



UNIVERSITÀ
DEGLI STUDI
DI TRIESTE

Laurea Magistrale in Geoscienze

A.A. 2021-2022

PETROFISICA INTEGRATA
II MODULO

UD2

Attributi istantanei

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ATTRIBUTI "GENERALI"

Hanno valore indipendentemente dal sito. Si tratta di solito di attributi "storici", i primi ad essere stati definiti e quindi maggiormente testati:

- parametri del riflettore (ampiezza, tempo, dip, azimuth)
- Spectral decomposition (ottenuta tramite Trasformata di Fourier - FT, Short Time Fourier Transform - STFT, Wavelet Transform - WT, Instantaneous Spectral Analysis - ISA)
- attributi istantanei
- edge detection/coerenza
- AVO

Partiremo quindi dalla **Trasformata di Fourier**, per poi considerare la **Trasformata di Hilbert** che è alla base del calcolo degli attributi istantanei.

TRASFORMATA DI FOURIER (FT)

trattazione continua

$$X(\omega) = \int_{-\infty}^{+\infty} x(t) \exp(-i\omega t) dt \quad = \text{FT } x(t) \text{ con } x(t) \text{ funzione continua nella variabile } (t)$$

SE (t)=tempo $\rightarrow \omega = 2\pi f$

$$x(t) = \int_{-\infty}^{+\infty} X(\omega) \exp(i\omega t) d\omega \quad = \text{FT}^{-1}$$

$X(\omega)$ Nel caso generale è una variabile complessa che può essere espressa nella forma:

$$X(\omega) = A(\omega) \exp[i\varphi(\omega)]$$

$A(\omega)$ = spettro di ampiezza = $A(\omega) = \sqrt{X_r^2(\omega) + X_i^2(\omega)}$

$\varphi(\omega)$ = spettro di fase = $\varphi(\omega) = \tan^{-1} X_i(\omega) / X_r(\omega)$

$X_r(\omega), X_i(\omega)$ = parti Reale e Immaginaria della FT $X(\omega)$

Da cui $X(\omega) = X_r(\omega) + iX_i(\omega)$ e, confrontando e considerando la notazione di Eulero per i complessi:

$$X_r(\omega) = A(\omega) \cos \varphi(\omega)$$

$$X_i(\omega) = A(\omega) \sin \varphi(\omega)$$

TRASFORMATA DI FOURIER (FT)

trattazione discreta

Una funzione discreta è una SERIE. Nel caso sismico considereremo serie temporali ottenute digitalizzando funzioni continue (analogiche) secondo intervalli di tempo Δt (solitamente costanti)

Quando viene digitalizzata la funzione continua assume la forma: $x(t) \rightarrow x(T)$

Con $T = n\Delta t$

$$x(T) = \sum_k x_k \delta(t - k\Delta t) \quad k = 0, 1, 2, \dots$$

$\delta(t - k\Delta t)$ È la funzione chiamata "Delta di Dirac" e Δt è l'intervallo di campionamento

La FT in questo caso sarà: $X(\Omega) = \sum_k x_k \exp(-i\omega k\Delta t) \quad k = 0, 1, 2, \dots$

Se introduciamo una nuova variabile $z \rightarrow z = \exp(-i\omega\Delta t)$ avremo che:

$$X(z) = \sum_k x_k z^k = x_0 + x_1 z + x_2 z^2 + \dots$$

Il polinomio $X(z)$ è la z-trasformata della funzione originaria, ovvero della serie temporale $x(t)$

In piu' dimensioni

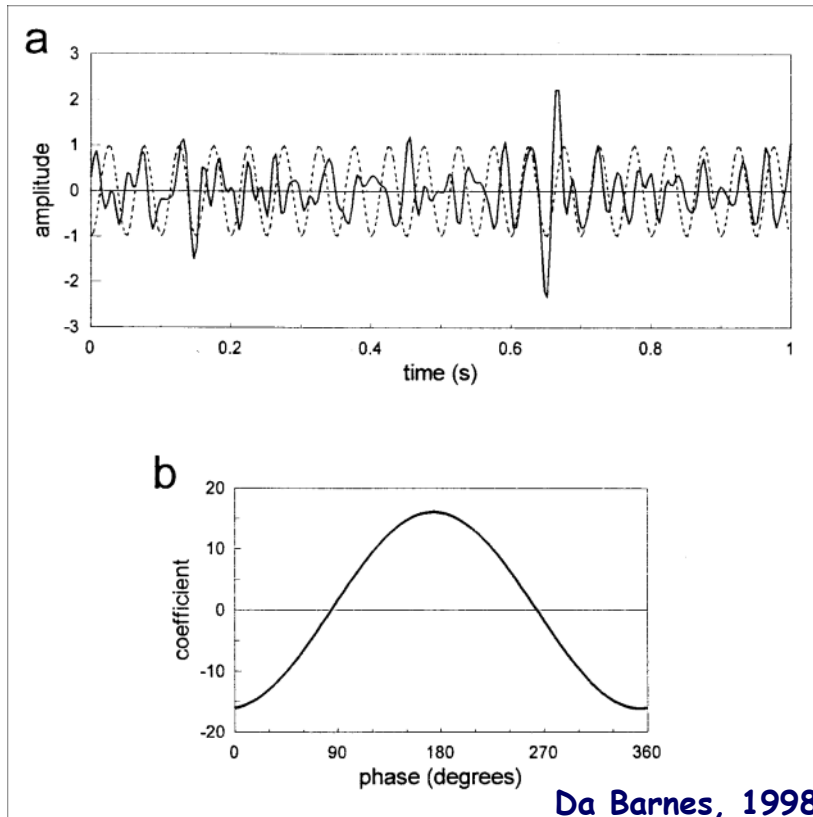
Per un generico campo d'onda in 2D (nel caso sismico t e x) $p(x, t)$ la sua FT sarà:

$$P(k_x, \omega) = \iint p(x, t) \exp(ik_x x - i\omega t) dx dt \quad \text{E la FT}^{-1}:$$

$$p(x, t) = \iint P(k_x, \omega) \exp(-ik_x x + i\omega t) dk_x d\omega$$

TRASFORMATA DI FOURIER (FT)

Considerazioni pratiche e applicative



- (a) Seismic trace compared with a 20 Hz cosine wave with 175° of phase.
- (b) Correlation coefficients (unnormalized) for the seismic trace and the cosine wave as a function of the phase of the cosine, determined every 5°. The largest coefficient is 16.1 at 175°; these are the approximate Fourier amplitude and phase for this trace at 20 Hz.

MAX coefficiente di correlazione
(per ogni frequenza) → **AMPIEZZA**

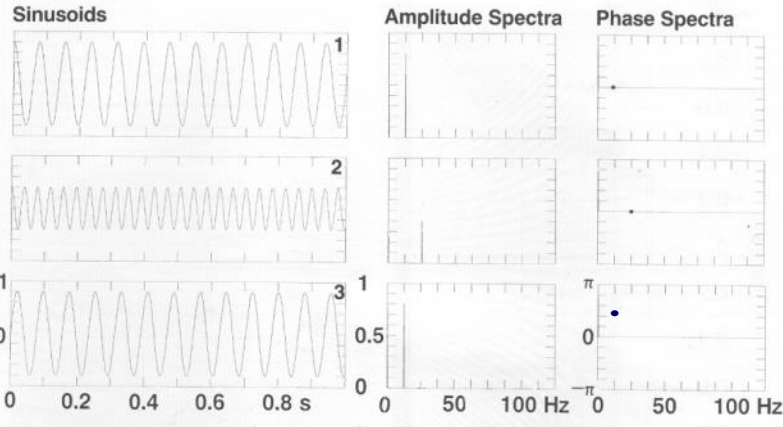
BEST angolo di fase → **FASE**

Quindi la FT determina il massimo coefficiente di correlazione e l'angolo di fase ad esso associato in una traccia sismica per tutte le frequenze

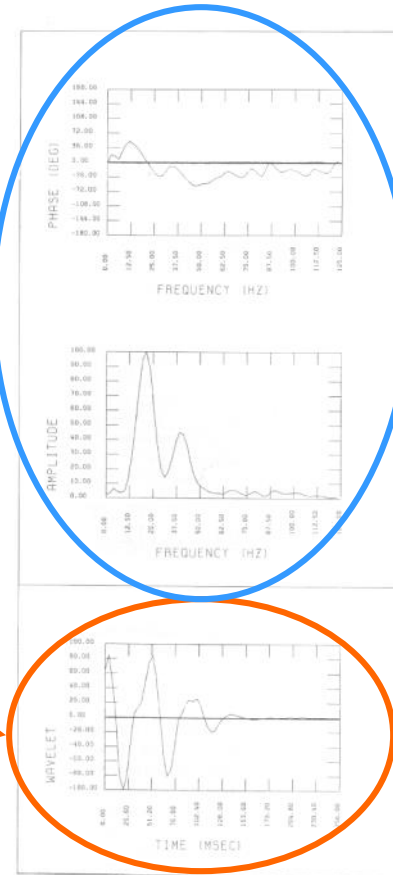
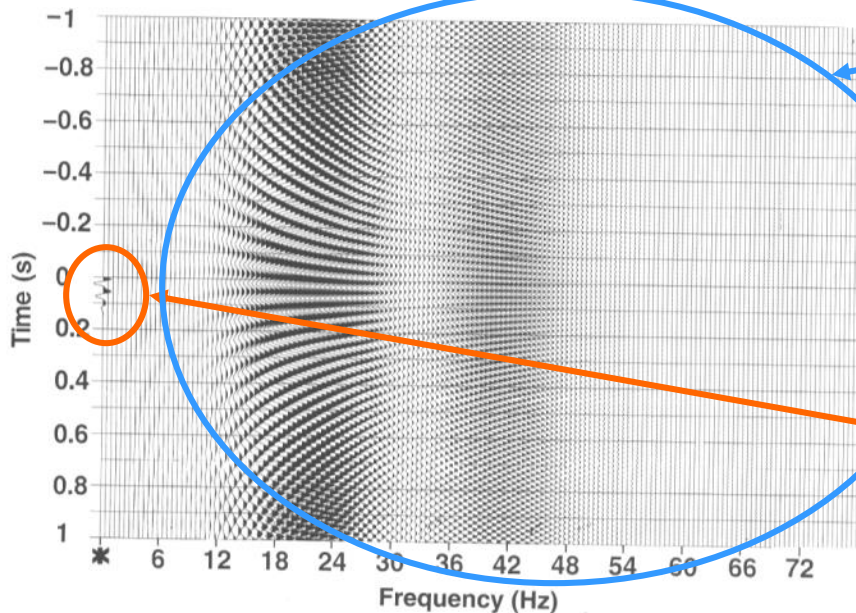
TRASFORMATA DI FOURIER (FT)

Considerazioni pratiche e applicative

Per segnali monofrequenza



Per segnali multifrequenza

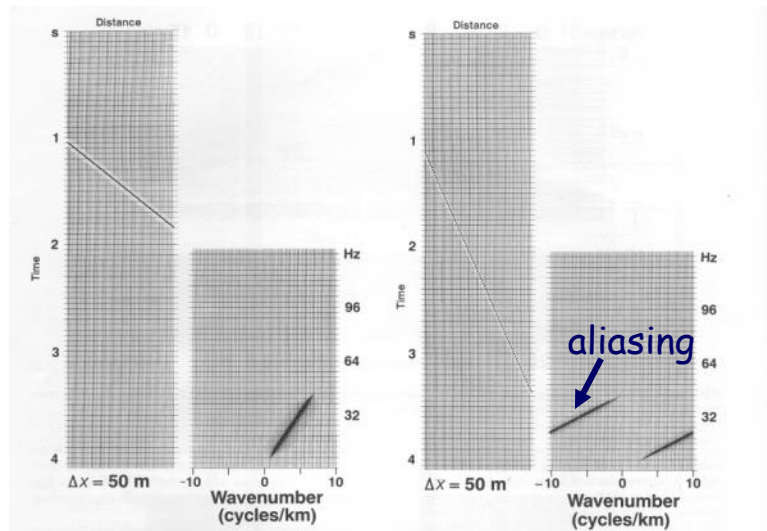
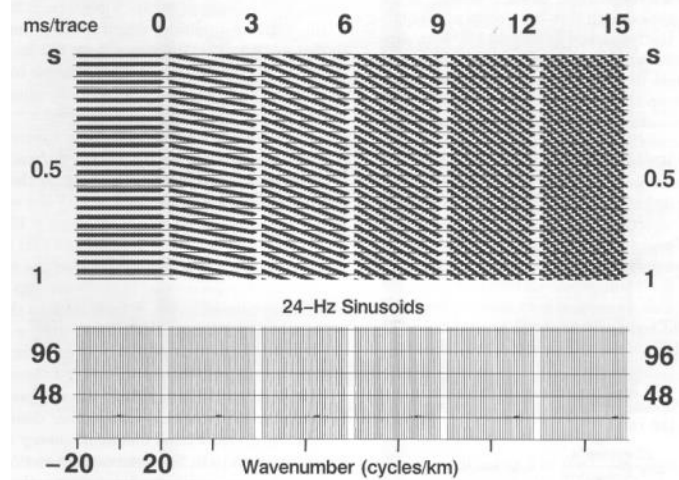


Quindi: la FT esprime il contenuto in frequenza e fase di una sequenza temporale di cui è una rappresentazione analogica alternativa

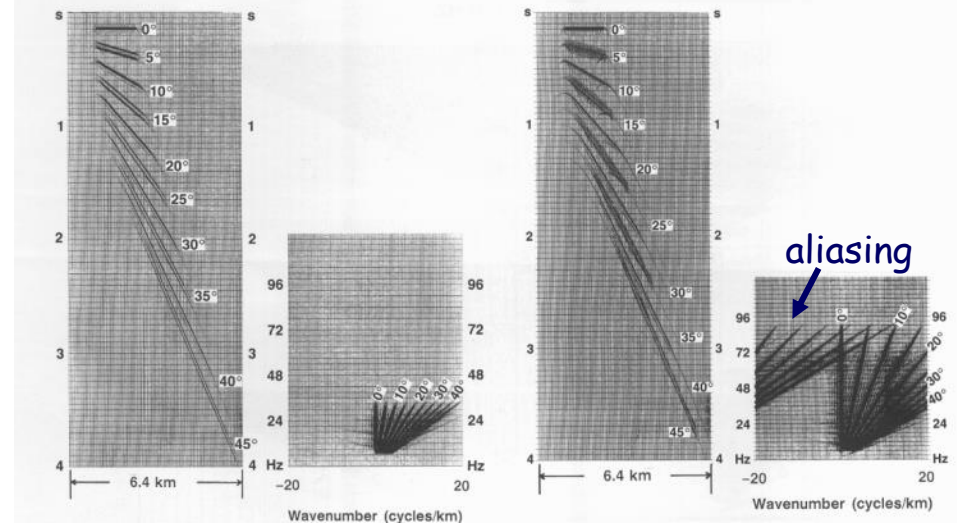
TRASFORMATA DI FOURIER (FT)

Considerazioni pratiche e applicative: 2D

Per segnali monofrequenza
e k =numero d'onda=cost



Per segnali multi frequenza
e k =numero d'onda costante



Per segnali multi frequenza
e k =numero d'onda=variabile

TRASFORMATA DI HILBERT (HT)

Una traccia sismica si può considerare una funzione complessa somma di una parte reale ed una immaginaria $u(t) = x(t) + iy(t)$ in cui $x(t)$ è la traccia sismica registrata e $y(t)$ la sua "quadratura", ovvero la traccia con la fase traslata nel tempo di 90° .
 $y(t)$ Si può ricavare matematicamente da $x(t)$ tramite la trasformata di Hilbert:

$$y(t) = \frac{1}{\pi} * x(t)$$

E' interessante esprimere $u(t)$ in coordinate polari (o di Eulero): $u(t) = A(t) \exp[i\varphi(t)]$
 In cui:

$$A(t) = \sqrt{x^2(t) + y^2(t)} \quad \text{AMPIEZZA ISTANTANEA o INVILUPPO o REFLECTION STRENGTH}$$

$$\varphi(t) = \tan^{-1} \frac{y(t)}{x(t)} \quad \text{FASE ISTANTANEA}$$

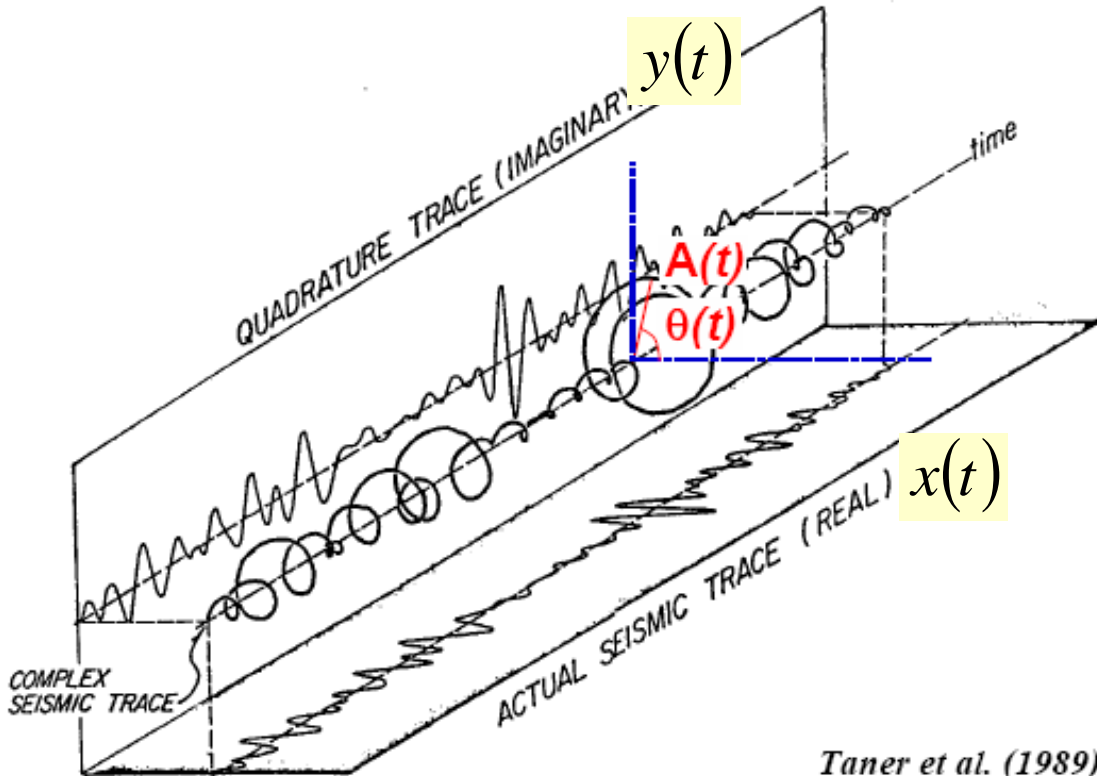
Se calcoliamo la variazione nel tempo della fase istantanea avremo:

$$\omega(t) = \frac{d\varphi(t)}{dt} \quad \text{FREQUENZA ISTANTANEA}$$

Le grandezze sopra descritte (e quelle da loro derivate) sono chiamate **ATTRIBUTI ISTANTANEI** perché calcolati, nel caso discreto, per ogni istante temporale $n\Delta t$.

TRASFORMATA DI HILBERT (HT)

Considerazioni pratiche e applicative



AMPIEZZA

$$A(t) = \sqrt{x^2(t) + y^2(t)}$$

FASE

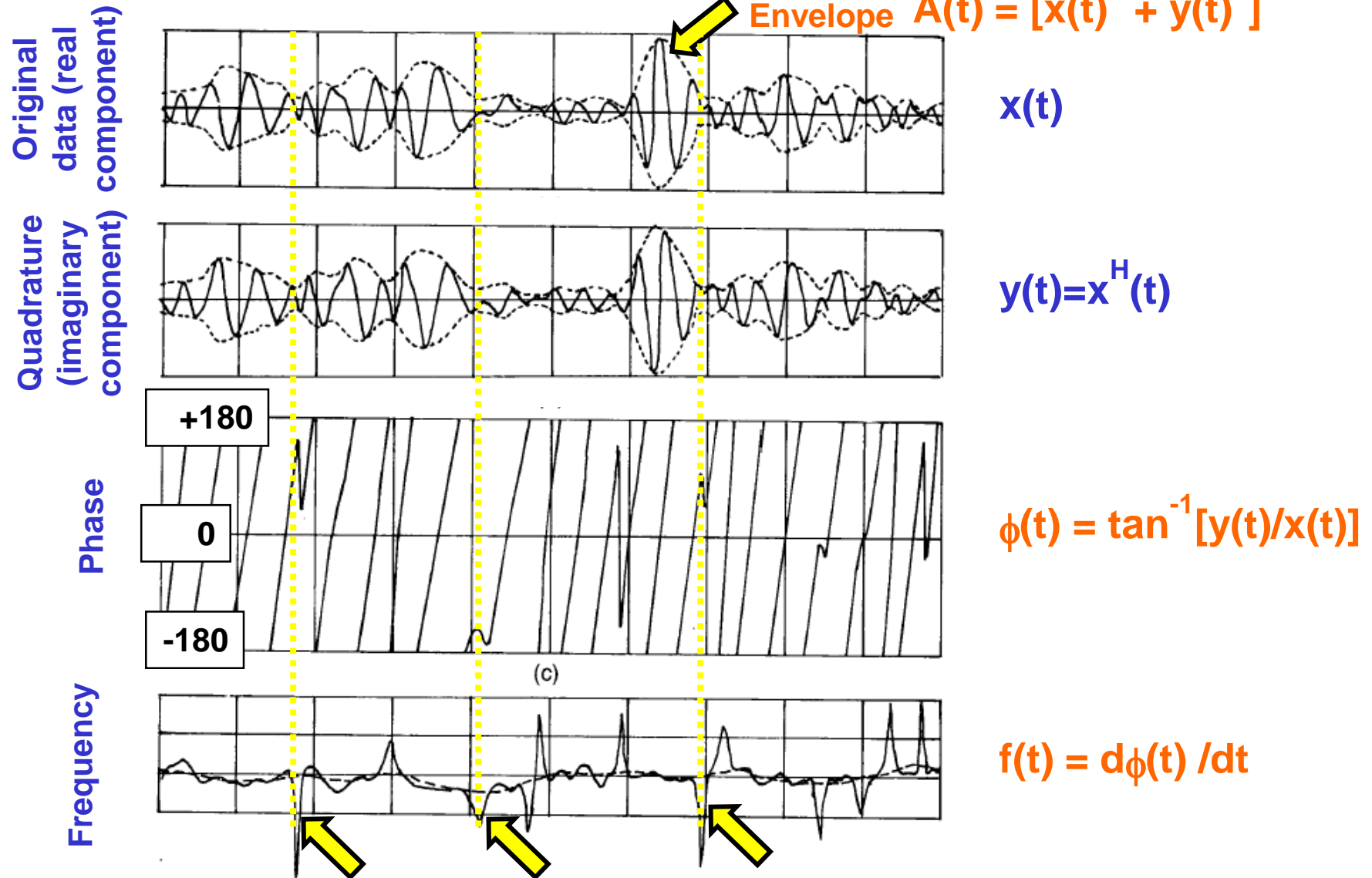
$$\phi(t) = \theta(t) = \arctg\left(\frac{y(t)}{x(t)}\right)$$

FREQUENZA

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

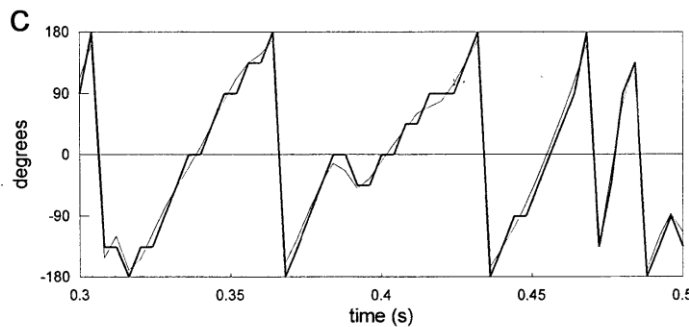
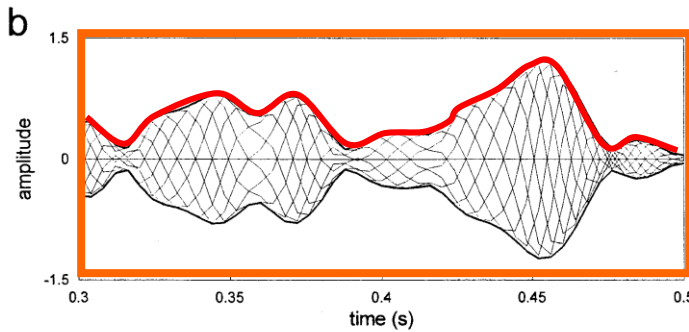
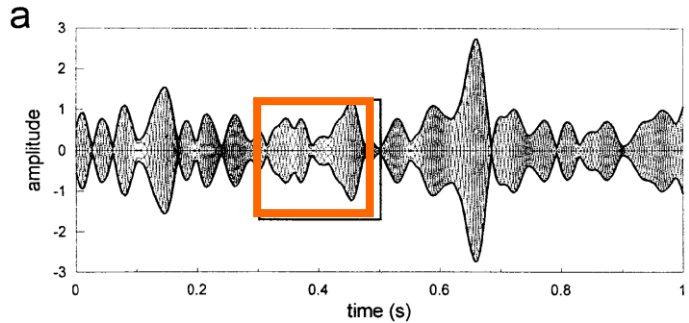
TRASFORMATA DI HILBERT (HT)

Considerazioni pratiche e applicative

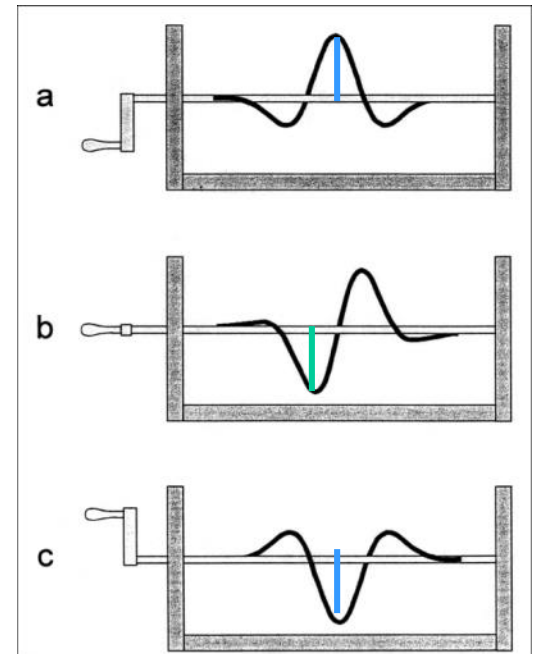
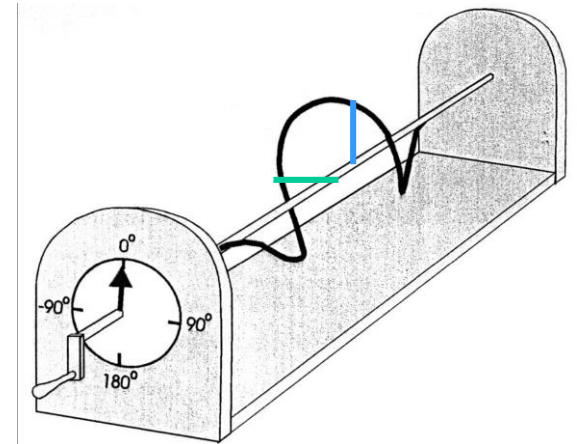


TRASFORMATA DI HILBERT (HT)

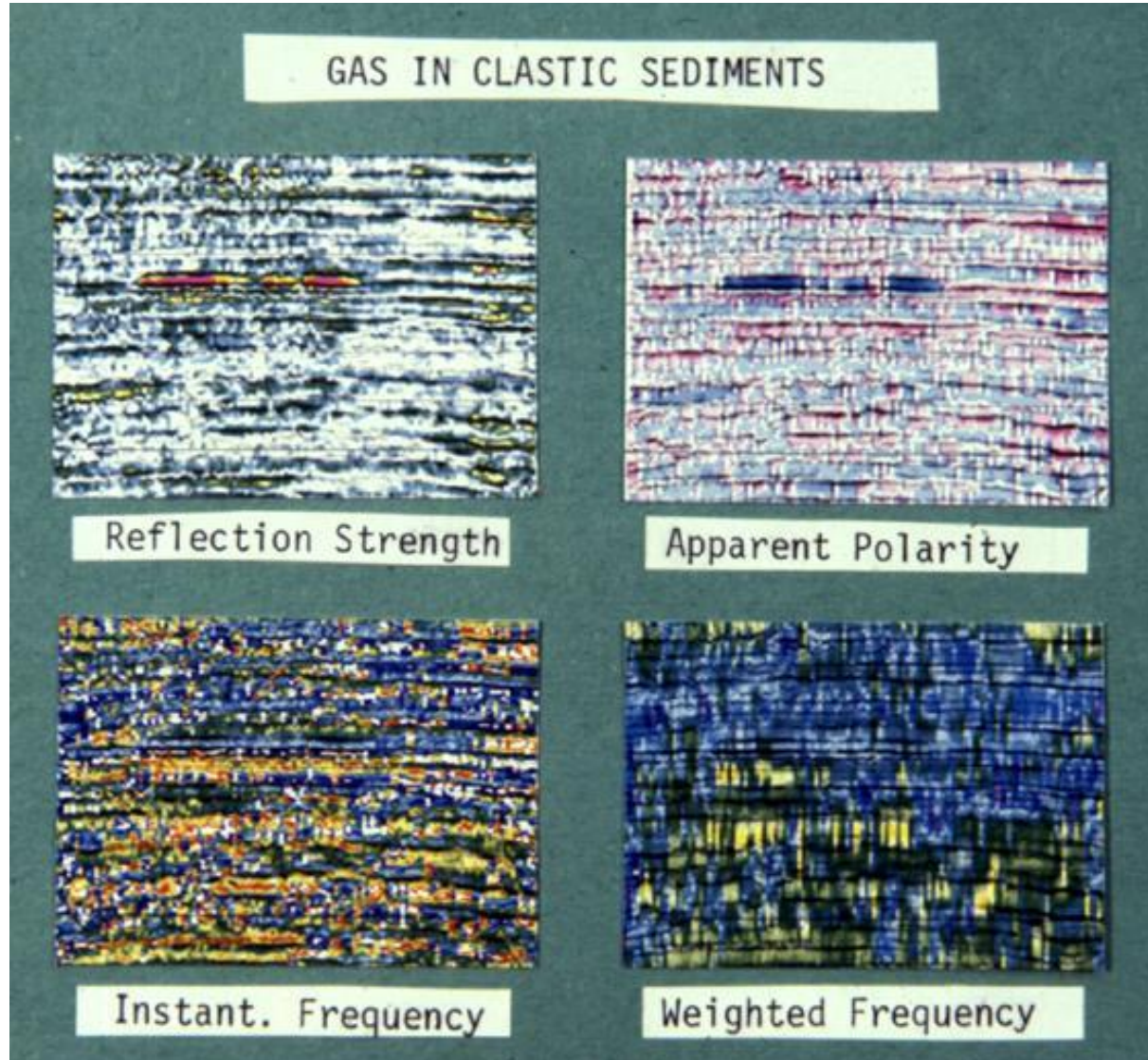
Considerazioni pratiche e applicative



(a) Traccia della slide precedente ruotata 0° , 45° , 90° , 135° , 180° , -135° , -90° , e -45° (linee sottili), delimitata dall'involucro (linee marcate).
 At any given time, the envelope is approximately the largest value found on the set of phase-rotated traces, and the instantaneous phase is approximately the negative of the phase of that trace with the largest value.
 (b) Close-up of the box.
 (c) Approximate instantaneous phase (dark line) overlying actual instantaneous phase (light line).

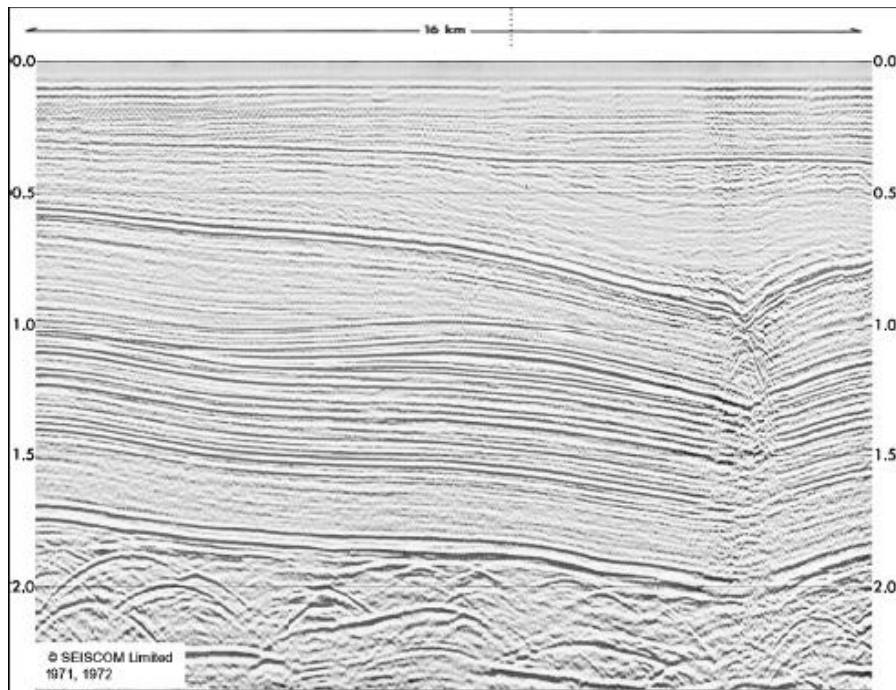


APPLICAZIONI ATTRIBUTI ISTANTANEI



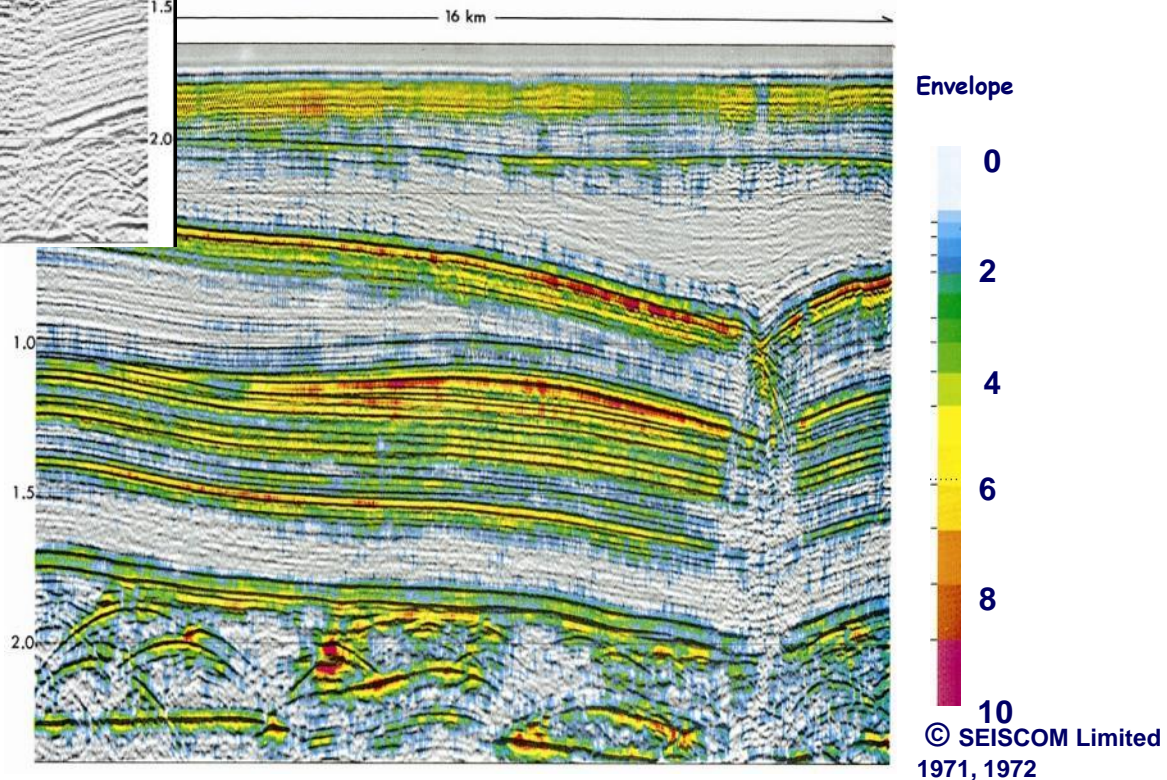
(T. Taner, Rock Solid Images anni '70)

APPLICAZIONI ATTRIBUTI ISTANTANEI



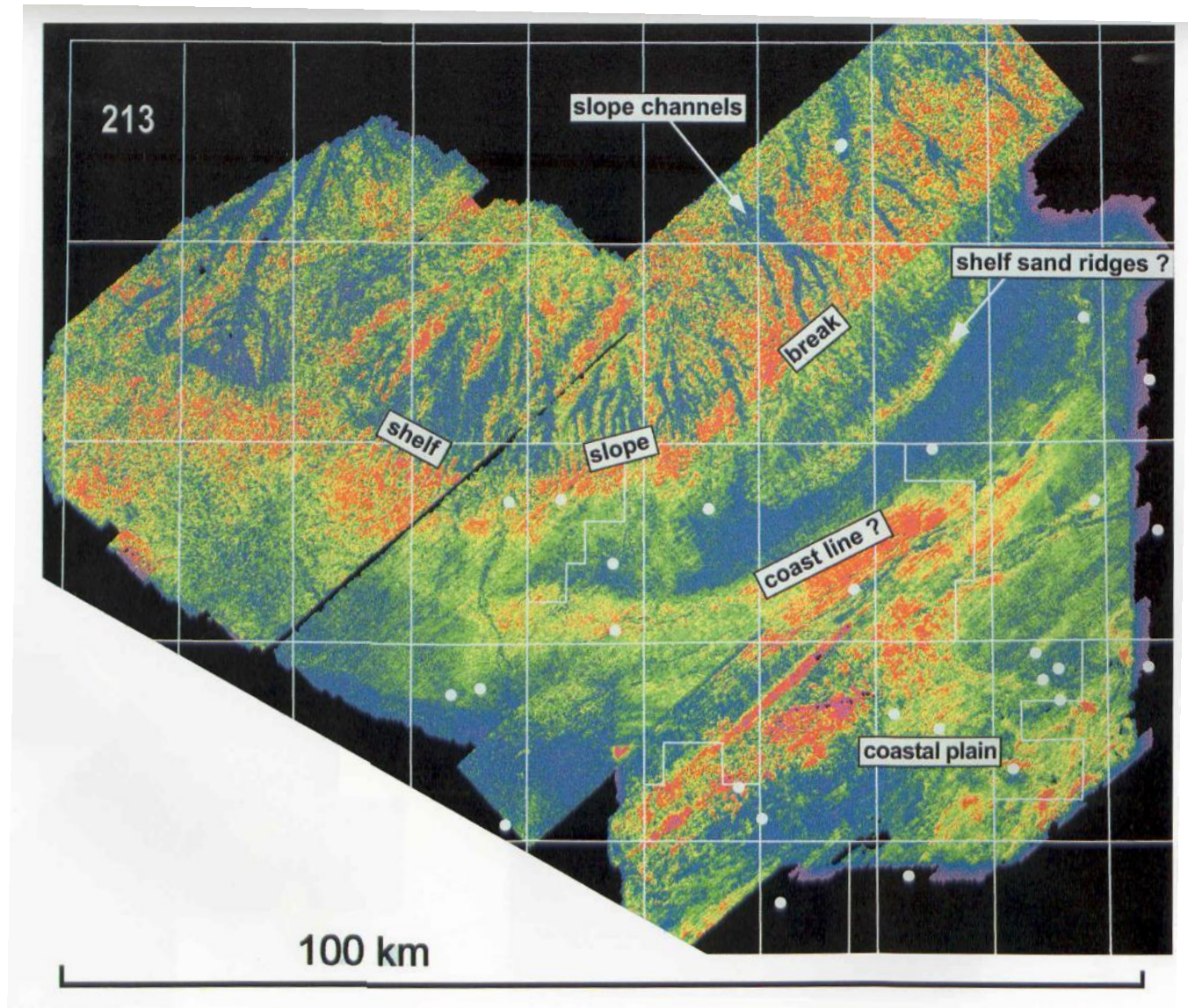
Variable density plot

Variable density plot
con sovrapposta
l'ampiezza istantanea

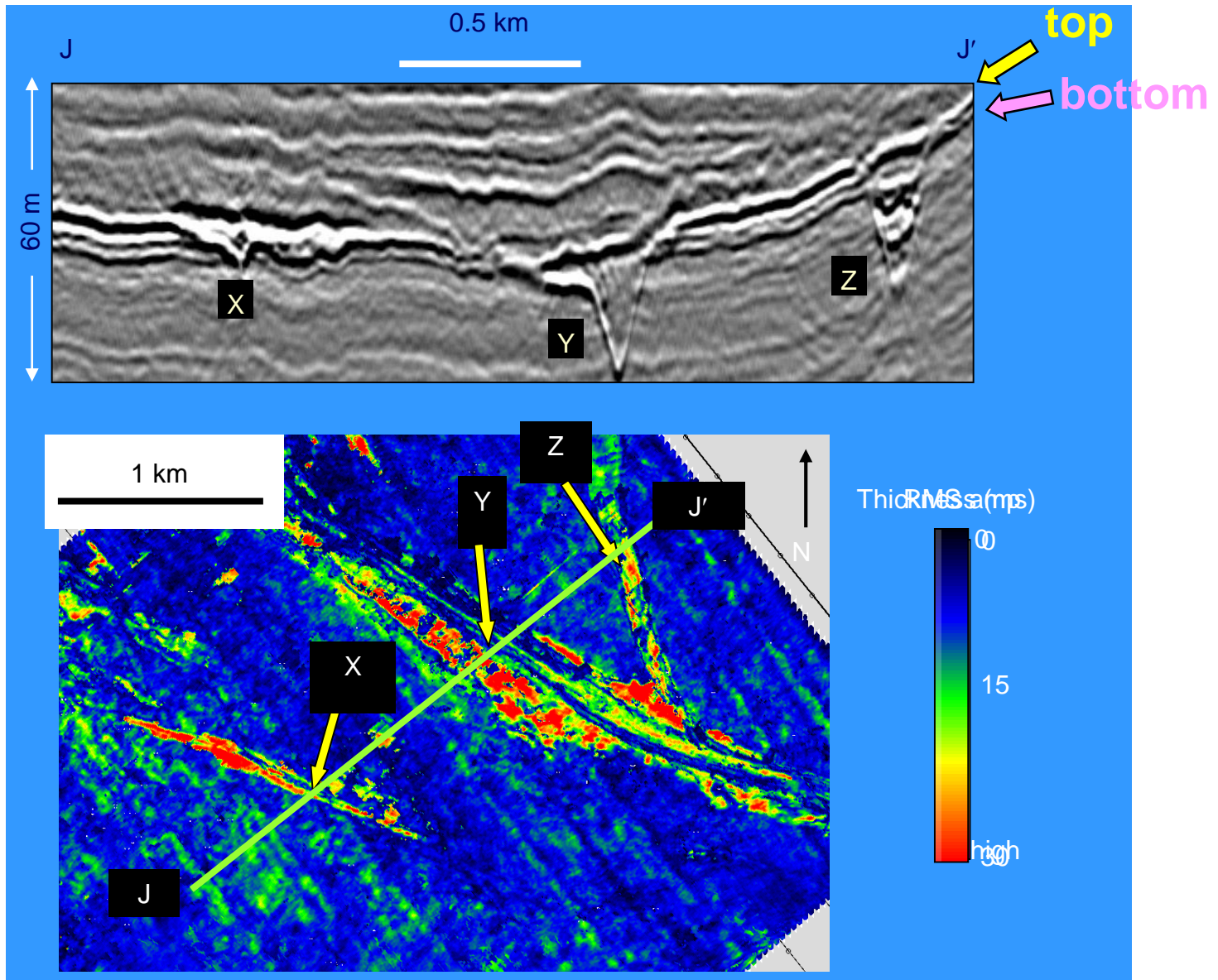


APPLICAZIONI ATTRIBUTI Istantanei

Top Balder Fm amplitude map from multiple 3-D surveys covering 5500 sq. km. of the Faroe Basin west of Shetland in U.K. waters. The colors show the **RMS MEAN INSTANTANEOUS AMPLITUDE** over a 50 ms window surrounding the Top Balder Fm, with **red** indicating high amplitude and **blue** indicating low amplitude.



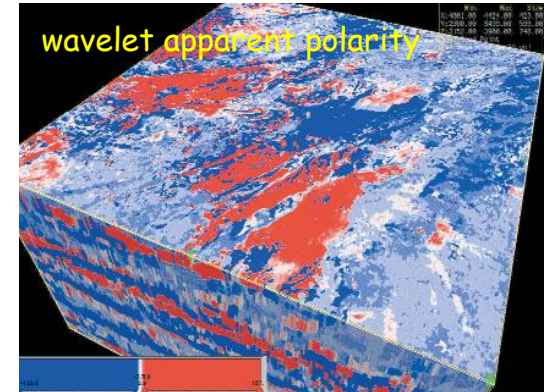
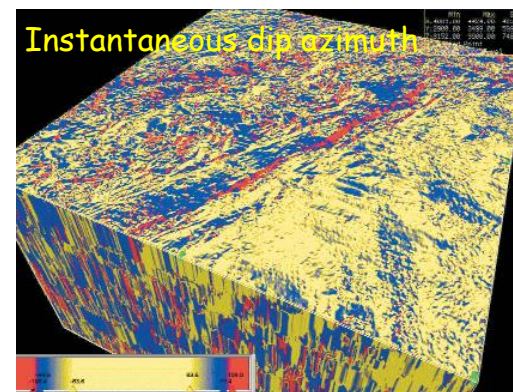
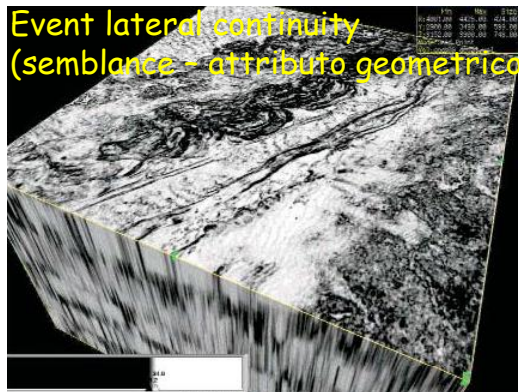
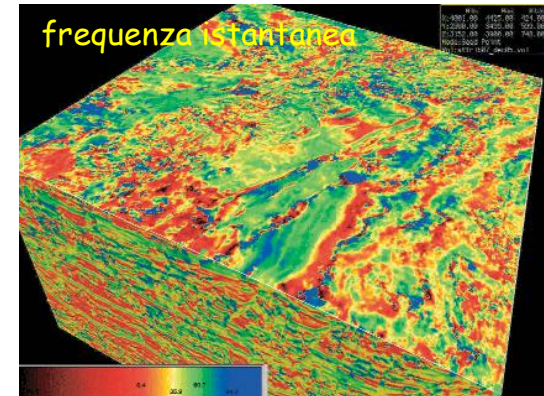
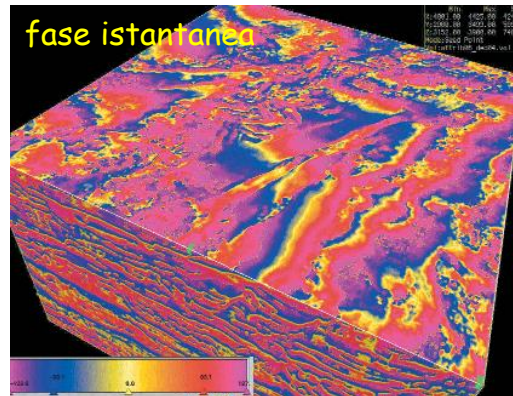
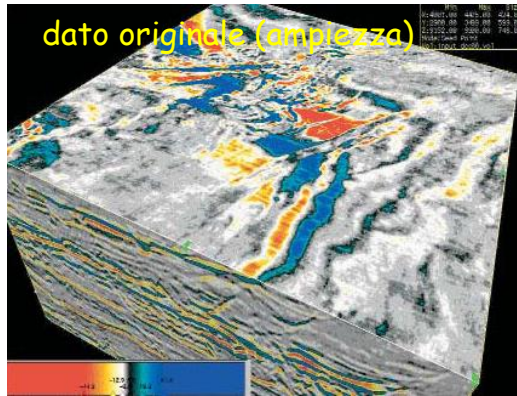
APPLICAZIONI ATTRIBUTI ISTANTANEI



Oyodele, 2005

APPLICAZIONI ATTRIBUTI ISTANTANEI

A Che cosa servono?

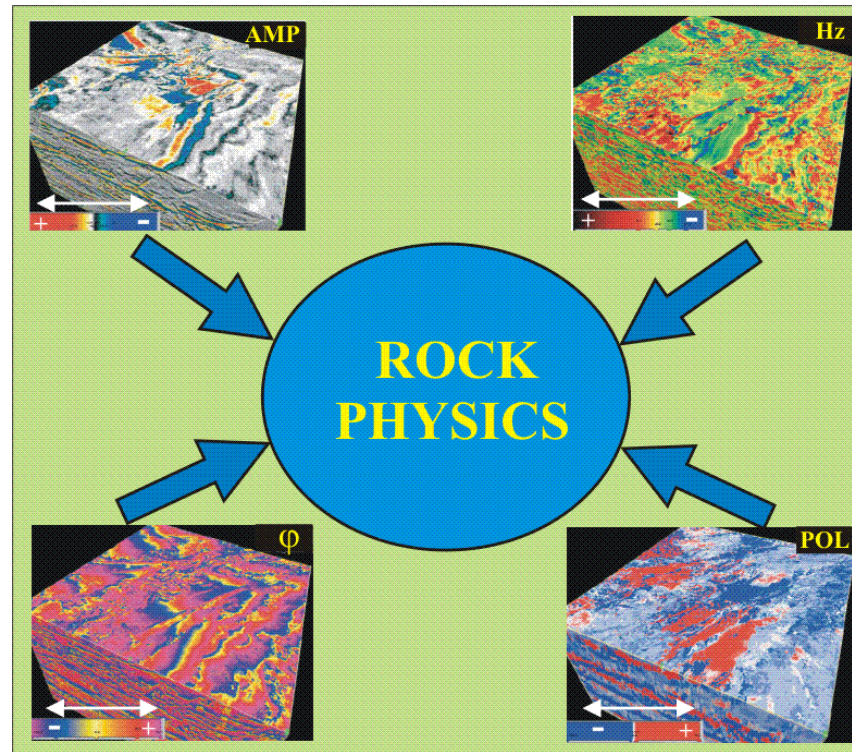


AMPIEZZA ISTANTANEA (trace envelope, reflection strength) SOLO POSITIVA

- Contrasti di impedenza acustica → riflettività
 - Bright spots, possibile accumulo di gas
 - Sequence boundaries
 - Evidenza *thin-bed*
 - Contatto tra fluidi diversi, zone di sovrappressione
- Cambiamenti principali di ambiente deposizionale
 - Correlazione spaziale della porosità e di altri parametri litologici
 - Indicazioni sulla velocità di gruppo dell'onda sismica → dispersione

APPLICAZIONI ATTRIBUTI ISTANTANEI

A Che cosa servono?



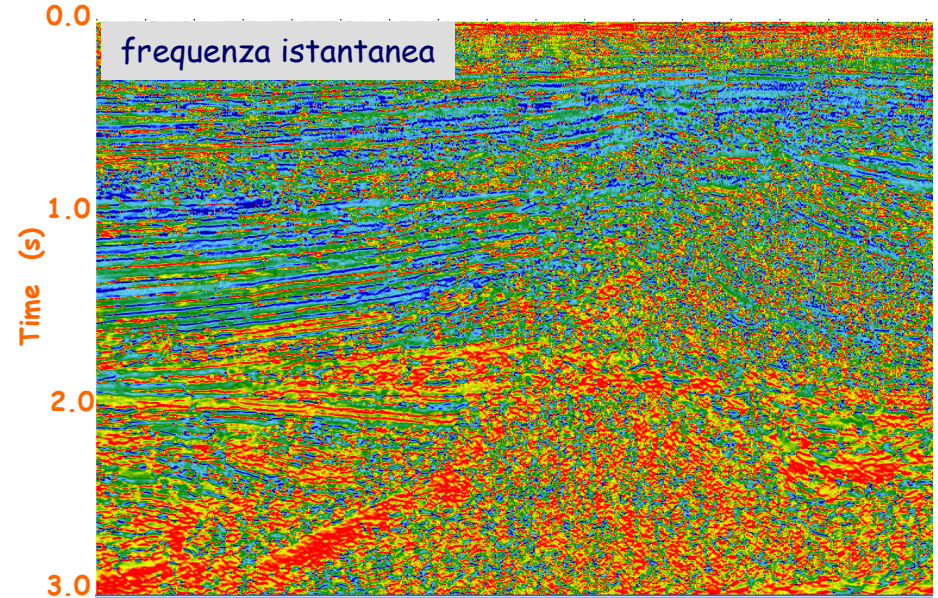
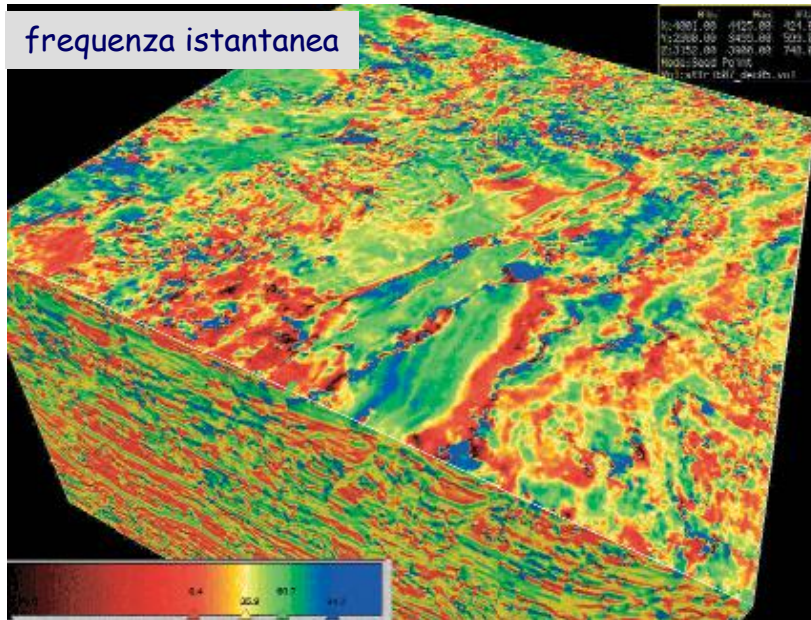
FASE ISTANTANEA

Dal momento che i fronti d'onda hanno fase costante, la Fase Istantanea evidenzia le forme/geometrie anche con dati rumorosi e basso S/N

- Continuità laterale/discontinuità anche con forti variazioni di ampiezza
- Individuazione di strati sottili
- Evidenzia eventi anche a bassissima ampiezza (dettagli stratigrafici, faglie, multiple,...)
- Velocità di fase

APPLICAZIONI ATTRIBUTI ISTANTANEI

A Che cosa servono?



FREQUENZA ISTANTANEA

Evidenzia le variazioni di frequenza (contenuto spettrale) ad un'interfaccia/discontinuità.

Molto sensibile al rumore → singolarità fittizie → artefatti

- Indicatore di idrocarburi (anomalia a bassa frequenza), soprattutto in sabbie non consolidate a olio
- Suggerisce variazioni granulometriche (Sand/Shale Ratio - SSR)
- fratture/faglie=zone a minor frequenza
- Suggerisce gli spessori degli orizzonti: alte f → laminazione, strati sottili; basse f → strati massivi.

Si possono calcolare tantissimi attributi derivati da q_s . 3: ad esempio derivata prima e seconda della AI, gradiente della FI, medie della FI,...



DOMANDE?



Approfondimenti:

Seismic Attribute Sensitivity to Energy, Bandwidth, Phase, and Thickness

Da Greg A. Partyka

BPAmoco (modificato)

OBIETTIVI

- 1 Review common attributes.
- 2 Summarize attribute sensitivity
 - to energy, bandwidth, and phase; via simple half-space models.
 - to thickness; via simple wedge models.

Model Descriptions

7 half-space models

- Laterally consistent reflectivity
- Laterally variable wavelet properties

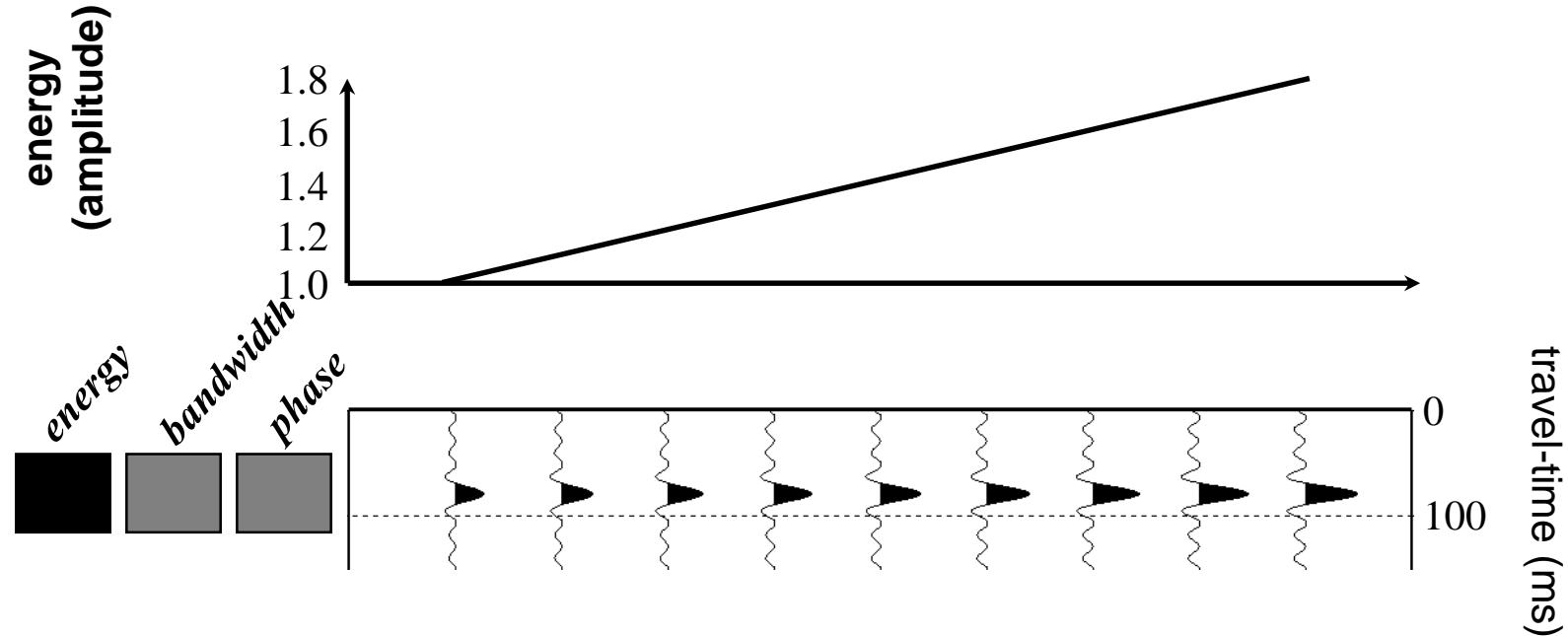
Statics, variable source & receiver coupling, and attenuation are three main causes for laterally variable wavelet properties.

3 wedge models

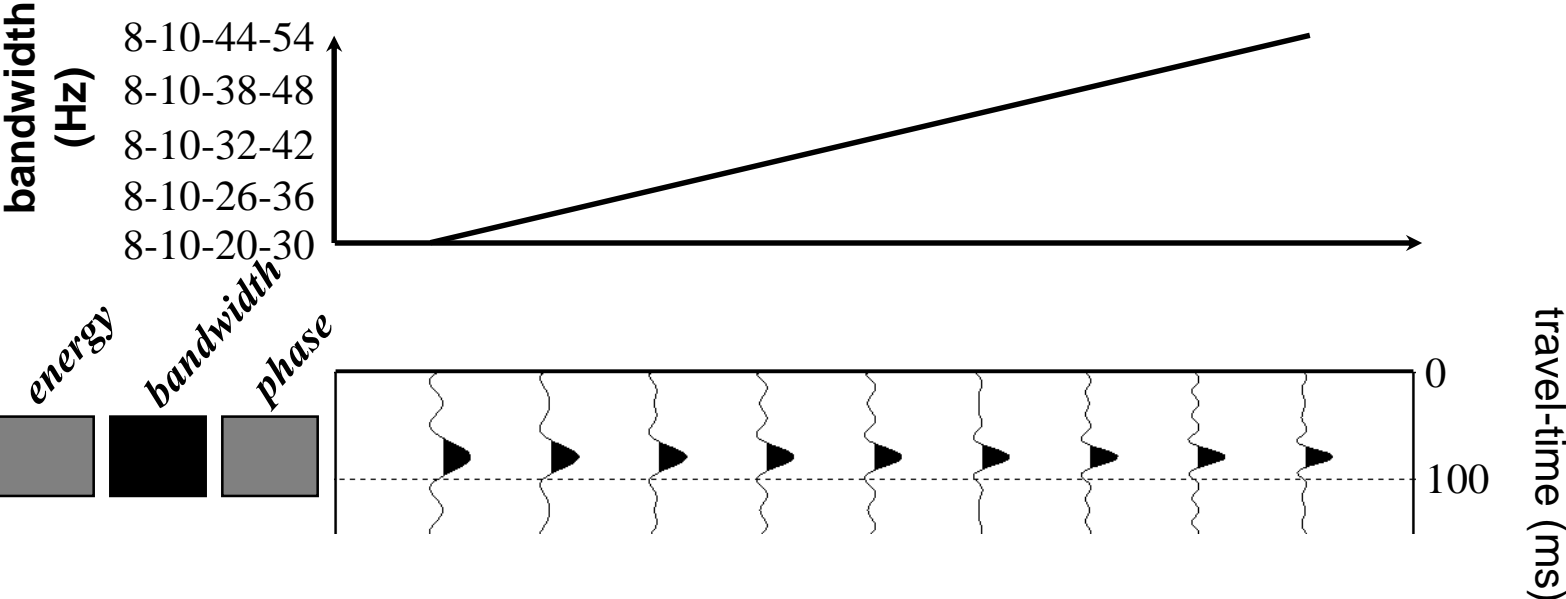
- Laterally consistent wavelet properties.
- Laterally variable reflectivity.

Lithology, fluid, and thickness are three main causes for laterally variable reflectivity.

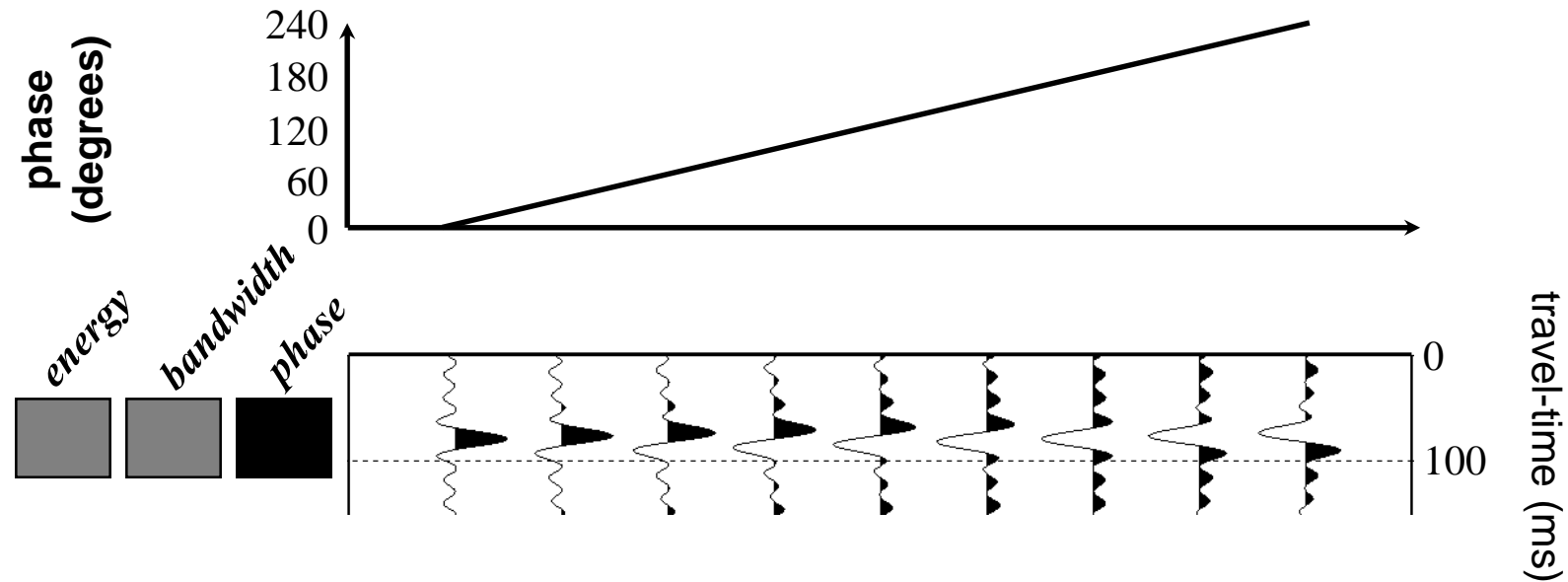
Energy Model



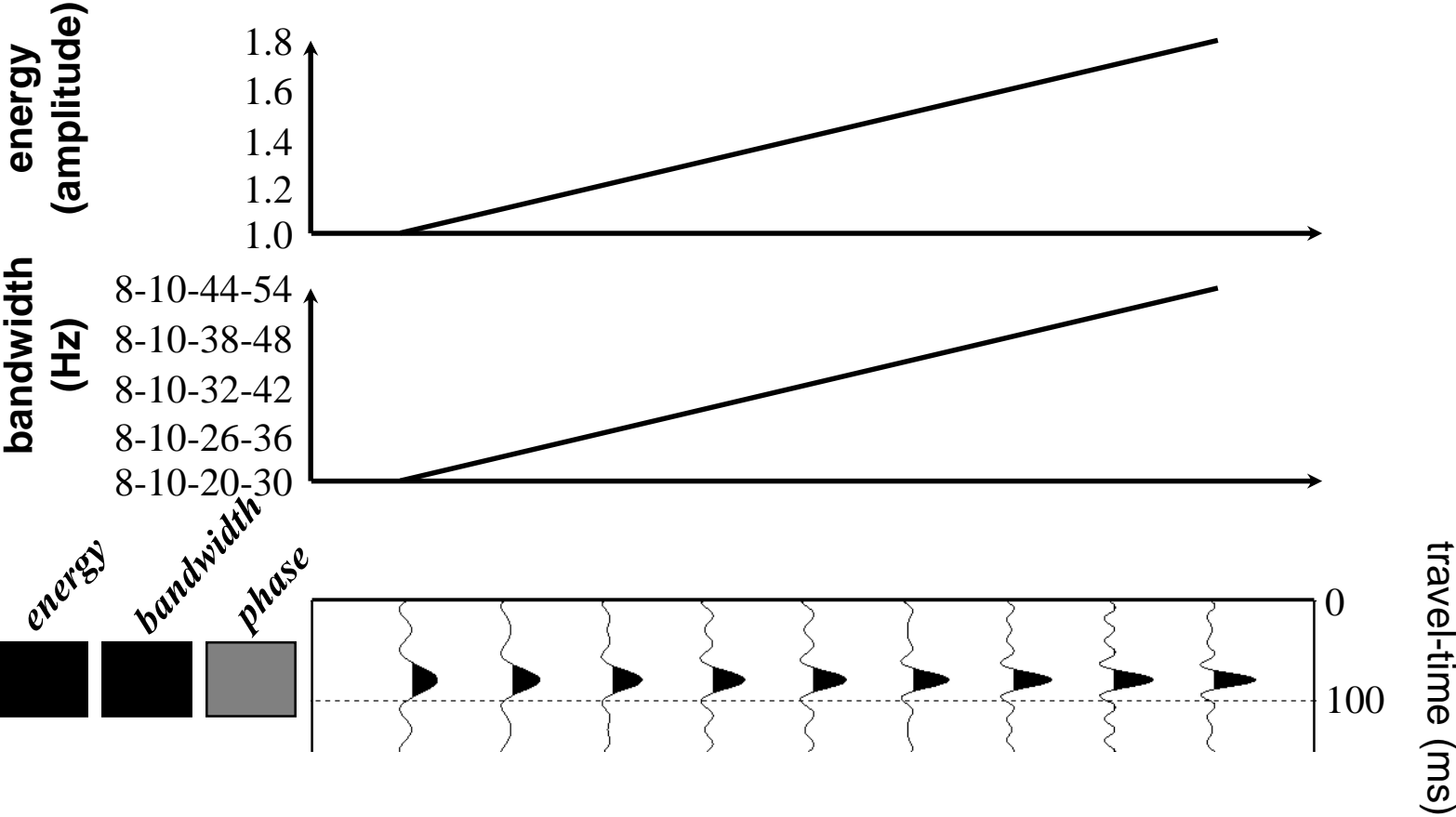
Bandwidth Model



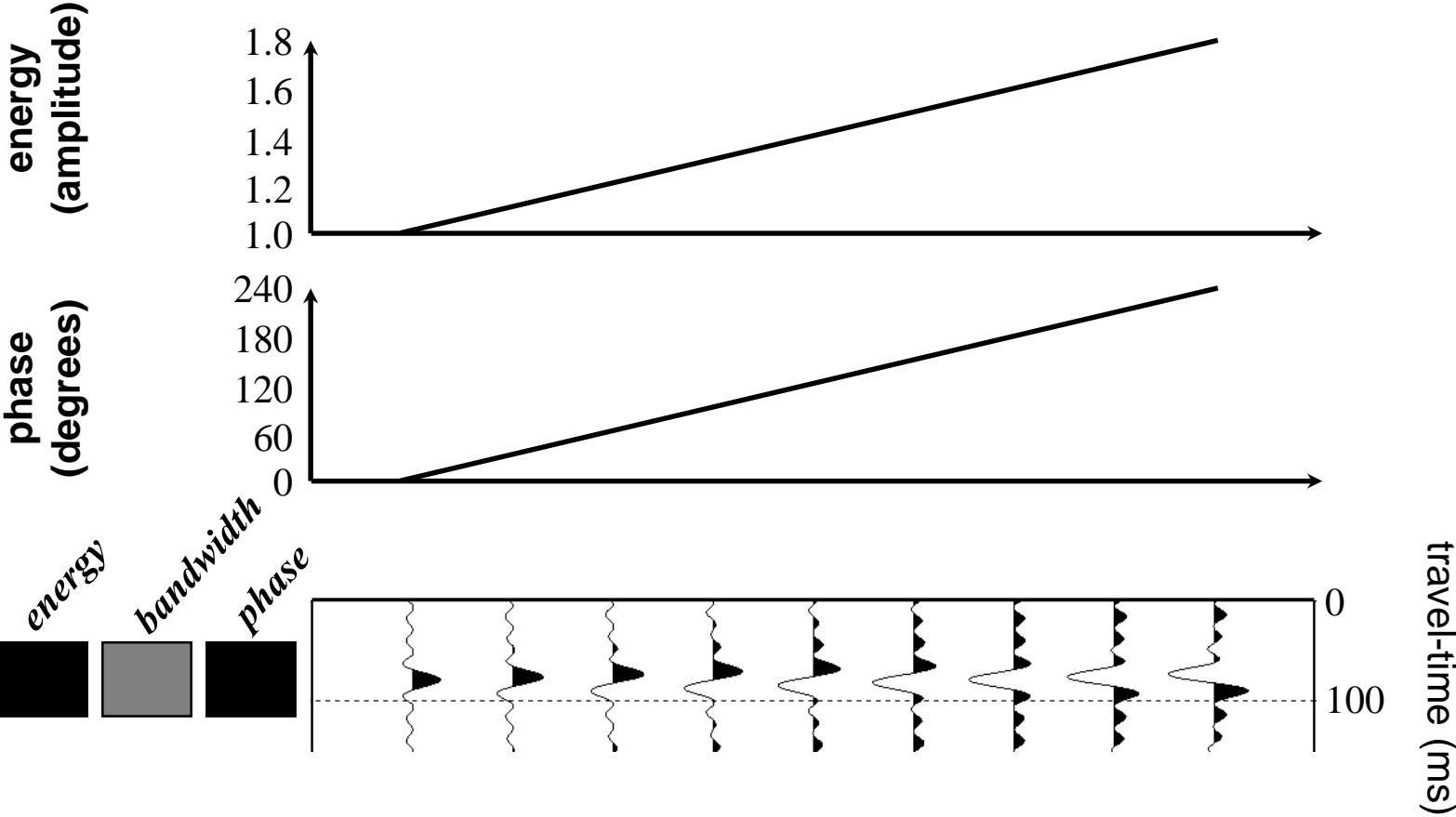
Phase Model



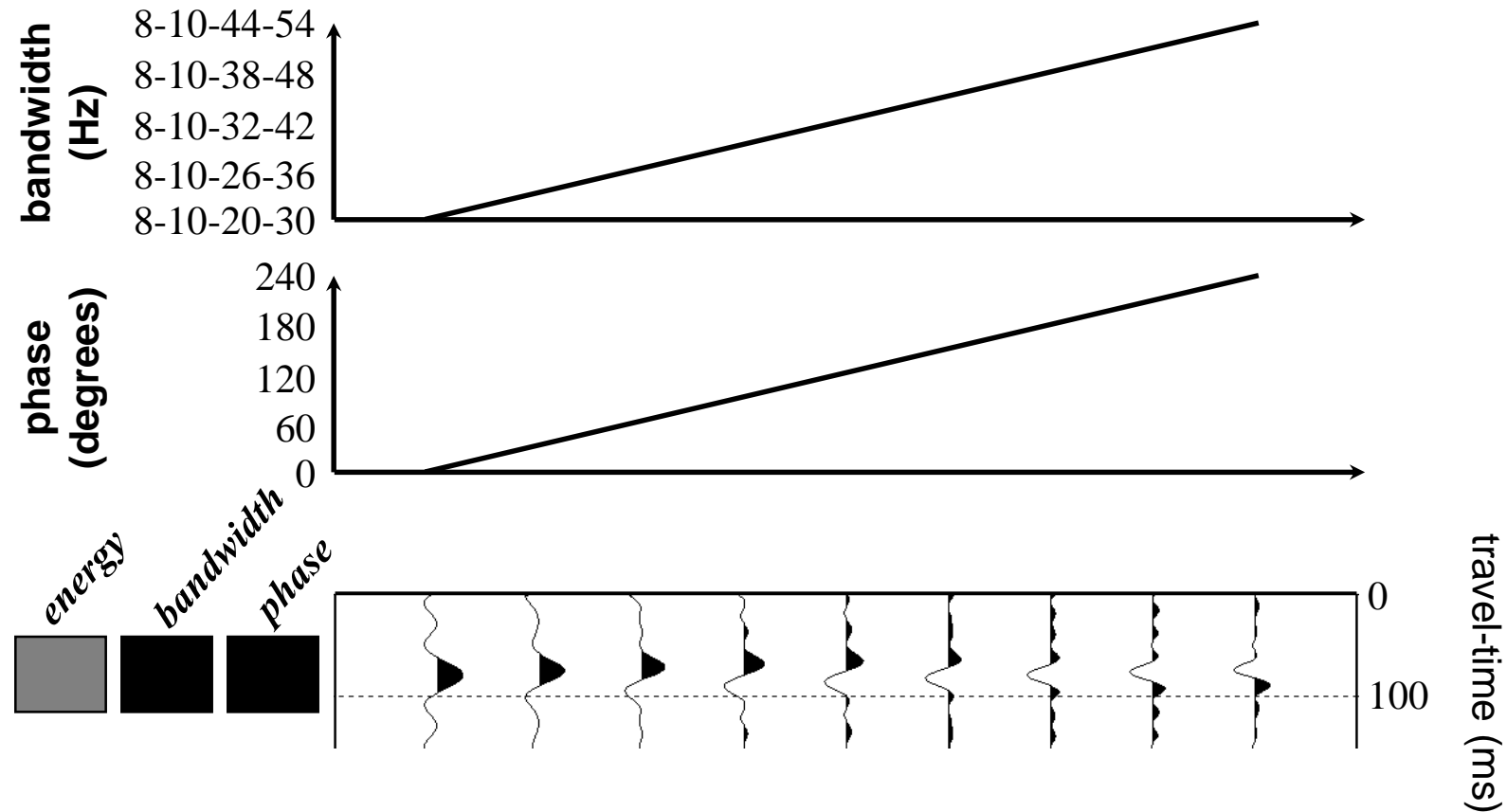
Energy-Bandwidth Model



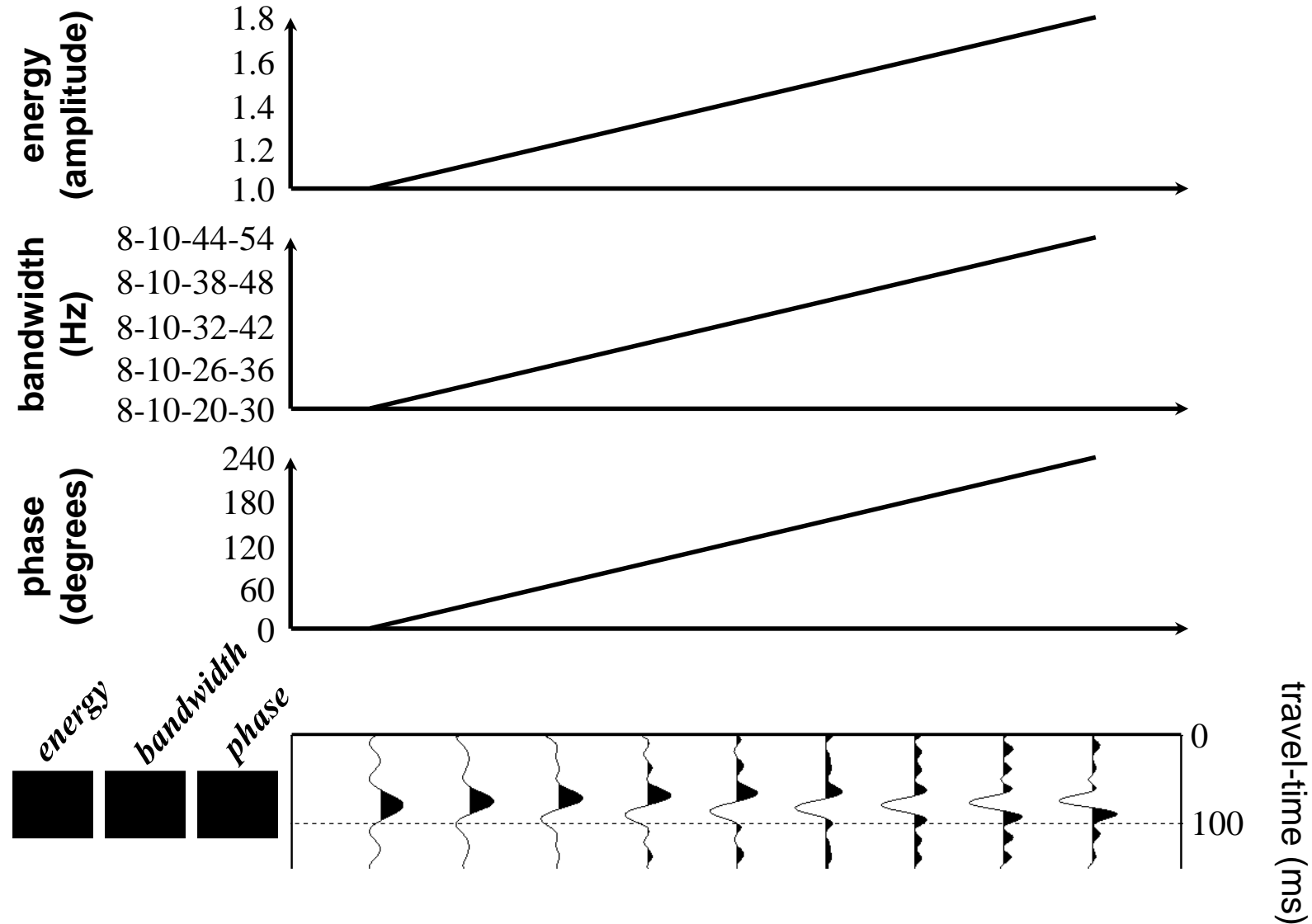
Energy-Phase Model



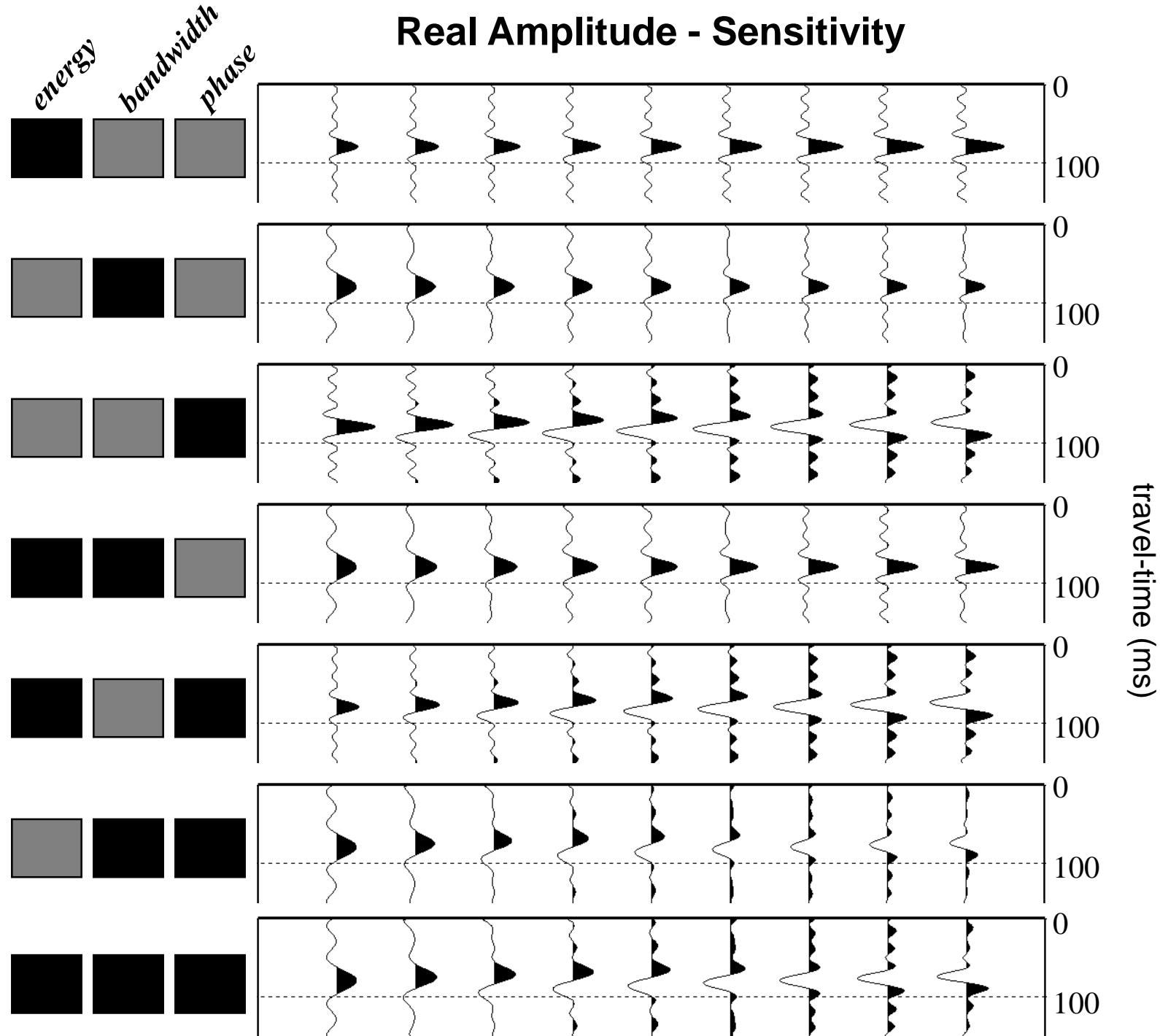
Bandwidth-Phase Model



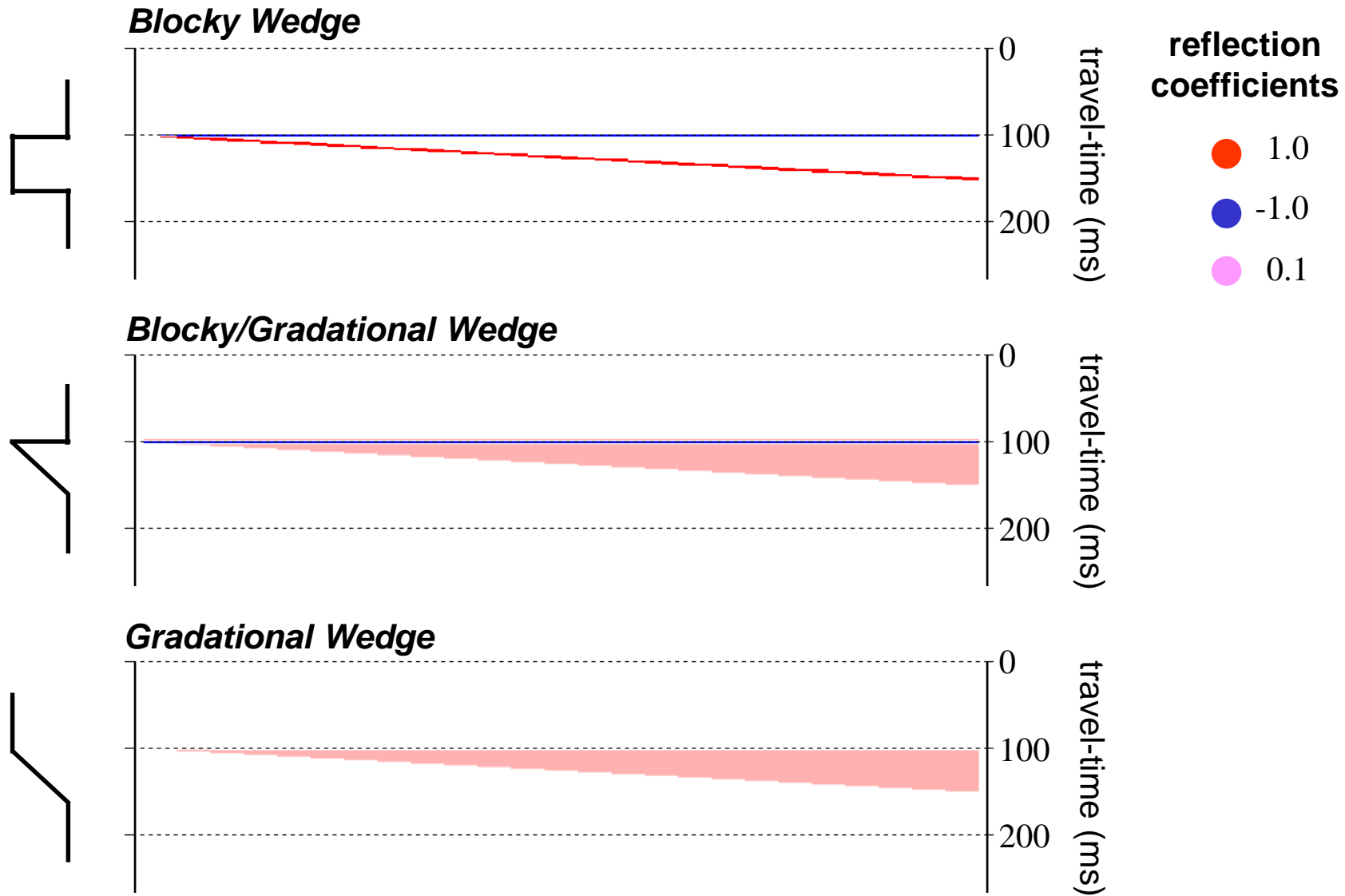
Energy-Bandwidth-Phase Model



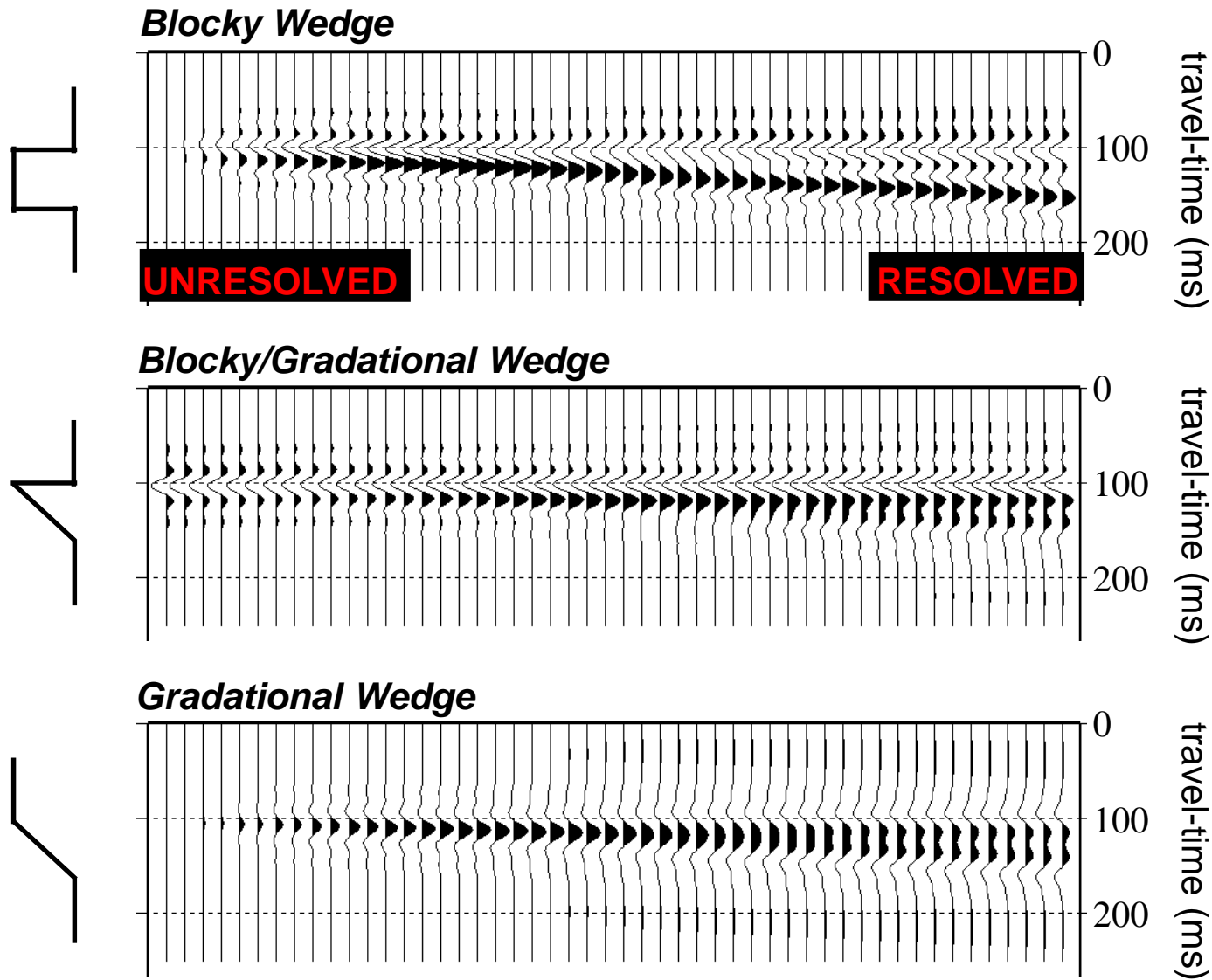
Real Amplitude - Sensitivity



Reflectivity Wedge Models



Real Amplitude (DATO ORIG.)

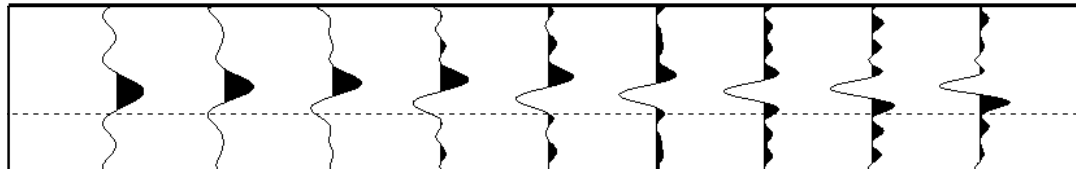


8-10-40-50Hz
Ormsby w.

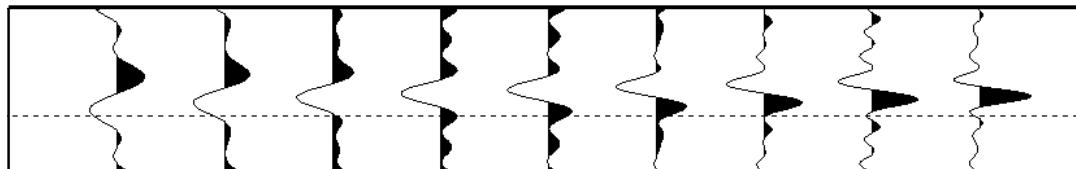
Instantaneous Attributes

- Characterize sample-by-sample variability.
- Include:
 - quadrature amplitude,
 - reflection strength,
 - instantaneous phase,
 - cosine of the instantaneous phase,
 - instantaneous frequency.

Quadrature Amplitude



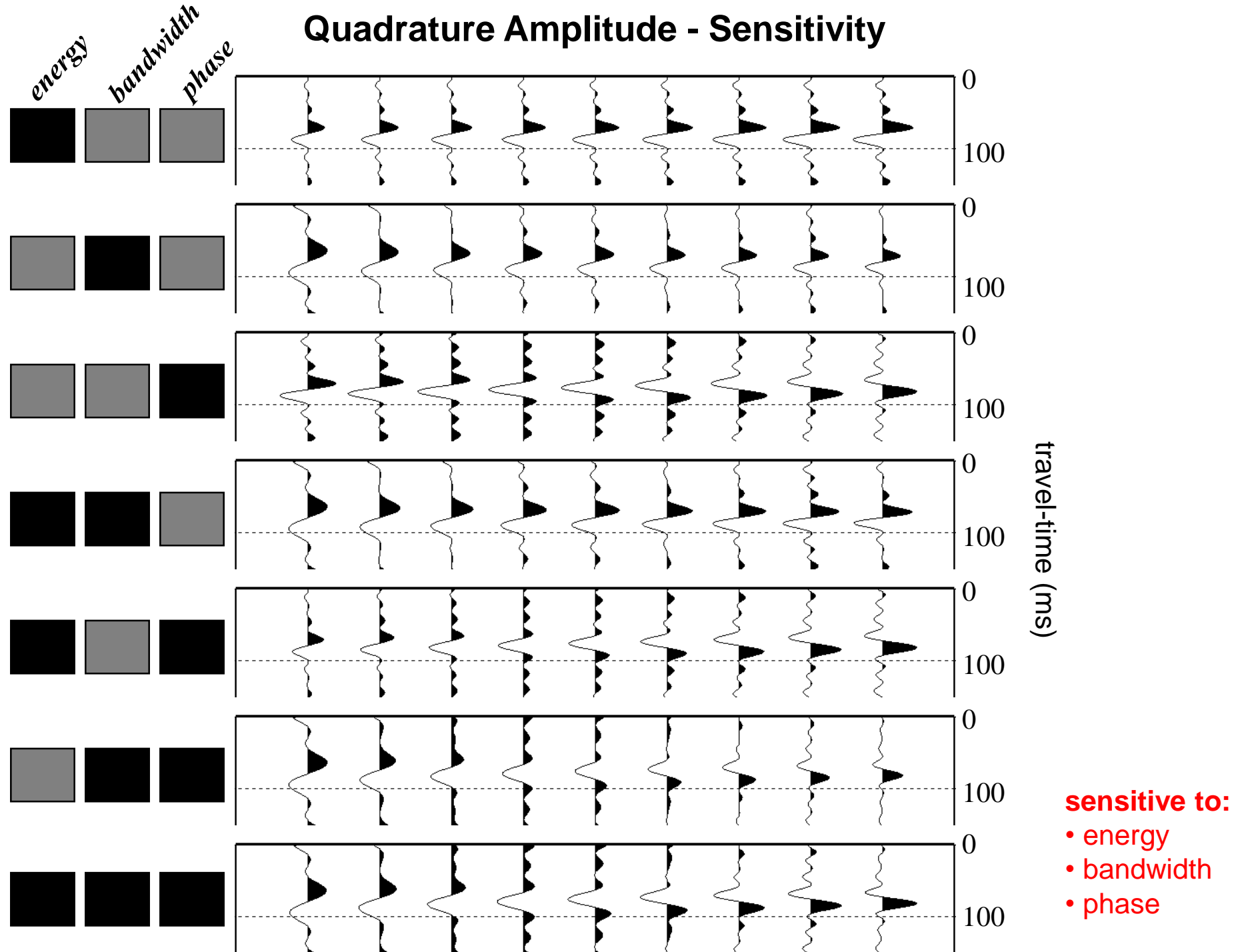
Real Amplitude



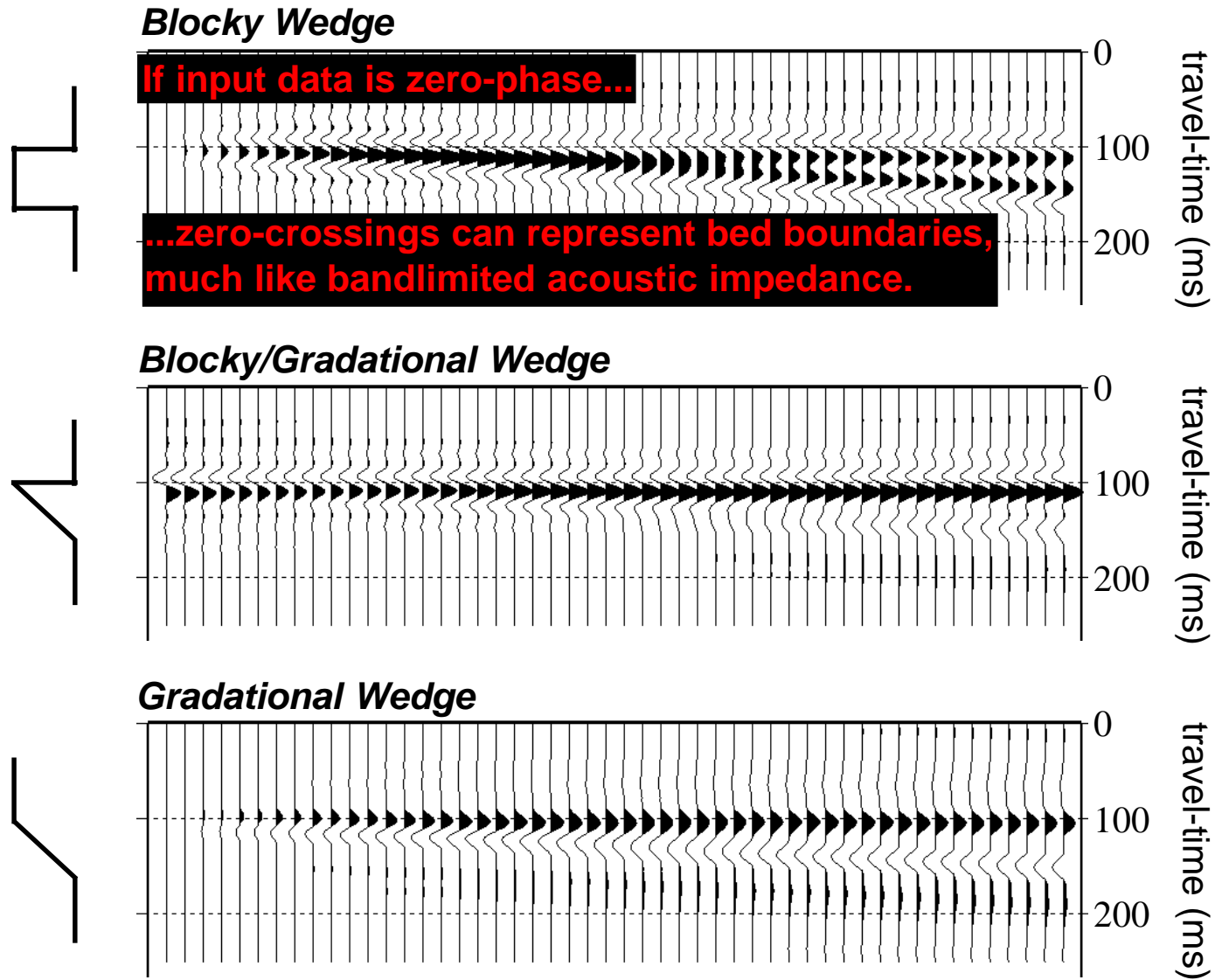
Quadrature Amplitude
Cioè shift di fase di 90°

- 90 degree phase rotation (or Hilbert transform).
- Zero-Crossings \rightleftharpoons Peaks & Troughs.
- Also called “the imaginary part of the seismic trace”.

Quadrature Amplitude - Sensitivity

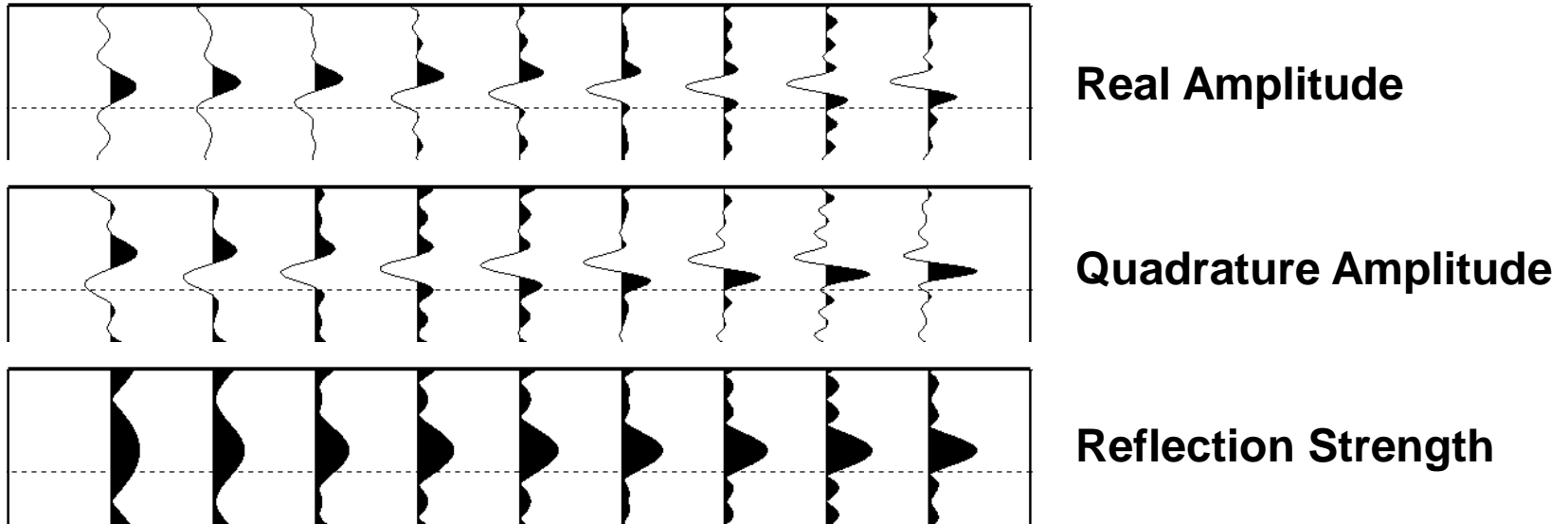


Quadrature Amplitude



Reflection Strength

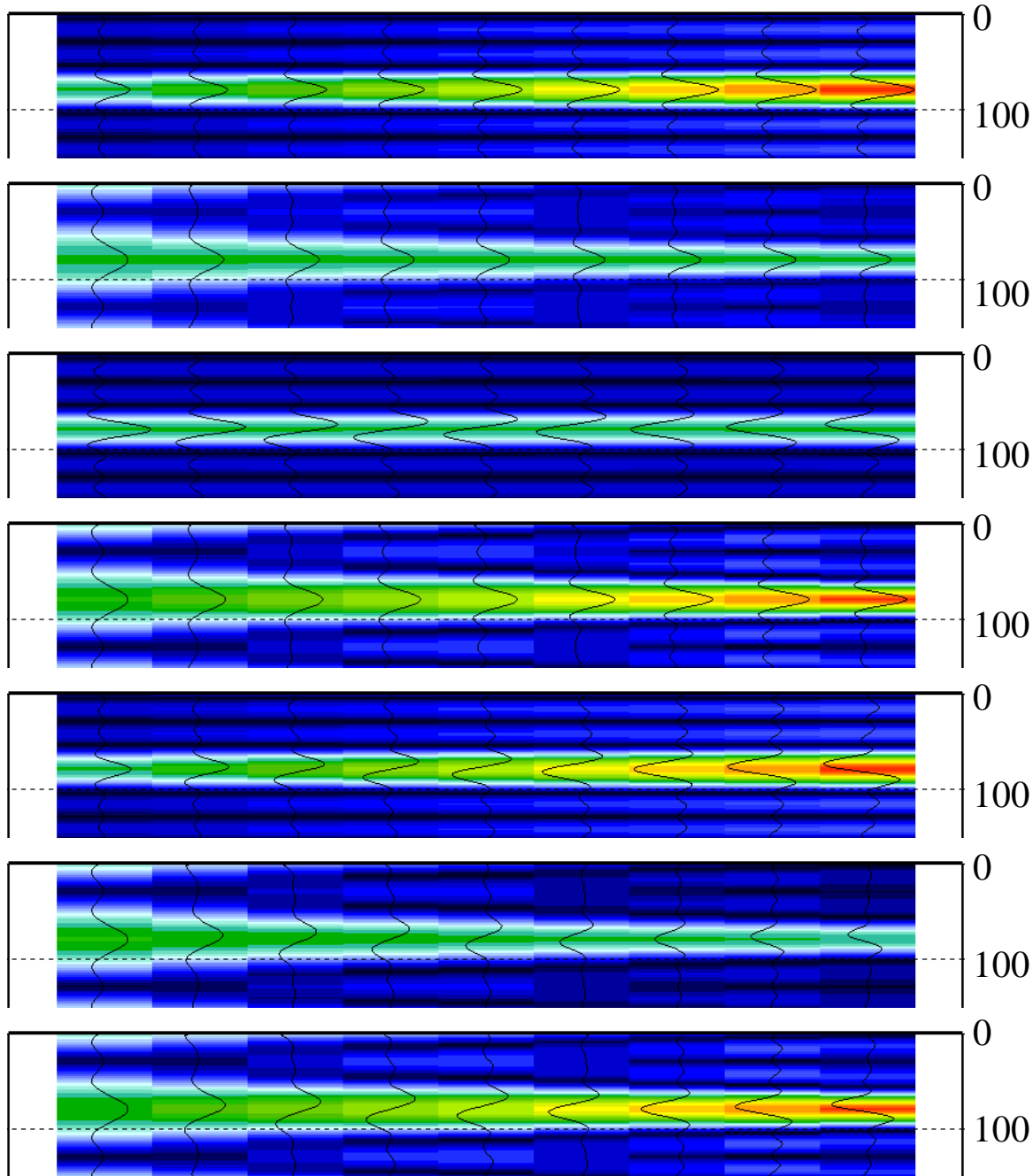
or energy envelope or
instantaneous amplitude



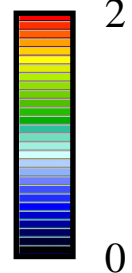
- Phase independent
- Always greater-than or equal-to zero

Reflection Strength - Sensitivity

energy
bandwidth
phase



energy

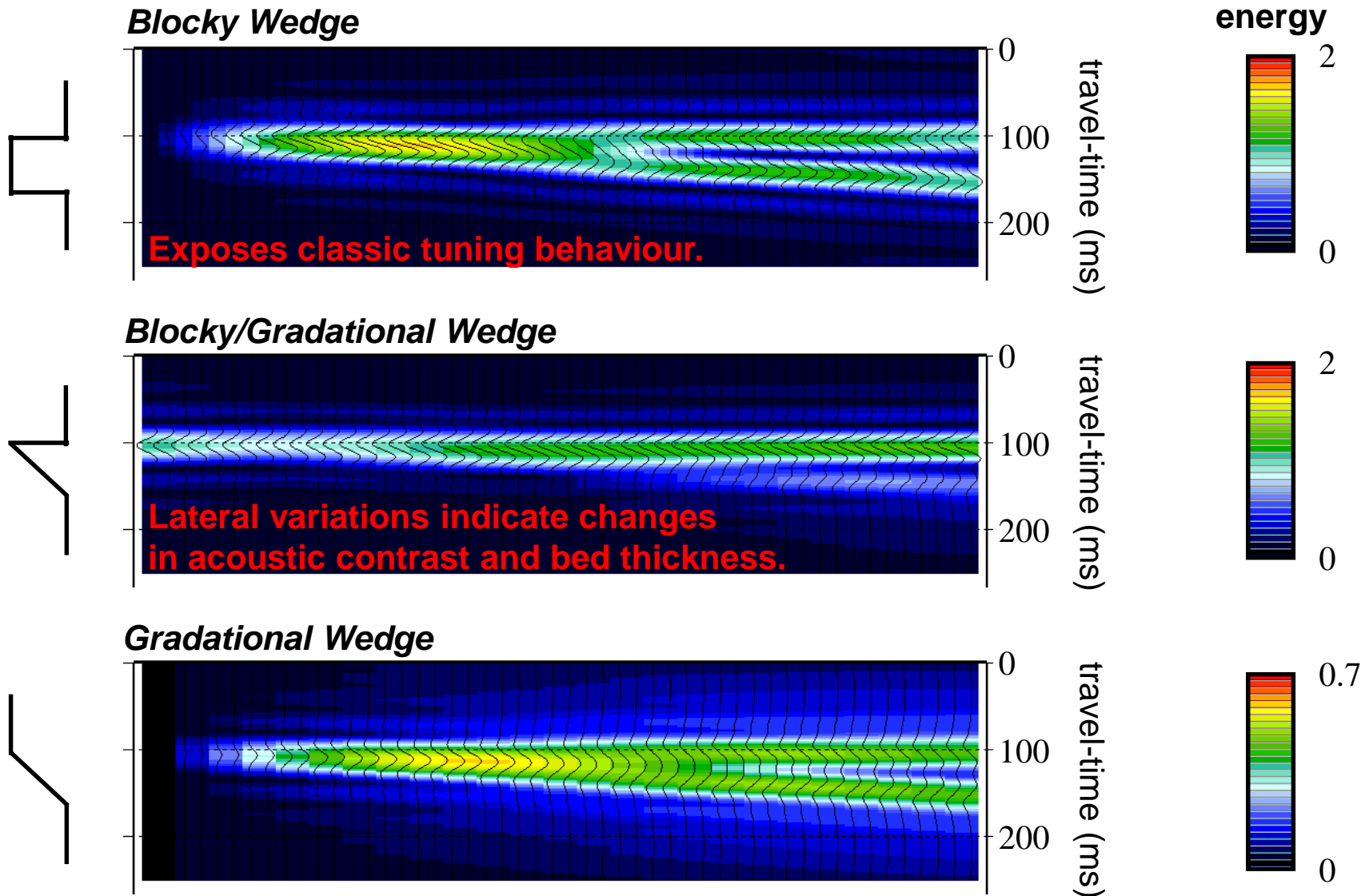


travel-time (ms)

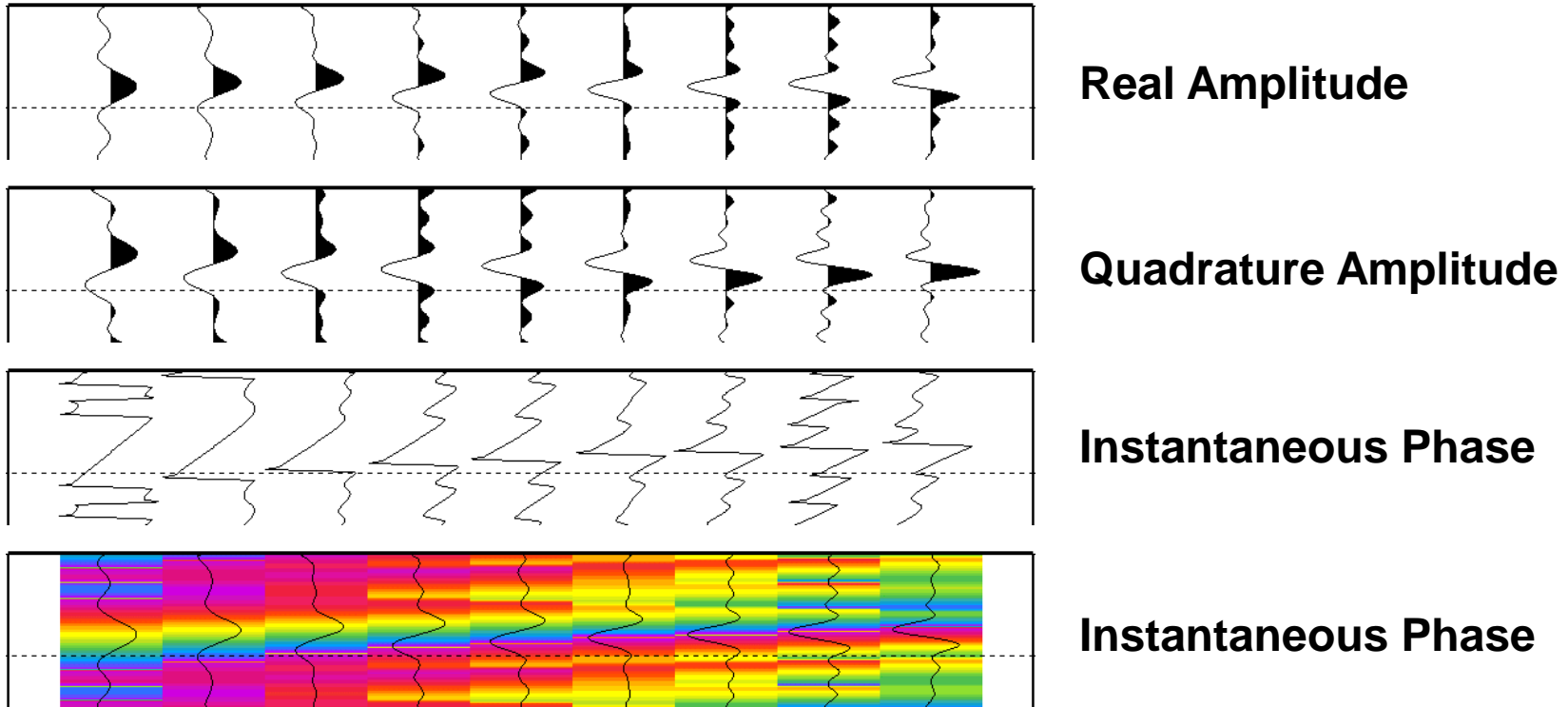
sensitive to:

- energy
- bandwidth

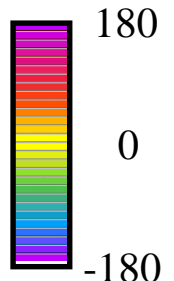
Reflection Strength



Instantaneous Phase

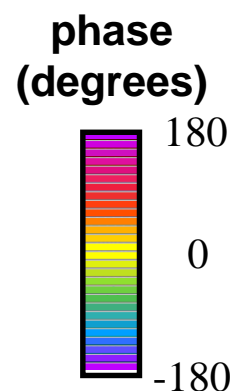
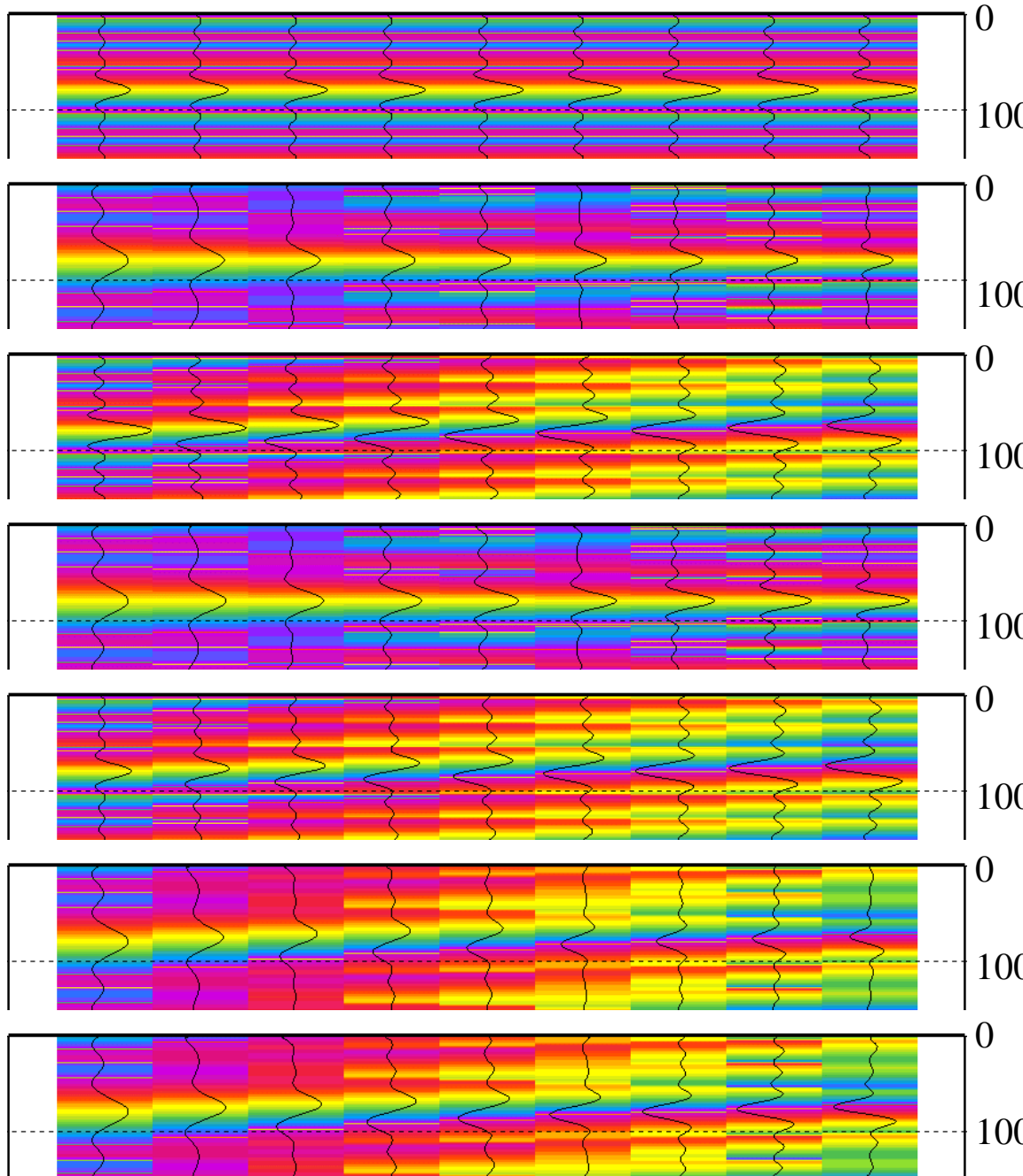


- Strong and weak events exhibit equal strength.
- Discontinuous at trough locations (± 180 degrees).
- Commonly displayed with a wrapped color bar.



Instantaneous Phase - Sensitivity

energy
bandwidth
phase

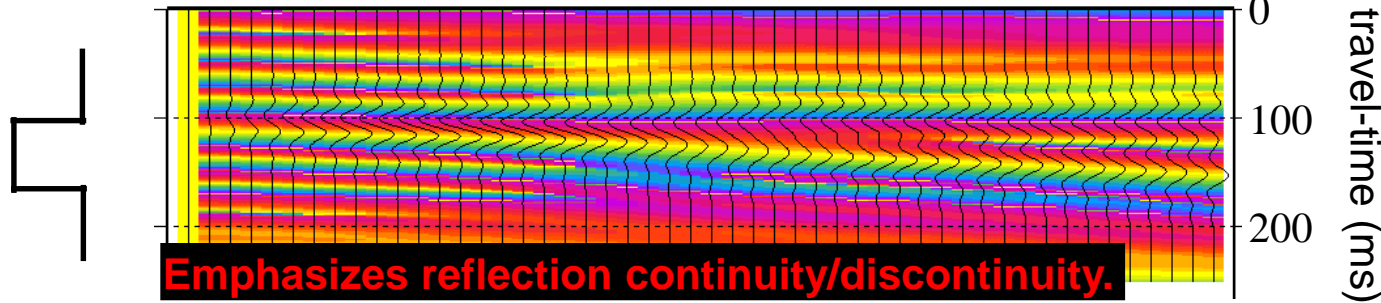


sensitive to:

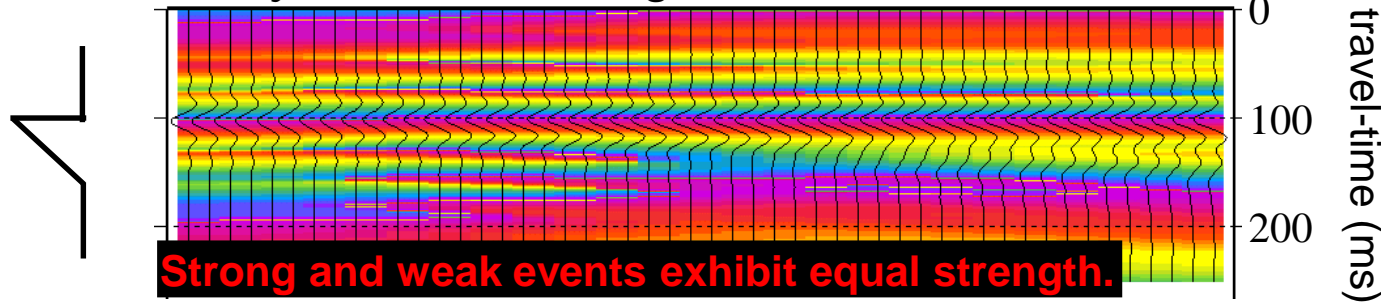
- bandwidth
- phase

Instantaneous Phase

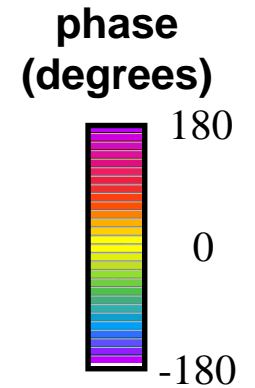
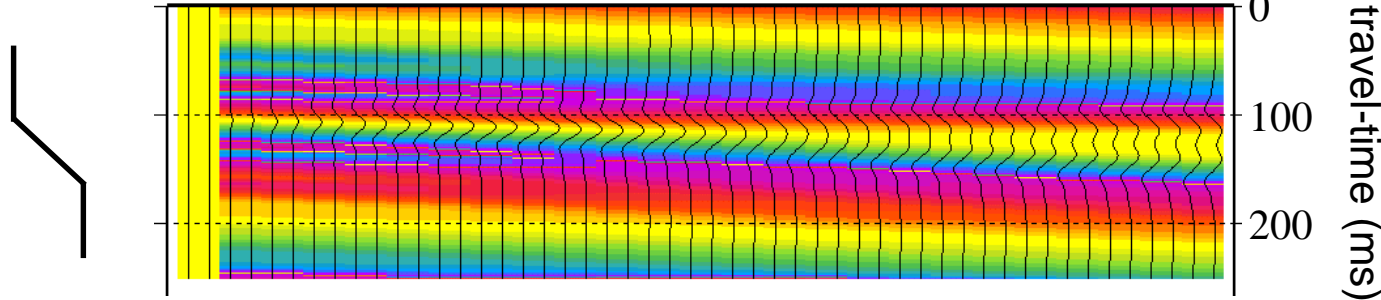
Blocky Wedge



Blocky/Gradational Wedge

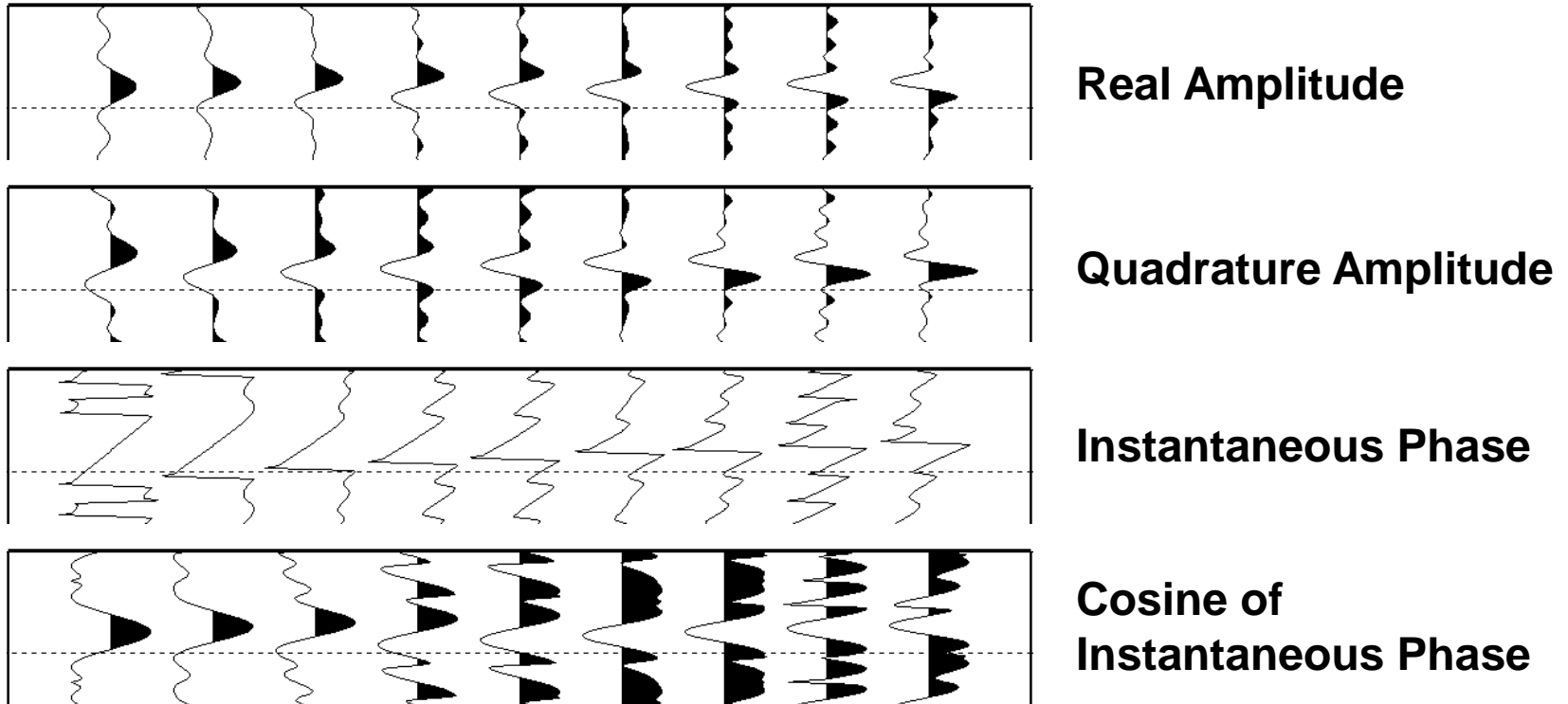


Gradational Wedge



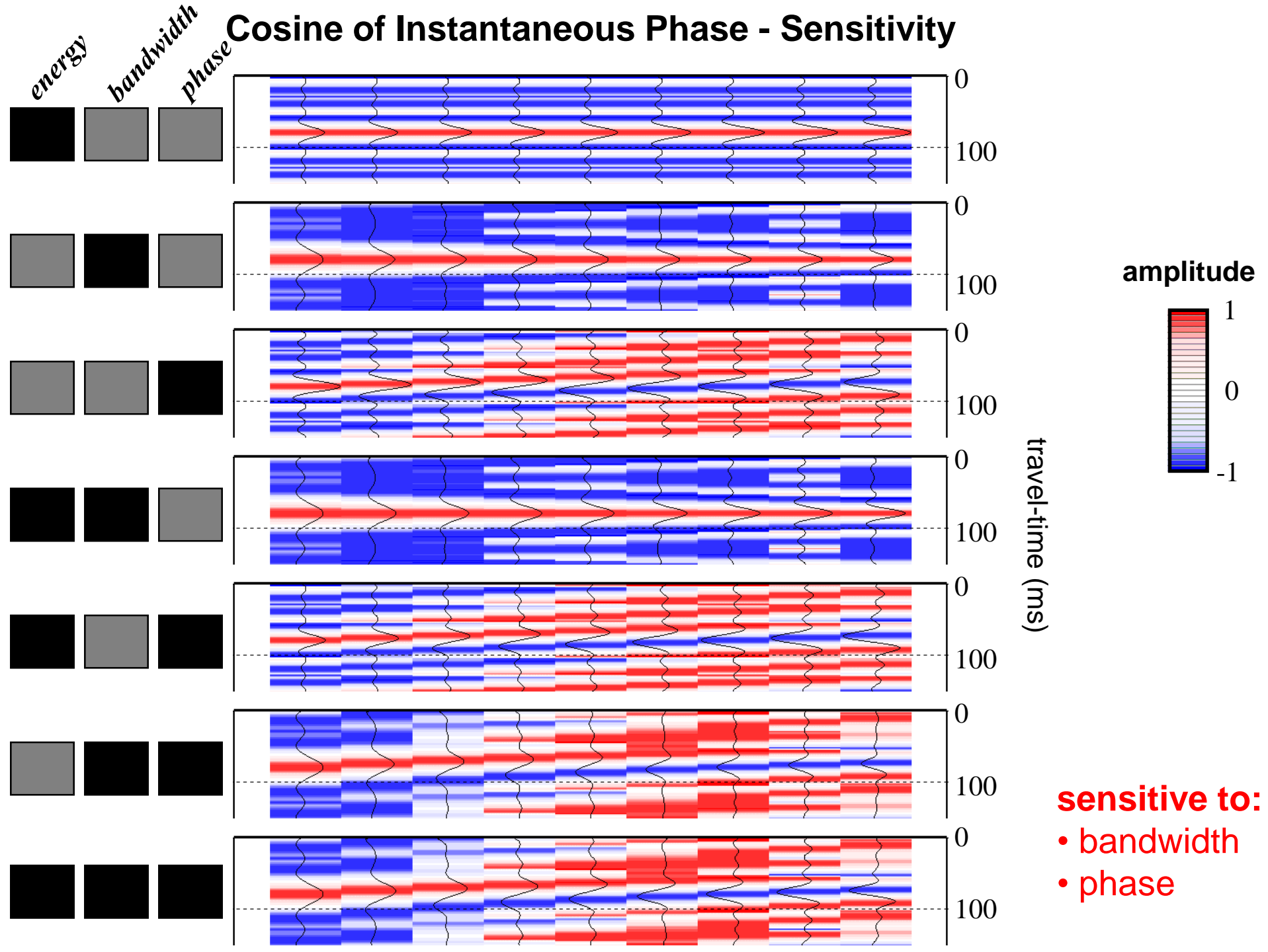
highlights:
 faults
 pinch-outs
 angularities
 onlap/offlap

Cosine of Instantaneous Phase

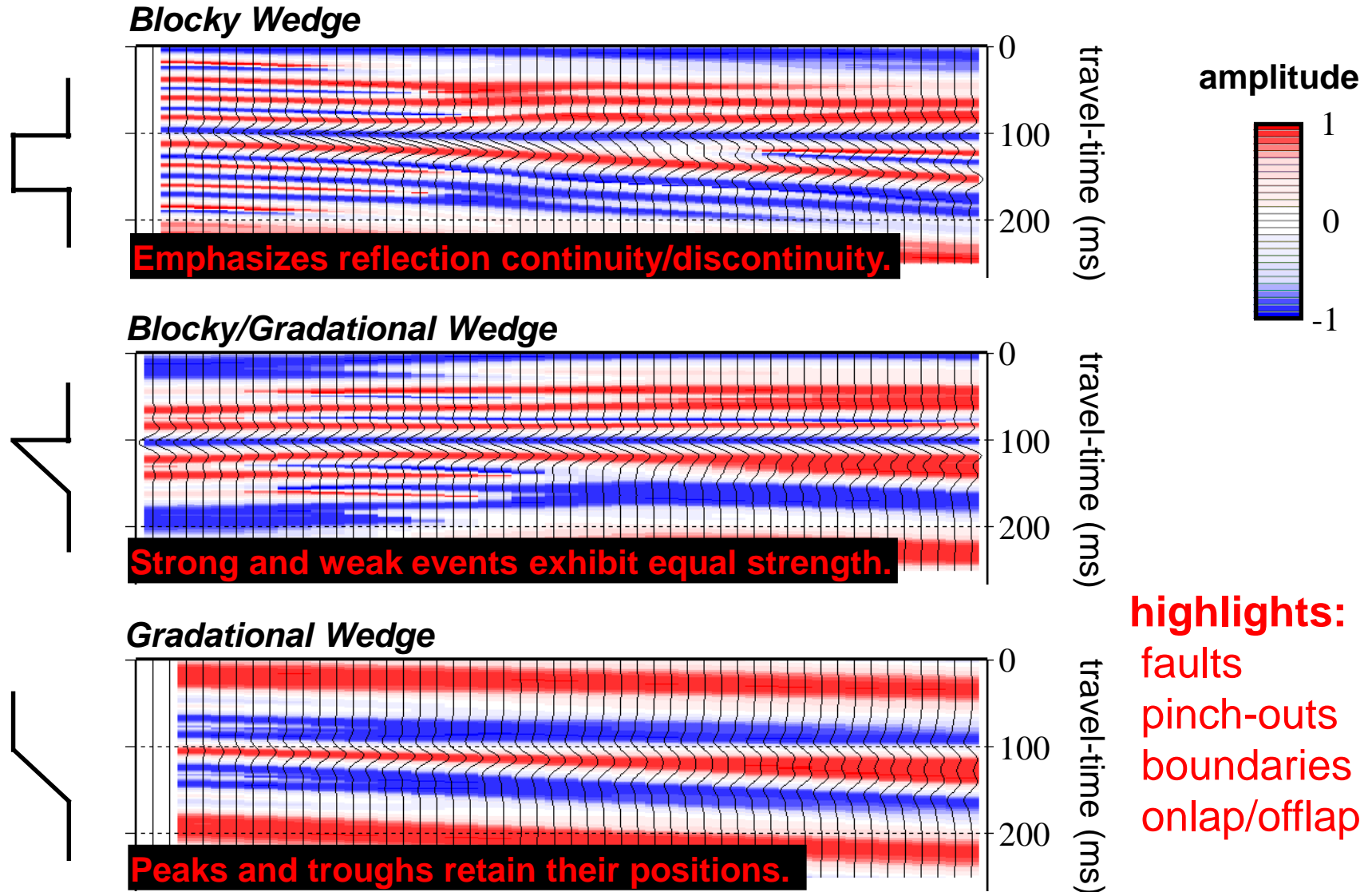


- Like instantaneous phase, but
- Avoids the +/-180 degree discontinuity that plagues phase.
- Can therefore be further processed.

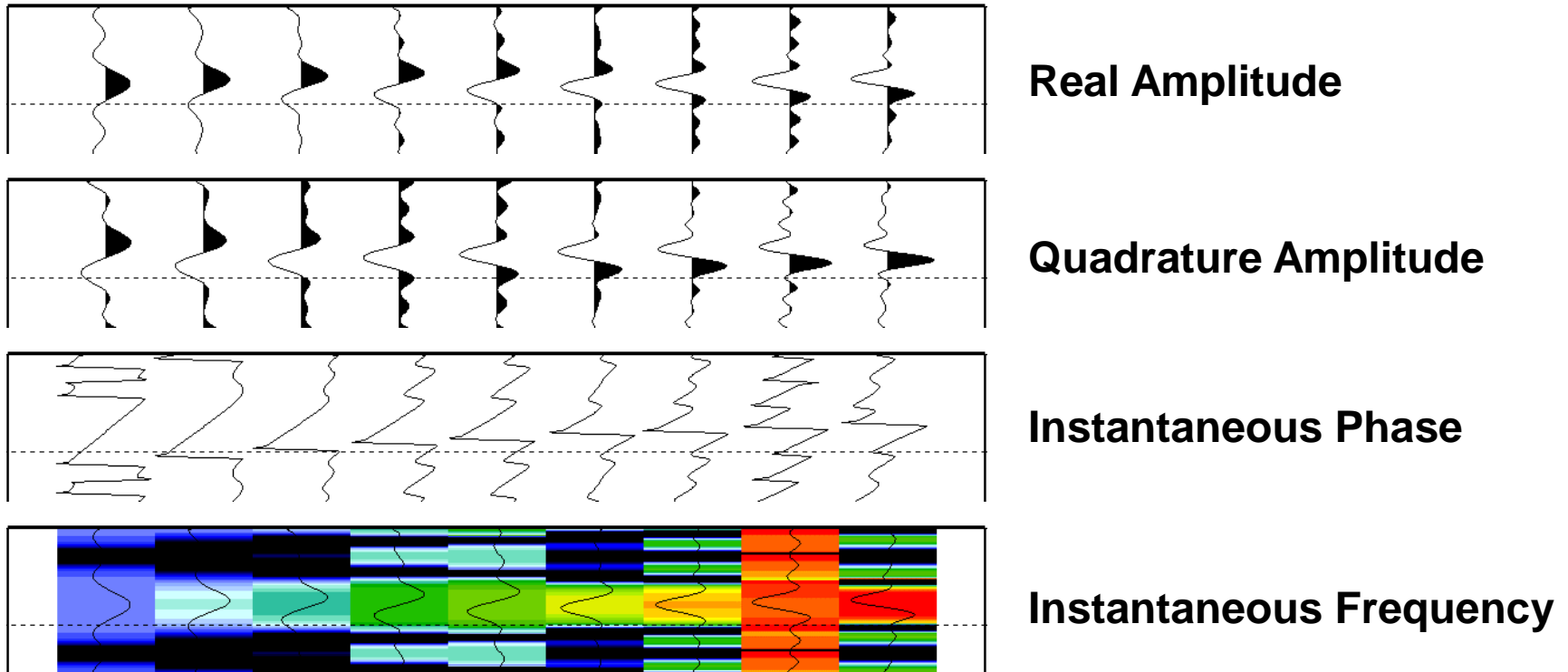
Cosine of Instantaneous Phase - Sensitivity



Cosine of Instantaneous Phase

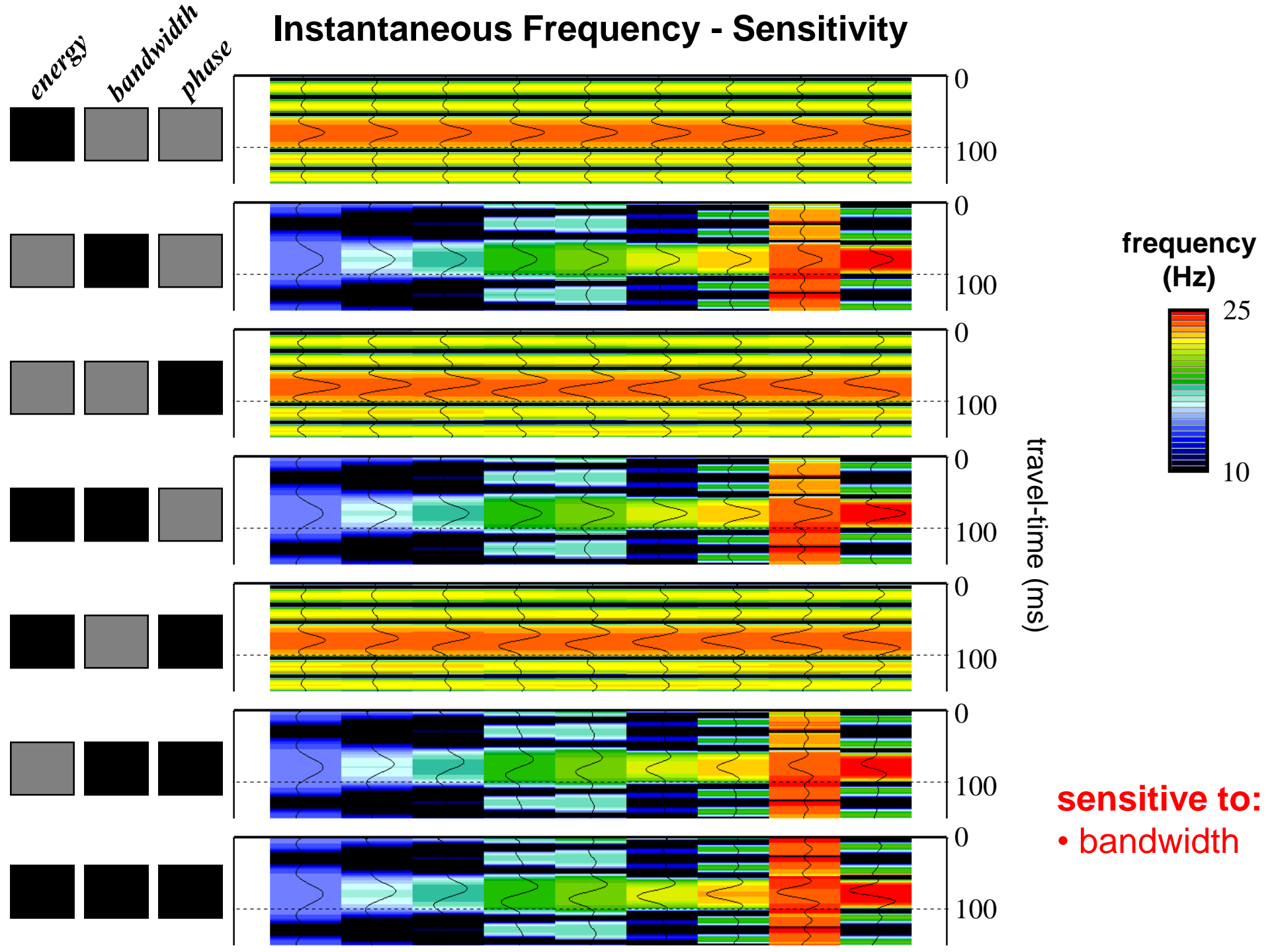


Instantaneous Frequency



- Rate of change of instantaneous phase.
- A measure of time-dependent mean frequency.

Instantaneous Frequency - Sensitivity



Instantaneous Frequency

Evidenzia zone di interferenza (ma anche di rumore)

