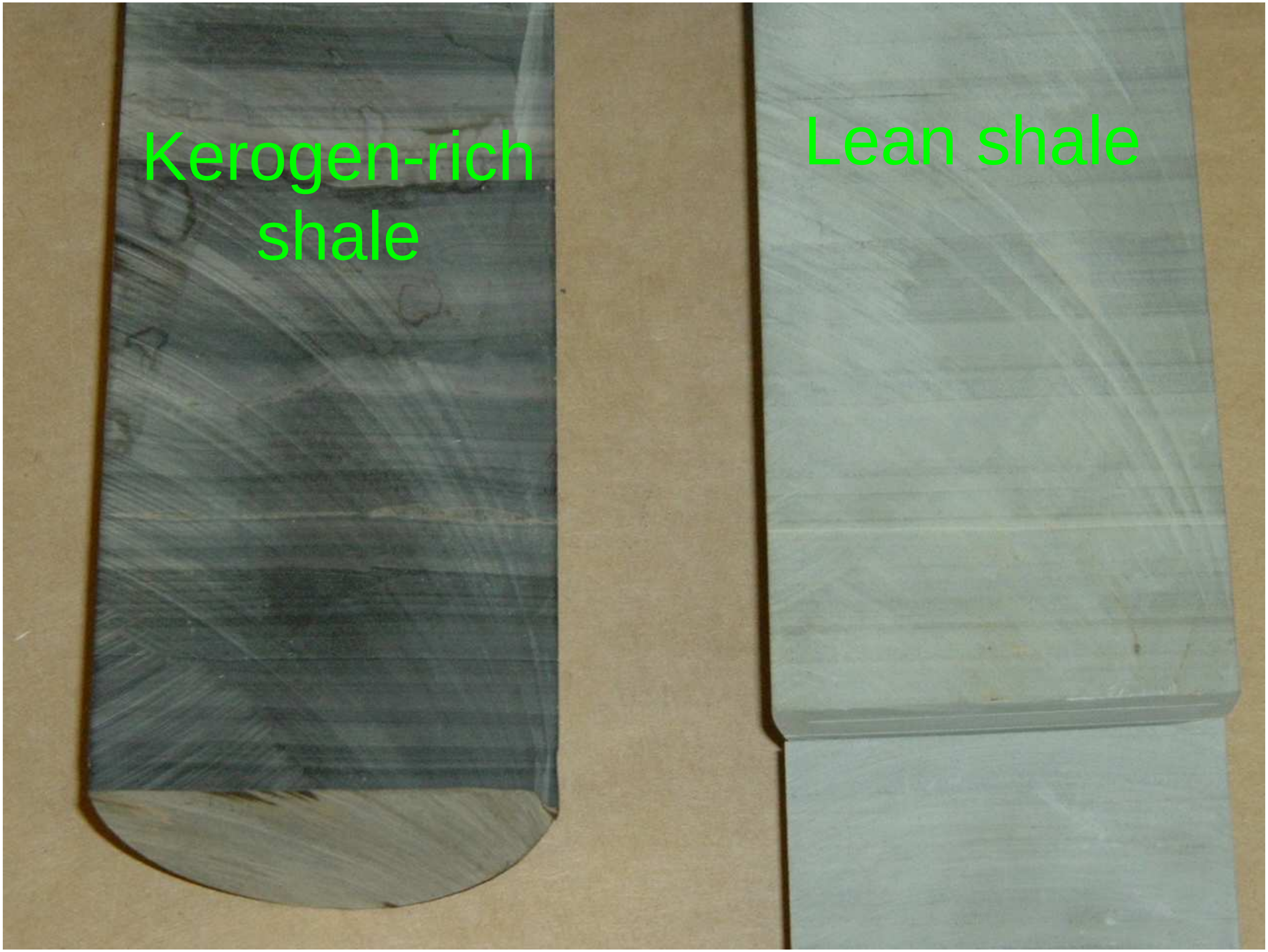
$$\epsilon = \epsilon_0 e^{-i\omega t}$$

$$\sigma = \sigma_0 e^{-i(\omega t - \delta)}$$

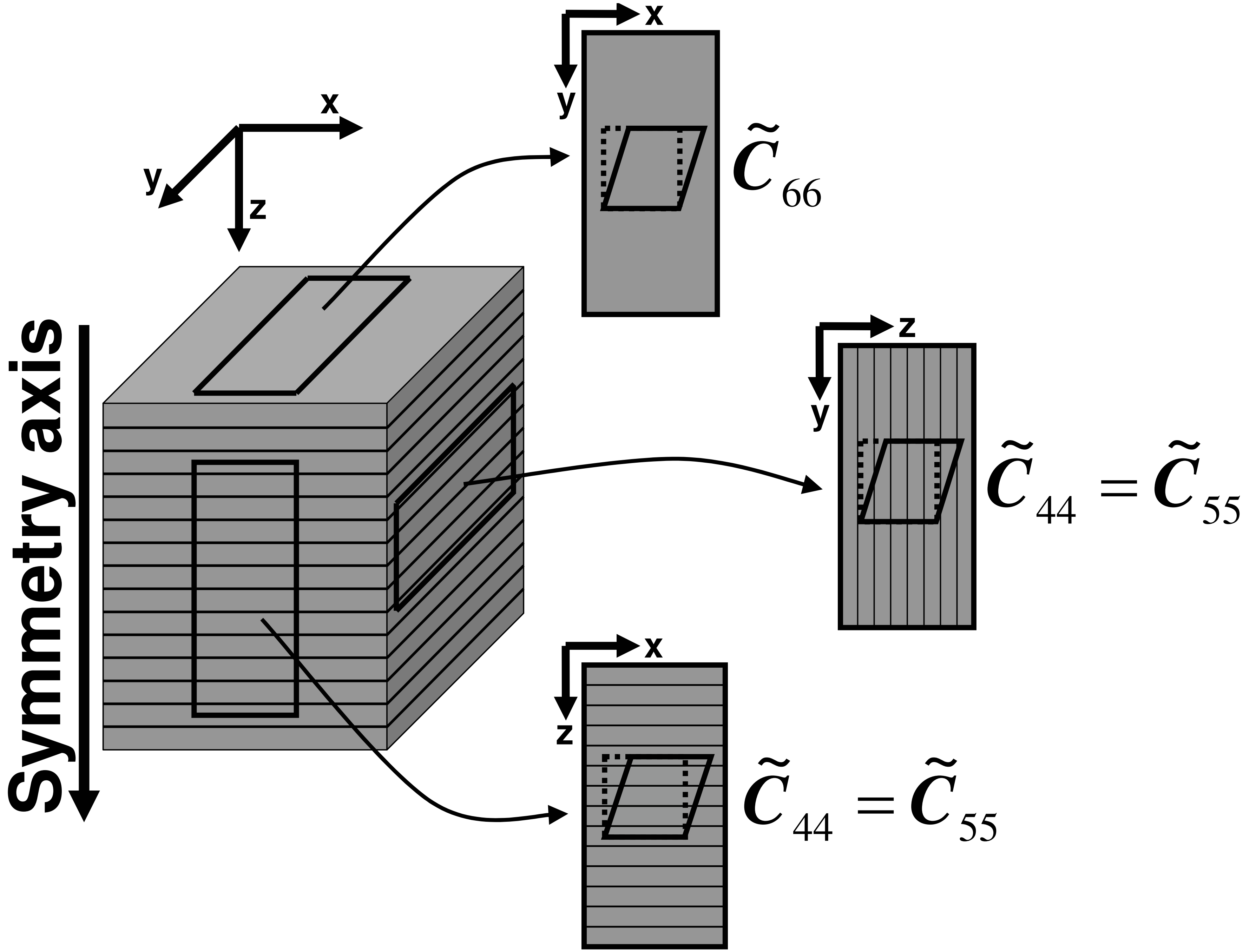
$$G = \frac{\sigma}{\epsilon} = G' + iG''$$

$$Q = \frac{1}{\tan\delta} = \frac{G'}{G''}$$

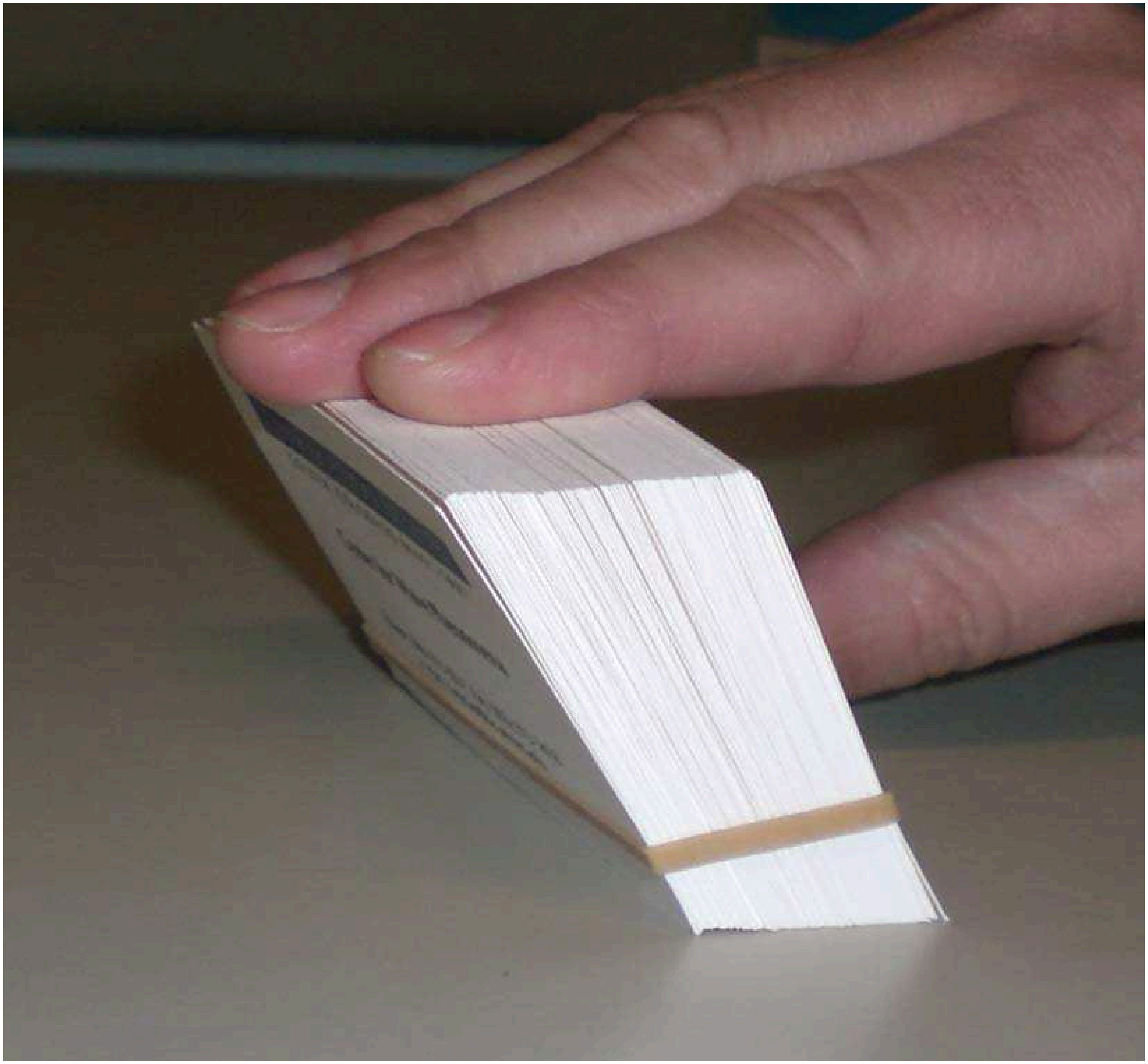
Oil Shale Samples



Different Samples

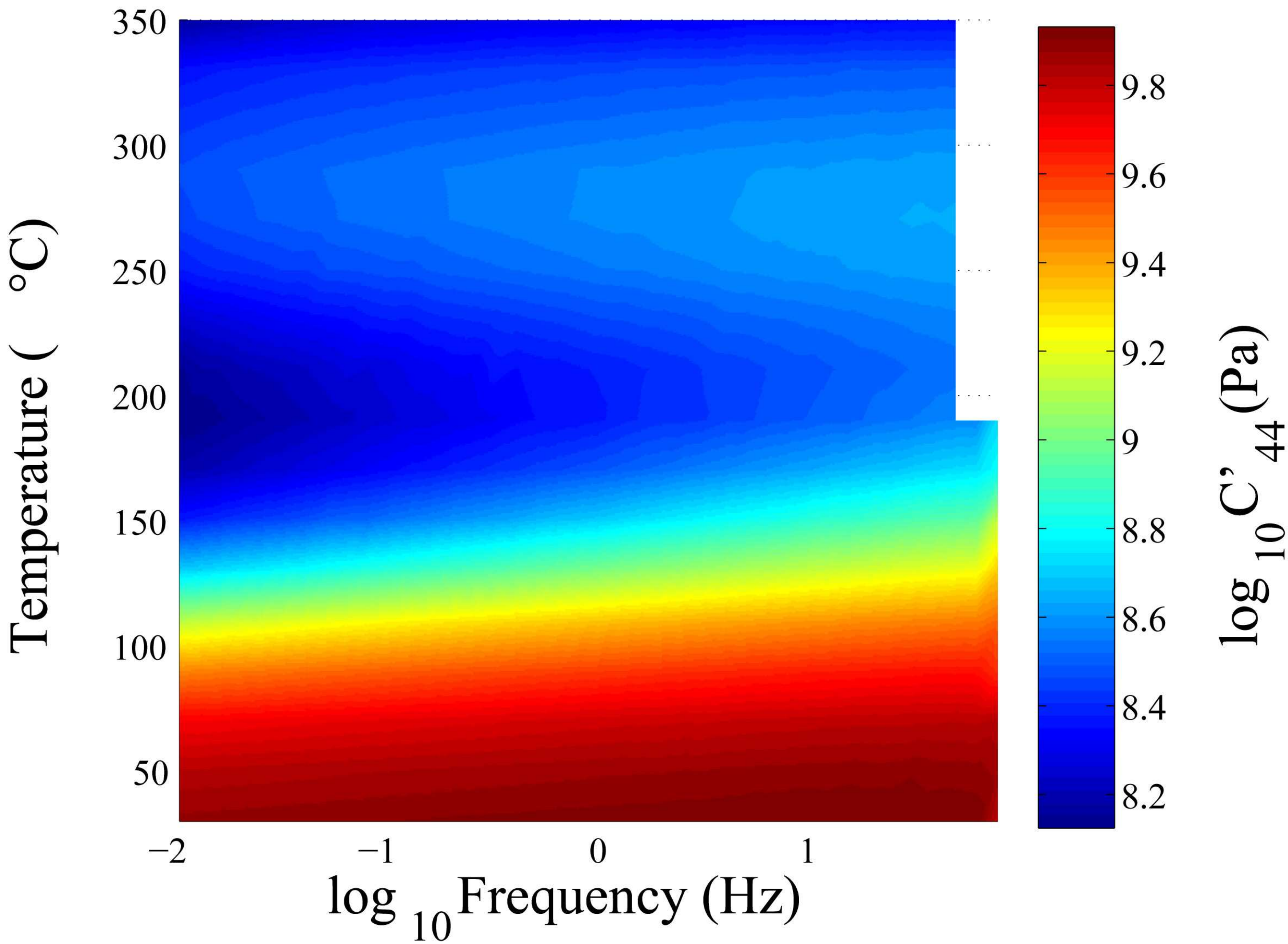


Deck of Cards Analogy: C_{44}

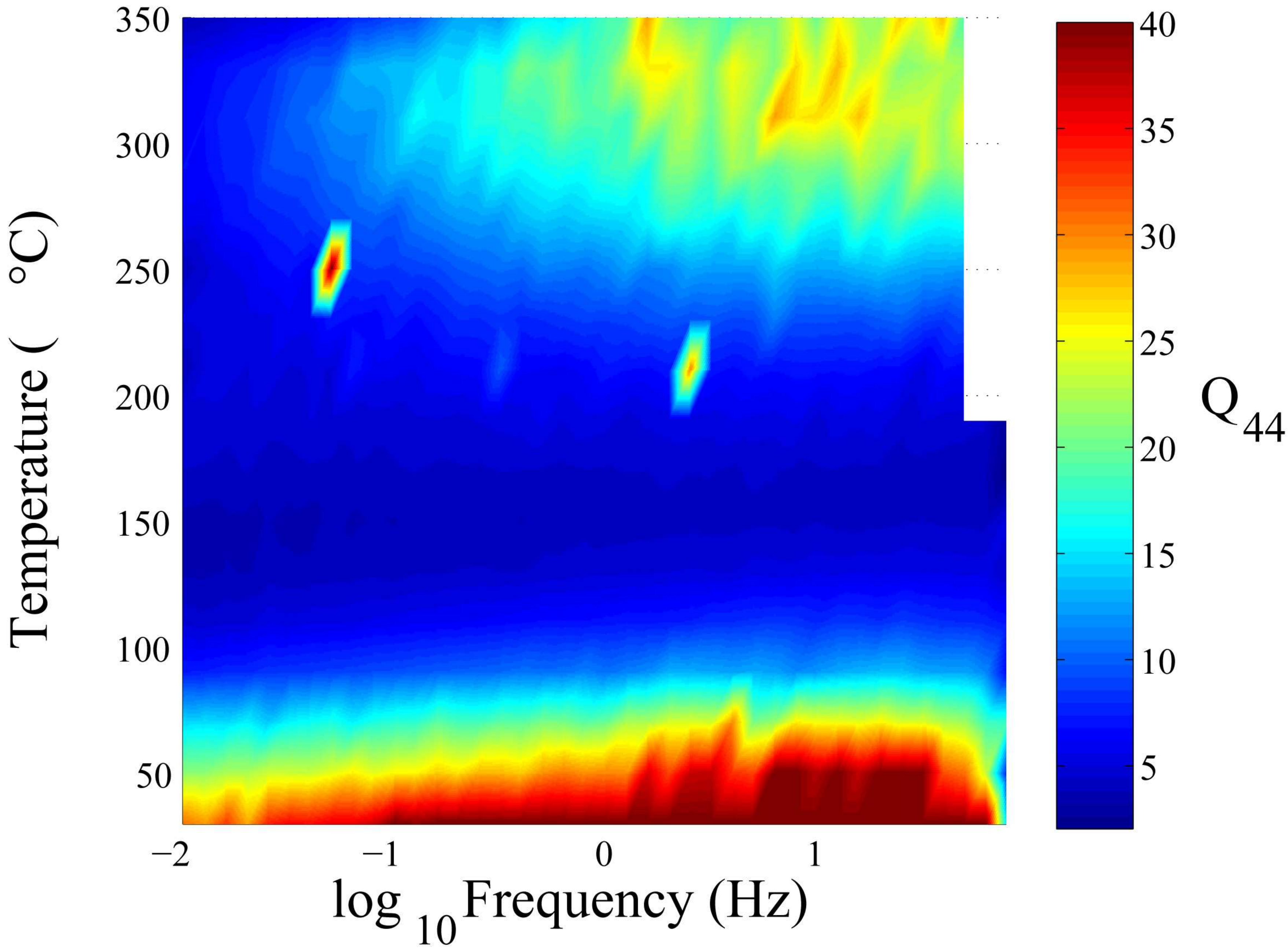


Deck of Cards Analogy: C_{66}

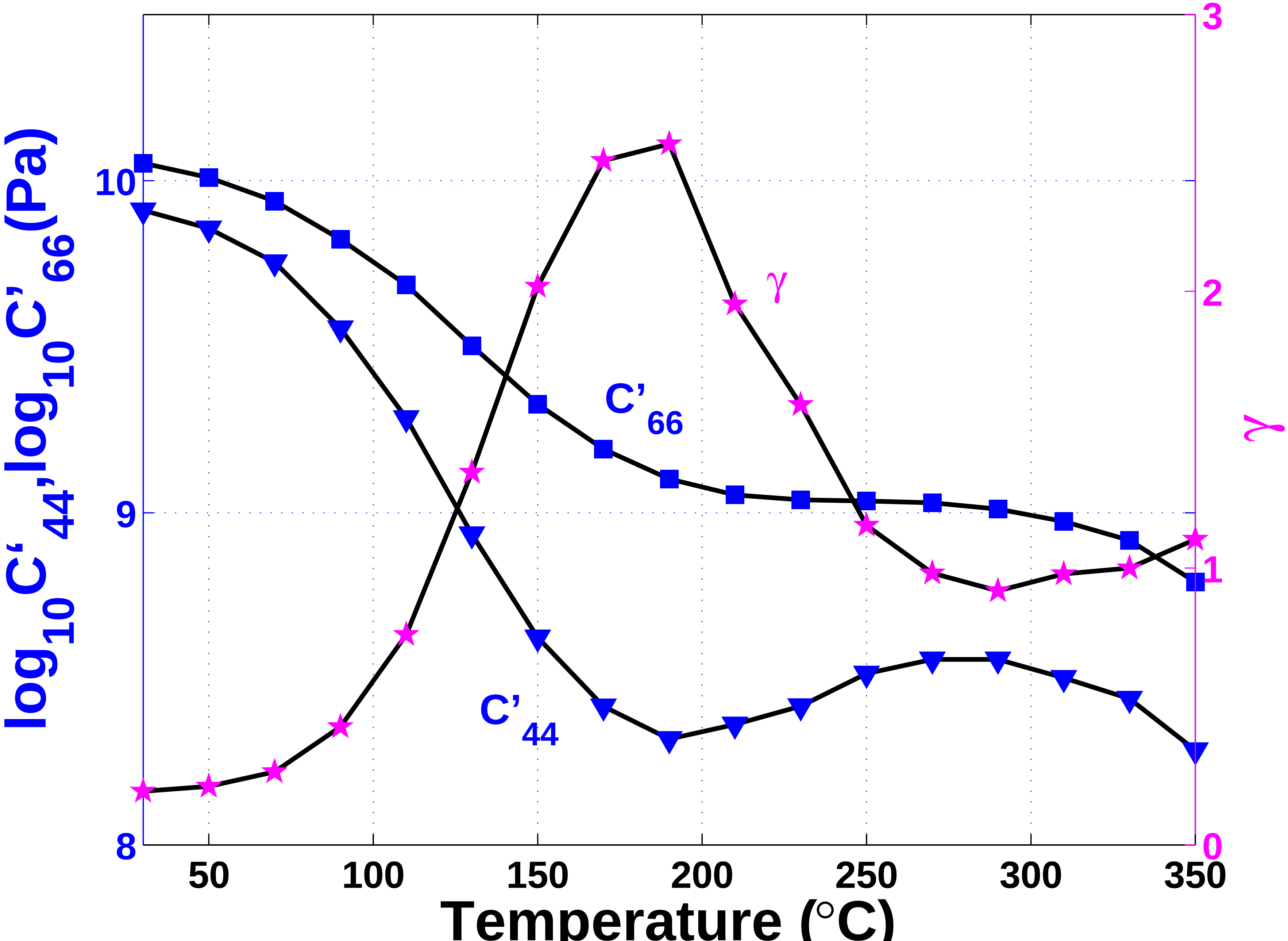
Kerogen-rich Shale C'_{44}



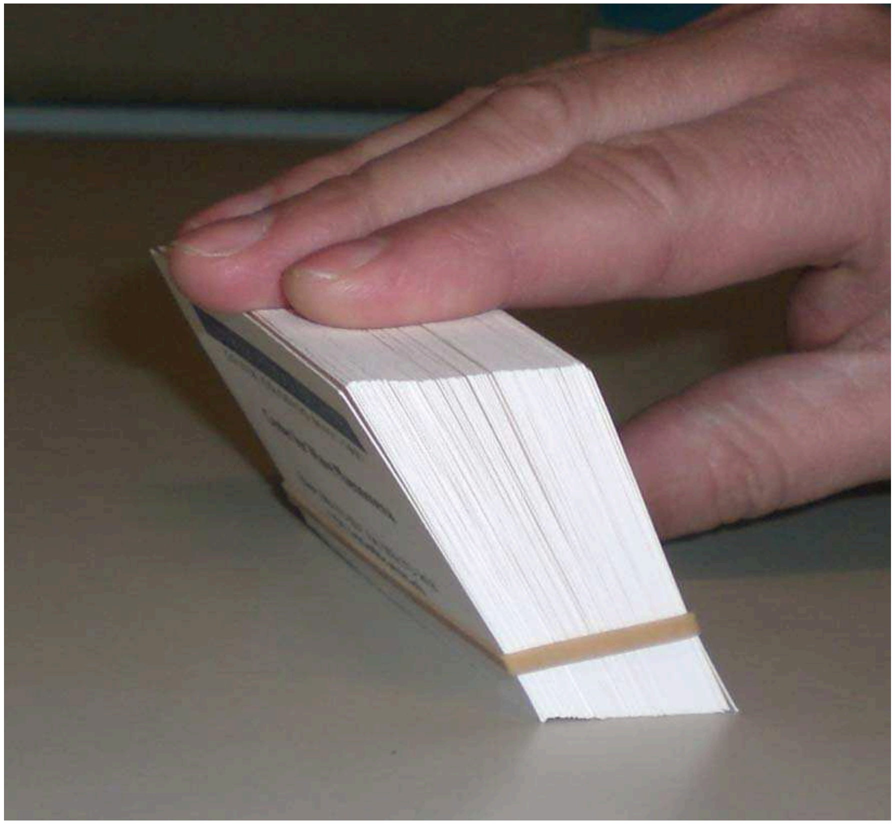
Kerogen-rich Shale Q_{44}



Velocity Anisotropy



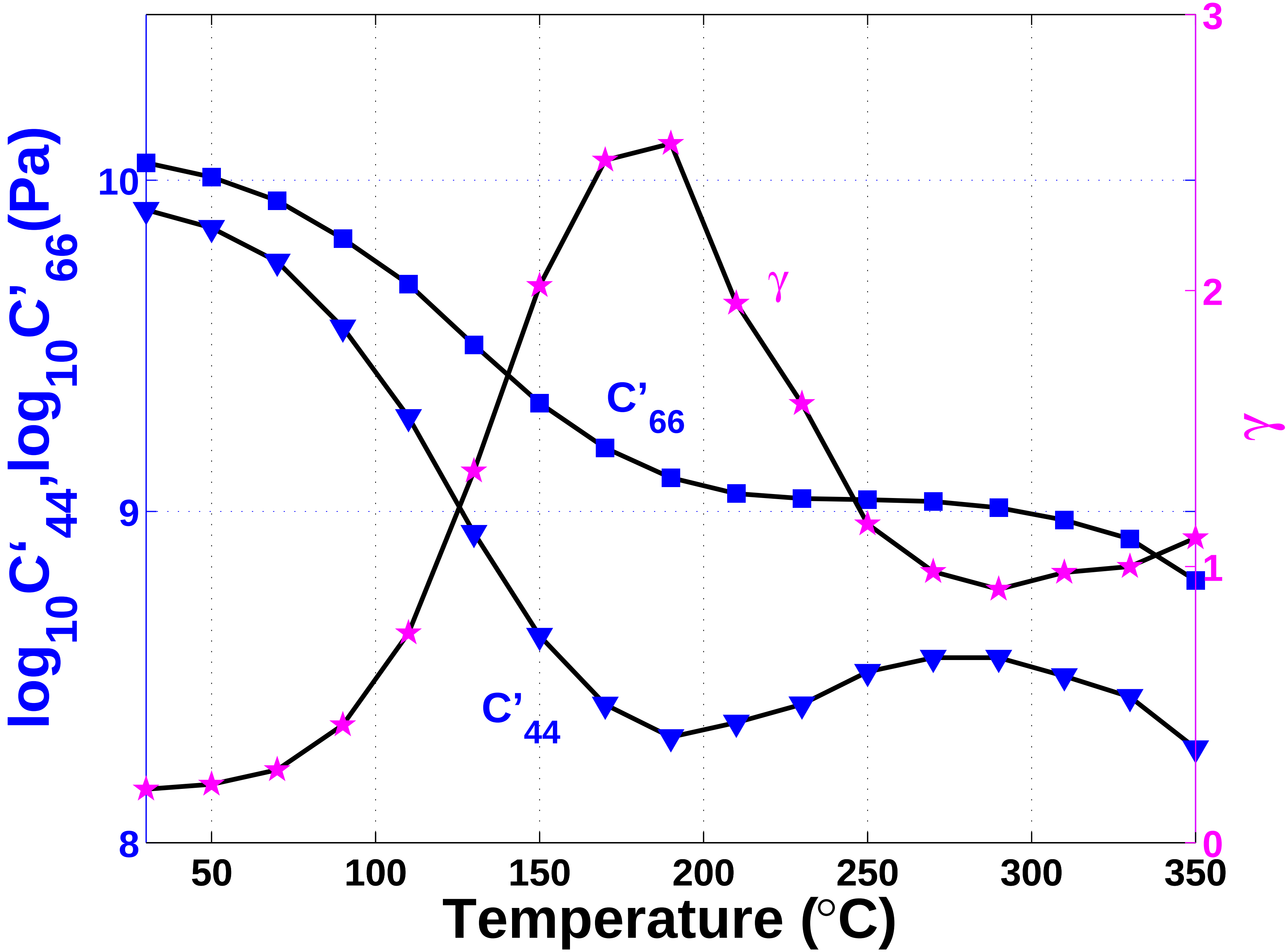
Deck of Cards Analogy



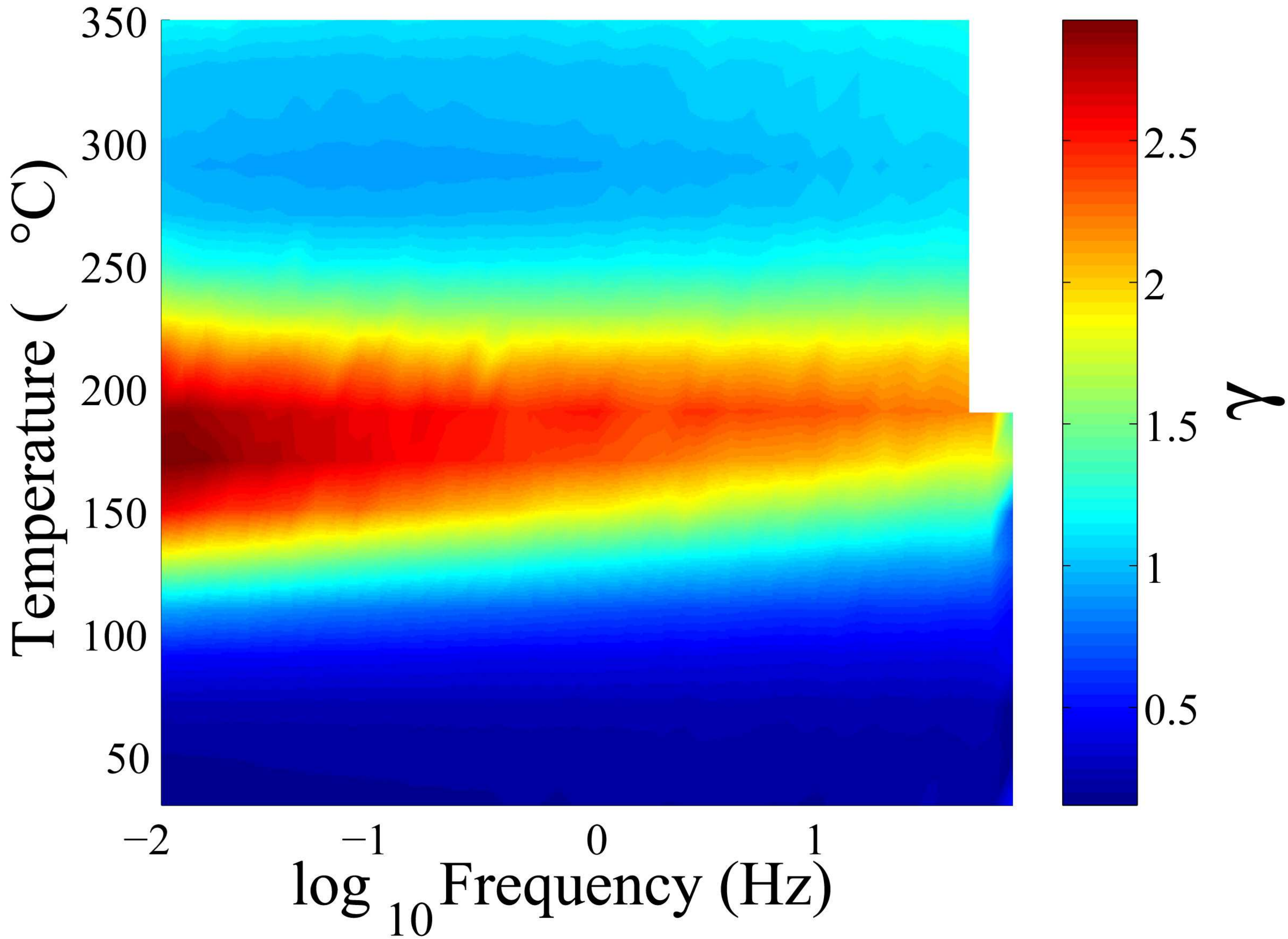
C_{44}

C_{66}

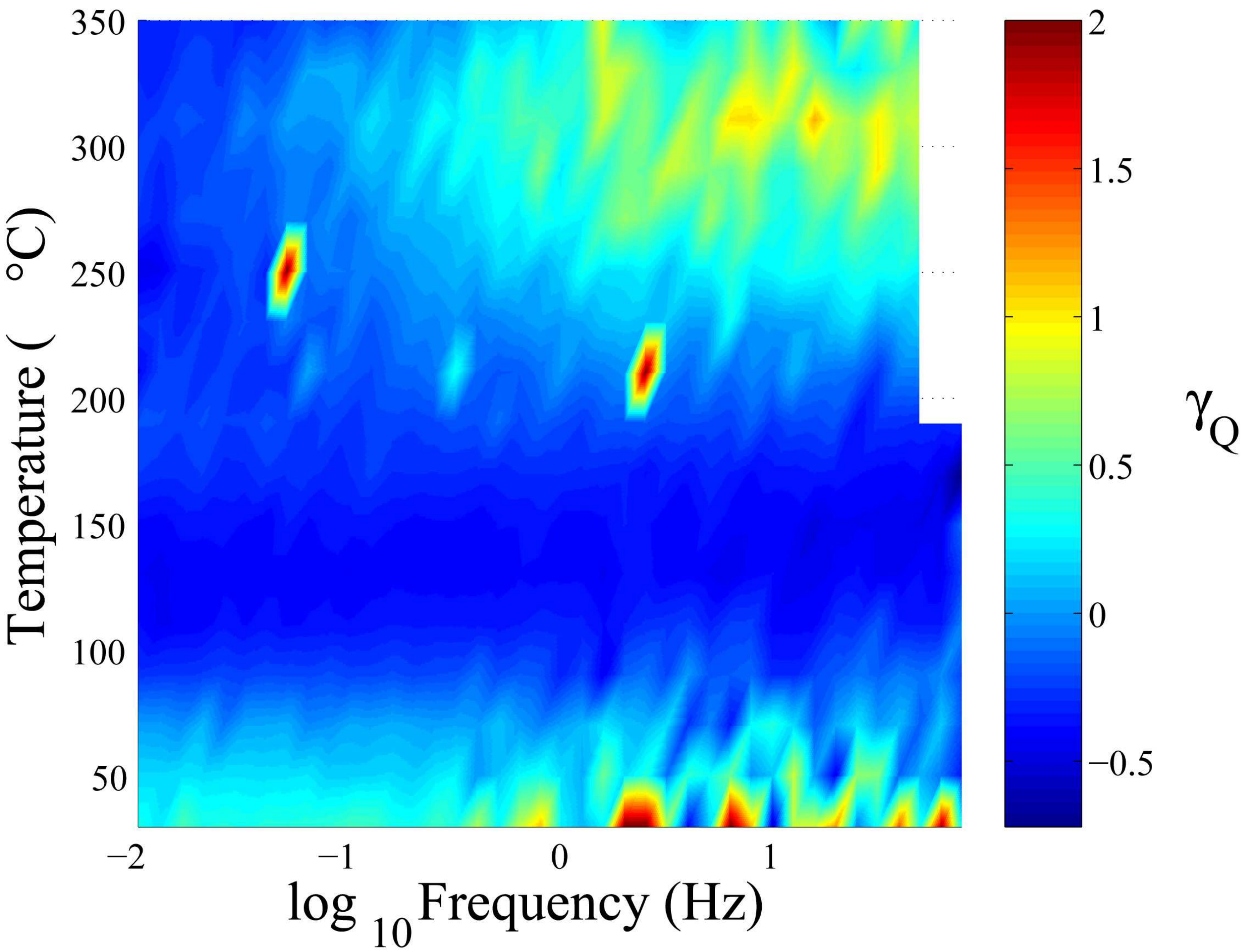
Velocity Anisotropy



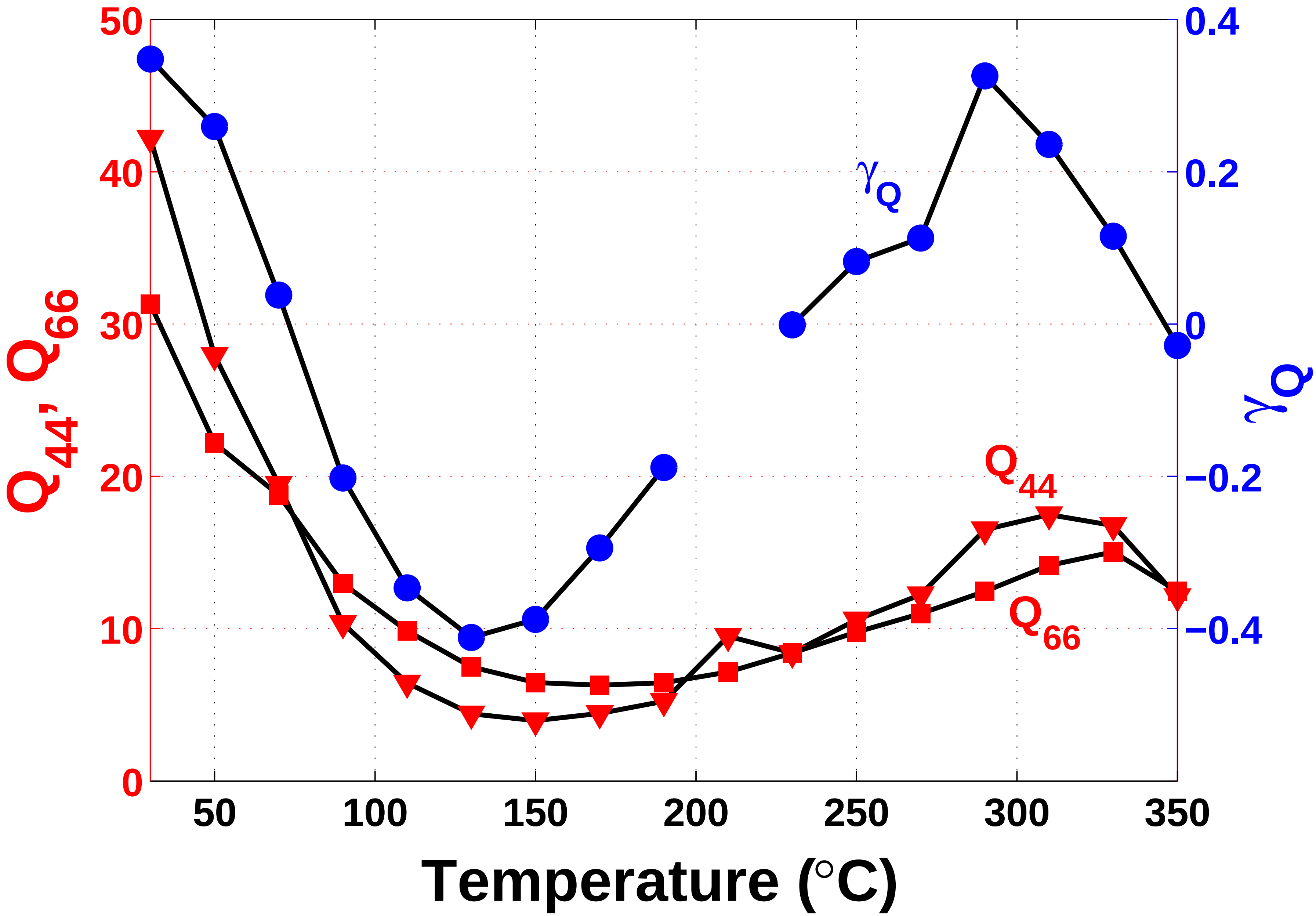
Anisotropy Parameter γ



Attenuation Anisotropy



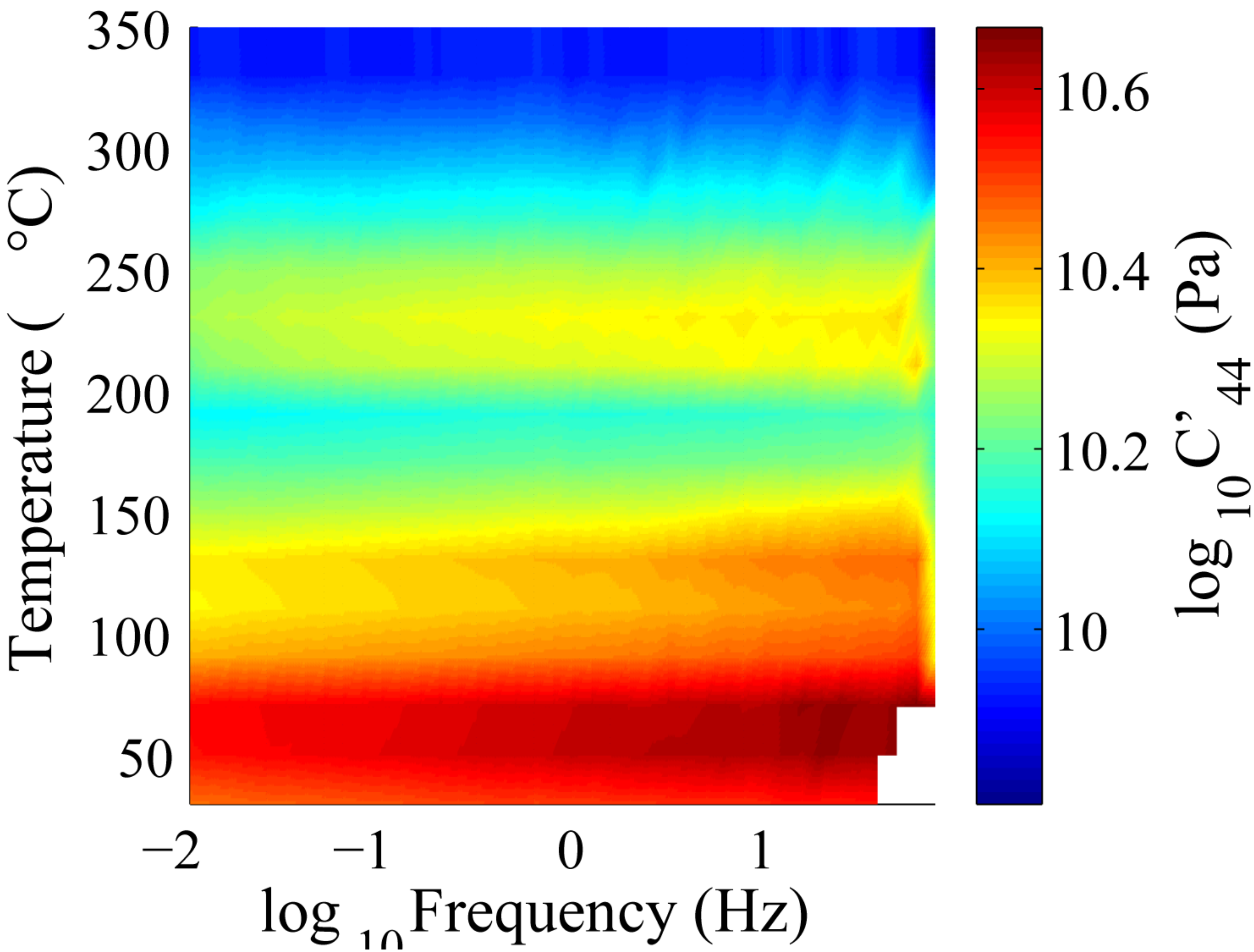
Attenuation Anisotropy (0.3 Hz)



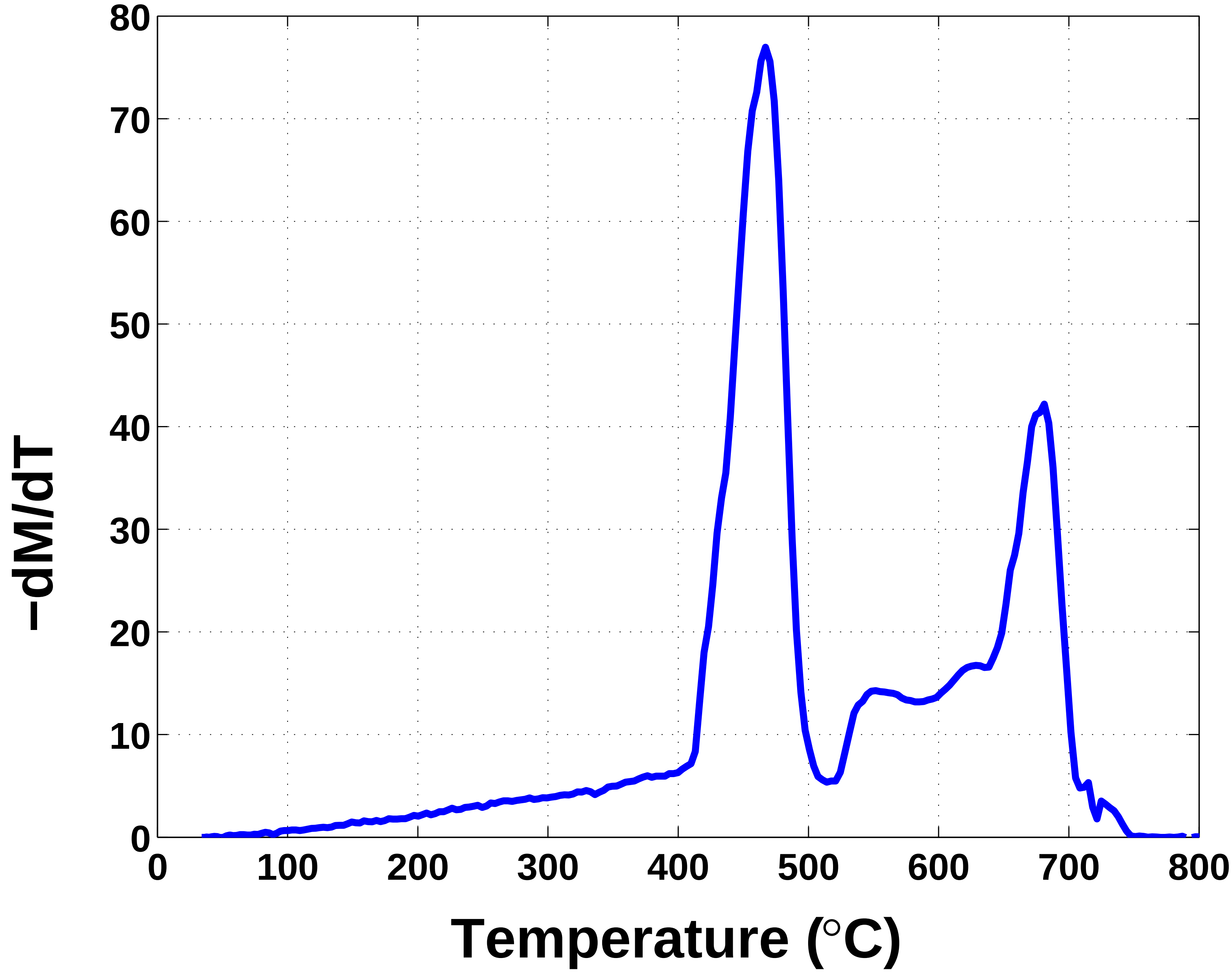
Conclusions

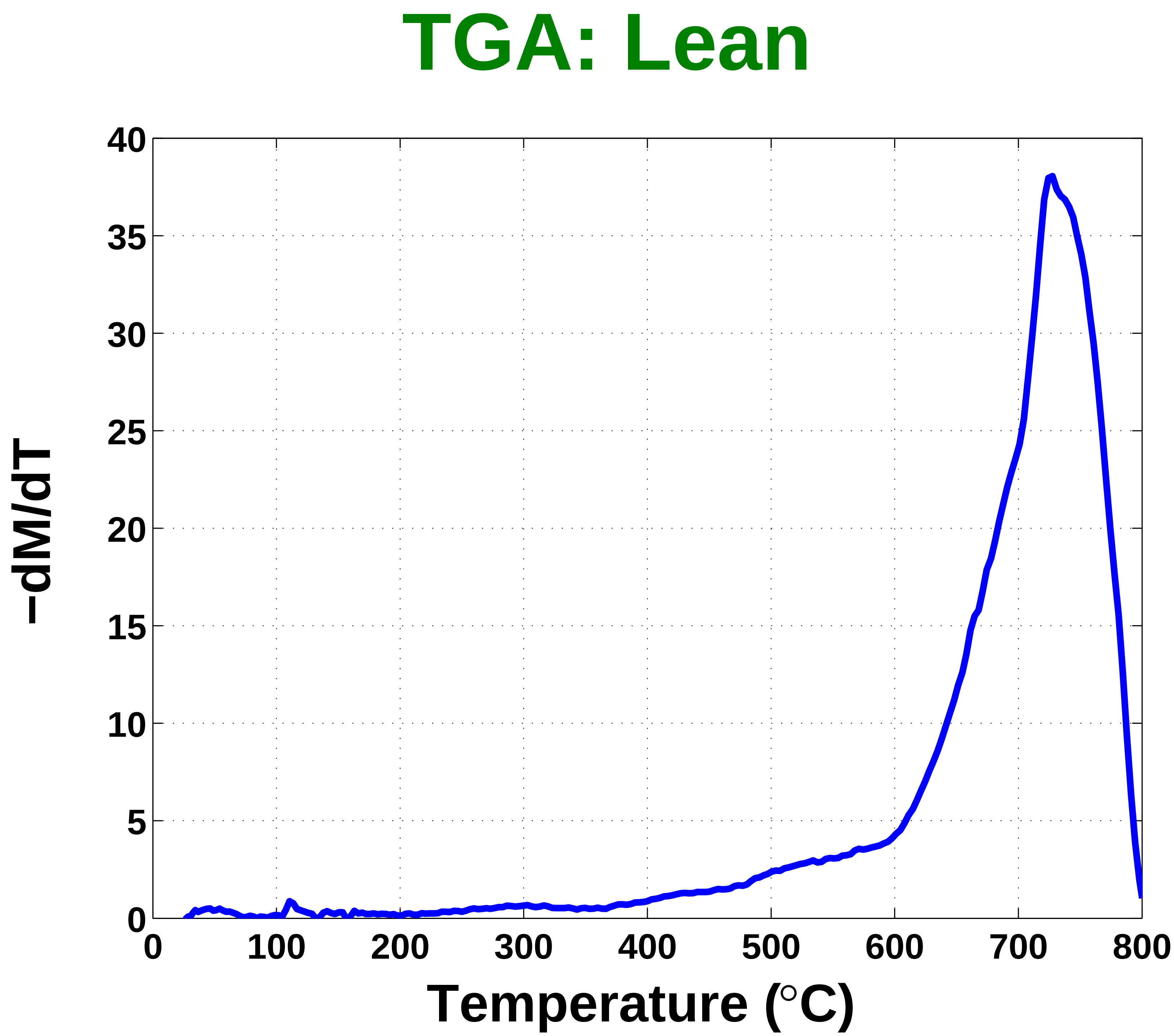
- Q, G: weak freq. dependence
- Q, G: strong temperature dependence
- Strong anisotropy
- $G'_{lean} > G'_{kerogen}$
  $Q_{lean} > Q_{kerogen}$

Lean Shale C'_{44}



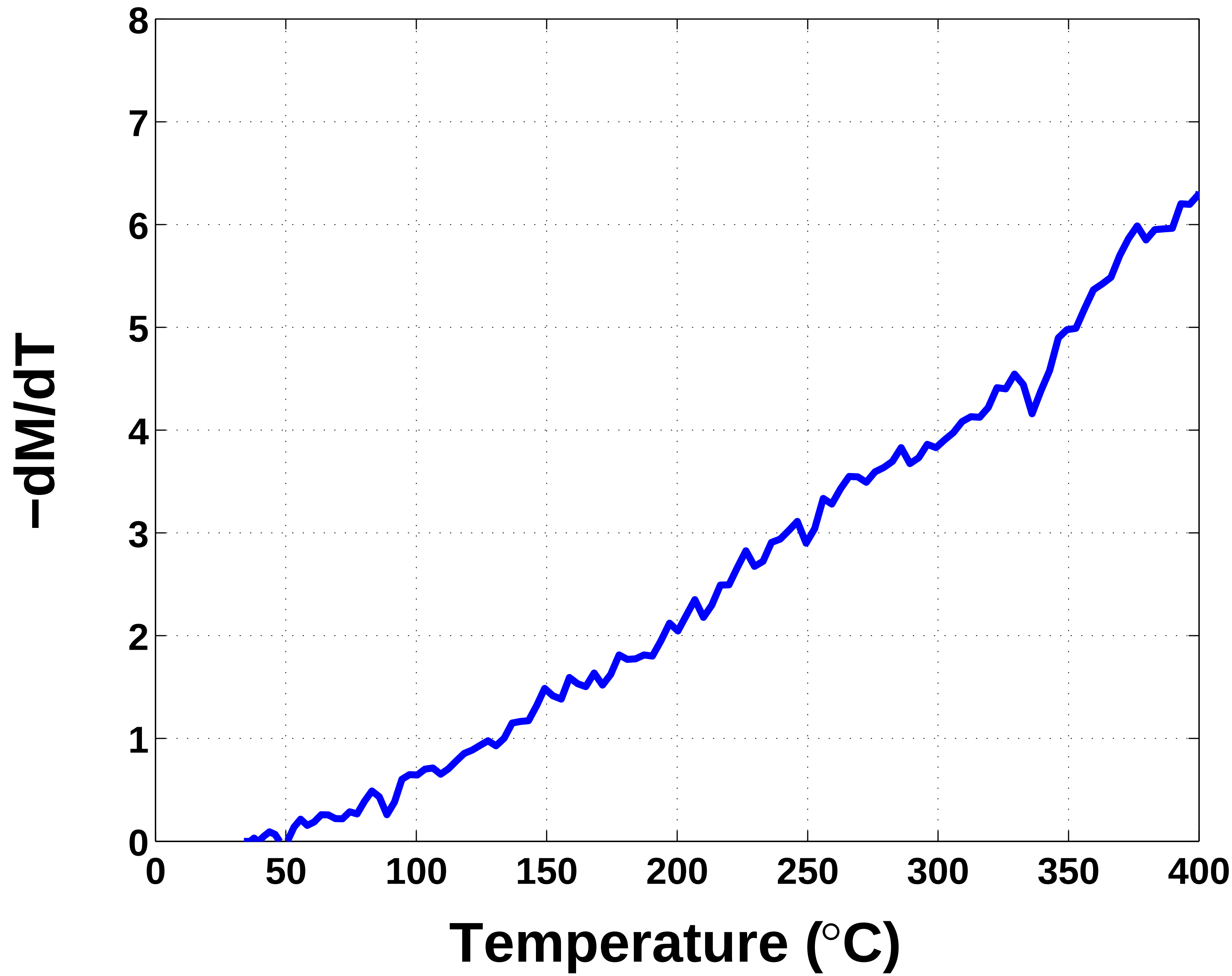
TGA: Kerogen-rich



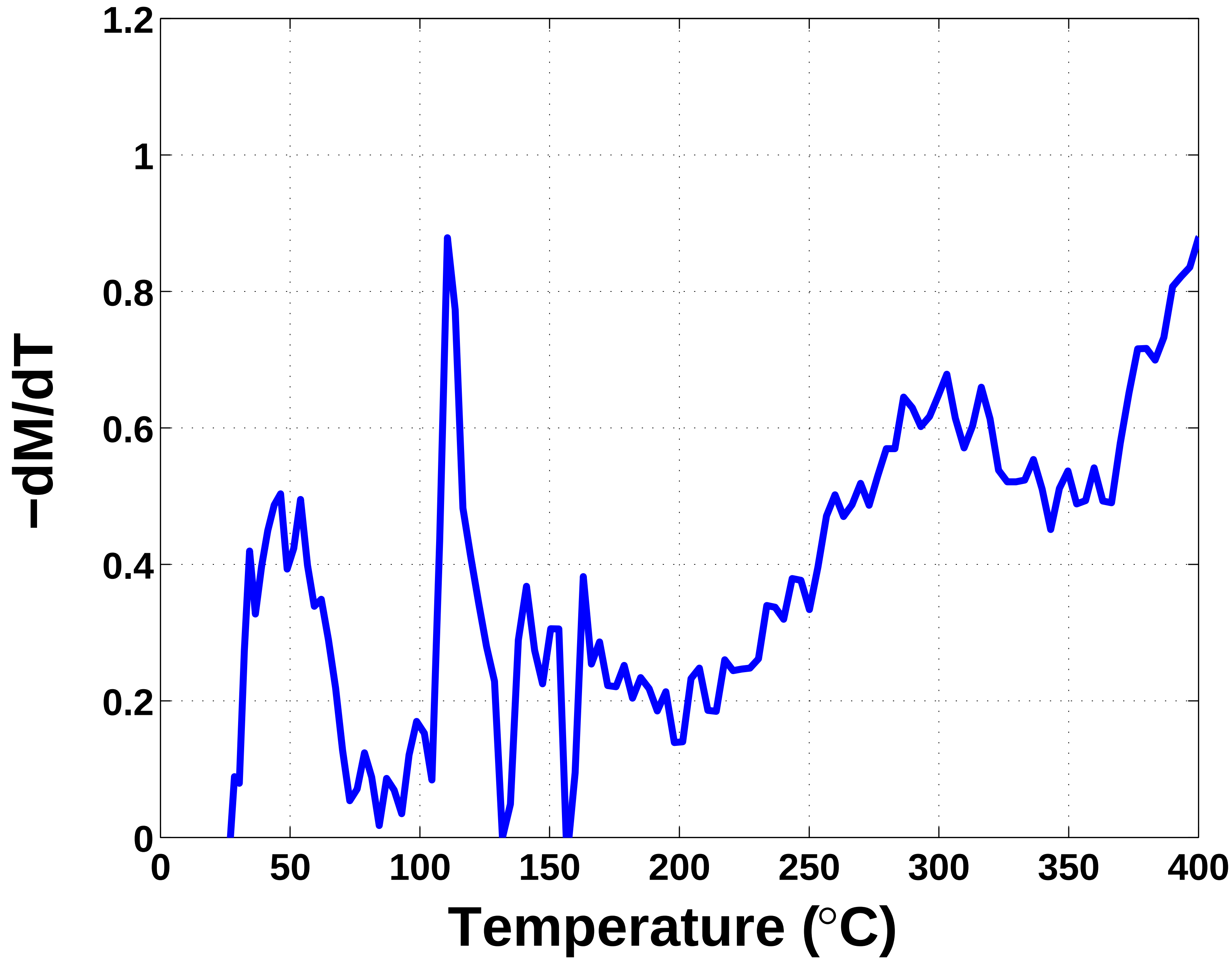


TGA: Lean
-dM/dT
Temperature (°C)
0
5
10
15
20
25
30
35
40
0
100
200
300
400
500
600
700
800

TGA: Kerogen-rich (zoom)



TGA: Lean



-dM/dT
Temperature (°C)
0
0.2
0.4
0.6
0.8
1
1.2
0
50
100
150
200
250
300
350
400

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