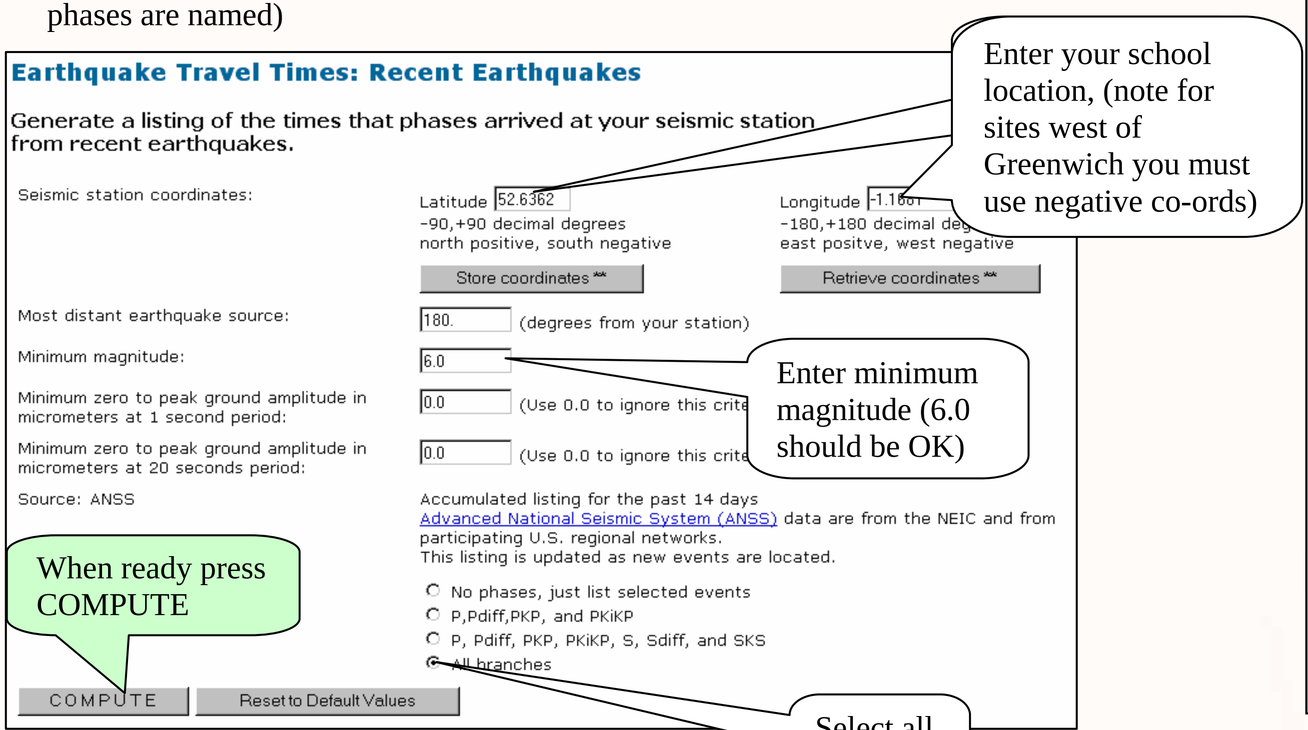
Decoding seismograms, theoretical travel times

Once you think you have located an earthquake on your record you can find out what the details of the seismogram are showing you by finding out the predicted arrival times of seismic waves from this event at your station. These predicted arrival times use an approximate velocity model for the Earth (called the IASP91 model) that should give arrival times at your station accurate to a second or two.

The website to use for this is http://neic.usgs.gov/neis/travel_times/artim.html
Seismic waves can travel from an earthquake to a recording site by a large number of different paths, some direct and some involving reflections and refractions from velocity contrasts within the earth. Each different raypath is called a 'phase' by seismologists (see appendix for how phases are named)



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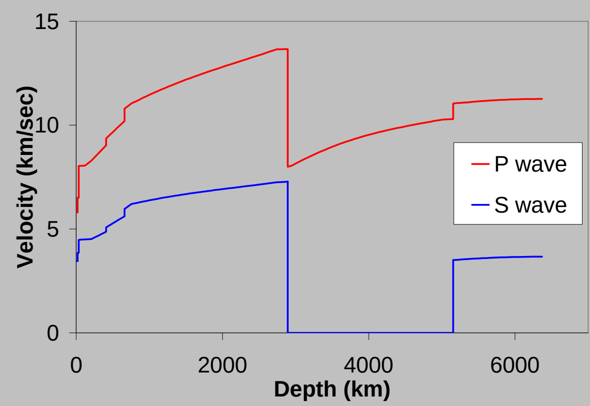
Simple velocity models of the Earth

To a first approximation the Earth behaves like a sphere where the seismic velocity varies only with depth. Such a model is referred to as a 1 dimensional or 1D model.

There are a number of 1D velocity models used by seismologists (**IASP91, PREM, AK135**) however the variations between them are to small to show on a simple plot like this. (Note that the S wave velocity in the liquid outer core is zero.)



When calculating a more realistic three dimensional velocity model for the earth scientists usually label the velocities as percentage variations from the simple 1D model.

You will then see the results for a number of recent earthquakes of the form

```
DATE-(UTC)-TIME       LAT     LON      DEPTH MAG   Q   COMMENTS
2006/08/24 21:50:36  51.16N 157.49E  43.0  6.5       US: NEAR EAST COAST OF KAMCH
   Expected 20s period surface wave amplitude [  2.44E+01 µm]  [  7.68E+00 µm/s]
   Expected 1s period body wave amplitude     [  5.92E-01 µm]  [  3.72E+00 µm/s]

 delta   azimuth (degrees clockwise from no
 (deg)      eq-to-station     station-to-eq
 75.03          346.7              13.7

                  travel   arrival time
   #  code        time(s)  dy hr mn sec
   1  P           697.05   0 22  2 13
   2  pP          709.78   0 22  2 25
   3  PcP         710.36   0 22  2 26
   4  sP          714.94   0 22  2 30
   5  PP          865.01   0 22  5  1
   6  PKiKP      1047.00   0 22  8  3
   7  pPKiKP     1060.45   0 22  8 16
   8  sPKiKP     1065.45   0 22  8 21
   9  SKiKP      1256.93   0 22 11 32
  10  S          1272.29   0 22 11 48
  11  pS         1288.33   0 22 12  4
  12  sS         1294.10   0 22 12 10
  13  SKSac      1301.73   0 22 12 17
  14  SKKSac     1302.43   0 22 12 18
  15  ScS        1305.57   0 22 12 21
  16  SPn        1305.95   0 22 12 21
  17  PnS        1312.17   0 22 12 28
  18  pSKSac     1319.22   0 22 12 35
  19  sSKSac     1324.50   0 22 12 40
  20  SS         1562.50   0 22 16 38
  21  PKKPdf     1844.95   0 22 21 20
  22  PKKPbc     1860.40   0 22 21 36
  23  SKKPdf     2054.89   0 22 24 50
  24  PKKSdf     2059.89   0 22 24 55
  25  SKKSdf     2269.62   0 22 28 25
  26  P'P'df     2341.72   0 22 29 37
  27  S'S'df     3198.91   0 22 43 54
  28  S'S'ac     3213.80   0 22 44  9
  29  LQ         1904.22   0 22 22 20
  30  LR         2113.42   0 22 25 49
```

The first line gives the origin time, location, and magnitude of the

The next line gives you the distance (in degrees) between your station and the event.

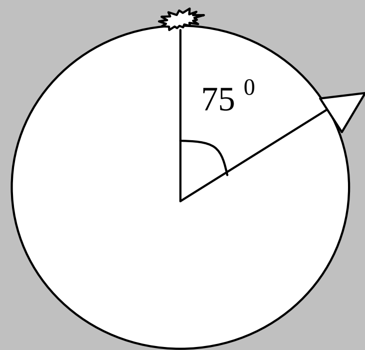
For each phase the estimated arrival time at your location is given

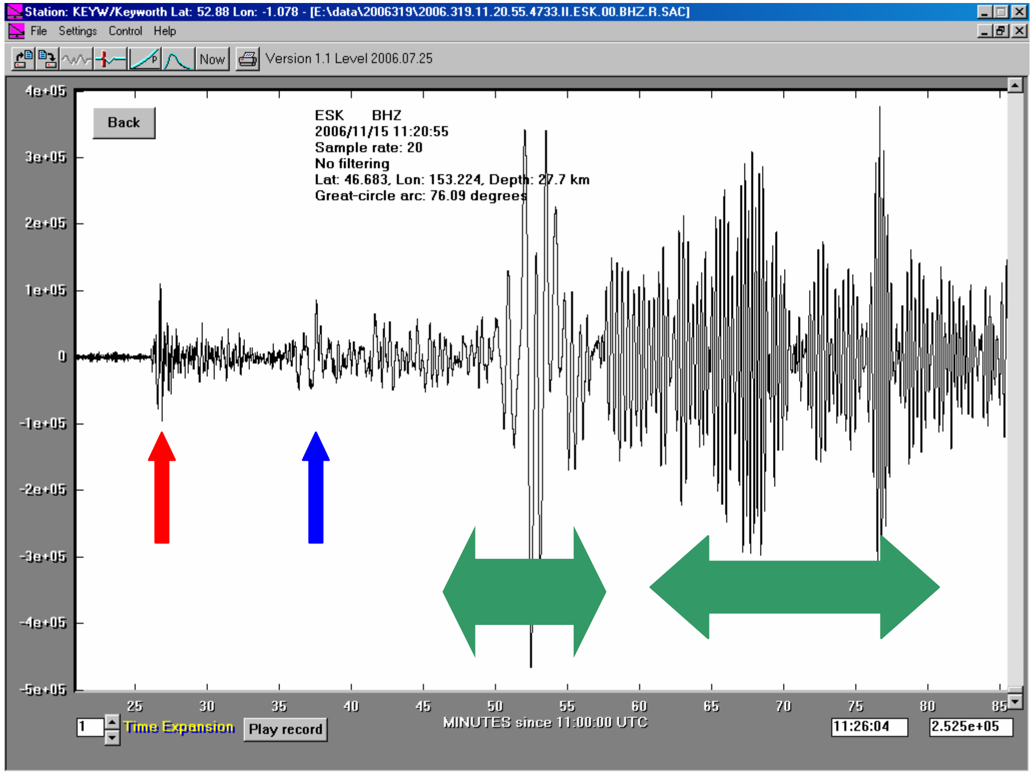
You will probably only see the main phases (highlighted) .
See later for phase naming conventions

You can now decode the seismogram that you have recorded or downloaded

Note that if you are looking at horizontal ground motions the initial P waves do not always show up well.
For this particular seismogram the event was approximately 75 degrees away (see box). For events greater than 103 degrees distance seismic rays have to pass through the earth's core which is liquid. This means that S-waves (transverse waves) cannot penetrate at these distances, this gives rise to the **S-Wave shadow zone**, the region beyond 103 degrees where recording stations will not detect directly arriving S-waves.

Epicentral distance in degrees is how seismologists refer to distance. This refers to the angle subtended at the centre of the earth by the great circle path on the surface linking earthquake and recording station. One degree of distance equals approximately 111km.





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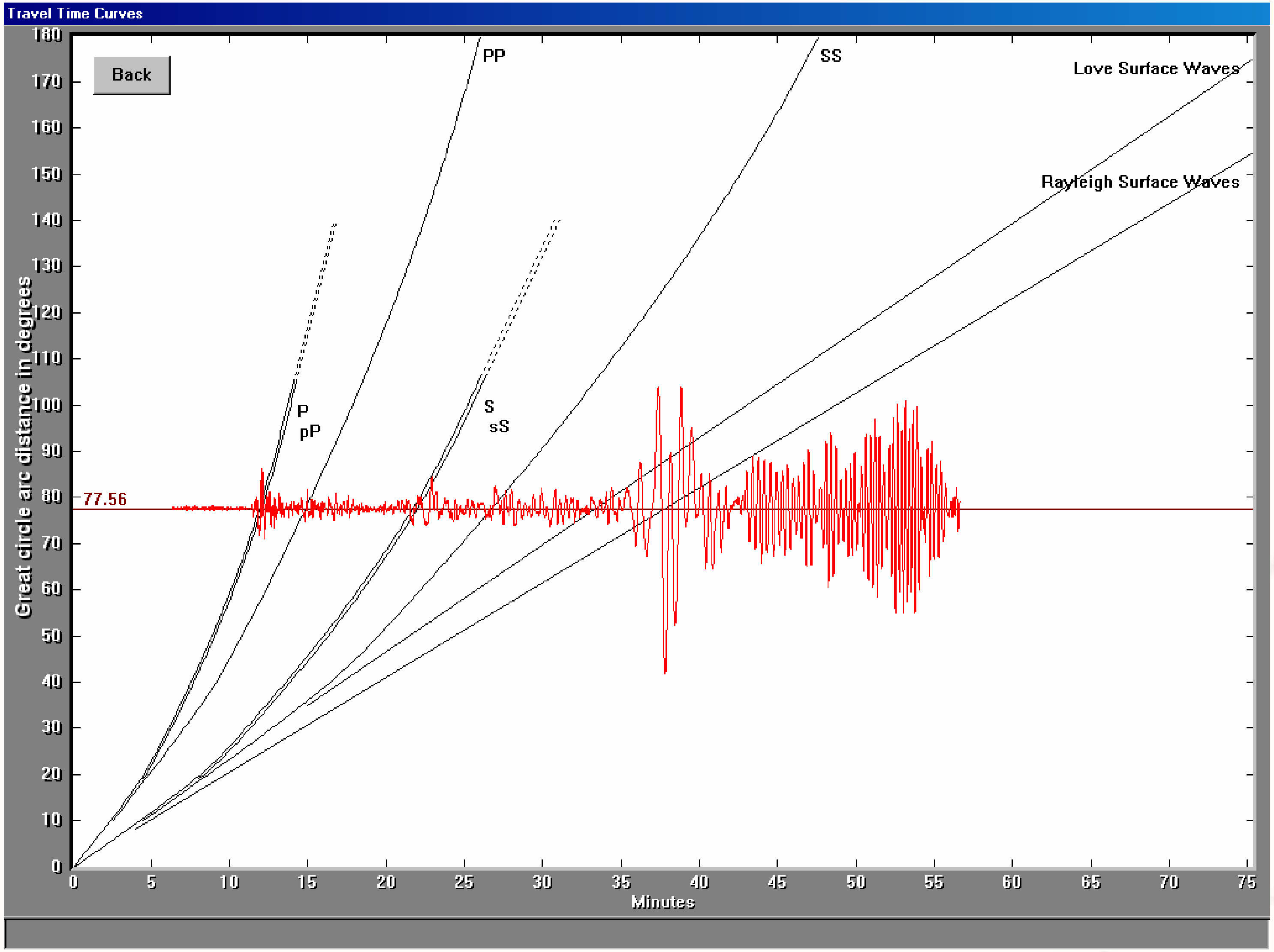
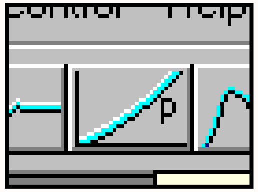
P-waves (compressional waves) are transmitted by liquids but P-waves which pass through the liquid core are bent (refracted) quite strongly by the large velocity contrast. This gives rise to a zone between 104 degrees and 143 degrees where direct P waves cannot be seen which is referred to as the **P wave shadow zone**

You should now be able to identify the various wiggles on your seismogram with the appropriate phase label and hence know the raypath through the earth that this energy travelled by.



Amaseis has a useful feature that allows you to overlay a set of traveltime curves on your seismogram that can either be useful for



identifying phases if you know how far away an event is, or for determining how far away an event is if you have managed to identify the phases.

If you have downloaded data from another station from the IRIS website you can load it into Amaseis and analyse it alongside your own data for comparison (use file open and make sure that your downloaded file has a filename of the form *****.sac)

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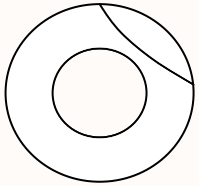
Naming the main seismic phases

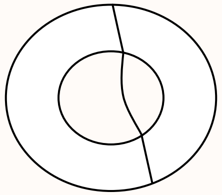
This is a simplified list of the main seismic phases that you might see on a seismic record from a distant earthquake. Each leg of a seismic raypath is assigned a letter. P indicating that the leg is traversed as a longitudinal wave, S as a transverse wave , K that the wave has travelled through the core (by necessity as a longitudinal wave). Each interaction at the Earth's surface or the core mantle boundary initiates a new leg.

Phases of distant shallow earthquakes

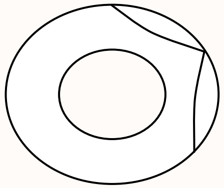
P, S *Direct longitudinal or transverse waves.*



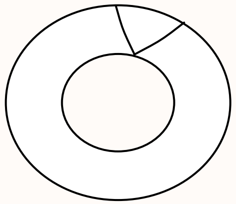
PKP , SKS *Direct longitudinal or transverse waves traversing the Earth's core. S waves passing through the core as P waves, transformed back into S waves on emergence.*



PP, SS *P or S waves reflected at the Earth's surface.*

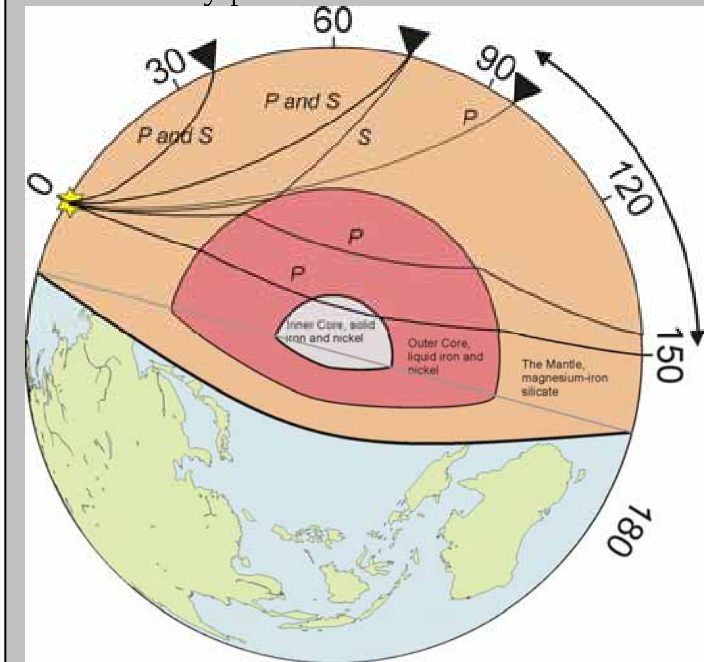


PcP, ScS *P or S waves reflected at the Earth's core boundary.*

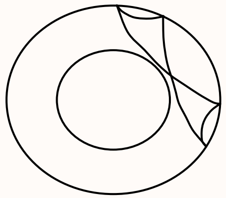


Curved ray-paths

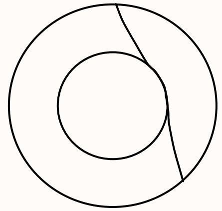
The speed of seismic waves through the Earth increases with depth (see the 1D velocity model box). This causes rays to be continuously refracted into curved ray-paths.



PS, SP *P and S waves reflected and transformed at the Earth's surface.*



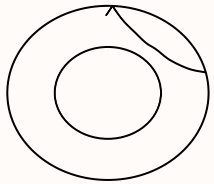
Pdiff ,Sdiff *P or S waves diffracted around the Earth's core.*



Phases of deep-focus earthquakes

The major branches of the travel-time curves carry the same descriptions as for shallow-focus events. Waves leaving the focus in an upward direction, and reflected at the surface are described by the letters p, s, as follows:

pP, sS etc *P or S waves reflected from the surface as P waves.*



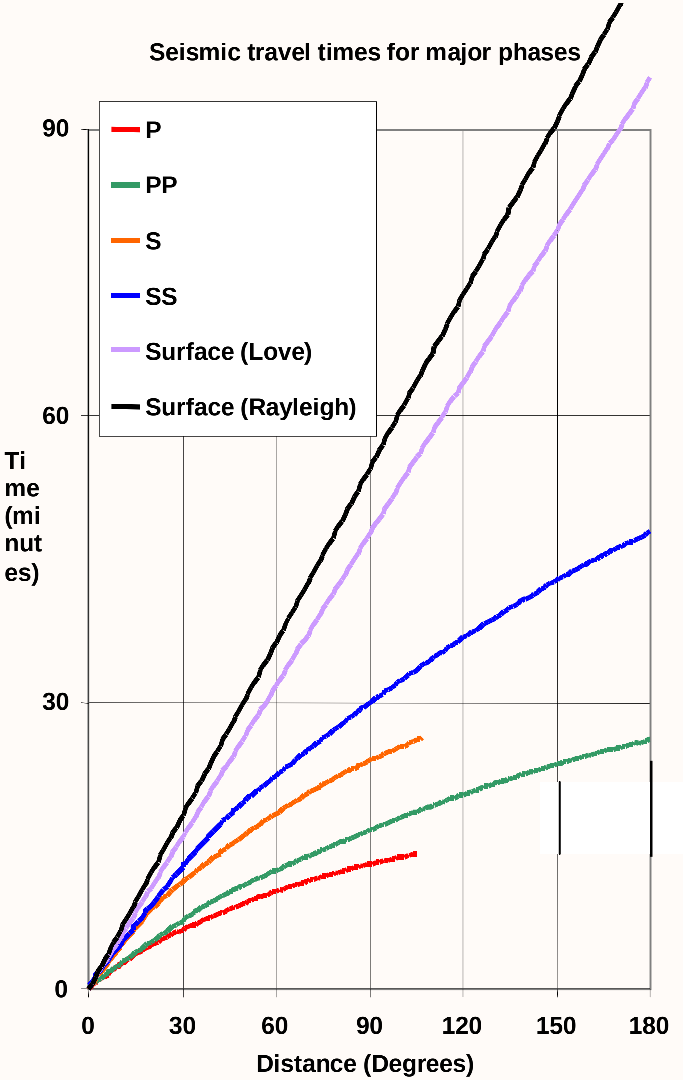
Surface waves

Surface waves travel around the free surface of the earth along great circle paths.

LQ *Love waves.* **LR** *Rayleigh waves.*

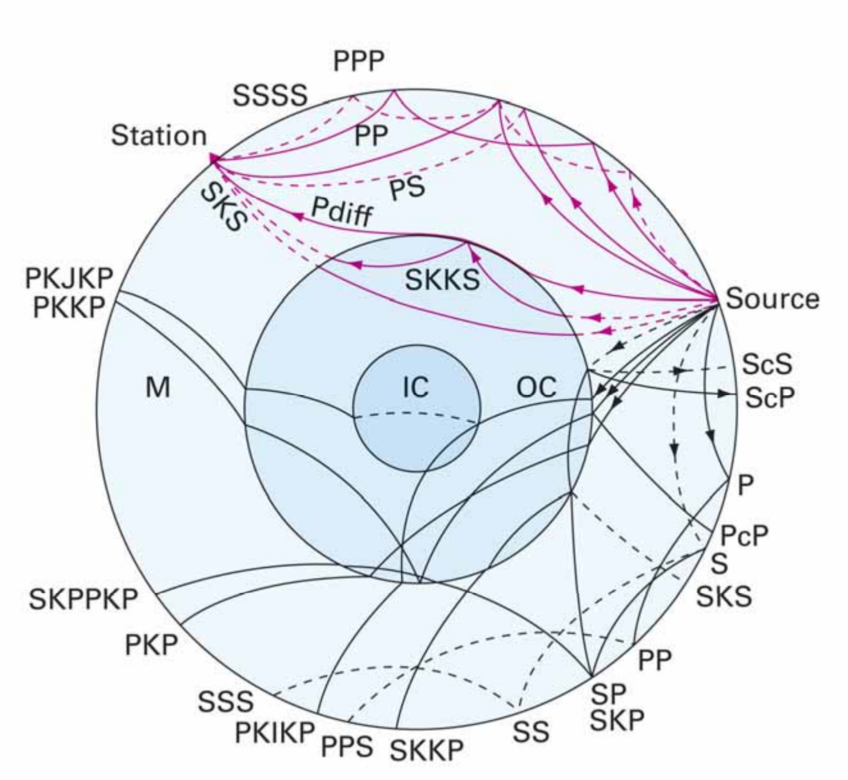
A complete list of seismic phase names can be found at www.iris.edu/data/vocab.htm
With a comprehensive graph of traveltimes at http://neic.usgs.gov/neis/travel_times/ttgraph.html

Theoretical travel-times graph



For a standard reference model of the Earth's velocity structure it is possible to calculate the theoretical arrival time of any particular ray-path (or seismic phase) for any given earthquake. A commonly used velocity model is called IASP91, a radially symmetrical velocity model where velocity varies only with depth. On the left is a graph of how the time taken for different raypaths varies with distance. Note that not all phases are present for all distances.

The diagram on the right shows some of the many possible routes that a seismic wave can take through the Earth's mantle, liquid outer core, and solid inner core.



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