

MODELLI DI SORGENTE COMPLESSA

Modelli cinematici

In essi viene **assegnato o determinato lo spostamento** sulla faglia. In base ad esso si determina la radiazione sismica.

E' un'approccio relativamente facile, occorre sapere calcolare solamente le funzioni di Green in modelli della Terra più o meno complessi (1D, 2D, 3D).

Viene ampiamente usato nella interpretazione dei dati osservazionali.

Tra i modelli cinematici menzioneremo brevemente solamente il **modello di Haskell** per una faglia di tipo rettangolare (terremoti grandi) e quello di **Madariaga** per una faglia di tipo circolare (terremoti medio-piccoli).

Modelli dinamici

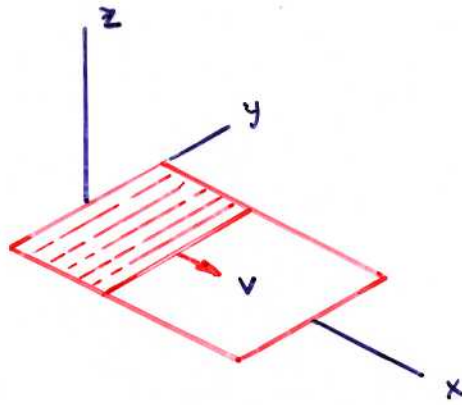
In essi vengono **assegnati o determinati gli sforzi** e la caduta di sforzi sulla faglia. In base ad essi si determina la radiazione sismica.

E' un problema complesso anche in 2D. Soluzioni analitiche esistono solo per fratture semiinfinite.

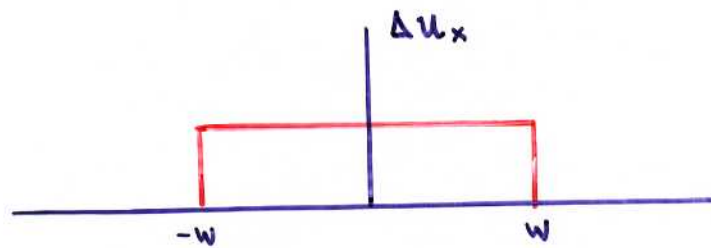
Per risolvere tali problemi si fa uso massiccio di modelistica al calcolatore con programmi agli elementi finiti, differenze finite, ecc.

Non vengono trattati in questo corso.

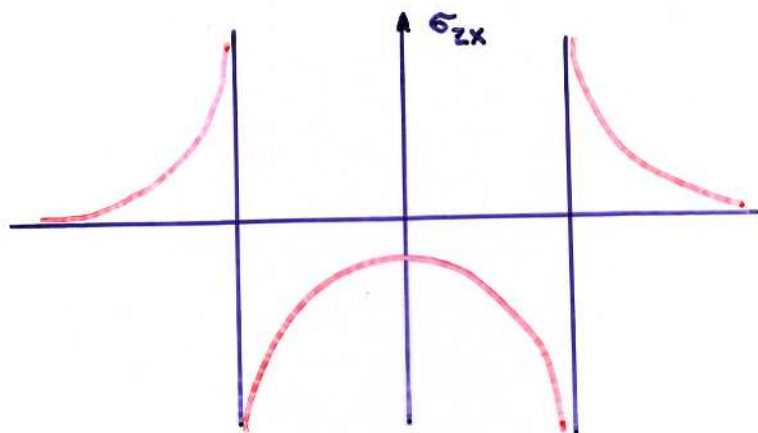
MODELLO DI HASKELL



$V = \text{VELOCITA' DEL FRONTE DI ROTTURA}$



SCORRIMENTO



SFORZI

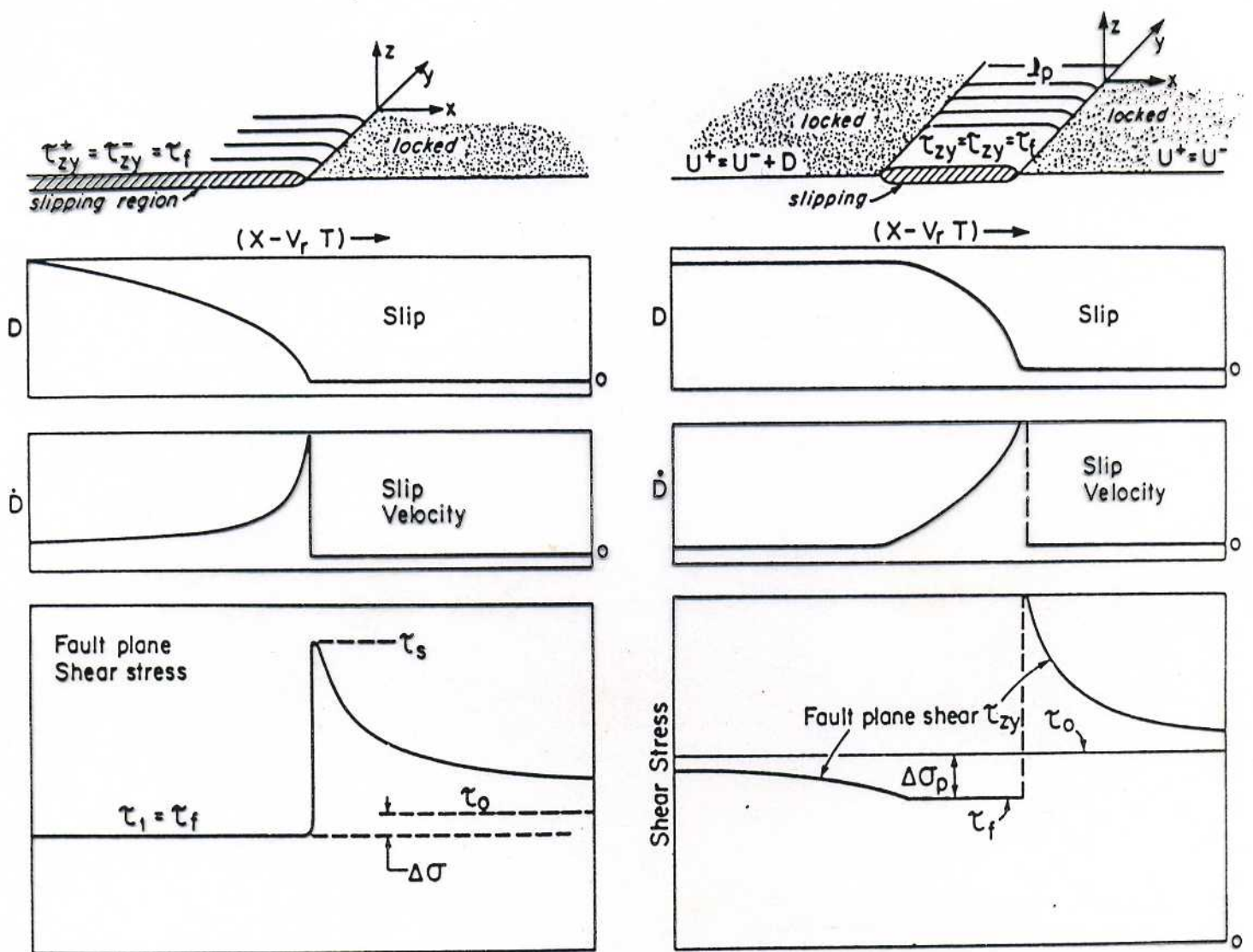
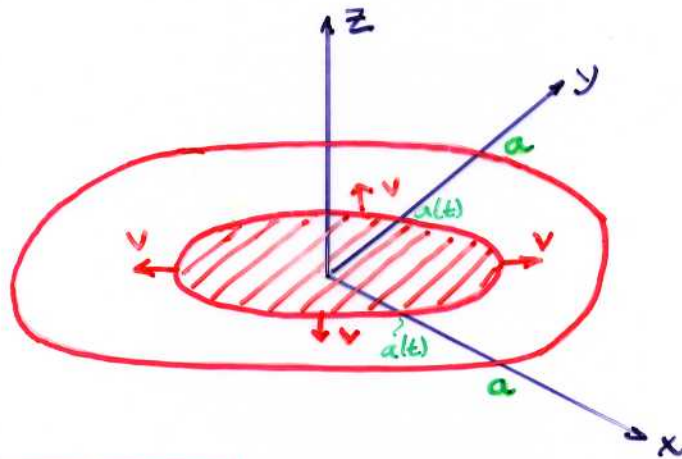


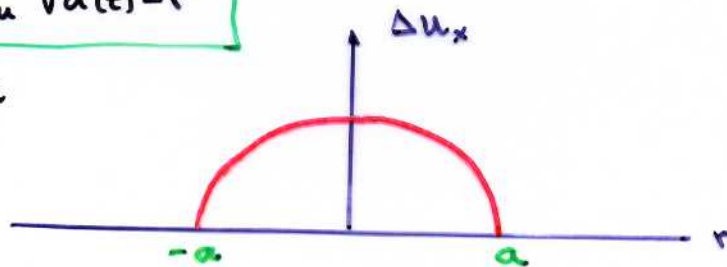
FIGURE 9.4 Two idealized models of rupture. On the left is the crack model of Kostrov (1966) for a crack propagating at rupture velocity v_r in the x direction. Fracture initiates when the stress at the crack tip exceeds the static strength of the fault, τ_s , and the stress on the slipping fault is a constant frictional level, τ_f . The ambient stress before rupture is τ_0 , and the stress drop, $\Delta\sigma$, is $\tau_0 - \tau_f$. Every point on the rupture surface continues to slide until the rupture front stops and sends a "healing pulse" back across the fault. On the right is the self-healing slip pulse model of Heaton (1990) in which slip-velocity-dependent friction heals the rupture surface behind the slip pulse. The sliding friction is very low and returns to a high level after the rupture. The static stress drop, $\tau_0 - \tau_1$, may be very low (~ 10 bars), but the average stress drop within the rupture pulse may be an order of magnitude larger. (From Heaton, 1990.)

MODELLO DI FRATTURA CIRCOLARE MADARIAGA

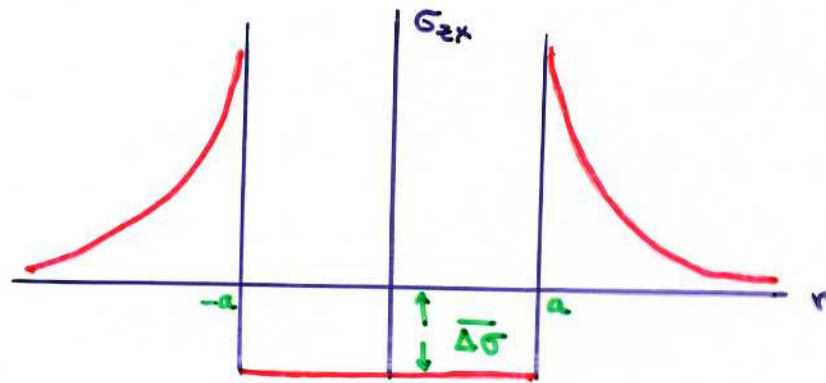


$$\Delta u_x(r, t) = C \frac{\Delta \sigma}{\mu} \sqrt{a^2(t) - r^2}$$

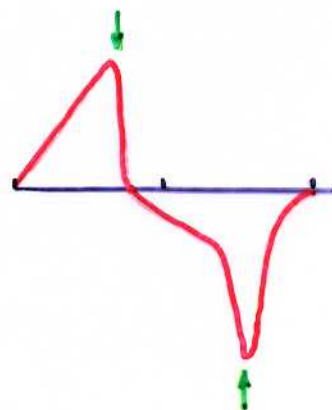
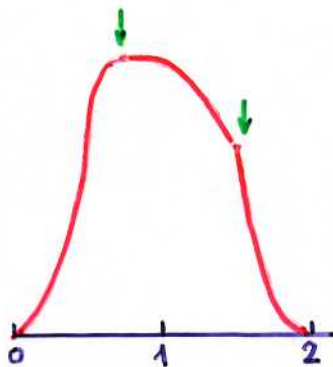
$$\bar{u} = 0.728 \frac{\Delta \sigma}{\mu} a$$



SCORRIMENTO



SFORZI



SPOSTAMENTO
E
VELOCITA'
ONDE P

FASI DI ARRESTO!

I modelli finora discussi non riescono a spiegare le osservazioni neanche nel campo lontano nel caso di grossi eventi ($M \sim 8$) e frequente base.

Tantomeno riescono a spiegare la grande complessità osservata nei segnali ad alta frequenza (broadband, accelerogrammi) ottenuti vicino alla sorgente.

La complessità di tali segnali è pertanto da associare alle condizioni di eterogeneità della crosta (lungo la faglia).

La rottura della faglia non è liscia ed uniforme, ma variabile ed eterogenea nello spazio.

Portioni di faglia che erano sottoposti a grandi sforzi prima del terremoto possono produrre grossi impulsi di radiazione, mentre altre parti della faglia offrono una resistenza molto grande in modo da fermare la rottura.

Pertanto alla fine degli anni '70 vennero proposti i seguenti modelli per spiegare la complessità osservata.

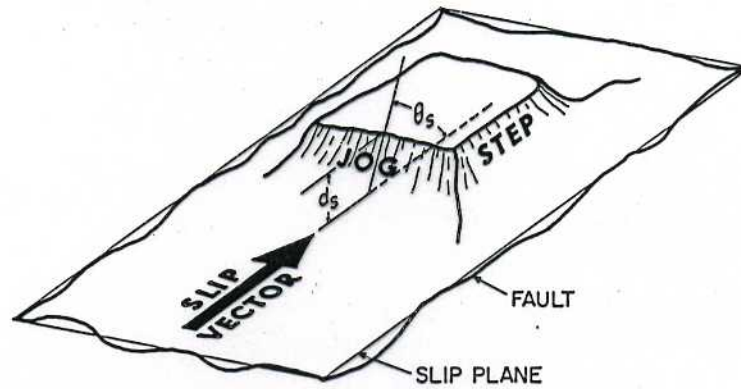


Fig. 3.28 Schematic diagram illustrating the definition of jogs and steps.

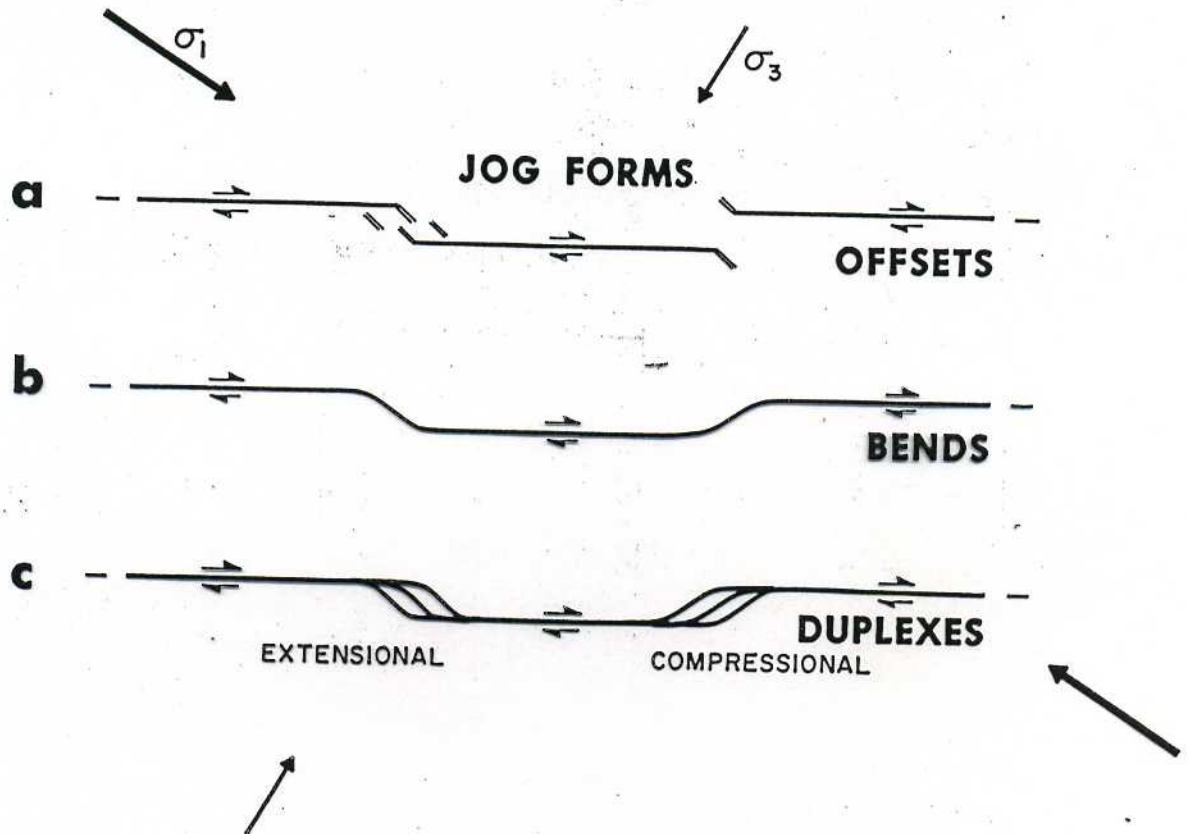


Fig. 3.29 Schematic diagram illustrating different types of stepover structures.

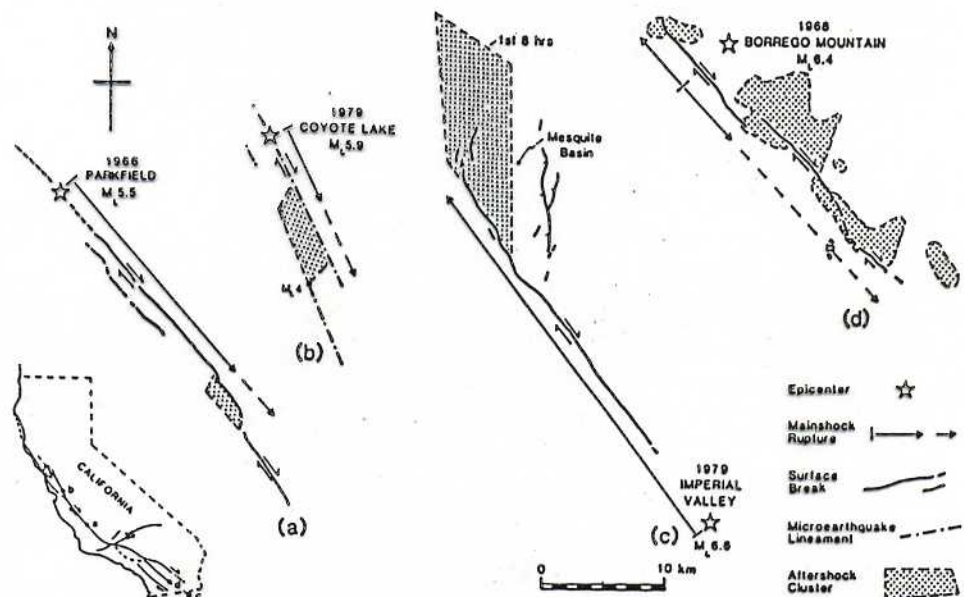


Fig. 3.33 Sketches showing ruptures terminated at jogs in the San Andreas fault zone: (a) Parkfield, 1966; (b) Coyote Lake, 1979; (c) Imperial Valley, 1979; (d) Borrego Mtn., 1968. (From Sibson, 1986c.)

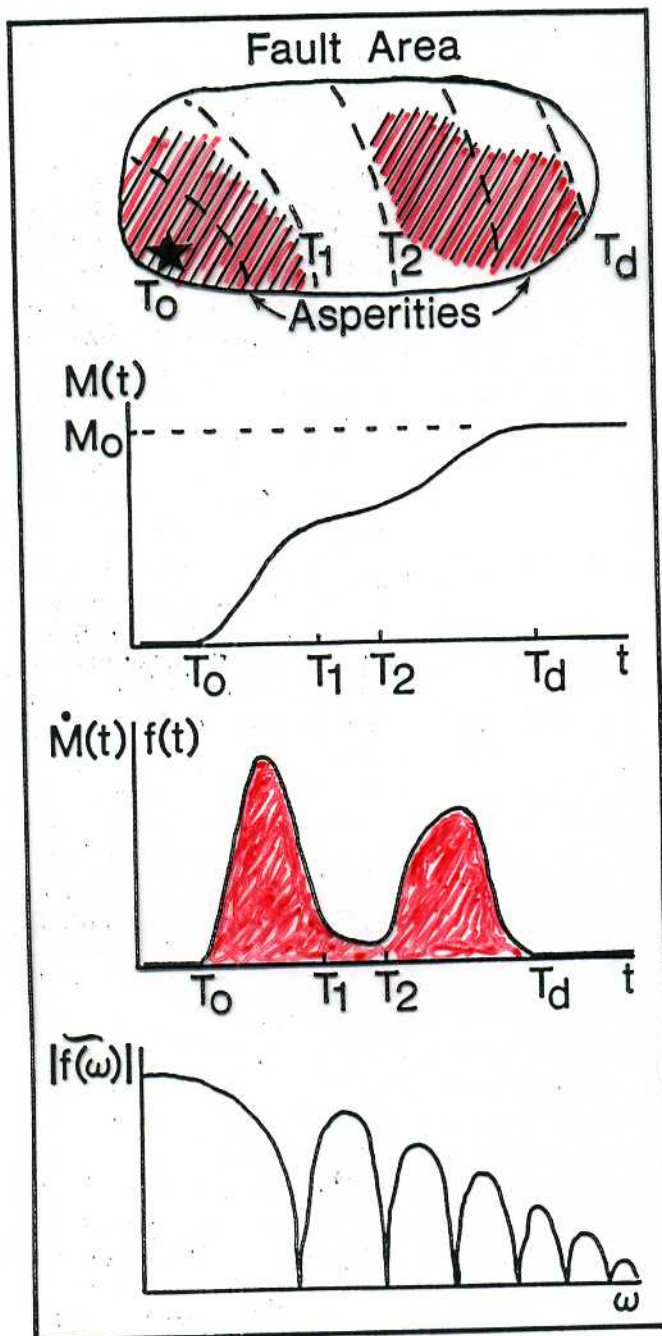


FIGURE 5. Seismic moment release and source time function. "Fault Area" shows a hypothetical rupture history where the rupture front starts at the hypocenter (star) and sweeps across the fault area. The dashed lines show the rupture front at various times. The fault area is heterogeneous, i.e. there are two regions of higher moment release: asperities. In the plot of $M(t)$, the seismic moment accumulates to reach the final value, M_0 , at time T_d . Teleseismic waves are generated by the moment rate function, also referred to as the source time function: $f(t) = \dot{M}(t)$. The integral of the source time function over source duration then returns the overall seismic moment. Note that the two asperities result in a "double-event" time function. Since $f(t)$ is a one-sided function, the spectral amplitude of $\hat{f}(\omega)$, the Fourier transform of $f(t)$, achieves the maximum value at zero frequency. The first spectral zero is related to time function duration, and the high frequency decay asymptote is controlled by the details of moment release.

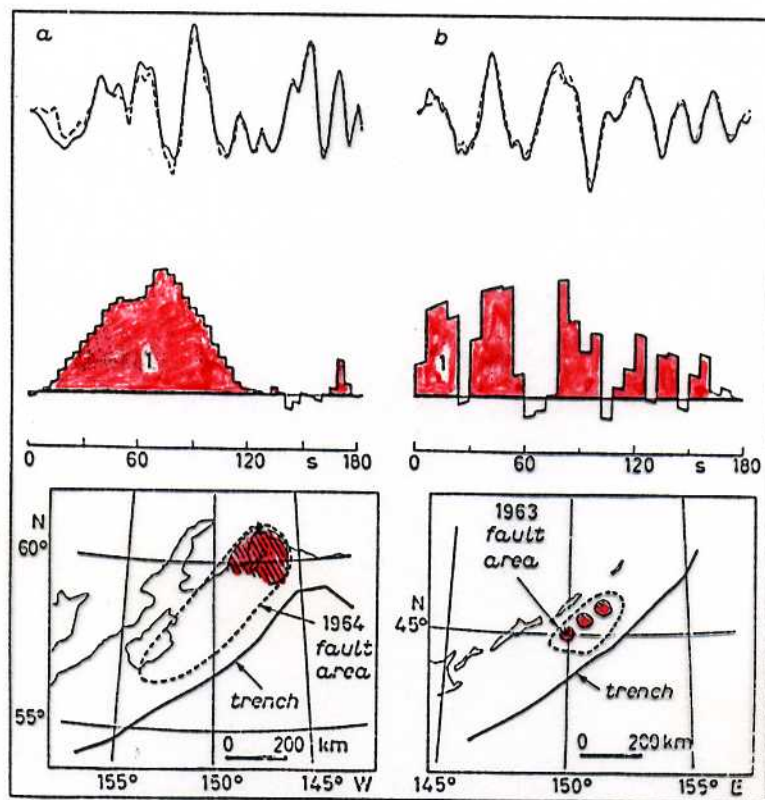


FIGURE 11.31 The source time functions for the 1964 Alaska and 1963 Kuril Islands earthquakes. Note the variation in temporal moment release, which is interpreted in terms of different fault zone stress heterogeneity, or asperities. (From Ruff, 1983.)

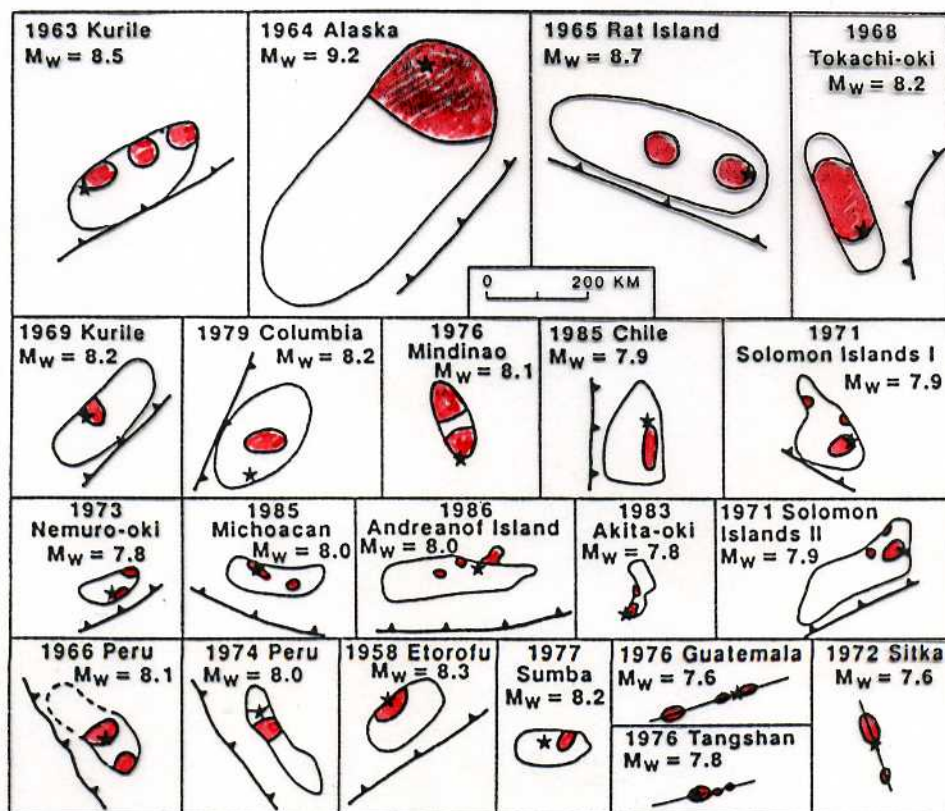


FIGURE 11.32 Schematic map-view summaries of aftershock zones (solid lines) and regions of high seismic moment release (stippled regions) inferred from seismic-wave analysis for 21 major earthquakes. Subduction zone events are shown with the nearby trench axis. (From Thatcher, *J. Geophys. Res.* **95**, 2609–2623, 1990; © copyright by the American Geophysical Union.)



POICHÉ LA RADIAZIONE DELLE ONDE SISMICHE È CONTROLLATA DALLA VELOCITÀ DI SCORRIMENTO ED ESSA RISULTA MASSIMA AI BORDI DELLA ROTTURA È IL

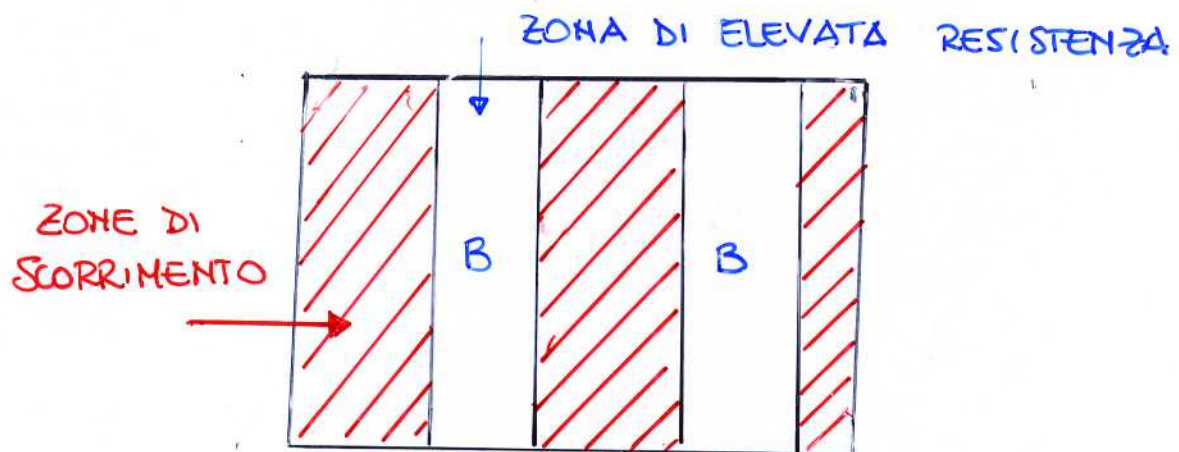
FRONTE DELLA ROTTURA A PRODURRE RADIAZIONI AD ALTA FREQUENZA

IL RESTO DELLA FAGLIA IRRADIA LE FREQUENZE BASSE.

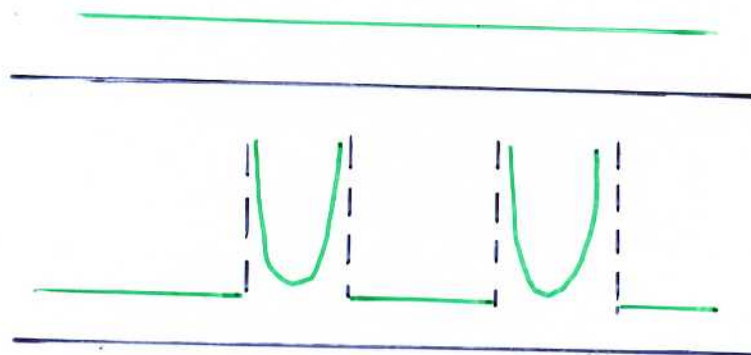
MODELLO A BARRIERE (DAS e AKI, 1977)

LA FAGLIA E' CARATTERIZZATA DA SFORZI UNIFORMI LUNGO LA SUA INTERA ESTENSIONE, I VALORI DI SFORZO CRITICO (σ_y) RISULTANO ESTREMAMENTE VARIABILI.

LE REGIONI AD ALTA RESISTENZA COSTITUISCONO BARRIERE (B) CHE IMPEDISCONO LA PROPAGAZIONE DELLA ROTTURA.



SFORZI
PRIMA DEL
TERREMOTO



DISTRIBUZIONE
DEGLI SFORZI
DOPO IL TERRE-
MOTO: LA FAGLIA
E' INTERESSATA
DA UNA DISTRIBUZIONE DI SFORZI
ETEROGENEA

SCORRIMENTO
SUL
PANO DI FAGLIA

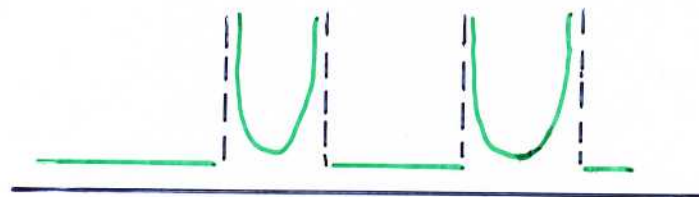
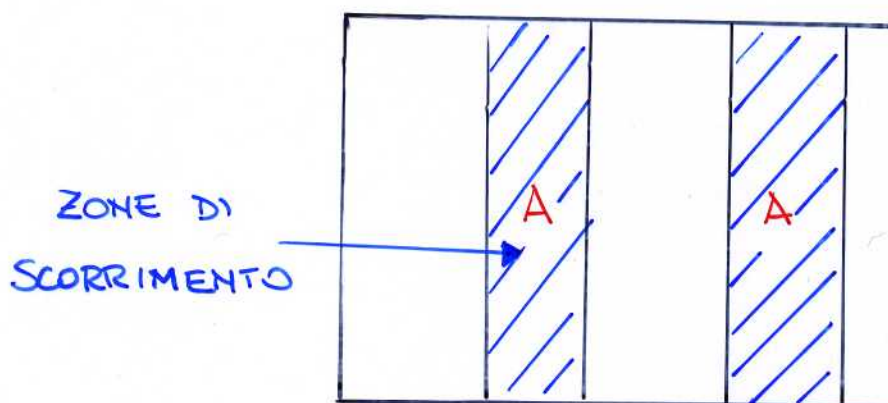


MODELLO AD ASPERITA' (KANAMORI e STEWART, 1978)

PROPONE UNO STATO DI SFORZI ESTREMAMENTE
VARIABILE SULL' INTERA AREA DI FAGLIA.

LE ZONE SOTTOPOSTE A SFORZO ELEVATO SONO
LE ASPERITA' CHE, ROMPENDOSI, DANNO LUOGO
AD UN TERREMOTO COMPLESSO.

ALLA FINE DELLA ROTTURA GLI SFORZI SUL
PIANO DI FAGLIA SONO OMOGENEI

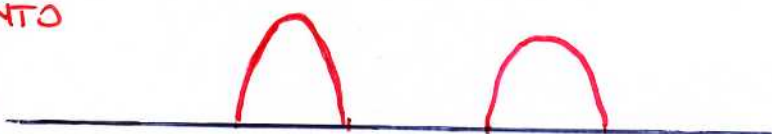


SFORZI
PRIMA DELLA
ROTTURA

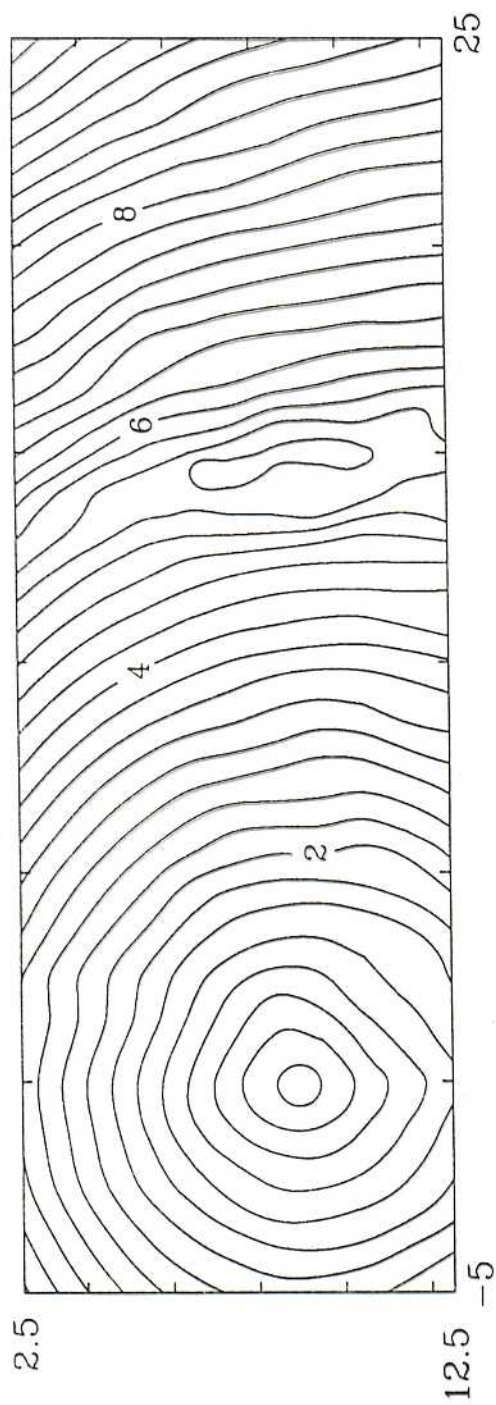


SFORZI
DOPO LA
ROTTURA

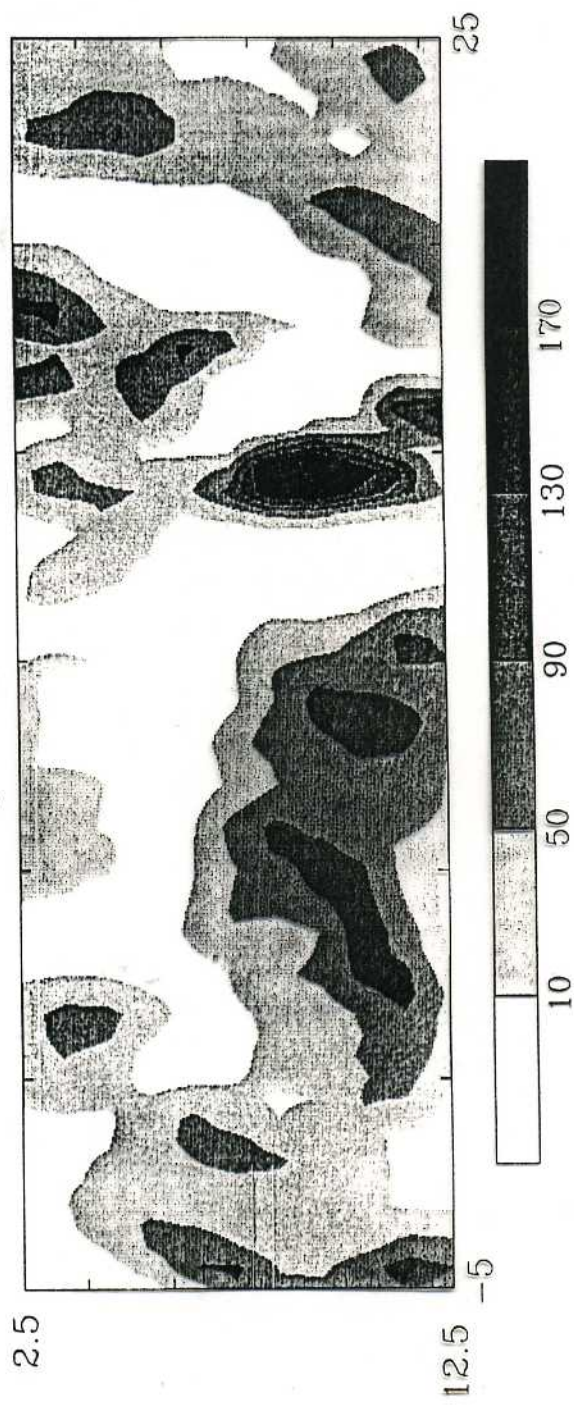
SCORRIMENTO
SUL PIANO
DI FAGLIA



Rupture Time (seconds)



Slip Amplitude (cm)



1979 IMPERIAL VALLEY

DISLOCATION CONTOURS

(Hartzell & Heaton, 1983)

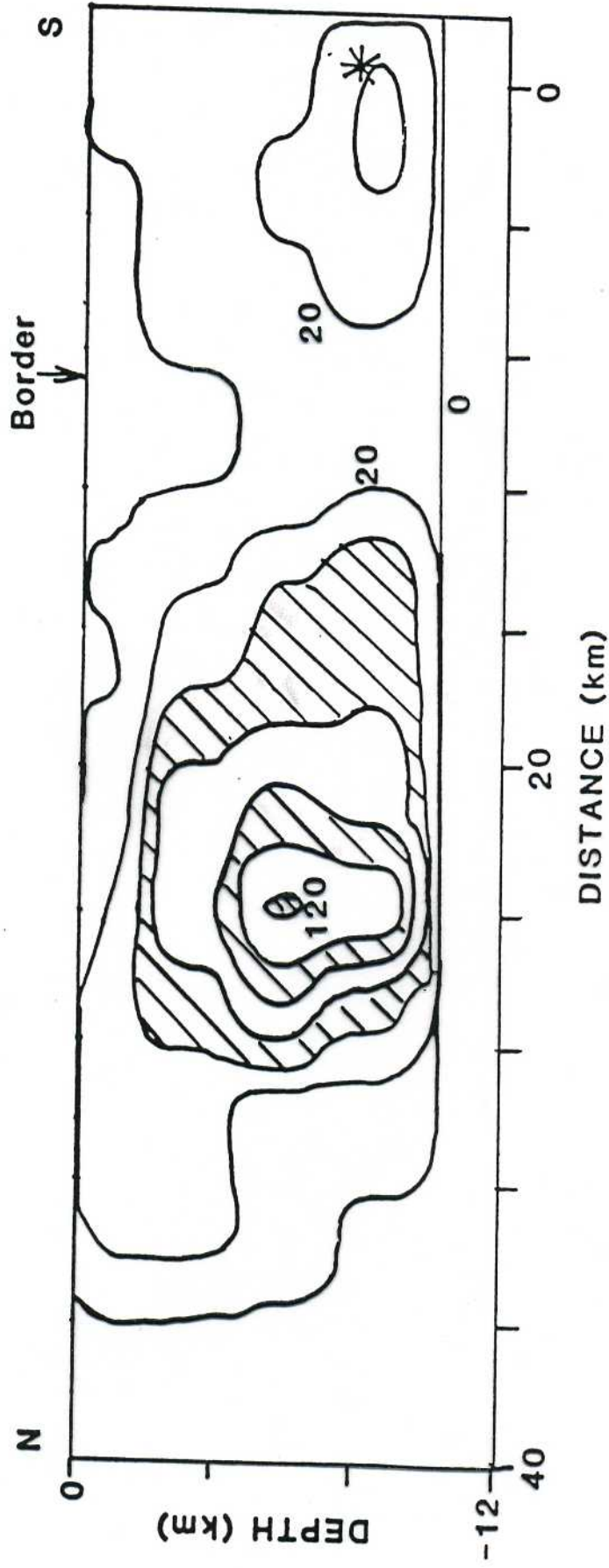
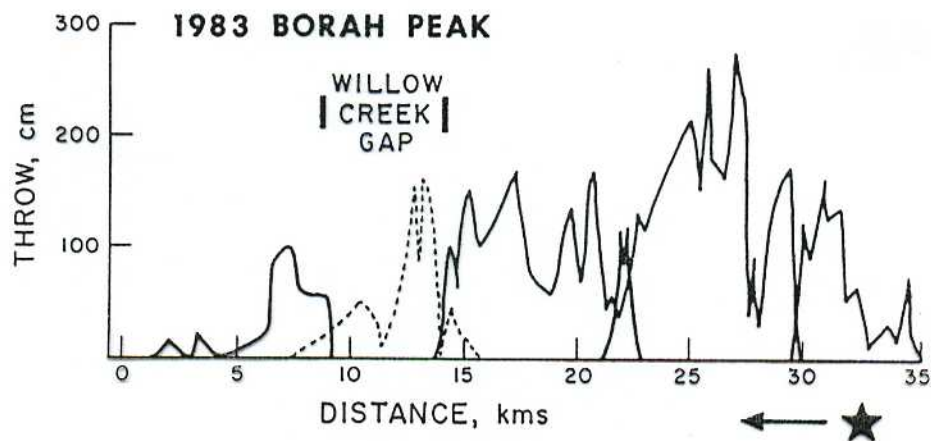
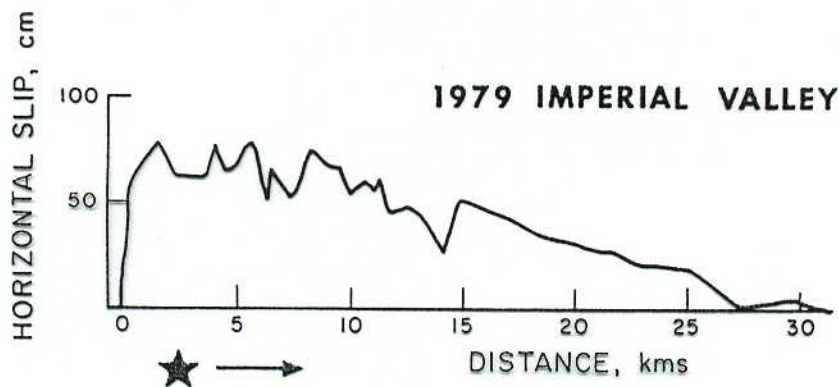


Figure 8. Slip distribution (cm) for 1979 Imperial Valley earthquake. Hypocenter shown by star. After Hartzell and Heaton, 1983.



a



b

Fig. 3.35 The distribution along strike of surface slip in two earthquakes of similar fault length. (a) Borah Peak, Idaho, 1983: normal faulting. Data from Crone and Machette (1984), dashed is slip on a secondary fault. (b) Imperial Valley, California, 1979: strike-slip faulting. Data from Sharp et al. (1982).