Seismic Attributes and Synthetic logs

- Synthetic logs (impedance inversion)
- Instantaneous attributes

- Reading:
  - Yilmaz, Chapter 8.5, 8.6

Synthetic logs

- The usual use of seismic records is to observe the continuity of the structure between boreholes
  - This is still mostly qualitative
- Idea: invert the equation for reflection coefficient:

$$R_i = \frac{Z_{i+1} - Z_i}{Z_{i+1} + Z_i} = \frac{Z_{i+1}/Z_i - 1}{Z_{i+1}/Z_i + 1}$$

to transform seismic traces into "synthetic logs":

$$Z_{i+1} = Z_i \frac{1 + R_i}{1 - R_i}$$ for impedance

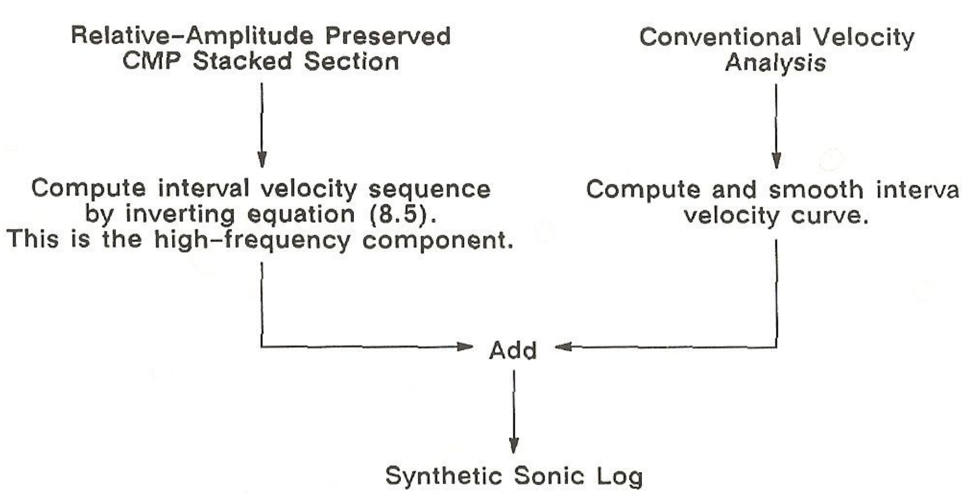
$$V_{i+1} = V_i \frac{1 + R_i}{1 - R_i}$$ for velocity (assuming density constant)

Synthetic logs

- Reflection records contain no near-zero frequencies, and so *recursive* calculation for Z or V:

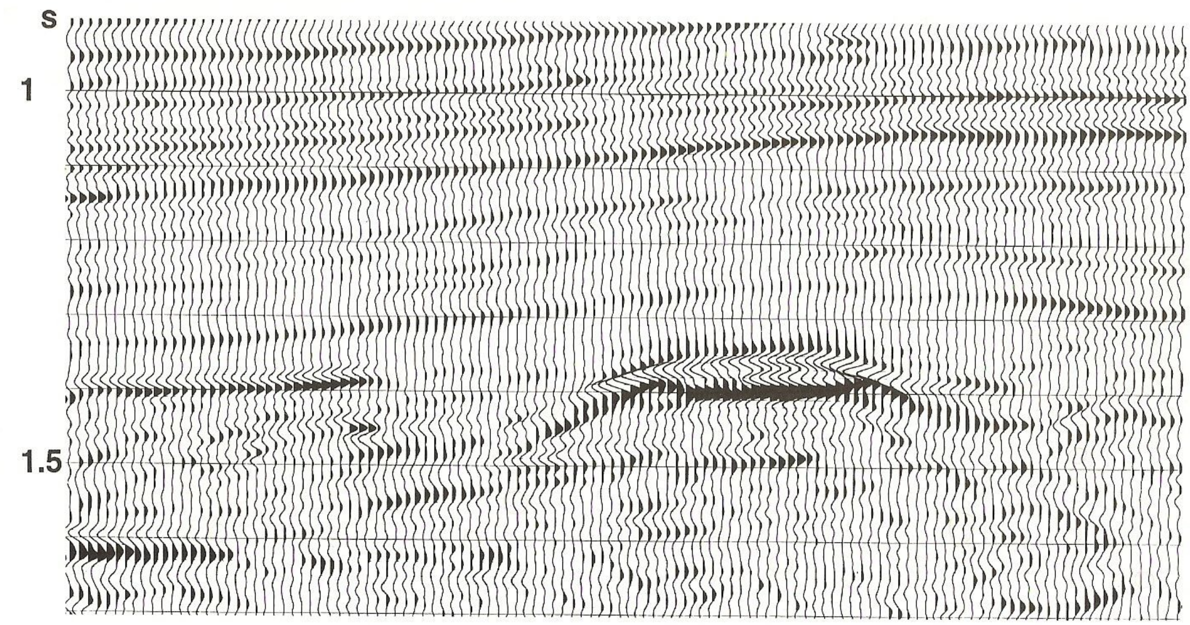
$$Z_{i+1} = Z_i \frac{1+R_i}{1-R_i}$$

  suffers from low-frequency *drift* of amplitudes
- This needs to be corrected by calibration using smoothed *Z* or *V* from well logs

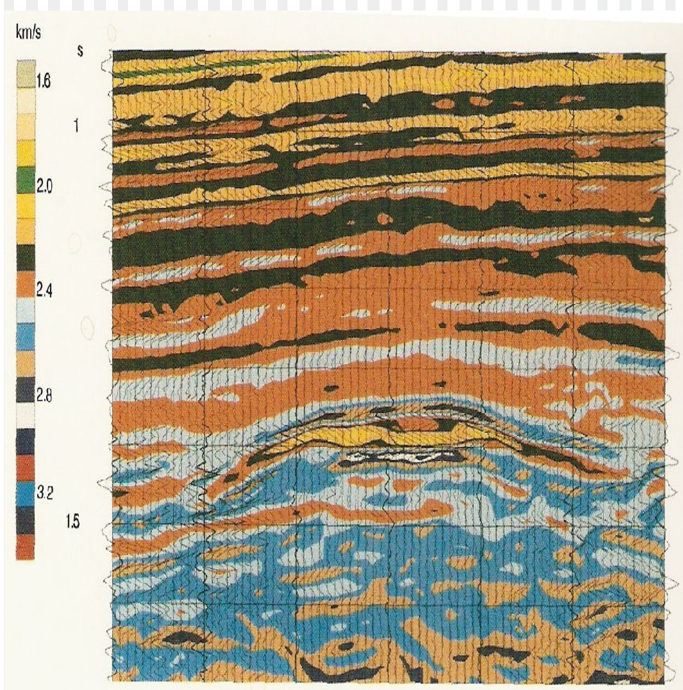


From Yilmaz, 1987

Synthetic logs



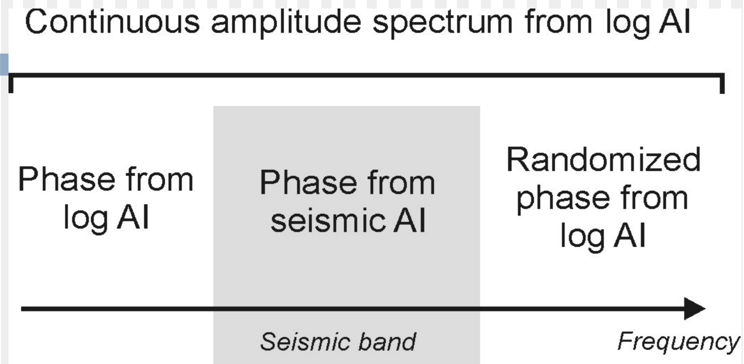
CMP stack containing a bright spot

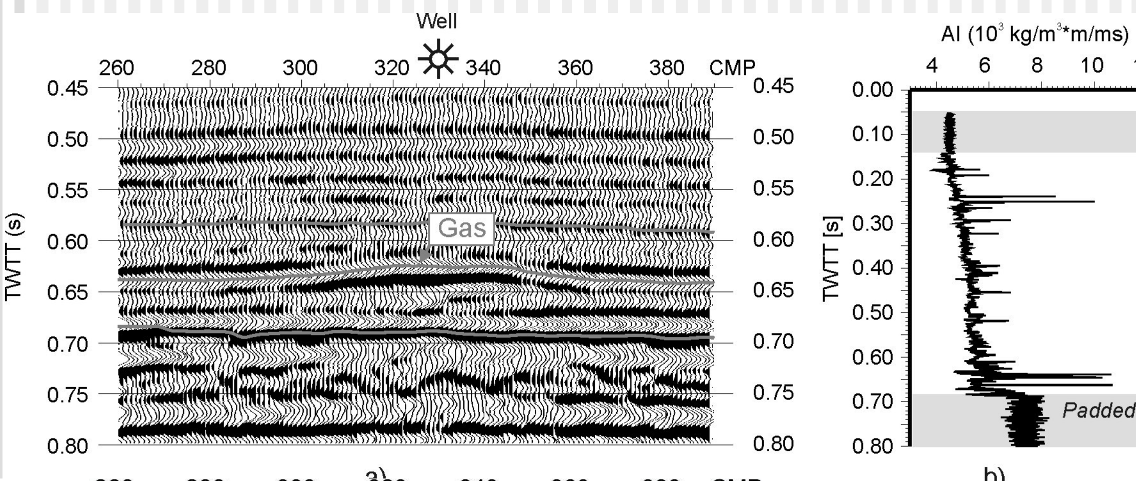


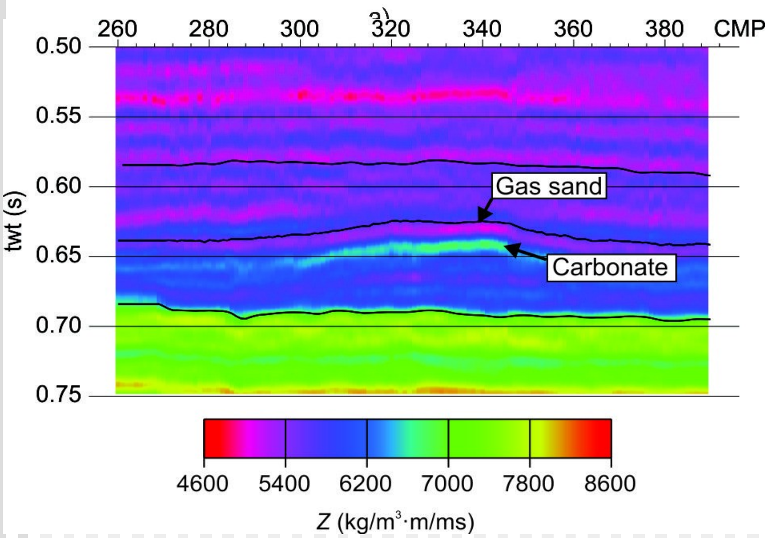
Synthetic velocity log inverted from this section

From Yilmaz, 1987

Accurate synthetic logs can be produced by calibrating seismic-impedance sections with complete well-log spectra







Impedance section having amplitude spectra of the log above

From Morozov and Ma, 2008

Attributes

- Generally, term *attributes* usually refers to quantities that are:
  - Derived quantitatively from data on sample-by sample basis
  - Often have unclear physical meaning
  - Nevertheless, useful to highlight certain aspects of the data
- *Instantaneous* attributes are usually single-trace attributes based on the concept of "complex trace", or "analytic signal"
  - This concept is based on Hilbert transform of the signal

Hilbert transform

- Hilbert transform transforms time-domain signal $u(t)$ into time-domain $u_H(t)$:

$$u_H(t) = \frac{1}{\pi t} * u(t)$$

$$u_H(t) = \frac{1}{\pi} \int \frac{1}{(t-\tau)} * u(\tau) d\tau$$

- In frequency domain:

$$u_H(\omega) = -i\, sgn(\omega)\, u(\omega)$$

- Most important examples:

$$[\sin(\omega t)]_H = -i \cos(\omega t)$$

$$[\cos(\omega t)]_H = i \sin(\omega t)$$

$$\left[e^{i\omega t}\right]_H = -i\, e^{i\omega t}$$

Complex trace

- Analytic (complex-valued) signal is defined as:

$$u_A(t) = u(t) + iu_H(t)$$

  - It combines the original and 90-degree shifted signal at each frequency

- so that:

$$u(t) = Re[u_A(t)]$$

- Decomposition to complex amplitude and phase:

$$u_A(t) = A(t)e^{i\phi(t)}$$

Slowly varying, Instantaneous amplitude ($A(t)$)

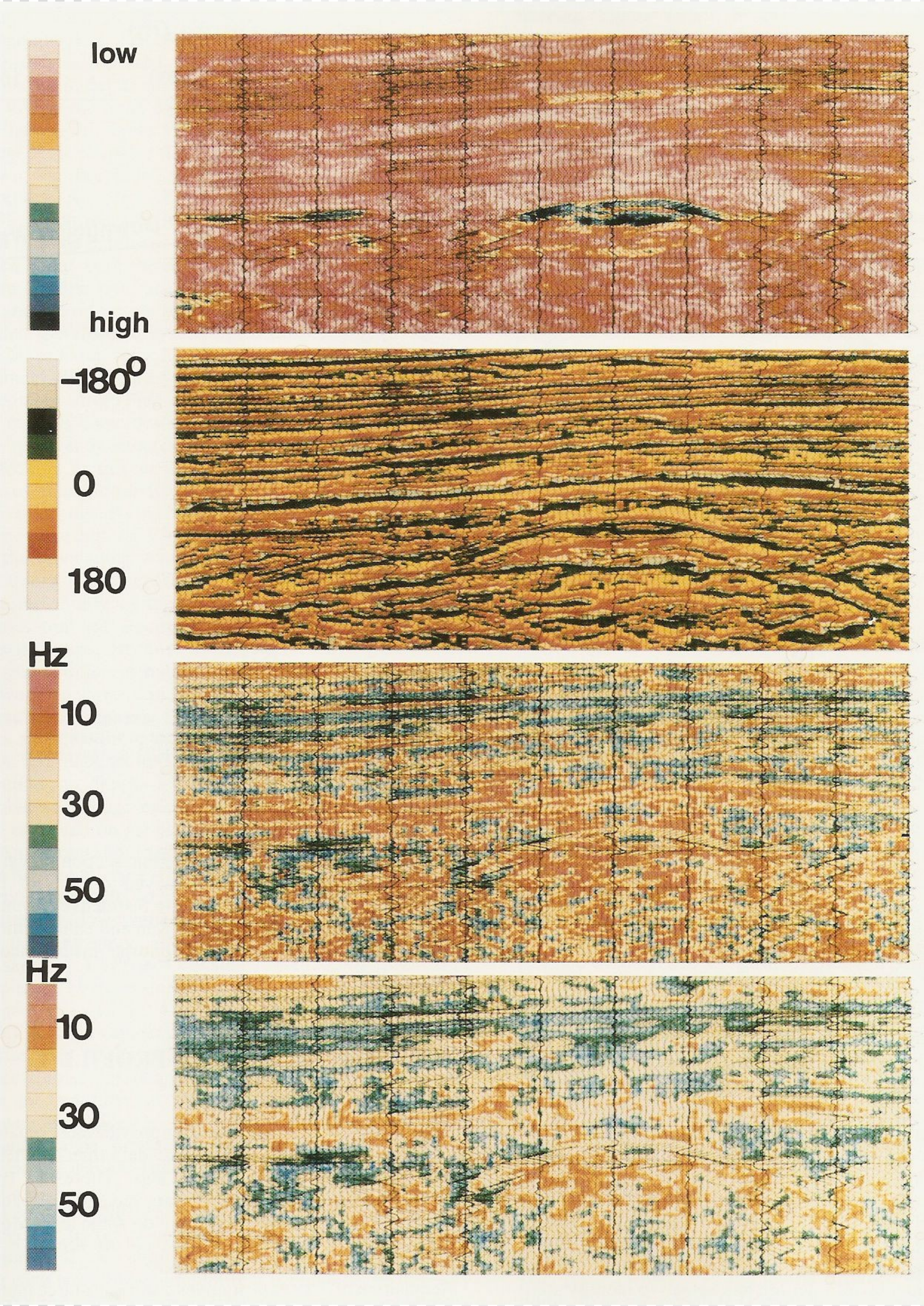
Quickly varying, Instantaneous phase ($\phi(t)$)

Instantaneous frequency

- "Instantaneous frequency" is the rate of temporal change in ϕ:

$$\omega(t) = \frac{d\,\phi(t)}{dt}$$

  - Note that the true Fourier frequency ω cannot be time-dependent
- Instantaneous frequency is often highly variable in seismic sections, and so it is often smoothed
- Areas of low instantaneous frequency are often interpreted as caused by attenuation
  - Although the above is hardly true, low inst. frequency has helped to identify some condensate reservoirs



Instant. amplitude

Instant. phase

Instant. frequency

Smoothed instant. frequency

From Yilmaz, 1987