The IASPEI Standard Seismic Phase List

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INTRODUCTION

At a meeting in Hanoi on 23 August 2001, the IASPEI Commission on Seismological Observation and Interpretation decided to set up a Working Group on Standard Phase Names. The working group has put together a modified standard nomenclature of seismic phases that is meant to be concise, consistent, and self-explanatory on the basis of agreed rules. We did not try to create a complete list of all phases. The list is open to further development. The list is not meant to satisfy specific requirements of seismologists to name various phases used in a particular type of research. Instead, it is hoped that the new list will ensure expanded standardized data reporting and exchange by data analysts and other users. This should result in a broad and unambiguous database for research and practical applications. At the same time the list and the principles outlined below may provide useful guidance for naming previously unknown seismic phases.

The new nomenclature partially modifies and complements an earlier one published in the last edition of the *Manual of Seismological Observatory Practice* (Willmore, 1979) and in the seismic bulletins published by ISC. It is more in tune with modern Earth and travel-time models. As opposed to former practice, the working group (hereinafter WG) tried to make sure that the phase name generally reflects the type of wave and the path it has traveled. Accordingly, symbols for characterizing onset quality, polarity, etc. will no longer be part of the phase name. The WG is also aware that seismic phases exist that are common in some regions but are only rarely or not found in other regions, such as Pb (P*), PnPn, PbPb, etc.

The extended list of phase names as presented below reflects significantly increased detection capabilities of modern seismic sensors and sensor arrays, even of rather weak phases which were rarely observed on the classical analog records. It also accounts for improved possibilities of proper phase identification by means of digital multichannel data processing such as frequency-wave number (*f-k*) analysis and polarization filtering, by modeling the observations with synthetic seismograms or by showing on the records the theoretically predicted onset times of phases. Finally, the newly adopted IASPEI Seismic Format (ISF) is much more flexible then the older formats used by NEIC, ISC, and other data centers (see `http://www.isc.ac.uk/Documents/isf.pdf`). It allows the reporting, computer parsing, and archiving of phases with long or previously uncommon names. ISF also accepts complementary parameters such as onset quality, measured back azimuth and slowness, and amplitudes and periods of other phases in addition to *P* and surface waves, for components other than vertical ones, and for instruments with nonstandard response characteristics.

This increased flexibility of the parameter-reporting format requires improved standardization, which limits the uncontrolled growth of incompatible and ambiguous parameter data. Therefore, the WG agreed on certain rules. They are outlined below prior to the listing of the standardized phase names. To facilitate the understanding of the phase names, ray diagrams are presented below. They have been calculated for local seismic sources on the basis of an average one-dimensional two-layer crustal model and for regional and teleseismic sources using the global 1D Earth model AK135 (Kennett *et al.*, 1995).

Before assigning abbreviated seismic phase names one should agree first on the language to be used and its rules. As in any other language we need a suitable alphabet (here plain Latin letters); numbers (here Arabic numbers); +/– signs; an orthography, which regulates, for example, the use of capital and lower-case letters; and a syntax, which describes the rules of correct order and mutual relationship of the language elements. One should be aware, however, that as with any historically developed language, the seismological nomenclature will inevitably develop exceptions to the rules and depend on the context in which it is used. Although not fully documented below, some exceptions will be mentioned. Note that our efforts are mainly aimed at standardized names to be used in international data exchange so as to build up unique, unambiguous global databases for research. Many of the exceptions to the rules are related to specialized, mostly local research applications. The identification of related seismic phases often requires specialized procedures of data acquisition and processing that are not part of seismological routine data analysis. Also, many of these exceptional phases are rarely or never used in seismic event location, magnitude determination, source mechanism calculations, etc., which are the main tasks of international data centers. We focus therefore on phases that are particularly important for seismological data centers as well as for the refinement of regional and global Earth models on the basis of widely exchanged and accumulated parameter readings. In addition, we added references to the first definition of some wave types and phase names.

STANDARD LETTERS, SIGNS, AND SYNTAX USED FOR DESCRIBING SEISMIC PHASES

Capital Letters

Individual capital letters that stand for primary types of seismic body waves include:

- P: longitudinal wave that has traveled through the Earth's crust and mantle, from *undae **p**rimae* (Latin) = first waves (Borne, 1904);
- K: longitudinal wave that has traveled through the Earth's outer core, from **K**ern (German) = core (Sohon, 1932; Bastings, 1934);
- I: longitudinal wave that has traveled through the Earth's **i**nner core (Jeffreys and Bullen, 1940);
- S: transverse wave that has traveled through the Earth's crust and mantle, from *undae **s**ecundae* (Latin) = second waves (Borne, 1904);
- T: wave that traveled partly as a sound wave in the sea, from *undae **t**ertiae* (Latin) = third waves (Linehan, 1940); and
- J: transverse wave that has traveled through the Earth's inner core (Bullen, 1946).

Exceptions

- A capital letter *N* used in the nomenclature does not stand for a phase name but rather for the number of legs traveled (or $N-1$ reflections made) before reaching the station. *N* should usually follow the phase symbol to which it applies. For examples see syntax below.
- The lower-case letters p and s may stand, in the case of seismic events below the Earth's surface, for the relatively short upgoing leg of P or S waves, which continue, after reflection and possible conversion at the free surface, as downgoing P or S waves. Thus seismic depth phases (*e.g.*, pP, sP, sS, pPP, sPP, pPKP, etc.) are uniquely defined. The identification and reporting of such phases is of utmost importance for source depth determinations (Scrase, 1931; Stechschulte, 1932).
- Many researchers working on detailed investigations of crustal and upper mantle discontinuities denote both the up- and downgoing short legs of converted or multiply reflected P and S phases as lower-case letters p and s, respectively.

Individual or double capital letters that stand for surface waves include:

- L: (relatively) long-period surface wave, unspecified, from *undae **l**ongae* (Latin) = long waves (Borne, 1904);
- R: **R**ayleigh waves (short-period up to very long-period mantle waves) (Angenheister, 1921);
- Q: Love waves, from **Q**uerwellen (German) = transverse waves (Angenheister, 1921);
- G: (very long-period) global (mantle) Love waves, firstly observed and reported by Gutenberg and Richter (1934); in honor of Gutenberg, Byerly proposed the usage of **G** for these waves (Richter, 1958);
- LR: long-period Rayleigh waves, usually relating to the Airy phase maximum in the surface-wave train; and
- LQ: long-period Love waves.

Lower-case Letters and Signs

Single lower-case letters generally specify the part of the Earth's crust or upper mantle in which a phase has its turning point or at which discontinuity it has been reflected and/or eventually converted:

- g: following the phase name characterizes waves "bottoming" (*i.e.*, having their turning point in case of P or S body waves) or just travel (surface waves) within the upper ("**g**ranitic") Earth's crust (*e.g.*, Pg, Sg, Rg) (Jeffreys, 1926);
- b: following the phase name characterizes body waves bottoming in the lower ("**b**asaltic") Earth's crust (Jeffreys, 1926) (*e.g.*, Pb, Sb; alternative names for these phases are P*, S*, [Conrad, 1925]);
- n: following the phase name characterizes a P or S wave that is bottoming or traveling as a head wave in the Earth's uppermost mantle (*e.g.*, Pn, Sn); introduced after Andrija Mohorovičić discovered the Earth's crust and separated the crustal from the **n**ormal (= *n*) mantle phase (Mohorovičić, 1910);
- m: (upward) reflections from the outer side of the Mohorovičić (**M**oho) discontinuity (*e.g.*, PmP, SmS);
- c: reflections from the *outer side* of the **c**ore-mantle boundary (CMB); usage proposed by James B. Macelwane (see Gutenberg, 1925);
- i: reflections from the outer side of the **i**nner core boundary (ICB); and
- *z*: reflections from a discontinuity at depth *z* (measured in km) (other than free-surface, CMB, or ICB). Upward reflections from the outer side of the discontinuity may additionally be complemented by a + sign (*e.g.*, P410+P; this, however, is not compulsory), while downward reflections from the inner side of the discontinuity must be complemented by a – sign (*e.g.*, P660–P).

Double lower-case letters following a capital-letter phase name indicate the travel-time branch to which this phase belongs. Due to the geometry and velocity structure of the Earth the same type of seismic wave may develop a triplication of its travel-time curve with different, in some cases well separated, branches. Thus it is customary to differentiate between different branches of core phases and their multiple reflections at the free surface or the CMB. Examples are PKPab, PKPbc, PKPdf, SKSac, SKKSac, etc. The separation of the different PKP branches with letters ab, bc, and df was introduced by Jeffreys and Bullen (1940).

Three lower-case letters may follow a capital-letter phase name to specify its character, *e.g.*, as a forerunner (pre) to the main phase caused by scattering (*e.g.,* PKPpre) or as a diffracted wave extending the travel-time branch of the main phase into the outer core shadow (*e.g.*, Pdif in the outer core shadow for P).

Syntax of Generating Complex Phase Names

Due to refraction, reflection, and conversion in the Earth most phases have a complex path history before they reach the station. Accordingly most phases cannot be described by a single capital letter code in a self-explanatory way. By combining the capital and lower-case letters as mentioned above, one can describe the character of even rather complex refracted, reflected, or converted phases. The order of symbols (syntax) regulates the sequence of phase legs due to refraction, reflection, and conversion events in time (from left to right) and in space.

EXAMPLES FOR CREATING COMPLEX STANDARD PHASE NAMES

Traditional examples of complex phase names are as follows.

Refracted and Converted Refracted Waves

- PKP is a pure refracted longitudinal wave. It has traveled the first part of its path as P through crust and mantle, the second through the outer core (K), and the third again as P through mantle and crust. An alternative name for PKP is P′ (Angenheister, 1921), which should be read as "P prime."
- PKIKP (alternative to PKPdf) is also a pure refracted longitudinal wave. It has traveled the first part of its path as P through crust and mantle, the second through the outer core, the third through the inner core, and the fourth and fifth parts back again through outer core and mantle/crust.
- SKS is a converted refracted wave. It has traveled as a shear wave through crust and mantle, being converted into a longitudinal P wave when refracted into the outer core and converted back again into an S wave when entering the mantle.
- SKP and PKS are converted refracted waves with only one conversion from S to P when entering the core or from P to S when leaving the core, respectively.

Pure Reflected Waves

- In the case of (downward only) reflections at the free surface or from the inner side of the CMB the phase symbol is just repeated, *e.g.*, PP, SS (Geiger, 1909), PPP, SSS, KK, KKK, etc.
- The case of (upward) reflections from the outer side of the Moho, the CMB, or the ICB is indicated by inserting m, c, or i, respectively, between the phase symbols, *e.g.*, PmP, PcP, ScS; PKiKP.
- Reflections from any other discontinuity in mantle or crust at depth z may be from the inner side (–; *i.e.*, downward back into the mantle) or from the outer side (+; *i.e.*, back toward the surface). To differentiate between these two possibilities, the sign has to follow z (or the respective number in km); for example, P410+P or P660–P.
- To abbreviate names of multileg phases due to repeated reflections one can also write Phasename*N*. This type of abbreviation is customary in the case of multiple phases with long phase names such as PmP2 for PmPPmP (free-surface reflection of PmP), SKS2 for SKSSKS (the alternative name for S′2, the free-surface reflection of SKS), PKP3 for PKPPKPPKP (double free-surface reflection of PKP; alternative name for P′3), or P4KP for PKKKKP (triple reflection of P at the inner side of the CMB).

Two additional notes are to be mentioned. First, PKP2 = PKPPKP are now alternative names for P′2 or P′P′, respectively. This should not be mistaken for the old usage of PKP2 for PKPab. Second, in the case of multiple reflections from the inner side of the CMB, the WG followed the established tradition of placing the number *N* not after but in front of the related phase symbol K.

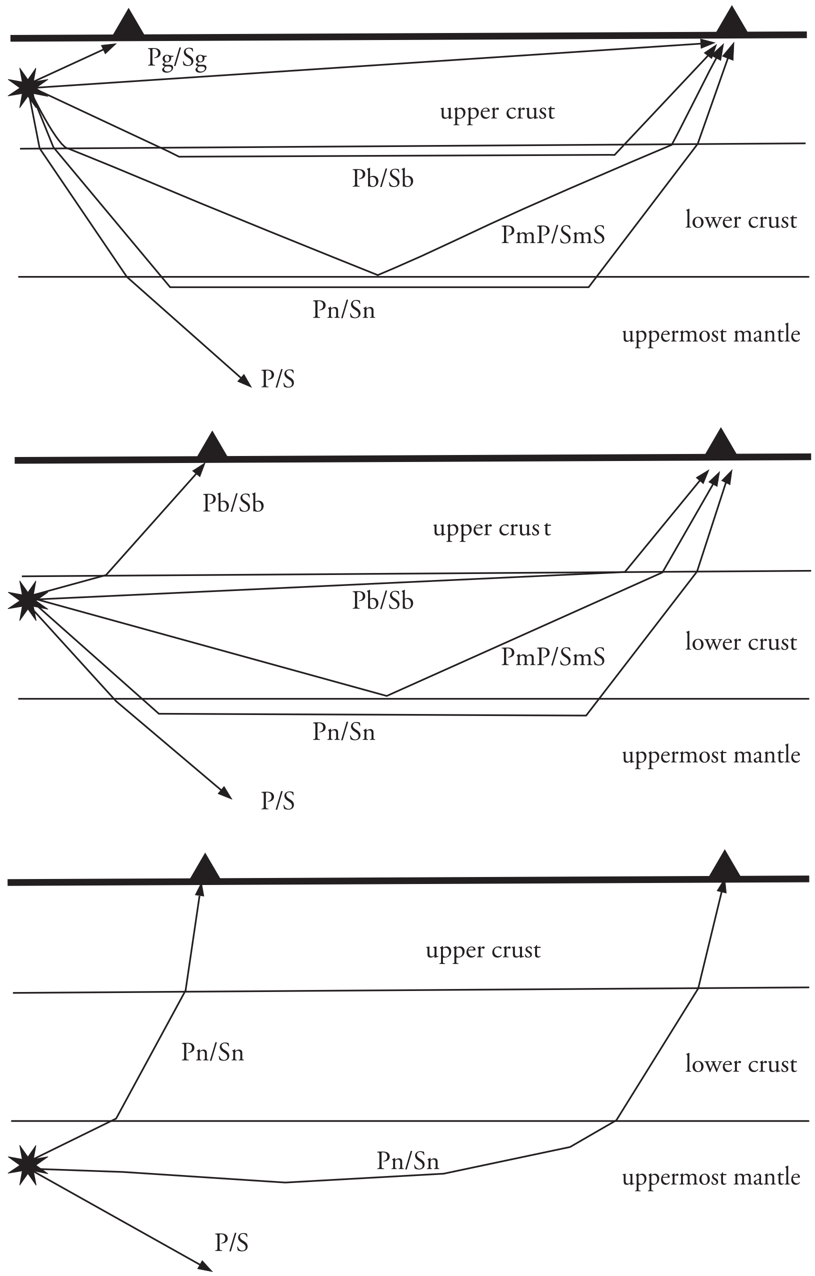
Reflected Waves with Conversion at the Reflection Point

When a phase changes its character from *P* to *S*, or vice versa, one writes:

- PS (first leg P, second leg S) or SP (first leg P, second leg S) in the case of reflection from the free surface downward into the mantle (Geiger and Gutenberg, 1912a, 1912b);
- PmS or SmP, respectively, for reflections/conversions from the outer side of the Moho;
- PcS or ScP for reflections/conversions from the outer side of the CMB; and
- Pz+S or Sz–P for reflection/conversion from the outer side or inner side, respectively, of a discontinuity at depth z. Note that the – is compulsory; the + is not.

In this context it is worth mentioning that mode conversion is impossible for reflections from the inner side of the CMB back into the outer core because the liquid outer core does not allow the propagation of S waves.

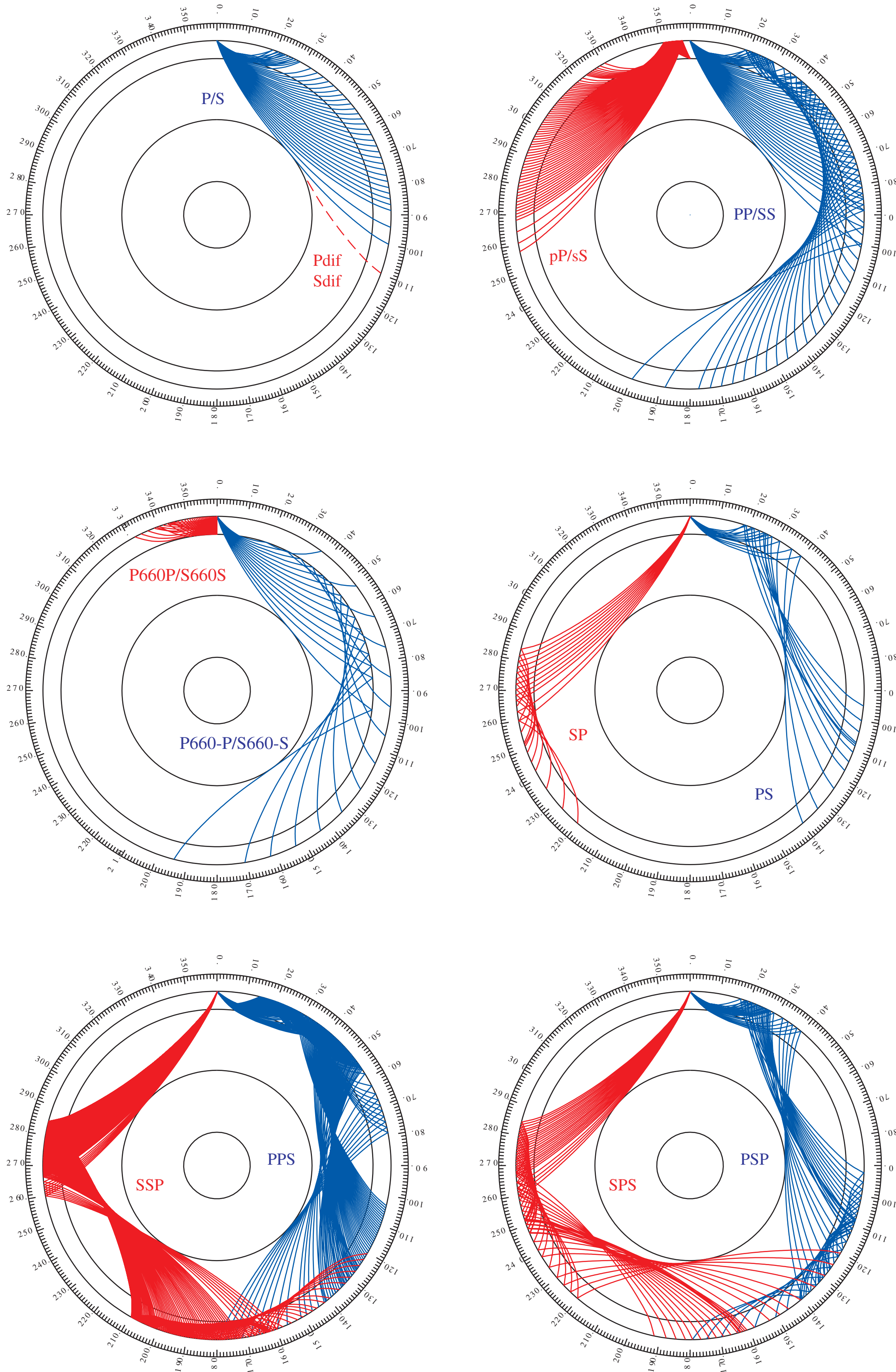
The WG determined the new IASPEI standard phase names along these lines and rules. Where the new names deviate from other traditionally used names the latter are given as well. Either the traditional names are still acceptable alternatives (alt) or they are old names (old) which should no longer be used.



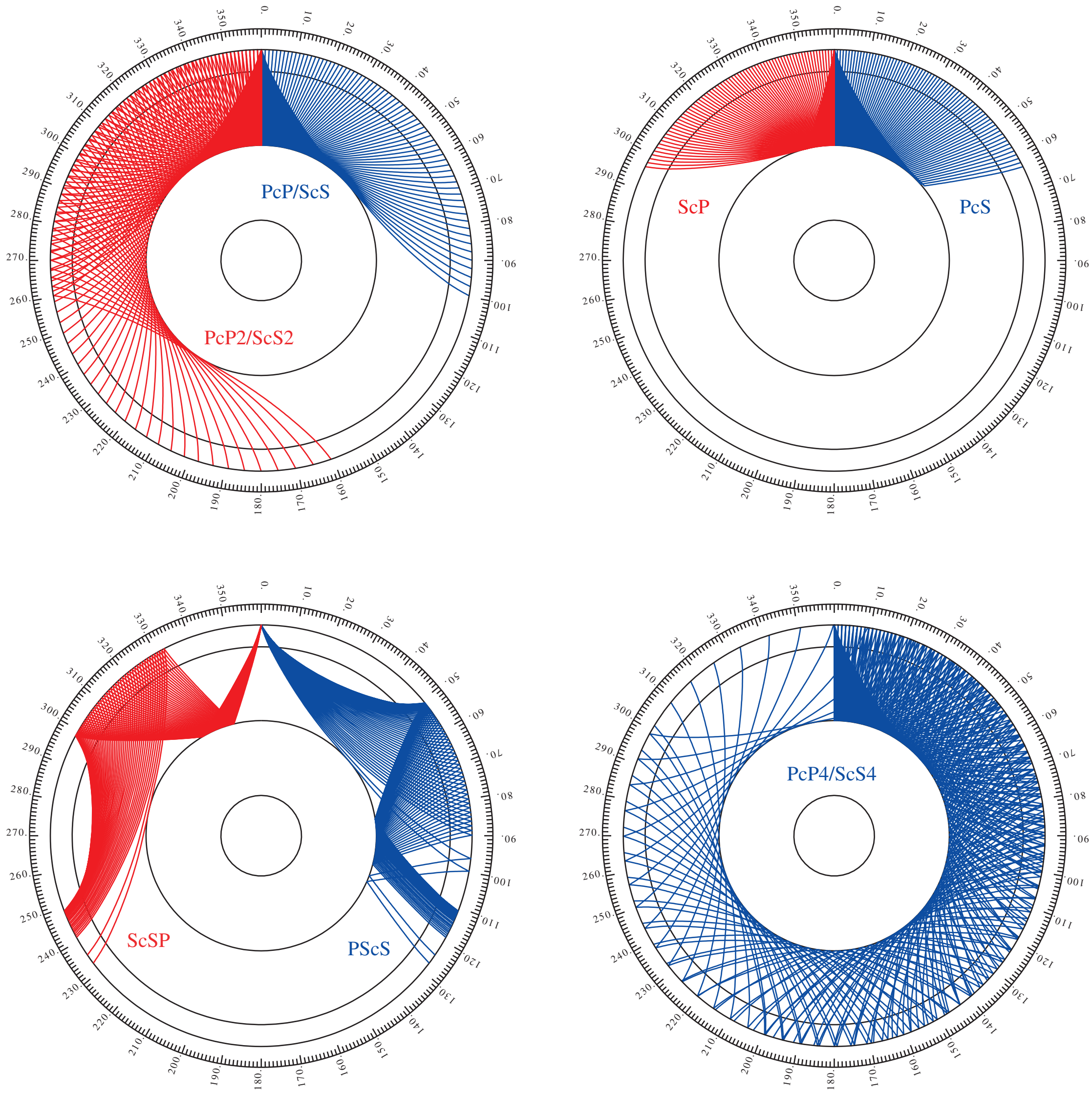
▲ **Figure 1.** Seismic "crustal phases" observed in the case of a two-layer crust in local and regional distance ranges (0° < D < about 20°) from the seismic source in the upper crust (top), lower crust (middle), and uppermost mantle (bottom).

RAY-PATH DIAGRAMS FOR SOME OF THE IASPEI STANDARD PHASES

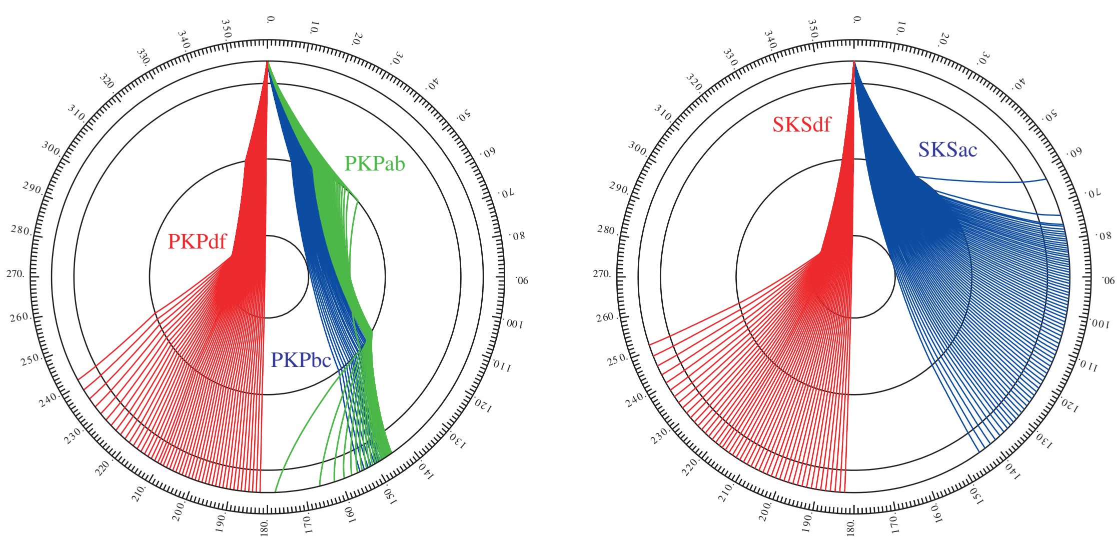
We show ray paths through the Earth for many of the mentioned phases. The three diagrams for crustal phases are sketches illustrating the principal ray paths in a two-layer crust (Figure 1). The rays in all other figures (Figures 2–6) were calculated by using the ray picture part of the WKBJ3 code (Chapman, 1978; Dey-Sarkar and Chapman, 1978); as the velocity model we chose the Earth model AK135 (Kennett *et al.*, 1995). For some types of P and S phases the ray paths through the Earth are very similar because the velocity ratio V_P/V_S does not change enough to give very different ray pictures. In these cases, we calculated only the ray paths for the P-type ray (*i.e.*, P, Pdif, pP, PP, P660P, P660-P, PcP, PcP2, and PcP4) and assume that the corresponding ray paths of the respective S-type phases are very similar. To show the different ray paths for phases with similar phase names, we plotted on many diagrams rays leaving the source once to the left and once to the right in different colors. The three most important discontinuities inside the Earth are indicated as black circles (*i.e.*, the border between upper and lower mantle, the CMB, and the ICB).



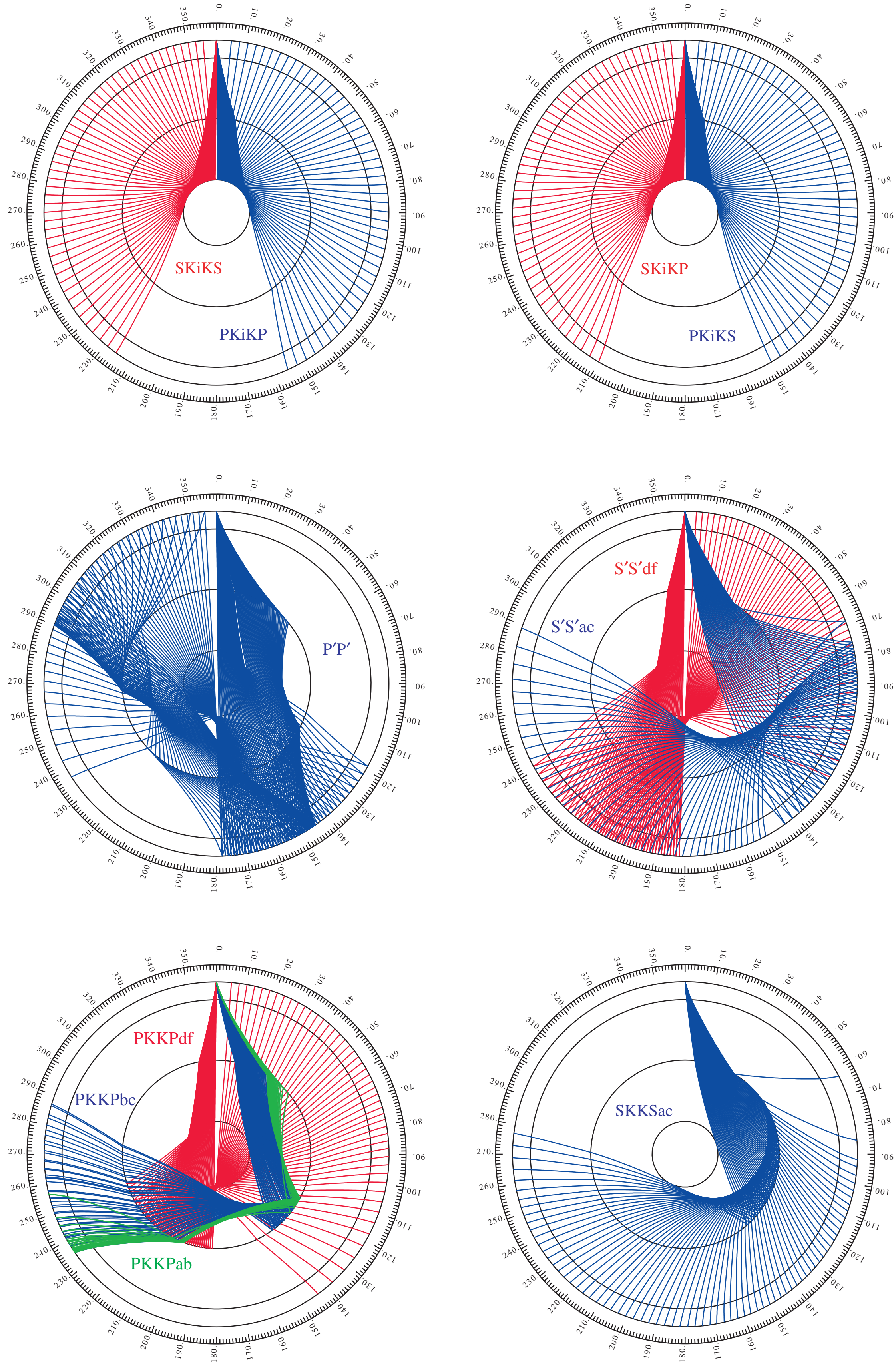
▲ **Figure 2.** Mantle phases observed at the teleseismic distance range D > about 20°.



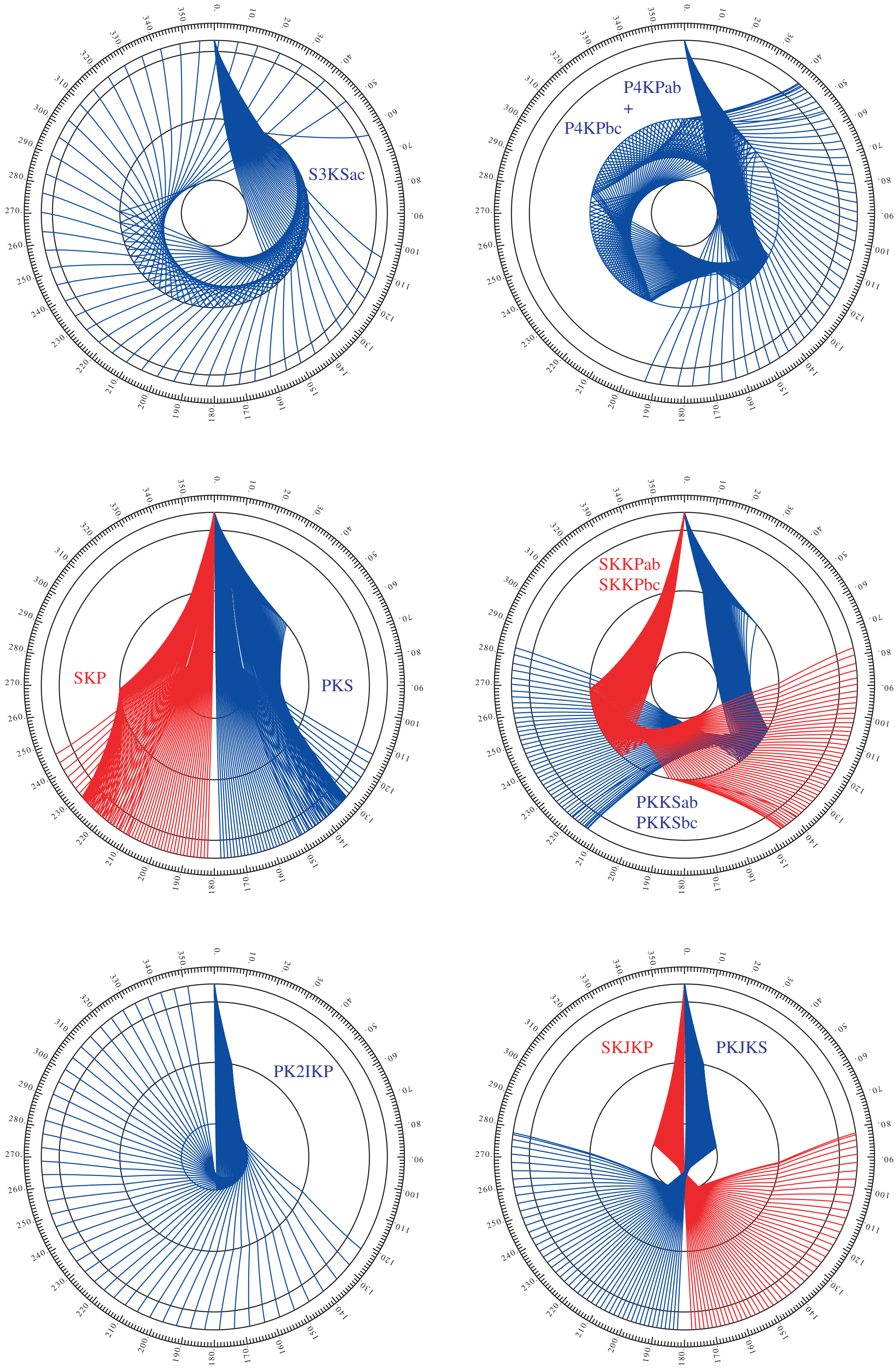
▲ **Figure 3.** Reflections from the Earth's core.



▲ **Figure 4.** Seismic rays of direct core phases.



▲ **Figure 5.** Seismic rays of singly reflected core phases.



▲ **Figure 6.** Seismic rays of multiply reflected and converted core phases.

IASPEI STANDARD SEISMIC PHASE LIST

After numerous consultations with the seismological community this list was finalized in May 2002 by the IASPEI Working Group on Phase Names, chaired by D. A. Storchak. Other members of the WG were R. D. Adams, P. Bormann, E. R. Engdahl, J. Havskov, B. N. L. Kennett, and J. Schweitzer. The list has finally been approved by the IASPEI Commission on Seismological Observation and Interpretation (CoSOI) and adopted by IASPEI in Sapporo on 9 July 2003.

Crustal Phases

Pg	At short distances, either an upgoing P wave from a source in the upper crust or a P wave bottoming in the upper crust. At larger distances also arrivals caused by multiple P-wave reverberations inside the whole crust with a group velocity around 5.8 km/s.
Pb	Either an upgoing P wave from a source in the lower crust or a P wave bottoming in the lower crust (alt: P*)
Pn	Any P wave bottoming in the uppermost mantle or an upgoing P wave from a source in the uppermost mantle
PnPn	Pn free-surface reflection
PgPg	Pg free-surface reflection
PmP	P reflection from the outer side of the Moho
PmP*N*	PmP multiple free surface reflection; *N* is a positive integer. For example, PmP2 is PmPPmP.
PmS	P to S reflection from the outer side of the Moho
Sg	At short distances, either an upgoing S wave from a source in the upper crust or an S wave bottoming in the upper crust. At larger distances also arrivals caused by superposition of multiple S-wave reverberations and SV to P and/or P to SV conversions inside the whole crust.
Sb	Either an upgoing S wave from a source in the lower crust or an S wave bottoming in the lower crust (alt: S*)
Sn	Any S wave bottoming in the uppermost mantle or an upgoing S wave from a source in the uppermost mantle
SnSn	Sn free-surface reflection
SgSg	Sg free-surface reflection
SmS	S reflection from the outer side of the Moho
SmS*N*	SmS multiple free-surface reflection; *N* is a positive integer. For example, SmS2 is SmSSmS.
SmP	S to P reflection from the outer side of the Moho
Lg	A wave group observed at larger regional distances and caused by superposition of multiple S-wave reverberations and SV to P and/or P to SV conversions inside the whole crust. The maximum energy travels with a group velocity around 3.5 km/s.
Rg	Short-period crustal Rayleigh wave

Mantle Phases

P	A longitudinal wave, bottoming below the uppermost mantle; also an upgoing longitudinal wave from a source below the uppermost mantle
PP	Free-surface reflection of P wave leaving a source downward
PS	P, leaving a source downward, reflected as an S at the free surface. At shorter distances the first leg is represented by a crustal P wave.
PPP	Analogous to PP
PPS	PP to S converted reflection at the free surface; travel time matches that of PSP
PSS	PS reflected at the free surface
PcP	P reflection from the core-mantle boundary (CMB)
PcS	P to S converted reflection from the CMB
PcP*N*	PcP multiple free-surface reflection; *N* is a positive integer. For example PcP2 is PcPPcP.
P*z*+P	P reflection from outer side of a discontinuity at depth *z*; *z* may be a positive numerical value in km. For example, P660+P is a P reflection from the top of the 660 km discontinuity. (alt: P*z*P)
P*z*–P	P reflection from inner side of discontinuity at depth *z*. For example, P660–P is a P reflection from below the 660 km discontinuity, which means it is precursory to PP.
P*z*+S	P to S converted reflection from outer side of discontinuity at depth *z* (alt: P*z*S)
P*z*–S	P to S converted reflection from inner side of discontinuity at depth *z*
PScS	P (leaving a source downward) to ScS reflection at the free surface
Pdif	P diffracted along the CMB in the mantle (old: Pdiff)
S	Shear wave, bottoming below the uppermost mantle; also an upgoing shear wave from a source below the uppermost mantle
SS	Free-surface reflection of an S wave leaving a source downward
SP	S, leaving source downward, reflected as P at the free surface. At shorter distances the second leg is represented by a crustal P wave.
SSS	Analogous to SS

SSP SS to P converted reflection at the free surface; travel time matches that of SPS.

SPP SP reflected at the free surface

ScS S reflection from the CMB

ScP S to P converted reflection from the CMB

ScS*N* ScS multiple free-surface reflection; *N* is a positive integer. For example ScS2 is ScSScS.

S*z*+S S reflection from outer side of a discontinuity at depth *z*; *z* may be a positive numerical value in km. For example S660+S is an S reflection from the top of the 660 km discontinuity. (alt: S*z*S)

S*z*-S S reflection from inner side of discontinuity at depth *z*. For example, S660–S is an S reflection from below the 660 km discontinuity, which means it is precursory to SS.

S*z*+P S to P converted reflection from outer side of discontinuity at depth *z* (alt: S*z*P)

S*z*-P S to P converted reflection from inner side of discontinuity at depth *z*

ScSP ScS to P reflection at the free surface

Sdif S diffracted along the CMB in the mantle (old: Sdiff)

Core Phases

PKP Unspecified P wave bottoming in the core (alt: P′)

PKPab P wave bottoming in the upper outer core; ab indicates the retrograde branch of the PKP caustic (old: PKP2)

PKPbc P wave bottoming in the lower outer core; bc indicates the prograde branch of the PKP caustic (old: PKP1)

PKPdf P wave bottoming in the inner core (alt: PKIKP)

PKPpre A precursor to PKPdf due to scattering near or at the CMB (old: PKhKP)

PKPdif P wave diffracted at the inner core boundary (ICB) in the outer core

PKS Unspecified P wave bottoming in the core and converting to S at the CMB

PKSab PKS bottoming in the upper outer core

PKSbc PKS bottoming in the lower outer core

PKSdf PKS bottoming in the inner core

P′P′ Free-surface reflection of PKP (alt: PKPPKP)

P′*N* PKP reflected at the free surface *N* – 1 times; *N* is a positive integer. For example, P′3 is P′P′P′. (alt: PKP*N*)

P′*z*–P′ PKP reflected from inner side of a discontinuity at depth *z* outside the core, which means it is precursory to P′P′; *z* may be a positive numerical value in km.

P′S′ PKP to SKS converted reflection at the free surface; other examples are P′PKS, P′SKP (alt: PKPSKS)

PS′ P (leaving a source downward) to SKS reflection at the free surface (alt: PSKS)

PKKP Unspecified P wave reflected once from the inner side of the CMB

PKKPab PKKP bottoming in the upper outer core

PKKPbc PKKP bottoming in the lower outer core

PKKPdf PKKP bottoming in the inner core

P*N*KP P wave reflected *N* – 1 times from inner side of the CMB; *N* is a positive integer.

PKKPpre A precursor to PKKP due to scattering near the CMB

PKiKP P wave reflected from the inner core boundary (ICB)

PK*N*IKP P wave reflected *N* – 1 times from the inner side of the ICB

PKJKP P wave traversing the outer core as P and the inner core as S

PKKS P wave reflected once from inner side of the CMB and converted to S at the CMB

PKKSab PKKS bottoming in the upper outer core

PKKSbc PKKS bottoming in the lower outer core

PKKSdf PKKS bottoming in the inner core

PcPP′ PcP to PKP reflection at the free surface; other examples are PcPS′, PcSP′, PcSS′, PcPSKP, PcSSKP. (alt: PcPPKP)

SKS unspecified S wave traversing the core as P (alt: S′)

SKSac SKS bottoming in the outer core

SKSdf SKS bottoming in the inner core (alt: SKIKS)

SPdifKS SKS wave with a segment of mantleside Pdif at the source and/or the receiver side of the ray path (alt: SKPdifS)

SKP Unspecified S wave traversing the core and then the mantle as P

SKPab SKP bottoming in the upper outer core

SKPbc SKP bottoming in the lower outer core

SKPdf SKP bottoming in the inner core

S′S′ Free-surface reflection of SKS (alt: SKSSKS)

S′*N* SKS reflected at the free surface *N* – 1 times; *N* is a positive integer

S′*z*–S′ SKS reflected from inner side of discontinuity at depth *z* outside the core, which means it is precursory to S′S′; *z* may be a positive numerical value in km.

S′P′ SKS to PKP converted reflection at the free surface; other examples are S′SKP, S′PKS. (alt: SKSPKP)

S′P SKS to P reflection at the free surface (alt: SKSP)

SKKS	Unspecified S wave reflected once from inner side of the CMB
SKKSac	SKKS bottoming in the outer core
SKKSdf	SKKS bottoming in the inner core
S*N*KS	S wave reflected $N-1$ times from inner side of the CMB; N is a positive integer.
SKiKS	S wave traversing the outer core as P and reflected from the ICB
SKJKS	S wave traversing the outer core as P and the inner core as S
SKKP	S wave traversing the core as P with one reflection from the inner side of the CMB and then continuing as P in the mantle
SKKPab	SKKP bottoming in the upper outer core
SKKPbc	SKKP bottoming in the lower outer core
SKKPdf	SKKP bottoming in the inner core
ScSS′	ScS to SKS reflection at the free surface; other examples are ScPS′, ScSP′, ScPP′, ScSSKP, ScPSKP. (alt: ScSSKS)

Near-source Surface Reflections (Depth Phases)

pP*y*	All P-type onsets (P*y*), as defined above, which resulted from reflection of an upgoing P wave at the free surface or an ocean bottom. WARNING: The character *y* is only a wild card for any seismic phase, which could be generated at the free surface. Examples are pP, pPKP, pPP, pPcP, etc.
sP*y*	All P*y* resulting from reflection of an upgoing S wave at the free surface or an ocean bottom; for example, sP, sPKP, sPP, sPcP, etc.
pS*y*	All S-type onsets (S*y*), as defined above, which resulted from reflection of an upgoing P wave at the free surface or an ocean bottom; for example, pS, pSKS, pSS, pScP, etc.
sS*y*	All S*y* resulting from reflection of an upgoing S wave at the free surface or an ocean bottom; for example, sSn, sSS, sScS, sSdif, etc.
pwP*y*	All P*y* resulting from reflection of an upgoing P wave at the ocean's free surface
pmP*y*	All P*y* resulting from reflection of an upgoing P wave from the inner side of the Moho

Surface Waves

L	Unspecified long-period surface wave
LQ	Love wave
LR	Rayleigh wave
G	Mantle wave of Love type
G*N*	Mantle wave of Love type; N is integer and indicates wave packets traveling along the minor arcs (odd numbers) or major arc (even numbers) of the great circle
R	Mantle wave of Rayleigh type
R*N*	Mantle wave of Rayleigh type; N is integer and indicates wave packets traveling along the minor arcs (odd numbers) or major arc (even numbers) of the great circle
PL	Fundamental leaking mode following P onsets generated by coupling of P energy into the waveguide formed by the crust and upper mantle
SPL	S wave coupling into the PL waveguide; other examples are SSPL, SSSPL.

Acoustic Phases

H	A hydroacoustic wave from a source in the water, which couples in the ground
HPg	H phase converted to Pg at the receiver side
HSg	H phase converted to Sg at the receiver side
HRg	H phase converted to Rg at the receiver side
I	An atmospheric sound arrival which couples in the ground
IPg	I phase converted to Pg at the receiver side
ISg	I phase converted to Sg at the receiver side
IRg	I phase converted to Rg at the receiver side
T	A tertiary wave. This is an acoustic wave from a source in the solid earth, usually trapped in a low-velocity oceanic water layer called the SOFAR channel (SOund Fixing And Ranging).
TPg	T phase converted to Pg at the receiver side
TSg	T phase converted to Sg at the receiver side
TRg	T phase converted to Rg at the receiver side

Amplitude Measurement Phases

A	Unspecified amplitude measurement
AML	Amplitude measurement for local magnitude
AMB	Amplitude measurement for body-wave magnitude
AMS	Amplitude measurement for surface-wave magnitude
END	Time of visible end of record for duration magnitude

Unidentified Arrivals

x	unidentified arrival (old: i, e, NULL)
rx	unidentified regional arrival (old: i, e, NULL)
tx	unidentified teleseismic arrival (old: i, e, NULL)
Px	unidentified arrival of P type (old: i, e, NULL, (P), P?)
Sx	unidentified arrival of S type (old: i, e, NULL, (S), S?)

REFERENCES

Angenheister, G. H. (1921). Beobachtungen an pazifischen Beben, *Nachrichten von der Königlichen Gesellschaft der Wissenschaften zu Göttingen, Mathematisch-physikalische Klasse*, 113–146.

Bastings, L. (1934). Shear waves through the Earth's core, *Nature* **134**, 216–217.

Borne, G. von dem (1904). Seismische Registrierungen in Göttingen, Juli bis Dezember 1903, *Nachrichten von der Königlichen Gesellschaft der Wissenschaften zu Göttingen, Mathematisch-physikalische Klasse*, 440–464.

Bullen, K. E. (1946). A hypothesis on compressibility at pressures of the order of a million atmospheres, *Nature* **157**, 405.

Conrad, V. (1925). Laufzeitkurven des Tauernbebens vom 28. November, 1923, *Mitteilungen der Erdbeben-Kommission der Akademie der Wissenschaften in Wien*, Neue Folge **59**, 23 pp.

Chapman, C. H. (1978). A new method for computing synthetic seismograms, *Geophysical Journal of the Royal Astronomical Society* **54**, 481–518.

Dey-Sarkar, S. K. and C. H. Chapman (1978). A simple method for the computation of body wave seismograms, *Bulletin of the Seismological Society of America* **68**, 1,577–1,593.

Geiger, L. (1909). Seismische Registrierungen in Göttingen im Jahre 1907 mit einem Vorwort über die Bearbeitung der Erdbebendiagramme, *Nachrichten von der Königlichen Gesellschaft der Wissenschaften zu Göttingen, Mathematisch-physikalische Klasse*, 107–151.

Geiger, L. and B. Gutenberg (1912a). Konstitution des Erdinnern, erschlossen aus der Intensität longitudinaler und transversaler Erdbebenwellen, und einige Beobachtungen an den Vorläufer, *Physikalische Zeitschrift* **13**, 115–118.

Geiger, L. and B. Gutenberg (1912b). Ueber Erdbebenwellen. VI. Konstitution des Erdinnern, erschlossen aus der Intensität longitudinaler und transversaler Erdbebenwellen, und einige Beobachtungen an den Vorläufern, *Nachrichten von der Königlichen Gesellschaft der Wissenschaften zu Göttingen. Mathematisch-physikalische Klasse*, 623–675.

Gutenberg, B. (1925). Bearbeitung von Aufzeichnungen einiger Weltbeben, *Abhandlungen der Senckenbergischen Naturforschenden Gesellschaft* **40**, 57–88.

Gutenberg, B. and C. F. Richter (1934). On seismic waves (first paper), *Gerlands Beiträge zur Geophysik* **43**, 56–133.

Jeffreys, H. (1926). On near earthquakes, *Month. Not. Royal Astronomical Society, Geophysical Supplement* **1**, 385–402.

Jeffreys, H. and K. E. Bullen (1940). *Seismological Tables*, London: British Association for the Advancement of Science, Gray Milne Trust, 50 pp.

Kennett, B. L. N., E. R. Engdahl, and R. Buland (1995). Constraints on seismic velocities in the Earth from traveltimes, *Geophysical Journal International* **122**, 108–124.

Linehan, D. (1940). Earthquakes in the West Indian region, *Transactions of the American Geophysical Union* **30**, 229–232.

Mohorovičić, A. (1910). Potres od 8. X 1909, *Godisnje izvješće Zagrebackog Meteoroloskog Opservatorija za godinu 1909, Dio IV, Potresi u Hrvatskoj i Slavonij godinu 1909 (Das Beben vom 8. X 1909, Jahrbuch des meteorologischen Observatoriums in Zagreb (Agram) für das Jahr 1909, 4. Teil Erdbeben in Kroatien und Slavonien im Jahre 1909)* **9**, 1–63.

Richter, C. F. (1958). *Elementary Seismology*, San Francisco and London: W. H. Freeman and Company, 768 pp.

Scrase, F. J. (1931). The reflected waves from deep focus earthquakes, *Proceedings of the Royal Society of London* **A-132**, 213–235.

Sohon, F. W. (1932). Seismometry, Part II of J. B. Macelwane and F. W. Sohon, *Introduction to Theoretical Seismology*, New York, 149 pp.

Stechschulte, V. C. (1932). The Japanese earthquake of March 29, 1928, *Bulletin of the Seismological Society of America* **22**, 81–137.

Willmore, P. L. (1979). *Manual of Seismological Observatory Practice*, World Data Center A for Solid Earth Geophysics, Report SE-20, September 1979, Boulder, Colorado, 165 pp.

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