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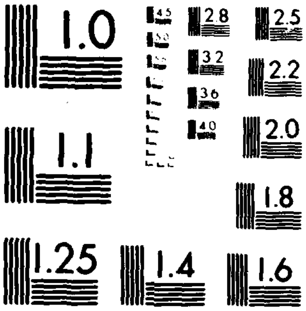

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Procurement Executive - Ministry of Defence

AWRE, Aldermaston

AWRE REPORT NO. 041/79

Earthquake Focal Mechanisms from Relative Amplitudes of P, pP and sP: Method and Computer Program

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ISBN 0 85518133 8

CONTENTS

CONTENTS (CONT)

SUMMARY

This report describes a FORTRAN computer program which determines the orientation (with confidence limits) of an assumed double couple earthquake source, given a series of teleseismically observed relative amplitudes, each of which relates the amplitudes of either P and pP, or P and sP, or pP and sP on one seismogram. Appropriate upper and lower limits are assigned in arbitrary units to the observed amplitude of each phase, with or without a polarity specification, and from these limits the program computes the corresponding range(s) of relative amplitudes for each pair of phases. All source orientations which are compatible with the range(s) of relative amplitudes are then identified, and can be displayed graphically. Those orientations which are compatible with all pairs of phases at all stations constitute the focal mechanism solution, with confidence limits which correspond directly to the confidence of the initial measurements. The program can be applied to shallow or deep earthquakes beneath land or sea.

1. OBJECT OF THE REPORT

This report describes a FORTRAN computer program (FALT) which finds all the orientations of an assumed double couple earthquake source which are compatible with a given series of teleseismically observed relative amplitudes, where each relative amplitude relates the amplitudes of either P and pP, or P and sP, or pP and sP, measured with "100% confidence limits" on one seismogram. Those orientations which are compatible with all pairs of phases at all stations constitute a focal mechanism determination with appropriate confidence limits.

Use of the program is described fully in section 2, which contains a description and explanation of all its features and their associated input and output options. Also of importance is discussion of the program's range of applicability to various types of earthquake and seismogram.

Section 3 contains some brief comments on the method, particularly as compared with the established "first motion" methods of determining fault plane orientations.

The appendices contain additional details to support section 2, but which are more appropriate for reference use. The schematic diagram of appendix A gives a broad outline of the program logic, and appendices B and C define the format of the program input. Appendix D gives computing time and storage requirements and related details, and appendices E, F and G contain the theory which is used in the computations. The program listing is given in appendices H and I.

This report is meant only as a users' guide to the program. Examples of its application to real earthquakes are published elsewhere. The program has been applied to a wide range of earthquakes, and the reader is referred to Pearce (1,2), Barley and Pearce (3) and Pearce (4). Without modification it has also been applied to a micro-earthquake beneath the Mid-Atlantic Ridge observed locally on ocean-bottom seismographs (5), but this type of application is not considered in this report.

2. USE OF THE PROGRAM

2.1 Introduction

Use of the program FALT is most easily described by means of an example, so in this section a set of seismograms from a real earthquake is discussed in order to introduce all the features of the program. In this way, the purpose of its input and output options can be more clearly demonstrated. Explanation of these options includes reference to the relevant variables in the program input, whose definitions and formats are stated formally in appendices B and C.

Figure 1 shows P wave seismograms recorded teleseismically at three short period arrays from a shallow earthquake in East Kazakhstan, whose body wave magnitude m_b was about 5.0. The seismograms are phased array sums of about twenty seismometers, but the only significance of using arrays here is the consequent improvement in signal-to-noise ratio over that of a single seismograph record.

In a previous study of these seismograms by Douglas et al. (6), modelling and other evidence provided strong indications that the two discrete arrivals recorded at Yellowknife (YKA) and Warramunga (WRA) are P and pP, and that the two arrivals at Gauribidanur (GBA) are P and sP, as shown in figure 1. The relative arrival times of the supposed pP and sP phases relative to the direct P wave agreed with this interpretation, and in order to generate matching theoretical seismograms, Douglas et al. had to resort to a process of trial and error to search for a double couple orientation which yielded polarities and relative amplitudes similar to those observed for P, pP and sP at all three stations. Their success in finding such an orientation, coupled with other evidence, was used to conclude that the event was indeed an earthquake with the specified source orientation and with the chosen phase identifications on each seismogram. However, this conclusion lacked an associated estimate of its reliability, which would be provided by, for example, a measure of the non-uniqueness of the compatible source orientation.

The purpose of the program FALT is to meet this requirement by providing a formal answer to the question "What range or ranges of source orientations, if any, are consistent with the polarities and relative amplitudes of P, pP and sP observed on all available seismograms, assuming chosen phase identifications on the seismograms, and assuming that the seismic source is an earthquake double couple?" Of fundamental importance is the use of only relative amplitudes; all reference to absolute amplitudes is entirely avoided. The significance of this can be seen from figure 2(a), which shows schematically the ray paths of P, pP and sP for a shallow earthquake. Attempts to contour the source radiation pattern by comparing absolute P amplitudes at different stations (eg, reference (7)) or by comparing phases with widely differing paths at the same station, all rely on correct allowance being made for the grossly variable effects of anelastic attenuation and scattering along different propagation paths within the Earth. Such effects may dominate that of the source radiation pattern and are difficult to allow for adequately, thereby severely limiting the success of such methods.

The notion of dividing orientations into those which are "acceptable" and "unacceptable" is another major departure from other methods of determining focal mechanisms, which typically produce one "best fit" orientation. It will be seen that the implications of this, which are summarised in section 3, are fundamental to the relative amplitude method.

In order to obtain time-separation of the P, pP and sP phases on shallow earthquake seismograms we must use short period records, or, alternatively, for larger earthquakes use could be made of broad band observations. From figure 2(a), we expect the amplitudes of P, pP and sP from a shallow earthquake to suffer the same loss along the path to a given station, except near the source, as only here do the phases traverse significantly different paths. Hence, the sensitivity of short period amplitudes to anelastic attenuation does not present a difficulty, since for relative amplitudes it cancels out.

The ray paths shown in figure 2(a) represent the three phases P, pP and sP, which are supposed to be present in figure 1. The waveform of each seismogram - and hence its interpretation - is unusually simple, so these seismograms might be considered to be "ideal" in terms of the development of the present method. Because few seismograms can be so easily interpreted, the following pages include discussion of the extent to which other types of seismogram or earthquake can be brought within the ambit of the relative amplitude method.

We can immediately ask whether the method can be applied to deep earthquakes, whose corresponding ray paths are shown schematically in figure 2(b). It is no longer valid to assume that the three phases traverse similar mantle paths, but in this case time-separation of the phases is obtained on long period seismograms, which are not so sensitive to differences in anelastic attenuation. So it is feasible to apply the method to those deep earthquakes which are large enough to yield long period seismograms (ie, which have a body wave magnitude m_b of about $5\frac{1}{2}$ or larger).

Before describing the method, it is noted that, by providing a quantitative answer to the question posed earlier, we establish whether or not any source orientations are compatible with the assumed phase identifications, and if some are, then we know how well the source orientation is constrained, which types of faults the solution represents, and whether it is non-unique (as evidenced by the existence of more than one compatible range of orientations). If no orientations are compatible, this might be evidence of an anomalous source mechanism, incorrect seismogram interpretation or merely the presence of one or more anomalous seismograms; the program includes features which assist in the investigation of such anomalies.

2.2 Method of specifying amplitude bounds numerically

We first consider the method by which relative amplitude measurements (with their correct confidence limits) are expressed for the phases identified on a seismogram. The inclusion of confidence limits in amplitude measurements means that the uncertainty in each measurement is implicit in the input data. This is not possible for first motion readings alone - giving rise to one of their main disadvantages, as explained in section 3.

The method of specifying amplitude bounds numerically has been designed so that the value for each phase, with appropriate confidence limits, can be correctly expressed in terms of actual measurements which can be made on a real seismogram. Accordingly, the amplitude information is specified for each phase separately, in units which are arbitrary - it being necessary only to maintain the same units for all phases on the same seismogram. Each amplitude can be assigned particular "100% confidence limits" having regard for the several uncertainties discussed in section 2.3. The program then converts these measurements into equivalent range(s) of relative amplitudes for each phase pair. Therefore, when we speak of measuring the "amplitude" of a phase in the present context, this is only a convenient step towards establishing relative amplitudes and does not refer to amplitude in any absolute sense.

The amplitude information from each phase is specified using three variables:-

(1) Lower bound on the signal amplitude, without attention to polarity.

(2) Upper bound on the signal amplitude, without attention to polarity.

(3) Signal polarity - either positive, negative or uncertain (ie, both polarities included).

The corresponding three variables in the program input are either PA2IN, PA1IN and SIGNP, or PPA2IN, PPA1IN and SIGNPP, as indicated in appendix B.

Amplitude assignments for the seismograms in figure 1 are included in the figure . We note that the specification of upper and lower bounds on an amplitude is independent of any choice of polarity (as it is in reality), so that the "large amplitude but uncertain polarity" situation is represented by a positive range and an identical negative range of amplidues as for sP at GBA. A lower amplitude phase (for example, sP at YKA) can be assigned a lower bound of zero with unspecified polarity, which gives one amplitude range centred on zero.

We note also that even if a phase is not visible on the seismogram (see, for example, pP at GBA), then an upper bound can still be placed on its amplitude. This ability of the relative amplitude method to utilise even the information which is implicit in the absence of phases is of great importance, since this indicates that the corresponding ray left the source near a null or "node" in the radiation pattern which provides a strong constraint on its orientation.

2.3 The correct assignment of 100% confidence limits to observed amplitudes

We now consider the criteria which decide the correct choice of amplitude bounds for each phase.

Application of the relative amplitude method to a given set of seismograms will yield one or more compatible regions in orientation space, or it may yield no compatible orientations. Whatever the result, its validity, and hence its correct interpretation, relies entirely on the specification of true 100% confidence limits on the amplitudes of each identified phase. Several factors contribute to the size of the uncertainty in each phase amplitude, and it is vital to allow for all of these when specifying each upper and lower amplitude bound. These contributory factors, which are treated below, typically lead to uncertainties of up to a factor of two for pP, and possibly more for sP.

Since the aim is to specify "100% confidence limits" it is first noted that a signal polarity must only be specified if it can be read unambiguously from the seismogram. In all other cases it must be left as unspecified, which results in both polarities being included for whatever amplitude range is specified for that phase. Four factors which contribute to uncertainty in the observed amplitudes are identified:-

2.3.1 Effect of microseismic noise

The uncertainty which the presence of seismic noise imposes on the observed signal amplitude depends mainly on the amplitude of the noise on the seismogram at or near the signal dominant period. Even when this is small, it can still be responsible for ambiguity in the signal polarity, which must then be left unspecified. Pearce and Barley (8) have introduced a method of adding synthetic noise to theoretical seismograms in order to establish the amount of signal distortion that is attributable to noise on any given observed seismogram. They showed that a surprisingly low level of microseismic noise can lead to incorrect, but apparently unambiguous, first motion readings on short period seismograms. In figure 1, microseismic noise is low at YKA, but noise with a dominant period similar to that of the signal could be substantially affecting signal amplitudes at WRA and GBA. If the earthquake were sufficiently large to yield broad band seismograms, the microseismic noise might still not contribute much uncertainty at YKA, since its dominant period (about 6 s) would be well separated from that of the signals (about 1 s).

2.3.2 Effect of seismograph response

The theoretical requirement is to measure the square root of the energy contained in the complete pulse. This is best done on a broad band record, where any difference in pulse length between the phases can be observed and allowed for, by aiming to use the area beneath the broad band displacement record. If the source emission has a finite duration, then narrow band seismographs (particularly those at short periods as in figure 1) record the derivative of the ground motion, which can, therefore, lead to gross discrepancies between the recorded amplitude and the broad band pulse energy. It is for this reason that subsequent matching of pulse shape and waveform, as well as amplitude, by the generation of theoretical seismograms using a source orientation computed by this program, is of value in providing additional interpretative evidence (as discussed in the example of figure 1 by Douglas et al. (6)). In general, for short period recordings of shallow earthquakes the best results are expected for a small source, whose duration of emission is less than 1 s and therefore lies well within the pass band of the seismograph. This is assumed to apply for the figure 1 example, and the ability of Douglas et al. to reproduce closely the pulse shapes of the phases provides strong support for this assumption. No formal allowance is made in the program for source finiteness; the radiation from a point double couple is used throughout (see appendix E). However, we do not expect source finiteness to have a major effect on observed relative amplitudes provided that the duration of the source radiation lies within the pass band of the seismograph. Long period seismograms cannot be used for shallow earthquakes because the phases of interest are not time-resolved. For deep earthquakes, the use of wide band long period seismograms (such as those of the WWSSN) allows reliable amplitude measurements to be made for larger earthquakes, as previously explained.

2.3.3 Effect of interfering arrivals

If another phase interferes with the phase being measured, the effect on a short period waveform is large, although the generation of theoretical seismograms is again able to assist in putting bounds on its possible amplitude. The example in figure 1 does not exhibit such interference, but this is unusual. When the coda is complex, it may only be possible to place an upper bound (without polarity) on the amplitudes of the reflected phases, but it can be shown that even this often imposes a significant constraint on the source orientation (4).

2.3.4 Effect of uncertainty in other parameters

Lastly, it must be remembered that other input parameters may themselves have an uncertainty which leads to a corresponding uncertainty in amplitude, whose effect must be included in the amplitude bounds. The effect of amplitude loss during surface reflection of pP and sP is calculated and allowed for in the program as described later, and there is an option to allow for other losses of pP or sP amplitude above the source, relative to direct P. However, these additional losses can only be estimated, as are the parameters which are needed to calculate reflection coefficients - namely the P and S wave velocities in the source layer and surface layer, and the surface layer density for undersea earthquakes. Specified takeoff angles at the source are also only approximate (see later) and represent a range of points on the focal sphere - the maximum effect of this angle occurs when a ray emerges from near a node (ie, a null in the radiation pattern) because it is then that the angular rate of change in radiated energy is highest. These angles also affect reflection coefficients, in the way described in section 2.6.1.

Specification of the parameters relevant to these uncertainties is discussed later; here a "check list" is given of those input variables whose uncertainties may affect amplitudes. They are: ALPHA, GAMMA, DIST, DEPTH, PPFCTF, SPFCTF, PPFCT1, SPFCT1, VPSRCE, VSSRCE, VPSURF, VSSURF and DSURF.

2.4 The possible phase pairs for earthquakes beneath land and sea

Since the present method is based on relative amplitudes, the basic element of information is provided, not by one phase, but by a phase pair. Hence, the fundamental unit of computation is to process a single phase pair in order to find those source orientations which are compatible with the given phase pair on a given seismogram. Any number of such phase pairs - from the same and other seismograms - can then be similarly processed, and their results combined to establish those (if any) source orientations which are compatible with all phase pairs. Mentioned below are all the types of phase pair which are included in the program.

For earthquakes beneath land, as for the example in figure 1, we expect three main phases, namely P, pP and sP as shown in figure 3(a). If both the P and pP and the P and sP phase pairs are included from the same seismogram, then additional orientations will, in general, be eliminated by also including the third possible phase pair, namely the corresponding pP and sP. This third phase pair should, therefore, be included whenever all three phases are utilised from the same seismogram.

For undersea earthquakes (specified using ISEA) we ideally expect to observe four rather than three main phases, as shown in figure 3(b). In this case pP is defined as the reflection at the sea bed, while the analogous reflection from the sea surface - denoted by pP(ssf) - can be utilised in addition to, or instead of, pP. There are then six possible phase pairs, ie, P and pP, P and sP, pP and sP, P and pP(ssf), pP(ssf) and sP, and pP and pP(ssf). If only three phases are used (that is, either P, pP and sP or P, pP(ssf) and sP), there are three phase pairs to include. If all four phases are used, there are five phase pairs to include. The sixth phase pair, namely pP and pP(ssf), should strictly be included, but since these two phases sample the same point on the focal sphere they should convey similar information. This means that no additional orientations would be eliminated, so the option to use this phase pair is not included.

In what follows, the phases pP reflected at a solid free surface, sea surface or sea bed are sometimes referred to collectively as "pP type phases", and sP reflected at a solid free surface or sea bed as "sP type phases".

The type of phase pair to which a set of measurements relates is identified by codes, using the variable PHASES.

2.5 Ray path specification

Having established a method of describing the relative amplitudes of phase pairs numerically, it is necessary to specify all the structural and ray path parameters which enable the theoretically expected relative amplitude to be calculated for a given source orientation and a given phase pair at a specified station.

First, the directions in which the ray paths leave the focal sphere, and the angles at which they are reflected at the surface, must be specified. These depend upon the azimuth and distance of the station from the earthquake, upon seismic velocities in the source and surface layers, and, to a lesser extent, upon focal depth. The specification of these values is considered in this section.

Secondly, it may be necessary to apply corrections to the calculated amplitudes of surface reflected phases to allow for loss of amplitude upon reflection at the Earth's surface, or at other crustal discontinuities. These corrections also depend upon seismic velocities and densities, and certain other geophysical parameters, and are discussed in section 2.6.

The azimuth of the station from the earthquake is specified explicitly using AZI. The takeoff angle of the direct P wave at source, and also of pP, can also be specified explicitly, using ALPHA and GAMMA respectively, although for all shallow earthquakes these angles are equal, so that if GAMMA is left blank, it is set to the value of ALPHA. The takeoff angle of sP, namely BETA, is not specified as input but is always deduced from GAMMA using the P and S wave velocities in the source layer (see appendix E). Thus, AZI and ALPHA (and for a deep earthquake possibly a separate GAMMA) are sufficient to fix the takeoff directions of P, pP and sP from the focal sphere. However, a separate estimation of ALPHA for a large number of stations is tedious and consists essentially of consulting tables of takeoff angles against distance and depth, and possibly applying a correction for source layer velocity in the case of intracrustal earthquakes. Because of this, such tables are stored in the program and provide an alternative means of setting ALPHA, by specifying instead the epicentral distance DIST and the focal depth DEPTH. The use of this option is controlled by INDANG. When using DIST and DEPTH to set takeoff angles, DEPTH is left blank for an intracrustal earthquake, and the computed P wave takeoff angles are then automatically corrected for the specified source layer velocity (VPSRCE) using Snell's law and assuming a sub-Moho velocity of 8.1 km/s. Where internal computation of P wave takeoff angle is requested, ALPHA is still read from the input for any phase pairs for which DIST is outside the teleseismic range (see under INDANG in appendix B).

A further advantage of this method of specifying takeoff angles is that adjustment of a single uncertain variable - say VPSRCE or DEPTH - can be used to investigate the corresponding effect on the range of acceptable orientations. The value of perturbation studies of this kind is discussed in section 2.12. Separate tables of pP takeoff angles are not included in the program, so GAMMA is still set equal to ALPHA unless it is separately specified.

Although the above options provide for most requirements, the provision to systematically perturb P wave takeoff angles by altering the source layer velocity or focal depth does not extend to pP, which is inconvenient when studying deep earthquakes. Furthermore, it might be instructive to investigate the effect of perturbing takeoff angles alone, without simultaneously altering source layer velocity which causes refraction coefficients to change. In order to provide for these possibilities, there is an option to perturb systematically all P takeoff angles and pP takeoff angles, using ANGPF and ANGPPF respectively. This perturbation is applied to ALPHA and GAMMA after GAMMA has been set to ALPHA (if applicable) and so allows for independent perturbation of ALPHA and GAMMA during investigation of anomalous observations. ANGPF and ANGPPF adjust takeoff angles as if the source layer P wave velocity were changed by a factor of ANGPF (or ANGPPF) (see under ANGPF in appendix B) but the value of VPSRCE, as required for calculating angles in the surface layer, is unchanged. Thus, ANGPF and ANGPPF are intended for use as experimental perturbation factors rather than as representing any known effect of structure or source.

2.6 Path corrections to the calculated amplitudes for shallow and deep earthquakes

When calculating the theoretically predicted relative amplitude for a phase pair at a given station for a specific source orientation, it is necessary to apply corrections to allow for any change in relative amplitude between the phases which occurs between their emergence at the source and their arrival at the seismograph. Following the argument of section 2.1 such corrections can be restricted to the parts of the ray paths which are close to the source. We therefore conclude that the only corrections to be applied are to compensate for the loss of amplitude of the surface reflected phases with respect to P which results from interaction of the former with crustal layering above the source, including the effect of energy loss upon reflection. In addition, a factor must be included in sP which relates the excitation of P and S waves by the source.

It is emphasized that all these corrections are applied to the theoretically expected amplitudes calculated in the program, which are then compared with the range(s) of relative amplitudes deduced from the seismogram;

thus, the numerical values corresponding to the observed amplitudes are not altered. Hence, all effects which result in loss of amplitude of a phase during propagation are represented by factors whose value is numerically less than unity.

The above effects are allowed for by three multiplicative factors. First a correction is applied by the program to any surface reflected phase to allow for energy partitioning upon reflection at the surface. A second correction to any surface reflected phase can be input directly, to allow for any other estimated amplitude effect above the source. A third correction applies to sP only; this allows for the relative excitation of S and P by the source. These corrections are now explained.

2.6.1 Allowance for reflection coefficients for surface reflected phases

The appropriate amplitude reflection coefficient for any surface reflected phase is normally calculated within the program, and corresponds either to the variable PPFCT3 (for pP type reflections at a solid free surface, sea surface or sea bed) or to SPFCT3 (for sP type reflections at a solid free surface or sea bed). In the case of a sea surface reflections, the coefficient includes the combined effect of upward refraction at the sea bed, reflection at the sea surface and downward refraction at the sea bed. The quantities PPFCT3 and SPFCT3 are multiplicative factors which are applied to the surface reflection amplitude, so that they are normally less than, or equal to, 1.0, but may be negative to allow for a polarity change upon reflection.

The relevant mathematical expressions derived from the appropriate Zöppritz equations are given in appendix E, from which it will be seen that, apart from being a function of ray angle at the surface, the coefficients depend upon the ratio of the P and S wave velocities in the surface solid layer. Where a sea layer is present, they also depend upon the ratio of the P wave velocities in the sea and surface solid layers, and upon the ratio of the densities in these layers. Hence, there are several structural variables to be specified, and they are input in the following way.

The P and S wave velocities in the source layer are input as VPSRCE and VSSRCE respectively, and in the surface solid layer as VPSURF and VSSURF. The ratios of these velocities are required to calculate ray angles at the surface given those at the source using Snell's law, and the ratio of the P and S velocities in the surface layer also appears explicitly in the equations for the reflection coefficients (see appendix E). (If the P wave takeoff angles at source are calculated from epicentral distance and depth, as described in section 2.5, then for intracrustal earthquakes VPSRCE is also used in that calculation if the earthquake is intracrustal.)

In the presence of a sea layer the density of the surface solid layer is input as DSURF and the velocity and density of the sea layer are set to 1.5 km/s and 1.0 g/cm^3 respectively and are held as constants in the program.

With regard to the numerical values of these coefficients, it should be noted that they tend to - 1.0 for all pP type phases as the ray approaches vertical incidence, the minus sign indicating that reflection yields a change in signal polarity, which always occurs for the near-vertical angles which are likely to be of interest. This numerical behaviour of the coefficient means that its value has little dependence upon the ray angle near normal incidence - it does not become numerically less than 0.9 for ray angles up to 14° from the vertical. A consequence of this is that we do not expect uncertainty in the surface layer velocity to introduce any significant uncertainty in the observed pP amplitude. By contrast the reflection coefficient of sP type phases tends to zero approaching vertical incidence, making its value highly sensitive to ray angle near the vertical. This must be borne in mind when placing the 100% confidence limits on the observed amplitudes of sP (see section 2.3.4).

As explained in appendix E, the reflection coefficient for the sP type phases also includes a factor to allow for the instantaneous change in geometrical spreading factor which the incident spherical S wavefront suffers on being reflected as P. This factor is expressed in terms of the pP takeoff angle alone.

Values of PPFCT3 and SPFCT3 are normally calculated as required for each phase pair. Alternatively, there is an option (using IFCT3) to set all values to + 1.0, so that the desired values can be incorporated into PPFCT1 and SPFCT1 (see below).

2.6.2 Allowance for other relative amplitude loss for surface reflected phases

A further multiplicative factor, whose value is input directly, can be applied to a surface reflected phase by the use of PPFCT1 (for a pP type phase) or SPFCT1 (for a sP type phase). The factors, which may be specified separately for each phase pair if required, are intended to allow for estimated loss of amplitude of the surface reflected phase relative to direct P, due to any other cause apart from surface reflection which was treated above. The factor might include the effect of energy partitioning at seismic discontinuities above the source other than the free surface, or that of anelastic attenuation or scattering above the source. Such effects do not lend themselves to the analytical treatment of the previous section, so the values are left to be estimated and supplied as direct input. In the example of figure 1, the absence of any other uninterpreted arrivals in the seismograms suggests that the the structure above the source is very "clean", and the specification of a factor under this heading would clearly not be warranted. However, this might not be so for a more complex seismogram if, despite its complexity, it could be modelled in terms of crustal reflections above the source (see, for example, chapter 5 of reference (2)). If, when setting PPFCT1 and SPFCT1, the Zöppritz equations are used to calculate the composite effect on pP and sP amplitude of a complex velocity structure above the source, then it may be more convenient to include the effect of the free surface or sea layer in that calculation. In order to provide for this, the user can suppress the calculations of PPFCT3 and SPFCT3 within the program. This is done using IFCT3.

The factors PPFCT1 and SPFCT1 have a further use in perturbation studies discussed in section 2.12, as one can study what effect a systematic change of surface reflected amplitudes to all stations has on the compatible range of source orientations. In order to facilitate this, the option to specify factors PPFCTF and SPFCTF is included; these can be used to apply the same amplitude correction to all pP type phases, and to all sP type phases, in a given set of phase pairs.

2.6.3 Allowance for relative excitation of S and P by the source

Expressions for the P and S wave amplitude leaving the source in any given direction are each normalised to unity in the calculations within the program. A relative amplitude relating two phases which both leave the source as P (ie, P and pP) is independent of all geophysical parameters. However, this is not so for the relative amplitude of a P and an S phase (ie, P and sP or pP and sP), as equations (E1) and (E2) in appendix E show. This factor corresponds to the relative excitation of P and S by the source, and is numerically close to 5.2, as shown in appendix E. This factor (SPFCT2) is applied to all sP type phases, and is set in the program to 5.2.

2.7 The procedure for searching orientation space

For the purpose of the relative amplitude method the point double couple source is described in terms of its equivalent far-field P and S wave radiation patterns, as given in appendix E, and illustrated in figures 4(c) and 5(c) respectively. With respect to the co-ordinate system of figures 4 and 5, a source orientation is defined in terms of the three angular variables, shown in figure 6(a) - namely the dip δ of the fault plane, the slip angle ψ in this plane and its strike σ from north. For a given phase pair (with corresponding station azimuth ξ and takeoff angles α, β and γ as shown in figure 6(b)) all source orientations are searched at an angular interval d, within the limits $d \leqslant \psi \leqslant \pi$; $d \leqslant \delta \leqslant \pi$ and $d \leqslant \eta \leqslant 2\pi$, as described in appendix F. (Here, η is simply the azimuth of the recording station measured from the strike, ie, $\xi - \sigma$). In appendix F it is explained that these bounds effectively include all possible orientations, with interchange of fault and auxiliary planes as separate solutions.

For each orientation in the search mesh, the theoretically expected relative amplitude is calculated (with its path corrections as described in section 2.6) and is tested against the acceptable relative amplitude range(s) corresponding to the input. The orientation is then classified as "acceptable" or "unacceptable" according to whether or not the calculated value lies within the acceptable range(s). Acceptable orientations are listed and displayed as described in section 2.8. In this way a picture of the acceptable regions in orientation space is built up as the search progresses.

The angular increment for search, d, is always the same in dip, slip angle and strike. It corresponds to the input variable DINCIN, which is converted to DINC within the program, after checking, and, if necessary, correcting its value to an integer submultiple of 90.0, which fulfils the requirements set out in appendix B. The choice of a suitable value of d is governed by several criteria. A minimum value is imposed by the availability of computing time and storage, since d is the major factor which determines these requirements - both of which are approximately inversely proportional to the cube of d. There is also a maximum number of search increments which can be usefully accommodated in the visual display of results described below. Conversely, seismograms of a given quality require a value of d which is small enough to exploit adequately the information which they contain.

It is found that $d = 5^{\circ}$ provides a satisfactory compromise for typical data, although $d = 10^{\circ}$ is more suitable for less accurate computations, or where a large number of stations is included. In section 2.12 the option to search over a restricted region of orientation space is introduced; this enables greater resolution (with d as small as 1°) to be used in certain cases, with no extra computing requirements. Further guidance on setting DINCIN is given in appendix B.

2.8 Method of displaying results - SUBROUTINE PLOTV

Although the source orientations compatible with each successive phase pair are listed if required by controlling IPRINT1, a clear interpretation of the acceptable regions in orientation space requires a form of three-dimensional display on which different types of orientation can be easily recognised. This is not provided by plotting pairs of great circles on a stereographic projection, since only several such pairs can be plotted without confusion, and because the arbitrary size and shape of the acceptable regions would not be discernible on such a plot. Dillinger et al. (9) and Guinn and Long (10) have represented arbitrarily shaped regions of orientation space by plotting on a stereographic projection the boundaries of the acceptable directions of the compression, tension and null axes, and Dillinger et al. contoured different degrees of compatibility in this way. However, even this method can be confusing if the regions for each axis are large or disconnected, or extend into both hemispheres.

Pearce (1) introduced an entirely different type of representation, which is particularly suitable for the present application. All those orientations (ψ_i, δ_i, σ_i) which are compatible with one (or a series) of phase pairs are each plotted as a short vector drawn at an angle σ_i from the Cartesian point (ψ_i, δ_i), using the type of three-dimensional display show in figure 7, which is referred to as a "vectorplot". Different combinations of ψ (the angle of slip in the fault plane) and δ (dip of the fault plane) represent the various types of fault, which are therefore characterised by their positions on the vectorplot. These are indicated in figure 7 by conventional lower hemisphere stereographic projections, which are oriented for northerly strike ($\sigma = 360^\circ$ - upward vector); other strike directions are interpreted by equivalent rotation of the projections. The positions of some important types of fault on the vectorplot are labelled - there is no need to calculate the effect of interchanging fault and auxiliary planes because the resulting fault types are represented elsewhere on the plot.

The value of this type of display is two-fold. First, the arbitrary shapes and sizes of any acceptable regions in orientation space are immediately apparent, and second, a given phase pair or series of phase pairs yields an easily interpretable pattern of vectors, whose distribution is characteristic of one or more classes of fault. Experience with different characteristic patterns leads to quick interpretation of results in terms of fault dynamics as for stereographic projections, but in a deeper sense because of the inclusion of confidence information. Because this type of vectorplot uses only a single vector length - to denote acceptance of an orientation - it is referred to as a "fixed length vectorplot" to distinguish it from the "variable length vectorplot" introduced in section 2.11.

Vectorplots are routinely generated using a separate subroutine, PLOTV, which is called by the main program, FALT. A vectorplot is then expanded to fill the frame in both the ψ and δ directions, so that searches over a restricted region of orientation space - introduced in section 2.12 - permit plots with longer vectors; this becomes valuable when the "variable length vectorplot" is introduced in section 2.11.

The example of figure 1 is now used to illustrate the use of the fixed length vectorplot; amplitude assignments are shown in figure 1. The phase pair P and sP at WRA is compatible with the orientations shown in figure 8, whose main features are immediately apparent. We see that reverse faults with all possible strikes are compatible (see figure 7) and that these may have a significant strike slip component. We also see that certain orientations with up to 100% strike slip component are compatible, but with only certain strikes. No orientations with any component of normal faulting are compatible.

For more formal presentation of vectorplots, as required for example in publications, the need for any artwork is avoided by using a separate program, PUBV, which plots fully annotated vectorplots given the machine readable output from FALT which is described in section 2.13.2. PUBV provides for full flexibility of presentation, including variable plot size and annotation, and options to display more than one vectorplot on the same page. Whereas figure 8 shows a typical routine output from FALT using PLOTV, the separate program PUBV was used to generate figures 9, 10 and 11. Details of PUBV are not included in this report.

2.9 Combination of results from a series of phase pairs

All phase pairs are processed separately as described above and in appendices E and F; each phase pair reveals an array of acceptable source orientations which can be represented in a vectorplot if required by controlling IPLOT1. Thus, the example of figure 1 would yield nine vectorplots similar to figure 8, but each with a different number and distribution of vectors according to the type of constraint which the corresponding phase pair imposes on the source orientation.

If the source is a simple double couple, and if the phase identifications are correct at all stations, then we expect at least one orientation to be compatible with all the phase pairs, and in any case we may wish to know which orientations remain acceptable as each new phase pair is introduced. In order to provide this the program uses the orientation array (variable array F in the program) which is a logical array with one element for each search point in orientation space. Its elements are initially set to a code corresponding to "acceptable" and as each phase pair is processed, the elements corresponding to any unacceptable orientations are reset in accordance with the procedure described in appendix G. In this way the orientation array retains the cumulative status of all orientations, and by accessing it after processing each phase pair listings or vectorplots can be generated which show those orientations which are compatible with all phase pairs so far processed (controlled by IPRNT2 and IPLOT2 and referred to as "cumulative acceptable orientations"). The listing and vectorplot showing any orientations which are compatible with all phase pairs are controlled by IPRNT4 and IPLOT4 and referred to as "orientations compatible with all phase pairs". The method by which the results from a series of phase pairs are combined is given in appendix G.

For the example in figure 1 we find that there are indeed some source orientations remaining after inclusion of all phase pairs, though, as expected, the number is much smaller than for a single phase pair. Figure 9 shows the resulting vectorplot, which indicates that only a range of near 45° dip-slip reverse faults is acceptable (see figure 7). Figure 9 emphasises the inadequency of merely quoting the defining angles of the two nodal planes with their confidence limits - the shape of the acceptable region in orientation space is far from rectilinear.

2.10 Measurement of the constraint imposed on the source orientation - the use of "significance" values

It has been shown that fixed length vectorplots give a clear indication of which type of source orientations are compatible with a given phase pair, or series of phase pairs. Of interest is N_i, the corresponding number of source orientations which is acceptable, or more strictly this number as a fraction of N, the total number of orientations in the whole of orientation space. The fraction of orientations which is incompatible with one or a series of phase pairs is especially important, as this is a measure of the degree of constraint placed upon the source orientation by the phase pair(s), and as such is a measure of their information content insofar as it relates to the source orientation. This fraction of incompatible orientations is given by the expression

$$\frac{N - N_i}{N}. \qquad \text{....(1)}$$

However, this expression is a measure of the constraint placed upon the fault plane orientation in the co-ordinate system (ψ, δ, σ) and, as such, is useful in terms of these usual geological parameters. This is not equal to the constraint imposed on the fault plane orientation in real space, in which rotation of a co-ordinate system through the same angle about any pole corresponds to the same distance moved in orientation space. This difference becomes clear for $\delta = \pi$ (exception (F2) referred to in appendix F), where any ψ and δ with the same sum represent the same orientation in real space.

The fraction of incompatible orientations in real space gives a correct measure of the constraint which a given phase pair or set of phase pairs places on the source orientations, and will be referred to as the "significance" of the phase pairs(s), and denoted by S. In order to obtain the significance we require that the volume element in orientation space represented by each search point be weighted according to the range of real orientations which it represents. A range of real orientations is given by the allowable range of any chosen axis, multiplied by the allowable range of rotations about that axis, and for ease of computation the axis through the strike is chosen (see figure 6(a)). For a small angular range in ψ, δ and σ, the allowable range of directions of this axis is $\Delta\sigma \times \Delta\psi \sin\sigma$, and its allowed rotation is $\Delta\delta$. Thus, if the angular variables are continuous, the significance is given by

$$S = 1 - \frac{\displaystyle\iiint_{\substack{\text{all}\\\text{acceptable}\\\text{orientations}}} \sin\delta \, d\psi \, d\delta \, d\sigma}{\displaystyle\int_{\psi=0}^{\pi}\int_{\delta=0}^{\pi}\int_{\sigma=0}^{\pi} \sin\delta \, d\psi \, d\delta \, d\sigma}. \qquad \text{....(2)}$$

For the discrete variables used here this gives

$$S = 1 - \frac{\displaystyle\sum_{\substack{\text{all}\\\text{acceptable}\\\text{orientations}}} d^3 \sin\delta}{4\pi^2}. \qquad \text{....(3)}$$

(where d in this equation is the search increment as defined earlier).

It is this quantity, S, which will be used when discussing the information content of seismograms. The significance of different types of phase pair, and combinations of phase pairs, is of great practical interest in the study of focal mechanisms, and is investigated by Pearce (4).

The above quantities are calculated and printed out for each phase pair, and for the cumulative status of orientations after processing each phase pair.

2.11 Partially acceptable orientations - use of the variable vector length in SUBROUTINE PLOTV

Although a vectorplot, using fixed length vectors as described earlier in section 2.8, is ideal for displaying those orientations which are compatible with single phase pairs, or with a well-behaved series of phase pairs, as in the example of figure 1, its usefulness for a series of phase pairs is limited by the fact that only one anomalous phase pair may be needed to eliminate all compatible orientations, in which case no vectors are plotted, and all information is lost. In such cases it is desirable to have information on the most compatible orientations in order to identify and study anomalous phase pairs more easily. In order to provide for this, PLOTV can alternatively generate "variable length vectorplots" using vectors of different lengths which denote possible values of a several-valued variable. When this is requested, any completely compatible orientations are plotted using a full length vector as before, but, in addition, the program retrieves from the orientation array those orientations which are incompatible with one or more phase pairs, and plots them as shorter vectors - the shortness of the vector denoting the number of incompatible phase pairs; the number of vector lengths is a variable (NVL) which is supplied by the user. Thus, a full length vector corresponds to "all phase pairs compatible" and the shortest length vector corresponds to "NVL-1 phase pairs are incompatible" - intermediate values being represented by corresponding intermediate lengths. By specifying the number of vector lengths (using NVL) the user controls the threshold of compatibility below which no vector is plotted. In this way the user is able to obtain uncluttered displays which clearly show the regions of maximum compatibility in cases where no orientations are compatible with all phase pairs. This can be achieved by choosing a value of NVL which eliminates the large number of unwanted vectors corresponding to orientations which are compatible with only a small number of phase pairs. By restricting NVL in this way, the important areas of the plot are emphasised, and it helps to enable the different vector lengths to be resolved visually. This is also helped by having a long full length vector. The length of the maximum length vector depends on the number of values of ψ and of δ in the search mesh, and the consequent visual resolution of vector lengths sets an upper limit on the useful value of NVL. Since it is usually desirable to have most of the plot free from vectors when all phase pairs have been included, NVL should be set to one or two more than the minimum number of incompatible orientations when all phase pairs have been included.

As in the case of the fixed length vectorplot, described earlier, listings of partially acceptable orientations and corresponding variable length vectorplots can be generated after processing each phase pair; these are referred to as "cumulative partially acceptable orientations", and are controlled by the variables IPRNT3 and IPLOT3. Again, after the final phase pair, listings and plots of "orientations partially compatible with all phase pairs" can be generated, and are controlled by IPRNT5 and IPLOT5.

Storage of partially acceptable orientations requires the elements of the logical orientation array F to contain more information than is possible using only the two logical values "TRUE" and "FALSE". To avoid the need for additional storage space each logical element must be used as a several-valued variable, and the method of achieving this is described in appendix G.

As an example of a variable length vectorplot with a useful value of NVL, the seismograms of figure 1 are again used. Figure 10 shows the orientations partially compatible with all the nine phase pairs, using 4 vector lengths (NVL = 4). As expected, the full length vectors in figure 10 correspond exactly with those of figure 9, except that a search increment of 10° instead of 5° is used in order to resolve more clearly the additional (shorter) vectors which indicate those orientations that are incompatible with one, two or three of the nine phase pairs. It is seen from figure 10 that there are no additional classes of fault which become compatible if any one or even two phase pairs are omitted, but the exclusion of three phase pairs permits a number of strike slip types of fault to become compatible.

It is emphasised that the option to plot partially acceptable orientations is in no way intended to detract from the principle that a given orientation is either "acceptable" or "unacceptable". The option is only intended to assist in the study of anomalous seismograms or sources, and the choice of a "most compatible oreintation" as a "best fit" source orientation should not be made without adequate explanation of the incompatible phase pairs.

The subroutine (PLOTV), which was written to display values in the orientation array as described above, is quite general, providing for vectorplots of any three-dimensional array whose elements are either logical or several-valued - although it is most suitable for cases where at least one dimension corresponds to an angle. There is also clearly an upper limit to the array dimensions (ie, number of mesh points) and the number of values (ie, of discrete vector lengths) which can be displayed on a convenient size plot. The subroutine PLOTV is listed in appendix I.

2.12 Searching restricted regions of orientation space

In the previous discussion it has been assumed that the user wishes to search systematically all possible source orientations, and this is normally necessary to ensure that no compatible type of orientation is omitted. However, there are certain situations where it may be advantageous to search only within a restricted region of orientation space; it enables considerable computing time to be saved, and it enables a finer search increment to be used without increasing program storage.

In order to provide for this, there is an option to specify any upper and lower bounds on slip angle, dip and strike, which lie within those corresponding to the "whole space" defined in appendix F, namely $d \leqslant \psi \leqslant 180^\circ$, $d \leqslant \psi \leqslant 180^\circ$ and $d \leqslant \sigma \leqslant 360^\circ$. The search is then only conducted within the rectilinear range of orientations so defined.

Details of the consequent saving in computing time are given in section D1 of appendix D. As for the search increment d (corresponding to DINCIN), this can be decreased provided the specified upper and lower limits on a slip angle, dip and strike are such that the number of search increments in <u>each angle separately</u> does not exceed the number of search increments for DINCIN = 5° over the whole space (ie, 36 for the slip angle and dip, and 72 for the strike). If it is desired to change these overall maxima, then the program storage must be altered, instructions for which are given in section D2 of appendix D.

When searching within a restricted region of orientation space, the search proceeds exactly as described for a search over all orientation space, and the corresponding vectorplots extend only over the limited range. Since the vectorplot is then expanded to fill the plotting frame, this permits longer vector lengths, which is particularly valuable when plotting partially acceptable orientations on a variable length vectorplot, as explained in section 2.11. The signficance values and other related quantities defined in section 2.10 are also calculated in the same way, but calculation of the fraction of acceptable orientations, and the significance, assumes that there are no additional orientations which are compatible outside the restricted region of search.

The following describes two types of situation in which it may be of value to limit searches to a restricted region of orientations.

First, considerable computing time and space can be saved (see section D1 of appendix D) by following a coarse search (say with DINCIN = 10° or 15°) by a finer search (say with DINCIN = 2° or even 1°) over the restricted regions of orientation space which the coarse search has shown to be most nearly compatible with the data. This is more likely to be appropriate for large deep earthquakes, where long period seismograms from a large number of stations may be available. It should be remembered that the tendency for a preliminary coarse search (say, with DINCIN = 10° or 15°) to completely miss compatible regions can be overcome by plotting partially acceptable orientations as described in section 2.11, which will still enable the regions of most compatibility to be defined, prior to conducting a finer search (say, with DINCIN = 2° or 1°). In general, regions of compatible orientations will occur in pairs, corresponding to interchange of fault and auxiliary planes, and these regions can be searched separately. If the required range of strikes for a required region spans north (ie, 360°), it will again be necessary to divide this into two search regions - one either side of north. If the required range of dips or slip angles borders on the limits of orentation space, then it may be desirable to check that there are no acceptable orientations beyond these limits. In order to do this it is necessary to know where in the orientation space a given type of orientation "reappears" after reaching the boundary of the space in a given direction, so that another search region can be specified. The recurrence pattern of slip angle, dip and strike beyond their principal values is given in appendix F, and is illustrated in figure 14.

The second use for restricted region searches is in the investigation of the change in mutual compatibility of phase pairs when uncertain input parameters are perturbed. For example, cases have been found where all phase pairs are nearly consistent with a certain range of double couple orientations, but no orientations exist which are compatible with <u>all</u> the phase pairs simultaneously (4). Remembering from section 2.3.4 that such quantities as source layer velocities are always themselves uncertain, perturbation of such quantities may change the orientations which are compatible with each phase pair in such a way as to render some orientations compatible with all phase pairs.

For studying the effect of changing takeoff angles (ALPHA and GAMMA) their values can be altered directly if the option to specify them directly is being used (this is controlled by INDANG, see section 2.5). Alternatively, if takeoff angles are set within the program from focal depth (DEPTH) and epicentral distance (DIST), then all takeoff angles can be changed systematically by altering the source layer P velocity (VPSRCE) for shallow earthquakes (with DEPTH = 0), or by altering DEPTH for deep earthquakes. Note that when takeoff angles are set from DIST for the shallow earthquake case, then because the takeoff angle is corrected for VPSRCE using Snell's law, it follows that angles at the surface are unchanged unless VPSURF is changed. A third method of studying the effect of changing takeoff angles is to apply a systematic correction to all phase pairs using ANGPF and/or ANGPPF as explained in section 2.5.

Perturbation of the surface layer velocities VPSURF and VSSURF changes the reflection coefficients at the surface (especially that of sP) by implicitly changing the ray angles at the surface. For undersea earthquakes an additional second order change is obtained by altering the surface layer density DSURF.

PPFCTF and SPFCTF (see section 2.6.2) provide for systematic perturbation of the amplitude lost by the surface reflected phases due to attenuation or discontinuities above the source (other than at the surface). (PPFCTF and SPFCTF also provide a convenient means of applying the same value of PPFCT1 or SPFCT1 to all phase pairs without specifying a value on each card.)

The perturbation studies described above are most conveniently carried out at high resolution (say with DINCIN = 1° or 2°) within the restricted range(s) of source orientations of interest. Such studies are mainly intended for identifying and explaining the origin of anomalous phase pairs (or sets of phase pairs), as in the case of the options to print and plot partially acceptable orientations described earlier.

The option to search a restricted region of orientation space is brought into effect using the variable REGION. The angular limits of search must then be specified using the variables PSI1, PSIN, DELTA1, DELTAN, STRIK1 and STRIKN.

As an example of a search over a restricted region in orientation space we again refer to the example of figure 1. Figure 11 shows those orientations which are compatible with all nine phase pairs, as deduced from a search at an increment of 3° over the restricted regions of search shown (these regions would normally have been chosen after a coarse search - say, with a 10° mesh - over all space). The regions of orientation space represented in figure 11 represent about one-eighth of all orientations, and used about half of the computing time used to produce figure 9.

2.13 Data manipulation, and the uses of input-results and a third output device

The previous discussion has shown how different features of the program FALT can be applied to the study of relative amplitude data in a variety of circumstances. Now we consider how the input information already described is read into the program and further special features are introduced which are aimed at minimising the demand on computing facilities, and which provide for more convenient manipulation and alteration of the data.

2.13.1 Organisation of standard input

It has been established that the single relative amplitude observation is the phase pair, which is individually processed to yield those source orientations with which it is compatible. For a given earthquake, any number of such phase pairs can be processed, during which cumulative information on compatible orientations is retained, providing us at the end with those orientations which are compatible (and maybe partially compatible) with all phase pairs. The data required to initiate the above sequence of computations will be referred to as a data block.

The standard input of a data block begins with a title card (Card 1) which describes the earthquake and if required identifies any special feature of this particular data block. This is followed by a card containing all the parameters which must remain constant within the data block (Card 2). These include the number of phase pairs, the search increment in orientation space, the source and surface layer velocities and other parameters for the calculation of pP and sP reflection coefficients, and the various output options. This card also has the provision to specify that only a restricted range of source orientations be searched, and if so the details of the search limits are given on an additional card (Card 2A). There then follows one card for each phase pair (Card(s) 3); a phase pair card includes the station name, its azimuth and distance from the earthquake, the takeoff angle of P (and pP if different), a code indicating the type of phase pair which this card relates, the upper and lower bounds on their amplitudes in arbitrary units (with any polarity specifications), and any path correction factors to be applied to calculated amplitudes. All input formats are given in appendix B.

It is noted that each phase pair corresponds to one input card, and that the phase pairs are processed sequentially according to the order of these cards. It follows that the order of the phase pair cards does not affect the final result, although it does affect the way in which the cumulative results develop as successive phase pairs are processed. It may be desirable to place all phase pair cards for a single station together, in order to see how much each successive station further constrains the orientation. Alternatively, it may be sensible to place cards with doubtful or poor quality measurements at the end in order to avoid contaminating the cumulative results at an early stage. Whatever the requirements, phase pairs can be re-ordered, removed or added to the data block merely by manipulating individual cards, and ensuring that the correct total number is entered in NOP on Card 2.

Not only can the sequence of the phase pairs from a given earthquake be changed within the data block to obtain a different cumulative status of the orientation array, but there may also be reason to divide the phase pairs into more than one data block. For example, the constraint imposed on the source orientation by each seismogram may be required separately. Referring again to the example of figure 1 we might ask how the three seismograms compare in their ability to constrain the source orientation (or how the significance value of each seismogram compares). In this case each station, comprising three phase pairs in this example, is run as a separate data block. However, in order to find the total constraint imposed by all three seismograms it would then be necessary to re-run all nine phase pairs in one data block, as was done to produce figure 9.

Other types of investigation can be envisaged where it is necessary to re-run a data block several times with only minor changes or corrections to one or two of its phase pairs. A common feature of such manipulations is that identical processing of the same phase pairs is repeated, perhaps many times, during the course of a study. Since the searching of orientation space for a given phase pair is the main computational burden of the program, its unnecessary repetition would constitute a major source of inefficiency in the uses of computing resources.

2.13.2 Output into a third output device

In order to overcome the above problem, the program is provided with an option to ultilise a "third output device" (in addition to the printer and the plotter) into which the results from a data block can be written in a standard format, and in a machine-readable form. An additional feature enables this standard output (then called an input-result) to be re-read and incorporated into a subsequent data block without the need to reprocess the corresponding set of phase pairs. Output into a third output device - which might be a disc, magnetic tape or punched cards - and the ability to read this output subsequently as an input-result enables data blocks containing one or more of the same phase pairs to be re-run without the time-consuming process of conducting a search in respect of the same phase pair more than once. When this additional output is requested, it is obtained in addition to the usual print and plot outputs, and is in two parts whose contents and formats are given in appendix C. The first part is a record of the input parameters of the data block, and contains the input details of each of its phase pairs, with the number of compatible orientations and the significance value calculated for each. The second part contains the complete status of the orientation array after processing of the data block is complete; that is, it contains any orientations which are compatible with all phase pairs in the data block, and also those orientations which are partially compatible with all phase pairs if these were retained (ie, if NVL > 1).

The number of the device into which the above output is written is specified using NDEV3, and the output has been designed with the view to meeting other requirements for subsequent processing as well as that of re-reading into this program as an input-result. IDEV3 controls the output, and there are three options. First, no output is written into the device; secondly, only the first section of output described above is written. This is primarily intended for theoretical studies, such as the plotting of graphs of significance against amplitude bounds, takeoff angle or other input variable, as studied by Pearce (4). It could be used for any case where a summary of results for each phase pair is needed for further processing, but where the (generally much longer) status of the orientation array is not needed.

The third option is to write both the first and second sections of the output as described above, and this option is used to generate an input-result, to be re-read into this program as described below. This third option may alternatively be required for presenting the compatible orientations in another form, either for producing improved quality plots as in figures 9, 10 and 11 using the program PUBV (section 2.8), or for plotting equivalent pairs of great circles on a stereographic net. This third option also provides for the output of compatible source orientations for possible input into a program to select those orientations which are also compatible with given pulse durations, as interpreted in terms of Doppler effects caused by rupture propagation (11). This is a possible means of discriminating between fault and auxiliary plane by allowing for the finite size of sources, and becomes particularly viable for elongated faults. Such a program is in preparation.

2.13.3 The use of input-results

In principle one can use the output feature described above to assemble a series of input-results, each corresponding to a different data block, relating to different observations of the same earthquake. In a further data block, which could be in the same or a subsequent job step, or in a subsequent program run, any of these input-results can be re-read. This is done by replacing one or more, or indeed all, of the phase pair cards in the new data block by one or more cards, each of which commands an input-result to be read in from a specified input device. The program recognises such an input-result card which is blank, except for the number of the device from which the input-result is to be read, which is NDEV. Instead of processing a phase pair, the program reads in the input-result from the specified device. (If the device corresponds to punched cards, the deck must be inserted immediately after the corresponding input-result card.) The program prints out the details of its constituent phase pairs, as retrieved from the input-result. The orientations compatible and partially compatible with all the phase pairs (also retrieved from the input-result) are printed and plotted as required by IPRNT1 and IPLOT1, and the status of the orientation array from the input-result is combined with that of the current data block. Cumulative acceptable orientations and cumulative partially acceptable orientations are then printed and plotted as after a phase pair, but this cumulative information on those orientations which are compatible or partially compatible with all previous phase pairs now implicitly includes those phase pairs contained in the input-result. Thus, the processing of an input-result card in a data block is exactly equivalent to processing the set of phase pair cards to which it corresponds, except that computing time is saved because orientation searches in respect of these phase pairs are avoided.

For example, suppose a data block contains nine phase pair cards which, for convenience, we number sequentially. In run 1, phase pairs 1 to 9 are processed in that order. In run 2, phase pairs 4 to 6 are processed and an output into a specified device is obtained. In run 3, phase pairs 1 to 3 are followed by an input-result card commanding the input-result from run 2 to be read in. Phase pairs 7 to 9 then follow. Runs 1 and 3 are then exactly equivalent. In this particular example, as well as yielding identical final results, the cumulative status of the orientation arrays is also identical for runs 1 and 3, except that during run 3 the orientation array is "updated" by the combined effects of phase pairs 4, 5 and 6 together - the cumulative effect of the individual phase pairs 4, 5 and 6 being unknown to run 3. The computing time required for run 3 is about 2/3 that required for run 1.

It must be remembered that all manipulations using input-results must relate to data blocks which have the same search increment, search region in orientation space, and number of vector lengths; all input-results are tested for such compatibility when they are read in, and any which do not satisfy these requirements are skipped by the program. It is, however, left to the user to ensure that other parameters, such as structural variables, factors and the earthquake parameters, are also compatible, as is required to maintain the "integrity" of the results. It must also be remembered that the variable NOP on Card 2 always corresponds to the total of phase pair cards plus input-result cards.

The principle of manipulating data using input-results which is introduced above can be applied quite generally to satisfy many types of processing requirement, as the following examples of its application show.

As already suggested, we may wish to know the constraint imposed on the source orientation by each seismogram. In this case the phase pairs corresponding to each seismogram are brought together and run as separate data blocks, an input-result being obtained from each. The constraint imposed on the source orientation by all the seismograms together can then be obtained with little additional computation by running a data block which contains all the corresponding input-result cards. Because this data block contains no phase pair cards at all, computation is very fast. Further, this data block can now be re-run "economically" with the input-results in any order as required.

In another example, a problem may arise if the number of phase pairs to be processed is so large that it requires more computing time than is available for a single job. This is more likely to happen for deep earthquakes where a large number of long period seismograms may be available. Here it is not necessary to run each seismogram as a separate data block, but instead the seismograms can be divided into several sets of phase pairs, each of which can be processed within the available job time. The input-result obtained from each set can then be combined in a final data block. Alternatively, it is possible to run the program exactly as if all the seismograms were being processed in the same data block. The first set of phase pairs is processed as one data block. In a second job, the data block comprises the second set of phase pairs, preceded by one input-result card corresponding to the input-result obtained from the first set. If there is a third set of phase pairs, it would begin with the input-result card corresponding to the input-result derived from the second set. By repeating this process as many times as necessary the cumulative status of acceptable orientations develops exactly as if the several sets of phase pairs were all processed sequentially in one data block.

In the above procedure it is seen that the second data block, which generates the input-result for the third data block, itself contains an input-result card as well as phase pair cards. This has no effect on the input-result generated by the second data block since the details of each successive phase pair are recorded in the output with no attention being paid to whether it was processed in that data block, or was part of an input-result. Thus, the phase pairs which correspond to a given input-result need not necessarily have been originally processed in the data block which generated that input-result.

In yet another example each phase pair could be processed in a data block on its own, thereby obtaining a separate input-result for each. A final data block, containing all the corresponding input-result cards, then combines them as if they were, instead, the phase pair cards. Because this final data block is thereby processed rapidly it is suitable for any studies where different ordering of the phase pairs is required (for example, to group types of phase pair, seismograms, etc). A further use arises where the data block is to be repeated with only minor changes to one or two of the phase pairs. The corresponding input-result cards are then merely replaced by their corresponding (modified) phase pair cards as required for successive runs, so that orientation searches only occur in respect of any phase pairs which have been modified. The format of an input-result is identical to the format of output to a third device, and is given in appendix C.

3. CONCLUDING REMARKS

To conclude, the relative amplitude method is compared with the traditional method of determining source orientations by first motions, and this comparison is used to highlight advantages of the relative amplitude method.

The determination of nodal plane orientations for assumed double couple earthquakes by traditional "first motion" methods utilises only the observed polarity of the initial P wave at each seismic station (occasionally supplemented by some S wave polarisation measurements). The process of finding an orientation which divides these readings into the four expected alternate polarity quadrants on the focal sphere relies both upon ideal behaviour of the source, and upon correct and unambiguous observation at all receivers. If, for whatsoever reason, there is no source orientation which satisfies all the readings, then polarities alone are generally insufficient to permit investigation of the origin of the "anomalous" behaviour. Mutually incompatible polarity readings are a common feature of solutions for smaller earthquakes, or for earthquakes which include readings from short period seismograms. Although long period seismograms are more "stable" in this respect, careful comparison between waveforms at different stations and an accurate awareness of the instrument response are vital if unusual types of waveform are to be interpreted correctly.

In some cases an uneven distribution of stations can result in the chosen orientation being fixed by only a small number of readings. Alternatively, there may be a large range of orientations compatible with the data, the likelihood of this being increased by the fact that teleseismic P waves can, at best, sample only a small annulus of the lower focal hemisphere. The situation is further complicated if "uncertain" polarity readings are included.

These difficulties, and the problems posed by uncertain, inconsistent or inadequate polarity readings, have fostered the development of algorithms which calculate a "best fit" source orientation in some statistical sense, by maximising the mutual compatibility of the available data (9,12-17). Such algorithms typically involve the use of weighting factors which may be of two types. First, a priori weighting factors may be applied to the input polarity readings in order to quantify their uncertainty. This was considered by Udias and Baumann (15) and Keilis-Borok et al. (17). Secondly, a posteriori weighting factors may be applied by the algorithm itself, either to suppress inconsistent polarities, or to militate against stations which are near to one of a provisionally calculated pair of nodal planes. Various such schemes have been used (12-14,16-18). Such algorithms are unable to place well-founded confidence limits upon their calculated "best fit" orientations. An algorithm by Guinn and Long (10) delineated compatible ranges of orientations instead of maximising a criterion function, but for non-ideal data sets they had to "allow" one or more inconsistent polarities to obtain any acceptable range.

It must be emphasised that, in reality, if there is a source orientation which is compatible with a given set of polarity or relative amplitude data, then it must form part of a range of compatible orientations, which may assume any shape in orientation space, and which may be split into more than one region in orientation space. Moreover, it is important to remember that, within an acceptable range of orientations, all orientations are equally probable. If, on the other hand, no orientations are compatible with a given set of data, then this anomalous behaviour must be attributable to a specific cause, such as an anomalous source or incorrect observation, and is not in itself a justification for adopting the "most compatible" orientation. The initial P wave polarity is but a small fraction of the source information present in each seismogram, since the far field double couple radiation pattern possesses angular variation in P wave amplitude as well as polarity, and also has an S wave radiation pattern whose amplitude and polarisation direction have angular dependence. Incorporation of this amplitude information into focal mechanism determinations would, in theory, do much to overcome the problems outlined above, but previous attempts to include this extra information have had limited success because the observed absolute amplitudes are dominated by the different effects which anelastic attenuation and scattering have on each phase. Similar problems arise when relating the amplitudes between any two phases observed at different stations, or between direct P and direct S even at the same station. Such effects cannot be allowed for adequately, and therefore conceal the true signature of the radiation pattern.

The use of relative amplitudes as well as polarity information, and the use of "100% confidence limits" on these amplitudes as described in this report together overcome many of the shortcomings described above. The following specific points may be mentioned:-

The notion of using 100% confidence limits means that the uncertainty of each measurement is embodied in the program input, and it follows that the boundaries of the resulting compatible regions in orientation space define equivalent confidences. This direct calculation of solutions with well-founded confidence bounds removes any need to specify weighting factors, or to maximise a criterion function. The method exploits the much "richer" signature of the source orientation which is present in amplitudes, using both those of P and S, and the specification of confidence limits maximises the utilisation of information provided by seismograms of differing qualities, enabling effective use to be made of poor quality seismograms. Studies have shown that this increase in available data sometimes enables well-constrained source orientations to be computed from only a few stations, and for shallow earthquakes at magnitudes below which first motion cannot usually be read with certainty. Alternatively, the redundancy of information provided by a large set of stations offers a means of testing the validity of the double couple, or indeed any other radiation pattern. (The method can be used to compute "first motion" solutions by placing extremely wide bounds on every amplitude.) Graphic presentation of the results using vectorplots provides for easy recognition of the arbitrary size and shape of acceptable regions in orientation space, and it also enables any anomalous or conflicting measurements to be easily identified. Special features of the program, notably the plotting of partially compatible orientations and the option to search within restricted regions of orientation space, assist in investigation of the origin of any such anomalous behaviour. The use of restricted region searches, and of input-results, enables such studies to be conducted with the minimum of computing resources.

The generation of theoretical seismograms, for example by the method of Hudson (19,20) and Douglas et al. (21), requires the same interpretation of relative amplitudes as that described above, in order to match theoretical and observed seismograms by correct choice of source orientation. The present program provides a systematic means of choosing such a source orientation, together with a quantitative measure of its non-uniqueness. Furthermore, the generation of theoretical seismograms which reproduce additional features of observed recordings provides additional support for the initial identifications of the phases upon which the validity of the orientation result depends.

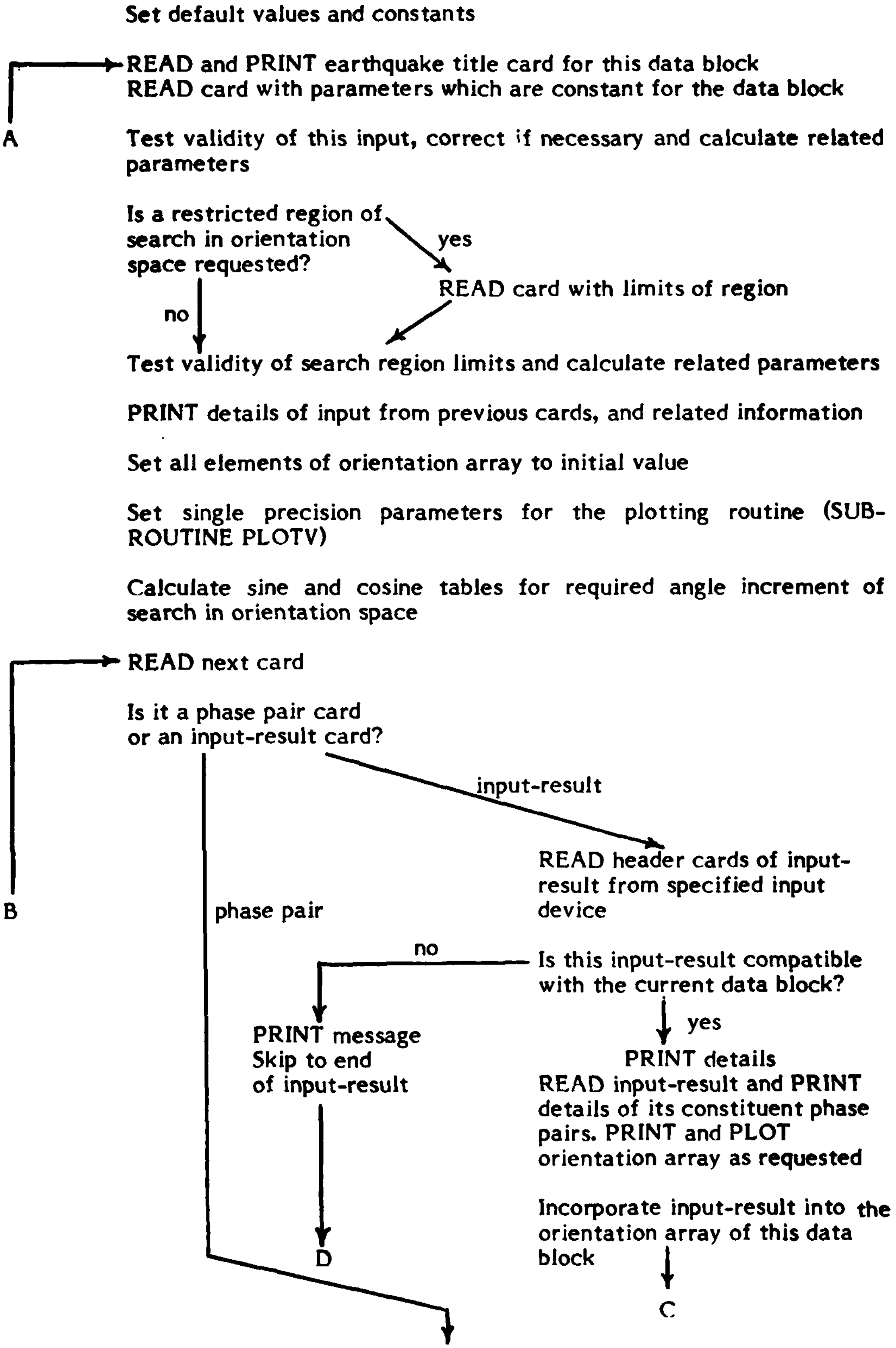
4. ACKNOWLEDGMENTS

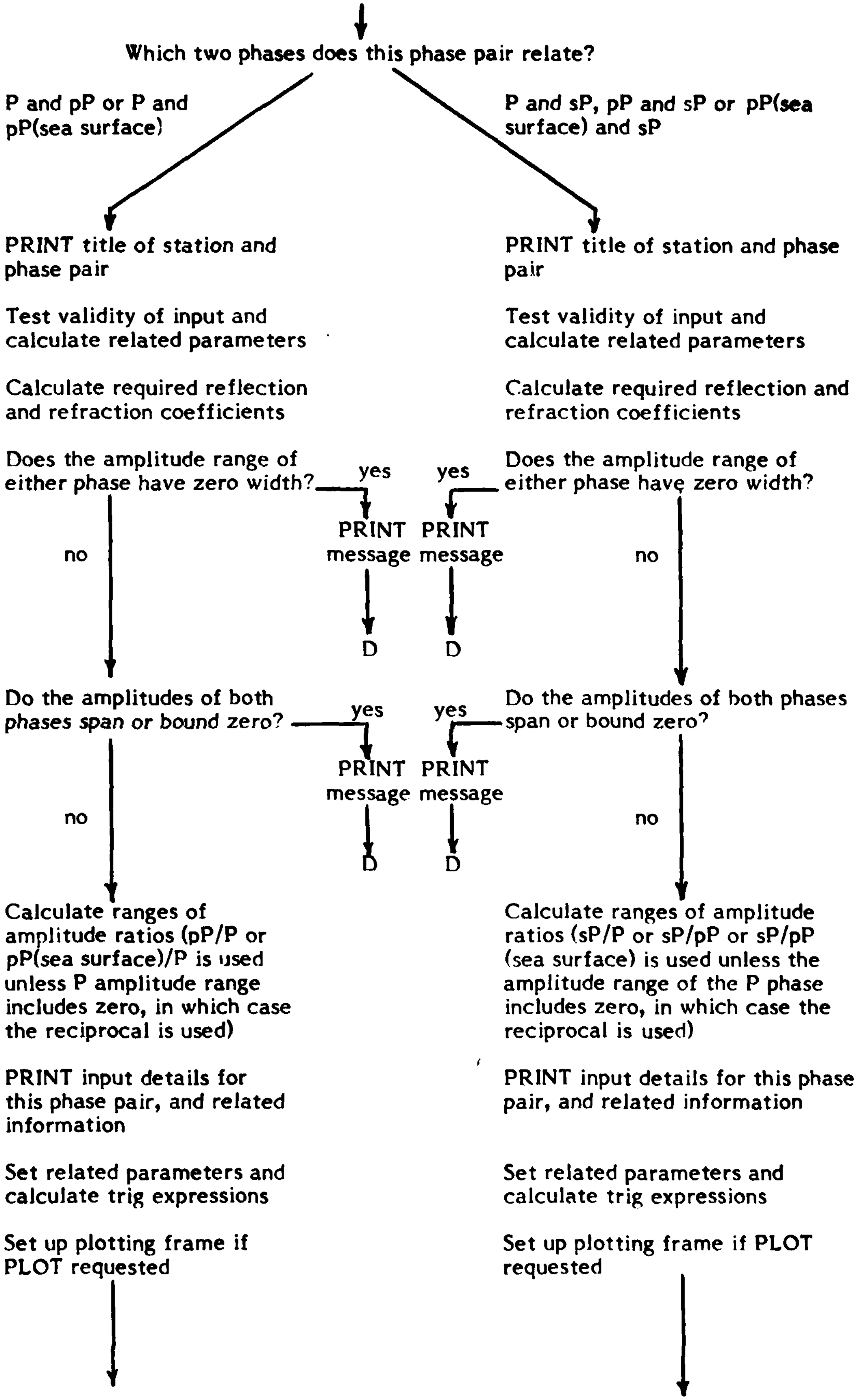
In developing the method described here, I have tried to be influenced by the practical requirements of those who have to study real seismograms. I thank Dr H I S Thirlaway, Messrs A Douglas, P D Marshall and J B Young and Drs B J Barley and R C Lilwall for many useful discussions.

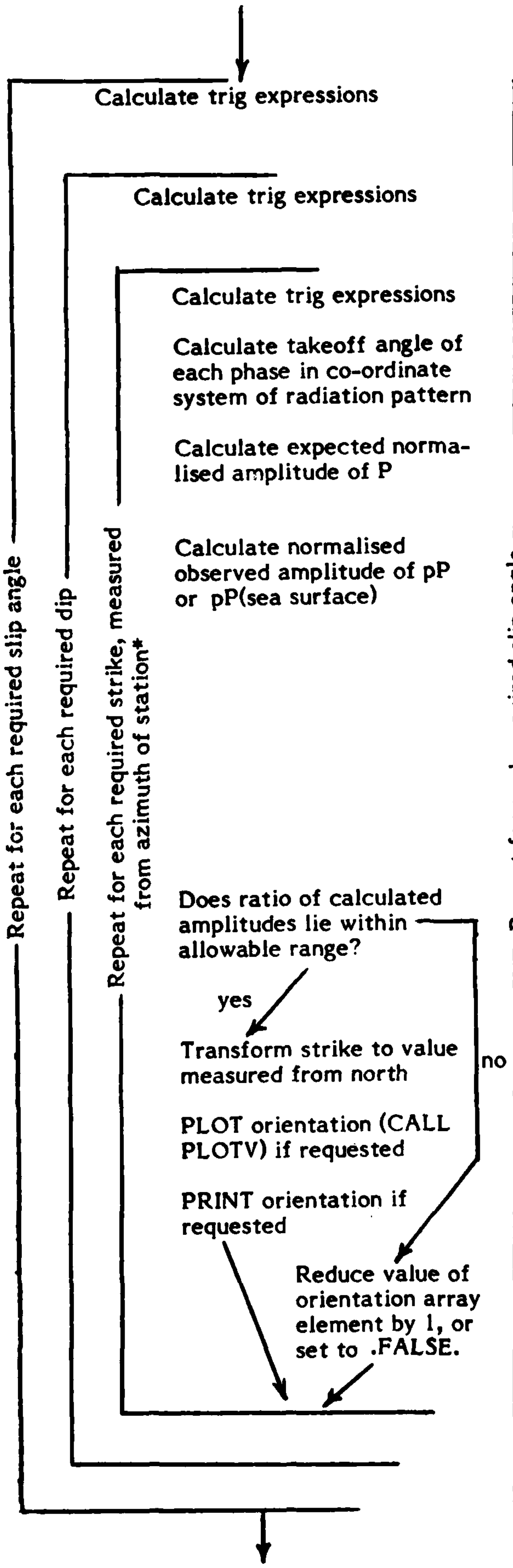
APPENDIX A

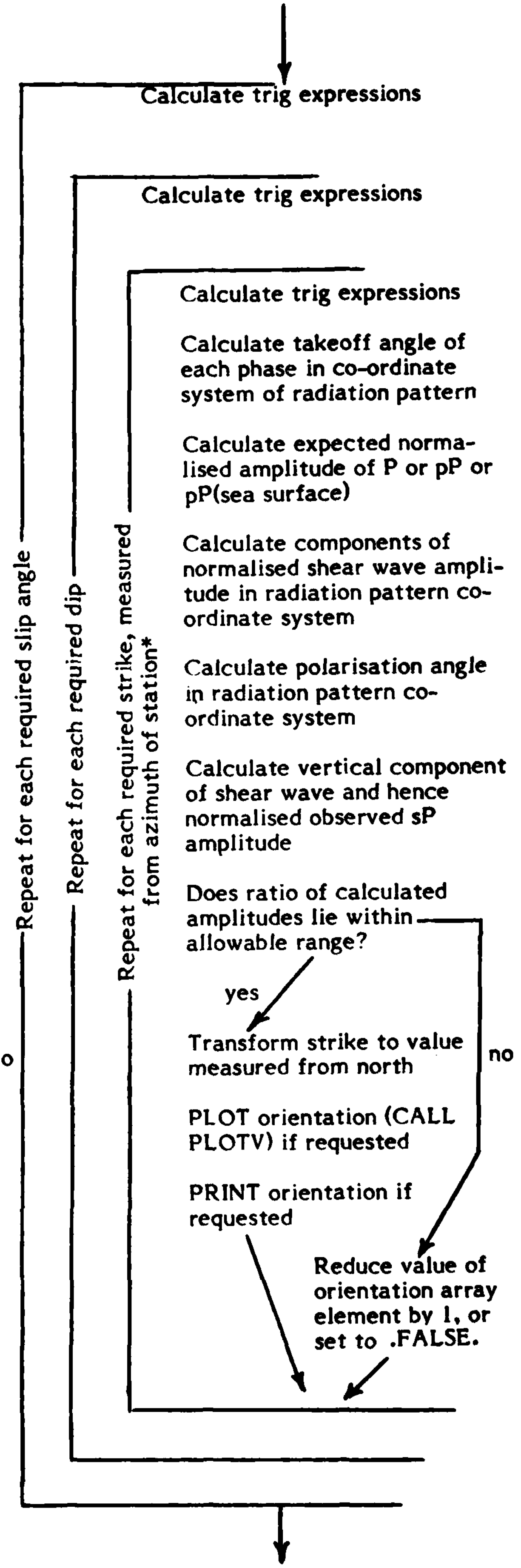
SCHEMATIC DIAGRAM OF PROGRAM

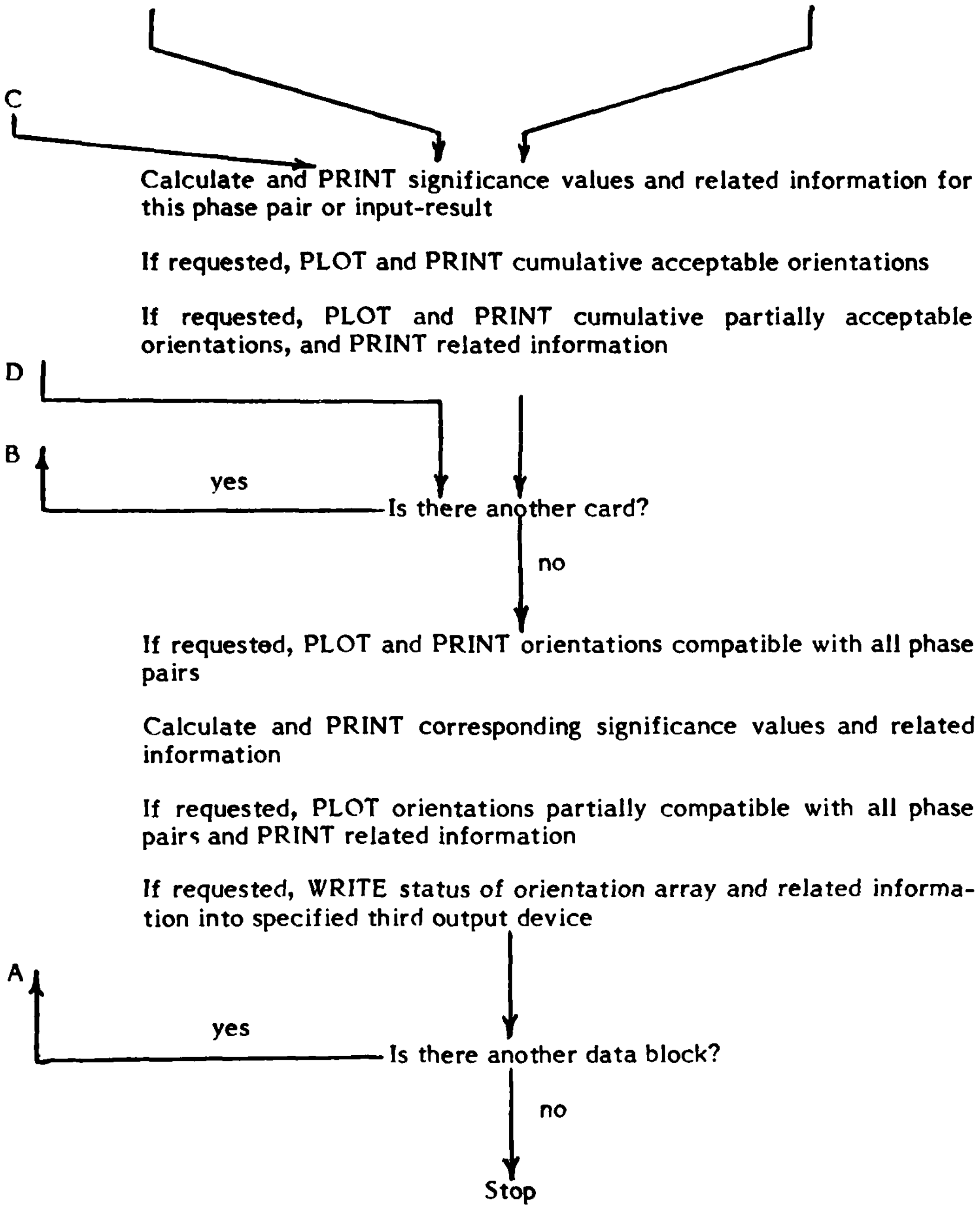
(The following gives a broad guide to the organisation of the program, but it is not a rigorous flow diagram.)




Which two phases does this phase pair relate?
P and pP or P and pP(sea surface)
P and sP, pP and sP or pP(sea surface) and sP
PRINT title of station and phase pair
Test validity of input and calculate related parameters
Calculate required reflection and refraction coefficients
Does the amplitude range of either phase have zero width?
yes
no
PRINT message
D
PRINT title of station and phase pair
Test validity of input and calculate related parameters
Calculate required reflection and refraction coefficients
Does the amplitude range of either phase have zero width?
yes
no
PRINT message
D
Do the amplitudes of both phases span or bound zero?
yes
no
PRINT message
D
Do the amplitudes of both phases span or bound zero?
yes
no
PRINT message
D
Calculate ranges of amplitude ratios (pP/P or pP(sea surface)/P is used unless P amplitude range includes zero, in which case the reciprocal is used)
PRINT input details for this phase pair, and related information
Set related parameters and calculate trig expressions
Set up plotting frame if PLOT requested
Calculate ranges of amplitude ratios (sP/P or sP/pP or sP/pP (sea surface) is used unless the amplitude range of the P phase includes zero, in which case the reciprocal is used)
PRINT input details for this phase pair, and related information
Set related parameters and calculate trig expressions
Set up plotting frame if PLOT requested


Calculate trig expressions
Calculate trig expressions
Calculate trig expressions
Calculate takeoff angle of each phase in co-ordinate system of radiation pattern
Calculate expected normalised amplitude of P
Calculate normalised observed amplitude of pP or pP(sea surface)
Does ratio of calculated amplitudes lie within allowable range?
yes
Transform strike to value measured from north
PLOT orientation (CALL PLOTV) if requested
PRINT orientation if requested
no
Reduce value of orientation array element by 1, or set to .FALSE.
Repeat for each required slip angle
Repeat for each required dip
Repeat for each required strike, measured from azimuth of station*


Calculate trig expressions
Calculate trig expressions
Calculate trig expressions
Calculate takeoff angle of each phase in co-ordinate system of radiation pattern
Calculate expected normalised amplitude of P or pP or pP(sea surface)
Calculate components of normalised shear wave amplitude in radiation pattern co-ordinate system
Calculate polarisation angle in radiation pattern co-ordinate system
Calculate vertical component of shear wave and hence normalised observed sP amplitude
Does ratio of calculated amplitudes lie within allowable range?
yes
Transform strike to value measured from north
PLOT orientation (CALL PLOTV) if requested
PRINT orientation if requested
no
Reduce value of orientation array element by 1, or set to .FALSE.
Repeat for each required slip angle
Repeat for each required dip
Repeat for each required strike, measured from azimuth of station*



Calculate and PRINT significance values and related information for this phase pair or input-result

If requested, PLOT and PRINT cumulative acceptable orientations

If requested, PLOT and PRINT cumulative partially acceptable orientations, and PRINT related information

Is there another card?

If requested, PLOT and PRINT orientations compatible with all phase pairs

Calculate and PRINT corresponding significance values and related information

If requested, PLOT orientations partially compatible with all phase pairs and PRINT related information

If requested, WRITE status of orientation array and related information into specified third output device

Is there another data block?

---

*If restricted region of search in orientation space is requested and the region of strikes requested spans the azimuth of the observation, the search is computed for all strikes beyond the azimuth for all required slip angles and dips, and the procedure is repeated for the remaining strikes.

APPENDIX B

DESCRIPTION AND FORMAT OF INPUT DATA

A concise description of the program input is given in the listing (appendix H); more detailed description is given here. Most of the variables are introduced and explained in section 2, and references to the text are given where appropriate.

For each data block, input is as follows:-

Card 1	Title card FORMAT 10A8
TITLE	Title of earthquake. Columns 65 to 80 should be used to identify this data block if more than one data block is to be processed in respect of the same earthquake.
Card 2	Card with parameters relating to the earthquake, and processing options for this data block. FORMAT I5,F5.0,F5.1,2F4.2,I2,10I1,I2,I3,I3,I2,5F5.2,2F4.2,I1,A1
NOP	Total number of phase pair cards and input-result cards in this data block (ie, number of phase pairs plus number of input-results). Comments on the inclusion of all relevant phase pairs are given in section 2.4, and section 2.13 gives guidance on how to organise phase pairs, input-results and data blocks to meet different requirements.
DINCIN	Angle increment for search (degrees) (see section 2.7). This is set in the program to DINC, which is adjusted to the nearest integer sub-multiple of 90°, provided that there is sufficient storage in the orientation array, F, and in the sine and consine tables SINTAB and COSTAB, which are here set to provide for a minimum search increment of 5° if all orientation space is included. (A finer search increment is possible for restricted region searches, see section 2.12.) A guide to required computing times and storage is given in section D1 of appendix D and instructions for modifying the storage are given in section D2 of appendix D. If DINCIN ≤ 0 or > 90, DINC is set to 30 (this is intended for test purposes only and is too coarse for meaningful results). Both computer time and storage are mainly determined by DINC, which can be set to provide for any required angular resolution, having regard to (1) available CPU time and storage, (2) quality of the input data, and (3) the size of the region in orientation space over which the search extends. Computer time and storage are both approximately inversely proportional to the cube of DINC, although this is only important when processing phase pairs - the processing of input-results being comparatively fast. In practice DINCIN = 5° provides adequate treatment of typical data, while yielding clear vectorplots of compatible orientations; a higher resolution over all

space could not be adequately plotted on a conventional size grid. DINCIN = 10° is appropriate for a coarse search, to be followed by a higher resolution search over restricted regions of interest, or for theoretical studies such as the plotting of graphs of significance against an input variable. DINCIN = 1° or 2° is suitable for restricted region searches with good quality data, in particular for studies of variations in the acceptable regions as a function of uncertain input parameters such as surface to source layer velocity ratio or takeoff angle.

DEPTH Depth of earthquake (km). Leave blank for an intracrustal earthquake. Only used if INDANG $\neq 0$ (see under INDANG below, and section 2.5).

ANGPF Perturbation factor for systematically adjusting all the P takeoff angles calculated or read in for each phase pair. Each P takeoff angle α is reset to $\sin^{-1}$ (ANGPF × $\sin \alpha$), so that the adjustment of angles is equivalent to multiplying the source layer velocity by a factor ANGPF for this purpose only (see under INDANG below). If left blank, is set to 1.0. The use of ANGPF is explained in section 2.5.

ANGPPF Perturbation factor for systematically adjusting all the pP takeoff angles γ, as for ANGPF above (see under INDANG below). If left blank, is set to 1.0. The use of ANGPPF is explained in section 2.5.

INDANG Indicator to specify how P and pP takeoff angles are calculated (see section 2.5). If left blank, the P wave takeoff angle is read directly for each phase pair (see ALPHA on Card(s) 3). If INDANG is non-zero, the P takeoff angle is determined for each phase pair from distance/depth tables contained within the program, using DEPTH from this card, and DIST from Card(s) 3. In this case if DEPTH is left blank, the earthquake is assumed to be intracrustal, and the angle is further corrected according to Snell's law using VPSRCE, and assuming a sub-Moho P wave velocity of 8.1 km/s. For any phase pair with DIST < 20 or DIST > 100 (or left blank) the P wave takeoff angle is read in using ALPHA even if INDANG is non-zero. The takeoff angle of pP is read in using GAMMA on Card(s) 3, or if this is zero, it is set to the value of ALPHA. After ALPHA and GAMMA have both been set, each can be adjusted using ANGPF and ANGPPF respectively as explained above. The takeoff angle of sP, namely BETA, is always calculated from the final value of GAMMA, using VPSRCE and VSSRCE.

IPRNT1, IPRNT2, IPRNT3, IPRNT4, IPRNT5. "Switches" for printing the orientations compatible with each card (whether phase pair or input-result), and for printing cumulative acceptable orientations, etc. If switch is non-zero, the corresponding list(s) of orientations are printed. Details of input data and a summary of the results for each phase pair or input-result, and for the cumulative results after each, are always printed. Note that lists of orientations, especially as requested by IPRNT1, IPRNT2 and IPRNT3, are likely to be very long.

IPRNT1 A list after each card of orientations compatible with that phase pair or input-result. For an input-result separate lists of those orientations incompatible with one or more phase pairs are printed.

IPRNT2 A list after each card (other than the first and last) of those orientations which are compatible with all the phase pairs so far processed, including those corresponding to any input-results, and referred to as "cumulative acceptable orientations".

IPRNT3 Separate lists after each card (other than the first and last) of those orientations which are compatible with all or incompatible with one or more of the phase pairs so far processed, including those phase pairs corresponding to any input-results, and referred to as "cumulative partially acceptable orientations".

IPRNT4 A list after the last card as for IPRNT2, and referred to as "orientations compatible with all phase pairs".

IPRNT5 Separate lists after the last card as for IPRNT3, and referred to as "orientations partially compatible with all phase pairs".

IPLOT1, IPLOT2, IPLOT3, IPLOT4, IPLOT5. "Switches", equivalent to IPRNT1 to IPRNT5, to control plots of compatible and partially compatible orientations. Each plotting frame displays a vectorplot of those orientations which are compatible or partially compatible with one or a series of phase pairs over the requested region of search in orientation space. The form of the vectorplots, which are generated using SUBROUTINE PLOTV, is described in section 2.8 (fixed length vectorplot) and 2.11 (variable length vectorplot). If switch is non-zero the corresponding vectorplot(s) of orientations are generated. Otherwise the frame(s) are omitted.

IPLOT1 One vectorplot after each phase pair or input-result, showing the orientations compatible with the card. For a phase pair a fixed length vectorplot is generated, but for an input-result a variable length vectorplot is generated to show the compatible and partially compatible orientations of this input-result.

IPLOT2 One fixed length vectorplot after each card (other than the first and last) showing "cumulative acceptable orientations".

IPLOT3 One variable length vectorplot after each card (other than the first and last) showing "cumulative partially acceptable orientations".

IPLOT4 One fixed length vectorplot after the last card showing "orientations compatible with all phase pairs".

IPLOT5 One variable length vectorplot after the last card showing "orientations partially compatible with all phase pairs".

IDEV3 Indicator for controlling output on to third output device (which is defined by NDEV3). Leave blank for no output. If set to 1, an annotated summary of input and results for each phase (including those in any input-results) is provided, according to the format shown in appendix C. If ≥ 2, this is followed by the status of the orientation array after completion of the last card, as required for use as an input-result (see appendix C). Outputs on to a third device are intended to provide results in a machine-readable form (eg, on cards, disc or magnetic tape) for further processing in one of the ways described in section 2.13.

NVL	Number of vector lengths for variable length vectorplots. This corresponds to the maximum number of phase pairs which must be incompatible with an orientation before the degree of incompatibility is no longer stored in the orientation array or displayed on the plot (see section 2.11). If left blank or negative, it is set to 1. The maximum possible value of NVL is governed by the dimension of VVLR and is set to 35. If > 35, it is set to 35. Section D3 of appendix D gives instructions for increasing this maximum to provide for a larger number of vector lengths, up to an absolute maximum of 255.
NDEV3	Number of the third ouput device into which will be written results according to IDEV3 (see section 2.13). If left blank, is set to 7 which is normally equivalent to punched cards.
ISEA	If left blank, earthquake is beneath land. Any non-zero punch indicates that the earthquake is beneath sea. The presence or absence of a sea layer decides what surface reflected phases are expected, as discussed in section 2.4. The specification of structural parameters related to a sea layer is explained in section 2.6.
VPSURF	P wave velocity of the surface layer (discounting any sea layer) (km/s). If $\leq$ 0.0, is set to 4.0 (see section 2.6.1).
DSURF	Density of the surface layer (discounting any sea layer) (g/cm^3). If $\leq$ 0.0, is set to 2.3 (see section 2.6.1).
VPSRCE	P wave velocity of the source layer (km/s). If $\leq$ 0, is set to 8.1 (see sections 2.5 and 2.6.1).
VSSURF	S wave velocity of the surface layer (km/s). If $\leq$ 0.0, is set to VPSURF/$\sqrt{3}$ (see section 2.6.1).
VSSRCE	S wave velocity of the source layer (km/s). If $\leq$ 0.0, is set to VPSRCE/$\sqrt{3}$ (see section 2.6.1).
PPFCTF	Multiplication factor for all PPFCT1 values (see under PPFCT1 in Card(s) 3). If left blank or zero, is set to 1.0.
SPFCTF	Multiplication factor for all SPFCT1 values (see under SPFCT1 in Card(s) 3). If left blank or zero, is set to 1.0.
IFCT3	If non-zero, all surface reflection coefficients (ie, PPFCT3 and SPFCT3) will be set to +1.0 instead of being calculated in the program as explained in section 2.6.1. This option is useful if the complete effect of a complex velocity structure above the source - including the free surface or sea surface and sea bed - has been calculated elsewhere, and can be incorporated into PPFCT1 and SPFCT1 (or PPFCTF and SPFCTF) as explained in section 2.6.2. Note that for sP, the change in geometrical spreading factor upon reflection (see appendix E) must then also be included in the calculations, and the convention used for the sign of the sP reflection coefficient must follow that used in the program.

REGION If left blank, search will include all orientation space. Any non-blank punch indicates that a restricted region of search in orientation space is requested; details are given on Card 2A. Some uses of the option to search only a restricted region of orientation space are described in section 2.12.

Card 2A Card defining limits of restricted region of search in orientation space (see section 2.12). (This card only to be included if REGION in Card 2 not left blank.)

FORMAT 3(F8.4,8X,F8.4)

PSI1	Smallest value of slip angle to be included in searches (degrees).
PSIN	Largest value of slip angle to be included in searches (degrees).
DELTA1	Smallest value of dip to be included in searches (degrees).
DELTAN	Largest value of dip to be included in searches (degrees).
STRIK1	Smallest value of strike to be included in searches (degrees).
STRIKN	Largest value of strike to be included in searches (degrees).

PSI1, DELTA1 and STRIK1 are corrected downwards, and PSIN, DELTAN and STRIKN are corrected upwards, to the nearest search increment in orientation space. If PSI1, DELTA1 or STRIK1 $\leq$ DINC, it is set to DINC; if PSIN or DELTAN > 180.0, it is set to 180; if STRIKN > 360.0, it is set to 360.0. A required search region whose strike spans north must be divided into two searches, one with strike up to and including 360.0 and the other with strike beginning at DINC. For details of recurrence of slip angle and dip see appendix F. For a restricted region search the choice of DINC and of the search bounds must be such that the number of search increments in each angle separately does not exceed the number corresponding to DINC = 5.0 for a search over all space, which has DINC $\leq$ slip angle $\leq$ 180.0, DINC $\leq$ dip $\leq$ 180.0, and DINC $\leq$ strike $\leq$ 360.0. This gives a maximum number of search increments of 36 in slip angle and dip, and 72 in strike, see section 2.11. If these conditions are not met, the region of search will be reduced as required. Array dimensions are discussed in sections D1 and D2 of appendix D.

Card(s) 3 NOP cards - one for each phase pair or input-result. Cards can be placed in any order, so that any desired grouping of the phase pairs can be achieved merely by changing the order of the cards. This will affect the development of the cumulative acceptable orientations but will leave the final result unchanged (see section 2.13).

If the card relates to an input-result, it must be left blank, except for NDEV, the number of the device from which the input-result is to be read, which is right-justified in columns 79 and 80. There is no default value for NDEV - any non-interger characters, or blank or zero will cause the card to be deleted. If device 5 (normally the card reader) is used to read the input-result, then the corresponding card deck must be placed immediately after this input-result card. The format of an input-result is identical to that of the output to the third output device, so that the data can be re-read without modification. This format is given in appendix C.

If the card relates to a new phase pair, it contains its details as follows:-

FORMAT A8, F5.0, 3F5.1, 2(A1,2F10.5), 2F4.2, A2

STANAM	Station name code and seismograph type if required (eg, "ESK SPZ " or "WOL LPZ "). This is used only as a title, but must not be left blank as a blank station name is used to identify an input-result card.
AZI	Azimuth of station from earthquake in degrees (measured positive clockwise from north). This is converted to its principal value ($0 < AZI \nless 360.0$) by the program so that positive or negative values will be correctly treated. It is then approximated to the nearest value of strike in the search mesh.
DIST	Epicentral distance from earthquake to station (degrees). Only used if INDANG is non-zero, to calculate P takeoff angles from tables stored within the program (see section 2.5).
ALPHA	Takeoff angle of P from downward vertical at the source (degrees) (see section 2.5). This is only used if INDANG = 0. This variable can have any value (values between 90 and 180 giving a P takeoff angle in the upper focal hemisphere, and values between 0 and -180 theoretically giving an azimuth change of 180°). This value (unlike AZI) is not approximated to a search mesh point. The P wave takeoff angles for all phase pairs can then be systematically adjusted using ANGPF on Card 2.
GAMMA	Takeoff angle of pP from upward vertical at the source (degrees) (see section 2.5). If left blank, is set to the value of ALPHA (before any adjustment using ANGPF). This is normal for shallow earthquakes. This variable offers a means of specifying a different takeoff angle for pP in cases where it may be justified for deep earthquakes. The pP takeoff angles for all phase pairs can then be systematically adjusted using ANGPPF on Card 2. Note that GAMMA refers to the takeoff angle of pP irrespective of which phase pair this card relates to. The sP takeoff angle (BETA) is derived from the final value of GAMMA when required, using the ratio of the P and S wave velocities in the source layer (VPSRCE/VSSRCE). Note that BETA is independent of v_p/v_s in any other layer.
SIGNP, PA2IN, PA1IN, SIGNPP, PPA2IN, PPA1IN.	In the following, Phase 1 represents P for a P and pP or a P and sP phase pair, and pP for a pP and sP phase pair. Phase 2 represents pP for a P and pP phase pair, and sP for a P and sP or a pP and sP phase pair. The types of phase pair are discussed in section 2.4, and this method of specifying amplitude information is further explained in section 2.2. For the present purpose pP includes its sea bed and sea surface analogues, and sP includes its sea bed analogue.

SIGNP Polarity of Phase 1 as observed on seismogram.

+ = positive (ie, up), - = negative (ie, down).

Any other punch or blank corresponds to uncertain or unknown polarity and so both polarities are included.

PA2IN, PA1IN Lower and upper bounds respectively on the possible amplitude of Phase 1 as observed on the seismogram, measured in arbitrary units. Amplitudes are specified by positive values - the polarity being controlled by SIGNP.

SIGNPP, PPA2IN, PPA1IN Same for Phase 2.

The above method of expressing relative amplitudes numerically was introduced in section 2.2; for comments on setting realistic 100% confidence limits on the amplitudes see section 2.3. Note that if the amplitude range of either phase has zero width, or if the amplitude ranges of both phases include zero, the phase pair is deleted by the program. (The inclusion of zero in both amplitude ranges permits all possible relative amplitudes, so that all source orientations would be compatible.)

PPFCT1 Multiplication factor applied to calculated pP amplitudes (if this phase pair includes a pP type phase) to represent any loss of pP amplitude during propagation with respect to that of P, other than at the sea bed, sea surface or free surface (whose refraction and reflection coefficients are normally allowed for in the program, see section 2.6.1). This factor is primarily intended to allow for energy partitioning at crustal discontinuities above the source, or anelastic attenuation above the source, as described in section 2.6.2. If left blank, is set to 1.0.

SPFCT1 Multiplication factor applied to calculated sP amplitude (if this phase pair includes an sP type phase) to represent any loss of sP amplitude relative to that of P, for the same purpose as PPFCT1 above. If left blank, is set to 1.0.

Note that PPFCT1 or SPFCT1 for all phase pairs may be scaled systematically by the use of PPFCTF and SPFCTF or Card 2. This enables a general factor to be specified for all phase pairs, and it enables perturbation studies to be performed easily on the loss of pP or sP energy above the source (see section 2.6.2).

PHASES Code to identify the type of phase pair to which this card relates (see section 2.4 for the possible types of phase pair). Punch 'PP' for a P and pP phase pair; 'SP' for a P and sP phase pair; '**'for a pPand sP phase pair (used only when both previous phase pairs are included from the same seismogram - see section 2.4). If the earthquake is beneath the sea (ISEA non-zero), then reflection at the sea bed is assumed for the above cases (this conforms to the standard definitions of pP and sP). Where pP reflected from the sea surface is used, punch 'PE' for a P and pP(ssf) phase pair or '*E' for a pP(ssf) and sP phase pair (S is not transmitted into the sea layer).

Any other punch or blank is assumed to be a P and pP phase pair.

Further complete data blocks may follow.

For normal termination of the program the last data block must be followed by one blank card.

APPENDIX C

FORMAT OF MACHINE-READABLE OUTPUT AND INPUT-RESULT

The standard format output into a third output device is intended to provide the results of processing a data block in a convenient machine-readable form, in addition to the routine printer and graphic outputs. As explained in section 2.13.2 it is in two sections, the first of which provides a summary of input data and results, and the second of which contains a list of all orientations which are compatible and partially compatible with all the phase pairs processed in the data block or read in as input-results. The format is designed so that, when both sections are requested, the output can be re-read directly as an input-result without alteration, as described in section 2.13. The format of an input-result is therefore essentially the same as that of the standard output. The formats have been spaced out to provide room for hollerith annotation of key variables, which is automatically included in the output to assist identification and interpretation of data sets. This hollerith information, which is indicated by H format fields in the list below, is skipped on input. The format list which follows is arranged in "Cards" although more generally these will be card images on disc or magnetic tape.

Section 1 of standard output from one data block.

Card 1 Header card

FORMAT 3A8,16H,A8,12H,A8,4H,A8

TCARD(I), I = 1,3 Standard heading used on input to identify this as a standard FALT dataset. The characters are FALTb-bSTANDARDbOUTPUTbb (where b denotes blank).

VDATE Version date of the program, in the form dd/mm/yy (where dd = day, mm = month, yy = year).

RDATE Date when program was run, in the form dd/mm/yy.

RTIME Time when program was run, in the form hh.mm.ss (where hh = hour, mm = minute, ss = second).

Card 2 Title card for earthquake (as for Card 1 of device 5 input).

Card 3 FORMAT 33H,I3,35H,F4.1,5H

NVL,DINC (as for device 5 input).

Card 4 FORMAT 16H,F4.0,4H,F4.0,12H,F4.0,4H,F4.0,16H,F4.0,4H,F4.0

PSI1, PSIN, DELTA1, DELTAN, STRIK1, STRIKN (as for device 5 input).

Card 5 Card with parameters relating to the earthquake (as for Card 2 of device 5 input).

Card 5A Card defining limits of restricted region of search in orientation space. (This card is only included if REGION in Card 5 is not left blank.) This card is the same as Card 2A of device 5 input.

Card 6	FORMAT 31H,I6,35H,I8
NCOMBR	Number of orientations in the search.
NCOMB	Total number of orientations in all orientation space.

One set of three cards, namely Cards 7A, 7B and 7C, now follow in respect of each phase pair.

Card 7A	This card is the same as Card 3 of device 5 input.
Card 7B	FORMAT 26H,I6,37H,F11.9
NTRUE	Number of orientations found which are compatible with this phase pair.
S	Fraction of all orientations which is incompatible with this phase pair.
Card 7C	FORMAT 69H,F11.9
SREAL	Fraction of all orientations in real space which is incompatible with this phase pair (ie, the significance).
Card 8	Blank card
Card 9	FORMAT 30H,I3
IOBS	(=NOBS). Total number of phase pairs (either processed in this data block or included in any input-results read in as part of this data block).
Card 10	FORMAT 26H,I6,37H,F11.9
NTRUE	Number of orientations which are compatible with all phase pairs.
S	Fraction of all orientations which is incompatible with all phase pairs.
Card 11	FORMAT 69H,F11.9
SREAL	Fraction of all orientations in real space which is incompatible with this phase pair (ie, the significance).

Section 2 of standard output from one data block.

Card 12	FORMAT 16H,I7,57H
NTOT	Total number of compatible and partially compatible orientations within the region of search.
Card 13	80H
Card 14	80H
Card(s)15	List of all compatible and partially compatible orientations, with the number of phase pairs incompatible with each (see section 2.13.2). For each card:- FORMAT 1X,I3,1X,I3,1X,I3,I3,4(1H,I3,1X,I3,1X,I3,I3),I5

III(I)	Slip angle in fault plane ψ (degrees).
JJJ(I)	Dip of fault plane δ (degrees).
KKK(I)	Strike of fault plane σ (degrees).
IVLN(I)	Number of phase pairs which are incompatible with this orientation.
ICARD	(columns 75 to 80). Card count for Card(s) 15. When read in as an input-result this is used to check the order of the input records.
Card 16	Card to indicate that the end of the dataset has been reached. (When read in as an input-result the program calculates this using NTOT, and this card only serves to confirm that the dataset is complete.) FORMAT A4
END	Standard characters which are used as an identifier. They are ENDb (where b denotes a blank).

APPENDIX D

PROGRAM TIME AND STORAGE REQUIREMENTS AND RELATED INFORMATION

D1. COMPUTING TIME AND PROGRAM STORAGE

Since both program storage and CPU time used are determined by the minimum allowed search increment (ie, the minimum value of DINC), the program can easily be modified to suit varied computing resources. The minimum value of DINC is governed by the dimensions of the orientation array F, which are related to the value of NDIM as described below. A suitable value of NDIM can be estimated from the following approximate statistics, which are derived for the present version of the program (*NDIM = 18*):-

(1) With NDIM = 18 the program requires 320 kb to compile.

(2) With NDIM = 18 the compiled program requires 256 kb.

Table D1 shows approximate CPU time requirements for different values of DINC (see DINCIN on Card 2), expressed in arbitrary units:-

TABLE D1

DINC	No. of Search Points (All Orientation Space)	Time for One P and pP Phase Pair (All Orientation Space) (Units)	Time for One P and sP or pP and sP Phase Pair (All Orientation Space) (Units)
15°	3456	1.5	2
10°	11664	4	6
5°	93312	20 - 35	40 - 50
2°	1458000	300 - 400	400 - 500
1°	11664000	2400 - 3200	3200 - 4000

Times for restricted region searches can be estimated by calculating the number of search points and estimating the equivalent number of units from the above table.

For the IBM370 installation, on which this program has been run, 1 unit = 1 s.

D2. INSTRUCTIONS FOR CHANGING PROGRAM STORAGE

As mentioned above, the program can be tailored to available resources simply by changing the dimensions of the array F (whose elements are 1 byte), and the value of NDIM (which is used only for testing the validity of input data, and is specified in a DATA initialisation statement). Set NDIM to the desired maximum available number of search increments in a 90° band, exclusive of lower limit (eg, if maximum resolution required is DINC = 5°, then NDIM = 18). Then the required dimensions of F are (NDIM*2, NDIM*2, NDIM*4), corresponding to (slip angle, dip, strike). Remember that DINCIN is always corrected to an integer submultiple of 90° before being equated to DINC.

With these changes the program logic will remain unaffected.

For higher resolution searches over restricted regions in orientation space, the number of search increments in slip angle, dip or strike must not exceed the corresponding dimension of F.

D3. INSTRUCTIONS FOR CHANGING THE MAXIMUM NUMBER OF VECTOR LENGTHS

If it should be necessary to increase the maximum number of vector lengths, to provide for larger values of NVL, this can be increased from 35 to a theoretical maximum of 255 as follows:-

(1) Set dimension of VVLR to (n + 1) where n is the desired maximum number of vector lengths.

(2) Set dimension of VVL to (4,n + 1).

(3) Set dimension of NTRUES to (n).

(4) Assign a unique code to the first byte of each new element of VVLR, setting the remaining 3 bytes to "blank". This is most easily achieved using hexadecimal "Z" specification in a DATA initialisation statement (Z00404040 must be reserved for VVLR(1)). The codes used in the orientation array are explained in appendix G.

APPENDIX E

METHOD OF CALCULATING THE RELATIVE AMPLITUDE BETWEEN TWO GIVEN PHASES WHICH IS EXPECTED AT A GIVEN STATION FROM A GIVEN SOURCE ORIENTATION

The procedure by which orientation space is searched and tested for a given phase pair is outlined in appendix A. Here, and in appendices F and G, the method by which the calculations are carried out is described.

At each search point in the mesh of possible source orientations the acceptable range of relative amplitudes is tested against the theoretically expected relative amplitude, calculated for the required phase pair at the given station location, for the particular source orientation. The method by which the theoretically expected relative amplitude is calculated is now given.

Let the seismic radiation from a point source be defined in spherical polar co-ordinates (r,θ,ϕ) about the source, where $\theta = 0$ is coincident with the X_3 Cartesian axis and ϕ is measured in a right-handed sense from the X_1 axis (figure 4(a)). Then for a double couple force system acting about the X_2 axis, as shown in figure 4(b), the time independent part of the far field P wave amplitude at unit distance from the source is given by (see, for example, reference (22)).

$$\underset{\sim}{A}_p(\theta,\phi) = \frac{K}{4\pi}\frac{1}{v_p}\frac{1}{\lambda + 2\mu}\sin 2\theta \cos\phi\,\hat{\underset{\sim}{r}}, \qquad \text{....(E1)}$$

where λ and μ are Lamé's parameters, v_p is the P wave velocity in the source medium, K is a constant dependent upon the magnitude of the couples, and $\hat{\underset{\sim}{r}}$ denotes the unit vector. Similarly, the S wave amplitude is given by

$$\underset{\sim}{A}_s(\theta,\phi) = \frac{K}{4\pi}\frac{1}{v_s}\frac{1}{\mu}(\cos 2\theta \cos\phi\,\hat{\underset{\sim}{\theta}} - \cos\theta \sin\phi\,\hat{\underset{\sim}{\phi}}), \qquad \text{....(E2)}$$

where v_s is the S wave velocity in the source medium. It is clear from equations (E1) and (E2) that, although the ratio of P and pP amplitudes at the focus is independent of all geophysical parameters, this is only approximately true for the ratio of P and sP, since the relative excitation of P and S depends upon Poisson's ratio.

Figure 4(c) is a three-dimensional polar diagram of the P wave radiation $\underset{\sim}{A}_p(\theta,\phi)$, viewed as for figures 4(a) and (b). The form of the S wave radiation $\underset{\sim}{A}_s(\theta,\phi)$ is shown similarly in figure 5, where its amplitude and polarisation direction are plotted on a three-dimensional representation of the focal sphere. Here the planes X_1X_2 and X_2X_3 are the "nodal planes" of P, which intersect at the "null vector" X_2 along which $\underset{\sim}{A}_p = \underset{\sim}{A}_s = \underset{\sim}{0}$. For a point source we note the familiar degeneracy of both P and S radiations under interchange of fault plane (arbitrarily chosen as the X_2X_3 plane) and auxiliary plane, X_1X_2. The integrated effect over an extended source has little influence on the radiation pattern if the source is small, but large or elongated faults given rise to significant variations of pulse length over the focal sphere, in which case the correct quantity to estimate is the square root of the energy contained in the (broad band) displacement pulse throughout its duration, as discussed in section 2.3.2.

The source orientation is the orientation of the above co-ordinate system X in space, which is defined in terms of the three angles introduced in section 2.7, namely the dip δ of the fault plane, the slip angle ψ in this plane, and its strike σ from north, as shown in figure 6(a).

The position of P, pP and sP on the focal sphere is defined by the azimuth of the station, ξ, and the takeoff angle of each phase - α, γ and β being used for P, pP and sP respectively (figure 6(b)). (These angles are respectively the variables AZI, ALPHA, GAMMA and BETA introduced in section 2.5.) $\alpha = \gamma$ is assumed for all shallow earthquakes, and β is determined from γ using the ratio of the P and S wave velocities in the source layer. We have

$$\sin \beta = \frac{v_s \sin \gamma}{v_p}. \qquad \text{....(E3)}$$

(Here reference to the phase "pP" includes the solid free surface, sea surface or sea bed reflections as these all emerge from the same point on the focal sphere.)

In order to calculate the amplitude of P or S along a given ray for a particular source orientation, we require the direction vector $\underset{\sim}{x} = \{x_1,x_2,x_3\}$ of the ray leaving the source expressed in the X co-ordinate system. This is found by applying a series of rotations to the direction vector along X_3, namely $\{0,0,1\}$. The required direction vectors for a P, pP and sP ray respectively are given by*:-

$$\begin{pmatrix} x_1 \\ x_2 \\ x_3 \end{pmatrix} = \begin{pmatrix} 1 & 0 & 0 \\ 0 & \cos\psi & -\sin\psi \\ 0 & \sin\psi & \cos\psi \end{pmatrix} \begin{pmatrix} \cos\delta & \sin\delta & 0 \\ -\sin\delta & \cos\delta & 0 \\ 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} 1 & 0 & 0 \\ 0 & \cos\eta & -\sin\eta \\ 0 & \sin\eta & \cos\eta \end{pmatrix} \begin{pmatrix} -\sin\alpha & 0 & \cos\alpha \\ 0 & -1 & 0 \\ \cos\alpha & 0 & \sin\alpha \end{pmatrix} \begin{pmatrix} 0 \\ 0 \\ 1 \end{pmatrix}, \qquad \text{....(E4)}$$

$$\begin{pmatrix} x_1 \\ x_2 \\ x_3 \end{pmatrix} = \begin{pmatrix} 1 & 0 & 0 \\ 0 & \cos\psi & -\sin\psi \\ 0 & \sin\psi & \cos\psi \end{pmatrix} \begin{pmatrix} \cos\delta & \sin\delta & 0 \\ -\sin\delta & \cos\delta & 0 \\ 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} 1 & 0 & 0 \\ 0 & \cos\eta & -\sin\eta \\ 0 & \sin\eta & \cos\eta \end{pmatrix} \begin{pmatrix} -\sin\gamma & 0 & -\cos\gamma \\ 0 & -1 & 0 \\ -\cos\gamma & 0 & \sin\gamma \end{pmatrix} \begin{pmatrix} 0 \\ 0 \\ 1 \end{pmatrix}, \qquad \text{....(E5)}$$

$$\begin{pmatrix} x_1 \\ x_2 \\ x_3 \end{pmatrix} = \begin{pmatrix} 1 & 0 & 0 \\ 0 & \cos\psi & -\sin\psi \\ 0 & \sin\psi & \cos\psi \end{pmatrix} \begin{pmatrix} \cos\delta & \sin\delta & 0 \\ -\sin\delta & \cos\delta & 0 \\ 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} 1 & 0 & 0 \\ 0 & \cos\eta & -\sin\eta \\ 0 & \sin\eta & \cos\eta \end{pmatrix} \begin{pmatrix} -\sin\beta & 0 & -\cos\beta \\ 0 & -1 & 0 \\ \cos\beta & 0 & \sin\beta \end{pmatrix} \begin{pmatrix} 0 \\ 0 \\ 1 \end{pmatrix}, \qquad \text{....(E6)}$$

where $\eta = \xi - \sigma$ is the azimuth of the recording station from the strike. The amplitudes of the corresponding P and S rays leaving the source are then given by

$$\underset{\sim}{A}_p = \frac{K}{4\pi} \frac{1}{v_p} \frac{1}{\lambda + 2\mu} \sin (2 \cos^{-1} (x_3)) \cos (\tan^{-1} (x_2/x_1)) \qquad \text{....(E7)}$$

and

$$\underset{\sim}{A}_s = \underset{\sim}{A}_{s_\theta} \underset{\sim}{\hat{\theta}} + \underset{\sim}{A}_{s_\phi} \underset{\sim}{\hat{\phi}} = \frac{K}{4\pi} \frac{1}{v_s} \frac{1}{\mu}\Big(\cos (2 \cos^{-1} (x_3)) \cos (\tan^{-1} (x_2/x_1))\underset{\sim}{\hat{\theta}}$$

$$+ \cos (\cos^{-1} (x_3)) \sin (\tan^{-1} (x_2/x_1))\underset{\sim}{\hat{\phi}}\Big). \qquad \text{....(E8)}$$

---

*In equation (3) of reference (1), the minus sign was omitted from the first element of the α matrix.

The normalised amplitude of the P phase at the station is obtained directly from equation (E7), using equation (E4). That for a pP phase is similarly obtained from equation (E8), using equation (E5), after which it is multiplied by a factor F (corresponding to PPFCT3 introduced in section 2.6.1) to allow for loss of pP amplitude due to reflection at the solid free surface, sea surface or sea bed, according to which type of pP phase is being considered. The energy partitioning equations for plane waves at a plane interface have been given by many authors, eg, (23-25). The equations for a solid/fluid interface have been given by Ergin (26). For the present purpose the matrices are expanded to obtain a separate algebraic expression corresponding to each surface-reflected phase.

For pP reflected at a solid free surface we obtain

$$F = \frac{2 \sin 2\gamma_1 \sin 2\beta_1 - R_1{}^2(\cos 4\beta_1 + 1)}{2 \sin 2\gamma_1 \sin 2\beta_1 + R_1{}^2(\cos 4\beta_1 + 1)}, \qquad \ldots.(E9)$$

where R_1 is the ratio of the P and S wave velocities in the surface layer, and where γ_1 and β_1 are respectively the pP and sP angles of incidence in the surface layer, which are derived from γ and β using Snell's law, given the velocity ratio between the surface and source layers. This correction is less than 10% for $\gamma_1 < 14^\circ$.

For pP reflected at the sea bed, expansion of the matrices gives a similar expression, but which depends also upon the ratio of the P wave velocities in the sea and surface (solid) layers, denoted by R_p, and upon the ratio of their densities, denoted by R_d. We obtain

$$F = \frac{R_1^2 \cos 2\beta_1 (R_d R_p \cos \gamma_1 - \cos 2\beta_1 \cos X) + \sin 2\gamma_1 (\sin 2\beta_1 \cos X + R_1 R_d R_p \sin \beta_1)}{\sin 2\gamma_1 (\sin 2\beta_1 \cos X + R_1 R_p R_d \sin \beta_1) + R_1^2 \cos 2\beta_1 (\cos 2\beta_1 \cos X + R_p R_d \cos \gamma_1)}, \qquad \ldots.(E10)$$

where $X = \sin^{-1} (R_p \sin \gamma_1)$.

For pP reflected at the sea surface F includes the effects of amplitude loss due to upward and downward refraction at the sea bed; reflection at the sea surface involves no amplitude loss but it does give a change in polarity. The product of the three factors then gives F:-

$$\left. \begin{aligned} F = {} & \frac{\begin{gathered} 2 \cos \gamma_1 \cos 2\beta_1 (\sin 2\gamma_1 \sin 2\beta_1 + R_1^2 \cos^2 2\beta_1) \\ + 2 \sin 2\gamma_1 \cos 2\beta_1 (R_1 \sin \beta_1 \cos 2\beta_1 - \cos \gamma_1 \sin 2\beta_1) \end{gathered}}{\begin{gathered} (R_p R_d \cos \gamma_1 + \cos 2\beta_1 \cos X)(\sin 2\gamma_1 \sin 2\beta_1 + R_1^2 \cos^2 2\beta_1) \\ + R_p R_d \sin 2\gamma_1 (R_1 \sin \beta_1 \cos 2\beta_1 - \cos \gamma_1 \sin 2\beta_1) \end{gathered}} && \text{(Upward refraction at sea bed)} \\ & \times -1.0 && \text{(Reflection at sea surface)} \\ & \times \frac{2R_1^2 \cos X \cos 2\beta_1}{\begin{gathered} \sin 2\gamma_1 (R_1^2 \sin \beta_1 + (\sin 2\beta_1 \cos X)/R_p R_d) \\ + R_1^2 \cos 2\beta_1 (\cos \gamma_1 + (\cos 2\beta_1 \cos X)/R_p R_d) \end{gathered}}. && \text{(Downward refraction at sea bed)} \end{aligned} \right\} \ldots.(E11)$$

The calculated pP amplitude may be multiplied by a second factor (corresponding to PPFCT1) to allow for loss of pP amplitude relative to that of P due to any other cause - for example, as a result of energy partitioning of pP at other seismic discontinuities above the source.

Calculation of the normalised sP amplitude at the station requires consideration of the mode conversion upon reflection at the free surface. Equation (E8), using equation (E6), gives its amplitude and polarisation direction in the X co-ordinate system. For calculation of the sP amplitude we are concerned only with $\underset{\sim}{A}_{s_v}$, the component of S amplitude in the vertical plane. This is given by

$$\underset{\sim}{A}_{s_v} = |\underset{\sim}{A}_s| \cos (\varepsilon_1 + \varepsilon_2), \qquad \ldots.(E12)$$

where ε_1 is the S polarisation direction measured relative to $\hat{\underset{\sim}{\theta}}$, and ε_2 is the angle between the vertical plane and $\hat{\underset{\sim}{\theta}}$, measured perpendicular to the ray direction $\underset{\sim}{x}$. Figure 12 shows the relevant geometry. Both $|\underset{\sim}{A}_s|$ and ε_1 follow directly from equation (E8) as follows:-

$$|\underset{\sim}{A}_s| = (|\underset{\sim}{A}_{s_\theta}|^2 + |\underset{\sim}{A}_{s_\phi}|^2)^{\frac{1}{2}}, \qquad \ldots.(E13)$$

$$\varepsilon_1 = \tan^{-1} (|\underset{\sim}{A}_{s_\phi}|/|\underset{\sim}{A}_{s_\theta}|), \qquad \ldots.(E14)$$

while ε_2 is calculated by expressing the direction of $\hat{\underset{\sim}{\theta}} = (\theta_1, \theta_2, \theta_3)$ in the co-ordinate system with its 3 axis along the takeoff ray and its 1 axis in the upward vertical plane (figure 12). This is obtained by applying a series of rotations to the expression for $\hat{\underset{\sim}{\theta}}$ defined in the X co-ordinate system of figure 5(a). We obtain

$$\begin{pmatrix}\theta_1\\ \theta_2\\ \theta_3\end{pmatrix} = \begin{pmatrix}-\sin\beta & 0 & -\cos\beta\\ 0 & -1 & 0\\ -\cos\beta & 0 & \sin\beta\end{pmatrix}\begin{pmatrix}1 & 0 & 0\\ 0 & \cos\eta & \sin\eta\\ 0 & -\sin\eta & \cos\eta\end{pmatrix}\begin{pmatrix}\cos\delta & -\sin\delta & 0\\ \sin\delta & \cos\delta & 0\\ 0 & 0 & 1\end{pmatrix}\begin{pmatrix}1 & 0 & 0\\ 0 & \cos\psi & \sin\psi\\ 0 & -\sin\psi & \cos\psi\end{pmatrix}\begin{pmatrix}\cos\theta\cos\phi\\ \cos\theta\sin\phi\\ -\cos\theta\end{pmatrix}. \qquad \ldots.(E15)$$

Substituting for $|\underset{\sim}{A}_s|$, ε_1 and ε_2 in equation (E12) gives the required expression for $\underset{\sim}{A}_{s_v}$:-

$$\underset{\sim}{A}_{s_v} = (A_{s_\theta}^{\ 2} + \underset{\sim}{A}_{s_\phi}^{\ 2})^{\frac{1}{2}} \cos \{\tan^{-1} (\underset{\sim}{A}_{s_\phi}/\underset{\sim}{A}_{s_\theta}) + \tan^{-1} (\theta_2/\theta_1)\}. \qquad \ldots.(E16)$$

Allowance for energy conversion from incident S to reflected P at the free surface is expressed as the product (corresponding to SPFCT3) of two scalar factors F_1 and F_2 applied to the amplitude $\underset{\sim}{A}_{s_v}$ - these being respectively an expression analogous to that for pP, to allow for the partitioning of an incident plane wave at the boundary as deduced from Zöppritz's equations, and an additional correction (not required for pP) to convert to an incident spherical wavefront. For the conversion of incident S to reflected P at a solid free surface we obtain

$$F_1 = -\frac{2R_1^2 \sin 4\beta_1}{2\sin 2\gamma_1 \sin 2\beta_1 + R_1^2(\cos 4\beta_1 + 1)}. \qquad \ldots.(E17)$$

The negative sign is necessary for compatibility with the definition of $\underline{A}_{s_v}$ shown in figure 12. The equivalent factor for sP reflected at the sea bed is given by

$$F_1 = -\frac{2R_1 \sin 2\beta_1 \cos 2\beta_1 \cos X}{\sin 2\gamma_1 (\sin 2\beta_1 \cos X + R_1 R_p R_d \sin \beta_1) + R_1^2 \cos 2\beta_1 (\cos 2\beta_1 \cos X + R_p R_d \cos \gamma_1)}. \quad \ldots.(E18)$$

The geometry of figure 13 serves to show the origin of F_2, which allows for the discontinuous change in geometric spreading factor caused by the change of the spherically expanding wavefront from S to P at the free surface. This factor depends only upon angles and velocities at the source, and can be expressed as

$$F_2 = \frac{\cos \gamma}{(R^2 - \sin^2 \gamma)^{\frac{1}{2}}}, \quad \ldots.(E19)$$

where R is the ratio of the P and S wave velocities in the source layer.

The sP amplitude must be multiplied by a further factor (corresponding to SPFCT2) to allow for the relative excitation of P and S waves at the source, which is given by the ratio of the premultipliers in equations (E2) and (E1). Here this ratio is set to 5.2, which is within 0.004 of its value for a Poisson solid.

Finally, a factor to allow for loss of amplitude relative to P due to any other cause (for example, as a result of energy partitioning at other discontinuities above the source) can be applied to sP in the same way as for pP discussed above; this factor corresponds to SPFCT1.

APPENDIX F

METHOD OF SEARCHING ORIENTATION SPACE AND OF STORING AND DISPLAYING RESULTS FOR A GIVEN PHASE PAIR

For a given phase pair at a given station the calculation described in appendix E is repeated for each required search point in orientation space, and for each point the calculated relative amplitude is tested against the acceptable range, the result being stored and displayed as required. This procedure is now described.

To establish appropriate angular bounds for the search in orientation space we require knowledge of the symmetry properties of the P and S wave double couple radiation patterns, shown in figures 4 and 5. In the X co-ordinate system of figure 4(a) we have, for the P wave radiation pattern,

$$\underset{\sim}{A}_P\Big|_{\substack{\theta=\Theta\\ \phi=\Phi}} = \underset{\sim}{A}_P\Big|_{\substack{\theta=\pm\Theta+m\pi\\ \phi=\Phi+n\pi}} \qquad \text{....(F1)}$$

for all integer m and n. This gives a two-fold degeneracy of orientations within the region $0 < \theta \leq \pi$, $0 < \phi \leq 2\pi$, which represents the full radiation pattern. In addition, for a point source, interchange of fault plane and auxiliary plane further doubles the degeneracy:-

$$\underset{\sim}{A}_P\Big|_{\substack{\theta=\Theta\\ \phi=\Phi}} = \underset{\sim}{A}_P\Big|_{\substack{\theta=\pm\Theta+m\pi\\ \phi=-\Phi+(2n+1)\pi/2}} \qquad \text{...(F2)}$$

Furthermore, the existence of alternate opposite polarity quadrants adds an antisymmetric property to the radiation pattern, which is given by

$$\underset{\sim}{A}_P\Big|_{\substack{\theta=\Theta\\ \phi=\Phi}} = -\underset{\sim}{A}_P\Big|_{\substack{\theta=\pm\Theta+m\pi\\ \phi=-\Phi+n\pi}} = -\underset{\sim}{A}_P\Big|_{\substack{\theta=\pm\Theta+m\pi\\ \phi=\Phi+(2n+1)\pi/2}} . \qquad \text{...(F3)}$$

The relations (F1) to (F3) are identical for the S wave radiation pattern.

The azimuth ξ of a station from the earthquake, and the corresponding P wave takeoff angle at source, α, (and possibly a different pP takeoff angle γ for a deep earthquake) are specified; these are defined in figure 6. For each phase pair all orientations are systematically searched using an angle increment d, within the following bounds:-

$$\left.\begin{array}{l} d \leq \psi \leq \pi, \\ d \leq \delta \leq \pi, \\ d \leq \eta \leq 2\pi, \end{array}\right\} \qquad \text{...(F4)}$$

these bounds representing the search limits when all orientation space is to be included.

This choice of bounds takes advantage of the two-fold symmetry of equation (F1), so that it includes only one of the two degenerate orientations of the X_2X_3 plane, thereby avoiding duplication of equivalent orientations. However, the additional two-fold degeneracy provided by interchange of fault and auxiliary planes (equation (F2)) is not exploited, so that both the alternatives appear as separate solutions within the bounds specified in relations (F4).

The vectorplot, illustrated in figure 7, was introduced in section 2.8 as a means of representing this three-dimensional "orientation space" in terms of the three angles ψ, δ and σ, within the limits defined by the relations (F4). Although the source orientation corresponding to any vector on the vectorplot can be easily interpreted using figure 7, we may also wish to interpret angles outside the bounds of relations (F4). This information is required if a region of acceptable orientations borders the edge of the region in slip angle or dip, and we wish to know whereabouts on the edge of the region it "reappears" (perhaps in order to specify bounds for a restricted region search as described in section 2.12).

Figure 14 shows a plot with the slip angle and dip extended beyond the search limits defined in relations (F4). Any orientation whose angles lie outside these limits can be translated into an identical orientation whose angles lie within the limits, and which correspond to "principal values" of the angles. Additional vectorplots similar to that of figure 7 are superimposed on figure 14 to show correspondence between orientations outside the search region, and the equivalent orientations within it. From this it can be seen whereabouts a region of orientations which reaches the edge of a vectorplot immediately reappears at another part of its boundary.

Examination of figures 7 and 14 shows that the boundaries of the search region as defined by relations (F4) do not rigorously fulfil the requirement of covering the complete range of orientations. Along the boundaries of the orientation space, a small number of orientations appear twice at the expense of a small number of others, which do not appear at all. This can be seen by the inexact fitting together of adjacent vectorplots in figure 14, and only arises through the use of a finite search increment. In this connection we note the two parts of the space where behaviour is anomalous. These are:-

(1) $(\pi, \pi/2, \eta)$ for all η - vertical strike slip. Here the two degenerate solutions included in the bounds do not involve interchange of nodal planes.

(2) (ψ, π, η) for all ψ and η - horizontal slip. Here all solutions with equal $(\psi + \eta)$ represent the same orientation in real space.

It must be emphasised that the size of the search increment d imposes a fundamental limit on the accuracy of results, and the non-rigorous behaviour described above is generally inside this limit. The bounds defined by relations (F4) are therefore used to keep the search limits simple for computation.

At each search point in orientation space the normalised amplitudes of the relevant two phases are calculated as described in appendix E, and their ratio (with attention to polarities) is tested against the acceptable range(s) of relative amplitudes corresponding to the input. The orientation is then accepted or rejected, according to whether or not the calculated value lies within the acceptable range(s) (section 2.7). The orientation is transformed, simply by an angular change in the strike, into the fixed co-ordinate system (ψ, δ, σ) and then displayed and printed as required if it has been accepted, or the value of the corresponding element of the orientation array is reduced if it has been rejected (see appendix G). Printing and plotting of the acceptable orientations is done as the search progresses, while the orientation array stores a cumulative record of orientations compatible or partially compatible with all completed phase pairs as described in appendix G.

APPENDIX G

METHOD OF COMBINING RESULTS FROM A SERIES OF PHASE PAIRS

The method by which the program combines the results from a series of phase pairs is now described.

The results from a series of phase pairs are combined by means of a logical array F, called the orientation array, each of whose elements corresponds to one orientation in the search mesh. (A given element of F will only correspond to the same orientation in other data blocks if these data blocks search all orientation space, or if they search identical restricted regions in orientation space (section 2.12).) The orientation array contains the "status" of each orientation and is updated during the processing of each new phase pair or input-result, so that it always contains the combined result of all the phase pairs so far processed. Note that any phase pairs which are contained in input-results are included implicitly (section 2.13.3).

If the retention of partially acceptable orientations is not requested, (using NVL) then we require to retain only those orientations which are compatible with <u>all</u> the phase pairs so far processed. To achieve this, all elements of the array are assigned a code which represents "acceptable" before processing of the data block commences, and the element corresponding to any orientation which is found to be unacceptable to a phase pair is reset to a code corresponding to "unacceptable" if this has not already been done during the processing of a previous phase pair. Thus, acceptable and unacceptable orientations can be identified, and by accessing the array after each phase pair or input-result card, we can obtain a listing or vectorplot of those orientations which are compatible with all phase pairs so far processed. These are the "cumulative acceptable orientations" described in section 2.8, and similar accessing of the array after processing the last card yields the "orientations compatible with all phase pairs". The cumulative fraction of compatible orientations and the significance (see section 2.10) are always output after the processing of each card, in the same way that these quantities are output for each individual phase pair or input-result card.

When the variable NVL is used to facilitate printouts or vectorplots of partially acceptable orientations, this information must be stored in the orientation array. In order to save the extra computer storage that would be needed for an integer orientation array, the logical (one byte per element) array is retained, and different one-byte binary codes are used to identify the different degrees of compatibility. Up to 35 different codes (given in the program listing) are available, and we shall assume that these correspond to the integers 1 to 35. In addition, the null code (equivalent to the logical .FALSE.) is used as explained below. The maximum of 35 codes can be increased if additional codes are required, by following the instructions of section D3 of appendix D.

Before processing begins, all elements of the orientation array are set to the code corresponding to the integer NVL (which corresponds to the number of vector lengths on vectorplots). Whenever an orientation is reached which is <u>incompatible</u> with the phase pair being processed, the corresponding array element value is decreased by 1. If it is already 1, it is set to .FALSE. This represents the "threshold of compatibility" below which the number of phase pairs that are incompatible with this orientation is no longer stored (or printed out or plotted). When an input-result is being processed, its orientation array also contains the partially compatible orientations corresponding to the data block from which it was derived. Each element in the current data block is compared with the corresponding element in the input-result. This latter value is subtracted from its original value of NVL, and the array element in the current data block is reduced by this difference (setting the element to .FALSE. if its value falls below 1). Elements which do not appear in the input-result are reduced in the current data block by NVL. Thus, the array elements acquire the same values as they would have acquired if the input-result card were replaced by its constituent phase pair cards.

Referring back to the simple case where no partially acceptable orientations are requested, we see that all array elements are then initially set to 1, and reset to .FALSE. when an incompatible phase pair is reached.

The above method of storing partially acceptable orientations means that a given code in an array element has a different meaning in data blocks with different values of NVL, and this explains why any manipulations with input-results must involve data blocks with the same value of NVL.

When a printout or vectorplot of cumulative acceptable orientations is requested, only those elements whose value is NVL are listed or plotted, and when a printout or vectorplot of cumulative partially acceptable orientations is requested, all elements whose value is not .FALSE. are retrieved. Those elements with value NVL are compatible with all phase pairs and have a full length vector. Those elements with a lower value - say, n - correspond to (NVL - n) phase pairs being unacceptable, and are plotted with correspondingly shorter length vectors - the shortest vector being reserved for any array elements whose value is 1. When listing partially acceptable orientations, a separate search is conducted for each value, so that separate listings are obtained of those orientations which are incompatible with each number of phase pairs.

It may happen that the number of phase pairs in a data block is less than NVL, in which case no orientation array elements will be set to .FALSE. In this case the orientations incompatible with all the phase pairs are not listed, or plotted, or included in the output, and allowance is made for this when re-reading an input-result.

APPENDIX H

LISTING OF RELATIVE AMPLITUDE PROGRAM (FALT)

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   FOCAL MECHANISMS FROM P, LITTLEP-P & LITTLES-P RELATIVE AMPLITUDES
   ------------------------------------------------------------------

*  THE FOLLOWING IS A SUMMARY OF THE PROGRAM DESCRIPTION AND INPUT  *
*  - FOR FULL DETAILS SEE PEARCE, AWRE REPORT NO. O 41/79 , HMSC    *
*  (1979).   FOR EXAMPLES OF ITS APPLICATION SEE PEARCE, GEOPHYS.   *
*  J. R. ASTR. SOC. VOL. 50 PP 381 - 394 (1977) OR PEARCE, PHD      *
*  THESIS, UNIV OF NEWCASTLE-UPON-TYNE (1977) OR PEARCE, GEOPHYS.   *
*  J. R. ASTR. SOC. VOL.    PP     -      (1979).                   *

   DESCRIPTION OF PROGRAM
   ----------------------

        THIS PROGRAM SYSTEMATICALLY SEARCHES FOR THOSE FAULT PLANE
   ORIENTATIONS WHICH ARE COMPATIBLE WITH A SERIES OF PHASE PAIRS,
   WHERE ONE 'PHASE PAIR' COMPRISES THE ACCEPTABLE RANGES OF
   *EITHER* P & LITTLEP-P *OR* P & LITTLES-P *OR* LITTLEP-P &
   LITTLES-P RELATIVE AMPLITUDES AT AN OBSERVING STATION.   THE
   RADIATION PATTERN RESULTING FROM A DOUBLE COUPLE FORCE SYSTEM
   ACTING AT A POINT IS ASSUMED (SEE E.G. HONDA, OCM. OBSERVATORY
   PUBS. 1957).   GIVEN THE AZIMUTH, TAKEOFF ANGLE OF P, AND RANGES
   OF ACCEPTABLE P & LITTLEP-P (OR P & LITTLES-P) AMPLITUDES IN
   ARBITRARY UNITS, WITH THEIR POLARITIES IF IDENTIFIABLE, THE
   PROGRAM SEARCHES THE THREE DIMENSIONAL PARAMETER SPACE DEFINED BY
   SLIP ANGLE IN THE FAULT PLANE (PSI), DIP OF FAULT PLANE (DELTA)
   AND AZIMUTH OF THE STATION FROM THE STRIKE (ETA) AT THE DESIRED
   ANGLE INCREMENT (DINC), AND STORES ACCEPTABLE ORIENTATIONS IN THE
   ARRAY F.   ACCEPTABLE ORIENTATIONS ARE CONVENIENTLY DISPLAYED AS
   'VECTORPLOTS' ON GRAPHIC OUTPUT USING SUBROUTINE PLOTV AND, IF
   REQUIRED, ARE PRINTED OUT.    AFTER REPEATING THIS PROCEDURE FOR
   EACH PHASE PAIR, THE FAULT PLANE ORIENTATIONS COMPATIBLE WITH ALL
   PHASE PAIRS ARE PLOTTED AND PRINTED.    THERE ARE ALSO OPTIONS TO
   PLOT ORIENTATIONS WHICH ARE COMPATIBLE WITH SOME BUT NOT ALL OF
   THE PHASE PAIRS.

   ALTHOUGH THE SEARCH NORMALLY COVERS ALL THE ORIENTATION SPACE, A
   RESTRICTED REGION OF THE SPACE MAY BE SPECIFIED, ENABLING A
   RESOLUTION (I.E. DINC) OF 1.0 DEG. TO BE ATTAINED WITH ACCEPTABLE
   SPACE AND TIME REQUIREMENTS.   (THIS IS INTENDED FOR USE AFTER A
   PRELIMINARY COARSE SEARCH - SAY WITH DINC = 5.0 OR 10.0 DEG. - HAS
   IDENTIFIED A COMPATIBLE REGION OF ORIENTATIONS.)


   ACCEPTABLE SOURCE ORIENTATIONS AND OTHER INFORMATION MAY BE OUTPUT
   IN A STANDARD MACHINE-READABLE FORM, AND IF REQUIRED RE-READ IN A
   SUBSEQUENT COMPUTATION IN PLACE OF A PHASE PAIR. THIS IS REFERRED
   TO AS AN 'INPUT-RESULT'.

   A SEPARATE PROGRAM, PURV, IS AVAILABLE WHICH GENERATES FULLY
   ANNOTATED VECTORPLOTS IN A FLEXIBLE FORMAT, E.G. FOR PUBLICATION.


   INPUT
   -----

   CARD 1   TITLE CARD
   ------
            FORMAT 10A8

   TITLE    TITLE OF EARTHQUAKE.
            COLUMNS 65 TO 80 SHOULD BE USED TO IDENTIFY THIS DATA
            BLOCK IF MORE THAN ONE DATA BLOCK IS TO BE PROCESSED IN
            RESPECT OF THE SAME EARTHQUAKE.

   CARD 2   CARD WITH PARAMETERS RELATING TO THE EARTHQUAKE, AND
   ------   PROCESSING OPTIONS.

            FORMAT I5,F5.0,F5.1,2F4.2,I2,10I1,I2,I3,I3,I2,5F5.2,
            2F4.2,I1,A1

   NOP      TOTAL NUMBER OF PHASE PAIR CARDS AND INPUT-RESULT CARDS
            IN THIS DATA BLOCK (IE NUMBER OF PHASE PAIRS PLUS NUMBER
            OF INPUT-RESULTS).

   DINCIN   ANGLE INCREMENT FOR SEARCH (DEGREES). THIS IS SET IN THE
            PROGRAM TO DINC, WHICH IS ADJUSTED TO THE NEAREST INTEGER
            SUB-MULTIPLE OF 90, PROVIDED THERE IS SUFFICIENT STORAGE
            IN THE ORIENTATION ARRAY, F, WHICH IS NORMALLY SET TO
            PROVIDE FOR A MINIMUM SEARCH INCREMENT OF 5 DEG. WHEN ALL
            ORIENTATION SPACE IS INCLUDED. (A FINER SEARCH INCREMENT
            IS POSSIBLE FOR RESTRICTED REGION SEARCHES.) IF DINCIN
            LESS THAN OR EQUAL TO 0 OR GREATER THAN 90 DINC IS SET TO
            30 (THIS IS INTENDED FOR TEST PURPOSES ONLY AND IS TOO
            COARSE FOR MEANINGFUL RESULTS).
            IN PRACTICE DINCIN = 5 PROVIDES ADEQUATE TREATMENT OF
            TYPICAL DATA, AND DINCIN = 10 IS APPROPRIATE FOR A COARSE
            SEARCH, TO BE FOLLOWED BY A HIGHER RESOLUTION SEARCH OVER
            RESTRICTED REGIONS OF INTEREST. DINCIN = 1 OR 2 IS SUIT-
            ABLE FOR RESTRICTED REGION SEARCHES.

   DEPTH    DEPTH OF EARTHQUAKE (KM). LEAVE BLANK FOR AN INTRA-
            CRUSTAL EARTHQUAKE. ONLY USED IF INDANG IS NONZERO.

   ANGPE    PERTURBATION FACTOR FOR SYSTEMATICALLY ADJUSTING ALL THE
            P TAKEOFF ANGLES CALCULATED OR READ IN FOR EACH PHASE
            PAIR. EACH P TAKEOFF ANGLE IS RESET TO ARCSIN(ANGPE*
            SIN(ALPHA)), SO THAT THE ADJUSTMENT OF ANGLES IS
            EQUIVALENT TO MULTIPLYING THE SOURCE LAYER VELOCITY BY A
            FACTOR ANGPE (FOR THIS PURPOSE ONLY). IF LEFT BLANK IS
            SET TO 1.0.
```

ANGPPF PERTURBATION FACTOR FOR SYSTEMATICALLY ADJUSTING ALL THE LITTLEP-P TAKEOFF ANGLES, AS FOR ANGPF ABOVE. IF LEFT BLANK IS SET TO 1.0.

INDANG INDICATOR TO SPECIFY HOW P AND LITTLEP-P TAKEOFF ANGLES ARE CALCULATED. IF LEFT BLANK THE P WAVE TAKEOFF ANGLE IS READ DIRECTLY FOR EACH PHASE PAIR (SEE ALPHA ON CARD(S) 3). IF INDANG NON-ZERO, THE P TAKEOFF ANGLE IS DETERMINED FOR EACH PHASE PAIR FROM DISTANCE/DEPTH TABLES CONTAINED WITHIN THE PROGRAM, USING DEPTH FROM THIS CARD, AND DIST FROM CARD(S) 3. IN THIS CASE IF DEPTH IS LEFT BLANK, THE EARTHQUAKE IS ASSUMED TO BE INTRACRUSTAL, AND THE ANGLE IS FURTHER CORRECTED ACCORDING TO SNELL'S LAW USING VPSRCE, AND ASSUMING A SUB-MOHO P WAVE VELOCITY OF 8.1 KM/S. FOR ANY PHASE PAIR WITH DIST LESS THAN 20 OR GREATER THAN 100 (OR LEFT BLANK) THE P WAVE TAKEOFF ANGLE IS READ IN USING ALPHA EVEN IF INDANG IS NON-ZERO. THE TAKEOFF ANGLE OF LITTLEP-P IS READ IN USING GAMMA ON CARD(S) 3, OR IF THIS IS ZERO, IT IS SET TO THE VALUE OF ALPHA. AFTER ALPHA AND GAMMA HAVE BOTH BEEN SET, EACH CAN BE ADJUSTED USING ANGPF AND ANGPPF RESPECTIVELY. THE TAKEOFF ANGLE OF LITTLES-P IS ALWAYS CALCULATED FROM THE FINAL VALUE OF GAMMA, USING VPSRCE AND VSSRCE.

IPRNT1, IPRNT2, IPRNT3, IPRNT4, IPRNT5. SWITCHES FOR PRINTING THE ORIENTATIONS COMPATIBLE WITH EACH CARD (WHETHER PHASE PAIR OR INPUT-RESULT), AND FOR PRINTING CUMULATIVE ACCEPT-ABLE ORIENTATIONS ETC. IF SWITCH IS NON-ZERO THE CORRES-PONDING LIST(S) OF ORIENTATIONS ARE PRINTED. SUMMARIES OF RESULTS ARE ALWAYS PRINTED.
NOTE THAT LISTS OF ORIENTATIONS, ESPECIALLY AS REQUESTED BY IPRNT1, IPRNT2 AND IPRNT3, ARE LIKELY TO BE VERY LONG.

IPRNT1 A LIST AFTER EACH CARD OF ORIENTATIONS COMPATIBLE WITH THAT PHASE PAIR OR INPUT-RESULT. FOR AN INPUT-RESULT SEPARATE LISTS OF THOSE ORIENTATIONS INCOMPATIBLE WITH ONE OR MORE PHASE PAIRS ARE PRINTED.

IPRNT2 A LIST AFTER EACH CARD (OTHER THAN THE FIRST AND LAST) OF 'CUMULATIVE ACCEPTABLE ORIENTATIONS'.

IPRNT3 SEPARATE LISTS AFTER EACH CARD (OTHER THAN THE FIRST AND LAST) OF 'CUMULATIVE PARTIALLY ACCEPTABLE ORIENTATIONS'.

IPRNT4 A LIST AFTER THE LAST CARD AS FOR IPRNT2, CONTAINING 'ORIENTATIONS COMPATIBLE WITH ALL PHASE PAIRS'.

IPRNT5 SEPARATE LISTS AFTER THE LAST CARD AS FOR IPRNT3, CONTAINING 'ORIENTATIONS PARTIALLY COMPATIBLE WITH ALL PHASE PAIRS'.

IPLOT1, IPLOT2, IPLOT3, IPLOT4, IPLOT5. SWITCHES, EQUIVALENT TO IPRNT1 TO IPRNT5, TO CONTROL PLOTS OF COMPATIBLE AND PARTIALLY COMPATIBLE ORIENTATIONS. IF SWITCH IS NON-ZERO THE CORRESPONDING VECTORPLOT(S) OF ORIENTATIONS ARE GENERATED.

IPLOT1 ONE VECTORPLOT AFTER EACH PHASE PAIR OR INPUT-RESULT, SHOWING THE ORIENTATIONS COMPATIBLE WITH THAT CARD. FOR A PHASE PAIR, A FIXED LENGTH VECTORPLOT IS GENERATED, BUT FOR AN INPUT-RESULT A VARIABLE LENGTH VECTORPLOT IS GENERATED TO SHOW THE COMPATIBLE AND PARTIALLY COMPATIBLE ORIENTATIONS OF THIS INPUT-RESULT.

IPLOT2 ONE FIXED LENGTH VECTORPLOT AFTER EACH CARD (OTHER THAN THE FIRST AND LAST) SHOWING 'CUMULATIVE ACCEPTABLE ORIENTATIONS'.

IPLOT3 ONE VARIABLE LENGTH VECTORPLOT AFTER EACH CARD (OTHER THAN THE FIRST AND LAST) SHOWING 'CUMULATIVE PARTIALLY ACCEPTABLE ORIENTATIONS'.

IPLOT4 ONE FIXED LENGTH VECTORPLOT AFTER THE LAST CARD, SHOWING 'ORIENTATIONS COMPATIBLE WITH ALL PHASE PAIRS'.

IPLOT5 ONE VARIABLE LENGTH VECTORPLOT AFTER THE LAST CARD, SHOWING 'ORIENTATIONS PARTIALLY COMPATIBLE WITH ALL PHASE PAIRS'.

IDEV3 INDICATOR FOR CONTROLLING OUTPUT ONTO THIRD OUTPUT DEVICE (WHICH IS DEFINED BY NDEV3). LEAVE BLANK FOR NO OUTPUT. IF SET TO 1, AN ANNOTATED SUMMARY OF INPUT AND RESULTS FOR EACH PHASE (INCLUDING THOSE IN ANY INPUT-RESULTS) IS PROVIDED. IF SET TO 2, THIS IS FOLLOWED BY THE STATUS OF THE ORIENTATION ARRAY AFTER COMPLETION OF THE LAST CARD, AS REQUIRED FOR USE AS AN INPUT-RESULT.

NVL NUMBER OF VECTOR LENGTHS FOR VARIABLE LENGTH VECTORPLOTS. THIS CORRESPONDS TO THE MAXIMUM NUMBER OF PHASE PAIRS WHICH MUST BE INCOMPATIBLE WITH AN ORIENTATION BEFORE THE DEGREE OF INCOMPATIBILITY IS NO LONGER STORED IN THE ORIENTATION ARRAY OR DISPLAYED ON THE PLOT. IF LEFT BLANK OR NEGATIVE IT IS SET TO 1. THE MAXIMUM POSSIBLE VALUE OF NVL IS GOVERNED BY THE DIMENSION OF VVLR AND IS SET TO 35. IF GREATER THAN 35 IT IS SET TO 35.

NDEV3 NUMBER OF THIRD OUTPUT DEVICE INTO WHICH WILL BE WRITTEN RESULTS ACCORDING TO IDEV3. IF LEFT BLANK IS SET TO 7 WHICH IS NORMALLY EQUIVALENT TO PUNCHED CARDS.

ISEA	IF LEFT BLANK, EARTHQUAKE IS BENEATH LAND. ANY NON-ZERO PUNCH INDICATES THAT THE EARTHQUAKE IS BENEATH SEA.
VPSURF	P WAVE VELOCITY OF THE SURFACE LAYER (DISCOUNTING ANY SEA LAYER) (KM/S). IF LESS THAN OR EQUAL TO 0.0 IS SET TO 4.0
DSURF	DENSITY OF THE SURFACE LAYER (DISCOUNTING ANY SEA LAYER) (GM/CC). IF LESS THAN OR EQUAL TO 0.0 IS SET TO 2.3.
VPSRCE	P WAVE VELOCITY OF THE SOURCE LAYER (KM/S). IF LESS THAN OR EQUAL TO 0 IS SET TO 8.1.
VSSURF	S WAVE VELOCITY OF THE SURFACE LAYER (KM/S). IF LESS THAN OR EQUAL TO 0.0 IS SET TO VPSURF/SQRT(3).
VSSRCE	S WAVE VELOCITY OF THE SOURCE LAYER (KM/S). IF LESS THAN OR EQUAL TO 0.0 IS SET TO VPSRCE/SQRT(3).
PPFCTF	MULTIPLICATION FACTOR FOR ALL PPFCT1 VALUES (SEE UNDER PPFCT1 IN CARD(S) 3). IF LEFT BLANK OR ZERO IS SET TO 1.0
SPFCTF	MULTIPLICATION FACTOR FOR ALL SPFCT1 VALUES. (SEE UNDER SPFCT1 IN CARD(S) 3). IF LEFT BLANK OR ZERO IS SET TO 1.0
IFCT3	IF NON-ZERO, ALL SURFACE REFLECTION COEFFICIENTS (IE PPFCT3 AND SPFCT3) WILL BE SET TO +1.0 INSTEAD OF BEING CALCULATED IN THE PROGRAM.
REGION	IF LEFT BLANK, SEARCH WILL INCLUDE ALL ORIENTATION SPACE. ANY NON-BLANK PUNCH INDICATES THAT A RESTRICTED REGION OF SEARCH IN ORIENTATION SPACE IS REQUESTED - DETAILS ARE GIVEN ON CARD 2A

CARD 2A CARD DEFINING LIMITS OF RESTRICTED REGION OF SEARCH IN ORIENTATION SPACE. (THIS CARD ONLY TO BE INCLUDED IF REGION IN CARD 2 NOT LEFT BLANK).

FORMAT 3(F8.4,8X,F8.4)

PSI1	SMALLEST VALUE OF SLIP ANGLE TO BE INCLUDED IN SEARCHES (DEGREES).
PSIN	LARGEST VALUE OF SLIP ANGLE TO BE INCLUDED IN SEARCHES (DEGREES).
DELTA1	SMALLEST VALUE OF DIP TO BE INCLUDED IN SEARCHES (DEGREES).
DELTAN	LARGEST VALUE OF DIP TO BE INCLUDED IN SEARCHES (DEGREES).
STRIK1	SMALLEST VALUE OF STRIKE TO BE INCLUDED IN SEARCHES (DEGREES).
STRIKN	LARGEST VALUE OF STRIKE TO BE INCLUDED IN SEARCHES (DEGREES).

PSI1, DELTA1 AND STRIK1 ARE CORRECTED DOWNWARDS, AND PSIN, DELTAN AND STRIKN ARE CORRECTED UPWARDS, TO THE NEAREST SEARCH INCREMENT IN ORIENTATION SPACE. IF PSI1, DELTA1 OR STRIK1 IS LESS THAN DINC IT IS SET TO DINC. IF PSIN OR DELTAN IS GREATER THAN 180.0 IT IS SET TO 180. IF STRIKN IS GREATER THAN 360.0 IT IS SET TO 360.0. A REQUIRED SEARCH REGION WHOSE STRIKE SPANS NORTH MUST BE DIVIDED INTO TWO SEARCHES, ONE WITH STRIKE UP TO AND INCLUDING 360.0 AND THE OTHER WITH STRIKE BEGINNING AT DINC. FOR A RESTRICTED REGION SEARCH THE CHOICE OF DINC, AND OF THE SEARCH BOUNDS, MUST BE SUCH THAT THE NUMBER OF SEARCH INCREMENTS **IN EACH ANGLE SEPARATELY** DOES NOT EXCEED THE NUMBER CORRESPONDING TO DINC=5.0 FOR A SEARCH OVER ALL SPACE, WHICH HAS SLIP ANGLE BETWEEN DINC AND 180.0, DIP BETWEEN DINC AND 180.0 AND STRIKE BETWEEN DINC AND 360.0. THIS GIVES A MAXIMUM NUMBER OF SEARCH INCREMENTS OF 36 IN SLIP ANGLE AND DIP, AND 72 IN STRIKE. IF THESE CONDITIONS ARE NOT MET THE REGION OF SEARCH WILL BE REDUCED AS REQUIRED.

CARD(S) 3 NCP CARDS - ONE FOR EACH PHASE PAIR OR INPUT-RESULT. CARDS CAN BE PLACED IN ANY ORDER. IF THE CARD RELATES TO AN INPUT-RESULT, IT MUST BE LEFT BLANK EXCEPT FOR NDEV, THE NUMBER OF THE DEVICE FROM WHICH THE INPUT-RESULT IS TO BE READ, WHICH IS RIGHT-JUSTIFIED IN COLUMNS 79 AND 80. IF DEVICE 5 (NORMALLY THE CARD READER) IS USED TO READ THE INPUT-RESULT, THEN THE CORRESPONDING CARD DECK MUST BE PLACED IMMEDIATELY AFTER THIS INPUT-RESULT CARD. IF THE CARD RELATES TO A NEW PHASE PAIR, IT CONTAINS ITS DETAILS AS FOLLOWS.

FORMAT A8,F5.0,3F5.1,2(A1,2F10.5),2F4.2,A2

STANAM	STATION NAME CODE AND SEISMOGRAPH TYPE IF REQUIRED, (EG 'ESK SPZ ' OR 'WOL LPZ '). THIS IS USED ONLY AS A TITLE, BUT MUST NOT BE LEFT BLANK.
AZI	AZIMUTH OF STATION FROM EARTHQUAKE IN DEGREES (MEASURED POSITIVE CLOCKWISE FROM NORTH). THIS IS CONVERTED TO ITS PRINCIPAL VALUE (BETWEEN 0.0 AND 360.0) AND APPROXIMATED TO THE NEAREST VALUE OF STRIKE IN THE SEARCH MESH.
DIST	EPICENTRAL DISTANCE FROM EARTHQUAKE TO STATION (DEGREES). ONLY USED IF INDANG IS NON-ZERO, TO CALCULATE P AND LITTLE-P TAKEOFF ANGLES FROM TABLES STORED WITHIN THE

PROGRAM.

ALPHA TAKEOFF ANGLE OF P FROM DOWNWARD VERTICAL AT THE SOURCE (DEGREES). THIS IS ONLY READ IN IF INDANG=0. (THIS VALUE (UNLIKE AZI) IS NOT APPROXIMATED TO A SEARCH MESH POINT.) THE P WAVE TAKEOFF ANGLES FOR ALL PHASE PAIRS CAN THEN BE SYSTEMATICALLY ADJUSTED USING ANGPF ON CARD 2.

GAMMA TAKEOFF ANGLE OF LITTLEP-P FROM UPWARD VERTICAL AT THE SOURCE (DEGREES). IF LEFT BLANK IS SET TO THE VALUE OF ALPHA (BEFORE ANY ADJUSTMENT USING ANGPF). THIS IS NORMAL FOR SHALLOW EARTHQUAKES. THE LITTLEP-P TAKEOFF ANGLES FOR ALL PHASE PAIRS CAN THEN BE SYSTEMATICALLY ADJUSTED USING ANGPPF ON CARD 2. NOTE THAT GAMMA REFERS TO THE TAKEOFF ANGLE OF LITTLEP-P **IRRESPECTIVE OF WHICH PHASE PAIR THIS CARD RELATES TO**. THE LITTLES-P TAKEOFF ANGLE (BETA) IS DERIVED FROM THE FINAL VALUE OF GAMMA WHEN REQUIRED, USING THE RATIO OF THE P AND S WAVE VELOCITIES IN THE SOURCE LAYER (VPSRCE/VSSRCE).

SIGNP, PA2IN, PA1IN, SIGNPP, PPA2IN, PPA1IN. IN THE FOLLOWING PHASE 1 REPRESENTS P FOR A P & LITTLEP-P OR A P & LITTLES-P PHASE PAIR, AND LITTLEP-P FOR A LITTLEP-P & LITTLES-P PHASE PAIR. PHASE 2 REPRESENTS LITTLEP-P FOR A P & LITTLEP-P PHASE PAIR AND LITTLES-P FOR A P & LITTLES-P OR A LITTLEP-P & LITTLES-P PHASE PAIR. (LITTLEP-P INCLUDES ITS SEA BED AND SEA SURFACE ANALOGUES AND LITTLES-P INCLUDES ITS SEA BED ANALOGUE).

SIGNP POLARITY OF PHASE 1 AS *OBSERVED* ON SEISMOGRAM. + = POSITIVE (IE UP) AND - = NEGATIVE (IE DOWN). ANY OTHER PUNCH OR BLANK CORRESPONDS TO UNCERTAIN OR UNKNOWN POLARITY AND SO BOTH POLARITIES ARE INCLUDED.

PA2IN, PA1IN. LOWER AND UPPER BOUNDS RESPECTIVELY ON THE POSSIBLE AMPLITUDE OF PHASE 1 AS OBSERVED ON THE SEISMOGRAM, MEASURED IN ARBITRARY UNITS. AMPLITUDES ARE SPECIFIED BY POSITIVE VALUES, THE POLARITY BEING CONTROLLED BY SIGNP.

SIGNPP, PPA2IN, PPA1IN. SAME FOR PHASE 2.

NOTE THAT IF THE AMPLITUDE RANGE OF EITHER PHASE HAS ZERO WIDTH, OR IF THE AMPLITUDE RANGES OF *BOTH* PHASES INCLUDE ZERO, THE PHASE PAIR IS DELETED BY THE PROGRAM. (THE INCLUSION OF ZERO IN BOTH AMPLITUDE RANGES PERMITS ALL POSSIBLE RELATIVE AMPLITUDES, SO THAT ALL SOURCE ORIENTATIONS WOULD BE COMPATIBLE).

PPFCT1 MULTIPLICATION FACTOR APPLIED TO CALCULATED LITTLEP-P AMPLITUDES (IF THIS PHASE PAIR INCLUDES A LITTLEP-P TYPE PHASE) TO REPRESENT ANY LOSS OF LITTLEP-P AMPLITUDE DURING PROPAGATION WITH RESPECT TO THAT OF P, OTHER THAN AT THE SEA BED, SEA SURFACE OR FREE SURFACE (WHOSE REFRACTION AND REFLECTION COEFFICIENTS ARE NORMALLY ALLOWED FOR IN THE PROGRAM). IF LEFT BLANK IS SET TO 1.0.

SPFCT1 MULTIPLICATION FACTOR APPLIED TO CALCULATED LITTLES-P AMPLITUDE (IF THIS PHASE PAIR INCLUDES A LITTLES-P TYPE PHASE) TO REPRESENT ANY LOSS OF AMPLITUDE RELATIVE TO THAT OF P, FOR THE SAME PURPOSE AS PPFCT1 ABOVE. IF LEFT BLANK IS SET TO 1.0.
NOTE THAT PPFCT1 OR SPFCT1 FOR ALL PHASE PAIRS MAY BE SCALED SYSTEMATICALLY BY THE USE OF PPFCTF AND SPFCTF ON CARD 2.

PHASES CODE TO IDENTIFY THE TYPE OF PHASE PAIR TO WHICH THIS CARD RELATES. PUNCH 'PP' FOR A P & LITTLEP-P PHASE PAIR, 'SP' FOR A P & LITTLES-P PHASE PAIR, '**' FOR A LITTLEP-P & LITTLES-P PHASE PAIR. IF THE EARTHQUAKE IS BENEATH THE SEA (ISEA NON-ZERO) THEN REFLECTION AT THE SEA BED IS ASSUMED FOR THE ABOVE CASES. WHERE LITTLEP-P REFLECTED FROM THE SEA SURFACE IS USED, PUNCH 'PE' FOR A P & LITTLEP-P(SSF) PHASE PAIR OR '*E' FOR A LITTLEP-P(SSF) & LITTLES-P PHASE PAIR. ANY OTHER PUNCH OR BLANK IS ASSUMED TO BE A P & LITTLEP-P PHASE PAIR.

FURTHER COMPLETE DATA BLOCKS MAY FOLLOW.

FOR NORMAL TERMINATION OF THE PROGRAM THE LAST DATA BLOCK MUST BE FOLLOWED BY ONE BLANK CARD.

```
0DOUBLE PRECISION SINTAB(360),COSTAB(360),TITLE(10),TITLEI(5),
1D90,DPI1,DINC,PPFCTF,DPINC,AZI,ALPHA,PA1,PA2,PPA1,PPA2,
2AZ,PAQ,RATMX1,RATMN1,SINAL,COSAL,RAT1,RAT2,RAT3,RAT4,QSMALL,
3SMALL,SPSD,SPCD,CPSD,CPCD,SESA,CESA,PSIN,DELTAN,DINCIN,
4 P11, P12, P21, P2223, P31, P3233,P1,P2,P3,PP1,PP2,PP3,AP,APP,
5ARAT,STARS(12),ULINE(10),FTRUE,S,FNCOMB,FNTRUE,STATON,STANAM,
6HOL1,HOL3,HOL4,HOL6,ANCIS,POSTIV,NEGTIV,BLANK8,HOLA,HOLB,
7PA1IN,PA2IN,PPA1IN,PPA2IN,RATMX2,RATMN2,PPFCT1,SPFCTF,ULINES(10)

 REAL*4 HOL2,HOL5,OR,BLANK4,PLUS,MINUS

0DOUBLE PRECISION BETA,SINBE,COSBE,PLITPP,PLITSP,SPFCT1,SPFCT2,
1SPFCT3,SPFCT,ROOT3,SPA1,SPA2,BETA1,
2SINPSI,COSPSI,SASP,SACP,CASP,CACP,SBSP,SBCP,CBSP,CBCP,
3SINDEL,COSDEL,CACD,SASD,SASPCD,SACPCD,CASPSD,CACPSD,SBSD,SBCD,
4CBSD,CBCD,SBSPCD,SBCPSD,SBCPCD,CBSPSD,CBCPSD,CBCPCD,
5SINETA,COSETA,SPM1,SPM2,SPM3,THETA,PHI,SINPHI,COSPHI,ASPTHE,
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6ASPPHI,SESI,SECI,CESI,CECI,SPANG1,SPANG2,ASP,SBSPSD,CBSPCD,SEST,
7CEST,SINTHE,LPPLSP,PFCT

0DOUBLE PRECISION PPFCT2,GAMMA,GAMMA1,SINGA,COSGA,PP11,PP21,PP31,
1PP12,PP2223,PP3233,SESG,CESG,VSEA,VPSURF,VPSRCE,VRAT1,VRAT2,CSEA,
2DSURF,DRAT1,PLPPE,LPPELS,PPFCT,PSI1,DELTA1,STRIK1,STRIKN,
3PN,DN,SN,VSSURF,VSSRCE,RSURF,RSRCE,PSURF,PSRCE,RSRS,FFACT1,FFACT,
4FREAL,SREAL,DEPTH,DIST

0REAL*8 TCARD(3), TCARDD(10),TITLED(10),DINCD,PSI1D,PSIND,DELT1D,
1DELTND,STRK1D,STRKND,PPFCFD,SPFCFD,VPSRFD,DSURFD,VPSRCD,VSSRFD,
2VSSRCD,DEPTHD,RSURFD,PSURFD,RSRCED,PSRCED,DUMMY,TITLEJ(5),ANGPFD,
3ANPPFD

 REAL*8 COEF(7,14),COEF01(7),COEF02(7),COEF03(7),COEF04(7),
1COEF05(7),COEF06(7),COEF07(7),COEF08(7),COEF09(7),COEF10(7),
2COEF11(7),COEF12(7),COEF13(7),COEF14(7),CEP(14),VP0,DISTMN,DISTMX,
3ANGPF,ANGFPF,DISTR,A1,A2

 REAL*8 VDATE,PDATE,RTIME

 REAL*4 PHASES,PP,SP,STRSTR,PE,STRE,F1R,VVLR(36),REGION,TITLEF(6)

 DIMENSION III(10),JJJ(10),KKK(10)

 EQUIVALENCE (TITLEI(1),STATON),(TITLEI(2),STANAM)
 EQUIVALENCE (TITLEJ(1),TITLEF(1))

0EQUIVALENCE                   (ISGNPP,ISGNSP),(SIGNPP,SIGNSP),
1(PPA1,SPA1),(PPA2,SPA2),(NODEPP,NODESP)

 LOGICAL*1 F(36,36,72),F1,VVL(4,36)

 EQUIVALENCE (F1,F1R),(VVL(1,1),VVLR(1))

 DIMENSION NTRUES(35)

 REAL*4 TENS,UNITS,ENC,ENDD,REGND
 REAL*4 DIGIT(10),TITLEH(5,5)

 LOGICAL*1 NDEVL(4),TENSL,UNITSL,BLANK1

 DIMENSION IIID(5),JJJD(5),KKKD(5),IVLNC(5),IVLN(8)

 EQUIVALENCE (PHASES,NDEVL(1)),(TENS,TENSL),(UNITS,UNITSL)

0EQUIVALENCE (COEF(1, 1),COEF01(1)),(COEF(1, 2),COEF02(1)),
1            (COEF(1, 3),COEF03(1)),(COEF(1, 4),COEF04(1)),
2            (COEF(1, 5),COEF05(1)),(COEF(1, 6),COEF06(1)),
3            (COEF(1, 7),COEF07(1)),(COEF(1, 8),COEF08(1)),
4            (COEF(1, 9),COEF09(1)),(COEF(1,10),COEF10(1)),
5            (COEF(1,11),COEF11(1)),(COEF(1,12),COEF12(1)),
6            (COEF(1,13),COEF13(1)),(COEF(1,14),COEF14(1))

 DIMENSION REQUIREMENTS
 ----------------------

          SINTAB(360),COSTAB(360),F(NDIM*2,NDIM*2,NDIM*4),
 WHERE NDIM = MAX(D90/DINC)  I.E. NDIM IS THE MAXIMUM POSSIBLE
 NUMBER OF INCREMENTS IN 90.0 DEGREE BAND EXCLUSIVE OF LOWER LIMIT.
 WHEN A RESTRICTED SEARCH REGION IS REQUESTED, THE DIMENSIONS OF F
 FIX THE MAXIMUM NUMBERS OF SEARCH INCREMENTS IN EACH DIMENSION
 (SLIP ANGLE, DIP AND STRIKE RESPECTIVELY).
          VVL(NDIMV,4),VVLR(NDIMV),NTRUES(NDIMV-1), WHERE NDIMV IS
 MAXIMUM VALUE OF NVL, PLUS ONE

 DATA NDIM/18/,SMALL/1.0D-14/,QSMALL/-1.0D-14/,NDIMV/36/
 DATA STATON/8HSTATION /
0DATA STARS/12*8H********/,ULINE/10*8H--------/,
1ULINES/10*8H========/
0DATA ANDIS/8H AND IS /,POSTIV/8HPOSITIVE/,NEGTIV/8HNEGATIVE/,
1OR/4H OR /,BLANK8/8H        /,BLANK4/4H    /,BLANK1/1H /
 DATA PLUS/4H+   /,MINUS/4H-   /

 DATA PP/4HPP  /,SP/4HSP  /,STRSTR/4H** /,PE/4HPE  /,STRE/4H*E  /

0DATA PLITPP/  Z4040D76897D74040/,PLITSP/  Z40400768A2D74040/,
1LPPLSP/  Z404097D768A2D740/,PLPPE/  ZD76897D7A2A29640/,
2LPPELS/  Z57D7A2A2896BA2D7/

 SUMMARY OF PHASE CODES
 ----------------------

 PHASE PAIR            P &      P &    LITP-P   P &        LITP-P
                       LITP-P   LITS-P (SEA BED LITP-P     (SEA SUR-
                       (SEA BED        IF UNDER (SEA SUR-  FACE IF
                       IF UNDER        SEA) &   FACE IF    UNDERSEA)
                       SEA)            LITS-P   UNDERSEA)  & LITS-P

 INPUT HOLLERITH       PP       SP     STRSTR   PE         STRE
 PLOTTING HOLLERITH    PLITPP   PLITSP LPPLSP   PLPPE      LPPELS
 VALUE OF INCP         1        2      3        4          5

 DATA F1R/4H    /
0DATA VVLR/ Z00404040,4H1   ,4H2   ,4H3   ,4H4   ,4H5   ,4H6   ,
14H7   ,4H8   ,4H9   ,4HA   ,4HB   ,4HC   ,4HD   ,4HE   ,4HF   ,
24HG   ,4HH   ,4HI   ,4HJ   ,4HK   ,4HL   ,4HM   ,4HN   ,4HO   ,
34HP   ,4HQ   ,4HR   ,4HS   ,4HT   ,4HU   ,4HV   ,4HW   ,4HX   ,
44HY   ,4HZ   /

0DATA DIGIT/4H0   ,4H1   ,4H2   ,4H3   ,4H4   ,4H5   ,4H6   ,
14H7   ,4H8   ,4H9   /
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      0DATA TITLEI/4H P   ,4H    ,4H    ,4H LIT,4HP-P ,
      1            4H P   ,4H    ,4H    ,4H LIT,4HS-P ,
      2            4H LIT,4HP-P ,4H    ,4H LIT,4HS-P ,
      3            4H P   ,4H    ,4HLITP,4H-P(S,4HSF) ,
      4            4H LIT,4HP-P(,4HSSF),4H LIT,4HS-P /
       DATA TCARD/8HFALT - S,8HTANDARD ,8HOUTPUT  /
       DATA END/4HEND /
       DATA TITLEF/4HINPU,4HT-RE,4HSULT,4H,DEV,4HICE ,4H    /
C
            DATA COEF01/  114.333400741, -774.634050709, 2133.255615952,
      1 -3039.372379017, 2348.892553647, -947.049765704,  194.185654022/
            DATA COEF02/   83.175496198, -567.867113917, 1581.097667831,
      1 -2283.242954442, 1791.680028642, -738.814848489,  163.723315779/
            DATA COEF03/   57.769408806, -400.270320049, 1134.812188994,
      1 -1570.706413385, 1335.899795499, -565.780708808,  139.078304124/
            DATA COEF04/   53.159096744, -363.057462708, 1016.478230158,
      1 -1480.889097561, 1174.694056367, -458.471828878,  129.896783304/
            DATA COEF05/   46.717137895, -321.147746728,  907.156935364,
      1 -1334.573561786, 1066.782466493, -460.081157557,  126.097047917/
            DATA COEF06/   51.992933483, -350.062225721,  967.285803113,
      1 -1391.753162567, 1050.959892218, -461.552579773,  127.220168635/
            DATA COEF07/   56.775055138, -378.159412397, 1031.079128273,
      1 -1459.955401384, 1123.733348088, -466.998315637,  128.874787678/
            DATA COEF08/   67.579423940, -447.552257854, 1206.151603194,
      1 -1677.655234801, 1259.565275810, -505.860094053,  134.408077722/
            DATA COEF09/   88.343649709, -585.094639974, 1570.971874105,
      1 -2170.356511977, 1615.465700657, -638.858341983,  158.886240926/
            DATA COEF10/   95.267927177, -625.541669240, 1662.628116165,
      1 -2299.859625019, 1667.289350018, -652.539913277,  164.454515825/
            DATA COEF11/   75.980981103, -494.569576279, 1304.301030570,
      1 -1766.972886552, 1289.346007695, -513.146411454,  148.851405402/
            DATA COEF12/   68.415328883, -441.960135453, 1155.795847821,
      1 -1549.917368613, 1118.742122191, -448.770012873,  143.235173081/
            DATA COEF13/   67.639910983, -429.068555158, 1098.133623800,
      1 -1435.704571418, 1007.981398099, -400.721117374,  138.845557863/
            DATA COEF14/   49.009040666, -318.062460720,  839.868132317,
      1 -1140.623592952,  840.107839931, -360.672478252,  138.619892851/
C
      0DATA DEP/  0.0 , 33.00, 96.38,159.76,223.14,286.52,349.90,
      1         413.26,476.66,540.04,603.42,666.80,730.18,793.56/
       DATA VP0/8.1D0/,DISTMN/20.D0/,DISTMX/100.D0/,NDEG/6/
C
       COMMON /LIBDAY/ VDATE
       COMMON/P/PI1
C
       PI1=ATAN(1.0)/45.0
       DPI1=DATAN(1.D0)/45.D0
C
       I90=90
       D90=I90
       TITLEI(3)=ULINE(1)
       TITLEI(5)=ULINE(1)
       SPFCT2=5.2D0
       ROOT3=DSQRT(3.D0)
       VSHA=1.5D0
       DSHA=1.D0
       REGION=BLANK4
       IS12=0
       IEN2=0
       FFACT1=16.D0*D90*D90/DPI1
       PHASES=BLANK4
       TENS=BLANK4
       TENSL=BLANK1
       UNITS=BLANK4
       UNITSL=BLANK1
       NDEVL(1)=BLANK1
       REGND=BLANK4
C
       CALL DATIM(RDATE,RTIME)
C
C      ..........           DO FOR EACH EARTHQUAKE DATA BLOCK   ..........
C
 1111  READ(5,1) TITLE
 1     FORMAT(10A8)
       DO 9 I=1,8
       IF(TITLE(I).NE.BLANK8) GO TO 1000
 9     CONTINUE
       GO TO 9999
C
 1000  WRITE(6,2) STARS,VDATE,RDATE,STARS,RTIME,TITLE,ULINE
 2    0FORMAT(1H1,12A8,5X,16HPROGRAM UPDATED ,A8/1X,
      196H* FOCAL MECHANISMS GIVEN  P, LITTLEP-P & LITTLES-P RELATIVE AMP
      2LITUDES AT A SERIES OF STATIONS *,5X,12HDATE OF RUN ,A8/
      31X,12A8,5X,12HTIME OF RUN ,A8//9X,10A8/9X,10A8)
      0READ(5,3) NCP,DINCIN,DEPTH,ANGPF,ANGPPF,INDANG,IPRNT1,IPRNT2,
      1IPRNT3,IPRNT4,IPRNT5,IPLOT1,IPLOT2,IPLOT3,IPLOT4,IPLOT5,IDEV3,
      2NVL,NDEV3,ISEA,VPSURF,DSURF,VPSRCE,VSSURF,VSSRCE,PPFCTF,SPFCTF,
      3IFCT3,REGION
 3     FORMAT(I5,F5.0,F5.1,2F4.2,I2,10I1,I2,I3,I3,I2,5F5.2,2F4.2,I1,A1)
       IF(NDEV3.LE.0) NDEV3=7
       IF(IDEV3.GT.0) WRITE(NDEV3,35) TCARD,VDATE,RDATE,RTIME,TITLE
 35   0FORMAT(3A8,16HPROGRAM UPDATED ,A8,12H AND RUN ON ,A8,4H AT ,A8/
      110A8)
C
C      PROTECTION ETC.
C
       I=3
       DINC=D90/DFLOAT(I)
       NINC=I
       IF(DINCIN.LE.0.D0.OR.DINCIN.GT.90.D0) GO TO 10
       DINC=D90
       DO 8 I=1,I90
```

```
      IF(MOD(I90,I).NE.0) GO TO 8
      IF(DABS(DINCIN-D90/DFLOAT(I)).GT.DABS(DINCIN-DINC)) GO TO 8
      DINC=D90/DFLOAT(I)
      NINC=I
 8    CONTINUE
C
 10   NP=NINC*2
      ND=NINC*2
      NS=NINC*4
      NTABLE=NINC*4
      NCOMB=NP*ND*NS
      FNCOMB=NCOMB
      FFACT=DINC*DINC*DINC/FFACT1
C
      PN=DFLOAT(NP)*DINC
      DN=DFLOAT(ND)*DINC
      SN=DFLOAT(NS)*DINC
C
      PSI1=DINC
      DELTA1=DINC
      STRIK1=DINC
      PSIN=PN
      DELTAN=DN
      STRIKN=SN
C
      IF(PPFCTF.EQ.0.D0) PPFCTF=1.D0
      IF(SPFCTF.EQ.0.D0) SPFCTF=1.D0
      IF(VPSURF.LE.0.D0) VPSURF=4.D0
      IF(VPSRCE.LE.0.D0) VPSRCE=8.1D0
      VRAT1=VSEA/VPSURF
      VRAT2=VPSURF/VPSRCE
      IF(DSURF.LE.0.D0) DSURF=2.3D0
      DRAT1=DSEA/DSURF
      IF(VSSURF.LE.0.D0) VSSURF=VPSURF/ROOT3
      IF(VSSRCE.LE.0.D0) VSSRCE=VPSRCE/ROOT3
      RSURF=VPSURF/VSSURF
      RSPS=RSURF*RSURF
      RSRCE=VPSRCE/VSSRCE
     OPSURF=(VPSURF*VPSURF-2.D0*VSSURF*VSSURF)/(2.D0*(VPSURF*VPSURF-
     1VSSURF*VSSURF))
     OPSRCE=(VPSRCE*VPSRCE-2.D0*VSSRCE*VSSRCE)/(2.D0*(VPSRCE*VPSRCE-
     1VSSRCE*VSSRCE))
      IF(NVL.GT.NDIMV-1) NVL=NDIMV-1
      IF(NVL.LE.0) NVL=1
      NVLP1=NVL+1
      IF(ANGPF.EQ.0.D0) ANGPF=1.D0
      IF(ANGPPF.EQ.0.D0) ANGPPF=1.D0
C
      IF(DEPTH.LT.DEP(1)) DEPTH=DEP(1)
      IF(DEPTH.GT.DEP(14)) DEPTH=DEP(14)
      DO 31 IDEP=2,14
      IF(DEP(IDEP).GT.DEPTH) GO TO 32
 31   CONTINUE
      IDEP=14
 32   IDEPM1=IDEP-1
C
     0IF(REGION.NE.BLANK4)
     1READ(5,4) PSI1,PSIN,DELTA1,DELTAN,STRIK1,STRIKN
 4    FORMAT(3(F8.4,3X,F8.4))
C
      IF(PSI1.LE.PSIN) GO TO 5
      PAG=PSI1
      PSI1=PSIN
      PSIN=PAG
 5    IF(DELTA1.LE.DELTAN) GO TO 6
      PAG=DELTA1
      DELTA1=DELTAN
      DELTAN=PAG
 6    IF(STRIK1.LE.STRIKN) GO TO 7
      PAG=STRIK1
      STRIK1=STRIKN
      STRIKN=PAG
C
 7    IF(PSI1.LT.DINC) PSI1=DINC
      IF(DELTA1.LT.DINC) DELTA1=DINC
      IF(STRIK1.LT.DINC) STRIK1=DINC
      IF(PSI1.GT.PN) PSI1=PN
      IF(DELTA1.GT.DN) DELTA1=DN
      IF(STRIK1.GT.SN) STRIK1=SN
      IF(PSIN.LT.DINC) PSIN=DINC
      IF(DELTAN.LT.DINC) DELTAN=DINC
      IF(STRIKN.LT.DINC) STRIKN=DINC
      IF(PSIN.GT.PN) PSIN=PN
      IF(DELTAN.GT.DN) DELTAN=DN
      IF(STRIKN.GT.SN) STRIKN=SN
C
      IP1=PSI1/DINC
      ID1=DELTA1/DINC
      IS1=STRIK1/DINC
      IP1M1=IP1-1
      ID1M1=ID1-1
      IS1M1=IS1-1
      IPN=(PN-PSIN)/DINC
      IPN=NP-IPN
      IDN=(DN-DELTAN)/DINC
      IDN=ND-IDN
      ISN=(SN-STRIKN)/DINC
      ISN=NS-ISN
      IF((IPN-IP1M1).GT.NDIM*2) IPN=IP1M1+NDIM*2
      IF((IDN-ID1M1).GT.NDIM*2) IDN=ID1M1+NDIM*2
      IF((ISN-IS1M1).GT.NDIM*4) ISN=IS1M1+NDIM*4
     NPR=IPN-IP1M1
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```
      NCR=ICN-IC1+1
      NSR=ISN-IS1+1
      NCOMBR=NPR*NCR*NSR
C
      PSI1=DFLOAT(IP1)*DINC
      DELTA1=DFLOAT(IC1)*DINC
      STRIK1=DFLOAT(IS1)*DINC
      PSIN=DFLOAT(IPN)*DINC
      DELTAN=DFLOAT(ICN)*DINC
      STRIKN=DFLOAT(ISN)*DINC
C
C
      IF(REGICN.NE.BLANK4) GC TO 11
      IS1=IS1
      ISN=ISN
 11  OWRITE(6,12)  NOP,DINCIN,DINC,NINC,PSI1,PSIN,DINC,DELTA1,DELTAN,
     1DINC,STRIK1,STRIKN,DINC
 12  OFORMAT(/
     120X,48HNUMBER OF PHASE PAIR/INPUT-RESULT CARDS           ,I4//
     220X,48HANGLE INCREMENT FOR SEARCH (AS INPUT)             ,F10.5,
     38H  DEG.  /
     420X,48HANGLE INCREMENT FOR SEARCH (CORRECTED)            ,F10.5,
     58H  DEG.  /
     620X,48HNUMBER OF ANGLE INCREMENTS IN 90.0 DEGREES        ,I4/
     720X,20HSLIP ANGLE GOES FROM,F6.1,3H TC,F6.1,17H IN INCREMENTS OF,
     8F6.1,8H  DEG.  /
     920X,20HDIP        GOES FROM,F6.1,3H TC,F6.1,17H IN INCREMENTS OF,
     AF6.1,8H  DEG.  /
     B20X,20HSTRIKE     GOES FROM,F6.1,3H TC,F6.1,17H IN INCREMENTS OF,
     CF6.1,8H  DEG.  )
C
      IF(REGICN.EQ.BLANK4) WRITE(6,13)
 13  OFORMAT(
     120X,39H(THESE LIMITS INCLUDE ALL ORIENTATIONS))
      IF(REGICN.NE.BLANK4) WRITE(6,14)
 14  OFORMAT(
     120X,69H***A RESTRICTED REGION OF SEARCH IN ORIENTATION SPACE IS RE
     2QUESTED***/
     320X,49H(THE LIMITS OF THE SEARCH REGICN ARE SHOWN ABOVE))
C
     OWRITE(6,15) PPFCTF,SPFCTF,BLANK1,IPRNT1,IPRNT2,IPRNT3,IPRNT4,
     1IPRNT5,IPLOT1,IPLOT2,IPLOT3,IPLOT4,IPLOT5,NVL,NDEV3,IDEV3
 15  OFORMAT(/
     120X,48HPPFCTF...SCALING FACTOR FOR PPFCT1 TO BE APPLIED/
     220X,48HTO ALL LITTLEP-P PHASES                          ,F7.2//
     320X,48HSPFCTF...SCALING FACTOR FOR SPFCT1 TO BE APPLIED/
     420X,48HTO ALL LITTLES-P PHASES                          ,F7.2,A1//
     520X,17HIPRNT1,2,3,4,5 = ,I1,4(1H,,I1),
     65X, 17HIPLOT1,2,3,4,5 = ,I1,4(1H,,I1)/
     720X,33HNUMBER OF VECTOR LENGTHS (NVL) = ,I3/
     820X,27HTHIRD OUTPUT DEVICE (IF USED) IS NO. ,I2,5X,8HIDEV3 = ,I2)
C
      WRITE(6,16) VPSURF,VSSURF,RSURF,PSURF,VPSRCE,VSSRCE,RSRCE,PSRCE
 16  OFORMAT(/
     118X,50H* P WAVE VELOCITY OF (SOLID) SURFACE LAYER         ,F7.2,
     28H  KM/SEC/
     318X,50H* S WAVE VELOCITY OF (SOLID) SURFACE LAYER         ,F7.2,
     48H  KM/SEC/
     520X,48HCORRESPONDING P TO S VELOCITY RATIO             ,F7.2/
     620X,48HCORRESPONDING POISSON'S RATIO                   ,F7.2//
     718X,50H* P WAVE VELOCITY OF SOURCE LAYER                  ,F7.2,
     88H  KM/SEC/
     918X,50H* S WAVE VELOCITY OF SOURCE LAYER                  ,F7.2,
     A8H  KM/SEC/
     B20X,48HCORRESPONDING P TO S VELOCITY RATIO             ,F7.2/
     C20X,48HCORRESPONDING POISSON'S RATIO                   ,F7.2)
C
      IF(INDANG.EQ.0) WRITE(6,17) INDANG
 17  OFORMAT(/
     120X,8HINDANG =,I2,38H - P AND LITTLEP-P TAKEOFF ANGLES WILL/
     220X,48HBE READ IN DIRECTLY FOR EACH PHASE PAIR (DEPTH  /
     320X,48HAND DISTANCE WILL NOT BE USED)                  )
C
      IF(INDANG.NE.0) WRITE(6,18) INDANG,DEPTH
 18  OFORMAT(/
     120X,8HINDANG =,I2,38H - P TAKEOFF ANGLES WILL BE CALCULATED/
     220X,48HFROM INTERNAL TABLES USING DEPTH AND DISTANCE   /
     320X,48HUNLESS DISTANCE IS OUT OF RANGE                 /
     420X,48HDEPTH OF EARTHQUAKE                             /F6.1,
     58H  KM     )
C
      IF(INDANG.NE.0.AND.DEPTH.EQ.0.00) WRITE(6,19)
 19  OFORMAT(
     120X,48HDEPTH IS ZERO - UNLESS DISTANCE IS OUT OF RANGE /
     220X,48HP TAKEOFF ANGLES AT DEPTH = 33 KM ARE READ FROM /
     320X,48HTABLES AND WILL BE CORRECTED FOR SOURCE LAYER   /
     420X,48HVELOCITY (VPSRCE) ASSUMING A SUB-MOHO VELOCITY  /
     520X,48HOF 8.1 KM/SEC                                   )
C
      IF(ISEA.EQ.0) WRITE(6,20)
 20  OFORMAT(/
     120X,48HSOURCE IS NOT BENEATH THE SEA                   )
C
      IF(ISEA.NE.0) WRITE(6,21) VSEA,DSEA,DSURF
 21  OFORMAT(/
     120X,48HSOURCE IS BENEATH THE SEA                       /
     218X,50H* ASSUMED P WAVE VELOCITY OF SEA LAYER             ,F10.5,
     38H  KM/SEC/
     418X,50H* ASSUMED DENSITY OF SEA LAYER                     ,F10.5,
     58H  GM/CC /
     618X,50H* DENSITY OF (SOLID) SURFACE LAYER                 ,F10.5,
     78H  GM/CC )
```

```
C
       IF(ANGPF.EQ.1.D0.AND.ANGPPF.EQ.1.D0) WRITE(6,22)
   22 0FORMAT(/
     120X,54HTAKEOFF ANGLES ARE NOT PERTURBED USING ANGPF OR ANGPPF)
C
       IF(ANGPF.NE.1.D0.OR.ANGPPF.NE.1.D0) WRITE(6,23) ANGPF,ANGPPF
   23 0FORMAT(/
     120X,48HALL P TAKEOFF ANGLES AND/OR ALL LITTLEP-P         /
     220X,48HTAKEOFF ANGLES WILL BE PERTURBED USING ANGPF AND/
     320X,29HANGPPF RESPECTIVELY (ANGPF = ,
     4F4.2,14H AND ANGPPF = ,F4.2,2H)./
     520X,48HTHE PRINTED TAKEOFF ANGLE VALUES INCLUDE THE      /
     620X,48HEFFECT OF THIS PERTURBATION                       )
C
C
       IF(IFCT3.NE.0) WRITE(6,24)
   24 0FORMAT(/
     120X,48H***WARNING***    ALL SURFACE REFLECTION           /
     220X,48HCOEFFICIENTS (PPFCT3 AND SPFCT3) SET TO +1.0.     /
     320X,48HTHEY MAY INSTEAD BE INCORPORATED INTO PPFCT1 AND/
     420X,48HSPFCT1 (OR PPFCTF AND SPFCTF) IF REQUIRED         )
       WRITE(6,25)
   25 0FORMAT(//
     118X,50H* USED ONLY FOR CALCULATING EMERGENT ANGLES AND    /
     220X,48HREFLECTION & REFRACTION COEFFICIENTS AT SEA BED /
     320X,48HAND/OR FREE SURFACE AS REQUIRED                   )
C
       IF(IDEV3.LE.0) GO TO 28
C
       WRITE(NDEV3,26) NVL,DINC,PSI1,PSIN,DELTA1,DELTAN,STRIK1,STRIKN
   26 0FORMAT(32HNUMBER OF VECTOR LENGTHS (NVL) = ,I3,35H,  SEARCH ANGLE
     1INCREMENT (DINC) = ,F4.1,5H DEG./16HSLIP ANGLE FROM ,F4.0,4H TO ,
     2F4.0,12H,  DIP FROM ,F4.0,4H TO ,F4.0,16H,   STRIKE FROM ,F4.0,
     34H TO ,F4.0)
     0WRITE(NDEV3,3) NOP,DINC,DEPTH,ANGPF,ANGPPF,INDANG,IPRNT1,IPRNT2,
     1IPRNT3,IPRNT4,IPRNT5,IPLOT1,IPLOT2,IPLOT3,IPLOT4,IPLOT5,IDEV3,
     2NVL,NDEV3,ISEA,VPSURF,DSURF,VPSRCE,VSSURF,VSSRCE,PPFCTF,SPFCTF,
     3IFCT3,REGION
     0IF(REGION.NE.BLANK4) WRITE(NDEV3,4) PSI1,PSIN,DELTA1,DELTAN,
     1STRIK1,STRIKN
       WRITE(NDEV3,27) NCOMBR,NCOMB
   27 0FORMAT(31HNO. OF ORIENTATIONS IN SEARCH =,I6,35H, TOTAL NO. OF ORT
     1NS. (ALL SPACE) =,I8)
C
   28  DO 30 I=1,NPR
       DO 30 J=1,NDR
       DO 30 K=1,NSR
       F(I,J,K)=VVL(1,NVLP1)
   30  CONTINUE
C
C      ASSIGN SINGLE PRECISION VARIABLES FOR PLOTV
C
       SPINC=DINC
       SDINC=DINC
       SSINC=DINC
       SPSI1=PSI1
       SDELT1=DELTA1
       SSTRK1=STRIK1
       SPSIN=PSIN
       SDELTN=DELTAN
       SSTRKN=STRIKN
C
C      GENERATE SINE AND COSINE TABLES
C
       DPINC=DINC*DPI1
       SINTAB(1)=DSIN(DPINC)
       COSTAB(1)=DCOS(DPINC)
       DO 40 I=2,NTABLE
       SINTAB(I)=SINTAB(I-1)*COSTAB(1)+COSTAB(I-1)*SINTAB(1)
       COSTAB(I)=COSTAB(I-1)*COSTAB(1)-SINTAB(I-1)*SINTAB(1)
   40  CONTINUE
C
       IOBS=0
C
C      ----------            DO FOR EACH PHASE PAIR CARD/INPUT-RESULT CARD
C
       DO 800 IOP=1,NOP
     0READ(5,51) STANAM,AZI,DIST,ALPHA,GAMMA,SIGNP,PAZIN,PAIIN,SIGNPF,
     1PPAZIN,PPAIIN,PPFCT1,SPFCT1,PHASES
   51  FORMAT(A8,F5.0,3F5.1,2(A1,2F10.5),2F4.2,A2)
C
       IF(STANAM.NE.BLANK8) GO TO 90
C
C      IIIIIIIIII            PROCESS INPUT-RESULT                   IIIIIIIIII
C
       WRITE(6,101) ULINE(1),IOP,NOP,ULINE,ULINE(1)
  101  FORMAT(1H1,A8,9HCARD NO. ,I3,4H OF ,I3,10A8,14H(INPUT-RESULT),A8)
C
C      SET NDEV FROM PHASES
C
       TENSL=NDEVL(1)
       UNITSL=NDEVL(2)
       I=1
       IF(TENS.EQ.BLANK4) GO TO 112
       DO 111 I=1,10
       IF(TENS.EQ.DIGIT(I)) GO TO 112
  111  CONTINUE
       GO TO 114
  112  DO 113 NDEV=1,10
       IF(UNITS.EQ.DIGIT(NDEV)) GO TO 116
  113  CONTINUE
C
```

```
 114  WRITE(6,115) PHASES
 115 OFORMAT(//20X,50HINPUT-RESULT DELETED - SPECIFIED DEVICE NUMBER IS
     1,A2,24H WHICH IS NOT AN INTEGER)
      GO TO 595
C
 116  NDEV=(I-1)*10+NDEV-1
      TITLEF(6)=PHASES
C
C     READ DATA IN
C
     OREAD(NDEV,121) TCARDD,TITLED,NVLD,DINCD,PSI1D,PSINC,DELT1D,DELTNC,
     1STRK1D,STRKND
 121 OFORMAT(10A8/10A8/33X,I2,35X,F4.1/16X,F4.0,4X,F4.0,12X,F4.0,4X,F4.0
     1,16X,F4.0,4X,F4.0)
C
C     PROTECTION ETC.
C
      DO 122 I=1,10
      IF(TCARDD(I).NE.TCARD(I)) GO TO 125
 122  CONTINUE
C
      IF(NVLD.NE.NVL) GO TO 125
      IF(DINCD.NE.DINC) GO TO 125
      IF(PSI1D.NE.PSI1) GO TO 125
      IF(PSIND.NE.PSIN) GO TO 125
      IF(DELT1D.NE.DELTA1) GO TO 125
      IF(DELTND.NE.DELTAN) GO TO 125
      IF(STRK1D.NE.STRIK1) GO TO 125
      IF(STRKND.NE.STRIKN) GO TO 125
      GO TO 130
C
 125  WRITE(6,126)
 126 OFORMAT(//20X
     1'INPUT-RESULT DELETED - EITHER INPUT-RESULT BEGINS WITH INCORRECT
     2HEADER CARD, OR SEARCH ANGLE INCREMENT'/20X,'OR SEARCH REGION OR N
     2UMBER OF VECTOR LENGTHS IS DIFFERENT FROM THAT OF THE CURRENT DATA
     3BLOCK'/)
 127  READ(NDEV,128) ENDD
 128  FORMAT(A4)
      IF(ENDD.NE.END) GO TO 127
      WRITE(6,129) NDEV
 129 OFORMAT(/20X,'DEVICE ',I2,' HAS BEEN WOUND ON TO END OF THIS INPUT-
     1RESULT')
      GO TO 595
C
 130  TITLEJ(4)=TITLED(9)
      TITLEJ(5)=TITLED(10)
     OREAD(NDEV,3) IDUMMY,IDUMMY,DEPTHD,ANGPFD,ANPPFD,INONGD,IDUMMY,
     1IDUMMY,IDUMMY,IDUMMY,IDUMMY,IDUMMY,IDUMMY,IDUMMY,IDUMMY,IDUMMY,
     2IDUMMY,IDUMMY,IDUMMY,ISEAD,VPSRFD,DSURFD,VPSRCD,VSSRFD,VSSRCD,
     3PPFCFD,SPFCFD,IFCT3D,REGND
     OIF(REGND.NE.BLANK4)
     1READ(NDEV,4)
      READ(NDEV,27)
      WRITE(6,131) (ULINES(I),I=1,2),TCARDD,TITLED,(ULINE(I),I=1,10)
 131 OFORMAT(/20X,23HSUMMARY OF INPUT-RESULT/20X,2A8,7H=======//20X,10A8
     1//20X,10A8/20X,10A8//20X,83HSEARCH INCREMENT, SEARCH REGION AND NO
     2. OF VECTOR LENGTHS AS FOR PRESENT DATA BLOCK)
      WRITE(6,15) PPFCFD,SPFCFD
      RSURFD=VPSRFD/VSSRFD
      RSRCFD=VPSRCD/VSSRCD
     OPSURFD=(VPSRFD*VPSRFD-2.D0*VSSRFD*VSSRFD)/(2.D0*(VPSRFD*VPSRFD-
     1VSSRFD*VSSRFD))
     OPSRCFD=(VPSRCD*VPSRCD-2.D0*VSSRCD*VSSRCD)/(2.D0*(VPSRCD*VPSRCD-
     1VSSRCD*VSSRCD))
     OWRITE(6,16) VPSRFD,VSSRFD,RSURFD,PSURFD,VPSRCD,VSSRCD,RSRCFD,
     1PSRCFD
      IF(INONGD.EQ.0) WRITE(6,17) INONGD
      IF(INONGD.NE.0) WRITE(6,18) INONGD,DEPTHD
      IF(INONGD.NE.0.AND.DEPTHD.EQ.0.D0) WRITE(6,19)
      IF(ISEAD.EQ.0) WRITE(6,20)
      IF(ISEAD.NE.0) WRITE(6,21) VSEA,DSEA,DSURFD
      IF(ANGPFD.EQ.1.D0.AND.ANPPFD.EQ.1.D0) WRITE(6,22)
      IF(ANGPFD.NE.1.D0.OR.ANPPFD.NE.1.D0) WRITE(6,23) ANGPFD,ANPPFD
      IF(IFCT3D.NE.0) WRITE(6,24)
      WRITE(6,25)
C
C     READ IN AND PRINT SUMMARY OF CONSTITUENT PHASE PAIRS
C
      WRITE(6,132) (ULINES(I),I=1,4)
 132 OFORMAT(1H1,14X,34HSUMMARY OF CONSTITUENT PHASE PAIRS/
     115X,4A8,2H==//
     2'  SN        A     D    TAO   TAL PP    FP          PM       PP    PM          P
     3M       PF   SF  PHASE  1     PHASE 2          S U M M A R Y    C F         '/
     4'  TA                  I    ANF   ANI HC    HI          HA       HC    HI          H
     5A       PA   PA                                    R E S U L T S              '/
     6'  AM              I    S    KC    KGT AL    AN          AX       AL    AN          A
     7X       FC   FC                         ------------------------------------'/
     8'  TE              M    T    ELP   ELP SA    S           S        SA    S           S
     9        CT   CT                         NO. OF      FRACTION         SIGNIFI-'/
     A'  I               U    A    CE    OE-  ER    EA          EA       E*    EA          E
     BA       TC   TO                         COMPAT-     OF ORTNS         CANCE     '/
     C'  O               T    N    F     F P   I     P           M        I     M
     DM       IR   IR                         IBLE        INCOMP-          (IN REAL'/
     E'  N               H    C    F     FO   IT    1P          1P       2T    2P          2
     FP                                       ORTNS.      ATIBLE           SPACE)    '/
     G'                       E          F    Y                          Y                '/)
C
 141 OREAD(NDEV,51) STANAM,AZI,DIST,ALPHA,GAPPA,SIGNP,PAZIN,PAIIN,
     1SIGNPP,PPAZIN,PPAIIN,PPFCT1,SPFCT1,PHASES
      IF(STANAM.EQ.BLANK8) GO TO 190
      IOBS=IOBS+1
```

```
      READ(NDEV,142) NTRUE,S,SREAL
 142  FORMAT(26X,I6,37X,F11.9/69X,F11.9)
C
      K=1
      IF(PHASES.EQ.SP) K=2
      IF(PHASES.EQ.STRSTR) K=3
      IF(PHASES.EQ.PF) K=4
      IF(PHASES.EQ.STRE) K=5
     0WRITE(6,143) IOBS,(ULINES(I),I=1,2),STANAM,AZI,DIST,ALPHA,GAMMA,
     1SIGNP,PA2IN,PA1IN,SIGNPP,PPA2IN,PPA1IN,PPFCT1,SPFCT1,
     2(TITLEH(J,K),J=1,5),NTRUE,S,SREAL
 143 0FORMAT(/15X,16HPHASE PAIR  NO. ,I3/15X,2A8,3H===//1X,A8,F5.0,
     13F5.1,2(A1,2F10.5),2F4.2,5A4,I7,2(1X,F11.9))
     0IF(IDEV3.GT.0) WRITE(NDEV3,51) STANAM,AZI,DIST,ALPHA,GAMMA,SIGNP,
     1PA2IN,PA1IN,SIGNPP,PPA2IN,PPA1IN,PPFCT1,SPFCT1,PHASES
      IF(IDEV3.GT.0) WRITE(NDEV3,506) NTRUE,S,SREAL
      GO TO 141
C
C     READ IN ORIENTATION ARRAY FROM INPUT-RESULT AND INTEGRATE WITH
C     ORIENTATION ARRAY OF THIS DATA BLOCK
C
 150  READ(NDEV,151) NOBSD
 151  FORMAT(30X,I3)
      READ(NDEV,142) NTRUE,S,SREAL
      READ(NDEV,155) ENDD,NTOTD
 155  FORMAT(A4,12X,I7//)
      IF(ENDD.NE.END) GO TO 157
      WRITE(6,156) NOBSD
 156 0FORMAT(/20X,' NO ORIENTATION ARRAY - INPUT RESULT DELETED'/
     120X'(I.E. PREVIOUS ',I3,' PHASE PAIRS DELETED)')
      IOBS=IOBS-NOBSD
      GO TO 999
C
 157  WRITE(6,161) (ULINES(I),I=1,5)
 161 0FORMAT(1H1,14X,42HRESULTS CORRESPONDING TO THIS INPUT-RESULT/
     115X,5A8,2H==)
      IF(IPRNT1.EQ.0) GO TO 165
      WRITE(6,163) (ULINE(I),I=1,7)
 163 0FORMAT(/20X,60HPRINTOUT OF COMPATIBLE AND PARTIALLY COMPATIBLE ORI
     1ENTATIONS/20X,7A8,4H----)
      WRITE(6,164)
 164 0FORMAT(/1X,30HSA = SLIP ANGLE IN FAULT PLANE,4X,24HDIP = DIP OF FA
     1ULT PLANE,4X,27HSTK = STRIKE OF FAULT PLANE,4X,35HN = NO. OF INCOM
     2PATIBLE PHASE PAIRS//8(16H  SA DIP STK  N)/)
      GO TO 167
 165  WRITE(6,166) (ULINE(I),I=1,7)
 166 0FORMAT(/20X,76HPRINTOUT OF COMPATIBLE AND PARTIALLY COMPATIBLE ORI
     1ENTATIONS - NOT REQUESTED/20X,7A8,4H----)
 167  IF(IPLOT1.EQ.0) GO TO 168
     0CALL SETUPV(TITLE,TITLEJ,9HSLIP ANG,8H      DIP,8H  STRIKE,SPSI1,
     1SPINC,SPSIN,SDELT1,SDINC,SDELTN,SSTRK1,SSINC,SSTRKN,3)
      CALL SETUPL(NVL)
C
 168  DO 169 I=1,NVL
 169  NTRUES(I)=0
      IFILL=1
      RREAL=0.D0
      ICARD=0
      NCARD=(NTOTD+4)/5
      I1=0
C
      DO 190 IPSI=IP1,IPN
      DO 190 IDELTA=ID1,IDN
      DO 190 ISTRIK=IS1,ISN
      I=IPSI-IP1M1
      J=IDELTA-ID1M1
      K=ISTRIK-IS1M1
      SPSI=DFLOAT(IPSI)*DINC
      SDELTA=DFLOAT(IDELTA)*DINC
      SSTRIK=DFLOAT(ISTRIK)*DINC
      IIII=IFIX(SPSI+0.5)
      JJJ1=IFIX(SDELTA+0.5)
      KKK1=IFIX(SSTRIK+0.5)
C
      IF(I1.NE.0) GO TO 173
      IF(ICARD.EQ.NCARD) GO TO 180
     0READ(NDEV,170) (IIID(I2),JJJD(I2),KKKD(I2),IVLND(I2),I2=1,5),
     1ICARDD
 170  FORMAT(5(1X,I3,1X,I3,1X,I3,I3),I5)
      ICARD=ICARD+1
      IF(ICARDD.NE.ICARD) WRITE(6,171) ICARDD,ICARD
 171 0FORMAT(/20X,'WARNING - ERROR IN INPUT OF ORIENTATION ARRAY - CARD
     1',I5,' IS WHERE CARD ',I5,' SHOULD BE'/)
      I1=I1+1
C
 173  IF(KKK1.NE.KKKD(I1)) GO TO 180
      IF(JJJ1.NE.JJJD(I1)) GO TO 190
      IF(IIII.NE.IIID(I1)) GO TO 180
C
C     ORIENTATION IS ON CARD
      IVLM=IVLND(I1)
      NTRUES(NVL-IVLM)=NTRUES(NVL-IVLM)+1
      IF(IPRNT1.EQ.0) GO TO 177
      III(IFILL)=IIII
      JJJ(IFILL)=JJJ1
      KKK(IFILL)=KKK1
      IVLN(IFILL)=IVLM
      IF(IFILL-8) 175,174,174
 174  WRITE(6,176) (III(I3),JJJ(I3),KKK(I3),IVLN(I3),I3=1,8)
      IFILL=1
      GO TO 177
 175  IFILL=IFILL+1
```

```
 176  FORMAT(8(1X,I3,1X,I .,1X,I3,I3,1H/))
 177  IF(IPLOT1.NE.0) CALL FLCTVL(SPSI,SDELTA,SSTRIK,NVL-IVLM)
      II=II+1
      IF(II.GT.5) II=0
      GO TO 181
C
C      ORIENTATION IS NOT ON CARD
 180  IVLM=NVL
      IF(NOBSP.LT.NVL) IVLM=NOBSP
 181  F1=F(I,J,K)
      IF(F1R.EQ.VVLR(1)) GO TO 190
      DO 182 II=1,NVL
      IVL=NVL-II+1
      IF(F1R.EQ.VVLR(IVL+1)) GO TO 183
 182  CONTINUE
 183  IVL=IVL-IVLM
      IF(IVL.LT.0) IVL=0
      F(I,J,K)=VVL(1,IVL+1)
 190  CONTINUE
C
C      FLUSH IFILL BUFFER
      IFILL=IFILL-1
     0IF(IFILL.NE.0) WRITE(6,176) (III(I3),JJJ(I3),KKK(I3),IVLM(I3),
     1I3=1,IFILL)
C
      READ(NDEV,129) ENDD
      IF(ENDD.NE.END) WRITE(6,195)
 195 0FORMAT(/20X,'WARNING - ERROR IN INPUT OF ORIENTATION ARRAY - ARRAY
     1 DOES NOT TERMINATE WITH ''END'' CARD')
C
      IF(IPLOT1.NE.0) WRITE(6,728) (ULINE(I),I=1,3)
      IF(IPLOTN.NE.0) CALL TOTALS
      IF(IPLOTN.EQ.0) WRITE(6,729) (ULINE(I),I=1,3)
C
C      SUMMARY OF RESULTS FOR THIS INPUT-RESULT
C
      WRITE(6,515) (LIN (I),I=1,2)
      WRITE(6,191) NTRUES(NVL),NCOMB,NOBSC
 191 0FORMAT( /10X,I8,' ORIENTATIONS OUT OF THE ',I8,' ARE COMPATIBLE WI
     1TH ALL THE ',I3,' PHASE PAIRS IN THIS INPUT-RESULT')
 192 0FORMAT( 10X,I8,' ORIENTATIONS OUT OF THE ',I9,' ARE INCOMPATIBLE
     1WITH ',I3,' OF THE ',I3,' PHASE PAIRS IN THIS INPUT-RESULT')
C
      IF(NVL.EQ.1) GO TO 194
      DO 193 I=2,NVL
      IF(I.GT.NOBS ) GO TO 194
      IVL=NVL-I+1
      IM1=I-1
      WRITE(6,192) NTRUES(IVL),NCOMB,IM1,NOBSC
 193  CONTINUE
 194  IF(REGION.EQ.BLANK4) WRITE(6,504)
      IF(REGION.NE.BLANK4) WRITE(6,505) NCCMBR,NCOMB
C
      GO TO 2000
C
C      IIIIIIIIII                                            IIIIIIIIII
C
C
C      90,DO,2000             PROCESS NEW PHASE PAIR            IIIIIIIIII
C
 90   IOBS=IOBS+1
      INDP=1
      IF(PHASES.EQ.PP)      INDP=1
      IF(PHASES.EQ.SP)      INDP=2
      IF(PHASES.EQ.STRSTR)  INDP=3
C
      IF(ISEA.EQ.0) GO TO 91
      IF(PHASES.EQ.PP)      INDP=4
      IF(PHASES.EQ.STRE)    INDP=5
      GO TO 92
C
 91   IF(PHASES.EQ.PP)      INDP=1
      IF(PHASES.EQ.STRE)    INDP=3
C
 92   WRITE(6,93) ULINE(1),ICP,NCP,ULINE
 93  0FORMAT(1H1,A8,9HCARD NO. ,I3,4H OF ,I3,5A8,22H------(NEW PHASE PAI
     1R),A8/)
      GO TO (801,600,600,801,600), INDP
C
C      -----------                                          -----------
C      PP PP PP PP       P, LITTLEP-P SECTION BEGINS        PP PP PP PP
C      -----------                                          -----------
C
 801  IF(INDP.EQ.4) GO TO 862
C
      TITLE1(4)=FLITPP
      IF(ISEA.EQ.0) WRITE(6,810) IOBS,STANAM,(LLINES(I),I=1,5)
 810 0FORMAT(15X,15HPHASE PAIR NO. ,I3,24X,8HSTATION ,A8,
     145H FOR PHASES P & LITTLEP-P(SOLID FREE SURFACE)/
     215X,2A8,2H**,24X,7A8,5H*****)
      IF(ISEA.NE.0) WRITE(6,861) IOBS,STANAM,(LLINES(I),I=1,8)
 861 0FORMAT(15X,15HPHASE PAIR NO. ,I3,24X,8HSTATION ,A8,
     134H FOR PHASES P & LITTLEP-P(SEA REC)/
     215X,2A8,2H**,24X,6A8,3H***)
      GO TO 864
C
 862  TITLE1(4)=FLPP
      WRITE(6,863) IOBS,STANAM,(LLINES(I),I=1,8)
 863 0FORMAT(15X,15HPHASE PAIR NO. ,I3,24X,8HSTATION ,A8,
     138H FOR PHASES P & LITTLEP-P(SEA SURFACE)/
     215X,2A8,2H**,24X,6A8,6H******)
C
```

```
C      PROTECTION ETC.
C
 864  AZ=AZI
     0IF(AZ.NE.0.D0)AZ=AZI-DMOD(AZI+DINC/2.D0,DINC)+DSIGN(DINC/2.D0,AZI+
     1DINC/2.D0)
C
 802  IF(AZ)803,803,804
 803  AZ=AZ+360.D0
      GO TO 802
C
 804  IF(AZ-360.D0)806,806,805
 805  AZ=AZ-360.D0
      GO TO 804
C
 806  IAZ=AZ/DINC+0.5D0
C
      IF(REGION.EQ.BLANK4) GO TO 892
      IE1=IAZ-ISN
      IEN=IAZ-IS1
      IF(IEN.GT.0) GO TO 891
      IEN=IEN+NS
      IE1=IE1+NS
 891  IF(IE1.GT.0) GO TO 892
      IE12=IE1+NS
      IE1=1
      IEN2=NS
C
 892  IF(DIST.LT.DISTMN.OR.DIST.GT.DISTMX) GO TO 888
      DISTR=DIST*DPI1
      A1=COEF(1,IDEPM1)
      A2=COEF(1,IDEP)
      DO 887 I=1,NDEG
      A1=A1*DISTR+COEF(I+1,IDEPM1)
      A2=A2*DISTR+COEF(I+1,IDEP)
 887  CONTINUE
      ALPHA=A1+(DEPTH-DEP(IDEPM1))*(A2-A1)/(DEP(IDEP)-DEP(IDEPM1))
      IF(DEPTH.NE.0.D0) GO TO 888
      PAQ=DSIN(A2*DPI1)*VPSRCE/VP0
      IF(PAQ.GT.1.D0) PAQ=1.D0
      ALPHA=DARSIN(PAQ)/DPI1
C
 888  IF(GAMMA.EQ.0.D0) GAMMA=ALPHA
      PAQ=DSIN(ALPHA*DPI1)*ANGPF
      IF(PAQ.GT.1.D0) PAQ=1.D0
      ALPHA=DARSIN(PAQ)/DPI1
      PAQ=DSIN(GAMMA*DPI1)*ANGPPF
      IF(PAQ.GT.1.D0) PAQ=1.D0
      GAMMA=DARSIN(PAQ)/DPI1
C
      BETA=DARSIN(DSIN(GAMMA*DPI1)/RSRCE)/DPI1
      GAMMA1=DARSIN(DSIN(GAMMA*DPI1)*VRAT2)
      BETA1=DARSIN(DSIN(BETA*DPI1)*VRAT2)
C
      IF(PPFCT1.EQ.0.D0) PPFCT1=1.D0
      IF(SPFCT1.EQ.0.D0) SPFCT1=1.D0
C
      IF(IFCT3.EQ.0) GO TO 870
      PPFCT3=1.D0
      GO TO 873
C
 870  IF(INDP.EQ.4) GO TO 872
C
      IF(ISEA.NE.0) GO TO 871
C     LITTLER-P(SOLID FREE SURFACE)
     0PPFCT3=(2.D0*DSIN(2.D0*GAMMA1)*DSIN(2.D0*BETA1)
     1-RSRS*(DCOS(4.D0*BETA1)+1.D0))/
     2        (2.D0*DSIN(2.D0*GAMMA1)*DSIN(2.D0*BETA1)
     3+RSRS*(DCOS(4.D0*BETA1)+1.D0))
      GO TO 873
C
C     LITTLER-P(SEA BED)
 871 0PPFCT3=(RSRS*DCOS(2.D0*BETA1)*(VRAT1*DRAT1*DCOS(GAMMA1)-DCOS(2.D0*
     1BETA1)*DCOS(DARSIN(VRAT1*DSIN(GAMMA1))))+DSIN(2.D0*GAMMA1)*(DSIN(2
     2.D0*BETA1)*DCOS(DARSIN(VRAT1*DSIN(GAMMA1)))+RSURF*VRAT1*DRAT1*DSIN
     3(BETA1)))/
     4        (RSRS*DCOS(2.D0*BETA1)*(VRAT1*DRAT1*DCOS(GAMMA1)+DCOS(2.D0*
     5BETA1)*DCOS(DARSIN(VRAT1*DSIN(GAMMA1))))+DSIN(2.D0*GAMMA1)*(DSIN(2
     6.D0*BETA1)*DCOS(DARSIN(VRAT1*DSIN(GAMMA1)))+RSURF*VRAT1*DRAT1*DSIN
     7(BETA1)))
      GO TO 873
C
C     LITTLER-P(SEA SURFACE)
 872 0PPFCT3=(2.D0*DCOS(GAMMA1)*DCOS(2.D0*BETA1)*(DSIN(2.D0*GAMMA1)*DSIN
     1(2.D0*BETA1)+RSRS*DCOS(2.D0*BETA1)*DCOS(2.D0*BETA1))+2.D0*DSIN(2.D
     20*GAMMA1)*DCOS(2.D0*BETA1)*(RSURF*DSIN(BETA1)*DCOS(2.D0*BETA1)-DCO
     3S(GAMMA1)*DSIN(2.D0*BETA1)))/
     4((VRAT1*DRAT1*DCOS(GAMMA1)+DCOS(2.D0*BETA1)*DCOS(DARSIN(VRAT1*DSIN
     5(GAMMA1))))*(DSIN(2.D0*GAMMA1)*DSIN(2.D0*BETA1)+RSRS*DCOS(2.D0*BET
     6A1)*DCOS(2.D0*BETA1))+VRAT1*DRAT1*DSIN(2.D0*GAMMA1)*(RSURF*DSIN(BE
     7TA1)*DCOS(2.D0*BETA1)-DCOS(GAMMA1)*DSIN(2.D0*BETA1)))
      PPFCT3=-PPFCT3
     0PPFCT3=PPFCT3*
     1RSRS*DCOS(DARSIN(VRAT1*DSIN(GAMMA1)))*DCOS(2.D0*BETA1)*2.D0/
     2(DSIN(2.D0*GAMMA1)*(RSURF*DSIN(BETA1)+DSIN(2.D0*BETA1)*DCOS(DARSIN
     3(VRAT1*DSIN(GAMMA1)))/(VRAT1*DRAT1))+RSRS*DCOS(2.D0*BETA1)*(DCOS(G
     4AMMA1)+DCOS(2.D0*BETA1)*DCOS(DARSIN(VRAT1*DSIN(GAMMA1)))/(VRAT1*DR
     5AT1)))
C
 873  PPFCT=PPFCT1*PPFCTF*PPFCT3
C
      ISGNP=0
      IF(SIGNP.EQ.PLUS) ISGNP=1
```

```
      IF(SIGNP.EQ.MINUS) ISGNP=-1
C
      ISGNPP=0
      IF(SIGNPP.EQ.PLUS) ISGNPP=1
      IF(SIGNPP.EQ.MINUS) ISGNPP=-1
C
      PA1=DABS(PA1IN)
      PA2=DABS(PA2IN)
      PPA1=DABS(PPA1IN)
      PPA2=DABS(PPA2IN)
C
      IF(PA1-PA2)811,808,812
 808  WRITE(6,809)
 809 0FORMAT(//20X,'PHASE PAIR DELETED - P OR LITTLEP-P AMPLITUDE RANGE
     1HAS ZERO WIDTH')
      GO TO 599
C
 811  PAQ=PA1
      PA1=PA2
      PA2=PAQ
 812  IF(PPA1-PPA2)813,808,814
 813  PAQ=PPA1
      PPA1=PPA2
      PPA2=PAQ
C
 814  NODEP=0
      NODEPP=0
      IF(PA2.GT.SMALL) GO TO 815
      NODEP=1
      IF(ISGNP.EQ.0) PA2=-PA1
 815  IF(PPA2.GT.SMALL) GO TO 819
      IF(NODEP.EQ.0) GO TO 818
      WRITE(6,817)
 817 0FORMAT(//20X,'PHASE PAIR DELETED - P AND LITTLEP-P APPLITUDE RANGE
     1S BOTH SPAN OR BOUND ZERO')
      GO TO 599
C
 818  NODEPP=1
      IF(ISGNPP.EQ.0) PPA2=-PPA1
C
C     CALCULATE RATIO RANGES
C
 819  IF(NODEP.EQ.1) GO TO 820
C
C     P IS NOT NODAL - LITTLEP-P/P IS USED
C
      RAT1=PPA1/PA1
      RAT2=PPA1/PA2
      RAT3=PPA2/PA1
      RAT4=PPA2/PA2
      GO TO 821
C
C     P IS NODAL - SHALL USE P/LITTLEP-P
C
 820  RAT1=PA1/PPA1
      RAT2=PA1/PPA2
      RAT3=PA2/PPA1
      RAT4=PA2/PPA2
C
C
C     SET RATIOS
C
 821  RATMX1=DMAX1(RAT1,RAT2,RAT3,RAT4)
      RATMN1=DMIN1(RAT1,RAT2,RAT3,RAT4)
      RATMX2=-RATMN1
      RATMN2=-RATMX1
C
C     OUTPUT OF PARAMETERS
C
      HOLA=ANDIS
      HOL1=NEGTIV
      HOL2=BLANK4
      HOL3=BLANK8
C
      IF(ISGNP) 834,831,833
C
 831  IF(NODEP.EQ.0) GO TO 832
      HOLA=BLANK8
      HOL1=BLANK8
      GO TO 834
C
 832  HOL2=OR
      HOL3=NEGTIV
C
 833  HOL1=POSTIV
C
 834  HOLB=ANDIS
      HOL4=NEGTIV
      HOL5=BLANK4
      HOL6=BLANK8
C
      IF(ISGNPP) 840,835,837
C
 835  IF(NODEPP.EQ.0) GO TO 836
      HOLB=BLANK8
      HOL4=BLANK8
      GO TO 840
C
 836  HOL5=OR
      HOL6=NEGTIV
C
 837  HOL4=POSTIV
```

```
C
 840 OWRITE(6,841) AZI,AZ,IAZ,ALPHA,GAMMA,DIST,PA2,PA1,HOLA,HOL1,HOL2,
     1HOL3,PPA2,PPA1,HOLB,HOL4,HOL5,HOL6
 841 OFORMAT(/
     120X,48HAZIMUTH OF STATION FROM EARTHQUAKE (POSITIVE     /
     220X,48H(CLOCKWISE) FROM NORTH) AS INPUT                 ,F10.5,
     38H  DEG.  /
     420X,48HAZIMUTH AS ABOVE (PRINCIPAL VALUE AND ROUNDED)  ,F10.5,
     58H  DEG.  /
     620X,48HAZIMUTH INCREMENT NUMBER                         ,I4//
     720X,48HTAKEOFF ANGLE OF P FROM DOWNWARD VERTICAL AT     /
     820X,48HSOURCE                                           ,F10.5,
     98H  DEG.  /
     A20X,48HTAKEOFF ANGLE OF LITTLEP-P FROM UPWARD VERTICAL /
     B20X,48HAT SOURCE                                        ,F10.5,
     C8H  DEG.  /
     D20X,48HEPICENTRAL DISTANCE                              ,F10.5,
     E8H  DEG.  //
     F20X,48HACCEPTABLE P AMPLITUDE RANGE IS FROM             ,F10.5,
     G4H TO ,F10.5,7H UNITS,,A8,A4,A8/
     H20X,48HACCEPTABLE LITTLEP-P AMPLITUDE RANGE IS FROM     ,F10.5,
     I4H TO ,F10.5,7H UNITS,,A8,A4,A8)
C
      WRITE(6,865) PPFCTF,PPFCT1,PPFCT
 865 OFORMAT(/
     120X,48HPPFCTF...LITTLEP-P MULTIPLICATION FACTOR         /
     220X,48HREPRESENTING AMPLITUDE LOSS AT REFLECTING        /
     320X,48HSURFACE (SOLID FREE SURFACE, SEA BED OR SEA      /
     420X,48HSURFACE) AND, IN THE LAST CASE, INCLUDING        /
     520X,48HAMPLITUDE LOSSES AT UPWARD AND DOWNWARD          /
     620X,48HREFRACTION AT THE SEA BED                        ,F10.5//
     720X,48HPPFCT1...LITTLEP-P MULTIPLICATION FACTOR         /
     820X,48HREPRESENTING AMPLITUDE LOSS RELATIVE TO P DUE TO/
     920X,48HANY OTHER CAUSE (BUT NOT INCLUDING PPFCTF)       ,F10.5//
     A20X,48HPPFCT (=PPFCT1*PPFCTF*PPFCT2)                    ,F10.5)
C
      IF(ALPHA.NE.GAMMA) WRITE(6,866)
 866 OFORMAT(/
     120X,48HP AND LITTLEP-P TAKEOFF ANGLES AT SOURCE ARE NOT/
     220X,48HEQUAL - SOURCE IS DEEP                           )
C
      IF(NODEP.EQ.0) GO TO 843
      WRITE(6,842)
 842  FORMAT(/20X,48HP AMPLITUDE RANGE SPANS OR BOUNDS ZERO            )
      GO TO 845
C
 843  IF(NODPP.EQ.0) GO TO 845
      WRITE(6,844)
 844  FORMAT(/20X,48HLITTLEP-P AMPLITUDE RANGE SPANS OR BOUNDS ZERO    )
C
C     DETERMINE RANGE(S) OF ACCEPTABLE AMPLITUDE RATIOS
C
 845  IF(NODEP.EQ.1) GO TO 851
C
C     P IS NOT NODAL - RATIO OF LITTLEP-P/P IS USED
C
      WRITE(6,846)
 846  FORMAT(/20X,48HRATIO OF LITTLEP-P/P IS USED                      )
C
      IF(ISGNP) 847,849,850
C
 847  IF(ISGNPP) 855,848,857
 848  IF(NODPP.EQ.1) GO TO 855
      GO TO 856
C
 849  IF(ISGNPP.EQ.0) GO TO 848
      GO TO 856
C
 850  IF(ISGNPP) 857,848,855
C
C     P IS NODAL - RATIO OF P/LITTLEP-P IS USED
C
 851  WRITE(6,852)
 852  FORMAT(/20X,48HRATIO OF P/LITTLEP-P IS USED                      )
C
      IF(ISGNP) 853,855,854
C
 853  IF(ISGNPP) 855,856,857
C
 854  IF(ISGNPP) 857,856,855
C
C     OUTPUT
C
 855  WRITE(6,858) RATMN1,RATMX1
      GO TO 895
 856  WRITE(6,858) RATMN1,RATMX1
 857  WRITE(6,858) RATMN2,RATMX2
 858 OFORMAT(/
     120X,54HACCEPTABLE RANGE OF OBSERVED AMPLITUDE RATIOS IS FROM ,
     2F10.5,4H TO ,F10.5/
     320X,48H(MAY BE P/LITTLEP-P OR LITTLEP-P/P - SEE ABOVE) )
C
 895  SINAL=DSIN(ALPHA*DPI1)
      COSAL=DCOS(ALPHA*DPI1)
C
      SINGA=DSIN(GAMMA*DPI1)
      COSGA=DCOS(GAMMA*DPI1)
C
      WRITE(6,996) (ULINES(I),I=1,3)
 996  FORMAT(1H1,14X,27HRESULTS FOR THIS PHASE PAIR/15X,3A8,3H***)
      IF(IPRNT1.EQ.0) WRITE(6,897) (ULINE(I),I=1,4)
 897 OFORMAT(/20X,51HPRINTOUT OF COMPATIBLE ORIENTATIONS - NOT REQUESTED
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     1/20X,4A8,3H---)
      IF(IPRNT1.NE.0) WRITE(6,898) (ULINE(I),I=1,4)
  898 0FORMAT(/20X,35HPRINTOUT OF COMPATIBLE ORIENTATIONS/20X,4A8,3H---)
      IF(IPRNT1.NE.0) WRITE(6,893)
  893 0FORMAT(/
     120X,30HSA = SLIP ANGLE IN FAULT PLANE,10X,24HDIP = DIP OF FAULT PL
     2ANE,10X,27HSTK = STRIKE OF FAULT PLANE//10(13H  SA DIP STK )/)
      IF(IPLOT1.EQ.0) GO TO 899
     0CALL SETUPV(TITLE,TITLE1,8HSLIP ANG,8H     DIP,8H  STRIKE,
     1SPSI1,SPINC,SPSIN,SDELT1,SDINC,SDELTA,SSTRK1,SSINC,SSTRKN,3)
C
  899  NTRUE=0
       IFILL=1
       FREAL=0.D0
C
C      **********           DO FOR EACH SLIP ANGLE
C
  401  DO 500 IPSI=IP1,IPN
C
       SPSI=DFLOAT(IPSI)*DINC
C
C      **********           DO FOR EACH DIP
C
       DO 500 IDELTA=ID1,IDN
C
       SDELTA=DFLOAT(IDELTA)*DINC
C
       SPSD=SINTAB(IPSI)*SINTAB(IDELTA)
       SPCD=SINTAB(IPSI)*COSTAB(IDELTA)
       CPSD=COSTAB(IPSI)*SINTAB(IDELTA)
       CPCD=COSTAB(IPSI)*COSTAB(IDELTA)
C
       P11=COSTAB(IDELTA)*COSAL
       P21=CPSD*COSAL
       P31=SPSD*COSAL
C
       PP11=COSTAB(IDELTA)*COSGA
       PP21=CPSD*COSGA
       PP31=SPSD*COSGA
C
C      **********           DO FOR EACH AZIMUTH FROM STRIKE
C
       DO 500 IETA=IE1,IEN
C
       SESA=SINTAB(IETA)*SINAL
       CESA=COSTAB(IETA)*SINAL
C
       SESG=SINTAB(IETA)*SINGA
       CESG=COSTAB(IETA)*SINGA
C
       P12=SINTAB(IDELTA)*SESA
       P2223=CPCD*SESA+SINTAB(IPSI)*CESA
       P3233=SPCD*SESA-COSTAB(IPSI)*CESA
C
       PP12=SINTAB(IDELTA)*SESG
       PP2223=CPCD*SESG+SINTAB(IPSI)*CESG
       PP3233=SPCD*SESG-COSTAB(IPSI)*CESG
C
       P1=P11-P12
       P2=-P21-P2223
       P3=-P31-P3233
C
       PP1=-PP11-PP12
       PP2=PP21-PP2223
       PP3=PP31-PP3233
C
       AP=DSIN(2.D0*DARCOS(P3))*DCOS(DATAN2(P2,P1))
       APP=DSIN(2.D0*DARCOS(PP3))*DCOS(DATAN2(PP2,PP1))*PPFCT
C
       ISTRIK=IAZ-IETA
       IF(ISTRIK.LE.0) ISTRIK=ISTRIK+NS
C
       IF(NODEP.EQ.1) GO TO 445
C
C      USE LITTLEP-P/P
C
       IF(ISGNP) 410,411,413
C
  410  IF(AP.GT.-SMALL) GO TO 490
       IF(ISGNPP) 420,412,430
C
  411  IF(AP.GT.SMALL) GO TO 412
       IF(AP.LT.-SMALL) GO TO 412
       GO TO 490
C
  412  IF(NODEPP.EQ.1) GO TO 420
       GO TO 440
C
  413  IF(AP.LT.SMALL) GO TO 490
       IF(ISGNPP) 430,412,420
C
C      TEST 1
  420  ARAT=APP/AP
       IF(ARAT.GT.RATMX1) GO TO 490
       IF(ARAT.LT.RATMN1) GO TO 490
       GO TO 480
C
C      TEST 2
  430  ARAT=APP/AP
       IF(ARAT.GT.RATMX2) GO TO 490
       IF(ARAT.LT.RATMN2) GO TO 490
       GO TO 480
```

```
C
C       TEST BOTH
 440    ARAT=APP/AP
        IF(ARAT.GT.RATMX1) GO TO 441
        IF(ARAT.LT.RATMN1) GO TO 441
        GO TO 480
 441    IF(ARAT.GT.RATMX2) GO TO 490
        IF(ARAT.LT.RATMN2) GO TO 490
        GO TO 480
C
C       USE P/LITTLEP-P
C
 445    IF(ISGNPP) 446,447,449
C
 446    IF(APP.GT.CSMALL) GO TO 450
        IF(ISGNP.EQ.1) GO TO 460
        GO TO 450
C
 447    IF(APP.GT.SMALL) GO TO 448
        IF(APP.LT.CSMALL) GO TO 448
        GO TO 450
C
 448    IF(ISGNP.EQ.0) GO TO 450
        GO TO 470
C
 449    IF(APP.LT.SMALL) GO TO 490
        IF(ISGNP.EQ.-1) GO TO 460
C
C       TEST 1
 450    ARAT=AP/AFP
        IF(ARAT.GT.RATMX1) GO TO 490
        IF(ARAT.LT.RATMN1) GO TO 490
        GO TO 480
C
C       TEST 2
 460    ARAT=AP/AFP
        IF(ARAT.GT.RATMX2) GO TO 490
        IF(ARAT.LT.RATMN2) GO TO 490
        GO TO 480
C
C       TEST BOTH
 470    ARAT=AP/AFP
        IF(ARAT.GT.RATMX1) GO TO 471
        IF(ARAT.LT.RATMN1) GO TO 471
        GO TO 480
 471    IF(ARAT.GT.RATMX2) GO TO 490
        IF(ARAT.LT.RATMN2) GO TO 490
C
C       ACCEPT
C
 480    SSTRIK=DFLOAT(ISTRIK)+DINC
        IF(IPLOT1.NE.0) CALL FLCTV(SPSI,SDELTA,SSTRIK)
        NTRUE=NTRUE+1
        FREAL=FREAL+SINTAB(IDELTA)
        IF(IPRNT1.EQ.0) GO TO 500
C
        III(IFILL)=IFIX(SPSI+0.5)
        JJJ(IFILL)=IFIX(SDELTA+0.5)
        KKK(IFILL)=IFIX(SSTRIK+0.5)
        IF (IFILL-10)489,481,481
C
 481    WRITE(6,482)(III(I),JJJ(I),KKK(I),I=1,10)
 482    FORMAT(10(1X,I3,1X,I3,1X,I3,1X))
        IFILL=1
        GO TO 500
C
 489    IFILL=IFILL+1
        GO TO 500
C
C       REJECT
C
 490    I=IPSI-IP1M1
        J=IDELTA-ID1M1
        K=ISTRIK-IS1M1
        IF(.NOT.F(I,J,K)) GO TO 500
        F1=F(I,J,K)
        DO 491 IVL=2,NVLP1
        IF(F1F.EQ.VVLR(IVL)) GO TO 492
 491    CONTINUE
        GO TO 500
 492    F(I,J,K)=VVL(1,IVL-1)
C
 500    CONTINUE
C
C       ***********
C
C       ***********
C
C       ***********
C
        IF(IE12.EQ.0) GO TO 5000
        IE1=IE12
        IEN=IEN2
        IE12=0
        IEN2=0
        GO TO 401
C
C       -----------                                                 -----------
C       PP PP PP PP      P, LITTLEP-P SECTION ENDS                  PP PP PP PP
C       -----------                                                 -----------
C
C
```

```
C      -----------                                               -----------
C      SP SP SP SP      P, LITTLES-P (AND LITTLEP-P,             SP SP SP SP
C      -----------       LITTLES-P) SECTION BEGINS               -----------
C
 600    GO TO (800,601,660,600,664), INOP
C
 601   TITLEI(4)=PLITSP
       WRITE(6,610) IOBS,STANAM,(ULINES(I),I=1,7)
 610 OFORMAT(15X,15HPHASE PAIR NO. ,I3,24X,8HSTATION ,A8,
     125H FOR PHASES P & LITTLES-P/
     215X,2A8,2H==,24X,5A8,1H=)
       GO TO 666
C
 660   TITLEI(4)=LPPLSP
       IF(ISEA.NE.0) GO TO 662
       WRITE(6,661) IOBS,STANAM,(ULINES(I),I=1,10)
 661 OFORMAT(15X,15HPHASE PAIR NO. ,I3,24X,8HSTATION ,A8,
     153H FOR PHASES LITTLEP-P(SOLID FREE SURFACE) & LITTLES-P/
     215X,2A8,2H==,24X,8A8,5H=====)
       GO TO 666
C
 662   WRITE(6,663) IOBS,STANAM,(ULINES(I),I=1,9)
 663 OFORMAT(15X,15HPHASE PAIR NO. ,I3,24X,8HSTATION ,A8,
     142H FOR PHASES LITTLEP-P(SEA BED) & LITTLES-P/
     215X,2A8,2H==,24X,7A8,2H==)
       GO TO 666
C
 664   TITLEI(4)=LPPELS
       WRITE(6,665) IOBS,STANAM,(ULINES(I),I=1,9)
 665 OFORMAT(15X,15HPHASE PAIR NO. ,I3,24X,8HSTATION ,A8,
     146H FOR PHASES LITTLEP-P(SEA SURFACE) & LITTLES-P/
     215X,2A8,2H==,24X,7A8,6H======)
C
C       PROTECTION ETC.
C
 666   AZ=AZI
     OIF(AZ.NE.0.D0)AZ=AZI-DMOD(AZI+DINC/2.D0,DINC)+DSIGN(DINC/2.D0,AZI+
     1DINC/2.D0)
C
 602   IF(AZ)603,603,604
 603   AZ=AZ+360.D0
       GO TO 602
C
 604   IF(AZ-360.D0)606,605,605
 605   AZ=AZ-360.D0
       GO TO 604
C
 606   IAZ=AZ/DINC+0.5D0
C
       IF(REGION.EQ.BLANK4) GO TO 692
       IE1=IAZ-ISN
       IEN=IAZ-IS1
       IF(IEN.GT.0) GO TO 691
       IEN=IEN+NS
       IE1=IE1+NS
 691   IF(IE1.GT.0) GO TO 692
       IE12=IE1+NS
       IE1=1
       IEN2=NS
C
 692   IF(DIST.LT.DISTMN.OR.DIST.GT.DISTMX) GO TO 688
       DISTR=DIST*DPI1
       A1=COEF(1,IDEPM1)
       A2=COEF(1,IDEP)
       DO 687 I=1,NDEG
       A1=A1*DISTR+COEF(I+1,IDEPM1)
       A2=A2*DISTR+COEF(I+1,IDEP)
 687   CONTINUE
       ALPHA=A1+(DEPTH-DEP(IDEPM1))*(A2-A1)/(DEP(IDEP)-DEP(IDEPM1))
       IF(DEPTH.NE.0.D0) GO TO 688
       PAQ=DSIN(A2*DPI1)*VPSRCE/VP0
       IF(PAQ.GT.1.D0) PAQ=1.D0
       ALPHA=DARSIN(PAQ)/DPI1
C
 688   IF(GAMMA.EQ.0.D0) GAMMA=ALPHA
       PAQ=DSIN(ALPHA*DPI1)*ANGPF
       IF(PAQ.GT.1.D0) PAQ=1.D0
       ALPHA=DARSIN(PAQ)/DPI1
       PAQ=DSIN(GAMMA*DPI1)*ANGPPF
       IF(PAQ.GT.1.D0) PAQ=1.D0
       GAMMA=DARSIN(PAQ)/DPI1
C
       BETA=DARSIN(DSIN(GAMMA*DPI1)/RSRCE)/DPI1
       GAMMA1=DARSIN(DSIN(GAMMA*DPI1)*VRAT2)
       BETA1=DARSIN(DSIN(BETA*DPI1)*VRAT2)
C
       IF(PPFCT1.EQ.0.D0) PPFCT1=1.D0
       IF(SPFCT1.EQ.0.D0) SPFCT1=1.D0
C
       IF(IFCT3.EQ.0) GO TO 689
       SPFCT3=1.D0
       GO TO 690
C
 689 OIF(ISEA.EQ.0)
C       LITTLES-P(SOLID FREE SURFACE)
     1SPFCT3=-2.D0*RSURF*DSIN(4.D0*BETA1)/(2.D0*DSIN(2.D0*GAMMA1)*
     2DSIN(2.D0*BETA1)+RSFS*(DCOS(4.D0*BETA1)+1.D0))*
     3DCOS(GAMMA*DPI1)/DSQRT(RSRCE*RSRCE-DSIN(GAMMA*DPI1)**2)
C
     OIF(ISEA.NE.0)
C       LITTLES-P(SEA BED)
     1SPFCT3=-2.D0*RSURF*DSIN(2.D0*BETA1)*DCOS(2.D0*BETA1)*DCOS(DARSIN(V
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     2RAT1*DSIN(GAMMA1)))/
     3(DSIN(2.D0*GAMMA1)*(DSIN(2.D0*BETA1)*DCOS(DARSIN(VRAT1*DSIN(GAMMA1
     4)))+RSURF*VRAT1*DRAT1*DSIN(BETA1))+RSRS*DCOS(2.D0*BETA1)*(DCOS(2.D
     50*BETA1)*DCOS(DARSIN(VRAT1*DSIN(GAMMA1)))+VRAT1*DRAT1*DCOS(GAMMA1)
     6))*DCOS(GAMMA*DPI1)/DSQRT(RSRCE*RSRCE-DSIN(GAMMA*DPI1)**2)
C
 690  SPFCT=SPFCT1*SPFCTF*SPFCT2*SPFCT3
C
      IF(INDP.EQ.2) GO TO 667
C
      IF(IFCT3.EQ.0) GO TO 693
      PPFCT3=1.D0
      GO TO 671
C
 693  GO TO (800,800,668,669,670), INDP
C
C     DIRECT P
 667  PFCT=1.D0
      GO TO 607
C
 668  IF(ISEA.NE.0) GO TO 669
C     LITTLEP-P(SOLID FREE SURFACE)
     0PPFCT3=(2.D0*DSIN(2.D0*GAMMA1)*DSIN(2.D0*BETA1)
     1-RSRS*(DCOS(4.D0*BETA1)+1.D0))/
     2         (2.D0*DSIN(2.D0*GAMMA1)*DSIN(2.D0*BETA1)
     3+RSRS*(DCOS(4.D0*BETA1)+1.D0))
      GO TO 671
C
C     LITTLEP-P(SEA BED)
 669 0PPFCT3=(RSRS*DCOS(2.D0*BETA1)*(VRAT1*DRAT1*DCOS(GAMMA1)-DCOS(2.D0*
     1BETA1)*DCOS(DARSIN(VRAT1*DSIN(GAMMA1))))+DSIN(2.D0*GAMMA1)*(DSIN(2
     2.D0*BETA1)*DCOS(DARSIN(VRAT1*DSIN(GAMMA1)))+RSURF*VRAT1*DRAT1*DSIN
     3(BETA1)))/
     4         (RSRS*DCOS(2.D0*BETA1)*(VRAT1*DRAT1*DCOS(GAMMA1)+DCOS(2.D0*
     5BETA1)*DCOS(DARSIN(VRAT1*DSIN(GAMMA1))))+DSIN(2.D0*GAMMA1)*(DSIN(2
     6.D0*BETA1)*DCOS(DARSIN(VRAT1*DSIN(GAMMA1)))+RSURF*VRAT1*DRAT1*DSIN
     7(BETA1)))
      GO TO 671
C
C     LITTLEP-P(SEA SURFACE)
 670 0PPFCT3=(2.D0*DCOS(GAMMA1)*DCOS(2.D0*BETA1)*(DSIN(2.D0*GAMMA1)*DSIN
     1(2.D0*BETA1)+RSRS*DCOS(2.D0*BETA1)*DCOS(2.D0*BETA1))+2.D0*DSIN(2.D
     20*GAMMA1)*DCOS(2.D0*BETA1)*(RSURF*DSIN(BETA1)*DCOS(2.D0*BETA1)-DCO
     3S(GAMMA1)*DSIN(2.D0*BETA1)))/
     4((VRAT1*DRAT1*DCOS(GAMMA1)+DCOS(2.D0*BETA1)*DCOS(DARSIN(VRAT1*DSIN
     5(GAMMA1))))*(DSIN(2.D0*GAMMA1)*DSIN(2.D0*BETA1)+RSRS*DCOS(2.D0*BET
     6A1)*DCOS(2.D0*BETA1))+VRAT1*DRAT1*DSIN(2.D0*GAMMA1)*(RSURF*DSIN(BE
     7TA1)*DCOS(2.D0*BETA1)-DCOS(GAMMA1)*DSIN(2.D0*BETA1)))
      PPFCT3=-PPFCT3
     0PPFCT3=PPFCT3*
     1RSRS*DCOS(DARSIN(VRAT1*DSIN(GAMMA1)))*DCOS(2.D0*BETA1)*2.D0/
     2(DSIN(2.D0*GAMMA1)*(RSURF*DSIN(BETA1)+DSIN(2.D0*BETA1)*DCOS(DARSIN
     3(VRAT1*DSIN(GAMMA1)))/(VRAT1*DRAT1))+RSRS*DCOS(2.D0*BETA1)*(DCOS(G
     4AMMA1)+DCOS(2.D0*BETA1)*DCOS(DARSIN(VRAT1*DSIN(GAMMA1)))/(VRAT1*DR
     5AT1)))
C
 671  PPFCT=PPFCT1*PPFCTF*PPFCT3
C
 607  ISGNP=0
      IF(SIGNP.EQ.PLUS) ISGNP=1
      IF(SIGNP.EQ.MINUS) ISGNP=-1
C
      ISGNSP=0
      IF(SIGNSP.EQ.PLUS) ISGNSP=1
      IF(SIGNSP.EQ.MINUS) ISGNSP=-1
C
      PA1=DABS(PA1IN)
      PA2=DABS(PA2IN)
      SPA1=DABS(SPA1IN)
      SPA2=DABS(SPA2IN)
C
      IF(PA1-PA2)611,608,612
C
 608  IF(INDP.NE.2) GO TO 672
C
      WRITE(6,609)
 609 0FORMAT(//20X,'PHASE PAIR DELETED - P OR LITTLES-P AMPLITUDE RANGE
     1HAS ZERO WIDTH')
      GO TO 599
C
 672  WRITE(6,673)
 673 0FORMAT(//20X,'PHASE PAIR DELETED - LITTLEP-P OR LITTLES-P AMPLITUD
     1E RANGE HAS ZERO WIDTH')
      GO TO 599
C
 611  PA0=PA1
      PA1=PA2
      PA2=PA0
 612  IF(SPA1-SPA2)613,608,614
 613  PA0=SPA1
      SPA1=SPA2
      SPA2=PA0
C
 614  NODEP=0
      NODESP=0
      IF(PA2.GT.SMALL) GO TO 615
      NODEP=1
      IF(ISGNP.EQ.0) PA2=-PA1
 615  IF(SPA2.GT.SMALL) GO TO 619
      IF(NODEP.EQ.0) GO TO 618
C
      IF(INDP.NE.2) GO TO 634
```

```
C
      WRITE(6,617)
  617 0FORMAT(//20X,'PHASE PAIR DELETED - P AND LITTLES-P AMPLITUDE RANGE
     1S BOTH SPAN OR BOUND ZERO')
      GO TO 599
C
  674 WRITE(6,675)
  675 0FORMAT(//20X,'PHASE PAIR DELETED - LITTLEP-P AND LITTLES-P AMPLITU
     1DE RANGES BOTH SPAN OR BOUND ZERO')
      GO TO 599
C
  618 NODESP=1
      IF(ISGNSP.EQ.0) SPA2=-SPA1
C
C     CALCULATE RATIO RANGES
C
  619 IF(NODEP.EQ.1) GO TO 620
C
C     P (OR LITTLEP-P) IS NOT NODAL -
C     LITTLES-P/P (OR LITTLES-P/LITTLEP-P) IS USED
C
      RAT1=SPA1/PA1
      RAT2=SPA1/PA2
      RAT3=SPA2/PA1
      RAT4=SPA2/PA2
      GO TO 621
C
C     P (OR LITTLEP-P) IS NODAL -
C     SHALL USE P/LITTLES-P (OR LITTLEP-P/LITTLES-P)
C
  620 RAT1=PA1/SPA1
      RAT2=PA1/SPA2
      RAT3=PA2/SPA1
      RAT4=PA2/SPA2
C
C
C     SET RATIOS
C
  621 RATMX1=AMAX1(RAT1,RAT2,RAT3,RAT4)
      RATMN1=AMIN1(RAT1,RAT2,RAT3,RAT4)
      RATMX2=-RATMN1
      RATMN2=-RATMX1
C
C     OUTPUT OF PARAMETERS
C
      HOLA=ANDIS
      HOL1=NEGTIV
      HOL2=BLANK4
      HOL3=BLANK8
C
      IF(ISGNP) 634,631,633
C
  631 IF(NODEP.EQ.0) GO TO 632
      HOLA=BLANK8
      HOL1=BLANK8
      GO TO 634
C
  632 HOL2=OR
      HOL3=NEGTIV
C
  633 HOL1=POSTIV
C
  634 HOLB=ANDIS
      HOL4=NEGTIV
      HOL5=BLANK4
      HOL6=BLANK8
C
      IF(ISGNSP) 640,635,637
C
  635 IF(NODESP.EQ.0) GO TO 636
      HOLB=BLANK8
      HOL4=BLANK8
      GO TO 640
C
  636 HOL5=OR
      HOL6=NEGTIV
C
  637 HOL4=POSTIV
C
  640 IF(INDP.NE.2) GO TO 677
C
     0WRITE(6,641) AZI,AZ,IAZ,ALPHA,BETA,DIST,PA2,PA1,HOLA,HOL1,HOL2,
     1HOL3,SPA2,SPA1,HOLB,HOL4,HOL5,HOL6
  641 0FORMAT(/
     120X,48HAZIMUTH OF STATION FROM EARTHQUAKE (POSITIVE    /
     220X,48HCLOCKWISE FROM NORTH) AS INPUT                  ,F10.5,
     38H  DEG.  /
     420X,48HAZIMUTH AS ABOVE, PRINCIPAL VALUED AND ROUNDED  ,F10.5,
     58H  DEG.  /
     620X,48HAZIMUTH INCREMENT NUMBER                        ,I4//
     720X,48HTAKEOFF ANGLE OF P FROM DOWNWARD VERTICAL AT    /
     820X,48HSOURCE                                          ,F10.5,
     98H  DEG.  /
     A20X,48HTAKEOFF ANGLE OF LITTLES-P FROM UPWARD VERTICAL /
     B20X,48HAT SOURCE                                       ,F10.5,
     C8H  DEG.  /
     D20X,48HEPICENTRAL DISTANCE                             ,F10.5,
     E8H  DEG.  //
     F20X,48HACCEPTABLE P AMPLITUDE RANGE IS FROM            ,F10.5,
     G4H TO ,F10.5,6H UNITS,2A8,A4,A8/
     H20X,48HACCEPTABLE LITTLES-P AMPLITUDE RANGE IS FROM    ,F10.5,
     I4H TO ,F10.5,6H UNITS,2A8,A4,A8)
```

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C
      WRITE(6,675) SPFCT3,SPFCT1,SPFCT2,SPFCT
 675 0FORMAT(/
     120X,48HSPFCT3...LITTLES-P MULTIPLICATION FACTOR          /
     220X,48HREPRESENTING AMPLITUDE LOSS AT REFLECTING         /
     320X,48HSURFACE (SOLID FREE SURFACE OR SEA BED)           ,F10.5//
     420X,48HSPFCT1...LITTLES-P MULTIPLICATION FACTOR          /
     520X,48HREPRESENTING AMPLITUDE LOSS RELATIVE TO P DUE TO/
     620X,48HANY OTHER CAUSE (BUT NOT INCLUDING SPFCTF)        ,F10.5//
     720X,48HSPFCT2...NORMALISATION RATIO BETWEEN MAXIMUM S  /
     820X,48HAND P AMPLITUDES AT SOURCE                        ,F10.5//
     920X,48HSPFCT (=SPFCT1*SPFCTF*SPFCT2*SPFCT3)              ,F10.5)
C
      IF(ALPHA.NE.GAMMA) WRITE(6,866)
C
      IF(NODEP.EQ.0) GO TO 643
      WRITE(6,642)
 642  FORMAT(/20X,48HP AMPLITUDE RANGE SPANS OR BOUNDS ZERO           )
      GO TO 645
C
 677 0WRITE(6,678) AZI,AZ,IAZ,GAMMA,BETA,DIST,PA2,PA1,HOLA,HOL1,HOL2,
     1HOL3,SPA2,SPA1,HOL8,HOL4,HOL5,HOL6
 678 0FORMAT(/
     120X,48HAZIMUTH OF STATION FROM EARTHQUAKE (POSITIVE    /
     220X,48HCLOCKWISE FROM NORTH) AS INPUT                    ,F10.5,
     38H  DEG.  /
     420X,48HAZIMUTH AS ABOVE, PRINCIPAL VALUED AND ROUNDED  ,F10.5,
     58H  DEG.  /
     620X,48HAZIMUTH INCREMENT NUMBER                          ,I4//
     720X,48HTAKEOFF ANGLE OF LITTLEP-P FROM UPWARD VERTICAL /
     820X,48HAT SOURCE                                         ,F10.5,
     98H  DEG.  /
     A20X,48HTAKEOFF ANGLE OF LITTLES-P FROM UPWARD VERTICAL /
     B20X,48HAT SOURCE                                         ,F10.5,
     C8H  DEG.  /
     D20X,48HEPICENTRAL DISTANCE                               ,F10.5,
     E8H  DEG.  //
     F20X,48HACCEPTABLE LITTLEP-P AMPLITUDE RANGE IS FROM    ,F10.5,
     G4H TO ,F10.5,6H UNITS,2A8,A4,A8/
     H20X,48HACCEPTABLE LITTLES-P AMPLITUDE RANGE IS FROM    ,F10.5,
     I4H TO ,F10.5,6H UNITS,2A8,A4,A8)
C
      WRITE(6,679) PPFCT3,PPFCT1,PPFCT,SPFCT3,SPFCT1,SPFCT2,SPFCT
 679 0FORMAT(/
     120X,48HPPFCT3...LITTLEP-P MULTIPLICATION FACTOR          /
     220X,48HREPRESENTING AMPLITUDE LOSS AT REFLECTING         /
     320X,48HSURFACE (SOLID FREE SURFACE, SEA BED OR SEA      /
     420X,48HSURFACE) AND, IN THE LAST CASE, INCLUDING        /
     520X,48HAMPLITUDE LOSSES AT UPWARD AND DOWNWARD          /
     620X,48HREFRACTION AT THE SEA BED                         ,F10.5//
     720X,48HPPFCT1...LITTLEP-P MULTIPLICATION FACTOR          /
     820X,48HREPRESENTING AMPLITUDE LOSS RELATIVE TO P DUE TO/
     920X,48HANY OTHER CAUSE (BUT NOT INCLUDING PPFCTF)        ,F10.5//
     A20X,48HPPFCT (=PPFCT1*PPFCTF*PPFCT3)                     ,F10.5//
     B20X,48HSPFCT3...LITTLES-P MULTIPLICATION FACTOR          /
     C20X,48HREPRESENTING AMPLITUDE LOSS AT REFLECTING         /
     D20X,48HSURFACE (SOLID FREE SURFACE OR SEA BED)           ,F10.5//
     E20X,48HSPFCT1...LITTLES-P MULTIPLICATION FACTOR          /
     F20X,48HREPRESENTING AMPLITUDE LOSS RELATIVE TO P DUE TO/
     G20X,48HANY OTHER CAUSE (BUT NOT INCLUDING SPFCTF)        ,F10.5//
     H20X,48HSPFCT2...NORMALISATION RATIO BETWEEN MAXIMUM S  /
     I20X,48HAND P AMPLITUDES AT SOURCE                        ,F10.5//
     H20X,48HSPFCT (=SPFCT1*SPFCTF*SPFCT2*SPFCT3)              ,F10.5)
C
      PFCT=PPFCT
C
      IF(ALPHA.NE.GAMMA) WRITE(6,866)
C
      IF(NODEP.EQ.0) GO TO 643
      WRITE(6,680)
 680  FORMAT(/20X,48HLITTLEP-P AMPLITUDE RANGE SPANS OR BOUNDS ZERO  )
      GO TO 645
C
 643  IF(NODESP.EQ.0) GO TO 645
      WRITE(6,644)
 644  FORMAT(/20X,48HLITTLES-P AMPLITUDE RANGE SPANS OR BOUNDS ZERO  )
C
C     DETERMINE RANGE(S) OF ACCEPTABLE AMPLITUDE RATIOS
C
 645  IF(NODEP.EQ.1) GO TO 651
C
C     P (OR LITTLEP-P) IS NOT NODAL -
C     RATIO OF LITTLES-P/P (OR LITTLES-P/LITTLEP-P) IS USED
C
      IF(INDP.EQ.2) WRITE(6,646)
 646  FORMAT(/20X,48HRATIO OF LITTLES-P/P IS USED                     )
C
      IF(INDP.NE.2) WRITE(6,681)
 681  FORMAT(/20X,48HRATIO OF LITTLES-P/LITTLEP-P IS USED             )
C
      IF(ISGNP) 647,649,650
C
 647  IF(ISGNSP) 655,648,657
 648  IF(NODESP.EQ.1) GO TO 655
      GO TO 656
C
 649  IF(ISGNSP.EQ.0) GO TO 648
      GO TO 656
C
 650  IF(ISGNSP) 657,648,655
C
C     P (OR LITTLEP-P) IS NODAL -
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C      RATIO OF P/LITTLES-P (OR LITTLEP-P/LITTLES-P) IS USED
C
 651   IF(INDP.EQ.2) WRITE(6,652)
 652   FORMAT(/20X,48HRATIO OF P/LITTLES-P IS USED                        )
C
       IF(INDP.NE.2) WRITE(6,682)
 682   FORMAT(/20X,48HRATIO OF LITTLEP-P/LITTLES-P IS USED                )
C
       IF(ISGNP) 653,655,654
C
 653   IF(ISGNSP) 655,656,657
C
 654   IF(ISGNSP) 657,656,655
C
C      OUTPUT
C
 655   IF(INDP.EQ.2) WRITE(6,658) RATMN1,RATMX1
       IF(INDP.NE.2) WRITE(6,683) RATMN1,RATMX1
       GO TO 695
C
 656   IF(INDP.EQ.2) WRITE(6,658) RATMN1,RATMX1
       IF(INDP.NE.2) WRITE(6,683) RATMN1,RATMX1
C
 657   IF(INDP.EQ.2) WRITE(6,658) RATMN2,RATMX2
       IF(INDP.NE.2) WRITE(6,683) RATMN2,RATMX2
C
 658 0FORMAT(/
     120X,54HACCEPTABLE RANGE OF OBSERVED AMPLITUDE RATIOS IS FROM ,
     2F10.5,4H TO ,F10.5/
     320X,48H(MAY BE P/LITTLES-P OR LITTLES-P/P - SEE ABOVE) )
C
 683 0FORMAT(/
     120X,54HACCEPTABLE RANGE OF OBSERVED AMPLITUDE RATIOS IS FROM ,
     2F10.5,4H TO ,F10.5/
     320X,48H(MAY BE LITTLEP-P/LITTLES-P OR LITTLES-P/          /
     420X,48HLITTLEP-P - SEE ABOVE)                              )
C
 695   GO TO (800,684,685,800,685), INDP
C
 684   SINAL=DSIN(ALPHA*DPI1)
       COSAL=DCOS(ALPHA*DPI1)
       GO TO 686
C
 685   SINAL=DSIN((180.D0-GAMMA)*DPI1)
       COSAL=DCOS((180.D0-GAMMA)*DPI1)
C
 686   SINBE=DSIN(BETA*DPI1)
       COSBE=DCOS(BETA*DPI1)
C
       WRITE(6,896) (ULINES(I),I=1,3)
       IF(IPRNT1.EQ.0) WRITE(6,897) (ULINE(I),I=1,4)
       IF(IPRNT1.NE.0) WRITE(6,898) (ULINE(I),I=1,4)
       IF(IPRNT1.NE.0) WRITE(6,893)
       IF(IPLOT1.EQ.0) GO TO 699
      0CALL SETUPV(TITLE,TITLE1,8HSLIP ANG,8H     DIP,8H  STRIKE,
      1SPSI1,SPINC,SPSIN,SDELT1,SDINC,SDELTN,SSTRK1,SSINC,SSTRKN,3)
C
 699   NTRUE=0
       IFILL=1
       FREAL=0.D0
C
C      ++++++++++          DO FOR EACH SLIP ANGLE
C
 201   DO 300 IPSI=IP1,IPN
C
       SPSI=DFLOAT(IPSI)*SINC
C
       SINPSI=SINTAB(IPSI)
       COSPSI=COSTAB(IPSI)
C
       SASP=SINAL*SINPSI
       SACP=SINAL*COSPSI
       CASP=COSAL*SINPSI
       CACP=COSAL*COSPSI
C
       SBSP=SINBE*SINPSI
       SBCP=SINBE*COSPSI
       CBSP=COSBE*SINPSI
       CBCP=COSBE*COSPSI
C
C      ..........          DO FOR EACH DIP
C
       DO 300 IDELTA=ID1,IDN
C
       SDELTA=DFLOAT(IDELTA)*DINC
C
       SINDEL=SINTAB(IDELTA)
       COSDEL=COSTAB(IDELTA)
C
       CACD=COSAL*COSDEL
       SASD=SINAL*SINDEL
C
       SASPCD=SASP*COSDEL
       SACPCD=SACP*COSDEL
       CASPSD=CASP*SINDEL
       CACPSD=CACP*SINDEL
C
       SBSD=SINBE*SINDEL
       SBCD=SINBE*COSDEL
       CBSD=COSBE*SINDEL
       CBCD=COSBE*COSDEL
C
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      SBSPSD=SBSP*SINDEL
      SBSPCD=SBSP*COSDEL
      SBCPSD=SBCP*SINDEL
      SBCPCD=SBCP*COSDEL
      CBSPSD=CBSP*SINDEL
      CBSPCD=CBSP*COSDEL
      CBCPSD=CBCP*SINDEL
      CBCPCD=CBCP*COSDEL
C
C     &&&&&&&&&&           DO FOR EACH AZIMUTH FROM STRIKE
C
      DO 300 IETA=IE1,IEN
C
      SINETA=SINTAB(IETA)
      COSETA=COSTAB(IETA)
C
      P1=CACD-SASD*SINETA
      P2=-CACPSD-SACPCD*SINETA-SASP*COSETA
      P3=-CASPSD-SASPCD*SINETA+SACP*COSETA
C
      AP=DSIN(2.D0*DARCOS(P3))*DCOS(DATAN2(P2,P1))*PFCT
C
      SPM1=-CBCD-SBSD*SINETA
      SPM2=CBCPSD-SBCPCD*SINETA-SBSP*COSETA
      SPM3=CBSPSD-SBSPCD*SINETA+SBCP*COSETA
C
      THETA=DARCOS(SPM3)
      PHI=DATAN2(SPM2,SPM1)
C
      SINTHE=DSIN(THETA)
      SINPHI=DSIN(PHI)
      COSPHI=DCOS(PHI)
C
      ASPTHE=DCOS(2.D0*THETA)*COSPHI
      ASPPHI=-DCOS(THETA)*SINPHI
C
      SEST=SINETA*SINTHE
      CEST=COSETA*SINTHE
C
      SESI=SINETA*SINPHI
      SECI=SINETA*COSPHI
      CESI=COSETA*SINPHI
      CECI=COSETA*COSPHI
C
     0SPANG1=-SBCD*COSPHI+SBCPSD*SINPHI-SBSPSD*SINTHE
     1+CBSD*SECI+CBCPCD*SESI-CBSPCD*SEST
     2+CBSP*CESI+CBCP*CEST
     0SPANG2=-SINDEL*CECI-COSPSI*COSDEL*CESI+SINPSI*COSDEL*CEST
     1+SINPSI*SESI+COSPSI*SEST
C
     0ASP=DSQRT((ASPTHE**2)+(ASPPHI**2))*DCOS(DATAN2(SPANG2,SPANG1)+
     1DATAN2(ASPPHI,ASPTHE))*SPFCT
C
      ISTRIK=IAZ-IETA
      IF(ISTRIK.LE.0) ISTRIK=ISTRIK+NS
C
      IF(NODEP.EQ.1) GO TO 345
C
C     USE LITTLES-P/P (OR LITTLES-P/LITTLEP-P)
C
      IF(ISGNP) 310,311,313
C
 310  IF(AP.GT.QSMALL) GO TO 390
      IF(ISGNSP) 320,312,330
C
 311  IF(AP.GT.SMALL) GO TO 312
      IF(AP.LT.QSMALL) GO TO 312
      GO TO 390
C
 312  IF(NODISP.EQ.1) GO TO 320
      GO TO 340
C
 313  IF(AP.LT.SMALL) GO TO 390
      IF(ISGNSP) 330,312,320
C
C     TEST 1
 320  ARAT=ASP/AP
      IF(ARAT.GT.RATMX1) GO TO 390
      IF(ARAT.LT.RATMN1) GO TO 390
      GO TO 380
C
C     TEST 2
 330  ARAT=ASP/AP
      IF(ARAT.GT.RATMX2) GO TO 390
      IF(ARAT.LT.RATMN2) GO TO 390
      GO TO 390
C
C     TEST BOTH
 340  ARAT=ASP/AP
      IF(ARAT.GT.RATMX1) GO TO 341
      IF(ARAT.LT.RATMN1) GO TO 341
      GO TO 380
 341  IF(ARAT.GT.RATMX2) GO TO 390
      IF(ARAT.LT.RATMN2) GO TO 390
      GO TO 380
C
C     USE P/LITTLES-P (OR LITTLEP-P/LITTLES-P)
C
 345  IF(ISGNSP) 346,347,345
C
 346  IF(ASP.GT.QSMALL) GO TO 390
      IF(ISGNP.EQ.1) GO TO 380
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      GO TO 390
C
 347  IF(ASP.GT.SMALL) GO TO 348
      IF(ASP.LT.CSMALL) GO TO 348
      GO TO 390
C
 348  IF(ISGNP.EQ.0) GO TO 350
      GO TO 370
C
 349  IF(ASP.LT.SMALL) GO TO 390
      IF(ISGNP.EQ.-1) GO TO 360
C
C     TEST 1
 350  ARAT=AP/ASP
      IF(ARAT.GT.RATMX1) GO TO 390
      IF(ARAT.LT.RATMN1) GO TO 390
      GO TO 380
C
C     TEST 2
 360  ARAT=AP/ASP
      IF(ARAT.GT.RATMX2) GO TO 390
      IF(ARAT.LT.RATMN2) GO TO 390
      GO TO 380
C
C     TEST BOTH
 370  ARAT=AP/ASP
      IF(ARAT.GT.RATMX1) GO TO 371
      IF(ARAT.LT.RATMN1) GO TO 371
      GO TO 380
 371  IF(ARAT.GT.RATMX2) GO TO 390
      IF(ARAT.LT.RATMN2) GO TO 390
C
C     ACCEPT
C
 380  SSTRIK=DFLOAT(ISTRIK)*DINC
      IF(IPLOT1.NE.0) CALL PLOTV(SPSI,SDELTA,SSTRIK)
      NTRUE=NTRUE+1
      FREAL=FREAL+SINDEL
      IF(IPRNT1.EQ.0) GO TO 300
C
      III(IFILL)=IFIX(SPSI+0.5)
      JJJ(IFILL)=IFIX(SDELTA+0.5)
      KKK(IFILL)=IFIX(SSTRIK+0.5)
      IF (IFILL-10)389,381,381
C
 381  WRITE(6,382)(III(I),JJJ(I),KKK(I),I=1,10)
 382  FORMAT(10(1X,I3,1X,I3,1X,I3,1X))
      IFILL=1
      GO TO 300
C
 389  IFILL=IFILL+1
      GO TO 300
C
C     REJECT
C
 390  I=IPSI-IP1M1
      J=IDELTA-ID1M1
      K=ISTRIK-IS1M1
      IF(.NOT.F(I,J,K)) GO TO 300
      F1=F(I,J,K)
      DO 391 IVL=2,NVLP1
      IF(F1F.EQ.VVLF(IVL)) GO TO 392
 391  CONTINUE
      GO TO 300
 392  F(I,J,K)=VVL(1,IVL-1)
C
 300  CONTINUE
C
C     &&&&&&&&&&
C
C     ..........
C
C     ++++++++++
C
      IF(IE12.EQ.0) GO TO 5000
      IE1=IE12
      IEN=IEN2
      IE12=0
      IEN2=0
      GO TO 301
C
C     -----------                                        -----------
C     SP SP SP SP       P, LITTLES-P (AND LITTLEP-P,     SP SP SP SP
C     -----------         LITTLES-P) SECTION ENDS        -----------
C
C     FLUSH IFILL BUFFER
 5000 IF(IPRNT1.EQ.0) GO TO 510
      IFILL=IFILL-1
      IF(IFILL.NE.0)WRITE(6,382)(III(I),JJJ(I),KKK(I),I=1,IFILL)
C
 510  IF(IPLOT1.EQ.0) GO TO 512
      WRITE(6,511) (ULINE(I),I=1,2)
 511 OFORMAT(/20X,42HFIXED LENGTH VECTORPLOT - HAS BEEN PLOTTED/20X,
     12A8,7H-------)
      NTRU=NTRUE
      CALL TOTAL(NTRU)
      GO TO 514
 512  WRITE(6,513) (ULINE(I),I=1,2)
 513 OFORMAT(/20X,39HFIXED LENGTH VECTORPLOT - NOT REQUESTED/20X,2A8,
     17H-------)
C
 514  FNTRUE=NTRUE
```

```
      FTRUE=FNTRUE/FNCOMB
      S=(FNCOMB-FNTRUE)/FNCOMB
      FREAL=FREAL*FFACT
      SREAL=1.00-FREAL
C
C     OUTPUT SUMMARY OF RESULTS FOR THIS PHASE PAIR
C
      WRITE(6,515) (ULINE(I),I=1,2)
 515  FORMAT(/20X,18HSUMMARY OF RESULTS/20X,2A8,2H--)
      WRITE(6,501) NTRUE,NCOMB,FTRUE,S,FREAL,SREAL
 501 0FORMAT(//10X,I8,' COMBINATIONS OF THE THREE ROTATION ANGLES ACCEPT
     1ABLE OUT OF ',I8//15X,'FRACTION OF FAULT PLANE ORIENTATIONS ACCEPT
     2ABLE = ',F12.9/ 15X,'FRACTION OF FAULT PLANE ORIENTATIONS INCOMPAT
     3IBLE ((NCOMB-NTRUE)/NCOMB) = ',F12.9//15X,'FRACTION OF FAULT PLANE
     4 ORIENTATIONS ACCEPTABLE IN REAL SPACE = ',F12.9/ 15X,'FRACTION OF
     5 FAULT PLANE ORIENTATIONS INCOMPATIBLE IN REAL SPACE (SIGNIFICANCE
     6) = ',F12.9)
      IF(REGION.EQ.BLANK4) WRITE(6,504)
 504 0FORMAT(/15X,'(REGION OF SEARCH INCLUDES ALL OF ORIENTATION SPACE)'
     1)
      IF(REGION.NE.BLANK4) WRITE(6,505) NCOMBR,NCOMB
 505 0FORMAT(/15X,'***REGION OF SEARCH IS RESTRICTED -',I8,' ORIENTATION
     1S OUT OF THE ',I8,' HAVE BEEN TESTED***'/
     215X,'(THE ABOVE STATISTICS ASSUME THAT THERE ARE NO ADDITIONAL COM
     3PATIBLE ORIENTATIONS OUTSIDE THE REGION OF SEARCH)')
     0IF(IDEV3.GT.0) WRITE(NDEV3,511) STANAM,AZI,DIST,ALPHA,GAMMA,SIGNP,
     1PAZIN,PAIIN,SIGNPP,PPAZIN,PPAIIN,PPECTI,SPECTI,PHASES
      IF(IDEV3.GT.0) WRITE(NDEV3,506) NTRUE,S,SREAL
 506 0FORMAT(26HNO. OF COMPATIBLE ORTNS. =,I6,37H,  FRACTION OF ORTNS. I
     1NCOMPATIBLE = ,F11.9/65HFRACTION OF ORIENTATIONS INCOMPATIBLE IN R
     2EAL SPACE (SIGNIFICANCE) = ,F11.9)
C
      GO TO 7000
C
C     OCCCCOCCC                                                CCCCCCCCC
C
 599  IF(IOP.NE.NOP) GO TO 800
C
 7000 IF(IOP.EQ.1.AND.NOP.NE.1) GO TO 800
C
C     PRINT AND PLOT CUMULATIVE ACCEPTABLE ORIENTATIONS/
C     --------------------------------------------------
C     PRINT AND PLOT ORIENTATIONS COMPATIBLE WITH ALL PHASE PAIRS
C     -----------------------------------------------------------
C
C
      IPRNTN=IPRNT2
      IF(IOP.EQ.NOP) IPRNTN=IPRNT4
      IPLOTN=IPLOT2
      IF(IOP.EQ.NOP) IPLOTN=IPLOT4
C
C     PRINTOUT, VECTORPLOT AND COMPUTATION OF SUMMARY OF RESULTS
C
      IF(IOP.NE.NOP) WRITE(6,701) (ULINES(I),I=1,4)
 701  FORMAT(/15X,34HCUMULATIVE ACCEPTABLE ORIENTATIONS/15X,4A8,2H==)
      IF(IOP.EQ.NOP) WRITE(6,741) (ULINES(I),I=1,5)
 741 0FORMAT(1H1,14X,44HORIENTATIONS COMPATIBLE WITH ALL PHASE PAIRS/
     115X,5A8,4H====)
      IF(IPRNTN.EQ.0) GO TO 711
      WRITE(6,8(9) (ULINE(I),I=1,4)
      WRITE(6,85 )
      IFILL=1
      GO TO 712
 711  WRITE(6,8 7) (ULINE(I),I=1,4)
 712  IF(IPLOTN.EQ.0) GO TO 713
     0IF(IOP.NE.NOP)
     1CALL S  PV(TITLE,40HCUMULATIVE ACCEPTABLE ORIENTATIONS        ,
     28HSLIP ANG,8H     DIP,8H  STRIKE,SPSII,SPINC,SPSIN,SDELTI,SDINC,
     3SDELTN,SSTRKI,SSINC,SSTRKN,3)
     0IF(IOP.EQ.NOP)
     1CALL S   PV(TITLE,40HORIENTATIONS CPTIBLE WITH ALL PHSE PRS ,
     28HSLIP ANG,8H     DIP,8H  STRIKE,SPSII,SPINC,SPSIN,SDELTI,SDINC,
     3SDELTN,SSTRKI,SSINC,SSTRKN,3)
C
 713  NTRUE=0
      FREAL=0.00
      DO 700 IPSI=IPI,IPN
      DO 700 IDELTA=IDI,IDN
      DO 700 ISTRIK=ISI,ISN
      FI=FI(IPSI-IPIM1,IDELTA-IDIM1,ISTRIK-ISIM1)
      IF(FIK.NE.VVLR(NVLFI)) GO TO 700
      IF(IPLOTN.EQ.0) GO TO 714
      SPSI=FLOAT(IPSI)*CINC
      SDELTA=FLOAT(IDELTA)*CINC
      SSTRIK=FLOAT(ISTRIK)*CINC
      CALL PLOTV(SPSI,SDELTA,SSTRIK)
 714  NTRUE=NTRUE+1
      FREAL=FREAL+SINTAB(IDELTA)
      IF(IPRNTN.EQ.0) GO TO 700
      III(IFILL)=IFIX(SPSI+0.5)
      JJJ(IFILL)=IFIX(SDELTA+0.5)
      KKK(IFILL)=IFIX(SSTRIK+0.5)
      IF(IFILL-10) 703,702,702
 702  WRITE(6,812)(III(I),JJJ(I),KKK(I),I=1,10)
      IFILL=1
      GO TO 700
C
 703  IFILL=IFILL+1
 700  CONTINUE
C
C     FLUSH IFILL BUFFER
      IF(IPRNTN.EQ.0) GO TO 704
```

```
      IFILL=IFILL-1
      IF(IFILL.NE.0)WRITE(6,482)(III(I),JJJ(I),KKK(I),I=1,IFILL)
C
 704  IF(IPLOTN.NE.0) WRITE(6,511) (ULINE(I),I=1,2)
      IF(IPLOTN.EQ.0) WRITE(6,513) (ULINE(I),I=1,2)
      NTRU=NTRUE
      IF(IPLOTN.NE.0) CALL TOTAL(NTRU)
      FNTRUE=NTRUE
      FTRUE=FNTRUE/FNCOMB
      S=(FNCOMB-FNTRUE)/FNCOMB
      FREAL=FREAL*FFACT
      SREAL=1.D0-FREAL
C
C     OUTPUT SUMMARY OF RESULTS
C
      WRITE(6,515) (ULINE(I),I=1,2)
      WRITE(6,501) NTRUE,NCOMB,FTRUE,S,FREAL,SREAL
      IF(REGION.EQ.BLANK4) WRITE(6,504)
      IF(REGION.NE.BLANK4) WRITE(6,505) NCOMBR,NCOMB
C
C     PRINT AND PLOT CUMULATIVE PARTIALLY ACCEPTABLE ORIENTATIONS/
C     ------------------------------------------------------------
C     PRINT AND PLOT ORIENTATIONS PARTIALLY COMPATIBLE WITH ALL
C     --------------------------------------------------------
C     PHASE PAIRS
C     -----------
C
      IPRNTN=IPRNT3
      IF(IOP.EQ.NOP) IPRNTN=IPRNT5
      IPLOTN=IPLOT3
      IF(IOP.EQ.NOP) IPLOTN=IPLOT5
C
      IF(IOP.NE.NOP) WRITE(6,716) (ULINES(I),I=1,5)
 716 0FORMAT(//15X,44HCUMULATIVE PARTIALLY ACCEPTABLE ORIENTATIONS/15X,
     15A8,4H****)
      IF(IOP.EQ.NOP) WRITE(6,746) (ULINES(I),I=1,6)
 746 0FORMAT(1H1,14X,54HORIENTATIONS PARTIALLY COMPATIBLE WITH ALL PHASE
     1 PAIRS/15X,6A8,6H******)
      IF(IPRNTN.EQ.0) GO TO 723
C
C     PRINTOUT
C
      WRITE(6,726) (ULINE(I),I=1,5)
 726 0FORMAT(/20X,45HPRINTOUT OF PARTIALLY COMPATIBLE ORIENTATIONS/20X,
     15A8,5H-----)
      IF(IOP.NE.NOP) WRITE(6,731) IOBS
 731 0FORMAT( //20X,'ORIENTATIONS COMPATIBLE WITH ALL THE ',I3,
     1' PHASE PAIRS SO FAR PROCESSSD')
      IF(IOP.EQ.NOP) WRITE(6,732) IOBS
 732 0FORMAT( //20X,'ORIENTATIONS COMPATIBLE WITH ALL THE ',I3,
     1' PHASE PAIRS')
C
      DO 739 II=1,NVL
      IF(II.GT.IOBS) GO TO 724
      IVL=NVL-II+1
      IIM1=II-1
      IF(IOP.NE.NOP.AND.IVL.NE.NVL) WRITE(6,733) IIM1,IOBS
 733 0FORMAT( //20X,'ORIENTATIONS INCOMPATIBLE WITH ',I3,' OF THE ',I3,
     1' PHASE PAIRS SO FAR PROCESSED')
      IF(IOP.EQ.NOP.AND.IVL.NE.NVL) WRITE(6,734) IIM1,IOBS
 734 0FORMAT( //20X,'ORIENTATIONS INCOMPATIBLE WITH ',I3,' OF ALL THE ',
     1I3,' PHASE PAIRS')
      WRITE(6,897)
      IFILL=1
C
      DO 738 IPSI=IP1,IPN
      DO 738 IDELTA=ID1,IDN
      DO 738 ISTRIK=IS1,ISN
      I=IPSI-IP1M1
      J=IDELTA-ID1M1
      K=ISTRIK-IS1M1
      FI=F(I,J,K)
      IF(FIR.NE.VVL(IVL+1)) GO TO 738
      SPSI=DFLOAT(IPSI)*DINC
      SDELTA=DFLOAT(IDELTA)*DINC
      SSTRIK=DFLOAT(ISTRIK)*DINC
      III(IFILL)=IFIX(SPSI+0.5)
      JJJ(IFILL)=IFIX(SDELTA+0.5)
      KKK(IFILL)=IFIX(SSTRIK+0.5)
      IF(IFILL-10) 737,736,736
 736  WRITE(6,482) (III(I),JJJ(I),KKK(I),I=1,10)
      IFILL=1
      GO TO 738
 737  IFILL=IFILL+1
 738  CONTINUE
C
C     FLUSH IFILL BUFFER
      IFILL=IFILL-1
      IF(IFILL.NE.0) WRITE(6,482) (III(I),JJJ(I),KKK(I),I=1,IFILL)
C
 739  CONTINUE
      GO TO 724
C
C     VECTORPLOT AND COMPUTATION OF SUMMARY OF RESULTS
C
 723  WRITE(6,727) (ULINE(I),I=1,5)
 727 0FORMAT(/20X,61HPRINTOUT OF PARTIALLY COMPATIBLE ORIENTATIONS - NOT
     1 REQUESTED/20X,5A8,5H-----)
 724  IF(IPLOTN.EQ.0) GO TO 725
     0IF(IOP.NE.NOP)
     1CALL SETUPV(TITLE,40HCUMULATIVE PARTIALLY ACCEPTABLE ORIENT'NS ,
     28HSLIP ANG,8H      DIP,8H  STRIKE,SPSI1,SPINC,SPSIN,SDELT1,SDINC,
```

```
     3SDELTN,SSTRK1,SSINC,SSTRKN,3)
     0IF(IOP.EQ.NOP)
     1CALL SETUPV(TITLE,40HCPTNS PRTIALY CMPTBLE WITH ALL PHSE PRS ,
     28HSLIP ANG,8H      DIP,8H  STRIKE,SPSI1,SPINC,SPSIN,SDELT1,SDINC,
     3SDELTN,SSTRK1,SSINC,SSTRKN,3)
      CALL SETUPL(NVL)
 725  IVL1=NVL-ICBS+1
      DO 717 I=1,NVL
 717  NTRUES(I)=0
C
      DO 720 IPSI=IP1,IPN
      DO 720 IDELTA=ID1,IDN
      DO 720 ISTRIK=IS1,ISN
      I=IPSI-IP1M1
      J=IDELTA-ID1M1
      K=ISTRIK-IS1M1
      IF(.NOT.F(I,J,K)) GO TO 720
      F1=F(I,J,K)
C
      DO 718 IVL=1,NVL
      IF(F1P.EQ.VVLR(IVL+1)) GO TO 719
 718  CONTINUE
C
 719  IF(IVL.LT.IVL1) GO TO 720
      NTRUES(IVL)=NTRUES(IVL)+1
      IF(IPLOTN.EQ.0) GO TO 720
      SPSI=DFLOAT(IPSI)*DINC
      SDELTA=DFLOAT(IDELTA)*DINC
      SSTRIK=DFLOAT(ISTRIK)*DINC
      CALL PLCTVL(SPSI,SDELTA,SSTRIK,IVL)
 720  CONTINUE
C
      IF(IPLOTN.NE.0) WRITE(6,728) (ULINE(I),I=1,3)
 728 0FORMAT(/20X,45HVARIABLE LENGTH VECTORPLOT - HAS BEEN PLOTTED/
     120X,3A8,2H--)
      IF(IPLOTN.NE.0) CALL TOTALS
      IF(IPLOTN.EQ.0) WRITE(6,729) (ULINE(I),I=1,3)
 729 0FORMAT(/20X,42HVARIABLE LENGTH VECTORPLOT - NOT REQUESTED/20X,3A8,
     12H--)
C
C     OUTPUT OF SUMMARY OF RESULTS
C
      WRITE(6,519) (ULINE(I),I=1,2)
     0IF(IOP.NE.NOP)
     1WRITE(6,721) NTRUES(NVL),NCOMB,ICBS
 721 0FORMAT(/10X,I8,' ORIENTATIONS OUT OF THE ',I8,' ARE COMPATIBLE WIT
     1H ALL THE ',I3,' PHASE PAIRS SO FAR PROCESSED')
     0IF(IOP.EQ.NOP)
     1WRITE(6,705) NTRUES(NVL),NCOMB,ICBS
 705 0FORMAT(/10X,I8,' ORIENTATIONS OUT OF THE ',I8,' ARE COMPATIBLE WIT
     1H ALL THE ',I3,' PHASE PAIRS')
 722 0FORMAT(10X,I8,' ORIENTATIONS OUT OF THE ',I8,' ARE INCOMPATIBLE WI
     1TH ',I3,' OF THE ',I3,' PHASE PAIRS SO FAR PROCESSED')
 706 0FORMAT(10X,I8,' ORIENTATIONS OUT OF THE ',I8,' ARE INCOMPATIBLE WI
     1TH ',I3,' OF ALL THE ',I3,' PHASE PAIRS')
C
      IF(NVL.EQ.1) GO TO 740
      DO 730 I=2,NVL
      IF(I.GT.ICBS) GO TO 740
      IVL=NVL-I+1
      IM1=I-1
     0IF(IOP.NE.NOP)
     1WRITE(6,722) NTRUES(IVL),NCOMB,IM1,ICBS
     0IF(IOP.EQ.NOP)
     1WRITE(6,706) NTRUES(IVL),NCOMB,IM1,ICBS
 730  CONTINUE
C
 740  IF(REGION.EQ.BLANK4) WRITE(6,504)
      IF(REGION.NE.BLANK4) WRITE(6,505) NCOMBR,NCOMB
C
C     OUTPUT TO THIRD OUTPUT DEVICE
C
      IF(IOP.NE.NOP.OR.IDEV3.LE.0) GO TO 800
      WRITE(NDEV3,751) ICBS
 751  FORMAT(/30HTOTAL NUMBER OF PHASE PAIRS = ,I3)
      WRITE(NDEV3,506) NTRUE,S,SREAL
      IF(IDEV3.EQ.1) GO TO 761
      NTOT=0
      DO 752 IVL=1,NVL
 752  NTOT=NTOT+NTRUES(IVL)
      WRITE(NDEV3,753) NTOT
 753 0FORMAT(1HLIST OF ALL THE ,I7,57H COMPATIBLE AND PARTIALLY COMPATI
     1BLE ORIENTATIONS FOLLOWS/80HFORMAT - (SA=SLIP ANGLE, DIP=DIP, STK=
     2STRIKE, N=NO. OF INCOMPATIBLE PHASE PAIRS)/80H  SA DIP STK  N/ SA
     3DIP STK  N/ SA DIP STK  N/ SA DIP STK  N/ SA DIP STK  N CARD)
C
      ICARD=0
      IFILL=1
      DO 760 IPSI=IP1,IPN
      DO 760 IDELTA=ID1,IDN
      DO 760 ISTRIK=IS1,ISN
      I=IPSI-IP1M1
      J=IDELTA-ID1M1
      K=ISTRIK-IS1M1
      IF(.NOT.F(I,J,K)) GO TO 760
      F1=F(I,J,K)
C
      DO 758 IVL=1,NVL
      IF(F1P.EQ.VVLR(IVL+1)) GO TO 759
 758  CONTINUE
C
 759  IF(IVL.LT.IVL1) GO TO 760
```

```
      SPSI=DFLOAT(IPSI)*CINC
      SDELTA=DFLOAT(IDELTA)*CINC
      SSTRIK=DFLOAT(ISTRIK)*CINC
      III(IFILL)=IFIX(SPSI+0.5)
      JJJ(IFILL)=IFIX(SDELTA+0.5)
      KKK(IFILL)=IFIX(SSTRIK+0.5)
      IVLN(IFILL)=NVL-IVL
  755 FORMAT(1X,I3,1X,I3,1X,I3,I3,4(1H/,I3,1X,I3,1X,I3,I3),I5)
      IF(IFILL-5) 757,756,756
  756 ICARD=ICARD+1
      WRITE(NDEV3,755) (III(I),JJJ(I),KKK(I),IVLN(I),I=1,5),ICARD
      IFILL=1
      GO TO 760
  757 IFILL=IFILL+1
  760 CONTINUE
C
C     FLUSH IFILL BUFFER
      IF(IFILL.EQ.1) GO TO 761
      DO 765 I=IFILL,5
      III(I)=0
      JJJ(I)=0
      KKK(I)=0
      IVLN(I)=0
  765 CONTINUE
      ICARD=ICARD+1
      WRITE(NDEV3,755) (III(I),JJJ(I),KKK(I),IVLN(I),I=1,5),ICARD
C
  761 WRITE(NDEV3,762) END
  762 FORMAT(A4)
C
  800 CONTINUE
C
C     ----------
C
      GO TO 1111
C
C     ..........                                                 ..........
C
 9999 CALL ENDJOB
      STOP
      END
```

APPENDIX I

LISTING OF PLOTTING SUBROUTINE (PLOTV)

```
 PLOTV
 -----

 MODIFIED 6/12/78 TO REMOVE CUMULATIVE RECORD OF VECTORS PLOTTED

 SUBROUTINE PLOTV(A,B,C)
 ENTRY SETUPV(TITLE,TITLEF,ANAME,BNAME,CNAME,A1,AI,AN,B1,BI,BN,C1,
1CI,CN,IF)
 ENTRY TOTAL(N)
 ENTRY SETUPL(NVL)
 ENTRY PLOTVL(A,B,C,L)
 ENTRY TOTALS

 THIS SUBROUTINE PLOTS SELECTED COMBINATIONS OF THE ANGLES A,B,C
 WITH A AS THE ABSCISSA, B AS THE DOWNWARD ORDINATE AND C AS A
 UNIT VECTOR OF ROTATION ABOUT THE POINT A,B CLOCKWISE FROM THE
 UPWARD VERTICAL.   FOR EACH FRAME TO BE PLOTTED, THE VECTORS CAN
 BE OF FIXED LENGTH, OR OF DISCRETE VARIABLE LENGTH L (TO REPRESENT
 A FOURTH VARIABLE WHICH CAN ASSUME SEVERAL VALUES).   WHEN USING
 THIS OPTION L CAN TAKE VALUES FROM 1 TO A MAXIMUM, NVL.   THE
 EQUIVALENT VECTOR LENGTHS ARE SCALED TO LIE BETWEEN ZERO (FOR L=0)
 AND THE MAXIMUM LENGTH (FOR L=NVL)

 METHOD OF USE
 ------ -- ---

 FOR EACH FRAME TO BE PLOTTED, EITHER THE FIXED VECTOR LENGTH
 OPTION OR THE VARIABLE VECTOR LENGTH OPTION MAY BE USED

 (A)   FIXED VECTOR LENGTH OPTION
       --------------------------

 FIRST
 -----
 CALL  SETUPV(TITLE,TITLEF,ANAME,BNAME,CNAME,A1,AI,AN,B1,BI,BN,C1,
1CI,CN,IF) TO SET UP THE PLOTTING FRAME

 TITLE   TITLE OF DATA BEING PROCESSED (REAL*8 TITLE(10))
 TITLEF  TITLE OF THE FRAME (REAL*8 TITLEF(5))
 ANAME   NAME OF THE A VARIABLE (REAL*8)
 BNAME   NAME OF THE B VARIABLE (REAL*8)
 CNAME   NAME OF THE C VARIABLE (REAL*8)
 A1      LOWEST A VALUE TO BE INCLUDED ON PLOT (DEGREES)
 AI      INCREMENT OF A VALUE TO BE USED ON PLOT (DEGREES)
 AN      HIGHEST A VALUE TO BE INCLUDED ON PLOT (DEGREES)
 B1      LOWEST B VALUE TO BE INCLUDED ON PLOT (DEGREES)
 BI      INCREMENT OF B VALUE TO BE USED ON PLOT (DEGREES)
 BN      HIGHEST B VALUE TO BE INCLUDED ON PLOT (DEGREES)
 C1      LOWEST C VALUE TO BE INCLUDED ON PLOT (DEGREES)
 CI      INCREMENT OF C VALUE TO BE USED ON PLOT (DEGREES)
 CN      HIGHEST C VALUE TO BE INCLUDED ON PLOT (DEGREES)
 IF      ADVFLM ARGUMENT

 SECONDLY
 --------
 CALL PLOTV(A,B,C) FOR EACH SET OF VALUES TO BE PLOTTED
 (TO SAVE TIME THIS CALL DOES NOT INCLUDE PROTECTION AGAINST
 ARGUMENTS SPECIFIED OUTSIDE THE RANGE INITIATED BY CALL SETUPV,
 OR LYING BETWEEN INCREMENTS)

 FINALLY (OPTIONAL)
 -------
 CALL TOTAL(N)    FLUSHES OUTPUT BUFFER AND SIGNIFIES COMPLETION OF
 THE FRAME BY DISPLAYING N (THE NUMBER OF POINTS PLOTTED) ON THE
 TOP RIGHT-HAND CORNER OF THE PLOT.   N IS SUPPLIED BY THE CALLING
 PROGRAM

 (B)   VARIABLE VECTOR LENGTH OPTION
       -----------------------------

 FIRST
 -----
 CALL SETUPV...  (AS ABOVE) )

 SECONDLY
 --------
 CALL SETUPL(NVL) WHERE NVL IS THE NUMBER OF DISCRETE VECTOR
 LENGTHS REQUIRED (MAXIMUM VALUE OF NVL IS GOVERNED BY THE
 DIMENSION OF THE ARRAY NT1 BELOW).   NOTE - IN PRACTICE, WHEN FINE
 INCREMENTS OF A OR B ARE USED, ONLY SEVERAL DISCRETE LENGTHS MAY
 BE RESOLVABLE VISUALLY ON THE PLOT

 THIRDLY
 -------
 CALL PLOTVL(A,B,C,L) FOR EACH SET OF VALUES TO BE PLOTTED
 (TO SAVE TIME THIS CALL DOES NOT INCLUDE PROTECTION AGAINST
 ARGUMENTS SPECIFIED OUTSIDE THE RANGE INITIATED BY CALL SETUPV,
 OR LYING BETWEEN INCREMENTS)

 FINALLY (OPTIONAL)
 -------
 CALL TOTALS    FLUSHES OUTPUT BUFFER AND SIGNIFIES COMPLETION OF
 THE FRAME BY DISPLAYING NVL (THE NUMBER OF VECTOR LENGTHS) ON THE
 TOP RIGHT-HAND CORNER OF THE PLOT

 NOTE - COMMON/P/PI1, WHERE PI1='PI'/180.0, MUST BE SET UP OUTSIDE
 THIS SUBROUTINE

 SUBROUTINE PLOTV(A,B,C)
 DOUBLE PRECISION TITLE(10),TITLEF(5),ANAME,BNAME,CNAME
 COMMON/P/PI1
```

```
C
C       PLOT VECTOR
C
        X=XC+A*XF
        Y=YC+B*YF
        IX=X
        IY=Y
        IXV=X+VL*SIN(C*PI1)
        IYV=Y-VL*COS(C*PI1)
        CALL VECTOR(IX,IY,IXV,IYV)
  999   RETURN
C
        ENTRY TOTAL(N)
        M=N
        CALL TSP(964,48,8)
        CALL HORAM(2HN=,2)
        CALL IFORM(M,5)
        CALL ENDFME
        GO TO 999
C
        ENTRY PLOTVL(A,B,C,L)
        X=XC+A*XF
        Y=YC+B*YF
        IX=X
        IY=Y
        FL=L
        VLL=VL1*FL
        IXV=X+VLL*SIN(C*PI1)
        IYV=Y-VLL*COS(C*PI1)
        CALL VECTOR(IX,IY,IXV,IYV)
        RETURN
C
        ENTRY TOTALS
        CALL TSP(964,48,8)
        CALL HORAM(4HNVL=,4)
        CALL IFORM(NVL1,3)
        CALL ENDFME
        GO TO 999
C
        ENTRY SETUPV(TITLE,TITLEF,ANAME,BNAME,CNAME,A1,AI,AN,B1,BI,BN,C1,
       1CI,CN,IF)
C
C       PROTECTION
C
        IF(AI) 10,11,12
   10   AI=-AI
        GO TO 12
   11   AI=1.
   12   IF(AN-A1)15,17,17
   15   Q=A1
        A1=AN
        AN=Q
   17   AN=AN+AMOD((AN-A1),AI)
C
        IF(BI)20,21,22
   20   BI=-BI
        GO TO 22
   21   BI=1.
   22   IF(BN-B1) 25,27,27
   25   Q=B1
        B1=BN
        BN=Q
   27   BN=BN+AMOD((BN-B1),BI)
C
        IF(CI) 30,31,32
   30   CI=-CI
        GO TO 32
   31   CI=1.
   32   IF(CN-C1) 35,37,37
   35   Q=C1
        C1=CN
        CN=Q
   37   CN=CN+AMOD((CN-C1),CI)
C
C       SET UP FRAME
C
        CALL ADVFLM(IF)
        CALL TSP(-4,48,8)
        CALL HORAM(TITLE,80)
        CALL HORAM(1H ,1)
        CALL HORAM(TITLEF,40)
C
        CALL TSP(-4,48,24)
        CALL HORAM(ANAME,8)
        CALL HORAM(9H-ACROSS (,9)
        CALL FFORM(A1,6,1)
        CALL HORAM(1H,,1)
        CALL FFORM(AI,6,2)
        CALL HORAM(1H,,1)
        CALL FFORM(AN,6,1)
        CALL HORAM(4H)    ,4)
        CALL HORAM(BNAME,8)
        CALL HORAM(7H-DOWN (,7)
        CALL FFORM(B1,6,1)
        CALL HORAM(1H,,1)
        CALL FFORM(BI,6,2)
        CALL HORAM(1H,,1)
        CALL FFORM(BN,6,1)
        CALL HORAM(4H)    ,4)
        CALL HORAM(CNAME,8)
        CALL HORAM(19H-CLOCKWISE (UP=0) (,19)
        CALL FFORM(C1,6,1)
```

```
      CALL HORAM(1H,,1)
      CALL FFORM(CI,6,2)
      CALL HORAM(1H,,1)
      CALL FFORM(CN,6,1)
      CALL HORAM(1H),1)
C
C     SET UP SCALE FACTORS
C
      X1=16.
      XN=1007.
      XF=(XN-X1)/(AN-A1+AI)
      XVL=XF*AI/2.
      XC=X1+XVL-A1*XF
C
      Y1=32.
      YN=1023.
      YF=(YN-Y1)/(BN-B1+BI)
      YVL=YF*BI/2
      VL=XVL
      IF(XVL.GT.YVL) VL=YVL
      YC=Y1+YVL-B1*YF
      IP=4
C
C     PLOT GRID
C
      NI=(AN-A1)/AI+1.5
      NJ=(BN-B1)/BI+1.5
      DO 40 I=1,NI
      IXP=XC+(A1+FLOAT(I-1)*AI)*XF
      DO 40 J=1,NJ
      IYP=YC+(B1+FLOAT(J-1)*BI)*YF
      CALL VECTOR(IXP-IP,IYP,IXP+IP,IYP)
      CALL VECTOR(IXP,IYP-IP,IXP,IYP+IP)
   40 CONTINUE
      GO TO 999
C
      ENTRY SETUPL(NVL)
      NVL1=NVL
      FNVL=NVL1
      VL1=VL/FNVL
      GO TO 999
      END
```

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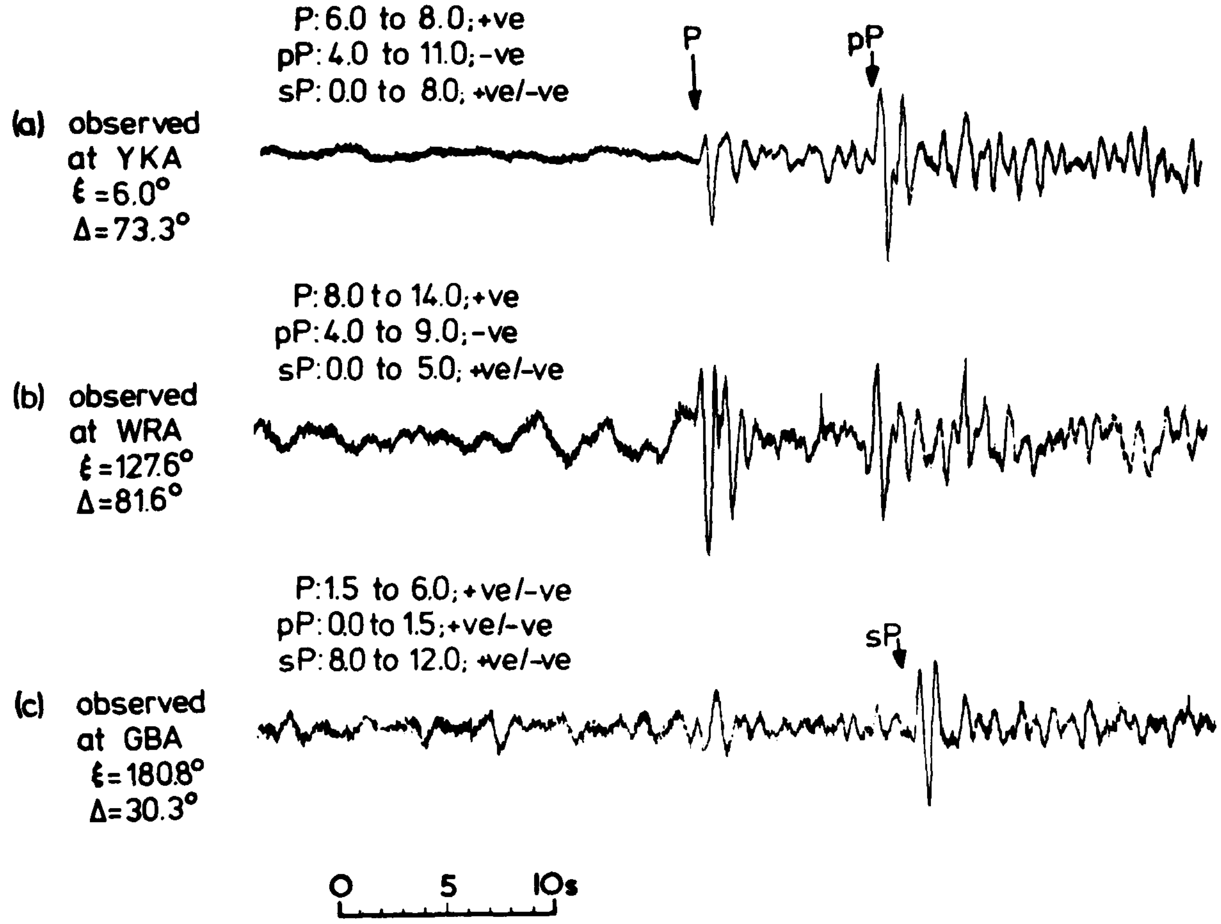

FIGURE 1. THREE TELESEISMIC SHORT PERIOD ARRAY OBSERVATIONS OF THE 1 MAY 1969 EAST KAZAKHSTAN EARTHQUAKE, ORIGIN TIME 04.00.08.7, LOCATION 43.98°N, 77.86°E AND BODY WAVE MAGNITUDE m_b = 4.9 (NEIS PARAMETERS). ξ AND Δ CORRESPOND TO AZIMUTH OF THE STATION FROM THE EARTHQUAKE AND EPICENTRAL DISTANCE RESPECTIVELY. PRESUMED PHASE IDENTIFICATIONS AND THEIR POSSIBLE AMPLITUDES (IN ARBITRARY UNITS) ARE SHOWN

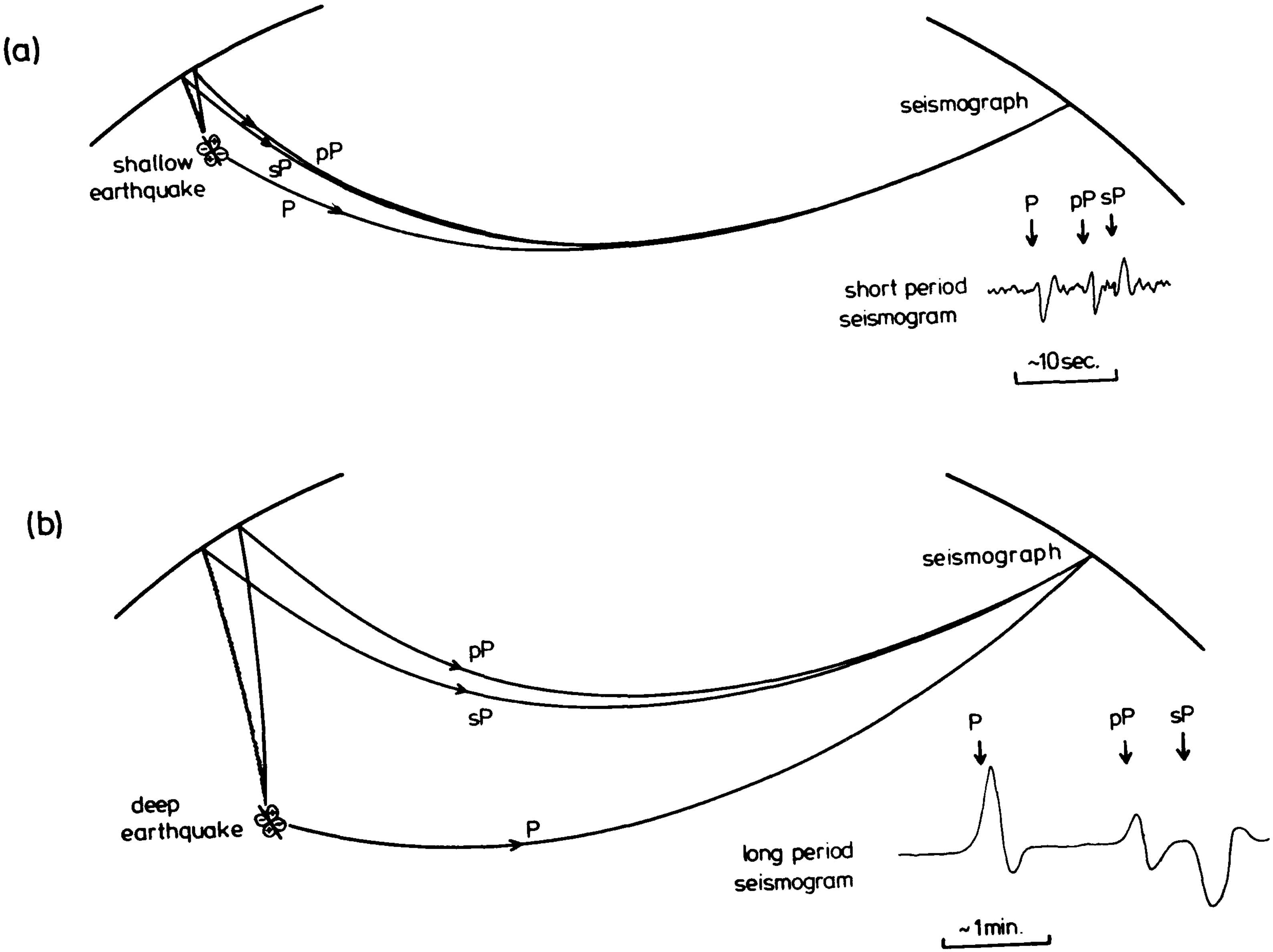

FIGURE 2. THE RELATIVE AMPLITUDE METHOD FOR (a) SHALLOW AND (b) DEEP EARTHQUAKES (DIAGRAMMATIC - NOT DRAWN TO SCALE)

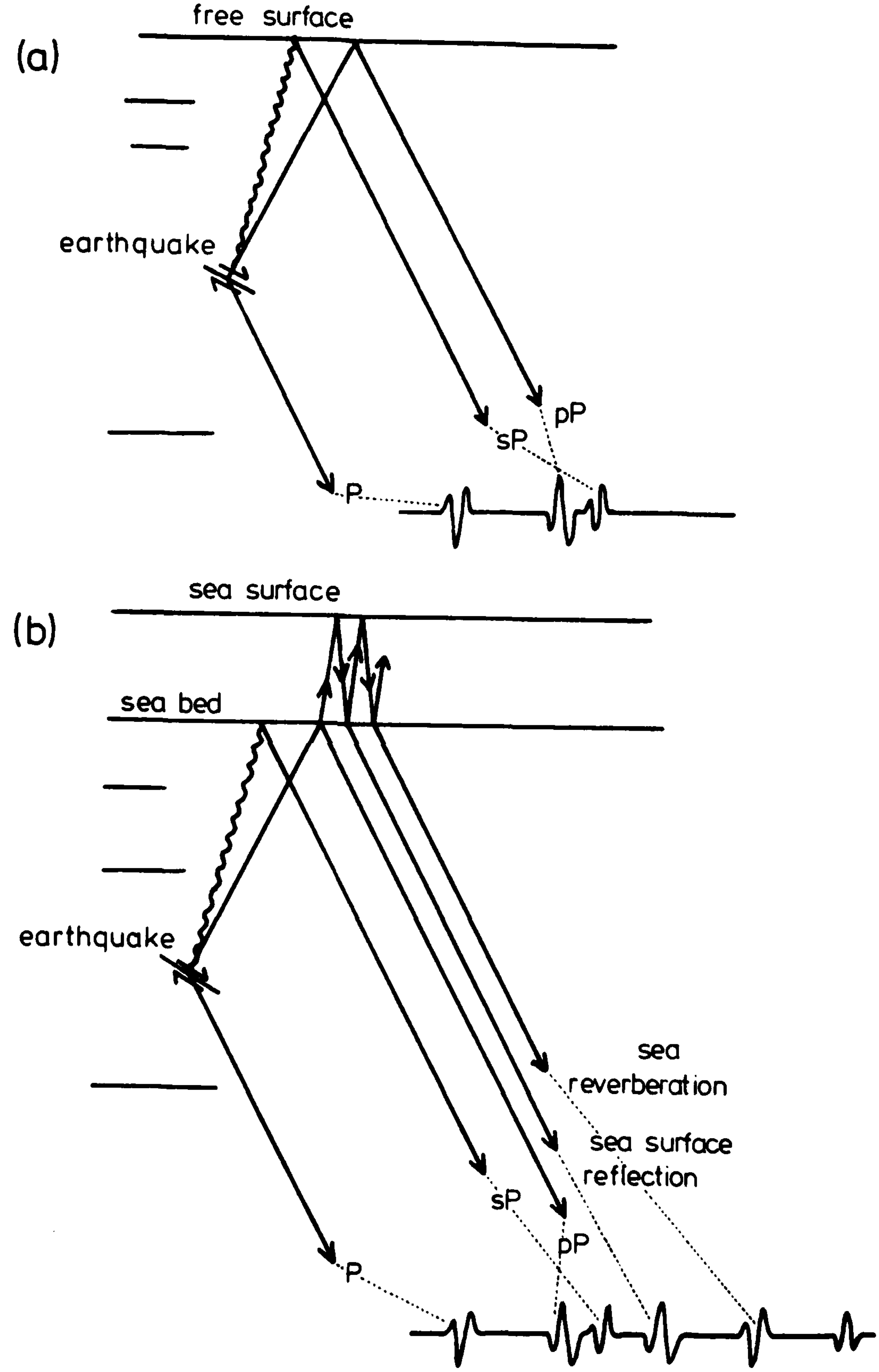

FIGURE 3. SURFACE REFLECTED PHASES FOR EARTHQUAKES (a) BENEATH LAND AND (b) BENEATH THE SEA. THE SEPARATE SEA BED AND SEA SURFACE P WAVE REFLECTIONS WOULD NOT NORMALLY BE RESOLVED ON A LONG PERIOD SEISMOGRAM

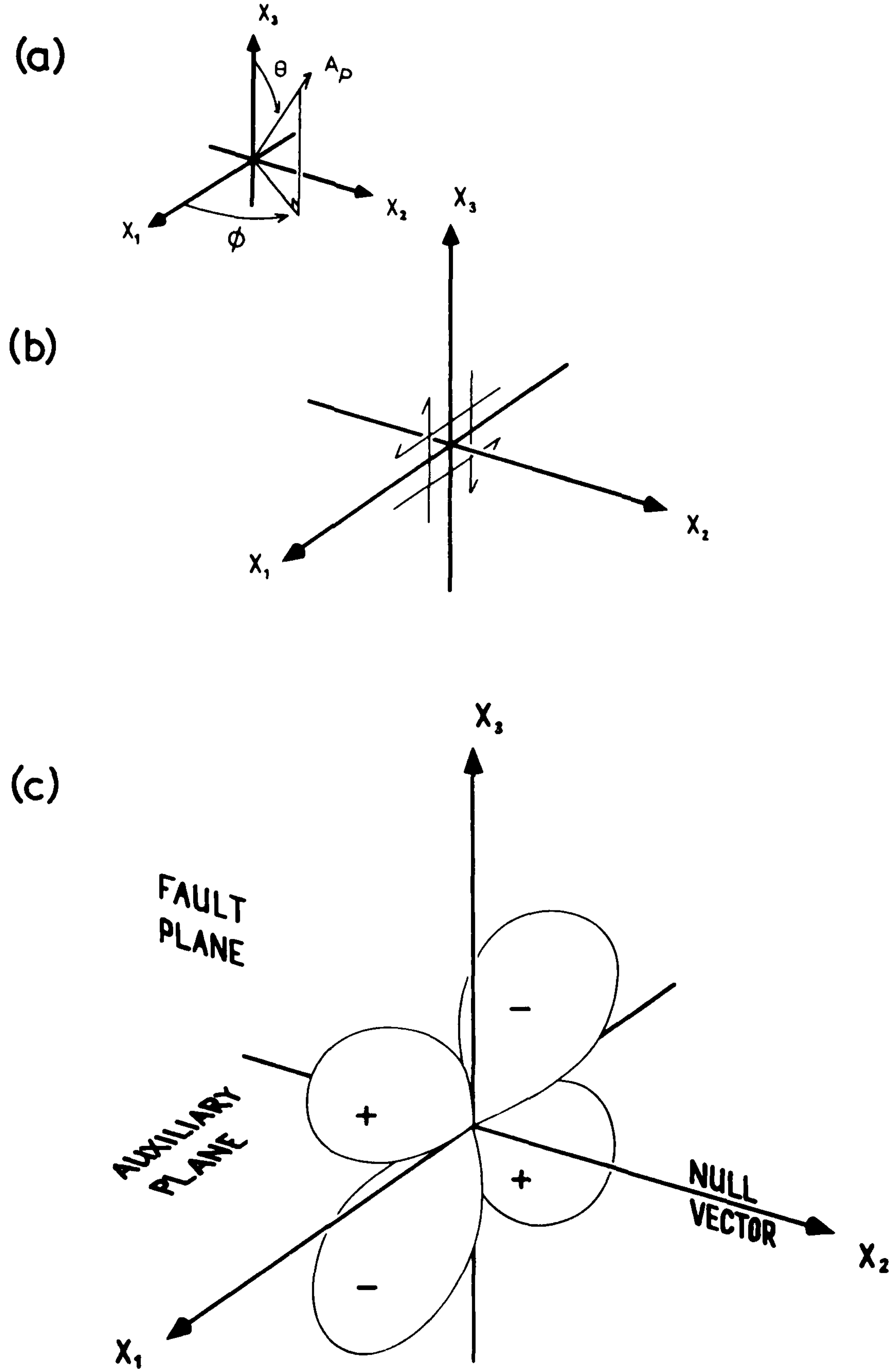

FIGURE 4. THE DOUBLE COUPLE SOURCE MECHANISM: (a) CO-ORDINATE SYSTEM USED; (b) DOUBLE COUPLE FORCE SYSTEM WITH THE PLANE X_2X_3 AS THE FAULT PLANE; (c) THE P WAVE AMPLITUDE RADIATION PATTERN IN THE FAR FIELD SHOWN AS A THREE-DIMENSIONAL POLAR DIAGRAM. ALL PARTICLE MOTION IS RADIAL, ie, IN THE DIRECTION OF PROPAGATION

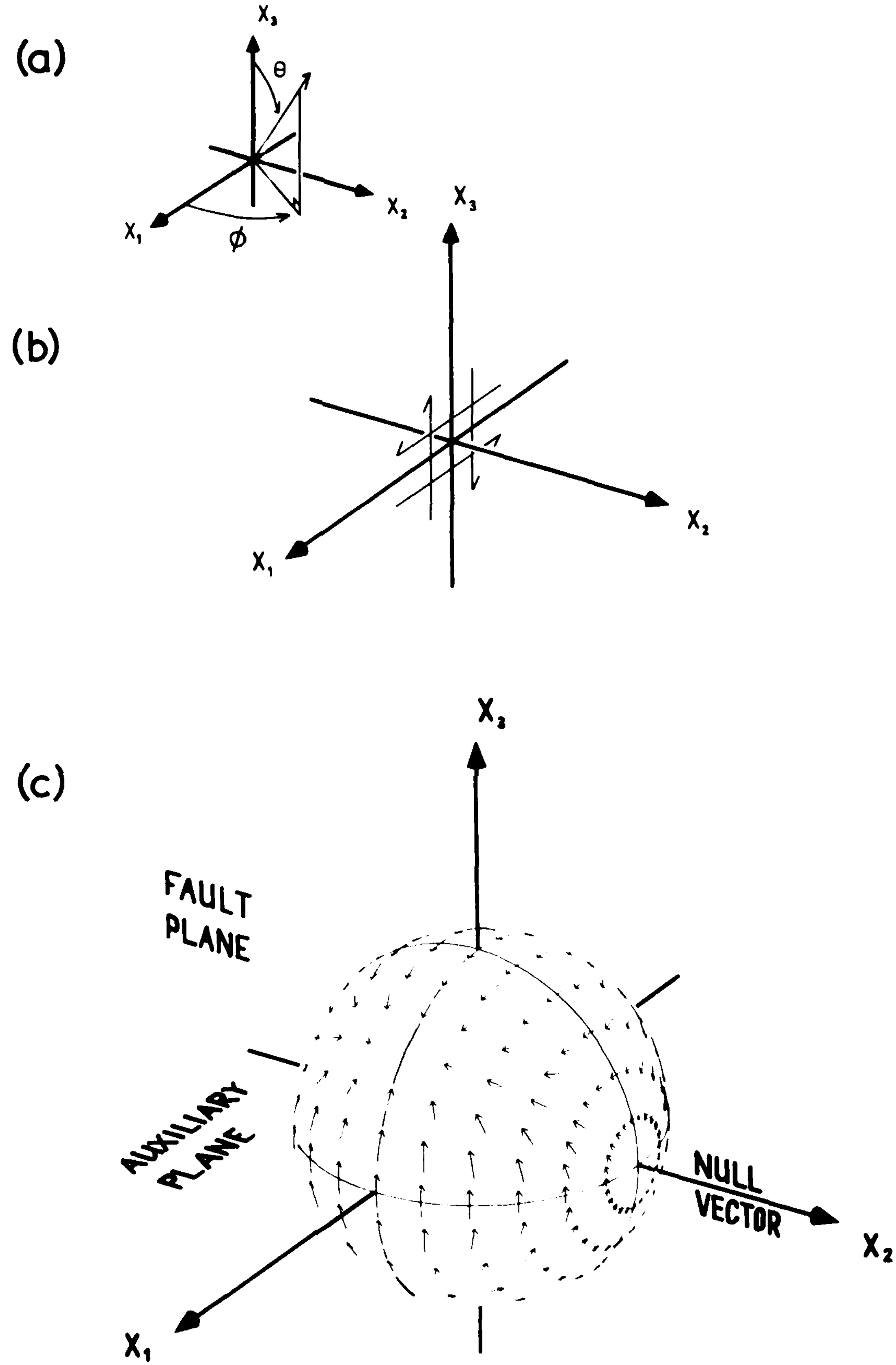

FIGURE 5. THE DOUBLE COUPLE SOURCE MECHANISM: (c) SHOWS THE FAR FIELD S WAVE RADIATION PATTERN. SINCE PARTICLE MOTION IS PERPENDICULAR TO THE PROPAGATION DIRECTION, THE AMPLITUDE AND POLARISATION DIRECTION IN ANY PROPAGATION DIRECTION CAN BE PLOTTED ON THE SURFACE OF A SPHERE CONCENTRIC WITH THE SOURCE. CORRESPONDING AMPLITUDE VECTORS FOR A RANGE OF DIRECTIONS ARE SHOWN ON A THREE-DIMENSIONAL PLOT (ORTHOGONAL PROJECTION)

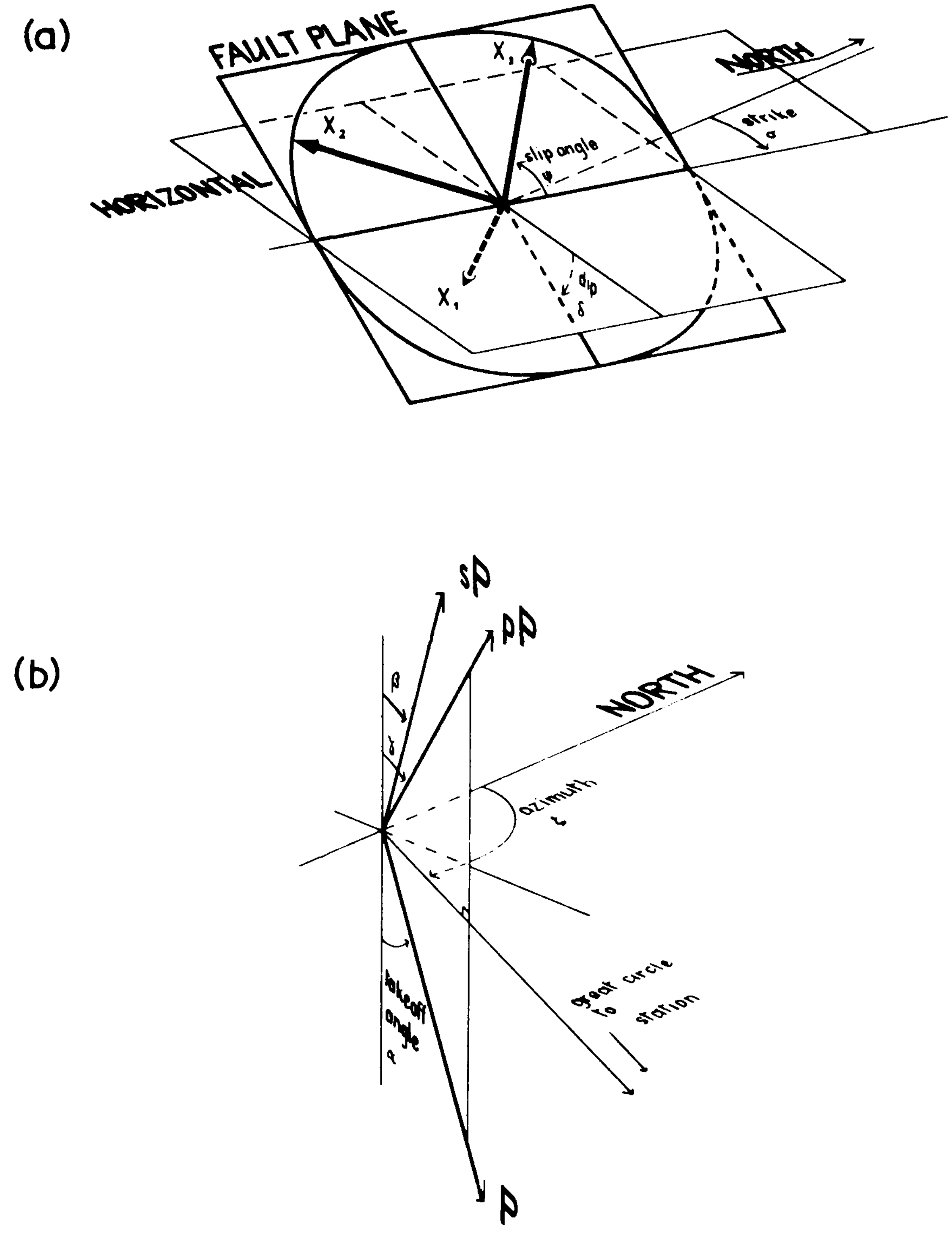

FIGURE 6. DEFINITION OF (a) SOURCE ORIENTATION AND (b) TAKEOFF DIRECTIONS

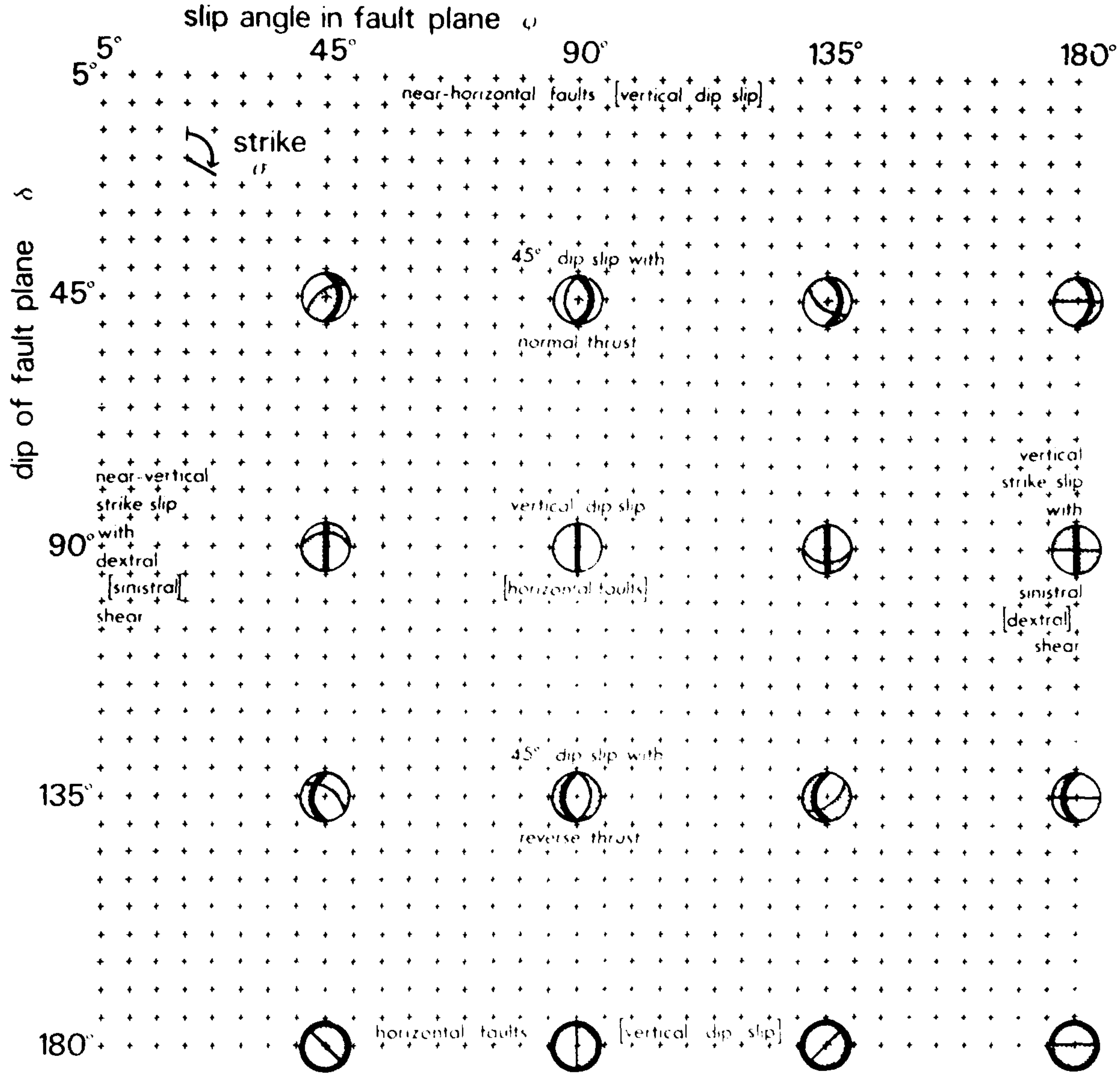

Figure 7. Method of representing acceptable fault plane orientations in terms of slip direction ω, dip δ and strike σ, as defined in Figure 6(a). Acceptable orientations are plotted as vectors from the Cartesian point defining ω and δ, in the direction of the strike σ. Lower hemisphere stereographic projections indicate the type of fault plane orientation represented by various combinations of ω and δ, and are shown oriented for strike σ = 360° (northerly) In each case the fault plane is shown by a thick line ——, the auxiliary plane by a thin line —— Shaded quadrants are negative Different parts of the plot characterize various fault types, and some of these are shown Where the interchange of fault and auxiliary planes yields a different fault type, this is shown in square brackets [ ].

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EARTHQUAKE FOCAL MECHANISMS FROM RELATIVE AMPLITUDES OF P, PP A--ETC(U)
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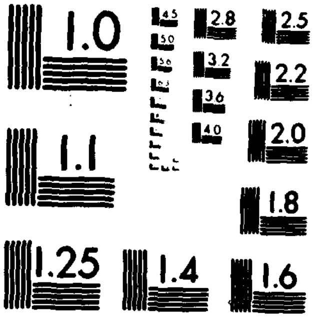

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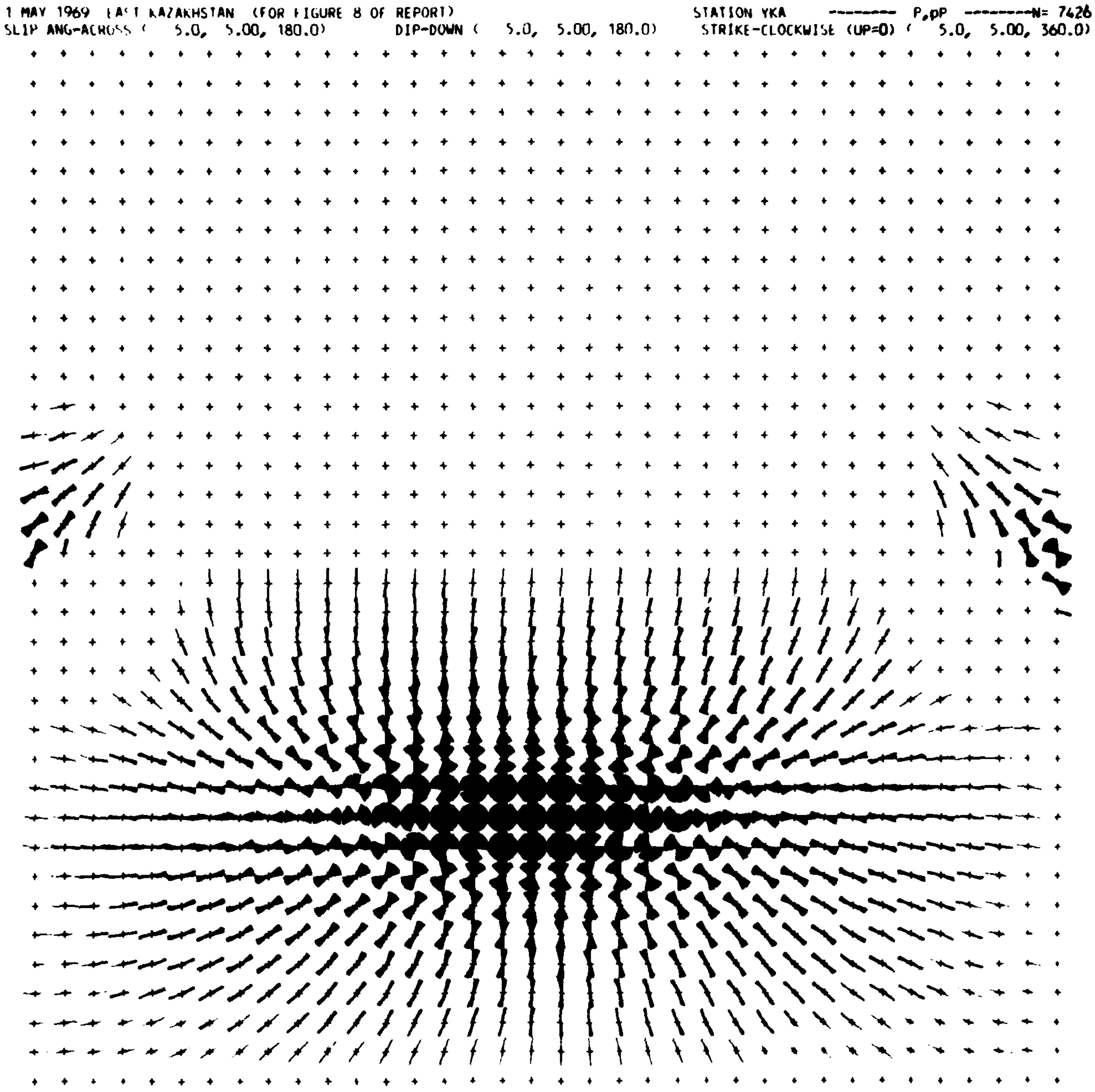

FIGURE 8. CONVENIENT GRAPHIC REPRESENTATION OF RESULTS FROM THE RELATIVE AMPLITUDE PROGRAM FALT USING A VECTORPLOT, WHICH IS ROUTINELY GENERATED BY THE PROGRAM USING SUBROUTINE PLOTV. THIS VECTORPLOT SHOWS THOSE ORIENTATIONS WHICH ARE COMPATIBLE WITH THE PHASE PAIR P AND pP AT YKA, AS SHOWN IN THE SEISMOGRAM OF FIGURE 1(a). EACH VECTOR REPRESENTS A COMPATIBLE ORIENTATION

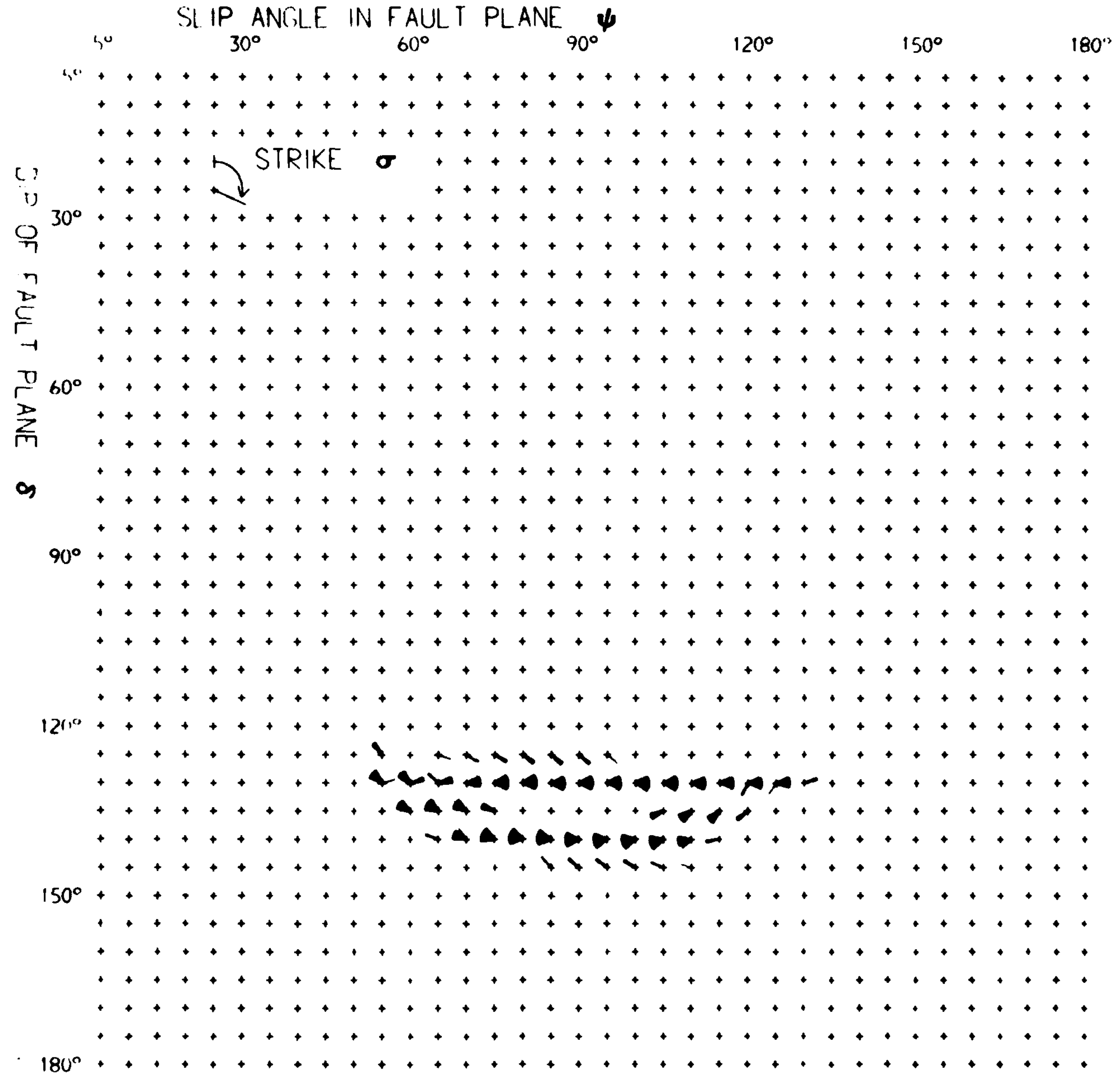

FIGURE 9. VECTORPLOT SHOWING THOSE ORIENTATIONS WHICH ARE COMPATIBLE WITH ALL THE NINE PHASE PAIRS IN FIGURE 1. THIS FIGURE, AND FIGURES 10 AND 11, WERE GENERATED USING THE SEPARATE PROGRAM PUBV, WHICH IS DESIGNED TO GIVE FULLY ANNOTATED VECTORPLOTS

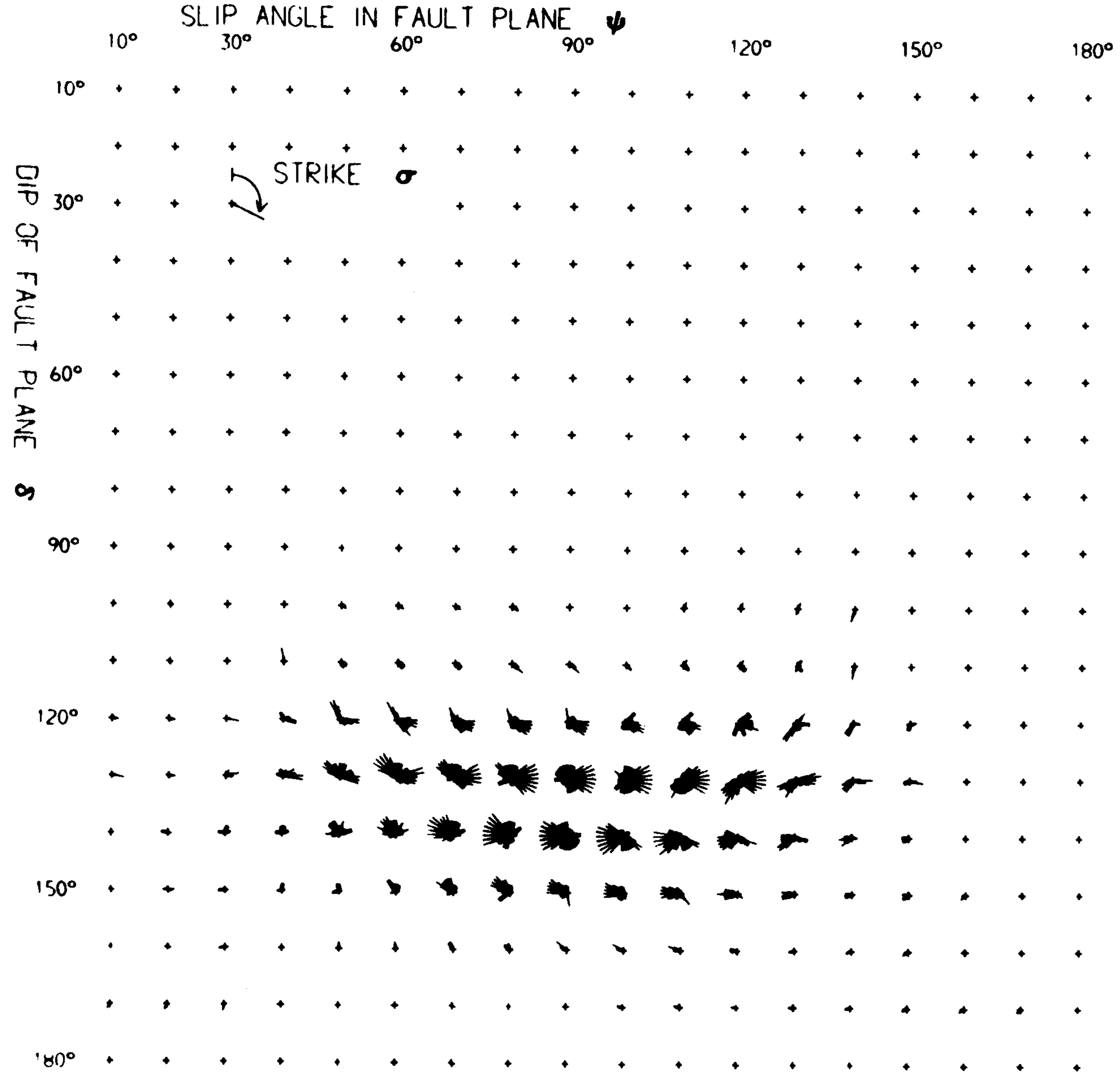

FIGURE 10. VARIABLE LENGTH VECTORPLOT SHOWING THOSE ORIENTATIONS WHICH ARE COMPATIBLE WITH ALL NINE PHASE PAIRS AS IN FIGURE 9, BUT ALSO SHOWING THOSE ORIENTATIONS WHICH ARE INCOMPATIBLE WITH ANY ONE, TWO OR THREE OF THE PHASE PAIRS - THIS BEING REPRESENTED BY PROGRESSIVELY SHORTER VECTORS. NOTE THAT PREDOMINANTLY STRIKE SLIP FAULTS CAN ONLY BE MADE COMPATIBLE BY EXCLUDING THREE OF THE NINE PHASE PAIRS

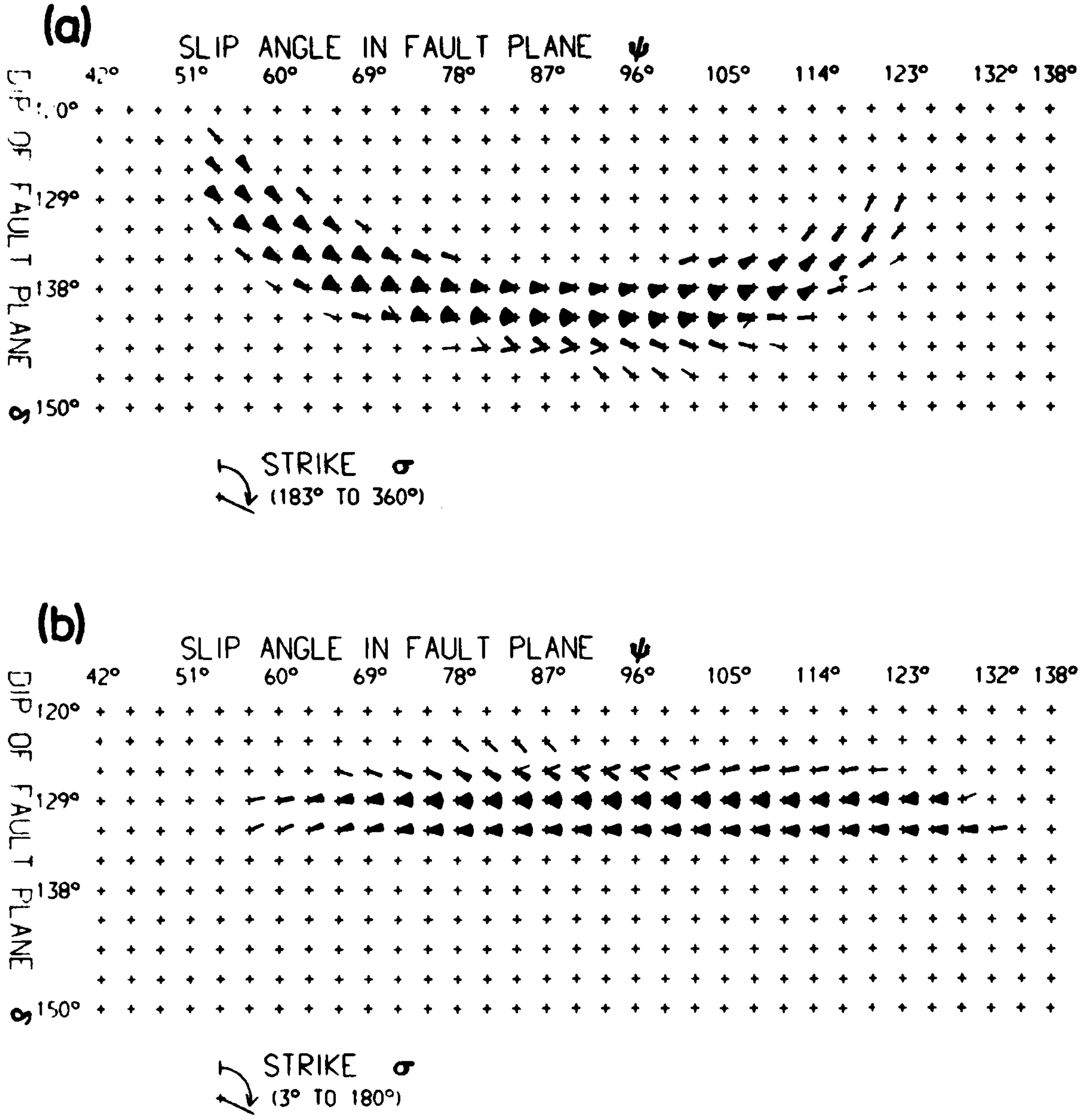

FIGURE 11. VECTORPLOTS SHOWING ORIENTATIONS COMPATIBLE WITH ALL NINE PHASE PAIRS, BUT RESULTING FROM TWO ORIENTATION SEARCHES OVER RESTRICTED REGIONS OF ORIENTATION SPACE (a) AND (b) AS SHOWN. A FINER SEARCH INCREMENT OF 3° IS USED

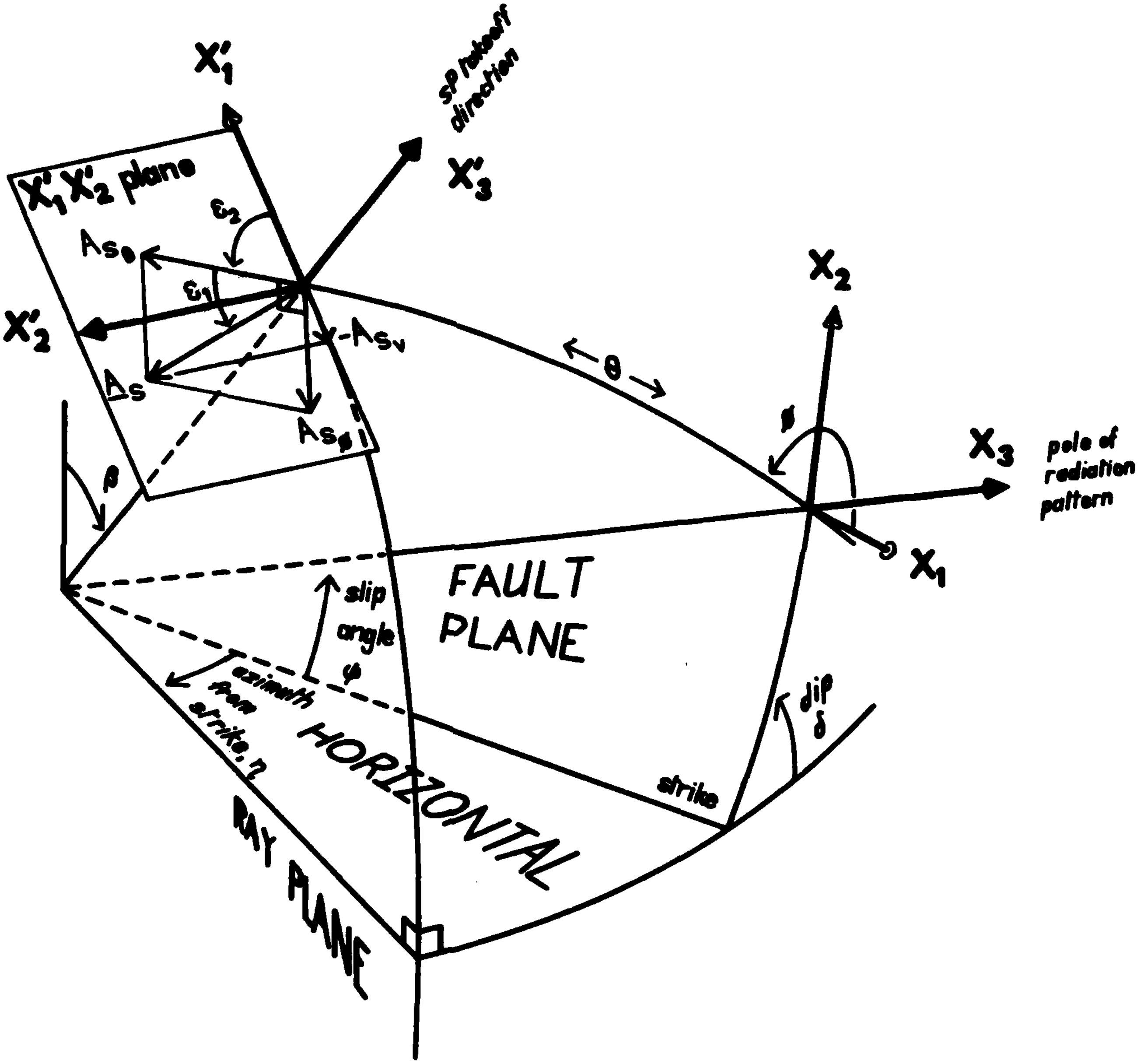

FIGURE 12. DIAGRAM TO ILLUSTRATE THE DEFINITION OF ε_1 AND ε_2 WHICH ARE REQUIRED TO CALCULATE THE VERTICAL COMPONENT OF S RADIATION FOR THE PHASE sP (EQUATIONS (E13) TO (E16))

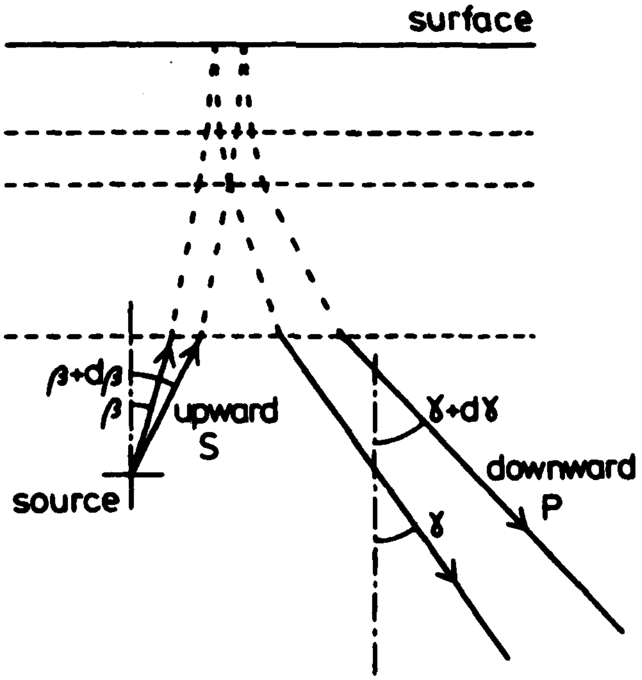

FIGURE 13. THE ORIGIN OF THE INSTANTANEOUS CHANGE IN GEOMETRICAL SPREADING FACTOR WHICH OCCURS FOR sP UPON CHANGE OF MODE FROM S TO P UPON REFLECTION

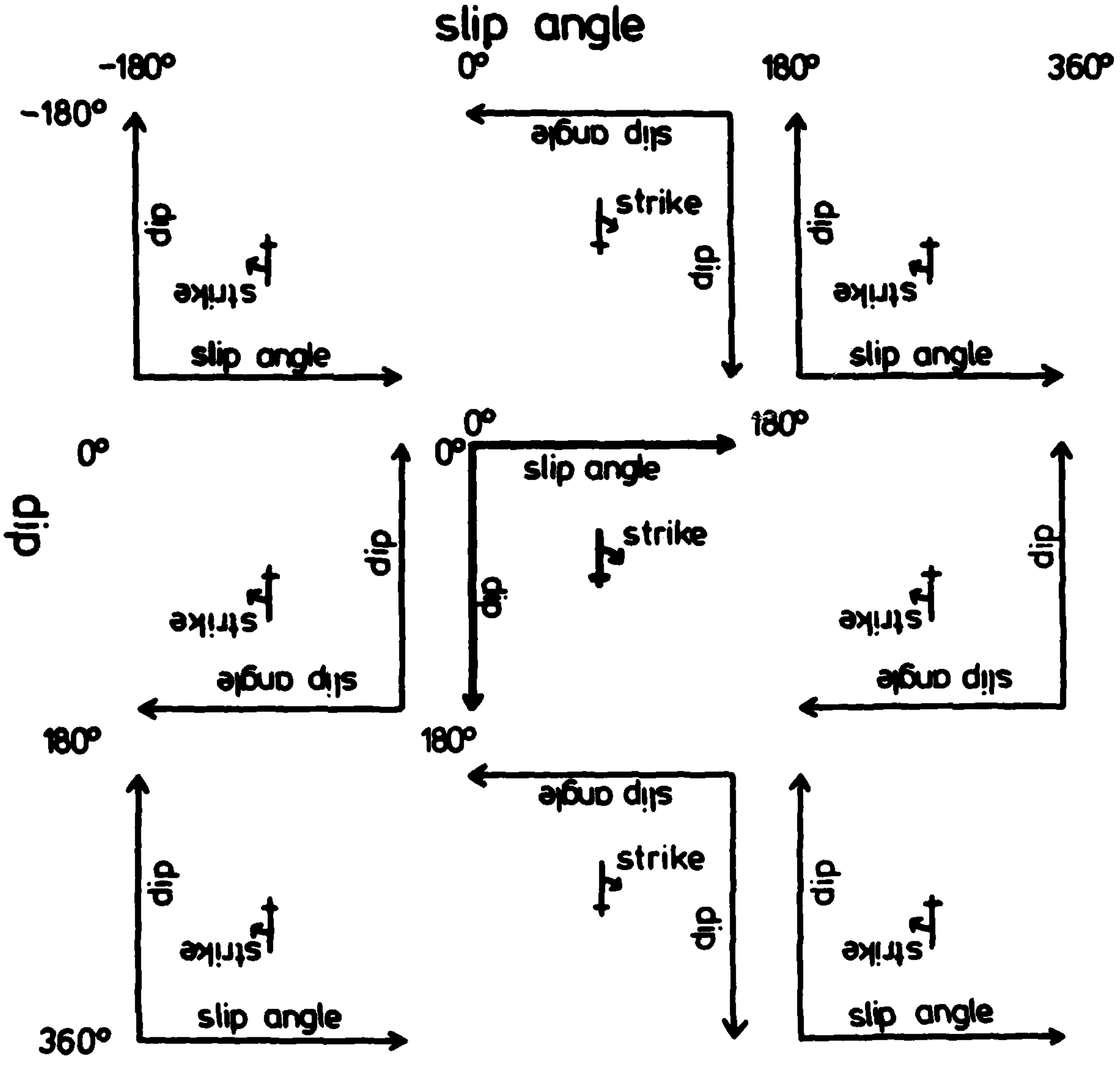

FIGURE 14. DIAGRAM TO ILLUSTRATE THE CORRESPONDENCE BETWEEN VALUES OF SLIP ANGLE ψ AND DIP δ WITHIN THE "PRINCIPAL VALUES" USED IN THE SEARCH, AND VALUES OF ψ AND δ OUTSIDE THIS RANGE. (VALUES OF STRIKE OUTSIDE ITS RANGE OF SEARCH CAN ALWAYS BE CONVERTED SIMPLY BY ADDITION OR SUBTRACTION OF 360° OR A MULTIPLE OF 360°)

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1. DRIC Reference (if known) -	2. Originator's Reference AWRE REPORT NO. 041/79	3. Agency Reference -	4. Report Security Classification UNLIMITED

5. Originator's Code (if known) -	6. Originator (Corporate Author) Name and Location Atomic Weapons Research Establishment, Aldermaston, Berkshire
5a. Sponsoring Agency's Code (if known) -	6a. Sponsoring Agency (Contract Authority) Name and Location -

7. Title

Earthquake Focal Mechanisms from Relative Amplitudes of P, pP and sP: Method and Computer Program

7a. Title in Foreign Language (in the case of Translation)

-

7b. Presented at (for Conference Papers). Title, Place and Date of Conference

-

8. Author 1.Surname, Initials Pearce R G	9a. Author 2 -	9b. Authors 3, 4 .... -	10. Date pp ref August 1979 103 26
11. Contract Number -	12. Period -	13. Project -	14. Other References -

15. Distribution Statement

No restriction

16. Descriptors (or Keywords) (TEST)

		Body waves	Radiation pattern
FORTRAN	Seismology	P wave	Fault plane
Seismogram CODA	Earthquakes	Teleseismic body waves	
CODA	P wave amplitude		

p subscript p

Abstract

This report describes a FORTRAN computer program which determines the orientation (with confidence limits) of an assumed double couple earthquake source, given a series of teleseismically observed relative amplitudes, each of which relates the amplitudes of either P and pP, or P and sP, or pP and sP on one seismogram. Appropriate upper and lower limits are assigned in arbitrary units to the observed amplitude of each phase, with or without a polarity specification, and from these limits the program computes the corresponding range(s) of relative amplitudes for each pair of phases. All source orientations which are compatible with the range(s) of relative amplitudes are then identified, and can be displayed graphically. Those orientations which are compatible with all pairs of phases at all stations constitute the focal mechanism solution, with confidence limits which correspond directly to the confidence of the initial measurements. The program can be applied to shallow or deep earthquakes beneath land or sea.

Some Metric and SI Unit Conversion Factors

(Based on DEF STAN 00-11/2 "Metric Units for Use by the Ministry of Defence",
DS Met 5501 "AWRE Metric Guide" and other British Standards)

Quantity	Unit	Symbol	Conversion
Basic Units			
Length	metre	m	1 m = 3.2808 ft 1 ft = 0.3048 m
Mass	kilogram	kg	1 kg = 2.2046 lb 1 lb = 0.45359237 kg 1 ton = 1016.05 kg
Derived Units			
Force	newton	N = kg m/s^2	1 N = 0.2248 lbf 1 lbf = 4.44822 N
Work, Energy, Quantity of Heat	joule	J = N m	1 J = 0.737562 ft lbf 1 J = 9.47817 × 10^{-4} Btu 1 J = 2.38846 × 10^{-4} kcal 1 ft lbf = 1.35582 J 1 Btu = 1055.06 J 1 kcal = 4186.8 J
Power	watt	W = J/s	1 W = 0.238846 cal/s 1 cal/s = 4.1868 W
Electric Charge	coulomb	C = A s	-
Electric Potential	volt	V = W/A = J/C	-
Electrical Capacitance	farad	F = A s/V = C/V	-
Electric Resistance	ohm	Ω = V/A	-
Conductance	siemen	S = 1 Ω^{-1}	-
Magnetic Flux	weber	Wb = V s	-
Magnetic Flux Density	tesla	T = Wb/m^2	-
Inductance	henry	H = V s/A = Wb/A	-
Complex Derived Units			
Angular Velocity	radian per second	rad/s	1 rad/s = 0.159155 rev/s 1 rev/s = 6.28319 rad/s
Acceleration	metre per square second	m/s^2	1 m/s^2 = 3.28084 ft/s^2 1 ft/s^2 = 0.3048 m/s^2
Angular Acceleration	radian per square second	rad/s^2	-
Pressure	newton per square metre	N/m^2 = Pa	1 N/m^2 = 145.038 × 10^{-6} lbf/in^2 1 lbf/in^2 = 6.89476 × 10^3 N/m^2
	bar	bar = 10^5 N/m^2	- 1 in. Hg = 3386.39 N/m^2
Torque	newton metre	N m	1 N m = 0.737562 lbf ft 1 lbf ft = 1.35582 N m
Surface Tension	newton per metre	N/m	1 N/m = 0.0685 lbf/ft 1 lbf/ft = 14.5939 N/m
Dynamic Viscosity	newton second per square metre	N s/m^2	1 N s/m^2 = 0.0208854 lbf s/ft^2 1 lbf s/ft^2 = 47.8803 N s/m^2
Kinematic Viscosity	square metre per second	m^2/s	1 m^2/s = 10.7639 ft^2/s 1 ft^2/s = 0.0929 m^2/s
Thermal Conductivity	watt per metre kelvin	W/m K	-
Odd Units*			
Radioactivity	becquerel	Bq	1 Bq = 2.7027 × 10^{-11} Ci 1 Ci = 3.700 × 10^{10} Bq
Absorbed Dose	gray	Gy	1 Gy = 100 rad 1 rad = 0.01 Gy
Dose Equivalent	sievert	Sv	1 Sv = 100 rem 1 rem = 0.01 Sv
Exposure	coulomb per kilogram	/kg	1 C/kg = 3876 R 1 R = 2.58 × 10^{-4} C/kg
Rate of Leak (Vacuum Systems)	millibar litre per second	mb l/s	1 mb = 0.750062 torr 1 torr = 1.33322 mb

*These terms are recognised terms within the metric system.

Some Metric and SI Unit Conversion Factors

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Derived Units			
Force	newton	$N = kg\ m/s^2$	1 N = 0.2248 lbf 1 lbf = 4.44822 N
Work, Energy, Quantity of Heat	joule	J = N m	1 J = 0.737562 ft lbf 1 J = 9.47817×10^{-4} Btu 1 J = 2.38846×10^{-4} kcal 1 ft lbf = 1.35582 J 1 Btu = 1055.06 J 1 kcal = 4186.8 J
Power	watt	W = J/s	1 W = 0.238846 cal/s 1 cal/s = 4.1868 W
Electric Charge	coulomb	C = A s	-
Electric Potential	volt	V = W/A = J/C	-
Electrical Capacitance	farad	F = A s/V = C/V	-
Electric Resistance	ohm	Ω = V/A	-
Conductance	siemen	$S = 1\ \Omega^{-1}$	-
Magnetic Flux	weber	Wb = V s	-
Magnetic Flux Density	tesla	$T = Wb/m^2$	-
Inductance	henry	H = V s/A = Wb/A	-
Complex Derived Units			
Angular Velocity	radian per second	rad/s	1 rad/s = 0.159155 rev/s 1 rev/s = 6.28319 rad/s
Acceleration	metre per square second	m/s^2	$1\ m/s^2 = 3.28084\ ft/s^2$ $1\ ft/s^2 = 0.3048\ m/s^2$
Angular Acceleration	radian per square second	rad/s^2	-
Pressure	newton per square metre	$N/m^2 = Pa$	$1\ N/m^2 = 145.038 \times 10^{-6}\ lbf/in^2$ $1\ lbf/in^2 = 6.89476 \times 10^3\ N/m^2$
	bar	$bar = 10^5\ N/m^2$	- $1\ in.\ Hg = 3386.39\ N/m^2$
Torque	newton metre	N m	1 N m = 0.737562 lbf ft 1 lbf ft = 1.35582 N m
Surface Tension	newton per metre	N/m	1 N/m = 0.0685 lbf/ft 1 lbf/ft = 14.5939 N/m
Dynamic Viscosity	newton second per square metre	$N\ s/m^2$	$1\ N\ s/m^2 = 0.0208854\ lbf\ s/ft^2$ $1\ lbf\ s/ft^2 = 47.8803\ N\ s/m^2$
Kinematic Viscosity	square metre per second	m^2/s	$1\ m^2/s = 10.7639\ ft^2/s$ $1\ ft^2/s = 0.0929\ m^2/s$
Thermal Conductivity	watt per metre kelvin	W/m K	-
Odd Units*			
Radioactivity	becquerel	Bq	$1\ Bq = 2.7027 \times 10^{-11}\ Ci$ $1\ Ci = 3.700 \times 10^{10}\ Bq$
Absorbed Dose	gray	Gy	1 Gy = 100 rad 1 rad = 0.01 Gy
Dose Equivalent	sievert	Sv	1 Sv = 100 rem 1 rem = 0.01 Sv
Exposure	coulomb per kilogram	/kg	1 C/kg = 3876 R 1 R = 2.58×10^{-4} C/kg
Rate of Leak (Vacuum Systems)	millibar litre per second	mb l/s	1 mb = 0.750062 torr 1 torr = 1.33322 mb

*These terms are recognised terms within the metric system.

DAT

FILM

7-8