Appendix 1. Glossary for Earthquake and Engineering Seismology

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The following glossary includes over 700 specialized terms (including some abbreviations and acronyms) that the readers may encounter in reading the literature in earthquake and engineering seismology. For each term, a brief definition is provided with citation to the originated paper if known. If it involves terms that are in this glossary, they are shown in *italic* at the first appearance. Further readings are also provided at the end of each term.

This glossary was prepared from glossary terms submitted by many of the Handbook chapter authors and from consultation of some standard reference sources, including Aki and Richards (2002), Ben-Menahem and Singh (1981), Clark (1966), EERI (1988), Hancock and Skinner (2000), Jackson (1997), James and James (1976), Lee and Stewart (1981), Meyers (2002), Richter (1958), Runcorn (1967), and Yeats *et al.* (1997).

A

A-type earthquake: Seismic *events* with clear *P-waves* and *S-waves* occurring beneath volcanoes. They are indistinguishable from normal shallow tectonic earthquakes. In the original definition by Minakami (1961), it was contrasted to the *B-type earthquake* attributed to an extremely shallow focal depth. In recent years the contrast has been attributed to the source process, and it is more often called volcano-tectonic (VT), or high-frequency (HF) earthquake. *See* Chapter 25.

acausal signal: Output signal that exists also for times prior to the application of an impulsive input. See Chapter 22.

acceleration: The rate of increase of particle velocity per unit time.

accelerogram: A record, or time history, of *acceleration* , produced by an *accelerograph.*

accelerograph: A *seismograph* designed to record *acceleration* on scale during the strong ground shaking caused by large earthquakes. Incorporating analog or digital recording, it begins recording when the motion exceeds a certain specified trigger level.

accelerometer: An *acceleration* sensor, or transducer, which converts acceleration to an electronic signal, typically voltage, proportional to the acceleration. In early analog *accelerographs*, the accelerometer converts acceleration to movement of light beam.

Accelerometers may be within an *accelerograph*, but for studies of structural systems they are typically located remotely and cabled to a central recorder. *See* Chapter 57.

acceptable risk: The probability associated with a social or economic consequence of an earthquake that is low enough (in comparison with other risks) to be judged acceptable by appropriate authorities. It is often used to represent a realistic basis for determining design requirements for engineered structures, or for taking certain social or economic actions. *See* Chapter 75.

acoustic emission: A term in rock mechanics indicating seismic radiation from dynamic formation of a *microcrack*. *See* Chapter 32, p. 509.

acoustic waves: See *air waves*.

active faults: Fault that has moved in historic (e.g., past 10,000 years) or recent geological time (e.g., past 500,000 years). Although faults that move in earthquakes today are "active", not all active faults generate earthquakes -- some are capable of moving aseismically (see *silent earthquake*, and *slow earthquake)*. More precise attempts (usually disastrous) have been made to define "active" faults for legal or regulatory purposes. *See* Chapter 31, and Yeats *et al.* (1997, p. 449).

ADC: An acronym for a*nalog to digital converter*.

adopting: A term in hazard mitigation referring to the initial commitment of resources in taking necessary precautions. *See* Chapter 75.

aelotropy: A term proposed by Kelvin (1904) for a*nisotropy*. See Chapter 53 (p. 875).

aftershock: A small earthquake occurring shortly after a larger earthquake in roughly the same location**.** The sequence of such earthquakes following a large one generally shows a regular decrease in the rate of occurrence, first discovered by Omori (1894), indicating a settling-down process as the rocks accommodate to their new post-earthquake position. *See* Chapter 43.

AGSO: An acronym for the Australian Geological Survey Organization

air waves: Audible sounds are sometimes generated by earthquakes; a local earthquake may sound like distant thunder. Instrumental measurements show that these sounds arrive simultaneously with the first *P*-waves. Long-period (minutes to hours) acoustic-gravity waves are also excited by great earthquakes, as well as by volcanic explosions, meteorite falls, and nuclear blasts in the atmosphere. See Ben-Menahem and Singh (1981, p. 773-775; 796-806).

air-coupled surface waves: Despite the great density contrast between air and ground, atmospheric pressure disturbances traveling over the Earth's surface can amplify *surface waves* if the *phase velocity* is equal to the acoustic velocity in the air. Such a coupling with air has been observed for *flexural waves* in ice sheets floating on the ocean and for *Rayleigh waves* in ground with low-velocity surface layers. A simultaneous arrival of *air waves* and tidal disturbances was observed after the famous explosion of the volcano Krakatoa in 1883.

Airy phase: Portions of dispersed wave trains associated with the maxima or minima of the *group velocity* as a function of *frequency*. Airy function can be used for an approximate calculation of the waveform. Examples are continental *Rayleigh waves* at periods around 15 seconds, *mantle Rayleigh waves* at periods of 200 to 250 seconds, and *surface waves* of period of the order of 10 seconds which travels across an ocean at a velocity near 1 km/sec. *See* Chapter 21 (p. 345), and Aki and Richards (2002, p. 256).

aleatory uncertainty: The variability in *seismic hazard analysis* due to random effects such as measurement error. Aleatory uncertainties cannot be reduced by refining modeling or analytical techniques (c.f. *epistemic uncertainty*).

altitude of ambiguity: The topographic relief (or error) required to create one fringe in an interferogram. The height of ambiguity is expressed in units of meters. *See* Chapter 37.

amplitude response: The gain of a system as a function of *frequency*, or the modulus of the complex *frequency response* of a system. *See* Chapter 18.

analog-to-digital converter: An electronic device that converts a voltage produced by, for example an *accelerometer*, to digital values, at a rate of typically 100 times or more per second.

anisotropy: A medium is anisotropic if its physical properties depend on the direction. *See seismic anisotropy*.

annual probability of exceedance: The level of a specified probabilistic seismic hazard or seismic risk that can be equaled or surpassed with an exposure time of one year.

anthropogenic earthquake: An earthquake that is a byproducts of human activities. *See* Chapter 40.

apparent stress: A term in earthquake source physics defined as rigidity times the radiated seismic energy divided by the *seismic moment* . It corresponds to the seismic efficiency times the absolute level of *shear stress* working on the fault plane, and was introduced by Wyss and Brune (1968). See Chapter 35 (p. 583-584), and Aki and Richards (2002, p. 55).

apparent velocity: If T (in sec) and Δ (in km) denote the travel-times and epicentral distances for a seismic phase arriving at points of the Earth's surface, then the apparent velocity is defined as $d\Delta/dt$. The apparent velocity is the reciprocal of the seismic ray parameter or horizontal slowness.

aquifer: A permeable rock body sufficiently saturated with water to yield economical quantity of water. *See* Chapter 39.

Arias Intensity: A broad band measure of the strength of a strong motion *accelerogram*, defined by the integral over all natural frequencies of the energy input to a damped *single degree of freedom* oscillator in response to the accelerograms. In practice, it is computed by:

$A = \frac{\cos^{-1}\zeta}{\sqrt{1-\zeta^2}}\int_0^\infty a^2(t)\,dt$, in which ζ is the fraction of critical damping (viscous) and a(t) is the accelerogram. The coefficient of the integral is a weak function of the damping factor.

Arkhanes (Crete): A temple that collapsed in 1700 BC exactly while the sacrifice of a youth was ongoing. *See* Chapter 46.

Armageddon (Megiddo): The site of the retroactively prophesized battle of the apocalypse and the earthquake that will happen during this battle as described in the Book of Revelation and also the site of ancient Megiddo in northern Israel which has been subject to many historical battles and many earthquakes. *See* Chapter 46.

array beam: The combination of output from each element of an array (say by *delay and sum processing*) to enhance signals with a given apparent-surface-speed and azimuth of approach. By choosing the speed and azimuth expected for a *hypocenter* of the source, this process can enhance the beam of seismic waves coming from the particular source location. *See* Chapter 23.

arrival time: The time that a seismic wave (e.g., *P-wave*) first arrived as recorded by a *seismograph*. Arrival times from an earthquake are used for locating the earthquake's *origin time* and *hypocenter* (e.g., by the Geiger's method).

asthenosphere: The weak lower portion of the near-surface thermal boundary layer and underlying mantle which undergoes significant ductile deformation under long-term loads. *See* Chapter 51.

asymptotic ray theory: The mathematical theory used to describe *high-frequency* seismic *rays*. The ray ansatz is constructed as a series in inverse powers of *frequency* in the frequency domain, or integrals of the source impulse in the time domain, with amplitude coefficients and travel time only functions of position along the ray. *See* Chapter 9.

attenuation relationship: A mathematical expression that relates a *ground motion parameter*, such as the peak ground acceleration, to the source and propagation path parameters of an earthquake such as the *magnitude*, source-to-site distance, fault type, etc. Its coefficients are usually derived from the analysis of earthquake records. *See* Chapter 60.

average annualized loss (AAL): The average economic loss expected per year for a specific property, portfolio of properties, or region as a result of one or more damaging earthquakes.

azimuth: In seismology, the horizontal angular distance from a fixed reference direction to a given position on the Earth's surface. It is usually measured in degrees with respective to north and is positive in the clockwise direction. In radar terminology, the along-track component of the vector between the ground and the satellite. The azimuth direction is parallel to the trajectory of the satellite. *See* Chapter 37.

azimuthal anisotropy: A term used when the seismic wave properties depend on the *azimuth* of propagation in the horizontal plane. For example, transversely isotropic structures of *hexagonal symmetry* with vertical axis do not exhibit azimuthal anisotropy. *See* Chapter 53.

B

B-type earthquake: Seismic events occurring under volcanoes with emergent onset of *P waves* , no distinct *S waves* , and a low-frequency content as compared with the usual tectonic earthquakes of the same magnitude. In the original definition by Minakami (1961) its character different from the *Type A earthquake* was attributed to the extremely shallow focal depth (< 1 km). More recently the difference has been attributed to the source process and now called more often long-period or low-frequency earthquakes. *See* Chapter 25.

***b* value**: A coefficient in the *frequency-magnitude relation* , log $N(M) = a - bM$, obtained by Gutenberg and Richter (1941; 1949), where M is the earthquake *magnitude* and $N(M)$ is the number of earthquakes with magnitude greater than M. Estimated b values for most seismic zones fall between 0.6 and 1.1. *See* Chapter 43 (p.723), and biographies of Beno Gutenberg and Charles Francis Richter in Chapter 89.

background seismicity: Seismicity that cannot be attributed to a specific fault or source zone in *seismic hazard analysis* .

band pass filter: *Filter* which removes low and high *frequency* portions of the input signal outside of the *passband*. *See* Chapter 22.

base moment: The moment, in the plane of response, experienced at the base of the structure during earthquake response or calculated during the earthquake resistant design process. The maximum base moment is an important response parameter, particularly for structural elements such as exterior columns at the lower levels of a building. Sometimes called "overturning moment". *See* Chapter 67.

base shear: The horizontal shearing force at the base of the structure. The maximum base shear, typically in the form of a fraction of the weight of the structure, is an important parameter in earthquake response studies and in earthquake resistant design. *See* Chapter 67.

base isolation: A technique to reduce the earthquake forces in a structure by the installation of horizontally flexible devices at the foundation level. Such devices greatly increase the lowest natural periods of the structure for horizontal motions and thereby lower the accelerations experienced by the structure. The most common applications of base isolation are to old historic buildings, hospitals and bridges. *See* Chapter 67.

baseline: In triangulation networks, the scalar distance between two bench marks which determines the scale of the network. In GPS, the same term has come to mean the vector difference in position between two bench marks. In INSAR, jargon for the (vector) separation or (scalar) distance between two orbital trajectories. *See* Chapter 37.

base-line correction: A term in analysis of strong motion records. It corrects a recorded signal for the bias in zero-acceleration value, and any long-period drift in the zero level that may arise from instrumental and environmental effects. *See* Chapter 58.

basin-induced surface waves: *Surface waves* generated at edges of a basin or at a strong lateral discontinuity inside the basin by incident *body (S or P) waves* . Their amplitude and waveforms depends on the basin structure along the ray path from the edge (or the discontinuity) to the site. If the site lies in the central part of a large sedimentary basin, the basin-induced surface waves appear much later than the direct and reverberated S-waves. The term "secondary surface waves" sometimes used for them is not appropriate since their amplitudes can be of the primary importance**.** *See* Chapter 61.

basin-transduced surface waves: *Surface waves* transduced at edges of a basin or at a strong lateral discontinuity inside the basin from incident surface waves. They are distinguished from *basin-induced surface waves* because of the difference in incident waves. We can observe these surface waves if the earthquake source is shallow and distant. At the edge of a basin we see refraction and mode conversion of both *Love* and *Rayleigh waves* and transformation among them. *See* Chapter 61.

bay: In a building structure, the horizontal distance between adjacent planar frames, walls or lines of columns. *See* Chapter 69.

Bayesian method: Any method accepting not only the interpretation of a probability as the limit of an experimental histogram, but also as the representation of subjective information. *See* Chapter 16, and biography of Thomas Bayes in Chapter 89.

BCIS: An acronym for the Bureau Central International de Seismologie. *See* Chapters 41, and 88.

Benioff zone: See *Subduction zone*.

block Toeplitz matrix: A matrix where all terms along each diagonal are the same. Given the entries in the leftmost column and the top row, a block Toeplitz matrix is fully specified. *See* Chapter 50.

body-wave magnitude (m_B and m_b): Earthquake *magnitude* calculated from amplitude/period ratios of *body waves* . m_B and m_b are based on data recorded by relatively long-period and short-period *seismographs*, respectively. The original body-wave magnitude introduced by B. Gutenberg (1945) is denoted by m_B. Body-wave magnitudes assigned by *USGS* and *ISC* are m_b (ISC uses the notation M_b). *See* Chapter 44.

body wave: Waves that propagate through an unbounded continuum are called body waves, as opposed to *surface waves*, which propagate along the boundary surface. *See* Chapter 21, and Aki and Richards (2002).

bog-burst: Large deposits of peat on a hillside can soak up rainfall like a sponge. If they soak up very large amounts of water, the weight of the absorbed water can become too great for the strength of the bog holding it. In such a case, the peat deposit may suddenly lose its cohesion, releasing an avalanche of water, mud and organic material. This is known as a bog-burst. In early records, the word "earthquake" is often used to describe bog-bursts and landslides as well as genuine earthquakes. *See* Chapter 48.5.

borehole sensor: A sensor installed below the earth's surface in borehole. *See* Chapter 19.

Born approximation: A perturbation method that iteratively solves an inhomogeneous wave equation, where waves are decomposed into primary waves which satisfy the homogenous wave equation and scattered waves of small amplitude. *See* Chapter 13, and biography of Max Born in Chapter 89.

brittle: Unable to accommodate inelastic strain without loss of strength. *See* Chapter 32, p. 507.

broadband body-wave magnitude (mB): See *body-wave magnitude* **.** *See* Chapter 41.

broadband seismogram: *Seismograms* recorded by a *broadband seismograph* . *See* Chapter 23.

broadband seismograph: Traditionally two types of *seismographs* were used to record seismic signals with periods longer than about 10 seconds and those shorter than about 1 seconds separately to avoid the strong ambient noise caused by ocean waves (*microseisms*). A broadband seismograph can record faithfully seismic signals in the period range roughly from 0.1 to 100 seconds thanks to the improved linearity range of the *seismometer* and *dynamic range* of the recorder. *See* Chapter 18.

broadband seismometer: Seismic sensor used in a *broadband seismograph***.**

Byerlee's law: The common observation from laboratory friction experiments that the coefficients of friction for nearly all rocks that comprise the lithosphere fall in the range 0.6 to 1. *See* Chapters 32 and 40.

C

c: This symbol is used to indicate the reflection at the core-mantle boundary for waves incident from the mantle. For example, *ScS* refers to waves traveled as *S waves* until reaching the core-mantle boundary and reflected there back to the surface propagating as S waves.

C-band: Radar frequency around 5 GHz with wavelength around 6 cm. *See* Chapter 37.

Caltech: An acronym for the California Institute of Technology, Pasadena, California.

cascade model of earthquakes: An extended version of the *characteristic earthquake model* in which several consecutive fault segments can rupture in a variety of combinations. The slip on each segment is assumed to be characteristic to the segment. *See* Chapter 5.

cataclasite: A cohesive fault-rock comprising mineral fragments derived predominantly from brittle cataclastic fragmentation -- textures range from essentially random-fabric to foliated. The cataclasite series (protocataclasite - cataclasite - ultracataclasite) reflects progressive reduction in grain size. *See* Chapter 29.

catalog (catalogue) of earthquakes: A chronological listing of earthquakes. Early catalogs were purely descriptive, i.e., they gave the date of each earthquake and some description of its effects. Modern catalogues are usually quantitative, i.e., earthquakes are listed as a set of numerical parameters describing origin time, *hypocenter* location, *magnitude*, *moment tensor*, etc. *See* Chapter 41 for an instrumental determined earthquake catalog (1900-1999), Chapter 42 for a catalog of deadly earthquakes (1500-2000), and Chapter 45 (p. 759-761) for a discussion of historical and modern earthquake catalogs.

causal signal: Output signal that does not exist for times prior to the application of an impulsive input. *See* Chapter 22.

caustic point: Point on the Earth's surface where the rate of change of the epicentral distance traveled by a ray with the change of its take-off angle changes its sign. At caustic point we should observe large concentration of arriving seismic energy. *See* Chapter 21.

CDP: An acronym for the Crustal Dynamics Project, a NASA research program in the 1980s. *See* Chapter 37.

CERESIS: An acronym for the Centro Sismologico Regional para la America del Sur

CGPS: An acronym for the Continuously operating *GPS* receivers and networks. *See* Chapter 37.

chaos: Solutions to deterministic equations are chaotic if adjacent solutions diverge exponentially in phase space; this requires a positive *Lyapunov exponent*. *See* Chapter 14.

characteristic earthquake model: A fault-specific earthquake model in which a given fault segment generates an earthquake of size and mechanism determined from the geometry of the segment At a specific location along a fault, the displacement (slip) is the same in successive characteristic earthquakes. Other earthquakes occurring on the fault are much smaller than these. In its application to *Seismic Hazard Analysis*, it refers to an earthquake of a specific size that is known or inferred to recur at the same location, usually at a rate greater than that extrapolated from the frequency-magnitude relation for smaller earthquakes in the area. See Chapter 5 (44-45), and Chapter 30 (p. 482-484).

charge: Electric charge flows in electric currents or accumulates on non-metallic surfaces. It is a basic property of matter and is conserved. The unit of electric charge is measured in Coulomb. One electron has a negative charge of 1.60×10^{-19} Coulomb**.** *See* Chapter 38.

Christoffel matrix: A symmetric real-valued matrix, of which eigenvalues give the seismic velocities and eigenvectors give the polarization directions of the waves. *See* Chapter 53, and biography of Elwin Brun Christoffel in Chapter 89.

CNES: Acronym for the Centre National d'Etudes Spatiales, the French space agency. *See* Chapter 37.

coda: That part of the *seismogram* which follows the arrival of a well defined wave. For example, the teleseismic *P coda* follows the arrival of teleseismic *P waves*. *See* Chapter 21.

coda attenuation: See *coda Q* .

coda magnitude: A type of earthquake magnitude based on either the duration of *coda waves* or some of their characteristics. Some authors have used this term interchangeably with *duration magnitude;* this practice is technically incorrect.

coda normalization method: A method to use the power of local earthquake S *coda* at a given lapse time as a measure of earthquake radiation energy, which is used for measurements of site amplification factors, attenuation per travel distance, and source energy. This method is based on the assumption of a uniform spatial distribution of coda energy density of a local earthquake at a long lapse time measured from the earthquake origin time. *See* Chapter 13.

coda waves (of a local earthquake): The *seismograms* of a local earthquake usually show some vibrations long after the passage of *body waves* and *surface waves*. This portion of the seismogram to its end is called the coda. They are believed to be back-scattering waves due to lateral inhomogeneity distributed throughout the Earth's *lithosphere*. *Coda* has been successfully used to obtain source spectra, as well as to measure seismic attenuation and site amplification factors by the *coda normalization method*. *See* Chapter 13.

coda Q: A parameter characterizing the amplitude decay of S *coda* of a local earthquake with the lapse time defined by Aki and Chouet (1975) assuming the single S to S *scattering*. The coda lasts longer for higher coda Q.

coefficient of friction (μ_f) : Coefficient of the linear relationship between *shear stress* (τ) and *normal stress* (σ_n) on a fault or joint that is slipping, $\tau = S_o + \mu_f \sigma_n$. *See* Chapter 32, p. 506.

coefficient of internal friction (μ_i) : Coefficient of the linear relationship between *shear stress* (τ) and *normal stress* (σ_n) resolved onto an incipient rupture plane, $\tau = S_o + \mu_i \sigma_n$. *See* Chapter 32, p. 505.

coherence: Degree of being in-phase between two wavefields. Mathematically it is the normalized cross-power spectrum of the two wavefields. It is the frequency-domain counterpart of the "correlation" in the time domain. *See* Chapter 13.

cohesion (S_o): The inherent shear strength of fault or joint surface; shear strength at zero *normal stress* in the equation: $\tau = S_o + \mu_I \sigma_n$. *See* Chapter 32, p. 506.

cohesive force: The force that acts in the cohesive zone of a crack located between the freely slipping crack surface and the intact elastic body ahead of the crack tip. The existence of a cohesive zone removes the stress singularity at the crack tip. *See* Chapter 15.

compensated linear-vector dipole: The force system representing a crack opening or closing under the constraint of no volume change. The corresponding moment tensor has zero trace (purely deviatoric). Traditionally called "cone-type mechanism" in Japan. *See* Chapter 50.

complex site effect: Dynamic amplification effects, e.g., those arising from a resonance condition, generated by propagation of earthquake waves in 2D/3D near-surface geological configuration, such as sedimentary valleys, and topographic irregularities. *See* Chapter 62.

compressional tectonic setting: A region undergoing lateral contraction and for which the vertical *principal stress* is the minimum. *See* Chapter 40.

compressional wave velocity: The velocity of an elastic wave in which the particle motion is in the same direction as propagation. *See* Chapter 83.

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Conrad discontinuity: Seismic boundary between the upper and middle crust that is usually defined by an increase in seismic velocity from 6.2-6.4 km/sec to about 6.6-6.8 km/sec. The term has fallen into disuse in recent years due to the lack of universality of such a discontinuity. *See* Chapter 54, and biography of V. Conrad in Chapter 89.

continental deformation: A term usually used to emphasize the contrast between deforming zones in the oceans and on the continents (see c*ontinental tectonics*). *See* Chapter 31.

continental tectonics: A term used to include the large-scale motions, interactions and deformation of the continental lithosphere. It is often used in contrast to plate tectonics. Whereas deforming zones in the oceanic plates are usually narrow and confined, on continents they are often spread over wide areas, requiring a different approach to their description and analysis. *See* Chapter 31.

contractional jog: A stepover between en échelon fault strands where slip transfer involves contraction and increased mean compressive stress within the stepover. *See* Chapter 29.

contractive soils: Granular soils that decrease or tend to decrease in volume during large shear deformation. The tendency to contract increases pore water pressures in undrained saturated soils during shear. Slopes and embankments underlain by contractive soils may suffer catastrophic strength loss and flow failure during earthquake shaking. *See* Chapter 70.

controlled-source seismology: Seismic investigations that utilize man-made seismic sources, such as chemical explosions detonated in boreholes. *See* Chapter 54.

converted waves: Conversion of *P* to *S* and *S* to *P* occurs at a discontinuity for non-normal incidence. These converted waves sometimes show distinct arrivals on the *seismogram* between the *P* and *S* arrivals, and may be used to determine the location of the discontinuity.

core (Earth's): Central part of the *Earth*'s interior at a depth of about 2900 kilometers. It represents about 16% of the Earth's volume and is divided into an inner, solid core, and an outer, fluid core. *See* Chapters 51 and 56.

core shadow zone: The *P velocity* drops markedly from the lowermost mantle to the outermost fluid core, creating the most pronounced low velocity zone inside the Earth. The existence of a low velocity zone creates a gap with no geometric rays emerging at the surface. The core shadow zone starts at the distance of about 97 degrees. *See* Chapters 21 and 56.

corner frequency: A *frequency* beyond which a flat part of the amplitude spectrum starts to decay rapidly with the increasing frequency. *See* Aki and Richards (2002, p. 511-516).

corrected acceleration: An acceleration time history that has been "corrected" from the raw acceleration data by removing drift, spikes, and any distorting effects created by the instrument. *See* Chapter 58.

corrected penetration resistance: A measure of in-situ soil property based on penetration test, such as standard penetration test resistance, (N1)60, corrected for the influence of overburden pressure, hammer energy, rod length, borehole diameter, and sampler type; or cone penetration resistance, qc1N, corrected for the influence of overburden pressure. *See* Chapter 70.

Coulomb friction: Coulomb friction is a simple constitutive law governing fault slip, in which a slip occur when stress exceeds strength defined by a coefficient of friction (a constant) times the normal stress. In contrast, the *rate-and-state dependent law* involves the *coefficient of friction*, which is not a constant but depends on the sliding speed (rate) and contacts (state) on the fault plane. *See* Chapter 73, and biography of Charles Augstin de Coulomb in Chapter 89.

CPU: An acronym for the central processing unit of a computer.

Crary waves: Crary waves are a train of sinusoidal waves with nearly constant frequency observed on a floating ice sheet (Crary, 1955). They are multi-reflected *SV*-waves with horizontal *phase velocity* near the speed of compressional waves in ice.

creep: Release of shear strain accomplished without significant radiated energy. *See creep events*, and Chapter 32 (p. 516).

creep events: Episodic slip across a fault trace observed at the surface over minutes to days. *See* Chapter 36.

creepmeters: Instruments for measuring displacement across a fault trace on the surface, usually with a baseline of length around 10 meters. *See* Chapter 36.

creep waves: Regional strain waves propagated along active faults had been suggested by Savage (1971). However, these slip waves have not yet been directly observed. *See* Chapter 36.

critically stressed crust: A state of *stress* in the *brittle* crust balanced by the frictional strength of crust. *See* Chapter 34.

cross-axis sensitivity: The susceptibility of a sensor to produce a spurious signal in response to motion perpendicular to the sensing direction of the sensor. Often due to limitations in the design or manufacturing of the mechanical suspension in the sensor, or misalignment of the components within the sensor. *See* Chapter 58.

cross-talk: The appearance of a signal on a channel due to electrical leakage from a signal on an adjacent channel. Often due to electrical problems with shielding, grounding, etc. *See* Chapter 58.

cross-track: Component of motion of a satellite perpendicular to its trajectory. *See* Chapter 37.

Crust (Earth's): Outmost layer of the *Earth* above the *Moho.* The crust in the continental regions is about 25-75 km thick, and that in the oceanic area is about 5-10 km thick. It represents less than 0.1% of the Earth's volume, with rocks that are chemically different from those in the *mantle*. *See* Chapters 54 and 55.

CUBE: Acronym for the Caltech-US Geological Survey Broadcast of Earthquakes. A program to develop and distribute real-time earthquake information in southern California. *See* Chapter 78.

cultural noise: *Seismic noise* generated by various human activities such as traffic, construction works, industries, etc. *See* Chapters 19 and 21.

cumulative seismic moment: The sum of the *seismic moments* of earthquakes which have occurred in a region from a fixed starting time till time t, as a function of t. This can be related to the cumulative tectonic motion across a plate boundary lying in the region, or to the cumulative tectonic *strain* within the region. *See* Chapter 5.

cyclic mobility: A condition in which *liquefaction* occurs and flow deformation commences in response to static or dynamic loads but deformation is arrested by dilation at moderate to large shear strains. *See* Chapter 70.

Cyclic Resistance Ratio (CRR): The capacity of a granular soil layer to resist *liquefaction* expressed as a ratio of the dynamic stress required to initiate liquefaction to the static effective overburden pressure. *See* Chapter 70.

Cyclic Stress Ratio (CSR): The seismic load placed on a granular soil layer expressed as the ratio of the average horizontal dynamic stress generated by earthquake to the static effective overburden pressure. *See* Chapter 70.

D

D" [G51]: A layer surrounding the fluid core of the Earth occupying the lowermost 200 km of the mantle, which is believed to be a region of strong thermal and chemical heterogeneity. *See* Chapter 51.

damage probability matrix: A matrix giving the probabilities of sustaining a range of losses for various levels of a ground-motion parameter.

damage scenario: A representation of the possible damage caused by earthquake to the built environment in an area, in terms of parameters useful for economical and engineering assessment or post-earthquake emergency management. *See* Chapter 62.

damping: A term in earthquake engineering indicating mechanism for the dissipation of the energy of motion. Viscous damping, which is proportional to the velocity of motion and is described by linear equations, is used to define different levels of *response spectra* and is commonly used to approximate the energy dissipation in the lower levels of earthquake response. *See* Chapter 67.

decibel (dB): A logarithmic measure of relative signal amplitude. Defined as 20 log(*A/Ao*), where *Ao* is the signal amplitude at some reference level, typically the minimum signal resolvable by the recorder. *See* Chapter 58.

declustering (of earthquake catalogs): The procedure for removing dependent earthquakes such as *foreshocks* and *aftershocks* . A declustered catalog contains only mainshocks and isolated earthquakes. The largest shock in each earthquake swarm is considered as the mainshock and remains in the *catalog*. *See* Chapter 43.

delay-and-sum processing: A procedure for making an array beam. Time delays are applied ***to*** the output of each of the seismometers of an array to bring the desired signals in phase, followed by summing of the output with appropriate weighting**.** *See* Chapter 23.

DEM: An acronym for Digital Elevation Model. An array of digitized elevations or topographic values. *See* Chapter 37.

depth phases *(pP, pwP, pS, sP, sS)*: The symbol *pP* has been used for *P-waves* propagated upward from the *hypocenter*, turned into downward propagating *P*-waves by reflection at the free surface (pwP at the ocean surface), and observed at teleseismic distances. *sS*, *sP*, and *pS* have analogous meanings. For example, *sP* corresponds to a phase that ascends from the focus to the surface as *S*-waves and then, after reflection, travels as *P*-waves to the recording station. These phases are useful for an accurate determination of *focal depth*. *See* Chapters 21 and 41.

design ground motion: A level of *ground motion* used in structural design. It is usually specified by one or more specific *strong-motion parameters* or by one or more time series. The structure is designed to resist this motion at a specified level of response, for example, within a given ductility level. *See* Chapter 68.

deterministic system: A dynamical system whose equations and initial condition are fully specified and are not stochastic or random. *See* Chapter 14.

deterministic earthquake scenario: A representation, in terms of useful descriptive parameters, of an earthquake of specified size postulated to occur at a specified location (typically an *active fault*), and of its effects. *See* Chapter 62.

deviatoric tensor: A tensor with no isotropic (explosive or implosive) component. The sum of the eigenvalues of a deviatoric tensor is zero. *See* Chapter 50.

diaphragm: In structural engineering, a planar structural element, such as a floor slab, that is very resistant to in-plane deformations. In earthquake response studies, floor diaphragms are often considered to respond to horizontal motion as rigid bodies. *See* Chapter 69.

differential pressure gauge: A device for measuring long period (0.1 to 2000 seconds) pressure fluctuations on the seafloor. *See* Chapter 19.

differential travel time: The difference between the arrival time of one seismic phase and that of another phase on the same *seismogram*. Differential travel times are often used to eliminate the uncertainty in the event origin time and to reduce the uncertainties in the structure near the source or receiver. *See* Chapter 56.

diffracted *P*: The *P-wave* ray path from a surface focus that grazes the Earth's core emerges at an epicentral distance of about 100°. Although geometrical optics predicts no direct arrivals of *P-waves* in the shadow zone beyond this distance, we continue to observe *P*-waves, especially of long period, up to distances of at least 130°. They are diffracted around the core boundary. *See* Aki and Richards (2002, p. 456-457).

diffraction: Wave phenomena which cannot be explained by geometrical optics commonly occur when the curvature of the surface of an obstacle is large compared with the curvature of the incident wave front. *See* Chapter 21.

diffusion: Process describing transport of mass or heat caused by differences in chemical potential, pressure or temperature. It can also describe seismic energy transport in randomly heterogeneous elastic media. *See* Chapter 36.

digital filter: A mathematical tool designed to modulate the *frequency* characteristics of a discrete time series by means of numerical calculations on a computer. *See* Chapters 22 and 63.

digitization: The conversion of an analog waveform, e.g., an *accelerogram* recorded optically on film, to a series of discrete x-y values corresponding to time-acceleration pairs, for use in subsequent computer processing. *See* Chapter 58.

dilational jog: A stepover between en échelon fault strands where slip transfer involves dilatation and reduced mean compressional stress within the stepover. *See* Chapter 29.

dilative: Granular soils that increase or tend to increase in volume during shear. *See* Chapter 70.

dilatometers: Borehole strainmeters measuring volumetric strain. *See* Chapter 36.

directivity focusing: The variation in wave amplitude as a function of *azimuth* relative to strike or dip of the fault source caused by the direction of movement of the rupture front. *See* Chapter 60.

directivity pulse: A concentrated pulse-like ground motion generated by constructive interference of S waves travelling ahead of the tip of a rupturing fault. *See* Chapter 60.

disasters: Accidental or uncontrollable events, actual or threatened in which individuals or society undergo severe danger that disrupts the social structure of a society. *See* Chapter 75.

discrimination: The work of identifying different types of *event*, and specifically of distinguishing between earthquakes and underground explosions, and/or between underground nuclear and chemical explosions. *See* Chapter 24.

dislocation modeling: Calculation of displacements or other deformation parameters of the Earth by representing an earthquake as a slip across an internal surface**.** *See* Chapter 36.

dislocation superlattice: A regular distribution of dislocations treated as a reference state. *See* Chapter 15.

dislocation: A line defect in the crystal lattice. In seismology the term is used to represent slip across an internal surface of a continuum (s*ee dislocation modeling*). *See* Chapters 15 and 36.

dispersion: Spreading of wave duration with propagation distance due to frequency-dependent velocity. *See* Chapter 21.

displacement: In strong motion seismology, the displacement of a point during earthquake shaking, typically obtained by doubly integrating the acceleration and applying certain corrective procedures. *See* Chapter 58.

displacement vector: In geodesy, movement of a point on the Earth's surface. Traditionally defined in a local (east, north, up) coordinate system centered at a reference point fixed to the Earth. In space geodesy, the reference point can be attached to the inertial frame. *See* Chapter 37.

Doppler effect: The Doppler effect is observed for waves radiated from a moving harmonic oscillator with a given *frequency*. The observed frequency is shifted from the source frequency depending on the direction with respect to the moving direction. *See* Chapter 37, and biography of Christian Doppler in Chapter 89.

DORIS: An acronym for the Détermination d'Orbite et Radiopositionnement Intégré par Satellite, a Doppler satellite navigation system developed by the French Space Agency. *See* Chapter 37.

double-difference: In INSAR, this term denotes the difference of two interferograms, each of which is the difference of two radar images. In GPS, this term describes a linear combination of four ray paths involving two satellites and two receivers. *See* Chapter 37.

double couple: A force system consisting of two orthogonal couples with the same moment and opposite sign. It is equivalent to a shear slip across an internal surface of an isotropic elastic medium. The corresponding *moment tensor* has both zero trace (purely deviatoric) and zero determinant. *See* Chapter 50.

double frequency microseisms: Describes microseismic noise on the Earth generated by ocean waves with the main spectral peak at half the wave period (hence the seismic noise is at double frequency) as explained by Longuet-Higgins (1950). *See* Chapter 19.

drift ratio: In earthquake engineering design and analysis, the ratio of the lateral interfloor deflection to the height between the two floors involved. The allowable drift ratio under design loading is often prescribed in building codes. *See* Chapter 67.

DSP: An acronym for digital signal processor. The processor implements mathematical operations, such as a Fast Fourier transform, numerically. Recent electronic *analog to digital converters* use DSP's to attain high resolution. *See* Chapter 63.

DTED: An acronym for Digital Terrain Elevation Data. *See* Chapter 37.

ductile: Able to accommodate inelastic *strain* without loss of strength. *See* Chapter 56, p. 516).

ductility: The property of a structure or a structural component that allows it to continue to have significant strength after it has yielded or cracked. Typically, a well-designed ductile structure or component will show, up to a point, increasing strength as its deflection increases beyond yielding or cracking. *See* Chapter 67.

ductility ratio: The ratio of the maximum deflection(or rotation) of a structure or structural component to the deflection(or rotation) at first yielding or cracking.

duration magnitude: The logarithm of the duration of a local earthquake *seismogram* is generally proportional to earthquake *magnitude* calculated from direct-wave amplitudes. Its physical basis is given by the back-scattering theory of *coda waves*, after which the duration must be measured from the earthquake origin time. More often it is measured from the onset of *P waves* which may cause a subtle but significant bias in the statistics of small earthquakes. *See* Chapter 13, and Lee and Stewart (1981, p. 155-157).

dynamic range: The amplitude ratio between the smallest and the largest signal that can be faithfully recorded by a system. Usually expressed in *decibels*. *See* Chapter 18.

dynamic ray equations: The dynamic ray equations govern the properties of *paraxial ray* which is defined as a ray generated by perturbing the source position or take-off direction of a central ray. They are expressed as ordinary differential equations for certain characteristics of wave field related to the amplitude and curvature of wave front in the vicinity of the central ray as a function of the travel time or the ray path length. *See* Chapter 9.

dynamic stress-change: A dynamic stress-change is a transient, or time-dependent stress change. It can result from time-dependent forces, such as those generated by seismic waves or the earth's tides, or viscoelastic behavior of the earth. *See* Chapter 73.

dynamics (of seismic source): A term concerned with the *stresses* or forces responsible for generating seismic deformation (cf. "kinematics"). *See* Chapter 31.

E

Earth: The third planet from the Sun in the solar system. It has an average radius of 6371 kilometers (km), a surface area of 5.1×10^8 km^2, a volume of 1.08×10^{12} km^3, and a mass of 5.98×10^{24} kilograms. Its structure consists of the *crust*, the *mantle*, and the *core*. See MacDonald (1966).

earth tides: Periodic strains primarily at diurnal and semi-diurnal periods generated in the solid earth by the gravitational attraction of the Sun and Moon. *See* Chapter 36.

earthquake engineering: The field of earthquake engineering is defined as encompassing man's efforts to cope with the harmful effects of earthquakes (Housner, 1967). It may be subdivided into three parts; (1) a study of those aspects of seismology and geology that are pertinent to the problem, (2) an analysis of the dynamic behavior of structures under the action of earthquakes, and (3) the development and application of appropriate methods of planning, designing and constructing. It overlaps with earth sciences on one hand and with social scientists, architects and planners, and with industry and government on the other hand.

earthquake focal mechanism: A description of the radiation pattern of seismic waves (traditionally by the sense of the first P wave motion and polarization of S wave motion, and now the moment tensor inversion of waveforms) in an earthquake which reveals the orientation and sense of slip on the causative fault plane. From the seismic radiation pattern alone it is not possible to distinguish between the fault plane and the auxiliary plane orthogonal to the slip direction. *See* Chapter 34.

earthquake intensity: *See seismic intensity.*

earthquake precursor: Anomalous phenomenon preceding an earthquake. *See* Chapter 72.

earthquake prediction: The human effort to predict the time, location, and magnitude of a future earth quake. Earthquake prediction programs have been promoted in Japan, China, the United States, the former Soviet Union, and other countries. Scientifically, earthquake prediction relies on anomalous phenomena that precede an earthquake. At present, we do not have the capability of issuing an earthquake warning based on accurate earthquake prediction information. *See* Chapter 72.

earthquake sequence: A series of earthquakes originating in the same locality. *See* Chapter 43.

earthquake source parameters: The parameters specified for an earthquake source depends on the applied model. They are origin time, *hypocenter* location, *magnitude*, *focal mechanism* and *moment tensor* for a point source model. They include fault geometry, rupture velocity, stress drop, slip distribution, etc. for a finite fault model. *See* Chapter 31.

earthquake storms: A sequence of large earthquakes, occurring over a period a few years to tens of years over distances of hundreds of kilometers. For example, along the North Anatolian fault between 1939 to 1999; the Mojave region between 1950 and the present, or the eastern Mediterranean between about 340 AD to 380 AD. *See* Chapter 46.

earthquake stress drop: The net effect of earthquakes is to lower the *shear stress* acting across the faulted area, though shear stress will be higher in adjacent un-ruptured portions of the fault. The "static stress drop" is a theoretically well-defined quantity that compares the "before" and "after" stress-strain states of the elastic volume that surrounds the fault. The definition of the overall static stress drop reduces to a weighted integral over just the fault portion that slips during the earthquake. "Dynamic stress drop" is a much more difficult concept since it is the time-space history of stress drop while the fault is slipping and even the average dynamic stress drop can be quite different from the average static stress drop of the earthquake. While "dynamic stress drop" is closer to the detailed processes of friction and waves, it is very difficult to estimate from observations. *See* Chapter 33.

edge effect (on ground motion in a basin): Special amplification effect found near the edge of a basin. In a two- or three-dimensional model of basin, basin-induced diffracted waves and surface waves generated at the edge by an incident body wave meet together in phase at some point causing constructive interference. As a result the amplitude of ground motion there becomes much larger than in the case of a simple one-dimensional model. The edge effect contributed importantly to the damage concentration in Kobe during the Hyogo-ken Nanbu earthquake of 1995. *See* Chapter 61.

EDM: An acronym for Electro-optical Distance Meter. The instrument and technique usually used for trilateration. *See* Chapter 37.

effective elastic thickness: The conceptual thickness of the layer within the *lithosphere* that can support significant deviatoric stresses over geological time scales. *See* Chapter 31.

effective normal stress: The *normal stress* minus the *pore pressure*. *See* Chapter 40.

effective stress: In soil mechanics, the sum of the inter particle contact forces acting across a plane through a soil element divided by the area of the plane. On a horizontal plane, the effective stress is defined as the total overburden pressure minus the instantaneous pore water pressure. In rock mechanics, it also means the *stress* above the *pore pressure*. *See* Chapters 32 and 70.

eikonal equation: Consider a wavefront originating from an impulsive source at a point, and define the travel time in space as its time of arrival. The eikonal equation equates the magnitude of gradient vector of the travel time to the reciprocal of the local wave speed. The term was originally used in relation to Hamilton's equations in analytical dynamics, which has some similarity with equations in the ray theory. *See* Chapter 9, and biography of William Rowan Hamiltion in Chapter 89.

elastodynamic equation: The basic equation governing the dynamic deformation of a solid body. It is derived from Newton's law on force and acceleration, generalized Hooke's law on *stress* and *strain* and the assumption of the existence of the strain energy function. For an infinitesimally small displacement, it can be reduced to a form equating density times the second time-derivative of the displacement to the sum of the divergence of the stress tensor (written in terms of the space-derivatives of the displacement) and the body force. *See* Chapter 15, Aki and Richards (2002, p. 11-36), and biography of Isaac Newton and of Robert Hooke in Chapter 89.

electrokinetic: Electric and magnetic fields generated by fluid flow in a porous medium. *See* Chapter 38.

electromagnetic: Coupled electric and magnetic field effects. *See* Chapter 38.

end of the Bronze Age: A catastrophic period in 1200 BC ± 25 years during which numerous cities in the eastern Mediterranean and the near east have inexplicably collapsed politically and physically. *See* Chapter 46.

envelope broadening: Phenomenon that wave envelope which has been impulsive at the time of radiation from the source is broadened with increasing travel distance because of diffraction and *scattering* by distributed *heterogeneities*. *See* Chapter 13.

epicenter: A point on the Earth's surface immediately above the earthquake focus called *hypocenter*. *See* Chapter 21, and Lee and Stewart (1981, p.130-139).

epistemic uncertainty: The variability in seismic hazard analysis due to uncertainty in model parametrization and other limitations of the methods employed. Epistemic uncertainty can be reduced by improvements in the modeling and analysis (cf. *aleatory uncertainty*). *See* Chapter 56.

ERI: An acronym for the Earthquake Research Institute, University of Tokyo, Tokyo, Japan.

ERS-1: An acronym for the European Remote Sensing satellite 1. Carries a C-band SAR and was launched in 1991. *See* Chapter 37.

ERS-2: Twin of *ERS-1*, launched in 1995. *See* Chapter 37.

ESA: Acronym for the European Space Agency. *See* Chapter 37.

ETHZ: An acronym for the Swiss Federal Institute of Technology, Zurich, Switzerland.

Euler pole: See *Euler vector*.

Euler vector: Rotation vector describing the relative motion between two plates. The magnitude of the Euler vector is the rotation rate, and its intersection with the earth's surface is the Euler pole. The linear velocity at any point on the plate boundary is the vector product of the Euler vector and the radius vector to that point. *See* Chapter 7, and biography of Leonhard Euler in Chapter 89.

event: A loose term used to represent an earthquake or any similar seismic disturbance. *See* Chapter 48.5.

event horizon: A term in paleoseismology indicating the ground surface at the time of an earthquake in the geologic past. *See* Chapter 30.

exceedance probability: Probability that a specified value of a strong-motion parameter is exceeded by a future recording within a specified period of time. *See* Chapter 60.

explosion earthquake: Seismic events associated with explosive volcanic activities. In addition to the usual seismic waves such as *P waves* and *S waves*, they often show *air waves* which travel through the air and are transmitted back into the ground in the vicinity of the *seismometer*. *See* Chapter 25.

exposure time: The time period used in the specification of probabilistic seismic hazard and seismic risk. It is usually chosen to represent the design or economic life of a structure.

extensional tectonic setting: A region in which the crust is undergoing lateral expansion and for which the vertical *principal stress* is the maximum. *See* Chapter 40.

F

failure envelope: Boundary of stress conditions associated with rock failure, as defined in *shear stress* versus *normal stress* space. Typically the slope of the failure envelope $d\sigma/d\sigma_n$ is steepest at low normal stress (σ_n). The slope is also referred to as the "pressure dependence" of failure strength. *See* Chapter 32, p. 508.

fault-fracture mesh: A mesh structure of interlinked minor faults (shear fractures) and extension fractures occupying a substantial volume of the rock-mass. *See* Chapter 29.

fault-rock: A rock whose textural/microstructural characteristics (usually involving grain-size reduction from the protolith) developed through deformation within a fault zone at depth. *See* Chapter 29.

fault-valve action: Fluid redistribution arising from a fault rupture transecting a superhydrostatic fluid-pressure gradient, leading to cyclic changes in fluid-pressure and fault strength coupled to the earthquake stress cycle. *See* Chapter 29.

fault breccia: A *fault-rock* made up of angular rock fragments derived from brittle fragmentation in a fine-grained or hydrothermal matrix. *See* Chapter 29.

fault creep: See *creep*.

fault dip: The inclination of a fault plane relative to the horizontal, in degrees. A dip of 0 degree is horizontal, 90 degrees is vertical. *See* Chapter 31.

fault gouge: A clayey, soft material formed when the rocks in a fault zone are pulverized during slippage. It is incohesive and is predominantly made up of mineral fragments derived from brittle cataclastic fragmentation -- textures range from essentially random-fabric to foliated. *See* Chapters 29 and 39.

fault model (of an earthquake): A model of an earthquake source in which a slip across a fault plane buried in an earth model causes the earthquake ground motion. *See* Chapter 5.

fault rake: A parameter describing the slip direction on a fault, measured as an angle in the fault plane between the fault strike and the slip vector. Slip in the direction of the maximum slope of the fault plane is a rake of 90º, positive for *reverse faults*, negative for *normal faults*. *See* Chapter 31.

fault strike: The azimuthal direction of the horizontal in the fault plane. *See* Chapter 31.

fault zone: The fault plane of the mathematical model of an earthquake is usually a planar surface in an elastic medium. The actual fault is a zone in which a non-elastic process occurs during the earthquake, sometimes called a break-down zone or cohesive zone. It includes the *fault gouge,* which has been studied geologically and petrologically. *See* Chapters 5, 29, and 30.

Fault-zone trapped mode: Seismic *guided waves* trapped in the low-velocity *fault zone*. They are useful for studying the three-dimensional structure of the fault zone. They have been used also to find the temporal change in the physical characteristics of the fault zone.

feedback: Adding part of the output signal of a linear system like an amplifier to the input signal in order to modify the response. Mostly used to stabilize the system (negative feedback). *See* Chapter 18.

felt area: The area of the Earth's surface over which the effects of an earthquake were perceptible. *See* Chapter 49.

FFT: An acronym for Fast Fourier Transform, an algorithm for fast computation of *Fourier Transform*.

filter: Electronic devices or algorithms which act on an input signal to produce an output signal with a desired modification in spectral characteristics. *See digital filter,* and Chapter 22.

finite element: A geometrical subdivision, generally small, of a larger structure or medium. Finite elements are commonly used in numerical studies of the response of complex structures or media to earthquake excitation. Typical finite elements include triangles and rectangles for analysis of two-dimensional problems, and tetrahedrons for three-dimensional problems. In applications, a structure is divided into many finite elements and field quantities such as density and displacement, for example, are assumed to vary over each element in a prescribed manner (e.g., linearly varying displacement) so the displacement and associated stresses and strains within each element are determined by the displacements at its corners or nodes. The displacements of the nodes of the finite elements then become the unknown vector in a matrix equation that is solved numerically. *See* Chapter 69.

first motion: The first half-cycle of a *body wave*, usually direct P. The direction (polarity) of first motion which for P is either away from or towards the source is assumed to be conserved along the ray path from the focus to a given station, given that corrections have been made for any polarity changes due to reflection of the wave at any boundary between source and receiver. First motions of P-arrivals are often used for determining *earthquake focal mechanism*. *See* Chapter 23.

flexural waves: A *normal mode* in an infinite plate in vacuum with motion antisymmetric with respect to the median plane of the plate. Examples in nature are the waves in floating ice. (For short waves, the period equation for a normal mode reduces to that for flexural waves in a plate modified slightly by the presence of water. For long waves, however, the gravity term in the period equation dominates, and the mode approaches that of gravity waves in water.)

fling step: The permanent displacement of the ground at or near a ruptured fault.

flow deformation: Shear deformations in soil that occur with little resistance within a liquefied layer or element. Deformations may be of limited excursion, as occurs in dilative soils, or unlimited excursion, as occurs in contractive soils. *See* Chapter 70.

flow failure: *Liquefaction*-induced failure of a slope or embankment underlain by contractive soils leading to large, rapid ground displacements. These failures are characterized by large loss of shear strength, large lateral displacements (several meters or more), and severe disturbance to the liquefied and overlying soil layers. *See* Chapter 70.

fluid overpressure: Fluid-pressure exceeding the *hydrostatic pressure* value appropriate to the depth. *See* Chapter 29.

fmax effect: The observed spectrum of a typical local earthquake shows steeper decay with increasing *frequency* beyond a limiting frequency called, “fmax”, than expected from the standard “omega-squared” model. This has been attributed to the earthquake source effect as well as to the recording site effect. *See* Chapters 5 and 57.

focal depth: The conceptual "depth" of an earthquake focus. If determined from the first motion arrival-time data, this represents the depth of rupture initiation (the "*hypocenter*" depth). If determined from waveforms that are long compared with the fault dimension, the depth represents some weighted average of the moment release in the earthquake (the "centroid" depth). *See* Chapter 31, and Lee and Stewart (1981, p. 130-139).

focal mechanism: See *earthquake focal mechanism*.

focusing effect (in local site amplification): Special amplification of *ground motion* found just above the corner of the basin bottom or layer interfaces. In a two- or three-dimensional basin with strong lateral variation, rays of an incident body wave are warped at these interfaces and constructive (or destructive) interference takes place at some point on the surface. *See* Chapter 61.

force-balance seismometer: A *seismometer* that compensates the inertial force acting on its suspended mass with a negative feedback force, and thereby keeps the mass at rest relative to the ground. *See* Chapter 18.

forensic seismology: Seismology applied to problems involving legal issues, such as the verification of compliance with any treaty limiting the testing of nuclear explosions. *See* Chapter 23.

foreshock: A small earthquake preceding the largest earthquake in an earthquake sequence. *See* Chapter 43.

Fourier transform: An integral transform mapping signals defined in the time domain f(t) into the complex frequency domain F(ω) by multiplying exp(iωt) and integrating over t from minus infinity to plus infinity. *See* Chapter 22, and biography of Jean Baptiste Joseph Fourier in Chapter 89.

fractal: An object that is quantified by a fractional dimension. A measure of a scale-invariant object. In some cases a power-law relation between the number of objects and their linear sizes. *See* Chapter 14.

fractal dimension: The fractional dimension of a *fractal* . The power in the power-law fractal scaling. *See* Chapter 14.

fractionation: Separation of a mixture in successive stages, such as by differential solubility in a water-solvent mixture. *See* Chapter 39.

fracture toughness: A measure of the energy expended in an increment of fracture. It is more difficult to propagate a fracture in a material with high fracture toughness than for low fracture toughness *See* Chapter 15 and Chapter 32, p. 509.

free-field motion: *Strong ground motion* that is not modified by the earthquake caused motions of nearby buildings or other structures or geologic features. In analyses, often defined as the motion that would occur at the interface of the structure and the foundation if the structure were not present. A fully instrumented building site typically includes one or more *accelerographs* located some distance from the structure to obtain a better approximation of the free-field motion. *See* Chapter 67.

frequency: The frequency is the number of periods per unit time, or the reciprocal of *period* . In the context of the *Fourier transform*, "frequency" is also used for the angular frequency, which is 2 pi times the frequency defined above. *See* Chapters 18 and 60.

frequency response: *Fourier transform* of the output signal of a linear system divided by the Fourier transform of the input signal. The frequency response of a linear system equals the Fourier transform of its *impulse response*. *See* Chapter 22.

friction: The ratio of *shear stress* to *normal stress* on a planar discontinuity such as fault or joint surface. *See* Chapter 23 (p. 506).

frictional instability: Condition that arises during quasi-static fault slip when the reduction of fault strength with displacement exceeds the elastic stiffness of the region surrounding the fault; under these conditions the slip rate accelerates rapidly. *See* Chapter 32 (p. 517).

friction-melting: Melting as a consequence of high temperature generated by *friction* during rapid localized fault slip. *See* Chapter 29.

frictional (FR) regime: That portion of the crust or *lithosphere* where fault motion is dominated by unstable (velocity weakening) pressure-sensitive frictional sliding. *See* Chapter 29.

Frozen waves: In the epicentral area of a great earthquake, walls, embankments, and the like are sometimes left in the form of a wave. These "frozen waves" are attributed to cracking open of the ground at the crests of the waves, sometimes with the emission of sand and water. Frozen waves are also seen on the surface of the Moon, concentric with very large impact craters.

fully-decoupled explosion: An underground explosion, carried out within a cavity large enough that the walls of the cavity are not stressed beyond their elastic limit. *See* Chapter 24.

G

Geiger's method: A commonly used method to locate an earthquake using the first *arrival times* of seismic waves. Geiger (1912) applied the Gauss-Newton method (an optimization procedure by least squares) to solve the earthquake location problem, but his method was not practical until the advance of computers in the late 1950s. *See* Chapters 85.7, 85.8 and 85.17, Lee and Stewart (1981, p. 132-139), and biographies of Ludwig Geiger, Karl Friedrich Gauss, and Isaac Newton in Chapter 89.

geochronology: Science of dating earth materials, geologic surfaces and processes. *See* Chapter 30.

geodynamo: Magneto-hydro-dynamic convection in the Earth's core that is responsible for the generation of the Earth's main magnetic field. *See* Chapter 56.

geometrical spreading: Decrease of elastic energy, per unit area of wavefront, due to the expansion of the wavefront with increasing distance. *See* Chapter 21, and Aki and Richards (2002, p. 94-95).

geophone: A term that is commonly used for an inexpensive electromagnetic *seismometer* that is light weight and responds to high-frequency (> 1 Hz) *ground motions.*

geotechnical engineering: The branch of engineering that deals with construction on, within, and with soil and rock. Common examples include structural foundations and earth dams.

geotechnical zonation: A mapping that portrays specified ground characteristics or mechanical properties in an area, typically showing zones that correspond to pre-defined geotechnical units. For example, a map of *shear wave* velocities derived from soil profile classifications. *See* Chapter 62.

geyser: A fountain of hot water and steam ejected intermittently from a source heated by magma or hot rocks. *See* Chapter 39.

GFZ: An acronym for the Geo-Forschungs Zentrum, Potsdam, Germany.

Global plate motion model: A set of *Euler vectors* specifying relative plate motions. Such models can be derived for time spans of millions of years using rates estimated from sea-floor magnetic anomalies, directions of motion from the orientations of transform faults, and the slip vectors of earthquakes on transforms and at *subduction zones*. They can also be derived for time spans of a few years using space-based geodesy. *See* Chapter 7.

GPS: An acronym for the Global Positioning System. A dual-frequency L-band satellite navigation system operated by the U.S. Department of Defense. *See* Chapter 37.

gravity loads: The vertical loads created in the elements of a structure by the force of gravity. Gravity loads are sometimes separated into dead load (the weight of the structure) and live load (the weight of furnishings and other contents). *See* Chapter 69.

gravity waves: *Normal modes* in a surface layer with very low shear velocity, such as unconsolidated sediments, may be affected significantly by gravity at long periods. Waves similar to the gravity waves in a fluid layer are possible in addition to the shortening of wavelength of normal modes by gravity. So-called “visible waves” with large amplitude and relatively long periods observed in the epicentral area of a great earthquake have been suggested to be gravity waves. *See* Chapter 28, p. 442-443, and Ben-Menahem and Singh (1981, p. 776-796).

Green's function: In seismology, vector displacement field generated by an impulsive force applied at a point in the Earth. Combining with the source function describing the discontinuities in displacement and traction across an internal surface, it can represent seismic displacements caused by earthquake faults and buried explosions by compact formulas. Green's function was first introduced by Green (1828). *See* Chapter 8 (p.84), Aki and Richards (2002, p. 27-28), Rickayzen (2002), and biography of George Green in Chapter 89.

ground failure: Permanent deformation of the ground (e.g., *liquefaction* , fault displacement, and landslides) resulting from an earthquake capable of causing damage to engineered structures. *See* Chapter 70.

ground motion: Vibration of the ground due to earthquakes. It is measured by a *seismograph* that records *acceleration*, velocity or displacement, and usually given in terms of an acceleration time series (an *accelerogram*) or a *response spectrum* . *See* Chapters 57, 60, and 74.

ground-motion (strong-motion) parameter: A parameter characterizing *ground motion*, such as peak acceleration, peak velocity, and peak displacement (peak parameters) or ordinates of *response spectra* and Fourier spectra (spectral parameters). *See* Chapter 60.

ground oscillation: A geotechnical term specifying ground condition in which *liquefaction* of subsurface layers decouples overlying nonliquefied layers from the underlying firm ground, allowing large transient ground motions or ground waves to develop within the liquefied and overlying layers. *See* Chapter 70.

ground roll: A term used in exploration seismology to refer to surface waves generated from explosions. They are characterized by low velocity, low frequency, and high amplitude, and are observed in regions where the near-surface-layering consists of poorly consolidated, low-velocity sediments overlying more competent beds with higher velocity.

ground settlement: Permanent vertical displacement of the ground surface due to compaction or consolidation of underlying soil layers. *See* Chapter 70.

ground shaking scenario: A representation for a site or region depicting the possible ground shaking level or levels due to earthquake, in terms of useful descriptive parameters. *See* Chapter 62.

ground truth: A jargon in nuclear test detection seismology, referring to information about the location of a seismic event that is derived from information not usually available to an analyst studying the event with a typical monitoring network. The ground truth can come from satellite observations, or from fault traces that break out at the Earth's surface, or from operation of a local network. Ground truth locations are sometimes associated with a number, e.g., "GT5", meaning a location believed to be accurate to within 5 km, obtained from ground truth. *See* Chapter 24.

group velocity: For dispersive waves with frequency-dependent *phase velocity*, $c(\omega)$, the wave packet propagates with the group velocity given by $d\omega/dk$, where k is the wave number given by $\omega/c(\omega)$. *See* Aki and Richards (2002, p. 253-254).

guided waves: Guided waves are trapped in a waveguide by total reflections or bending of rays at the top and bottom boundaries. An outstanding example is the acoustic waves in the *SOFAR channel*, a low-velocity channel in the ocean. Since the absorption coefficient for sound in seawater is quite small for frequencies on the order of a few hundred cycles per second, transoceanic transmission is easily achieved. If we consider the Earth's surface as the top of a waveguide, *surface waves*, such as Rayleigh, Love, and their higher modes, are guided waves. The fault-zone trapped mode is a guided wave in the low velocity fault zone. Where they can exist, guided waves may propagate to considerable distances, because they are effectively spreading in only two spatial dimensions.

***G*-waves (*Gn*)**: Another name for long-period *Love waves*. Because the *group velocity* of Love waves in the Earth is nearly constant (4.4 km/sec) over the period range from about 40 to 300 seconds, their waveform is rather impulsive, and they have received this additional name. They are called *G*-waves after Gutenberg. It takes about 2.5 hours for *G*-waves to make a round trip of the Earth. After a large earthquake, a sequence of *G*-waves may be observed. They are named *G*1, *G*2, . . ., *Gn*, according to the arrival time. The odd numbers refer to *G*-waves traveling in the direction from epicenter to station, and the even numbers to those leaving the epicenter in the opposite direction and approaching the station from the antipode of the epicenter. *See* Chapter 21 (p. 346).

Gutenberg-Richter's relation: An empirical relation expressing the frequency distribution of magnitudes of earthquakes occurring in a given area and time interval. It is given by: $\log N(M) = a - bM$, where M is the earthquake *magnitude,* $N(M)$ is the number of earthquakes with magnitude greater than M, and a and b are constants (see *b value*). It was obtained by Gutenberg and Richter (1941; 1949), and is equivalent to the power-law distribution of earthquake energies or moments. *See* Chapter 43 (p. 723), and biographies of Beno Gutenberg and Charles Francis Richter in Chapter 89.

H

H/V spectral ratio: Ratio of Fourier amplitude spectra of horizontal and vertical components of ambient noise, or of earthquake *ground motions*, recorded at a site. Typically used to identify the presence of site-specific dominant frequencies in such motions. *See* Chapter 62.

Hales discontinuity: See *N discontinuity*.

half-life: The time required for a mass of radioactive isotope to decay to one half of its initial amount. *See* Chapter 39.

Hazard master model: A type of master model of earthquakes in which the *Probabilistic Seismic Hazard Analysis (PSHA)* is used for unifying multi-disciplinary data regarding earthquakes in a given region. The integration of the multi-disciplinary data is done in the end product, in contrast to a physical master model. *See* Chapter 5.

head waves: Head waves are observed in a half-space that is in welded contact with another half-space with higher velocity when the seismic source is located in the lower-velocity medium.

The ray path of head waves is along the interface, and the wavefront in the lower-velocity half-space is a part of the surface of an expanding cone. For this reason, head waves are sometimes called "conical waves." *See* Aki and Richards (2002, p. 203-209).

heterogeneity: A medium is heterogeneous when its physical properties change along the space coordinates. A critical parameter affecting seismic phenomena is the scale of heterogeneities as compared with the seismic wavelengths. For a relatively large wavelength, for example, an intrinsically isotropic medium with oriented heterogeneities may behave as a homogeneous anisotropic medium. *See* Chapter 53.

hexagonal symmetry: Symmetry by rotation of 60° around one axis, the 6-fold symmetry axis. Hexagonal symmetry and cylindrical symmetry are equivalent for the elastic properties. There are 5 independent elastic parameters in hexagonal symmetry systems. *See* Chapter 53.

high pass filter: Filter which removes the low frequency portion of the input signal. *See* Chapter 22.

hodograph: In the early seismology era, the term sometimes used for the time of arrival of various seismic phases as a function of epicentral distance. *See* Chapter 1.

horizontal-to-horizontal spectral ratio: Spectral ratio of horizontal components at a target site to those at a reference site. If a reference site is virtually site-effect free, this corresponds to the true site amplification of the target site. Care must be taken to use a deep borehole station as a reference site, because seismic motion in a borehole are modified differently from the surface motion by the presence of the free surface. *See* Chapter 61.

H/V (horizintal-to-vertical) spectral ratio: Ratio of Fourier amplitude spectra of horizontal and vertical components of ambient noise, or of earthquake *ground motions*, recorded at a site. Typically used to identify the presence of site-specific dominant frequencies in such motions. If this technique is applied to microtremor data, it is sometimes called "Nakamura's method". If applied to the P and S portion of seismic data from distant sources to invert a one-dimensional structure, it is called the "receiver function method". *See* Chapter 62.

hydrology: The science that deals with water on and under the ground surface, including its properties, circulation, and distribution. *See* Chapter 39.

hydrophone: A device for measuring pressure fluctuations in the ocean using a piezoelectric sensor. *See* Chapter 19.

hydrostatic pressure: There are two variations on the usage of this term. In one usage, it simply refers to a stress state that is isotropic, i.e., *shear stresses* are zero. Another common usage is that "hydrostatic pressure" is a special case of "lithostatic pressure" where the density of the overlying column is chosen to be water density. *See* Chapter 33.

hypocenter: A point in the earth where the rupture of the rocks initiates during an earthquake. Its position, in practice, is determined from arrival times of the onsets of *P* and *S waves*. Also called earthquake focus. The point on the earth's surface vertically above the hypocenter is called the *epicenter*. See Lee and Stewart (1981, p. 130-139).

I

I, i : The symbol *I* is used to indicate that part of a ray path has traversed the Earth's inner core as a *P*-wave. For example, *PKIKP* refers to *P-waves* that have penetrated to the interior of the inner core and returned to the surface without conversion to *S-waves* throughout the entire path. On the other hand, *i* is used to indicate reflection at the boundary between outer and inner core (for example, *PKiKP*) in the same manner that *c* is used for reflection at the core-mantle boundary.

IAEE: An acronym for the International Association for Earthquake Engineering. *See* Chapter 81.2

IASPEI: An acronym for the International Association of Seismology and Physics of the Earth's Interior. *See* Chapters 4 and 81.3.

IDNDR: An acronym for the UN International Decade for Natural Disaster Reduction.

igneous rock: A rock that has formed by the solidification of silicate melts at or near the Earth's surface. *See* Chapter 83.

IGS: An acronym for the International GPS Service, an organization responsible for worldwide coordination of continuous GPS measurements. *See* Chapter 37.

impulse response: Output signal of a stationary linear system to an impulsive (delta function) input. *See* Chapter 18 (p. 289), and Aki and Richards (2002, p. 218-219).

induced earthquake: An earthquake that results from stress changes due to man-made sources like filling of a high dam or natural sources like the fault slip of a major earthquake.
See Chapter 40.

INGV: An acronym for the Istituto Nazionale di Geofisica e Vulcanologia, Rome, Italy.

interferometry, 2-pass differential: Approach to calculating interferograms, which uses two radar images and a digital elevation model. Also called DEM-elimination. *See* Chapter 37.

interferometry, 3-pass: Approach to calculating interferograms, which uses three radar images but no elevation model. Also called double-differencing. *See* Chapter 37.

infragravity waves. Infragravity waves are the component of ocean waves at periods longer than 25 seconds. Infragravity waves control long period (>30 seconds) vertical component seismic noise levels at the seafloor and at coastal sites on land. Infragravity waves are trapped along shorelines as edgewaves or surfbeat and are generated by nonlinear mechanisms by the interaction of shorter period (wind driven) ocean waves along coastlines. *See* Chapter 19 (p. 306-307).

inhomogenous plane waves: Plane waves with amplitudes varying in a direction different from the direction of propagation. The velocity of propagation is lower than that of the regular plane waves. For example, *Rayleigh waves* are composed of inhomogeneous *P* and *S waves* propagating horizontally with amplitude decaying with depth. They are also called "evanescent waves." *See* Aki and Richards (2002, p. 149-157).

inner core anisotropy: Refers to elastic *anisotropy* of the inner core. The P velocity along the north-south direction in the inner core is about 3% faster than along east-west directions although the amount appears to vary spatially. *See* Chapter 56.

inner core rotation: The *geodynamo* is expected to drive the inner core to rotate relative to the mantle. The observational evidence for such a differential inner core rotation has been reported but it is still under debate. *See* Chapter 56.

INSAR: An acronym for INterferometric (analysis of) Synthetic Aperture Radar (images). *See* Chapter 37.

Intensity: When capitalized, Intensity typically refers to the *Modified Mercalli Intensity* or one of the other common, non-instrumental, measures of the strength of earthquake motion. See *seismic intensity*.

Internet: The Internet is a worldwide electronic network that consists of mutually connected computers. Seismic data or program files can be transferred on the Internet. *See* Chapter 63.

inverse problem: A typical problem in physics is that of the modeling of natural phenomena. Through such a modeling, and given some parameters describing the system under study, one may predict the outcome of some possible observables. An inverse problem, does the contrary: infer the values of the parameters characterizing a system, given the value of some (indirect) observations. An inverse problem can be formulated as a problem of data fitting or, more generally, as a problem of probabilistic inference. *See inversion*, and Chapter 16.

inverse refraction diagram (for tsunami): A refraction diagram drawn from coastal observation points. Iso-time contours correspond to the travel time encompassed by the ray path to each station from the source region on the map. *See* Chapter 27 (p. 443).

inversion: Given a model hypothesized for explaining a set of observed data, inversion is a procedure for determining the model parameters from the observed data. Various issues involved in this procedure, such as the evaluation of the resolution and error in the estimated parameters, constitute the *inverse problem*. In contrast the prediction of observables for a model with assumed parameters is called the forward problem. *See* Chapters 16 and 52.

IRIG: An acronym for the Inter-Range Instrumentation Group, which was responsible for standardization of time-code format and timing techniques in the White Sands Missile Range, New Mexico, in the 1960s.

ISC: An acronym for the International Seismological Centre. *See* Chapter 81.6.

Ishimoto-Iida's relation: An empirical relation expressing the frequency of occurrence of the maximum amplitudes of earthquakes recorded at a seismograph station obtained by Ishimoto and Iida (1939). Although the concept of magnitude was not known at the time, the power law found for the amplitude distribution is reducible to the power law for earthquake energy implied in *Gutenberg-Richter's frequency-magnitude relation*. They immediately recognized the significance of the departure from the Boltzmann exponential law for statistical energy distribution. *See* Chapter 43.

isoseismal: A line bounding the area within which the intensity from a particular earthquake was predominantly equal to or higher than a given value. *See* Chapter 49.

isotope: Various species of atoms of a chemical element with the same atomic number but different atomic weights. *See* Chapter 39.

ISS: An acronym for the International Seismological Summary. *See* Chapters 41, and 88.

ITRF: An acronym for the International Terrestrial Reference Frame. The geodetic reference frame defined by a combination of *VLBI*, *SLR*, *DORIS* and *GPS* currently used to represent absolute coordinates for sub-centimeter geodetic measurements. *See* Chapter 37.

IUGG: An acronym for the International Union of Geodesy and Geophysics. *See* Chapter 81.1.

J

J: The symbol *J* is used to indicate that part of a ray path has traversed the Earth's inner core as an *S-wave*. Unambiguous observations of waves such as *PKJKP* and *SKJKP* have not yet been achieved, but they may be possible with suitable sources and instrument responses.

Jericho: Situated right on the Dead Sea transform fault. Rebuilding many of the over 20 levels of destruction (and rebuilding) at these sites can be attributed to historical and prehistorical earthquakes. *See* Chapter 46.

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JERS-1: An acronym for the Japanese Earth Resource Satellite 1. *See* Chapter 37.

JMA: An acronym for the Japan Meteorological Agency.

JMA magnitude (M_J): Magnitude for earthquakes in Japan and its vicinity, assigned by JMA using data from the JMA network. M_J is fairly close to M_S for shallow earthquakes and m_B for intermediate and deep earthquakes. *See* Chapter 44.

JMA seismic intensity scale: The *seismic intensity* scale used by JMA. Modified four times since it started in 1884. From 1996 onward, the scale has 10 grades designated as 0, 1, 2, 3. 4, 5-, 5+, 6-, 6+, and 7. *See* Chapter 44.

JPL: An acronym for the Jet Propulsion Laboratory at Pasadena, California. *See* Chapter 37.

Julian day: Number of days since January 0 in a calendar year. It is a compact way to identify a given day in a given year.

K

K: *P-waves* in the outer core are designated as *K* (the German word for core is Kern). For example, *S-waves* traveling steeply downward in the mantle, converted to *P*-waves at the core boundary, propagated through the outer core as *P*-waves, and converted back to *S*-waves at re-entry to the mantle are designated as *SKS*. Just as *PP*, *PPP*, etc. are used to designate surface reflections, *KK*, *KKK*, etc. are used for *P*-waves in the core reflected at the core-mantle interface from below.

kiloton: An energy unit, now defined as a trillion (10^{12}) calories. The term originates from an estimate of the energy released by the explosion of a thousand tons of TNT. *See* Chapter 24.

kinematic ray equations: The ordinary differential equations governing the geometry of a ray path. The independent variable is typically the traveltime or ray path length, and the dependent variables, the ray position and direction. *See* Chapter 9.

kinematics (of seismic source): A description of the deformation or motions within a seismic source region in geometrical terms such as fault slip or transformational strain, without reference to the *stresses* or forces that are responsible (cf. "dynamics"). *See* Chapter 31.

Kirchhoff surface integral method: This method originates from Kirchhoff's solution of the Cauchy problem, i.e., finding a solution of wave equation for a given initial conditions on the wave function and its time derivative defined for the whole space. The solution was expressed as a surface integral of functions given as initial conditions properly time-shifted and weighted over a spherical surface centered at the observation point. It can be generalized to an integral over a non-spherical surface enclosing the region where the homogeneous wave equation is valid. It can be used, for example, to represent scattered waves from a rough surface as a surface integral. The integral reduces to ray-theoretical solution for the planar surface. *See* Chapter 9, and biographies of Augustin Louis Cauchy and Gustav Kirchhoff in Chapter 89.

L

L (LQ, LR): The symbol *L* is used to designate long-period surface waves. When the type of surface wave is known, *LQ* and *LR* are used for *Love waves and Rayleigh waves*, respectively. *See* Chapter 21 (p. 344-346).

L-band: An acronym for Radar frequency around 1.2 GHz with wavelength around 25 cm. *See* Chapter 37.

Landsat: Series of optical imaging satellites. *See* Chapter 37.

Laplace transform: An integral transform mapping signals r(t) defined in the positive time domain (r(t) = 0 for t<0) into the complex domain by multiplying exp(-st) and integrating over t from 0 to infinity. *See* Chapter 22, and biography of Pierre Simon de Laplace in Chapter 89.

lapse time: Time measured beginning from the earthquake origin time. *See* Chapter 13.

LASA: An acronym for the Large Aperture Seismic Array in Montana. *See* Chapter 23.

lateral-force coefficient: A numerical coefficient, specified in terms of a fraction or percentage of the weight of a structure, used in earthquake resistant design to specify the horizontal seismic forces to be resisted by the structure. *See* Chapter 68.

lateral spread in ground failure: Lateral displacement of the ground down gentle slopes or toward a free face as a consequence of *liquefaction* accompanied by flow within subsurface granular layers. *See* Chapter 70.

Layer 2 of oceanic crust: Upper part of the oceanic crust, characterized by velocities lower than about 6.5 km/sec and by high velocity gradients (typically 0.5-1.0 per second). *See* Chapter 55.

Layer 2A of oceanic crust: A layer of particularly low velocities (typically 2-4 km/sec) found in the vicinity of ridge axes, bounded by a sharp velocity increase at its base, and commonly interpreted as an the extrusive basalt layer. *See* Chapter 55.

Layer 3 of oceanic crust: Lower part of the oceanic crust, characterized by velocities normally in the range 6.5-7.2 km/sec and by low velocity gradients (typically 0.1-0.2 per second) *See* Chapter 55.

leaking modes: *Normal modes* in a layered half-space, in general, have cutoff frequencies below which the phase velocity exceeds the *P*- and/or *S*-velocities of the half-space, and the energy leaks through the half-space as *body waves*. Because of the leakage, the amplitude of leaky modes attenuates exponentially with distance. *See* Aki and Richards (2002, p. 312-324).

***Lg*-waves**: Short-period (1-6 seconds) large amplitude arrivals with predominantly transverse motion (Ewing et al., 1957). *Lg*-waves propagate along the surface with velocities close to the average shear velocity in the upper part of the continental crust. The waves are observed only when the wave path is entirely continental. As little as 2° of intervening ocean is sufficient to eliminate the waves. When *Lg*-waves arrive in two distinct groups, they are called *Lg*1 and *Lg*2. *See* Chapter 21 (p. 336-337).

***Li*-waves**: These are similar to *Lg*-waves, but their existence is not as widely accepted as that of *Lg*. The velocity of *Li*-waves is 3.8 km/sec (as compared to 3.5 km/sec for *Lg*) and may be associated with the lower continental crust (Båth, 1954).

linear analysis: A calculation or theoretical study that assumes material properties stay within their linear ranges and that the deflections are small in comparison to characteristic lengths.

These assumptions permit the response to be described by linear differential or matrix equations. *See* Chapter 67.

linearise: To linearise a relationship means that we use a linear approximation to that relationship by keeping only the first-order terms in the Taylor expansion. *See* Chapter 52.

linearity: The ability of a system to produce output from any input using its frequency response alone. *See* Chapter 18.

liquefaction: The transformation of a granular material from a solid state into a liquefied state as a consequence of increased pore water pressures and reduced effective stress. In Engineering Seismology, it refers to the loss of soil strength as a result of an increase in *pore pressure* due to ground motion. *See* Chapter 70.

lithosphere: The rigid upper portion of the near-surface thermal boundary layer of the Earth at temperatures below about 650°C which can store elastic energy under long-term loads. This definition may or may not agree with the seismic lithosphere, which is composed of the crust and the uppermost mantle "lid" above the low velocity layer. See Chapters 51 and 54.

lithostatic stress: There are two variations on the usage of this term. One usage, also called the "lithostatic load" or "lithostatic pressure", gives the vertical *normal stress* as a function of depth due to the gravitational force of the overlying rock column. Another usage, the "lithostatic stress state", combines the "lithostatic load" with assumptions about the *strain* history and rheology of the rock column to produce the complete stress tensor. *See* Chapter 33.

local magnitude (M_L): *Magnitude* introduced by Richter (1935) for earthquakes in southern California. It is based on data recorded by Wood-Anderson seismometers (Anderson and Wood, 1925), which had been out of use since the 1970s. *See* Chapter 44, and biography of Charles Francis Richter in Chapter 89.

local site conditions: Qualitative or quantitative description of the topography, geology and soil profile at a site which affect *ground motions* at the site during an earthquake. *See* Chapter 60.

log-periodic behavior: Power-law (fractal) behavior when the power is not real, but complex. *See* Chapter 14.

long-period: In traditional seismometry with limited dynamic range, *seismographs* were naturally divided into two types; long-period seismographs for periods above the spectral peak (periods around 5 seconds) of the microseismic noise generated by ocean waves and short-period seismographs for periods below it. A long-period seismograph response usually has a bandwidth from about 10 to 100 seconds. *See* Chapter 18.

long-period event: Seismic events occurring under volcanoes with emergent onset of *P waves*, no distinct *S waves*, and a low-frequency content (1 to 5 Hz) as compared with the usual tectonic earthquakes of the same magnitude. Minakami (1961) classified them as the *Type B* to separate them from the *Type A*, which are indistinguishable from usual tectonic earthquakes. Recently, they are found in the *subduction zone* to the depth of about 40 km, not directly associated with individual volcanoes. Their seismic sources are believed to involve fluid such as magma or water. Also called *low-frequency event*. *See* Chapter 25.

long (oceanic) wave: A kind of oceanic *gravity wave*. When the wavelength is much larger than the water depth, it is called long wave or shallow water wave. Most *tsunami* can be treated as long wave. *See* Chapter 28.

longitudinal waves: Displacement associated with far-field *P-waves* in a homogeneous isotropic solid is parallel to the direction of propagation. For this reason, *P*-waves are also called "longitudinal waves." *See* Aki and Richards (2002, p. 73-74).

look vector: Parallel to the line of sight between a radar and its target on the ground. *See* Chapter 37.

loss: In earthquake damage, an adverse economic or social effect (or cumulative effects) of an earthquake (or earthquakes), usually specified as a monetary value or as a fraction or percentage of the total value of a property or portfolio of properties.

loss function: A mathematical expression or graphical relationship between a specified *loss* and a specified *ground-motion parameter* (often the *Modified Mercalli intensity*) for a given structure or class of structures.

Love-Rayleigh wave discrepancy: Observed *phase velocities* of *Love waves* and *Rayleigh waves* require a transverse isotropy in the crust and the uppermost mantle. Love waves are faster than predicted for isotropic models that explain Rayleigh waves. This discrepancy is found universally, both in tectonically active regions like Japan and stable regions like central United States. See Chapter 53.

Love wave: SH-waves trapped near the surface of the Earth and propagating along it. Their existence was first predicted by Love (1911) for a homogeneous layer overlying half-space with an S velocity greater than that of the layer. They can exist, in general, in a vertically heterogeneous media, but not in a homogeneous half space with a planar surface. *See* Chapter 21, and biography of Augustus Edward Hough Love in Chapter 89.

low-frequency event: See *long-period event*.

low pass filter: *Filter* which removes the high *frequency* portion of the input signal. *See* Chapter 22.

low velocity zone: The region in the upper mantle in which velocities are lower than the overlying lid, i.e., the uppermost layer of mantle. Commonly associated with the presence of partial melt and with ductile flow in the *asthenosphere*. *See* Chapter 51.

Lyapunov exponent: Solutions to deterministic equations are chaotic if adjacent solutions diverge exponentially in phase space; the exponent is known as the Lyapunov exponent. Solutions are chaotic if the solution is positive. *See* Chapter 14.

M

macroscopic precursor: Earthquake precursor detected by human sense organs, for example, anomalous animal behavior, gush of well water, earthquake light, and rumbling. *See* Rikitake and Hamada (2002).

macroseismic: Pertaining to the observed (felt) effects of earthquakes. *See* Chapter 49.

macroseismology: The study of the felt effects of earthquakes. *See* Chapter 49.

magnetization: Property of magnetized matter such as amount of magnetism or magnetic dipole moment per unit volume. *See* Chapter 38.

magnetogram: A graphic record of the variation of some parameter of the Earth's magnetic field, produced by a *magnetometer* .

magnetometer: Device for measuring magnetic fields and/or recording the variation of some parameter of the Earth's magnetic field with time. *See* Chapter 38.

magnitude: A quantity intended to measure the size of earthquake and is independent of the place of observation. *Richter magnitude* (M_L) was originally defined in 1935 as the logarithm of the maximum amplitude of seismic waves in a seismogram written by a Wood-Anderson seismograph at a distance of 100 km from the epicenter. Empirical tables were constructed to reduce measurements to the standard distance of 100 km, and the zero of the scale was fixed arbitrarily to fit the smallest earthquake then recorded. The concept was extended later to construct magnitude scales based on other data, resulting in many types of magnitudes, such as *body-wave magnitude* (m_b), *surface-wave magnitude* (M_S), and *moment magnitude* (M_W). In some cases, magnitudes are estimated from *seismic intensity* data, *tsunami* data, or duration of *coda waves*. Earthquakes are classified by magnitude (M) as major if $M > 7$, as moderate if M ranges from 5-7, as small if M ranges from 3-5, and as micro if $M < 3$. An earthquake with magnitude greater than about 7 3/4 is often called “great”. *See* Chapter 44, and Lee and Stewart (1981, p. 153-157).

mainshock: The largest shock in an earthquake sequence.

mantle (Earth’s): Zone of the *Earth*’s interior below the *crust* and above the *core*. The mantle represents about 84% of the Earth’s volume and is divided into the upper mantle and the lower mantle, with a transition zone between. *See* Chapter 51, and Jeanloz (2002).

mantle Rayleigh waves: Just as long-period *Love waves* are given another name, G-waves, long-period *Rayleigh waves* are sometimes called “mantle Rayleigh waves”.

marine microseisms: An ever-present, nearly periodic seismic signal originating from ocean waves and surf. Its amplitude is typically between 0.1 and 10 microns and its period between 4 and 8 seconds. The marine microseisms divide the spectrum of seismic signals into a short-period and a long-period band. See *double frequency microseisms* and *microseisms*.

Maslov asymptotic ray theory: At caustics, ray theory breaks down as the rays are focused and the amplitude predicted is singular. Maslov asymptotic ray theory generalizes ray theory by using an ansatz, which integrates over neighboring rays with appropriate phase delays. Maslov asymptotic ray theory reduces to ray theory when the latter is valid, but remains valid at caustics. *See* Chapter 9.

master model of earthquakes: A concept developed at the Southern California Earthquake Center to use as a framework for integrating multi-disciplinary earth science information regarding earthquakes in Southern California for the purpose of transmitting it to people living there. A first generation master model for southern California is described in WGCEP(1995). *See* Chapter 5.

maximum credible earthquake (MCE): The maximum earthquake, compatible with the known tectonic framework, that appears capable of hitting an area**.** *See* Chapter 62.

maximum probable earthquake (MPE): The maximum earthquake that could hit an area with the largest probability of occurrence**.** *See* Chapter 62.

metamorphic facies: A set of metamorphic rocks characterized by particular mineral associations, indicating origin under a specific pressure-temperature range. *See* Chapter 83.

metamorphic rock: A rock derived from pre-existing rocks by mineralogical, chemical, and/or structural changes, essentially in the solid-state, in response to changes in pressure, temperature, shearing stress, and chemical environment. *See* Chapter 83.

Metropolis method: A general method for sampling a probability, including high-dimensional spaces. *See* Chapter 16.

microcracks: An ensemble of minute cracks that can join to form a crack. *See* Chapter 15.

microseisms: Continuous ground motion constituting background noise for any seismic experiment. Microseisms with frequencies higher than about 1 Hz are usually caused by artificial sources, such as traffic and machinery, and are sometimes called "microtremors", to be distinguished from longer-period microseisms due to natural disturbances. At a typical station in the interior of a continent, the microseisms have predominant periods of about 6 seconds. They are caused by the pressure from standing ocean waves, which may be formed by waves traveling in opposite directions in the source region of a storm or near the coast (Longuet-Higgins, 1950). Also called *double frequency microseism* and *marine microseism*. *See* Chapters 19 and 21, and Aki and Richards (2002, p. 616-617).

mitigation: The proactive use of information, land use, technology, and societies' resources to prevent or minimize the effects of disasters on society. *See* Chapter 75.

MM (Modified Mercalli) seismic intensity scale: Twelve-grade seismic intensity scale (I to XII) published by H. O. Wood and F. Neumann in 1931. It is used in many countries in and outside of North America**.** *See* Richter (1958, 137-139).

modal: A term referring natural modes of vibration or their properties, for example, modal damping. *See* Chapter 67.

mode shape: The shape a structure assumes when it oscillates solely at one of its natural frequencies. Mathematically, a mode shape is an eigenvector of the eigenvalue problem posed by linear, free vibration of a structure. *See* Chapter 67.

Moho: A short word for "Mohorovicic discontinuity", the seismic boundary between the crust and mantle named after A. Mohorovicic who discovered it from the travel time data in Europe (Mohorovicic, 1909). The velocity contrast across the boundary is such that the lower crust typically has a compressional-wave velocity of 6.5-7.4 km/sec, while the uppermost mantle a velocity greater than 7.6 km/sec with an average value of 8.1 km/sec. *See* Chapters 54 and 55, and biography of Andrija Mohorovicic in Chapter 89.

Mohorovicic discontinuity: See *Moho*.

Mohr diagram: A two dimensional diagram of a particular plane (Mohr plane) of the three dimensional stress state. The Mohr plane contains two of the *principal stresses* $\sigma_i > \sigma_j$, and depicts the *shear* and *normal stresses* on planes of all possible orientation whose normals lie in the Mohr plane. The shear and normal stresses define a circle (Mohr circle) of radius $(\sigma_i-\sigma_j)/2$, ordinate $(\sigma_i-\sigma_j)/\sin(2\beta)/ 2$ and abcissa $(\sigma_i+\sigma_j)/2 + (\sigma_i-\sigma_j)/\cos(2\beta)$. β is the angle between σ_i and the normal to the plane of interest. Details on use and construction of Mohr diagrams can be found in Jaeger and Cook [1971]. *See* Chapter 32 (p. 508).

moment connection: A connection between elements of a structure that is capable of transmitting moment as well as shear force. In a moment frame, the joints between the beams and columns are typically designed to take the full moment developed in the beam. *See* Chapter 69.

moment frame: An unbraced planar frame. Moment frames resist lateral forces by flexure of the comprising beams and columns. *See* Chapter 69.

moment magnitude (M_W): *Magnitude* computed using the scalar *seismic moment* M_O, and was introduced by Kanamori (1977). M_W is proportional to 1.5 times the base 10 logarithm of M_O. When available this is the preferred magnitude scale, because it does not saturate for very large or great earthquakes. *See* Chapter 44.

moment tensor: A symmetric second-order tensor that characterizes an internal seismic point source completely. For a finite source, it represents a point source approximation and can be determined from the analysis of seismic waves whose wavelengths are much greater than the source dimensions. *See* Chapter 50, and Aki and Richards (2002, p. 49-51).

Monte Carlo method: Any mathematical method using at its core a random (or, more frequently, pseudo-random) generation of numbers. Monte Carlo methods are typically used to randomly explore high-dimensional spaces, where a systematic exploration is unfeasible. *See* Chapter 16.

MSK seismic intensity scale: Twelve-grade intensity scale (I to XII) proposed by S. Medvedev, W. Sponheuer, and V. Kárník aiming at worldwide use (Sponheuer and Kárník, 1964), by further modifying the *MM (Modified Mercalli) seismic intensity scale*. *See* Chapter 49 (p. 810-811).

multi-degree of freedom: A term applied to a structure or other dynamical system that possess more than a *single degree of freedom*. *See* Chapter 67.

mylonite: A cohesive, penetratively foliated (and usually lineated) fault-rock (L-S tectonite) with at least one of the major mineral constituents (usually quartz) having undergone grain-size reduction through dynamic recrystallization accompanying crystal plastic flow. The mylonite series (protomylonite - mylonite - ultramylonite) reflects progressive reduction in grain size, generally under greenschist facies metamorphic conditions. *See* Chapter 29.

mylonitic gneiss: A comparatively coarse-grained, banded mylonitic *fault-rock* (L-S tectonite) developed in a high-strain ductile shear zone under amphibolite facies metamorphic conditions, in which most of the mineral constituents have undergone dynamic recrystallization. *See* Chapter 29.

N

N discontinuity: A seismic boundary within the *lithosphere* at a depth of 60-120 km reported particularly in Eurasia. Also called “Hales discontinuity”. *See* Chapter 54 (p. 898).

natural frequency: Reciprocal of *natural period*. Measured in Hertz or, with an added coefficient of 2π, radians per second. *See* Chapter 60.

natural period: In earthquake engineering, period of an oscillator or structure during free vibration. Typically measured in seconds. *See* Chapter 60.

near field: A term for the area near the causative fault of an earthquake, often taken as extending a distance from the fault equal to the length of fault rupture. It is also used to refer a distance to a seismic source comparable or shorter than the wavelength concerned.

NOAA: An acronym for the National Oceanic and Atmospheric Administration.

noble gas: A gas in group 0 of the periodic table of the elements (Neon, Argon, Krypton, Xenon, and Radon); it is monatomic and chemically inert. *See* Chapter 39.

noise: Unwanted part of data superimposed on a wanted signal. Noise is often modeled as a *stationary random process*, but may also contain signal-dependent components. One man's noise can be the other man's signal. *See* Chapter 18.

node: A reference point, typically a corner, in a finite element. Because the variation of field quantities of interest, such as displacement, *strain*, velocity, etc., are assumed to vary within finite elements in specified ways, their values become functions of values of key variables at the nodes. *See* Chapter 69.

non-linear analysis: A calculation or theoretical development that includes material changes such as yielding or cracking, or the effects of large displacements such as the increased moment at the base of a structure caused by lateral displacements of floor masses. These effects cannot be considered within the framework of linear equations. *See* Chapter 67.

nonstructural: The parts of a building system that do not support loads (e.g., partitions, exterior claddings, lighting fixtures).

normal fault: A fault that involves lateral extension, where one block moves over another down the dip of the fault plane. *See* Chapter 31.

normal modes: Normal modes were originally defined as free vibrations of a system with a finite number of degrees of freedom, such as a finite number of particles connected by a massless spring. Each mode is a simple harmonic vibration at a certain frequency called an "eigenfrequency". There are as many independent modes as the number of degrees of freedom. An arbitrary motion of the system can be expressed as a superposition of normal modes. Free vibrations of a finite continuum body, such as the Earth, are also called normal modes. In this case, there are an infinite number of normal modes, and an arbitrary motion of the body can be expressed by their superposition. The concept of normal modes has been extended to waveguides in which free waves with a certain phase velocity can exist without external force. Examples are *Rayleigh waves* in a half-space and *Love waves* in a layered half-space. In these cases, however, one cannot express an arbitrary motion by superposing normal modes. *See* Chapter 8 (p. 90-92), Chapter 10, and Aki and Richards (2002, p. 331-383).

normal stress: For a particular orientation of an area element, the normal stress is the force component that is normal to the unit area element. *See* Chapter 33.

NORSAR: An acronym for the NORwegian Seismic ARray in Norway. *See* Chapter 23.

number of deaths (from an earthquake): The number of people killed by an earthquake is often given only very approximately. Widely different figures are found in different literature for a historical earthquake. Even in recent years, such inconsistency may arise due to omission, double counting, difference in the definition of earthquake-related death, inclusion or exclusion of missing people, etc. *See* Chapter 42.

O

OBS: An acronym for *ocean bottom seismometer*.

ocean bottom seismometer/hydrophone (OBS/OBH): A receiver for seismic signals which is located at or near the seabed. An OBH is commonly moored a few meters above the seabed and has a single hydrophone sensor. An OBS commonly rests on the seabed and in addition to a hydrophone has a three-component seismographs, which may be inside the recording package or deployed as a separate package for better coupling. *See* Chapter 55.

Omori's relation (Omori's law): A relation expressing the temporal decay of the aftershock frequency. Occasionally called "hyperbolic law". The modified Omori relation generalizes it to a power law dependence on time with the power allowed to deviate from –1. Also see *p value*. *See* Chapter 43, and biography of Fusakichi Omori in Chapter 89.

one-dimensional amplification of seismic waves: In site effect studies a one-dimensional structure means a structure varying only in the vertical direction. It is also called a horizontally-layered structure. The amplification for incident body waves can be theoretically calculated by considering multiple transmission and reflection at each interface of horizontal layers including the free surface. There is no amplification for surface waves incident on such a structure since it is assumed to be homogeneous in the horizontal directions. *See* Chapter 61.

organized noise: Seismic noise whose power spectrum is not uniformly distributed, but is concentrated at particular wave numbers and frequencies. *See* Chapter 23.

origin time: The instant of time when an earthquake begins at the *hypocenter*. It is usually determined from arrive times of seismic waves by the *Geiger's method*.

orthorhombic symmetry: Symmetry with respect to three mutually orthogonal planes. There are 9 independent elastic parameters for an orthorhombic material. Olivine crystals are orthorhombic. *See* Chapter 53.

oversampling: A sampling technique in which the analog input signal is first sampled at a sampling rate much higher than the final sampling rate and subsequently decimated digitally. *See* Chapter 22.

P

P*: Designates *P-waves* refracted through an intermediate layer in the Earth's *crust* with a velocity near 6.5 km/sec. The upper boundary of this layer has been called the *Conrad discontinuity*. See Chapter 21.

P': Another symbol for *PKP*.

passband: The portion of the frequency spectrum that a *filter* passes with less than 3-*decibel* attenuation. See Ballou (1987).

***P* coda**: The portion of *P-waves* after the arrival of the primary waves. They may be due to *P* to *S* conversions at interfaces or to multiple reflections in layers or to *scattering* by three-dimensional inhomogeneities.

P_dP or *PdP*: This wave is like the surface reflection *PP*, except that the reflection occurs at an interface at depth *d* (expressed in kilometers, e.g., $P_{600}P$) instead of at the surface.

P_d , P_u , P_r : The travel time for *P*-waves near Δ = 20° shows a triplication due to a sharp velocity increase in the upper mantle below the low-velocity layer. Three branches are designated in the order of decreasing dt/dΔ as P_d (direct), P_u (upper), and P_r (refracted).

p value: An index in the modified *Omori relation* showing the decay of aftershock frequency in time. A higher p value indicates more rapid decay. Estimated p values for most aftershock sequences fall between 0.9 and 1.5. In original Omori's relation the p value is fixed to 1. *See* Chapter 43.

paleoearthquake: An ancient earthquake.

paleoseismic event: A *paleoearthquake* that caused surface faulting.

Paleoseismology: The study of earthquakes decades, centuries or millenia after their occurrence. *See* Chapter 30.

parabolic approximation: An approximation to the wave equation in which the second derivative with respect to the global ray direction is neglected. It can be justified when the wavelength is much smaller than the characteristic length of the heterogeneity. The wave equation then becomes parabolic in type. This approximation includes diffraction and forward *scattering* but neglects backscattering in the formulation. *See* Chapter 13.

paraxial ray: Originally defined for an optical system with a symmetrical axis of rotation. A ray of light near this axis and has a small inclination to the axis is called a paraxial ray. In seismic ray theory it is defined as a ray generated by perturbing the source position or take-off direction of a central ray. The dynamic ray equation governs the properties of the paraxial ray. *See* Chapter 9.

participation factor: A factor that apportions scaled versions of the input to a multi-degree of freedom system to the various modes of the system. The factor is not unique and depends on how the mode shapes are normalized. In one common normalization scheme the participation factors add to unity; in this case the participation factor for a mode is the fraction of excitation that mode receives. *See* Chapter 67.

passive-source seismology: seismic investigations that utilize data from naturally occurring seismic events. *See* Chapter 54.

path effect: The effect of the propagation path on seismic *ground motions*. It is implicitly assumed that the source, path and site effects on ground motions are separable.

p-delta effect: The destabilizing moment of gravity created when the masses of a vertical structure, such as a building, experience lateral displacements.

pendulum: A mechanical sensing element of a *seismometer*, consisting of a mass free to pivot about some point. In the simple or common pendulum, the mass is below the pivot, and constrained to move in a vertical plane; in the inverted pendulum, the mass is directly over the pivot; and in the horizontal pendulum, the mass is to one side of the pivot, and is constrained to move in a nearly horizontal circle. *See* Chapter 18, p. 284-285).

percolation cluster: A grid of sites is considered in two or three dimensions. The probability that a site is permeable is specified, and there is a sudden onset of flow through the grid at a critical value of this probability. *See* Chapter 14.

period (of a signal): Most seismic signals are aperiodic but can be mathematically represented as a superposition of periodic sinusoidal (time-harmonic) signals. Speaking of “the period” of a seismic signal usually means that time-harmonic components around this period predominate. *See* Chapter 18.

period: The length of time required to complete one cycle or a single oscillation of a periodic process. See also n*atural period*.

permeability (hydraulic): Rate of fluid flow through rock per unit pressure gradient. *See* Chapters 36 and 38.

permeability (magnetic): A coefficient relating magnetic flux density to magnetic field intensity. *See* Chapter 38.

permittivity: Constant relating force between two charges separated by a distance. *See* Chapter 38.

phase response: The phase of the complex frequency response. *See* Chapter 18.

physical master model: A type of *master model of earthquakes* in which universally applicable laws of physics and chemistry are applied to geologic processes to integrate earth science information regarding earthquakes in a given region. Its construction has been an ultimate goal beyond that of the *hazard master model* at the Southern California Earthquake Center. *See* Chapter 5.

piercing line: A term in paleoseismology indicating a feature that crosses a fault, is well defined, and is datable using one or more geochronologic methods. The point where a piercing line intersects a fault is called “piercing point”. *See* Chapter 30.

piezomagnetism: Changes in rock magnetism resulting from stress loading. *See* Chapter 38.

pinned connection: A connection that can transmit shear but not moment, like a hinge. Historically, actual pins were used in such connections, particularly in bridges, but in modern construction most such "pinned joints" are welded or bolted joints not designed to transmit significant moments.

PKIKP: *P wave* transmitted through the outer and inner core of the Earth. *See* Chapter 21 (p. 342), and Chapter 53 (p. 880-881).

PKJKP: *P wave* that travels as a converted shear wave through the solid inner core (known as a J wave). The PKJKP phase has yet to be reliably observed and has become the Holy Grail of teleseismic body wave seismology. *See* Chapter 56.

PKP precursors: PKP phases become first geometric arrivals beyond the *core shadow*. However, sometimes on a short period seismogram at distance range of about 128 to 140 degrees, clearly visible waves arrive a few to 10 seconds prior to the PKP phases. The precursors are believed to be *scattering* from heterogeneous lowermost mantle or the whole mantle. *See* Chapter 21 (p. 341-342), and Chapter 56.

PKP triplication: In a travel time curve, a triplication, which has three distinct branches of seismic phases, is the result of wave propagation through a zone of a steep velocity increase with depth. The PKP triplication is associated with the marked P velocity increase from the bottom of fluid outer core to the top of the solid inner core. *See* Chapter 56.

planar frame: An assemblage of vertical columns and horizontal beams, with or without inclined braces, where all members lie in a single plane.

***PL*-waves**: A train of long-period waves (30 to 50 seconds) observed in the interval between *P-waves* and *S-waves* for distances less than about 30°. They show normal dispersion (longer periods arriving earlier). They are explained as a *leaking mode* of the crust-mantle waveguide. *See* Aki and Richards (2002, p. 323).

plastic hinge: A term given to a point on a structural element, typically a beam or column, where the element has yielded to the extent that increased curvature occurs without increase in the resisting moment. *See* Chapter 59.

plastic strain rate: Irreversible strain rate expressed by a tensor. *See* Chapter 15.

plate boundary zone: The zone of diffuse deformation, often marked by a distribution of seismicity, active faulting, and topography, within which relative plate motion is accommodated. Plate boundary zones are typically narrow under ocean and broad under continent. *See* Chapter 7.

plate driving forces: Forces that drive the motion of Earth's lithospheric plates. Terms such as "ridge push", "slab pull" and "basal shear" have been used to describe them. *See* Chapter 34.

plate waves: The period equation for normal modes in an infinite plate in a vacuum can be split into two. One of the equations governs the mode with motion symmetric with respect to the median of the plate, and the other governs the mode with antisymmetric motion. The former is sometimes called the *M*1-wave, and the latter *M*2. For example, *M*11 and *M*12 are the fundamental and first higher modes of the *M*1 wave, respectively. For very short waves, both *M*11 and *M*21 approach *Rayleigh waves* in an elastic half-space made of the plate material. For wavelengths that are long compared with plate thickness, *M*21 are called flexural waves. They are dispersive, with phase velocities decreasing to zero with increasing wavelength.

P_n or *Pn*: Beyond a certain critical distance, generally in the range from 100 to 200 km, the first arrival from seismic sources in the *crust* corresponds to waves refracted from the top of the mantle. Called P_n, these waves are relatively small, with long-period motion followed by larger and sharper waves of shorter period called $\bar{P}$, which are propagated through the crust. The P_n-wave has long been interpreted as a *head (conical) wave* along the interface of two homogeneous media -- namely, crust and mantle. The observed amplitude, however, is usually greater than that predicted for head waves, implying that the velocity change is not exactly step-like but has a finite gradient at or below the transition zone. The designation P_n has been applied to short-period *P*-waves that propagate over considerable distances (even up to 20°) with horizontal phase velocities in the range 7.8-8.3 km/sec. An interpretation in terms of head waves at the *Moho* is unsatisfactory (although the horizontal velocity and travel times would be explained), because head waves must decay rapidly with distance. More likely is an explanation in terms of guided waves, within a high-*Q* layer several tens of kilometers in thickness at the top of the mantle. (cf. S_n). *See* Chapter 21 (p. 335-338), and Chapter 54.

Po, So: A designation for *Pn* and *Sn* propagating across ocean basins. *See* Chapter 19.

$\bar{P}$ (*Pg*): Travel-time curves at short distances (up to a few hundred km) for seismic sources in the Earth's *crust* usually consist of two intersecting straight lines; one with velocity about 6 km/sec at shorter distances and the other about 8 km/sec at greater distances. The former is attributed to direct *P*-waves propagating through the crust and is designated as $\bar{P}$ or *Pg*, which stands for granitic layer. The latter is *Pn*. *See* Chapter 21 (p. 335-338).

point process: A series of events distributed according to a probabilistic rule. *See* Chapter 43.

Poisson's ratio: An elastic body like a metal bar under uniaxial tension shows elongation along the tension axis and shrinkage in the transverse direction. The ratio of the transverse strain to the longitudinal strain is called Poisson’s ratio. Poisson’s ratios for rocks are typically around 0.25. *See* Chapter 83, and biography of Simeon Denis Poisson in Chapter 89.

Poisson process: A point process in which events are statistically independently and uniformly distributed. *See* Chapter 43, and biography of Simeon Denis Poisson in Chapter 89.

polarization anisotropy: A term used (in contrast to *azimuthal anisotropy*) to refer to an anisotropic medium in which the seismic-wave properties depend apparently on the polarization of the waves, and not on the azimuth of their propagation direction. SH/SV differences of velocity and *Love/Rayleigh-wave discrepancies* are often referred to "polarization anisotropy" while azimuthal variations of velocity would be due to "azimuthal anisotropy". *See* Chapter 53.

pore-fluid factor: The ratio of fluid pressure to overburden pressure ($\lambda_v = P_f/\sigma_v$) employed as a measure of the degree of overpressuring. For typical rock densities, $\lambda_v \sim 0.4$ and $\lambda_v = 1.0$ denote hydrostatic and lithostatic fluid-pressure conditions, respectively. *See* Chapter 29.

pore pressure: In soil mechanics, the pressure within the fluid that fills voids between soil particles. In rock mechanics, the pressure due to liquids in formations that offsets the strengthening effect of *normal stresses* acting on a fault. At a given depth, the ambient pore pressure is usually assumed equivalent to that of a column of water extending upward to the ground surface or within a rock mass. Also called the neutral stress. *See* Chapters 36, 40, and 70.

porosity: Void volume per unit volume of a porous material usually expressed as a percentage. . *See* Chapter 36.

precursor time: The time span between the onset of an anomalous phenomenon and the occurrence of the main shock.

pre-event memory: In a triggered recording by a digital *seismograph*, it refers to buffered signal memory from which the ground motion can be retrieved for a time segment prior to the time the instrument was triggered. *See* Chapter 58.

preliminary tremors: In early seismological studies, the term used for the small motions at the start of an earthquake record. For local earthquakes, this corresponds to the waves in the interval between the first P arrival and the main S arrival in modern terms. Omori found that its duration is proportional to the epicentral distance with the coefficient of about 8 km/sec. *See* Chapter 1, and biography of Fusakichi Omori in Chapter 89.

pressure: If a material element has zero "*shear stress*", then the *principal stresses* all share the same value; this value is the pressure. Any rotation of the coordinate system produces the same value for the normal stresses, hence a stress state with zero shear stress is isotropic and the stress tensor can be written as the product of the scalar quantity "pressure" and the identity matrix. Even if shear stresses are present, the isotropic component of the stress state can be extracted from the general stress tensor. The pressure is simply the average value of the three normal stresses regardless of the coordinate system orientation. *See* Chapter 33.

pressure solution: Water assisted ductile deformation mechanism whereby minerals are sequentially dissolved from highly stressed regions, transported through fluid by diffusion or advection, and precipitated in low stress regions. *See* Chapter 32 (p. 528).

principal axes *(of a tensor)*: Three orthogonal axes at which the rotated tensor has only diagonal elements. For example, in the case of the seismic *moment tensor* corresponding to a double couple source, the principal axes are called the compression axis, tension axis and null axis. *See* Chapter 50.

principal displacement zone (PDZ): The zone of concentrated slip (sometimes referred to as the fault core) accommodating most of the displacement within the more distributed deformation (damage zone) defining a major fault zone. *See* Chapter 29.

principal part *(of seismogram)*: In early seismological studies, the term used for the largest motions seen from an earthquake; in modern terms, mostly *surface waves* for teleseismic events and *S waves* for local earthquakes. *See* Chapter 1.

principal plane: The most favorably oriented plane for shear fracture. Given planes of equal shear strength and of all possible orientation, the principal plane is that which minimizes the work done in shear. The orientation is given by tan $2\beta=1/\mu_*$, where β is the angle between the greatest *principal stress* and the normal to the plane of interest, and μ_* is the *coefficient of friction* for a fault or the coefficient of internal friction for an intact rock. *See* Chapter 32 (p. 508).

principal stresses: *Normal stresses* acting on the plane perpendicular to the *principal axes* of a stress tensor. Shear stresses vanish on these planes. *See* Chapters 33 and 34.

prior information: The information one may have on the parameters characterizing a system, prior to any actual measurement. *See* Chapter 16.

probabilistic earthquake scenario: A representation, in terms of useful descriptive parameters, of earthquake effects with a specified *probability of exceedance* during a prescribed period in an area. *See* Chapter 62.

probabilistic seismic hazard analysis (PSHA): Available information on earthquake sources in a given region is combined with theoretical and empirical relations among earthquake *magnitude*, distance from the source and local site conditions to evaluate the *exceedance probability* of a certain *ground motion parameter*, such as the peak acceleration, at a given site during a prescribed period. *See* Chapters 5 and 65.

probability of exceedance: The probability that an earthquake *ground motion parameter* will be greater than the value predicted for some time period in a given area. *See* Chapter 74.

probable maximum loss (PML): A probable upper limit of the *losses* that are expected to occur as a result of a damaging earthquake, normally defined as the largest monetary loss associated with one or more earthquakes proposed to occur on specific faults or within specific source zones.

pseudotachylyte: A black aphanitic *fault-rock* retaining evidence of a melt origin (relic glass, devitrification or quench textures) attributed to heat generated by localized seismic slip. Also developed in association with impact structures or at the base of some landslides. *See* Chapter 29.

push over analysis: An analysis used to estimate the capacity of a structure to resist collapse from strong ground motion. Typically used in earthquake resist design studies, the analysis employs a selected force profile that is increased in intensity until the analysis indicates a structural element will fail or yield. That member is replaced by its yielding resistance, or removed if failed, and the force profile increased until another member yields or fails. The process is repeated until the overall structure has a constant or declining resistance under increased load. The deflection profile at this final stage approximates the structure's ultimate, non-linear, earthquake resistance. *See* Chapter 59.

***P*-waves**: Compressional elastic waves are called *P-waves* in seismology, *P* standing for "primary." In a homogeneous isotropic body, the velocity of *P*-waves is equal to $\sqrt{[(\kappa + 4/3\ \mu)/\rho]}$, where κ, μ, and ρ are bulk modulus, rigidity, and density, respectively. The particle displacement associated with *P*-waves is often parallel to the direction of wave propagation. For this reason, *P*-waves are sometimes called "longitudinal waves". *See* Chapter 21 (p. 334-336).

Q

Q inverse(Q^{-1}): The reciprocal of Q value quantitatively characterizes the decay rate of wave energy per cycle for *body waves* or *surface waves*. It is called spacial Q^{-1} if measured from the amplitude attenuation per unit distance and temporal Q^{-1} if measured from that per unit lapse time. They can be different for dispersed waves. *See* Chapter 13.

quasi-isotropic ray theory: Quasi-isotropic ray theory describes rays in weakly anisotropic media and includes the coupling between quasi-shear rays. The quasi-isotropic ray ansatz depends on the signal period and the anisotropic part of the model parameters. *See* Chapter 9.

quasi-plastic (QP) regime: That portion of the *crust* or *lithosphere* where fault motion is governed by localized ductile shearing in which temperature-sensitive crystal plastic and/or diffusional flow mechanisms dominate. *See* Chapter 29.

R

Radar: An acronym for RAdio Detection And Ranging. *See* Chapter 37.

RADARSAT: An acronym for Multi-mode, C-band radar satellite, launched by Canada in 1995. *See* Chapter 37.

radial anisotropy: A term sometimes used to denote *hexagonal symmetry* with a vertical symmetry axis. Traditionally called *transverse isotropy*. *See* Chapter 53.

radiation damping: The dissipation of energy through the transmission of vibratory energy that is not reflected or confined. Radiation damping occurs, for example, in the idealized problem of a vibrating structure imbedded in a linear, elastic half space, even when the material of the half space is not dissipative. *See* Chapter 67.

radiative transfer theory: Phenomenological theory that describes multiple *scattering* process based on the energy conservation law, which neglects the interference between wave packets. It is often applied to model the propagation of high-frequency seismic-wave energy in heterogeneous Earth media. *See* Chapter 13.

radioactivity: The emission of radiation or energetic particles during the decay of an unstable atomic nucleus. *See* Chapter 39.

radiocarbon dating: Geochronology using radioactive ^{14}C. *See* Chapter 30.

random media: A mathematical model for a medium whose spatial variation in parameters is described by random functions. Their autocorrelation functions or power spectral density functions give their statistical properties. *See* Chapter 13.

random walk: The typical path followed by a molecule in Brownian motion. By extension, the path followed in a parameter space when using a *Monte Carlo method*. *See* Chapter 16, and biography of Robert Brown in Chapter 89.

range: Distance along the line of sight between the satellite and the ground. *See* Chapter 37.

rate and state dependent friction: A class of constitutive relationships that describe sliding *friction* over a wide range of conditions and time scales, developed by Ruina [1983] and Rice and Ruina [1983] as a generalization of equations of Dieterich [1978, 1979]. These relations consist of a base frictional resistance and depend on the sliding speed (rate) and contacts (state) on the fault plane. *See* Chapter 37 (p. 521) and Chapter 73.

rate strengthening: A term used to describe a positive dependence of fault shear strength on sliding velocity; always produces aseismic fault slip. *See* Chapter 32 (p. 521).

rate weakening: A term used to describe a negative dependence of shear strength on sliding velocity; can lead to frictional instability (seismic slip) under some circumstances. *See* Chapter 32 (p. 521).

ray Green's function: The approximate *Green's function* obtained using *asymptotic ray theory*. *See* Chapter 9, and biography of George Green in Chapter 89.

Rayleigh damping: A form of *damping* used in the matrix analysis of structures in which the damping matrix is a constant times the mass matrix plus another constant times the stiffness matrix. Rayleigh damping produces viscous damping factors in the modes that are dependent on the natural frequencies of the mode. The constants are chosen to produce desired damping factors over the important modes of response. *See* Chapter 67, and biography of Lord Rayleigh in Chapter 89.

Rayleigh wave: Coupled *P* and *SV waves* trapped near the surface of the Earth and propagating along it. Their existence was first predicted by Rayleigh (1887) for a homogeneous half-space, for which the velocity of propagation is 0.88 to 0.95 times the shear velocity and their particle motion is retrograde elliptic near the surface. They can exist, in general, in a vertically heterogeneous media bounded by a free surface. *See* Chapter 8 (p. 87-88), Chapter 21 (p. 334-335), Aki and Richards (2002, p. 155-157), and biography of Lord Rayleigh in Chapter 89.

receiver functions: Spectral ratio of the horizontal component of *S waves* to the vertical component of *P waves* recorded at a single station from a teleseismic event. Assuming a horizontally layered structure beneath the station, it gives an estimate of the seismic velocity structure, particularly nature of discontinuities, of the crust and the uppermost mantle. *See* Chapter 54.

recurrence interval: The average time interval between consecutive *events* which occur repeatedly. *See* Chapter 30.

recursive technique: A computational technique based on a formula which relates certain coefficients, say for a filter, at the nth step with those at the $(n+1)$th step. Desired coefficients are obtained at the nth step by an iterative use of the formula starting with the initial values at the 0th step. *See* Chapter 50.

reflection seismology: Study of Earth's structure by the use of seismic waves originating from a near-surface source and reflected back to the surface from sub-surface discontinuities.

reflection/transmission coefficients: The amplitudes of reflected and transmitted waves relative to the incident wave at an sub-surface discontinuity. The coefficients are found by imposing boundary conditions that the seismic displacement and the *traction* acting on the discontinuity surface are continuous across the surface. These conditions physically mean a welded contact and absence of extra-seismic sources at the discontinuity. Coefficients are traditionally defined for seismic energies carried by each component waves, but more recently they are given for amplitudes of their particular components. *See* Chapter 9.

refraction diagram (tsunami): A chart indicating *tsunami* wavefronts from the source. It is used to predict tsunami travel times from a given source area. *See* Chapter 28.

refraction seismology: Study of Earth's structure by the use of seismic waves from a near-surface source refracted back to the surface after propagation along deep interfaces.

regional strain: A description of the overall deformation of a region. *See* Chapter 31.

regional waves: Seismic waves which propagate laterally in the *crust* and uppermost *mantle*. Examples are *Pg, Pn, Sn, Lg,* and *Rg*. These waves are distinguished from teleseismic waves which propagate in the deep interior of the *Earth*. Regional waves typically propagate over epicentral distances up to 1500 km (somewhat further, for *Lg*), and their travel speed can be very different for different regions. For example, *Pn wave*, which travels along the top of mantle, can arrive 8 seconds earlier in some regions and 5 seconds later in other regions as compared to the global average arrival time for the same distance. *See* Chapter 24.

renewal process: A *point process* in which the statistical distribution of the intervals between consecutive events are statistically independent and stationary. *See* Chapter 43.

residual strength: Shear resistance within cohesive soils at very large shear deformations or within contractive granular soils in the liquefied state. *See* Chapter 70.

resistivity: Electrical resistance between the opposite faces of a cube of material with unit side length. *See* Chapter 38.

response-spectral ordinate: A term in engineering seismology, indicating the amplitude of a *response spectrum* at a specified value of undamped *natural period* or *frequency* . *See* Chapter 60.

response spectrum: The maximum response to a specified acceleration time series of a set of *single-degree-of-freedom* oscillators with chosen levels of viscous damping, plotted as a function of the undamped *natural period* or undamped *natural frequency* of the system. The response spectrum is used for the prediction of the earthquake response of a building or other structure. *See* Chapter 57.

return period: The average time between exceedance of a specified level of *ground motion* at a specific location; it is equal to the inverse of the *annual probability of exceedance*.

reverse fault: A fault that involves lateral shortening, where one block moves over another up the dip of the fault. Reverse faults that dip less than about 30 degrees are often called "*thrust fault*". *See* Chapter 31.

Rg: *Short-period*, fundamental-mode *Rayleigh waves* (in the range 8 to 12 seconds) observed for continental paths are sometimes designated as "*Rg*" (Ewing *et al*., 1957). *See* Chapter 21 (p. 337).

Richter scale: Also called Richter magnitude scale, or *local magnitude* (M_L). In public it means all magnitude scales. See *magnitude*.

ripple-firing, delay-firing, millisecond delay initiation: These are all terms used to characterize mine-blasting activity, in which a particular shot is carried out as a series of separate charges, fired in a sequence instead of all together. Ripple-firing is the term commonly used, but experts usually refer to delay-firing (where a common delay is 8 milliseconds between charges), and in some cases to millisecond delay initiation (where a specifically timed pattern of charges is executed that may entail delays that are designed for a particular blasting objective, such as fragmenting rock to a pre-determined size and moving the fragments a pre-specified distance). *See* Chapter 24.

root n improvement: More precisely, "square root n" improvement as expected from *delay-and-sum processing* of n independent recordings with noise that has uniform power. *See* Chapter 23.

Rytov method: A method to find an approximate solution for the logarithm of wavefield (complex phase function) for waves in smoothly varying inhomogeneous media. In Rytov approximation the second order term of the gradient of the complex phase function is often neglected. *See* Chapter 13.

***Sa*-waves**: Sa-waves typically have periods of 10 to 30 seconds and a group velocity of 4.4 to 4.5 km/sec measured along the surface. They can have both *SV*- and *SH*-components of motion. Their waveforms are usually complex and vary from station to station in an irregular manner.

SAR: An acronym for Synthetic Aperture Radar. *See* Chapter 37.

saturation (of a magnitude scale): Above a certain magnitude level, the *magnitude* determined from amplitudes or amplitude/period ratios of seismic waves recorded by a specific seismograph increases only slowly or does not increase as the physical size of the earthquake (such as measured by the *moment magnitude*, M_W,) increases. This behavior, sometimes called saturation, is due to the long period limit of the frequency response of the *seismograph* and is more prominent for magnitudes based on short-period seismographs. Magnitudes m_b, M_L, m_B, and M_S saturate for earthquakes with M_W larger than about 6.0, 6.5, 7.0, and 8.0, respectively. Earthquakes with magnitude m_b >6.5, M_L >7.0, m_B >7.5, or M_S >8.5 have rarely been found due to almost complete saturation. No saturation occurs for M_W and M_t. *See* Chapter 44.

scale invariance: The phenomenon which appears identical at a variety of scales. *See* Chapter 14.

scattering: In physics, it refers to an alteration in direction of motion of a particle because of collision with another particle. In seismology, the particle is replaced by a wave, and it represents the change in wave properties such as waveforms and ray directions by inclusions or *heterogeneities* in the material properties of the medium. *See* Chapter 13.

scattering coefficient: *Scattering* power per unit volume of heterogeneous media having a dimension of the reciprocal of length. This quantity characterizes the coda excitation of a local earthquake and the strength of scattering attenuation in heterogeneous media. *See* Chapter 13.

SCEC: An acronym for the Southern California Earthquake Center. A consortium of researchers in universities and governments working on earthquakes in southern California, started in 1991 as one of the centers of the Science Technology Center Program of the US National Science Foundation. *See* Chapter 5.

SCR: An acronym for tectonically stable continental region, where crustal strain rates are exceedingly low. *See* Chapter 40.

ScS: Waves traveled as *S waves* in the mantle until reaching the core-mantle boundary and reflected there back to the surface propagating also as S waves. *See* Chapter 21 (p. 341), and Chapter 53.

SEASAT: An acronym for the L-band radar satellite with altimeter, which flew only for several months in 1978. *See* Chapter 37.

sedimentary rock: A rock formed from the consolidation of sediment.

segment or segmentation model: The assumption that earthquake faults are divided into discrete, identifiable sections that behave distinctively over multiple rupture cycles. *See* Chapter 30.

seiche: A free oscillation (resonance) of the surface of an enclosed body of water, such as a lake, pond, or bay with a narrow entrance. They are sometimes excited by earthquakes and by *tsunamis*. The period of oscillation ranges from a few minutes to a few hours, and the oscillation may last for several hours to one or two days.

seismic albedo: The ratio of *scattering coefficient* to total attenuation coefficient**,** i.e., the sum of absorption coefficient and scattering coefficient. This term derives from the original term "albedo" in astrophysics. *See* Chapter 13.

seismic anisotropy: A term used for effective material parameters which depend on the direction of propagation or polarization of seismic waves. It includes isotropic media with aligned small-scale *heterogeneities* that may behave anisotropic for seismic wavelengths longer than the heterogeneity scale. See *anisotropy***.** *See* Chapters 52 and 53.

seismic array: An array of *seismographs* distributed over the surface or volume (with bore-hole sites) of the *Earth* whose outputs are transmitted to and recorded at a central station. Since 1960's many arrays have been constructed for detecting underground nuclear tests like LASA (Large Aperture Seismic Array) in Montana and NORSAR (NORwegian Seismic ARray) in Norway. *See* Chapter 23.

seismic bulletin: Compilation or listing of seismic data from different stations (mainly phase arrival times, amplitudes and periods of waves) associated in seismic *events*. When enough and consistent data are available, event locations and magnitudes are also computed and listed. The most important global seismic bulletin for 1964 to present is the bulletin of International Seismological Centre (*ISC*). Prior to 1964 the most relevant global bulletins are those of the International Seismological Summary (ISS) and the Bureau Central International de Seismologie (BCIS). *See* Chapters 41, and 88.

seismic catalog: Compilation or listing or earthquake focal parameters. The basic focal parameters reported by most seismic catalogs are: earthquake origin time, latitude, longitude, depth, and some indicator of the size (e.g. *magnitude*). Unlike *seismic bulletins*, seismic catalogs do not include the data (mostly phase arrival times) that were used to obtain the *hypocenter* location or the other focal parameters. See *catalog*.

seismic core phase: A general term referring to seismic body-wave phase that enters the Earth's core. *See* Chapter 56.

seismic gap: An area of a seismic zone in which seismic activity is low as compared to the neighboring areas of the same zone.. Such an area is often considered to be the seat of the next large earthquake following the idea of Fedotov (1965) who found that great earthquakes in the northern Pacific tended to occur in regions lacking earthquakes for several decades, and tended to rupture discrete segments which will eventually fill the whole seismic zone without overlapping. *See* Chapter 72.

seismic hazard: Any physical phenomenon associated with an earthquake (e.g., *ground motion* or ground failure) that has the potential to produce a *loss* . It is also used without regard to a loss to indicate the probable level of ground shaking occurring at a given point within a certain period of time. *See* Chapters 65 and 74.

seismic hazard analysis (SHA): The calculation of the seismic hazard, expressed in probabilistic terms (see *probabilistic seismic hazard*) for a site or group of sites, the result of which is usually displayed as a *seismic hazard curve* or *seismic hazard map* . *See* Chapters 65 and 74.

seismic hazard curve: A plot of probabilistic seismic hazard (usually specified in terms of *annual probability of exceedance*) or return period versus a specified *ground-motion parameter* for a given site.

seismic hazard map: A map showing contours of a specified *ground-motion parameter* or *response spectrum* ordinate for a given probabilistic seismic hazard or return period.

seismic intensity: The degree of ground shaking estimated from its effect on construction and natural objects. The intensity scales are essential for assigning *magnitude* to earthquakes for which instrumental data are not available. The most recent (used in Chapter 48.5) is the European Macroseismic Scale, which has twelve degrees, running from 1 (not felt) to 12 (total devastation). Other examples include *MM (modified Mercalli) seismic intensity scale* in the US and *JMA seismic intensity scale* in Japan. In Japan, intensities are also measured instrumentally after the installation of intensity meters in 1991-1995. *See* Chapter 49.

seismic lid: The mantle part of the seismic *lithosphere* overlying the low velocity zone. *See* Chapter 51.

seismic moment: The magnitude of the component couple of the double couple that is the point force system equivalent to a fault slip in an isotropic elastic body. It is equal to rigidity times the fault slip integrated over the fault plane. It can be estimated from the far-field seismic spectrum at wave lengths much longer than the source size. It can also be estimated from the near-field seismic, geologic and geodetic data, and the consistency among various observations supports the validity of the fault origin of an earthquake. Also called “scalar seismic moment” to distinguish it from *moment tensor*. *See* Chapter 28 (p. 445-446), and Aki and Richards (2002, p. 48-49).

seismic network: A network of *seismographs* deployed for a specific purpose. A *seismic array* or a telemetered seismic network is a seismic network in which all *seismometers* or seismographs are connected to a central recording station with a common time base. *See* Chapters 17 and 87.

seismic noise: *See microseisms.*

seismic rays and tubes: A seismic ray is a path in 3D space along which seismic energy can be considered to propagate like a particle. For high-frequency seismic signals, this is a useful approximation and simplification. Neighboring rays form a ray tube and the energy flux is confined within its walls. *See* Chapter 9.

seismic refraction/wide-angle reflection profiles: Also referred to as Deep Seismic Sounding (DSS) profiles. Seismic velocity structures in the lithosphere derived from data recorded with long offsets (100-300 km) between sources and receivers consisting of widely-spaced geophones (100-5,000 m). *See* Chapter 54.

seismic risk: The risk to life and property from earthquakes. In probabilistic risk analyses, the probability that a specified loss will exceed some quantifiable 1evel during a given exposure time. *See* Chapter 65.

seismic risk analysis (SRA): The calculation of *seismic risk* for a given property, or portfolio of properties, usually performed in a probabilistic framework and displayed as a *seismic risk curve* or *seismic hazard map* . *See* Chapter 65.

seismic risk curve: A plot of *seismic risk* (usually specified in terms of *annual probability of exceedance* or *return period*) versus a specified loss for a given property or portfolio of properties.

seismic station: A modern seismic station, like the one in *TriNet* , has a weak motion sensor (e.g., a *broadband seismometer*), a strong motion sensor (e.g., an *accelerometer*), and a data logger with *GPS* timing, onboard storage, and real-time communication devices.

seismic tomography: An imaging method using a set of seismic data obtained from a two-dimensional array of *seismographs* distributed over Earth's surface to deduce the three-dimensional structure of Earth's interior. In most cases, velocity structures are obtained from the travel time data. Various computational techniques have been developed for data from different types of seismic sources including natural sources like teleseismic events and local earthquakes as well as controlled sources like explosions, air guns and bore-hole sources. *See* Chapter 52.

seismic wave onset: The beginning of a seismic wavelet.

seismic zoning map: A map used to portray seismic hazard or seismic design variables. For example, maps used in building codes to identify areas of uniform seismic design requirements.
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seismicity: A term introduced by Gutenberg and Richter (1949) to describe quantitatively the space, time and magnitude distribution of earthquake occurrences. Seismicity within a specific source zone or region is usually quantified in terms of a *Gutenberg-Richter relationship*. *See* Chapter 43.

seismite: Sedimentary units or features resulting from earthquake shaking. *See* Chapter 30.

seismoelectric: Electric fields generated by crustal stress changes during earthquakes. *See* Chapter 38.

seismogenic thickness: The thickness of the *brittle* layer within the *lithosphere* in which earthquakes occur. On the continents this thickness is typically 10 to 15 km, corresponding to the region at temperature lower than 300-400 degree C. *See* Chapter 31.

seismogenic zone: That portion of the crust or *lithosphere* capable of generating earthquakes. *See* Chapter 29.

seismogram: A record of *ground motions* made by a *seismograph*. *See* Chapters 17 and 21.

seismograph: Instrument that detects and records *ground motions* (and especially vibrations due to earthquakes) along with timing information. It consists of a *seismometer*, a precise timing element, and a recording device or data logger. *See* Chapters 17 and 18.

seismological parameter: Parameter used to characterize a seismological property of the source, propagation path, or site-response characteristics of an earthquake. *See* Chapter 60.

seismology: A branch of earth science dealing with mechanical vibrations of the Earth caused by natural sources like earthquakes and volcanic eruptions, and controlled sources like underground explosions.

seismomagnetic: Magnetic fields generated by crustal stress changes during earthquakes. *See* Chapter 38.

seismometer: A sensor that responds to *ground motions* and produces a signal that can be recorded. *See* Chapters 17 and 18.

seismometer array: *See seismic array*.

seismoscope: A device that indicates some feature of *ground motion* during an earthquake, but without producing the time-dependent record. Seismocopes are forerunners of *seismographs*.

self-organized criticality: A system in a marginally steady state in which the input is continuous and the output is a series of “avalanches” satisfying a power-law (fractal) frequency-size distribution. *See* Chapter 14.

serpentinization: A process by which the upper mantle reacts chemically with seawater to generate serpentine minerals. This process can cause substantial reductions in both P- and S-wave velocities. *See* Chapter 55.

$\bar{S}$ **(*Sg*)**: *S-waves* propagating through the crust like $\bar{P}$ or *Pg*. These waves are seen with simple impulsive onsets at short distances (up to a few tens of km). At greater distances, onset may not be impulsive (due to multiple paths all trapped in the crust) and *Sg* then is an alternate name for the wave also called *Lg*.

SH, SV: *S-waves* with polarization direction in the horizontal and vertical planes, respectively. For a vertically heterogeneous medium, SH-waves do not interact with *P-waves* and are simpler than SV-waves. In an anisotropic medium in which *shear-wave splitting* occurs according to the local symmetry of the medium, SH and SV classification becomes meaningless in general.

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shadow zone: Distance range along the Earth's surface in which a direct phase is not observed as a result of downward deflection of the ray path by a low velocity zone at depth. *See* Chapter 51.

shake map: A map of earthquake *ground motion* showing the geographical distribution of ground shaking as described by a specific parameter such as peak acceleration. *See* Chapter 78.

shallow water wave: A kind of oceanic *gravity wave*. When the wavelength is much larger than the water depth, it is called long wave or shallow water wave. Most *tsunami* can be treated as shallow water wave. *See* Chapter 28.

Shanidar: A cave in northern Iraq in which several Neanderthal skeletons were uncovered, dating back to 50,000 BP presumably crushed by roof collapse caused by repeated earthquakes. The oldest known casualty of earthquakes on earth. *See* Chapter 46.

shear connection: A connection between a beam and a column designed to transmit only the shear force from the beam to the column and not the moment. In a steel frame building shear connections typically have the web of the beam welded or bolted to the column, but show gaps between the flanges of the beam and the surface of the column.

shear-coupled *PL*-waves: This is a long-period wavetrain that follows *S* for distances up to about 80°. It has been explained as being due to the coupling of *S-waves* with a *leaking mode* of the crust-mantle waveguide, i.e., *PL*-waves. The coupling of *PL*-waves with *SS* and *SSS* has also been observed.

shear stress: There is some confusion over the usage of this term (see text for discussion in Chapter 33). Perhaps the most practical definition follows from the definition of "*normal stress*": shear stress is the force component that is tangential to a unit area element of particular orientation. In three-dimensions, there are two independent force components tangential to an area element, thus further specification is required. Another definition of shear stress cites the difference between two *principal stresses*, while still another definition cites half the difference between two principal stresses. The latter definition is compatible with the Mohr's Circle representation (see *Mohr diagram*) of the stress state.

Shear waves: See *S-waves*.

shear-wave splitting: Behavior of *S waves* in an anisotropic medium which shows a split into two *shear waves* with mutually perpendicular polarization directions and different propagation velocities. *See* Chapter 53.

short-period: In traditional seismometry with limited *dynamic range*, *seismographs* were naturally divided into two types; long-period seismographs for periods above the spectral peak (periods around 5 seconds) of the microseismic noise generated by ocean waves and short-period seismographs for periods below it. A short-period seismograph response usually has a bandwidth from 0.1 second or less to about 1 second. *See* Chapter 18.

short-period body-wave magnitude (mb): See *body-wave magnitude*.

Sigma-Delta modulation: A technique for *analog to digital conversion* commonly used in seismic acquisition systems. *See* Chapter 22.

signal-to-noise improvement: A measure of how well a wanted signal is enhanced by processing, relative to the ambient noise and unwanted signals. Assuming that the processing leaves the signal unchanged, the signal-to-noise improvement is often expressed as the square root of the ratio of the noise power (or its average over channels for an array) before processing to the power after processing. *See* Chapter 23.

signal: The wanted part of given data. The remaining part is called noise.

signal association: A major problem in detection of seismic events using a *seismic network* is to sort out and correctly identify the sources of overlapping *events*. This work is called signal association and is challenging particularly for global networks, which commonly locate more than 100 events per day. *See* Chapter 24.

signal detection: The detection of weak signals imposed upon noise can be accomplished by noting significant changes in amplitude, or frequency content. If the signal to be detected has a waveform that is known beforehand, for example, from a prior event in the same location and recorded at the same station, then correlation methods or matched filtering can be applied for detection. *See* Chapter 24.

signal to noise ratio (SNR): The ratio of the power (variance) of the signal to that of the noise for a given frequency band. *See* Chapter 19.

silent earthquake: Fault failure without any seismic radiation. *See* Chapter 36.

simulated annealing: A trick used to solve optimization problems, taking its roots in a thermodynamical analogy. Simulated annealing is based on the Metropolis algorithm. *See* Chapter 16.

single-degree-of-freedom (SDOF) system: An oscillator or structure with a single mode or period of vibration whose response is describable mathematically by a single variable. *See* Chapter 60.

single frequency microseisms: A secondary peak near 14-second period in seismic noise related to the action of ocean waves usually 20-40 dB smaller than the main peak due to the *double frequency microseism* . Called the single frequency peak because the seismic noise is at the same frequency as the ocean waves. *See* Chapter 19.

SIR-C: An acronym for Shuttle Imaging Radar C. *See* Chapter 37.

site category: Category of site conditions affecting earthquake ground motions based on geology, seismic velocity, or other observations. For example, in the *USGS* recommendation site condition is classified into A (hard rock) to F (very soft soil) and a different amplification factor is assigned for each category. *See* Chapter 61.

site classification: Description of the ground characteristics at a site in geological terms (e.g. crystalline rock, Quaternary deposits, ...), or by means of a geotechnical characterization of the soil profile, e.g. *S-wave* velocity. *See* Chapter 62.

site effect: The effect of local geologic and topographic conditions at a recording site on *ground motions*. It is implicitly assumed that the source, path and site effects on ground motions are separable. *See* Chapter 61.

site response: The modification of earthquake *ground motion* in the time or frequency domain caused by local site conditions. *See* Chapters 60 and 61.

Skempton's coefficient: A poroelastic constant B relating changes in mean stress σ_m to pore fluid pressure p, $B = dp/d\sigma_m$. *See* Chapter 32 (p. 526).

SKS: Mantle *shear wave* transmitted through the outer core as a *P wave*. *See* Chapter 21 (p. 341-343), Chapter 53, and Aki and Richards (2002, Box 5.9, p. 181-182).

slab: Subducted oceanic plate, typically a dipping tabular region of relatively high seismic velocity, and low temperature. Deep earthquakes only occur within subducted slabs, and such *seismicity* extends to depths down to 700 km. *See* Chapter 51.

SLC: An acronym for Single Look Complex. Radar image including both phase and amplitude information, after processing by the synthetic aperture resolution reconstruction process. *See* Chapter 37.

slip moment: A geological term for *seismic moment* . *See* Chapter 36.

slip vector: The direction of slip in a fault plane, showing the relative motion between the two sides of the fault. *See* Chapter 31.

slip waves: See *creep waves*.

slope-intercept method: A graphical technique used to infer seismic velocities and layer thicknesses from seismic traveltime data, based on the assumption that the crust is built up of uniform layers bounded by horizontal discontinuities. *See* Chapter 55.

slow earthquake: Fault failure occurring without significant seismic radiation. *See* Chapter 36.

SLR: An acronym for Satellite Laser Ranging. *See* Chapter 37.

S_n or *Sn*: Early use of the designation S_n was in reference to short-period *S-waves* that were presumed to propagate as *head waves* along the top of the mantle. Quite commonly, the term is also now applied to a prominent arrival of short-period *shear waves* that may be observed (with a straight-line travel-time curve) at epicentral distances as great as 40°. *See* Chapter 21 (p. 335-336).

SOFAR channel: A depth region of low acoustic velocity under the ocean. It is a very efficient wave guide for the seismic *T phase* from earthquake sources. *See* Chapter 21.

soil-structure interaction: A term applied to the consequences of the deformation and forces induced into the soil by the movement of a structure. The common fixed-base assumption in the analysis of structures implies no soil-structure interaction.

sound waves: See *air waves*.

source-to-site distance: Shortest distance between an observation point and the source of an earthquake that is represented as either a point (point-source distance measure) or a ruptured area (finite-source distance measure). *See* Chapter 60.

source directivity effect: The effect of the earthquake source on the amplitude and duration of the seismic motions propagating in different directions. Directivity effects are comparable to, but not exactly the same as the *Doppler effect* for a moving oscillator, resulting from the propagation of fault rupture in one or more directions with finite speeds. *See* Chapter 62.

source effect: The effect of the earthquake source on seismic motions. It is implicitly assumed that the source, path and site effects on *ground motions* are separable. *See* Chapter 5.

source zone: An area in which an earthquake is expected to originate. More specifically, an area considered to have a uniform rate of *seismicity* or a single probability distribution for purposes of a *seismic hazard* or *seismic risk analysis*.

space-based geodesy: Space-based technologies to measure the positions of geodetic monuments on the Earth. A fundamental departure from the traditional geodesy is its reference to an inertial reference frame rather than those fixed to the Earth. Current accuracy of better than a centimeter for sites thousands of kilometers apart are good enough for measuring the present-day plate motion. *See* Chapters 7 and 37.

Sparta earthquake in 469 BC: The occurrence of this earthquake triggered an uprising by indigenous people and neighboring enemies. *See* Chapter 46.

spectrum intensity (S.I.): A broad band measure of the intensity of strong ground motion defined by the area under a response spectrum between two selected natural periods or frequencies. First introduced by Housner (1952) as the area under the 20 per cent damped response spectrum between periods of 0.1 and 2.5 seconds.

SPOT: An acronym for the Satellite Pour l'Observation de la Terre, a series of optical imaging satellites with a resolution of 10 or 20 m for Earth observation. *See* Chapter 37.

spread footing: A support structure for a wall, column or pier that is essentially a horizontal mat, usually of reinforced concrete, lacking piles or caissons. The footing works by spreading the load over an area wide enough to reduce the bearing stresses to permissible levels.

SRSS (Square Root of the Sum of Squares): A technique used in earthquake engineering analysis and design wherein the maximum contributions of different modes to a variable of interest, determined from a response spectrum or spectra, are combined by squaring them, adding, and taking the square root of the sum. The result gives an estimate of how the modal responses, whose time of maximum occurrence is not known, combine to produce the maximum total response.

SRTM: An acronym for the Shuttle Radar Topographic Mission. *See* Chapter 37.

state of tectonic stress: The magnitude and orientation of *principal stresses* in the Earth. Principal stresses are usually aligned with horizontal and vertical. *See* Chapter 34.

static fatigue: A laboratory observed phenomenon in mechanical engineering, material science, and rock mechanics consisting of an inherent time delay between the application of a stress increase and the occurrence of brittle failure (stress drop) induced by the stress change. *See* Chapter 32 (p. 523).

static stress-change: A static stress-change is a permanent stress-change, e.g., associated with the final slip (offset) on an earthquake fault. *See* Chapter 73.

station calibration: In a global monitoring of seismic *events*, it is used to obtain the characteristics of waves arriving at a particular seismic station, e.g., the azimuthal variation and distance dependence of travel times for different seismic phases. More broadly, the term applies to the bias in magnitude estimation from amplitudes of various types of waves observed at a station with respect to the network-average. *See* Chapter 24.

stationary random process: An ensemble of time series for which the ensemble-averaged statistical properties such as mean and variance do not vary with time. If the statistical averages taken over time for a single member of the ensemble are the same as the corresponding averages taken across the ensemble, the stationary random process is also ergodic.

steady-state strength: The shear resistance of contractive soil in the liquefied state. With respect to *liquefaction*, the steady-state strength and the residual strength are used interchangeably. *See* Chapter 70.

steepest ascent method: A method for finding a local maximum of a function that is based in small steps following the local direction of maximum ascent. *See* Chapter 16.

steepest descent method: A method for finding a local minimum of a function that is based in small steps following the local direction of maximum descent. *See* Chapter 16.

stick-slip: A periodic or quasi-periodic faulting cycle consisting of a relatively long period of static, predominately elastic loading followed by rapid fault slip seen on laboratory fault surfaces loaded at a constant rate of shear stressing; stick-slip is considered the laboratory time scale equivalent of periodic earthquake recurrence. *See* Chapter 32 (p. 518).

stochastic *process*: A physical process with some random or statistical element in its structure. *See* Chapter 14.

Stoneley waves: Waves trapped at a plane interface of two elastic media. They are always possible at a solid-fluid interface with the phase velocity lower than the compressional velocity of fluid. It can exist at a solid-solid interface only in restrictive cases. *See* Chapter 19, Aki and Richards (2002, p. 156-157), and biography of Robert Stoneley in Chapter 89.

strain: Deformation or change in shape and size of a body under applied forces. *See* Chapter 36.

strain events: Episodic strain transients recorded by strainmeters. *See* Chapter 36.

strain hardening: The property of a material to resist post-yield strains with increasing stress, as opposed to the constant post yield stress of a perfectly plastic material.

strain steps: Step-like changes in strain recorded by strainmeters. *See* Chapter 36.

stress: Force exerted per unit area of an internal surface by the body on one side (which includes the normal vector) of the surface to that on the other. It must specify the direction of normal to the surface as well as the direction of force, thus requiring a tensor for its complete representation. In three dimensions, forces can act in three directions and an area element can have three independent orientations. Hence there are nine components of stress, though the typical symmetry conditions reduce the stress description to six independent components. In contrast, traction is a force vector defined for a particular surface. *See* Chapters 33, 34, and 36.

stress corrosion: A *stress* degradation process that is related to the action of some chemical agents. *See* Chapter 15.

stress drop: See *earthquake stress drop*.

stress map: Map showing the orientation and relative magnitude of horizontal *principal stress* orientations. *See* Chapter 34.

stress shadow: A region where earthquakes are not supposed to occur because the *stress* has been decreased from the critical failure level. A fault can remain in a stress shadow until forces such as those generated by long-term tectonic loading or nearby earthquakes increase the stress on the fault towards the critical level. *See* Chapter 73.

Strike-slip fault: A fault on which the movement is parallel to the strike of the fault, e.g., the San Andreas fault. *See* Yeats *et al.,* (1997, p.167-248).

strong ground motion: A *ground motion* having the potential to cause significant risk to a structure's architectural or structural components, or to its contents. One common practical designation of strong ground motion is a peak ground acceleration of 0.05g or larger. *See* Chapter 60.

strong motion: *See strong ground motion*.

strong motion parameter: Parameter characterizing the amplitude of *strong ground motion* in the time domain (time-domain parameter), or frequency domain (frequency-domain parameter). *See* Chapter 60.

strong motion seismograph (accelerograph) (instrument): *Seismograph* designed to record faithfully the *strong ground motion* generated by an earthquake. They were originally developed by earthquake engineers, because the seismographs designed by seismologists to record weak motions from distant earthquakes were too fragile to record strong motions. Typical strong-motion seismograph has a tri-axial *accelerometer*, which records acceleration up to 2 g on scale. It is often called *accelerograph*. *See* Chapters 57, and 63.

strong motion sensor (in Trinet): In *TriNet* the strong motion sensors have a linear frequency response from DC to an upper corner at 50 or 80 Hz. USGS/Caltech sensors clip at 2g and the CDMG sensors clip at 4g. Strong motion sensor is often called *accelerometer*. *See* Chapter 78.

strong motion station (in Trinet): In *TriNet* the strong motion station has a tri-axial set of strong motion sensors, datalogger with *GPS* timing, and real-time or near real-time communication capability. These stations are deployed in free-field to serve as a reference site to those of important engineered structures. *See* Chapter 78.

structural geology: The study of geologic structures and their formation processes. In areas directly related with earthquakes, it includes the relation between faults, folds and deformation of rocks on all scales. *See* Chapter 31.

subduction zone: A zone of convergence of two lithospheric plates characterized by thrusting of one plate beneath the other. Subduction zones (where most of the world’s greatest earthquakes occurred) are also called Wadati-Benioff zones in honor of K. Wadati and H. Benioff, who studied the seismicity off the coast of Japan and noticed that the earthquake locations suggested a dipping boundary. *See* Chapter 6 (p. 62-64), and biographies of Hugo Benioff and Kiyoo Wadati in Chapter 89.

substructure: Generally, that portion of a structure that lies below the ground, for example the basement parking in a tall building. In analyses, the substructure can include a portion of the surrounding ground as well as all or part of the structural foundation. *See* Chapter 69.

superstructure: That portion of a structure that is above the surface of the ground or other reference elevation at which significant change in the structure occurs. *See* Chapter 69.

surface *P*-waves: The ray path of surface *P* consists of two segments: an *S-wave* path from the source to the free surface with an apparent horizontal velocity equal to the *P*-wave velocity, and a *P-wave* path along the free surface to the receiver. The surface *P*-waves appear at the critical distance and can be a sharper arrival than the direct *S*-waves, although they attenuate very rapidly with distance. In some respects they behave like *head waves*.

surface reflections (*PP, SS, SP, PS, PPP, SSS*): *P-waves* that have undergone one reflection at the surface before arriving at the recording station are denoted as *PP* if the wave initially left the *hypocenter* in the downward direction (in contrast to *pP*, which leaves in an upward direction). Those reflected twice at the surface are denoted as *PPP*. Likewise, *PS* is a once-reflected wave arriving at the station as an *S-wave* after conversion by reflection from *P*-waves.

surface-wave magnitude (M_S): Earthquake *magnitude* determined from *surface wave* records. The one introduced by Gutenberg (1945) uses maximum amplitudes of surface waves with periods around 20 seconds. This magnitude is computed only for events shallower than 50 or 60 km, and saturates for earthquakes larger than magnitude 8. The surface-wave magnitudes assigned by *USGS* and *ISC* are calculated from a formula called the IASPEI formula or Prague formula developed by Vanek *et al.* (1962) using amplitude/period ratios. *See* Chapters 41 and 44

surface waves: Seismic waves trapped near the Earth's surface and propagating along it. See *Love waves* and *Rayleigh waves. See* Chapters 11 and 21.

SV: See ***SH, SV***.

swarm (of earthquakes): A sequence of earthquakes occurring closely clustered in space and time with no dominant main shock. *See* Chapters 25 and 43.

S-waves: Elastic shear waves are called *S*-waves in seismology, *S* standing for "secondary." In a homogeneous isotropic body, the velocity of *S*-waves is equal to $\sqrt{(\mu/\rho)}$, where μ and ρ are rigidity and density, respectively. The particle displacement associated with *S*-waves is perpendicular to the direction of wave propagation if the medium is isotropic. For this reason, waves are sometimes called "transverse waves". *See* Chapter 21 (p. 334-336).

synthetic (ground motion): Time-history of a *ground motion* for engineering purposes calculated by a deterministic or stochastic simulation for models of earthquake source, propagation path and recording site structures. *See* Chapter 62.

synthetic seismograms: Computer-generated *seismograms* for a model of Earth's structure. Various methods are used for different purposes. For example, in oceanic crustal studies, the most commonly used methods are the time-domain ray theory approach (for two-dimensional structures) and the frequency-domain reflectivity method (for one-dimensional structures). *See* Chapter 55.

T

T phase, T wave: Tertiary wave in seismology introduced by Linehan(1940), next to P(primary) and S(secondary) waves. It is generated by an earthquake in and near the oceans, propagated in the oceans as acoustic wave guided in the *SOFAR channel* and converted back to seismic wave at the ocean-land boundary near the recording site. *See* Chapter 21.

tamped explosion: A chemical, single-fired explosion in which the explosive is buried under the ground firmly to avoid venting into the atmosphere**.** *See* Chapter 24.

tectonoelectric: Electric fields generated by non-seismic crustal stress changes. *See* Chapter 38.

tectonomagnetic: Magnetic fields generated by non-seismic crustal stress changes. *See* Chapter 38.

teleseism: An earthquake recorded at an epicentral distance larger than about 20 degrees or 2000 km. *See* Chapter 21.

tensor strainmeters: Borehole strainmeters measuring three horizontal strain components from which the principal strain components can be derived. *See* Chapter 36.

TERRAscope: A *seismic network* of ultra-broad band (360 or 120 seconds on the low end and 8 or 50 Hz on the high end) instruments with dataloggers that have onsite storage, *GPS* timing, and real-time transmission capability. The TERRAscope network of 24 stations has been integrated into *TriNet*. *See* Chapter 78.

thermal fluid pressurization: transient thermal pressurization of fault zone fluids as a consequence of heat generated during seismic slip. *See* Chapter 29.

three-dimensional site amplification: Traditionally the site amplification of *ground motion* has been modeled by a depth-dependent one-dimensional structure. The three-dimensional amplification considers a structure varying in all directions such as the irregular topography and sub-surface interfaces. The computational load increases dramatically as we proceed from 1-D to 3-D through the intermediate 2-D approximation. *See* Chapter 61.

thrust fault: A *reverse fault* that dips at shallow angles, typically less than about 30 degrees. *See* Chapter 31.

tilt noise: A noise on a horizontal-component *seismogram* created by rotation (local tilt) around a horizontal axis. Slight tilts produce large apparent accelerations as a component of the acceleration of gravity is rotated into the horizontal components. *See* Chapter 19.

tiltmeters: Instruments for measuring the horizontal gradient of vertical displacement or tilt of the Earth's surface. *See* Chapter 36.

time history: An engineering term for a *seismogram* or a time-dependent response, examples include an *accelerogram* or the displacement of point in a structure. *See* Chapter 56.

tomogram: An image of (usually a slice through) the interior of a body (in this case, the Earth) formed using *tomography*. *See* Chapter 52.

tomography: The science and art of creating images of the interior of a body. *See seismic tomography* for imaging the Earth**.** *See* Chapter 52.

topographic site effects: Site effects caused by surface irregularities such as canyons or mountains. In practice, it is difficult to separate topographic effects from effects caused by subsurface layering. *See* Chapter 61.

total overburden stress: The vertical stress in a soil layer due to the weight of overlying soil, water, and surface loads. *See* Chapter 70.

trace: In observational seismology, a trace is a plot of the time history of seismic waveforms recorded by a channel of a *seismograph* . An analog signal recorded usually on film or smoked paper by an accelerometer is often referred to as a trace. *See* Chapter 58.

traction: Force exerted per unit area of a particular internal or external surface by the body on one side (containing the normal vector) of the surface to that on the other. This is a vector in contrast to the stress tensor.

transducer: A device that converts a signal in one physical form to that in another. For example, a seismic transducer convert seismic motion into electric current.

transfer function: *Laplace transform* of the *impulse response* of a linear system (*filter*), or Laplace transform of the output signal divided by that of the input signal. *See* Chapters 18 and 22.

transform fault: A strike-slip fault that extends throughout the lithosphere and joins two other plate margins. It was proposed by Wilson (1965) and confirmed by Sykes (1967). See Chapter 57 (p. 57), and biography of J. Tuzo Wilson in Chapter 89.

transition zone: A term in the study of the Earth's interior, referring to the depth range from 410 to about 800 km, in which solid state phase transitions produce strong velocity gradients and sharp seismic discontinuities. Sometimes used only for the depth range 410-660 km between the major discontinuities at those depths. *See* Chapter 51.

transmitting boundary: In analytical studies, a boundary to a region of interest that approximates the effects of media outside the boundary. Transmitting boundaries or boundary elements are often used in finite element studies to include the effects of far extents of solid or fluid domains.

transport equation: The ordinary differential equations describing the variation of the amplitude coefficients along a ray. *See* Chapter 9.

transverse isotropy: A term introduced by Love (1927) to describe a medium with one axis of cylindrical symmetry. In the geophysical literature, this axis is often implicitly considered as vertical, so that the velocity and polarization are independent of the azimuth of propagation in the horizontal plane. *See* Chapter 53.

traveltime and wavefront: High-frequency seismic signals in a smoothly varying medium propagate approximately without dispersion along rays. The traveltime is the time taken for the signal to propagate from one point to another along a ray, and a wavefront is a surface in 3D space of points with the same traveltime for a common source point. *See* Chapter 9.

trench log: A map of an excavation or trench wall that exposes geologic formations or structures for detailed study. Trench logs constitute primary data records for many paleoseismic investigations. *See* Chapter 30.

triaxial seismometer: A set of three seismic sensors whose sensitive axes are perpendicular to each other. *See* Chapter 18.

triggered earthquake: An earthquake that results from stress changes that are small compared to ambient stress levels at the earthquake source. *See* Chapter 40.

triggering: In seismology and earthquake engineering, the turning on of an instrument, especially an accelerometer turned on by strong motion of a prescribed level. In soil mechanics, the onset of a liquefied condition. *See* Chapter 70.

TriNet: A coined word referring to the three agencies that built and operate a modern ground network in southern California: the California Institute of Technology, the California Division of Mines and Geology, and the US Geological survey. TriNet also refers to the *seismic network* itself. *See* Chapter 78.

triplication: Behavior of the travel-time curve showing three arrivals for the same range of epicentral distance caused by a sharp increase of velocity with depth. This happens when a part of ray paths refracted from below the zone of velocity increase appears at shorter distances than that from above the zone. These two travel-time branches are connected by the so called receding branch associated with ray paths through the zone. *See* Chapter 51.

tromometer: Originally a simple-pendulum *seismoscope*, observed with a microscope, to measure background vibrations. Used through about 1900 as another term for *seismometer*. *See* Chapter 1.

tsunami: *Gravity waves* set up on the surface of the sea by disturbances in the sea bed, such as a submarine earthquake, landslide, or volcanic explosion. Tsunami amplitudes are typically small in the open ocean, but can reach damaging amplitudes near shore or in shallow or confined waters. Also called seismic sea waves. *See* Chapter 26.

tsunami earthquakes: Earthquakes that generate much larger *tsunamis* than expected from their magnitudes. *See* Chapter 26.

tsunami magnitude (M_t): *Magnitude* of an earthquake determined from the heights of *tsunami* at a given travel distance, representing the strength of a tsunami source. The tsunami magnitude M_t, as referenced to *moment magnitude* (M_W), was introduced by Abe (1979). *See* Chapters 26 and 44.

tsunami run-up height: *tsunami* height on land measured at maximum inundation distance from coast. *See* Chapters 26.

tsunamigenic earthquake: An earthquake associated with *tsunamis*. Most large shallow earthquakes under the sea are tsunamigenic. *See* Chapter 26.

tube waves in a borehole: In an empty cylindrical hole, a kind of surface wave can propagate along the axis of the hole with energy confined to the vicinity of the hole. They exhibit dispersion with phase velocity increasing with the wavelength. At wavelengths much shorter than the hole radius, they approach *Rayleigh waves*. The phase velocity reaches the shear velocity at wavelengths of about three times the radius. Beyond this cutoff wavelength, they attenuate quickly by radiating *S*-waves. In a fluid-filled cylindrical hole, in addition to a series of multi-reflected conical waves propagating in the fluid, tube waves exist without a cutoff for the entire period range. At short wavelengths, they approach *Stoneley waves* for the plane liquid-solid interface. For wavelengths longer than about 10 times the hole radius, the velocity of tube waves becomes constant, given in terms of the bulk modulus κ of the fluid and the rigidity μ of the solid, by $\upsilon = c / \sqrt{(1 + \kappa/\mu)}$, where c is the acoustic velocity in the fluid.

two-dimensional site amplification: *Site effect* calculated for a structure varying in the vertical direction and in only one horizontal direction. In a purely two-dimensional case, incident waves are assumed to be homogeneous along the same horizontal direction. The case in which the incident wave field is allowed to be three-dimensional, such as spherical waves, is sometimes called 2.5-dimensional. *See* Chapter 61.

U

Ubeidiya: The oldest human made structure on earth – a pebble floor in northern Israel about 1.2 million years ago. Originally, horizontal it is now tilted at 60° or so due to fault motion on the Dead Sea transform. *See* Chapter 46.

ULF: Ultra-low frequency electromagnetic fields. *See* Chapter 38.

underplating: Addition of igneous material to the base of the crust, a process thought to have occurred at volcanic rifted margins and beneath some ocean islands. *See* Chapter 55.

uniform hazard response spectrum: In *probabilistic hazard analysis*, a *response spectrum* with ordinates having equal probability of being exceeded. *See* Chapter 56.

uniform shear beam: A beam with constant properties, but arbitrary cross-section, that can deform only in shear and whose response is described by a one-dimensional wave equation. A cantilevered shear beam is often used as a simplified model of a building. *See* Chapter 67.

unreinforced masonry: Construction that employs brick, stone, clay tile or similar materials, but lacks steel bars or other strengthening elements. *See* Chapter 67.

USCGS: An acronym for the United States Coast and Geodetic Survey.

USGS: An acronym for the United States Geological Survey.

UTC: An acronym for the Universal Time Coordinated, a time scale defined by the International Time Bureau and agreed upon by international convention.

V

velocity fields: A term in geodesy describing the deformation within a region given by the velocities of various points relative to some reference frame. *See* Chapters 31.

viscous damping: The most commonly used type of *damping* for analytical or numerical studies of earthquake response. A viscous damper generates a force proportional to the relative velocity of its two attachment points in a direction that opposes the motion. Viscous damping is one of the few forms of damping that can be described by linear equations. *See* Chapter 67.

visible earthquake waves: Slow waves with long period and short wavelengths reported by eyewitnesses in the epicentral area of a great earthquake.

VLBI: An acronym for Very Long Baseline Interferometry. X-band. Radar frequency around 9 GHz with wavelength around 3 cm. *See* Chapter 37.

volcanic tremor: The seismic signals generated by volcanic activity are quite variable in character, ranging from those indistinguishable from tectonic earthquakes to continuous vibrations with relatively low frequencies (0.5-5 Hz). The continuous vibrations are known as volcanic, or harmonic, tremor. Harmonic tremor has a very uniform appearance, whereas spasmodic tremor is pulsating and consists of higher frequencies with a more irregular appearance. *See* Chapter 25.

Volume (Vol. n): A defined stage of the operations of processing strong motion data, typically ranging from Vol. 1 (raw *acceleration* data) through Vol. 3 (*response spectra*). *See* Chapter 58.

W

Wadati-Benioff zone: See *Subduction zone*.

wave-number filtering: Analysis of array seismic data assuming that the wave field is composed of plane harmonic waves with *frequency* ω propagating along the surface with an *apparent velocity* c. The wave number k is ω/c.. Wave number filtering is to enhance wanted signals in a known region of the frequency-wave number space. *See* Chapter 23.

waveform inversion: A term used both in earth structure and earthquake source studies, indicating the use of the whole waveform data instead of their particular characteristics like arrival time of a certain phase, sense of the first motion, or maximum amplitude. Various inversion procedures can be used for estimating the model parameters of earth structure and earthquake source, by minimizing the misfit between the observed and *synthetic seismograms* based on trial parameters. *See* Chapter 31.

WEGENER: An SLR geodetic network around the Mediterranean. *See* Chapter 37.

WGS84: An acronym for World Geodetic System, 1984. A system of coordinates conventionally used for (coarse) *GPS* coordinates. Includes an ellipsoid with inverse flattening 1/f = 298.25722 and semi-major axis = 6378.137 km (DMA, 1987). *See* Chapter 37.

wide-angle seismic method: A modern term for seismic experiments in which the source and receiver are widely separated compared to the target depth. This term is preferred over the traditional "seismic refraction" method because of the recognition that much of the information on crustal structure in modern experiments comes from reflected phases. *See* Chapter 55.

WWSSN: An acronym for the World-Wide Standardized Seismograph Network. *See* Chapters 17 and 20.

Z

z-transform: A discrete equivalent of the *Laplace transform*. *See* Chapter 22, and Claerbout (1976, p. 1-8).

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