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TECHNICAL NOTE

# PROGRAM BTLS TECHNICAL DESCRIPTION, SELECTION OF INPUT DATA, AND RUNNING INSTRUCTIONS

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1982

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This Technical Note has been prepared to document the Bottom Loss Program that uses geoacoustic parameters to calculate Bottom Loss. It is intended to be a technical description of the Bottom Loss Program, a selection guide for input data, and a users instruction manual.

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This report documents the computer program BTLS which is used to compute geophysical parameters of the ocean bottom from measurements of bottom loss of underwater sound and simulated bottom loss of underwater sound from geophysical parameters of the ocean bottom. Physical assumptions and the mathematical model used for the computations are discussed, and sources or derivations of all necessary equations used in the program are given. Guidelines are provided for interpretation of experimentally measured results and selection of input data to use in computations. Instructions are given for the input of data and running the computer program.

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PROGRAM BTLS DESCRIPTION

## I. INTRODUCTION

This is a description of the computer program entitled PROGRAM BTLS provided by Science Applications, Inc. (SAI) of McLean, Va. It is based mainly upon the principles discussed in an article by C.W. Spofford, R.R. Greene, and J.B. Hersey of SAI, "The Estimation of Geo-Acoustic Ocean Sediment Parameters from Measured Bottom-Loss Data," to be published in the Journal of the Acoustical Society of America, under contract to Naval Ocean Research and Development Activity, contract number NORDA SEAS N00 14-78-C-0211.

Individual statements, computations, or formulas used in the computer program and subroutines are discussed and analyzed in order to relate them more clearly to the physics and assumptions made by Spofford et al. (1982). This is done to enable the user to more readily have access to an understanding of the program and its proper utilization. It may also enable such modifications (if any) as may be desirable to be made.

The geo-acoustical model upon which Program BTLS is based is shown in Figure 1 which is reproduced below. The sediment is characterized by a compressional-wave sound-speed profile given by (equation 13 of Spofford et al. (1982)).

$$C(Z) = C_o \left[ (1+B) \left( 1 + \frac{2\, g_o z}{C_o (1+B)} \right)^{1/2} - B \right] \qquad (1)$$

where $g_o$ is the gradient at the top of sediment, Z is the depth below the top of the sediment, C is the sound speed (with $C(o)=C_o$), and B is a parameter which controls the shape of the profile. From this equation an expression for the sound speed gradient as a function of sound speed C (Z) is found to be (equation 14 of Spofford et al. (1982))

$$g(z) = \frac{dC}{dz} = g_o \frac{(1+B)}{\frac{c(z)}{C_o} + B} \qquad (2)$$

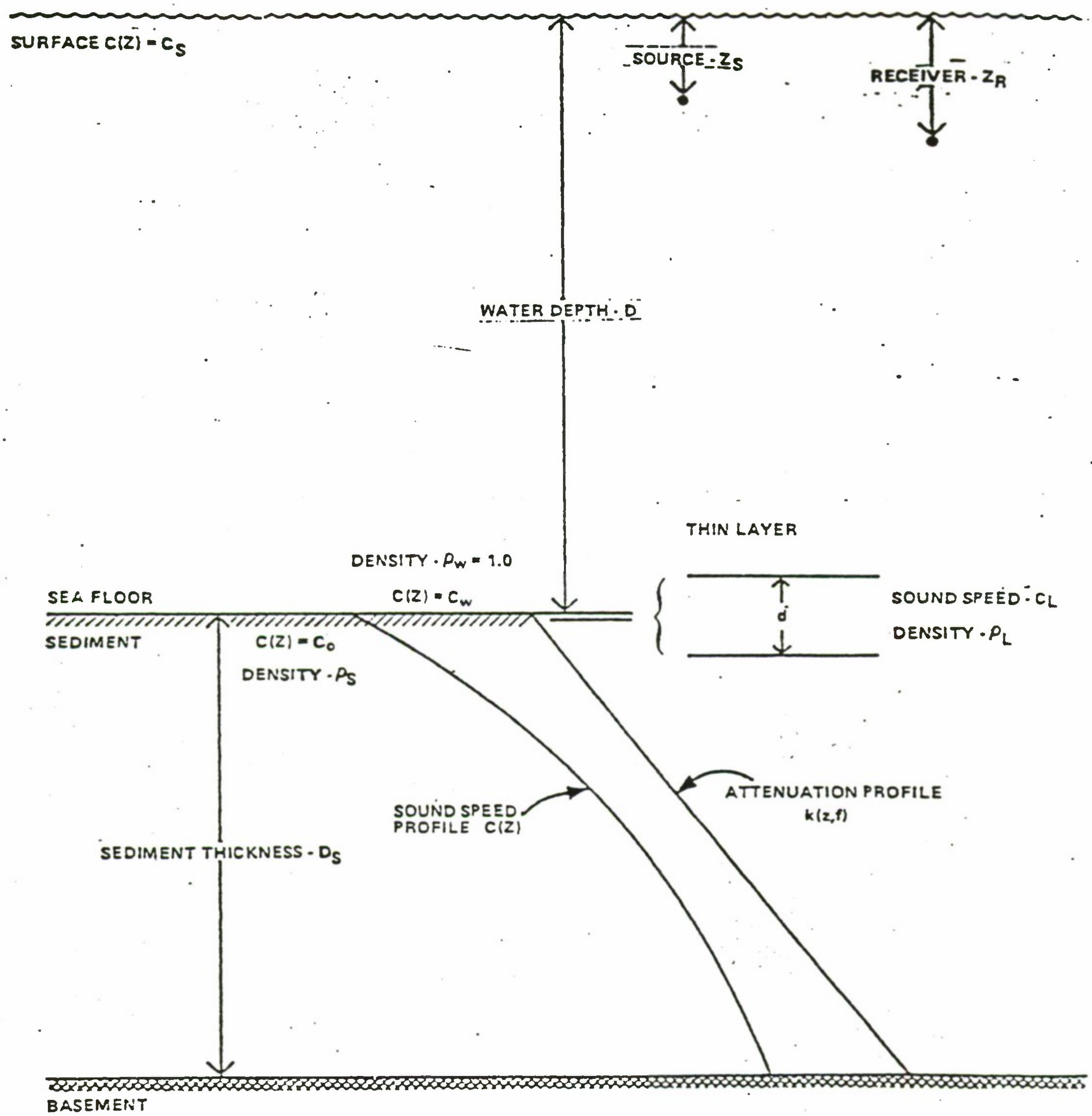



Figure 1. Simplified geo-acoustic model used to simulate bottom-loss measurements.

From Spofford et al. (1982)

These two equations are used for ray calculations involving the sediment and are of major importance in the model.

It is assumed in the model that a thin layer characterized by a high sound speed overlies the sediment, and at the bottom of the sediment there is a basement with acoustic properties different from the sediment.

Various possible ray paths for which computations are done by Program BTLS are shown in Figure 2.

Pages showing the GEO-PARAMETER INPUTS and INVERSION PARAMETER INPUTS follow Figure 2.

A copy of PROGRAM BTLS is provided for convenience in Appendix A, a computer derived flow chart is in Appendix B, and Appendix C contains a computer run stream example. The computer program and subroutines are discussed in the order in which they appear in the printout.

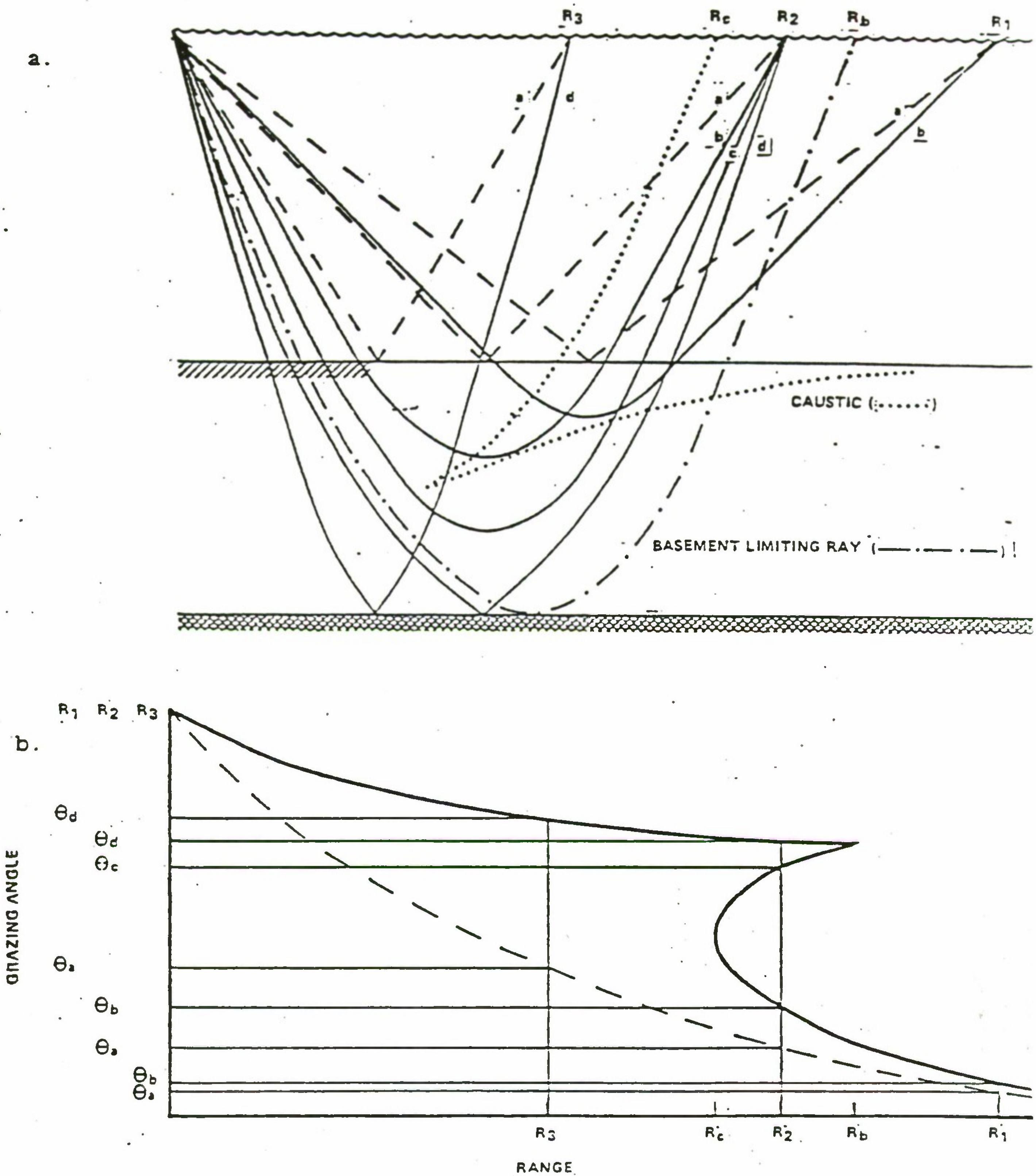



Figure 2. Ray paths (a) and angle-versus-range curves (b) for sediment reflected (——) and refracted/basement-reflected (——) paths.
From Spofford et. al.(1982)

&BTLS9

TABLE 1. GEOPARAMETER INPUTS

| INPUT CODE | PARAMETERS | UNIT |
|---|---|---|
| T | Two-way travel time thickness of sediment in tenths of second | 0.1s |
| NNFILE | Arbitrary file or station number | |
| IOPT | Input Option: 0 for geo-parameters<br>1 for inversion parameters | |
| ZB | Water Depth | m |
| ZS | Source Depth | m |
| ZR | Receiver Depth | m |
| CS | Sound speed at source or receiver, whichever is shallower | m/s |
| C1 | Sound speed at bottom of water | m/s |
| | GEO-ACOUSTIC PARAMETERS follow: | |
| RATIO | Ratio of speed in sediment to speed at bottom of water | - |
| G | Gradient at top of sediment | 1/s |
| BETA | Cononical curve type | - |
| GAM | Attenuation profile gradient | $dB/m^2/kHz$ |
| REF | Basement reflection coefficient | - |
| ALPHØ | Surface sediment attenuation | dB/m/kHz |
| RH2 | Thin layer density | $g/cm^3$ |
| RH3 | Sediment density | $g/cm^3$ |
| D | Thin layer thickness in meters | m |

&BTLS9

TABLE 2. INVERSION PARAMETER INPUTS

| INPUT CODE | PARAMETER | UNIT |
|---|---|---|
| T | Two-way travel time thickness of sediment in tenths of second | 0.1 s |
| NNFILE | Arbitrary file or station number | |
| IOPT | Input Option: 0 for geo-parameters<br>1 for inversion parameters | |
| ZB | Water depth | m |
| ZS | Source depth | m |
| ZR | Receiver depth | m |
| CS | Sound speed at source or receiver, whichever is shallower | m/s |
| C1 | Sound speed at bottom of water | m/s |
| DBLOSS<br>FREQ | A value of loss, frequency and angle -<br>example: DBLOS=7<br>frequency = 200 Hz<br>angle = $20^{o}$ | dB<br><br>Hertz<br>degrees |
| ALOSSØ | Low frequency loss level at high angles | dB |
| ALOSSM | Minimum loss level at high angles | dB |
| FM | Frequency of minimum loss (of ALOSSM) | Hertz (Hz) |
| TIR | Angle of total internal reflection | degrees |
| THC | Angle of caustic | degrees |
| RATIO | Ratio of speed in sediment to speed at bottom of water | - |
| G | Gradient at top of sediment | 1/s |
| BETA | Canonical curve type<br>Sound speed profile parameter | - |
| GAM | Attenuation profile gradient | $dB/m^2kHz$ |
| REF | Basement Reflection coefficient in pressure units | - |

## II. THE PROGRAM

We now consider PROGRAM BTLS. If IOPT = 1, inversion parameters are computed as follows:

### OPTIONS AND ERROR CHECKING

The angle of total internal reflection is designated by TIR. This angle is found by use of Snell's law,

$$\frac{\cos\Theta_1}{C_1} = \frac{\cos\Theta_2}{C_2} \qquad (3)$$

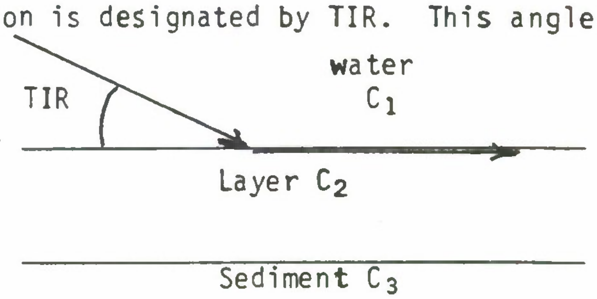



Figure 3. Ray Path for Total Internal Reflection

where $C_1$ and $C_2$ are speeds of sound at the bottom of water and in the layer respectively while $\Theta_1$ = TIR is the grazing angle in the water at the water-layer interface and $\Theta_2 = 0$, i.e. the refracted ray is parallel to the water-layer boundary. Thus $\cos TIR = \frac{C_1}{C_2}$ and

$$RATIO = \frac{C_2}{C_1} = 1/\cos TIR, \qquad (4)$$

if TIR is expressed in radians or

$$\frac{C_2}{C_1} = 1/\cos\left(TIR \times \frac{\pi}{180}\right) \qquad (5)$$

for TIR input in degrees. Then

$$C_2 = C_1 \times RATIO \qquad (6)$$

and since it is assumed the sound goes into the sediment below the layer, the assumption is made that the speed of sound in the sediment below the layer is the same as in the layer so $C_3 = C_2$.

IF GRADIENT G IS NOT SPECIFIED, CALCULATE IT FROM THE CAUSTIC ANGLE, THC

If $G \neq 0$ go to 300

If $THC \leq 0$ let THC = 30 degrees. This is a starting estimate of the angle in degrees.

Call GCOMP (the last subroutine in the program).

SUBROUTINE GCOMP

This subroutine is used to compute the sound speed gradient, $g_o$, at the top of the sediment. Quantities are defined as follows:

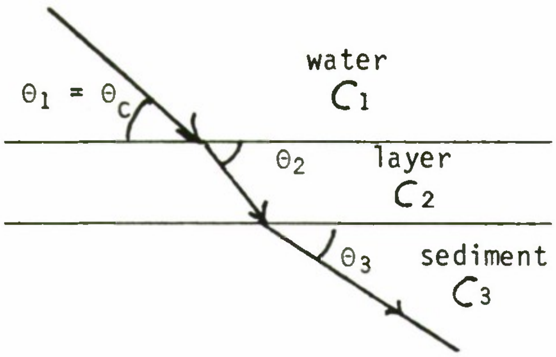



Figure 4. Ray path showing angle designations.

THRC = 30

THCØ = THC = $\Theta_c$

B = Beta

THRC = 30 X $\pi/180$ converts angle to radians.

THINC = 1 an angle increment of 1 degree.

D1 = 2*ZB-ZR-ZS is twice the effective depth, $\bar{D}$, given by equation (10) of Spofford et al.(1982).

TH3 = $\Theta = \cos^{-1} \frac{c_3}{c_1} \cos\Theta_c$ from Snell's law and figure 4. (7)

$$\text{FACT 1} = F1 = \frac{2BC_3}{1+B} \quad (8)$$

$$\text{FACT 2} = F_2 = 1 + \frac{1}{2B}\left(1 + \frac{\Theta_3}{\sin\Theta_3\cos\Theta_3}\right) \quad (9)$$

In order to obtain the equation for GZERO = $g_o$ in the program, we need the equation for the range as given by equations (16) and (21) of Spofford et al. (1982) which can be obtained as follows:

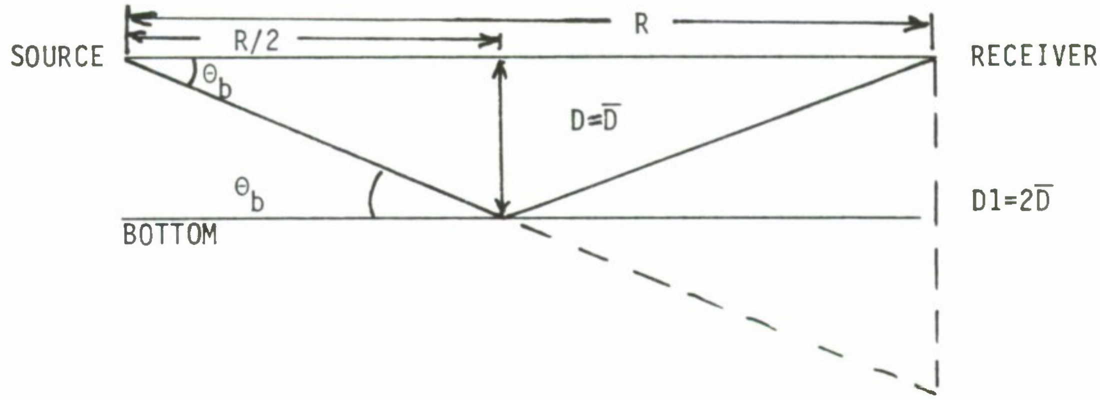



Figure 5. Diagram showing range, depth, and apparent bottom grazing angle relationship.

$$\tan \Theta_b = \frac{D}{R/2} = \frac{2\bar{D}}{R} = \frac{D1}{R} \qquad (10)$$

where D1 = twice the effective depth.

For sound refracted in the bottom, an increment, $R_s$, must be added as shown.

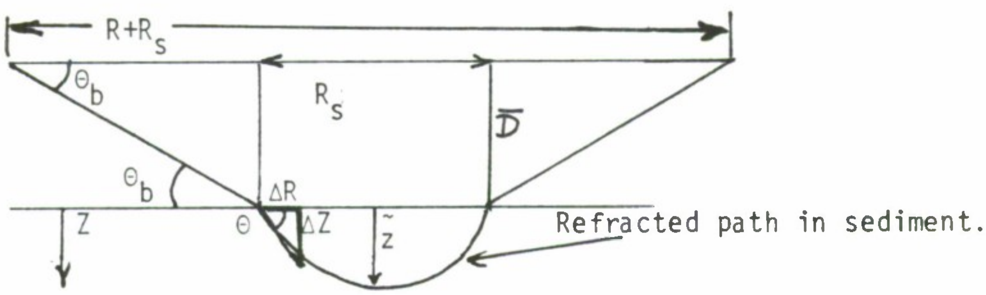



Figure 6. Range increment for refraction in sediment.

In the sediment $\tan\Theta = \frac{\Delta z}{\Delta R}$ so

(11) $dR = \frac{dz}{\tan\Theta(z)}$ and eq. (16) of Spofford et al. (1982) is

(12) $R_s = 2\int_0^{\tilde{z}} \frac{dz}{\tan\Theta(z)}$ where $\tilde{z}$ is either

the turning point depth for the refracted ray, or the basement depth for rays which reflect from the basement. Snell's law applies in the sediment where the sound speed gradient is assumed to be vertical so (letting subscript o refer to the top of the sediment)

$$\cos\Theta(z) = \frac{\cos\Theta_0}{C_0} C(z) \qquad (13)$$

and taking a derivative with respect to z we get

$$-\sin\Theta(z)\cdot\frac{d\Theta(z)}{dZ} = \frac{\cos\Theta_0}{C_0}\frac{dC(Z)}{dZ} = \frac{\cos\Theta_0}{C_0} g(Z) \qquad (14)$$

where g(z) is the sound speed gradient in the sediment.

$$\tan\Theta(z) = \frac{\sin\Theta(z)}{\cos\Theta(z)} = \frac{(-\cos\Theta_0/C_0)\, g(z)}{(\cos\Theta_0/C_0)\, C(z)\left(\frac{d\Theta(z)}{dZ}\right)}, \qquad (15)$$

$$\tan\Theta(Z) = -\frac{g(z)}{C(z)\frac{d\Theta(Z)}{dZ}}, \qquad (16)$$

$$\cot\Theta(z) = \frac{C(z)\frac{d\Theta}{dZ}}{g(z)}, \qquad (17)$$

$$R_s = 2\int_0^{\tilde{z}} \cot\Theta(z)\,dZ = 2\int_0^{\tilde{z}} -\frac{C(z)}{g(z)}\frac{d\Theta(z)}{dZ}\,dZ. \qquad (18)$$

In the model it is assumed $g(z) = \frac{g_0(1+B)C_0}{C(Z)+BC_0}$ and we have

$$C(z) = \frac{C_0\cos\Theta(z)}{\cos\Theta_0} \text{ so} \qquad (19)$$

$$\frac{C(Z)}{g(z)} = \frac{C_0\cos\Theta(z)}{\cos\Theta_0}\left(\frac{C(z)+BC_0}{g_0(1+B)C_0}\right) \qquad (20)$$

$$= \frac{BC_0\cos\Theta(z)}{g_0(1+B)\cos\Theta_0} + \frac{C(z)\cos\Theta(z)}{g_0(1+B)\cos\Theta_0} \qquad (21)$$

$$= \frac{BC_0\cos\Theta(Z)}{g_0(1+B)\cos\Theta_0} + \frac{C_0\cos^2\Theta(z)}{g_0(1+B)\cos^2\Theta_0} \qquad (22)$$

$$= \frac{C_0}{g_0(1+B)\cos\Theta_0}\left[\frac{B\cos\Theta(z)}{1} + \frac{\cos^2\Theta(z)}{\cos\Theta_0}\right] \qquad (23)$$

Changing variable for integration from z to θ gives

$$R_S = \frac{-2C_0}{g_o(1+B)\cos\theta_o}\int_{\theta_o}^{\theta'}\left[B\cos\theta(z) + \frac{\cos^2\theta(z)}{\cos\theta_o}\right] d\theta. \quad (24)$$

Interchanging limits changes the sign to give upon integration.

$$R_S = \frac{2C_o}{g_o(1+B)\cos\theta_o}\left[B\sin\theta + \left(\frac{\theta}{2}+\frac{\sin 2\theta}{4}\right)\frac{1}{\cos\theta_o}\right]_{\theta=\theta'}^{\theta=\theta_o}, \quad (25)$$

$$R_S = \frac{C_o}{g_o(1+B)\cos\theta_o}\left[2B\sin\theta + \frac{\theta}{\cos\theta_o} + \frac{\sin\theta\cos\theta}{\cos\theta_o}\right]_{\theta=\theta'}^{\theta=\theta_o}. \quad (26)$$

Letting θ' = 0 in this equation for a path refracted in the sediment without reaching the basement gives

$$R = \frac{2D}{\tan\theta_b} + \frac{C_o}{g_o(1+B)\cos\theta_o}\left[\frac{\theta_o}{\cos\theta_o} + \sin\theta_o(1+2B)\right]. \quad (27)$$

Now substitute as follows: 2D = D1, $\theta_b = \theta rc = THRC$, $\theta_o = \theta_3$ and find with $C_o = C_3$

$$R = \frac{D1}{\tan\theta rc} + \frac{C_3\sin\theta_3}{g_o(1+B)\cos\theta_3}\left[\frac{\theta_3}{\sin\theta_3\cos\theta_3} + (1+2B)\right], \quad (28)$$

$$R = \frac{D1}{\tan\theta_{rc}} + \frac{2BC_3\tan\theta_3}{g_o(1+B)(2B)}\left[(2B+1) + \frac{\theta_3}{\sin\theta_3\cos\theta_3}\right], \quad (29)$$

$$R = \frac{D1}{\tan\theta rc} + \left(\frac{2BC_3}{1+B}\right)\left(\frac{\tan\theta_3}{g_o}\right)\left[1 + \frac{1}{2B} + \frac{\theta_3}{2B\sin\theta_3\cos\theta_3}\right], \quad (30)$$

$$R = \frac{D1}{\tan\theta rc} + \frac{F_1 F_2 \tan\theta_3}{g_o}. \quad (31)$$

This is the same as the equation for R in the program. Take the derivative of R with respect to $\theta_3$ which can then be set equal to zero since we expect $\frac{dR}{d\theta_3} = 0$ for the caustic ray.

$$\frac{dR}{d\theta_3} = -D1\csc^2\theta_{rc}\frac{d\theta rc}{d\theta_3} + \frac{F_1}{g_o}\left[\left(\frac{dF_2}{d\theta_3}\right)\tan\theta_3 + F_2\sec^2\theta_3\right] = 0 \quad (1)$$

Find $\frac{d\theta rc}{d\theta_3}$ as follows:

Snell's law is $\cos\theta_{rc} = \frac{C_1}{C_3}\cos\theta_3$, (33)

and taking a derivative gives

$$-\sin\theta_{rc}\frac{d\theta_{rc}}{d\theta_3} = -\frac{C_1}{C_3}\sin\theta_3, \tag{34}$$

$$\frac{d\theta_{rc}}{d\theta_3} = \frac{C_1}{C_3}\frac{\sin\theta_3}{\sin\theta_{rc}}, \text{ and} \tag{35}$$

$$\frac{dF_2}{d\theta_3} = \frac{1}{2B}\left[\frac{1}{\sin\theta_3\cos\theta_3} + \frac{\theta_3\sec\theta_3\tan\theta_3}{\sin\theta_3} - \frac{\theta_3\csc\theta_3\cot\theta_3}{\cos\theta_3}\right]. \tag{36}$$

By use of identies we can write

$$\frac{dF_2}{d\theta_3} = \frac{1}{2B\sin\theta_3\cos\theta_3}\left[1 + \theta_3\left(\frac{\sin^2\theta_3 - \cos^2\theta_3}{\sin\theta_3\cos\theta_3}\right)\right]. \tag{37}$$

Substitution of (2) and (3) into (1) gives

$$-D1\csc^2\theta_{rc}\left(\frac{C_1}{C_3}\right)\frac{\sin\theta_3}{\sin\theta_{rc}} + \frac{F_1}{g_0}\left\{\frac{\tan\theta_3}{2B\sin\theta_3\cos\theta_3}\right. \tag{38}$$

$$\left.\times\left[1 + \theta_3\left(\frac{\sin^2\theta_3 - \cos^2\theta_3}{\sin\theta_3\cos\theta_3}\right)\right] + F_2\sec^2\theta_3\right\} = 0. \tag{39}$$

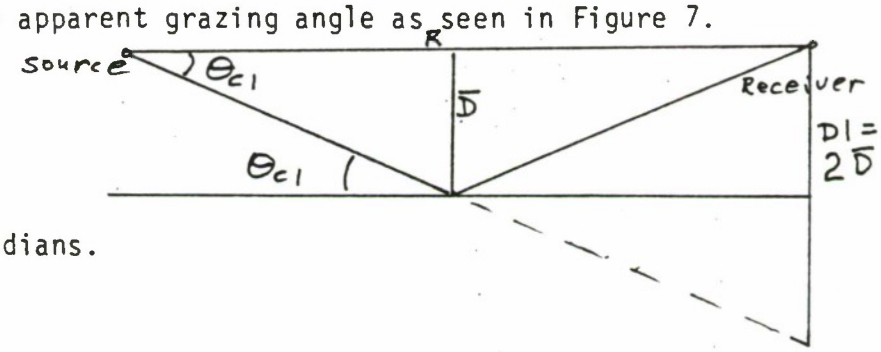
Solving this equation for $g_0$ and using some identities gives the result

$$g_0 = \left(\frac{C_3\sin^2\theta_{rc}}{C_1 D1\sin\theta_3}\right)\left\{\frac{C_3}{(1+B)\cos^2\theta_3}\left[1 - \theta_3\left(\frac{\cos^2\theta_3 - \sin^2\theta_3}{\sin\theta_3\cos\theta_3}\right)\right] + \frac{F_1 F_2}{\cos^2\theta_3}\right\}. \tag{40}$$

which is the same as the equation in the program for the sound speed gradient at the top of the sediment GZERO.

The program follows an iterative procedure as follows:

THC1 = $\theta_{c1} = \tan^{-1}\frac{D1}{R}$ = apparent grazing angle as seen in Figure 7.




THC1 is converted to radians.

Figure 7. Apparent grazing angle.

MAXIT = 100 is maximum number of iterations beginning with computations of $g_0$ and R for THRC = 30. Then THRC is incremented by 1 degree, converted to radians, TH3 is computed from Snell's law and new values of $g_0$, R, and THC2 are computed.

If $|THCO-THC| \leq .01$, the computation is finished and THC=THC2. Otherwise iterations continue with the increment changing sign and being divided by 2 until convergence occurs. When convergence is obtained, the output is printed:

THC = THC2 and

G = GZERO.

Nonconvergence is indicated by the output statement

ITERATIONS AND STILL NO SOLUTION.

RETURN

END (of Subroutine GCOMP)

Write statements start printout

CHANGE DEGREES TO RADIANS

THETA } This is done for these angles.

THC

TIR

CALL ROUTINE WHICH CALCULATES THE REMAINING GEOPHYSICAL PARAMETERS FROM THE INVERSION INPUTS

CALL GEOPHYS

SUBROUTINE GEOPHYS

COMPUTE DENSITIES RH2, RH3

$$Z_1 = C_1 \rho_1 \quad (41)$$

$$D = \frac{C_1}{4FM} = \frac{\lambda_2}{4} \quad (42)$$

= quarter wavelength in layer at top of sediment.

Note: speed of sound in the layer, $C_2$, should be used here instead of speed of sound in water, $C_1$, in order to get the correct layer thickness D.

R = EXP(-ALOG(10)*ALOSSØ/20 can be written (43)

$R = \exp(-\ln 10)\ \frac{ALOSSØ}{20}$. We can see this as follows: (44)

The reflection coefficient R = (pressure of reflected wave)/(pressure of incident wave). Thus ALOSSØ = -20 $\log_{10} R$ is the low frequency loss levels at high angles.

$$\frac{-ALOSSØ}{20} = \log_{10} R = \frac{\ln R}{\ln 10} \quad (45)$$

$$\ln R = -(\ln 10)\ \frac{ALOSSØ}{20}$$. Then e raised to power lnR gives the equation for R.

$Z_3 = (1+R)/(1-R)Z_1$. This is the impedance $Z_3$ of a medium into which a wave (46) is traveling from another medium which has impedance $Z_1$ and is given by eq. (2.14) of Brekhovskikh(1980) with subscripts changed to correspond to our situation. Normal incidence as assumed.

$$R = e^{-(\ln 10)\ \frac{ALOSSM}{20}} \quad (47)$$

ALOSSM is the minimum loss level at high angles. This should occur when the layer thickness D = $\lambda 2/4$. For these conditions according to eq. (3.23) of Brekhovshikh(1980),

$$R = \frac{Z_2^2 - Z_1 Z_3}{Z_2^2 + Z_1 Z_3}. \quad (48)$$

If ALOSSM is a minimum, then R is a maximum. When R is maximum, then $Z_2$ is greater than $Z_1$ and $Z_3$ and we have a high acoustical impedance layer which acts as a good sound reflector. If the value of $Z_2$ is between those of $Z_1$ and $Z_3$ we have good transmission and a small reflection coefficient. When $Z_2 = \sqrt{Z_1 Z_3}$, $R=0$ and the incident ray is completely transmitted. In this (49) case there is no minimum value of loss at a particular frequency for high angles. Solve the equation for $Z_2$.

$$R Z_2^2 + R Z_1 Z_3 = Z_2^2 - Z_1 Z_3 \quad (50)$$

$$Z_2^2 (R-1) = - Z_1 Z_3 (R+1) \quad (51)$$

$$Z_2 = \sqrt{\frac{1-R}{1+R} Z_1 Z_3} \quad (52)$$

in agreement with the second expression for $Z_2$ in this subroutine.

SPRAT = $C_3/C_1$ is the sound speed ratio. (53)

RH2 = $\rho_2 = \frac{Z_2}{C_2}$ is the density in the layer. (54)

RH3 = $\rho_3 = \frac{Z_3}{C_3}$ is the density in the sediment. (55)

COMPUTE DISSIPATION CONSTANT ALPHθ

THETA = $\cos^{-1} \frac{C_2}{C_1} \cos$ (THETA) = $\theta_2$ is the angle in the layer corresponding to (56)

the bottom grazing angle THETA which is input data. The sound speed $C_2$ is assumed to be the speed at the top of the sediment as well as in the layer.

BS = $\sin \theta_2$ (57)

BC = $\cos \theta_2$ (58)

V32 = $\frac{Z_3 - Z_2}{Z_3 + Z_2}$ used to calculate the layer reflection. (59)

V21 = $\frac{Z_2 - Z_1}{Z_2 + Z_1}$ and transmission coefficients. These represent equations (31) (60)

and (32) respectively of Spofford et al.(1982)..

AUX = $\frac{4\pi DF}{C1} \sin \theta_2 = \delta$ gives twice the phase length for propagation of a wave (61)

through the layer as is shown below. Note: $C_1$ should be changed to $C_2$, the speed of sound in the layer, in the last expression for AUX.

$$V = \left| \frac{V_{21} + V_{32}(\cos\delta + i\sin\delta)}{1 + V_{21}V_{32}(\cos\delta + i\sin\delta)} \right| \quad (62)$$

This is the reflection coefficient for a plane layer. It corresponds to equation (3.20) of Brekhovskhik(1980) with appropriate changes in subscripts giving equation (30) of Spofford et al.(1982) and use of the relation $\cos\delta + i\sin\delta = e^{i\delta}$.

$$T = \frac{16 Z_1 Z_3 \left( \frac{Z_2}{(Z_1+Z_2)(Z_2+Z_3)} \right)^2}{[1 + V_{21}V_{32}(\cos\delta + i\sin\delta)]^2} \quad (63)$$

This is a two-way transmission coefficient. It corresponds to the use of the transmission coefficient equation (3.21) of Brekhouskhik(1980) two times; once for transmission from water (1), to layer (2), to sediment (3), and once for transmission from sediment (3), to layer (2), to water (1).

For a wave propagating downward, we have from equation (3.21) of Brekhovskhik(1980)

$$W = \frac{4Z_1 Z_2}{(Z_1+Z_2)(Z_2+Z_3)} \times \frac{1}{e^{-ik_{2z}d} + V_{32}V_{21}e^{ik_{2z}d}}, \quad (64)$$

Taking account of coordinate axis directions and layer numbering for our case we should have

$$W \rightarrow T_1 = \frac{4Z_3 Z_2}{(Z_3+Z_2)(Z_2+Z_1)} \frac{1}{e^{i\alpha} + V_{12}V_{23}e^{-i\alpha}} \quad (65)$$

and for a wave traveling upward

$$T_2 = \frac{4Z_1 Z_2}{(Z_1+Z_2)(Z_2+Z_3)} \frac{1}{e^{-i\alpha} + V_{23}V_{12}e^{i\alpha}} \quad (66)$$

The two-way layer transmission coefficient is then the product

$$T = T_1 T_2 = 16 Z_1 Z_3 \left(\frac{Z_2}{(Z_1+Z_2)(Z_2+Z_3)}\right)^2 \times \frac{1}{\left(e^{i\alpha} + V_{12}V_{23}e^{-i\alpha}\right)\left(e^{-i\alpha} + V_{32}V_{21}e^{i\alpha}\right)}, \quad (67)$$

$$T = \frac{16 Z_1 Z_3 \left(\frac{Z_2}{(Z_1+Z_2)(Z_2+Z_3)}\right)^2}{1 + V_{32}V_{21}\left(e^{i2\alpha} + e^{-i2\alpha}\right) + (V_{32}V_{21})^2}, \quad (68)$$

$$T = \frac{16 Z_1 Z_3 \left(\frac{Z_2}{(Z_1+Z_2)(Z_2+Z_3)}\right)^2}{1 + 2V_{32}V_{21}\cos 2\alpha + (V_{32}V_{21})^2}, \quad (69)$$

where

$$\alpha = k_{2z}d = k_2 d \sin\theta_2 = \frac{2\pi FD}{C_2}\sin\theta_2, \quad (70)$$

the phase length for travel through the layer, and we see

$$AUX = \frac{4\pi FD \sin\theta_2}{C_1} = 2\alpha = \delta, \quad (71)$$

the expression in the subroutine. Note $C_1$ should be changed to $C_2$ here.

The denominator of T given in the subroutine is the same as in the last expression for T. Sign changes of the Z's due to changes of direction which might be troublesome cancel out.

$$AUX = \frac{10^{-DBLOSS/10} - V^2}{T} \quad (72)$$

$$ALS = -10 \log_{10}\left(\frac{10^{-DBLOSS/10} - V^2}{T}\right) = DL. \quad (73)$$

We can arrive at this relation by starting with the assumption that losses behave linearly in sediments as expressed by equation (13) of Spofford et al. (1982)

$L = K \cdot S \cdot f_K$ where $K$ is the absorption coefficient, S is path length, and $f_k$ is frequency.

This can be rewritten in integral form. From Snell's law and differentiation we find

$$\cos\theta(z) = \frac{\cos\theta_0}{C_0} C(z), \text{ and} \quad (74)$$

$$-\sin\theta(z)\frac{d\theta(z)}{dz} = \frac{\cos\theta_0}{C_0} g(z), \text{ where } g(z) = \frac{dC(z)}{dz}, \quad (75)$$

$$DL = -2\int_0^{\tilde{z}} \frac{C_0 f_K (K_0 + K_0' z)\, dz}{\cos\theta_0\, g(z)} \left(\frac{d\theta}{dz}\right). \quad \text{Using } g(z) = \frac{g_0(1+B)C_0}{C(z)+BC_0} \quad (76)$$

$$DL = \frac{-2C_0 f_K}{g_0(1+B)C_0\cos\theta_0}\int_0^{\tilde{z}} (K_0 + K_0' z)(C(z)+BC_0)\frac{d\theta}{dz}\, dz, \quad (77)$$

$$DL = \frac{-2 f_K}{g_0(1+B)\cos\theta_0}\int_{\theta_0}^{\theta'} \left[K_0 C(z) + K_0'(z)C(z) + BK_0C_0 + K_0' BC_0 z\right] d\theta \quad (78)$$

The sound speed profile for the model is assumed to be, as given by equation (13) of Spofford et al.(1982):

$$C(z) = \left[2g_0(1+B)C_0 z + (1+B)^2 C_0^2\right]^{\frac{1}{2}} - BC_0, \quad (79)$$

from which

$$(C + BC_0)^2 = 2g_0(1+B)C_0 z + (1+B)^2 C_0^2, \quad (80)$$

$$(C + BC_0)^2 - (1+B)^2 C_0^2 = 2g_0(1+B)C_0 z, \quad (81)$$

$$z = \frac{(C+BC_0)^2 - (1+B)^2 C_0^2}{2g_0(1+B)C_0} = \frac{(C+BC_0)^2 - (1+B)^2 C_0^2}{2\sigma} \quad (82)$$

where

$$\sigma = g_0(1+B)C_0 \quad (83)$$

Substituting Z into the equation for DL gives

$$DL = \frac{-2f_K}{g_o(1+B)\cos\theta_o}\int_{\theta_o}^{\theta'}\left\{\frac{K_oC_o\cos\theta}{\cos\theta_o} + \frac{K_o'C_o\cos\theta}{2\sigma\cos\theta_o}\left[\left(\frac{C_o\cos\theta}{\cos\theta_o}+BC_o\right)^2 - (1+B)^2C_o^2\right]\right.$$

$$\left. + BK_oC_o + \frac{BC_oK_o'}{2\sigma}\left[\left(\frac{C_o\cos\theta}{\cos\theta_o}+BC_o\right)^2 - (1+B)^2C_o^2\right]\right\} d\theta \qquad (84)$$

Let $D = \dfrac{-2f_K}{g_o(1+B)\cos\theta_o}$

$$DL = D\int_{\theta_o}^{\theta'}\left\{\frac{K_oC_o\cos\theta}{\cos\theta_o} + \frac{K_o'C_o\cos\theta}{2\sigma\cos\theta_o}\left[\frac{C_o^2\cos^2\theta}{\cos^2\theta_o} + \frac{2BC_o^2\cos\theta}{\cos\theta_o} + B^2C_o^2\right.\right.$$

$$\left. - C_o^2 - 2BC_o^2 - B^2C_o^2\right] + BK_oC_o$$

$$\left. + \frac{BC_oK_o'}{2\sigma}\left[\frac{C_o^2\cos^2\theta}{\cos^2\theta} + \frac{2BC_o^2\cos\theta}{\cos\theta_o} + B^2C_o^2 - C_o^2 - 2BC_o^2 - B^2C_o^2\right]\right\} d\theta \qquad (85)$$

$$DL = C_oD\int_{\theta_o}^{\theta'}\left\{\frac{K_o\cos\theta}{\cos\theta_o} + \frac{K_o'C_o^2}{2\sigma\cos\theta_o}\left[\frac{\cos^3\theta}{\cos^2\theta_o} + \frac{2B\cos^2\theta}{\cos\theta_o} - (1+2B)\cos\theta\right]\right.$$

$$\left. + BK_o + \frac{BC_o^2K_o'}{2\sigma}\left[\frac{\cos^2\theta}{\cos^2\theta_o} + \frac{2B\cos\theta}{\cos\theta_o} - (1+2B)\right]\right\} d\theta \qquad (86)$$

$$DL = C_oD\left[\frac{K_o\sin\theta}{\cos\theta_o} + \frac{K_o'C_o^2}{2\sigma\cos\theta_o}\left\{\frac{1}{\cos^2\theta_c}\left(\sin\theta - \frac{\sin^3\theta}{3}\right) + \frac{2B}{\cos\theta_o}\left(\frac{\theta}{2}+\frac{\sin 2\theta}{4}\right)\right.\right.$$

$$- (1+2B)\sin\theta \quad + \quad BK_o\theta$$

$$\left.\left. + \frac{BC_o^2K_o'}{2\sigma}\left\{\frac{1}{\cos^2\theta_o}\left(\frac{\theta}{2}+\frac{\sin 2\theta}{4}\right) + \frac{2B}{\cos\theta_o}\sin\theta - (1+2B)\theta\right\}\right]_{\theta_o}^{\theta'} \qquad (8$$

Interchanging the limits of integration and factoring gives

$$DL = \frac{2C_0 f_K}{g_0(1+B)\cos\theta_0}\left[\left(\sin\theta - \frac{\sin^3\theta}{3}\right)\frac{K_0' C_0^2}{2\sigma\cos^3\theta_0}\right.$$
$$+\left(\frac{\theta+\sin\theta\cos\theta}{2}\right)\left(\frac{2BC_0^2K_0' + BC_0^2K_0'}{2\sigma\cos^2\theta_0}\right)$$
$$+\left(\sin\theta\right)\left(\frac{2\sigma K_0 - (1+2B)K_0'C_0^2 + 2B^2C_0^2K_0'}{2\sigma\cos\theta_0}\right)$$
$$\left.+\left(\theta\right)\left(BK_0 - \frac{BC_0^2K_0'(1+2B)}{2\sigma}\right)\right]_{\theta'}^{\theta_0} \qquad (88)$$

This is equation (23) of Spofford et al.(1982). Note that in the second line of equation (23) of Spofford et al.(1982) the power of cos $\theta_0$ should be 2 instead of 4. Now consider figure 8.

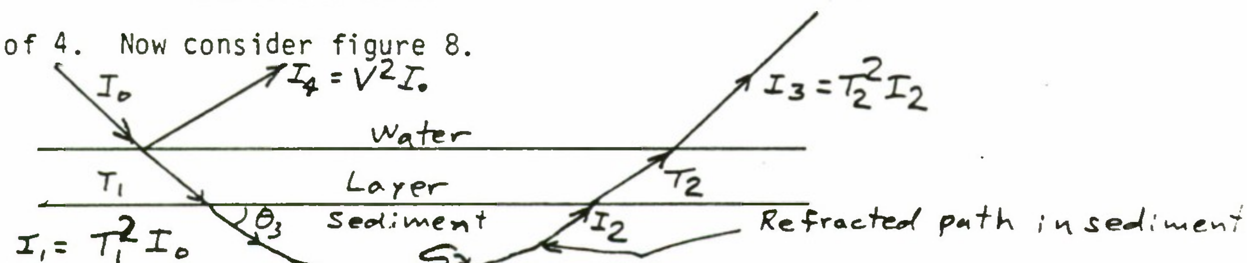



Figure 8. Intensity Relationships for reflected and refracted paths.

Loss due to attenuation in the sediment only is

$$DL = -10 \log_{10} \frac{I_2}{I_1} \qquad (89)$$

We see $I_1 = T_1^2 I_0$ and

$I_3 = T_2^2 I_2$ where $T_1$ and $T_2$ are transmission coefficients defined previously. The intensity of the reflected ray

$I_4 = V^2 I_0$ where V is the layer reflection coefficient defined previously. The intensity of the sound leaving the bottom after reflection from and transmission through the layer is

$$I_5 = I_3 + I_4, \qquad (90)$$
$$I_5 = T_2^2 I_2 + V^2 I_0 \qquad (91)$$

$$\frac{I_5}{I_0} = V^2 + \left(T_2^2/I_0\right)I_2 \qquad (92)$$

An expression for $I_2$ is needed.

Now $10 \log I_2 = 10 \log I_1 - DL$ , (93)

$$\log I_2 = \log I_1 - DL/10, \qquad (94)$$

$$I_2 = \text{antilog}\,(\log I_1 - DL/10). \qquad (95)$$

Thus $\dfrac{I_5}{I_0} = V^2 + (T_2^2/I_0)\,\text{antilog}\,(\log I_1 - DL/10),$ (96)

$$\frac{I_5}{I_0} = V^2 + (T_2^2/I_0)\,\text{antilog}\,(\log T_1^2 I_0 - DL/10). \qquad (97)$$

The measured loss

$$DBLOSS = -10 \log \frac{I_5}{I_0}, \qquad (98)$$

$$-DBLOSS/10 = \log\left[V^2 + (T_2^2/I_0)\,\text{antilog}\,(\log T_1^2 I_0 - DL/10)\right]. \qquad (99)$$

Note that

$$10^{-DBLOSS/10} = V^2 + (T_2^2/I_0)\,\text{antilog}\,(\log T_1^2 I_0 - DL/10) \qquad (100)$$

$$10^{-DBLOSS/10} - V^2 = (T_2^2/I_0)\,\text{antilog}\,(\log T_1^2 I_0 - DL/10) \qquad (101)$$

$$\log\left(I_0 \frac{10^{-DBLOSS/10} - V^2}{T_2^2}\right) = \log T_1^2 I_0 - DL/10 \qquad (102)$$

$$\log \frac{10^{-DBLOSS/10} - V^2}{T_1^2 T_2^2} = -DL/10 . \quad \text{Let } T_1 T_2 = T. \qquad (103)$$

Now $DL = -10 \log_{10} \dfrac{10^{-DBLOSS/10} - V^2}{T} = ALS$ (104)

as given by the expression in the program. Note that this denominator should be changed to $T^2$ to agree with the preceding equation.

Equation (23) of Spofford et al.(1982) for the dissipation loss in the sediment can be rewritten in terms of frequency FK in kHz, SIG = $\sigma$, AMU = $\mu$, ANU = $\nu$, ALPHØ = $\alpha_0 = k_0$, and GAM = $\gamma$ as expressed in the program as

$$\begin{aligned}\frac{DL}{f_K} = \frac{2C_2}{g_0(1+B)\cos\theta_2}\Bigg[&\frac{\gamma C_2^2}{2\sigma\cos^3\theta_2}\left(\sin\theta_2 - \frac{\sin^3\theta_2}{3}\right)\\ &+\left(\frac{B\gamma C_2^2 + 2\gamma\nu C_2}{4\sigma\cos^2\theta_2}\right)\left(\theta_2 + \sin\theta_2\cos\theta_2\right)\\ &+\left(\frac{\gamma(\nu^2-\mu) + 2B\gamma\nu C_2}{2\sigma\cos\theta_2}\right)\sin\theta_2 + \frac{B\gamma(\nu^2-\mu)}{2\sigma}\theta_2\Bigg]\\ &+\alpha_0\left(\frac{\sin\theta_2}{\cos\theta_2} + B\theta_2\right)\frac{2C_2}{g_0(1+B)\cos\theta_2}, \end{aligned} \qquad (105)$$

where $\theta' = 0$, $\theta_2 = \theta_o$ the grazing angle of the ray in the layer with the top of the sediment, $\gamma = k_o'$ the gradient of the absorption coefficient and $\alpha_o = k_o$. Solving for $\alpha_o$ we obtain as in the subroutine

$$\alpha_o = \frac{ALS}{F_K} - \frac{2C_2}{g_o(1+B)\cos\theta_2}\left[\frac{\gamma C_2^2}{2\sigma\cos^3\theta}\left(\sin\theta_2 - \frac{\sin^3\theta_2}{3}\right) + \left(\frac{B\gamma C_2^2 + 2\gamma\nu C_2}{4\sigma\cos^2\theta_2}\right)\left(\theta_2 + \sin\theta_2\cos\theta_2\right) + \left(\frac{\gamma(\nu^2-\mu) + 2B\gamma\nu C_2}{2\sigma\cos\theta_2}\right)\sin\theta_2 + \frac{B\gamma(\nu^2-\mu)\theta_2}{2\sigma}\right] \times \left(\frac{g_o(1+B)\cos\theta_2}{2C_2}\right)\left(\frac{\sin\theta_2}{\cos\theta_2} + B\theta_2\right)^{-1} \qquad (106)$$

which is the equation for the dissipation constant at the top of the sediment. For this computation, it is assumed that the speed, $C_2$, and angle, $\theta_2$ are the same in the layer and at the top of the sediment. Also, note that Fk is the center frequency of a one-octave frequency band used for processing measured data.

RETURN

END (of SUBROUTINE GEOPHYS)

GO TO 499.

499 CALL CANGLE

<u>SUBROUTINE CANGLE</u>

D1=2ZB-ZR-ZS is twice the effective depth, $\bar{D}$, given by equation (10) of <u>Spofford et al.</u>(1982).

CALCULATE SEDIMENT THICKNESS

B = beta

CZP = 2000

Sound speed at the top of the sediment is assumed to be $C_2$. The equation for one-way travel time in the sediment is needed. The necessary equation can be derived by assuming the sound is propagating downward in the Z direction. By definition

$$C(z) = \frac{dz}{dt} \quad \text{so} \qquad (107)$$

$$dt = \frac{dz}{C(z)} \quad \text{and} \qquad (108)$$

$$t = \int \frac{dz}{C(z)}. \qquad (109)$$

The sound speed gradient in the sediment is given by the model as

$$g = \frac{dC}{dZ} = \frac{g_o(1+B)C_2}{C + BC_2}. \qquad (110)$$

Let $\sigma = g_o(1+B)C_2$. Then (111)

$$dZ = \frac{(C+BC_2)}{g_o(1+B)C_2}\,dC = \frac{(C+BC_2)\,dC}{\sigma}, \qquad (112)$$

$$t = \frac{1}{\sigma}\int_{C_2}^{C(z)} \frac{C + BC_2}{C}\,dC, \qquad (113)$$

$$t = \frac{1}{\sigma}\int_{C_0}^{C(z)} \left(1 + B\frac{C_2}{C}\right)dC = \frac{1}{\sigma}\Big[C + BC_2 \ln C\Big]_{C_2}^{C(z)}, \qquad (114)$$

$$t = \frac{1}{\sigma}\Big[C(z) + BC_2 \ln C(z) - C_2 - BC_2 \ln C_2\Big], \qquad (115)$$

$$t = \frac{1}{\sigma}\left[C(z) - C_2 + BC_2 \ln \frac{C(z)}{C_2}\right], \qquad (116)$$

$$t = \frac{C_2}{\sigma}\left[\frac{C(z)}{C_2} - 1 + B \ln \frac{C(z)}{C_2}\right], \qquad (117)$$

$$t = \frac{1}{g_o(1+B)}\left[\left(\frac{C(z)}{C_2} - 1\right) + B \ln \frac{C(z)}{C_2}\right]. \qquad (118)$$

This is the one-way travel time for sound in the sediment and is equation (3) in "DOCUMENTATION OF BOTTOM LOSS UPGRADE PARAMETERS." This equation cannot be solved in closed form for depth of sediment BZ=z so we will find C(z) at the bottom of the sediment (basement depth) by use of Newton's method of approximating a root and use C(z) to find z. From the last equation

$$g_o(1+B)t = \frac{C(z)}{C_2} - 1 + B \ln C(z) - B \ln C_2, \qquad (119)$$

$$C_2 g_o(1+B)t = C(z) - C_2 + BC_2 \ln C(z) - BC_2 \ln C_2, \qquad (120)$$

$$C_2\big[g_o(1+B)t + 1 - B \ln C_2\big] = C(z) + BC_2 \ln C(z). \qquad (121)$$

Thus, in the subroutine we find

$A = C_2\big[g_o(1+B)t + 1 - B\ln C_2\big]$ as on the left side of the previous equation. (122)

The formula for Newton's method is

$A_1 = A - \frac{f(A)}{f'(A)}$ where $A$ is an approximation and $A_1$ is an improved (123) value. Let A = CZP and $A_1$ = CZ, then

$$CZ = CZP - \frac{f(CZP)}{f'(CZP)} \quad \text{where} \qquad (124)$$

$$f(CZP) = A - CZP - BC_2 \ln CZP \quad \text{and} \qquad (125)$$

$f'(CZP) = -1 - \frac{BC_2}{CZP}$ gives the result (126)

$$CZ = CZP + \frac{(A - CZP - BC_2 \ln CZP)}{1 + \frac{BC_2}{CZP}} \tag{127}$$

as in the subroutine. Starting with CZP = 2000 as a first approximation, iterations continue until convergence is completed. This is chosen to occur (as in the subroutine)

$IF|CZ-CZP| < .01$ , let

$CZP = CZ = C(z)$.

From the formula $g = \frac{dC}{dz} = \frac{g_0(1+B)C_2}{C + BC_2}$ (128)

we find Z by integration to be

$$Z = \int dz \tag{129}$$

$$Z = \int_{C_2}^{CZ} \frac{C + BC_2}{g_0(1+B)C_2} dC, \tag{130}$$

$$Z = \frac{1}{g_0(1+B)C_2} \int_{C_2}^{CZ} (C + BC_2) dC, \tag{131}$$

$$Z = \frac{1}{g_0(1+B)C_2} \left[ \frac{C^2}{2} + BC_2C \right]_{C_2}^{CZ}, \tag{132}$$

$$Z = \frac{1}{g_0(1+B)C_2} \left[ \frac{(CZ)^2}{2} + \frac{2BC_2CZ}{2} - \frac{C_2^2}{2} - \frac{2BC_2^2}{2} \right], \tag{133}$$

$$Z = \frac{1}{g_0(1+B)C_2} \left[ (CZ)^2 + 2BC_2CZ + B^2C_2^2 - C_2^2 - 2BC_2^2 - B^2C_2^2 \right]. \tag{134}$$

70 $$BZ = Z = \frac{1}{g_0(1+B)C_2} \left[ (CZ + BC_2)^2 - C_2^2(1+B)^2 \right], \tag{135}$$

as in the subroutine, gives the sediment thickness.

COMPUTE REFINED CRITICAL ANGLE THRC = $\pi/4$

CALL TOTCRIT

SUBROUTINE TOTCRIT

Check that $C_3 < C_2$

This insures that if total internal reflection occurs, it will be from the top of the (high speed) layer and the layer is distinct from the sediment beneath.

IF (C3≤C2) GO TO 1Ø (where angle is computed)

Print format "C3 MUST BE LESS THAN OR EQUAL TO C2"

COMPUTE TIR = ANGLE OF TOTAL INTERNAL REFLECTION

TIR = θ

If C2≤C1 GO TO 100. In this case TIR is not calculated. For total internal reflection, it is required that C2>C1.

$$TIR = \cos^{-1} \frac{C_1}{C_2} \qquad (136)$$

from Snell's law when refracted ray angle = 0.

100 CONTINUE.

COMPUTE THC = CRITICAL ANGLE (CAUSTIC).

This is done by an iterative procedure. Start with definitions as follows:

$$PI2 = \pi/2 \qquad (137)$$

$$DELT = \pi/100 \qquad (138)$$

$D1 = 2ZB - ZR - ZS = 2\bar{D}$, twice average depth of water below source and receiver (139)

$$D2 = \frac{2 C_3 B}{g_0(1+B)} \qquad (140)$$

$$FAC = C_3/C_1 \qquad (141)$$

$$TH3 = \cos^{-1} \frac{C_3}{C_1} \quad THRC = \cos^{-1} \frac{C_3}{C_1} \quad \theta_{rc} = \theta_3 \qquad (142)$$

as in figure 9.

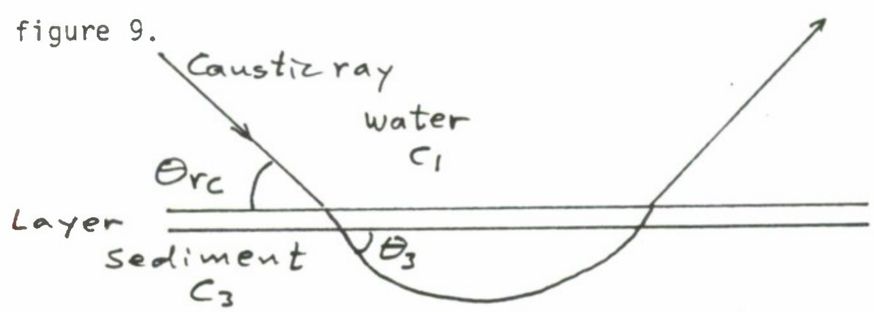



Figure 9. Angles for the caustic ray are illustrated.

For the first approximation use $\theta rc = \pi/4$.

An approximate range is found by using $\theta rc$ and $\theta_3$ in the range equation found by combining equations (16) and (21) of Spofford et al.(1982).

$$R = \frac{D1}{\tan\theta_{rc}} + \frac{2BC_3\tan\theta_3}{g_o(1+B)}\left[1 + \left(1 + \frac{\theta_3}{\sin\theta_3\cos\theta_3}\right)\frac{1}{2B}\right] . \qquad (143)$$

Here the lower limit in the equation is zero,

$$R = \frac{D1}{\tan\theta_{rc}} + D2\tan\theta_3\left[1 + \left(1 + \frac{\theta_3}{\sin\theta_3\cos\theta_3}\right)\frac{1}{2B}\right] . \qquad (144)$$

MINIMIZE EXPRESSION FOR RANGE BY CONJUGATE DIRECTIONS.

The range is varied by incrementing the angle $\theta rc$ by delt = $\frac{\pi}{100}$ radian:

$$AUX = \theta rc + \frac{\pi}{100} \qquad (145)$$

It is assumed the incremented angle AUX is between $\pi/2$ and the angle of total internal reflection.

IF (AUX $\geq \frac{\pi}{2}$) GO TO 500.

IF (AUX $\leq$ TIR) GO TO 500.

The angle $\theta_3$ is recomputed in terms of the incremented value of $\theta rc$ and a new range RAUX is computed by the same formula that gives R above. If the new range, RAUX, is less than the old one, R, the procedure is repeated until the new one, RAUX, becomes greater than the old one, R. When this occurs, the increment delt is change to $-\frac{delt}{3}$ and the process repeats until convergence occurs, i.e. IF $|delt| \leq 1 \times 10^{-4}$. The idea of this iterative process can be illustrated by figure 10 shown here adapted from figure 8.b. of Spofford et al.(1982).

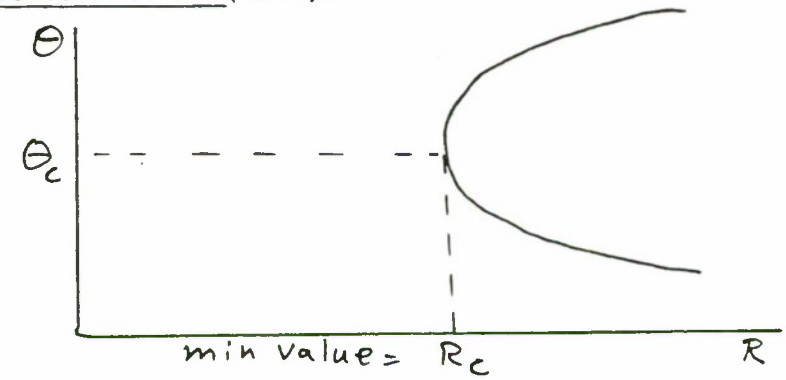



Figure 10. Illustration of minimum value of range at the caustic angle.

The angle $\Theta_C$ is desired. We find the angle by varying the range R as a function of angle $\Theta$ until R is a minimum. When this occurs, $\Theta=\Theta_C$ the caustic angle. If convergence does not occur, the procedure is stopped, and the statement "CRITICAL ANGLE FAILED TO CONVERGE" is printed.

BOTTOM ANGLE OF REFRACTED RAY AT CRITICAL ANGLE

$THC = \tan^{-1} \frac{D1}{R} = \Theta_C$ is found from the range and twice the effective depth (146) as shown in figure 11. This is the observed angle of the caustic ray as illustrated.

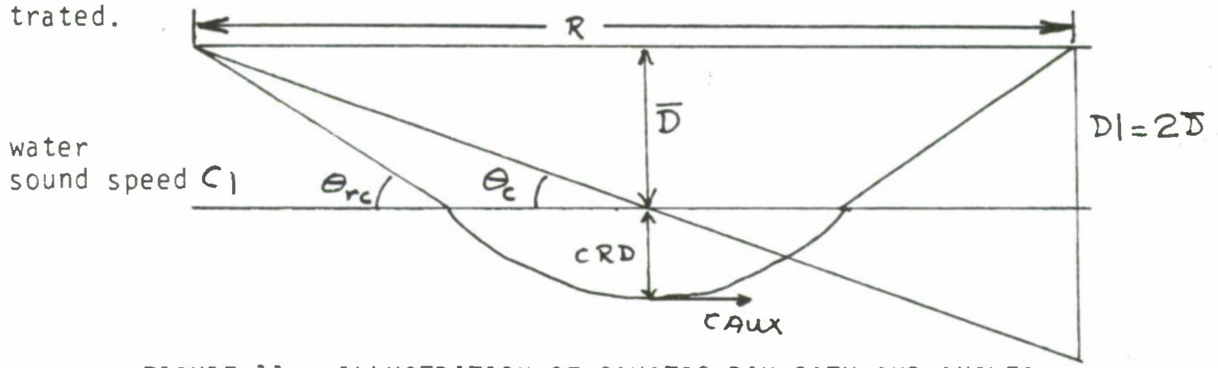



FIGURE 11. ILLUSTRATION OF CAUSTIC RAY PATH AND ANGLES

The speed at the greatest depth in the sediment reached by the basement grazing ray found from the formula for the sound speed profile as a function of the depth assumed by the model is

$$CB = \sqrt{2g_0(1+B)C_3BZ + C_3^2(1+B)^2} - BC_3 \qquad (147)$$

$THIB = \cos^{-1} \frac{C1}{CB} = \Theta_{1B}$, the grazing angle in the water for the basement grazing (148) ray is found from Snell's law.

RETURN

END (of SUBROUTINE TOTCRIT)

We now continue with SUBROUTINE CANGLE

COMPUTE CRITICAL RAY DEPTH CRD

From Snell's law, the speed at the greatest depth of the caustic ray is

$$CAUX = \frac{C_1}{\cos\Theta_{rc}} \qquad (149)$$

We previously found the equation for BZ the sediment thickness as a function of CZ the sound speed at the corresponding depth. Now let's use the same equation with BZ = CRD, CZ = CAUX and $C_2 = C_3$ the sound speed at the top of the sediment so

$$CRD = \frac{1}{2g_0(1+B)C_3}\left[(CZ + BC_3)^2 - C_3^2(1+B)^2\right] \qquad (150)$$

as given in SUBROUTINE CANGLE and illustrated in figure 11.

CALCULATE VELOCITY, VELOCITY GRADIENT, AND ATTENUATION CONSTANT AT DEPTH OF 500 METERS.

Setting depth in sediment Z = 500 meters and using the formula for the assumed sound speed profile we find the speed in the sediment at depth 500 meters to be

$$BSPD = \left[2g_0(1+B)(C_3)(500) + C_3^2(1+B)^2\right]^{\frac{1}{2}} - BC_3 \qquad (151)$$

where $C_3$ is sound speed at the top of the sediment. The sound speed gradient at 500 meters depth in the sediment is, from the assumed sound speed gradient equation,

$$BGRAD = \frac{g_0(1+B)C_3}{BSPD + BC_3} . \qquad (152)$$

The sound absorption coefficient is found to be

$$ALBOT = K = K_0 + k_0' Z \qquad (153)$$

$$= \alpha_0 + \gamma(500)$$

COMPUTE TWO WAY TRAVEL TIME IN SECONDS

TWTT = 2T

SPRAT = $C_2/C_1$

COMPUTE BASEMENT CRITICAL ANGLES THIB, TH3B

Sound speed in the sediment at the basement level is found from the sound speed profile equation

$$CB = \sqrt{2g_0(1+B)C_3(BZ) + (1+B)^2C_3^2} - BC_3 \qquad (154)$$

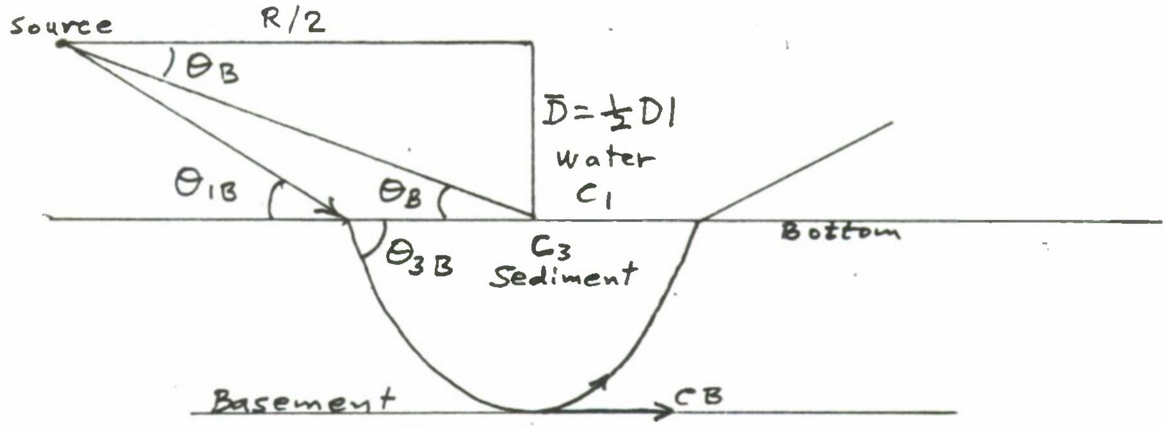



Figure 12. Illustration of basement grazing ray path.

For a refracted ray with its vertex at the basement as shown in figure 12, Snell's law gives

$$\cos\theta_{1B} = \frac{C_1}{C_B} \qquad (155)$$

$$\theta_{1B} = \cos^{-1}\frac{C_1}{C_B} \qquad (156)$$

which is the largest bottom grazing angle for a ray which is refracted above the basement, and

$$\theta_{3B} = \cos^{-1}\frac{C_3}{C_B} \quad . \qquad (157)$$

In terms of these angles the range equation becomes

$$R = \frac{D1}{\tan\theta_{1B}} + \frac{2BC_3\tan\theta_{3B}}{g_0(1+B)}\left[1 + \frac{1}{2B}\left(1 + \frac{\theta_{3B}}{\sin\theta_{3B}\cos\theta_{3B}}\right)\right] \qquad (158)$$

as in SUBROUTINE CANGLE.

COMPUTE SMALLEST APPARENT ANGLE FOR BASEMENT REFLECTION.

From the value of R found last

$$\theta_B = \tan^{-1}\frac{D1}{R} \qquad (159)$$

as shown in figure 12. If the angle is larger than this, there will be a reflection from the basement.

CHANGE RADIANS TO DEGREES

$\theta_B = \theta_B \times 180/\pi$

$A = TIR \times 180/\pi$ = angle of total internal reflection

$A_1 = \theta_c \times 180/\pi$ = apparent caustic angle in the water at the bottom

$A_2 = \theta_{rc} \times 180/\pi$ = caustic ray grazing angle in the water at the bottom

$A_3 = \theta_{1B} \times 180/\pi$ = smallest bottom grazing angle in the water for reflection from the basement.

PRINT OUT CRITICAL ANGLES

Format "CRITICAL ANGLES" - - -

RETURN

END (of subroutine CANGLE). We go back to main program and

PRINT GEO-PARAMETERS in Format "GEO-PARAMETERS" - - -

CALL ROUTINES FOR FREQUENCY--INDEPENDENT INTERMEDIATE VARIABLE

The subroutines REFL, REFR, and BASE are used to compute quantities needed in the bottom loss subroutine, LOSS. CALL REFL

**SUBROUTINE** REFL

NSAP = smallest angle to reach surface due to sound profile.

COMPUTE NSAP

NSAP = 1 is defined.

IF (C1≥CS) go to 100.

For a ray path as shown in figure 13,

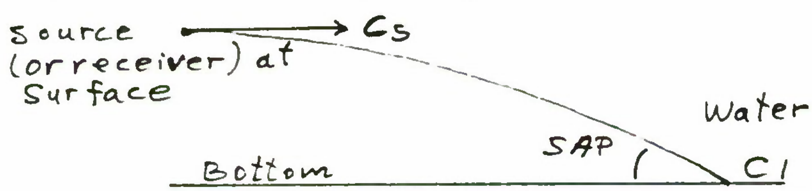



Figure 13. Illustration of ray path with limiting smallest angle SAP.

a ray may be horizontal at the source and have a bottom grazing angle SAP where Snell's law gives

$$\frac{C_S}{1} = \frac{C_1}{\cos SAP} \qquad (160)$$

SAP = $\cos^{-1}\frac{C_1}{C_S}$ If $C_1 \geq C_S$ this calculation will be skipped--the angle (161) is unrealistic.

NSAP = SAP + 1 is redefined.

SAP is printed in format "SMALLEST ANGLE TO REACH SURFACE." - - -

COMPUTE REFLECTION COEFFICIENTS FOR ANGLES GREATER THAN TIR, SAP

NTIR = TIR + 1 angle in degrees.

N = MAX0 (NTIR,NSAP) says pick the largest of the angles expressed as integers in degrees.

$Z = \rho_1 C_1$
$Z_2 = \rho_2 C_2$
$Z_3 = \rho_3 C_3$

These are constants to be used in computing impedances needed to find reflection coefficients.

DELT = $\pi/_{180}$ is used to convert angle in degrees to radians and as an increment in angle for a one degree change.

TH = (NSAP-1)$\pi/_{180} = \theta$ is angle equal to SAP.

FAC 2 = $C_2/C_1$
FAC 3 = $C_3/C_1$
FAC S = $C_s/C_1$

These are speed ratios.

AR = 2ZR/CS = twice travel time from receiver to surface.

AS = 2ZS/CS = twice travel time from source to surface.

D1 = $2\overline{D}$ = twice average distance from source and receiver to bottom.

DO 200 I = NSAP, 90 and IF (I<N) GO TO 2ØØ insure the following calculations are performed for angles varying by steps of 1 degree:

For angles greater than the larger of TIR,SAP Surface Scattering Travel Time Differences, SIN2, Reflection Coefficients, Travel Time, and Geometric Intensity are computed. If SAP<TIR, for each step from SAP to TIR Surface Scattering Travel Time Differences only are computed because total internal reflection occurs in this range of angles, so the reflection coefficient is unity and special calculations of the other quantities are not applicable. For each step from TIR to 90 all quantities are calculated.

SURFACE SCATTERING TRAVEL TIME DIFFERENCES

The sine of the angle made by the ray at the source is found from Snell's law

$$\cos\Theta_s = \frac{C_s}{C_1} \cos\Theta_1 \quad \text{and the identity} \qquad (162)$$

$$\sin^2\Theta_s = 1 - \cos^2\Theta_s \quad \text{where } \Theta_1 \text{ is the bottom grazing angle.} \qquad (163)$$

$$S = \sin\Theta_s = \sqrt{1 - \left(\frac{C_s}{C_1}\right)^2 \cos^2\Theta_1}$$

Travel time difference can be found as illustrated by the following figure.

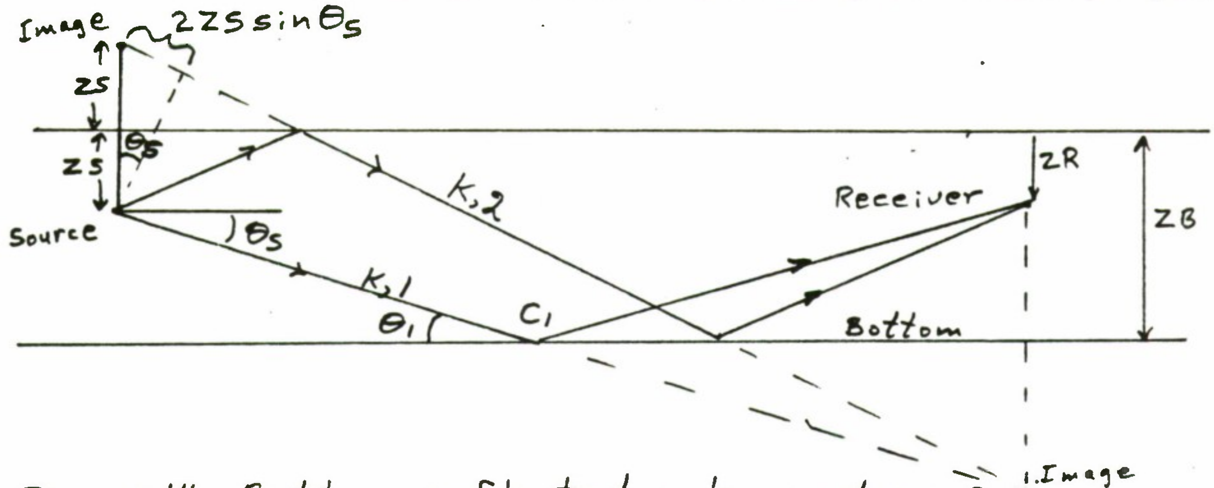



Figure 14. Bottom reflected only and surface scattered path difference.

Two different paths are designated K,1 and K,2. The assumption is made that the bottom grazing angle is approximately the same for the two paths. Then the surface reflected path, K,2, will be longer than the path K,1 by approximately 2ZS $\sin\Theta_S$ and the travel time difference is

$$2\left(\frac{ZS}{CS}\right)\sin\Theta_S \quad \text{which is} \tag{164}$$

$$RDTS(I) = (AS)(S) = 2(ZS/CS)\sqrt{1-\left(\frac{C_S}{C_1}\right)^2\cos^2\Theta_1}\,. \tag{165}$$

Interchanging source and receiver in Figure 14 yields

$$RDTR(I) = 2(ZR/CS)\sqrt{1-\left(\frac{C_S}{C_1}\right)^2\cos^2\Theta_1}\,. \tag{166}$$

RS1N2(I) = $\sin\Theta_2$ the grazing angle in the high speed layer by a procedure similar to the one which yields S above.

## R E F L E C T I O N   C O E F F I C I E N T S

$$A_1 = Z1/\sin\Theta_1 = \frac{\rho_1 C_1}{\sin\Theta_1} \tag{167}$$

$$A_2 = Z_2/RSIN2(I) = \frac{\rho_2 C_2}{\sin\Theta_2} \tag{168}$$

$$A_3 = Z_3/\sin\Theta_3 = \frac{\rho_3 C_3}{\sin\Theta_3} \tag{169}$$

These are the acoustic impedances of the water, layer, and sediment.

RV32(I)
RV21(I)
} These are reflection coefficients for the boundaries designated.

$$RGI(I) = \frac{\cos\theta_1}{R} = \frac{1}{R/\cos\theta_1} = \frac{1}{\text{slant range}} \quad (170)$$

is the factor for spherical spreading which represents decrease of amplitude with range.

RETURN

END (of SUBROUTINE REFL) (Go back to main program.)

CALL REFR

SUBROUTINE REFR

NTIR = TIR+1 gives angle in degrees.

NTHC = THC+1 Caustic angle + 1 degree.

N = NTHC - NTIR integer giving difference between the caustic angle and angle of total internal reflection in degrees.

DEL = π/180 is an increment of 1 degree expressed in radians.

TH is the caustic grazing angle expressed in radians = θrc.

$Z_1$, $Z_2$, $Z_3$ } factors used to compute reflection and transmission coefficients.

FAC2, FAC3, FACS } sound speed ratios

SEST = θrc, BEST = θrc } Starting estimates of small and big angles.

D1 through D14 are factors to be used in computation of geometric amplitude and other quantities to follow. They are expressed in terms of the same quantities used before, e.g. in SUBROUTINE GCOMP and GEOPHYS.

DO 1Ø I=1,90 sets the array for transmission coefficients = 0.

DO 1ØØ I=1,N and

J = NTHC-1 insures computation is done for each integer angle between caustic angle and angle of total internal reflection.

R = D1/tanTH gives the range not including that portion required for refraction in the bottom.

CALL REFRANG

## SUBROUTINE REFRANG

IF TH>TIR go to 100. Otherwise print

"SPECULAR ANGLE OF REFRACTED RAY LESS THAN TIR"

and stop computation.

$D1 = 2\bar{D}$

$PI2 = \pi/2$

$D2 = 2C_3B/g_o(1+B)$

$D3 - \frac{1}{2B}$

$FAC3 = C_3/C_1$

$R = D1/\tan TH$

$T3 = \cos^{-1}\left(\frac{C_3}{C_1}\right)\cos(SEST) = \theta_3$ gives (by Snell's law) angle in sediment for (171)

bottom grazing angle SEST.

$$VAL = \left[\frac{2\bar{D}}{\tan SEST} + \frac{2C_3B}{g_o(1+B)}\tan\theta_3\left(1+\frac{1}{2B}\left(1+\frac{\theta_3}{\sin\theta_3\cos\theta_3}\right)\right)\right] - R \quad (172)$$

VAL = R' - R as shown in Figure 15, the difference between a computed range from estimated angles and the actual range.

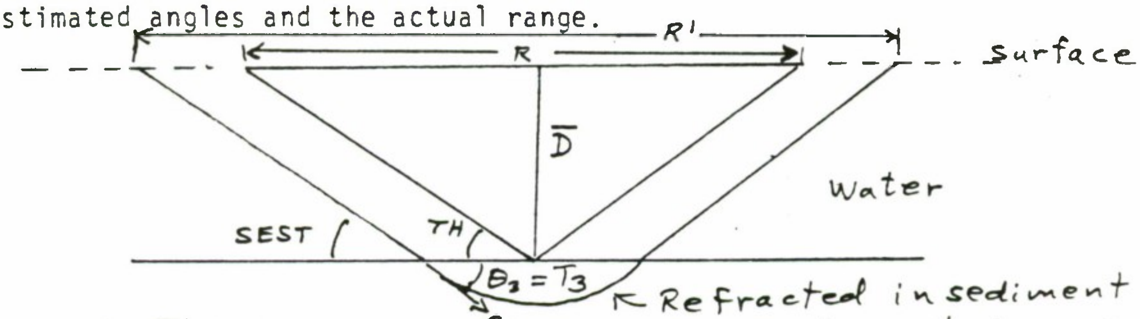



Figure 15. The range as found from estimated angles and the actual range.

$DEL = \frac{SEST-TIR}{10.0001}$ is angle increment.

The angles SA and BA correspond to rays a and b for range R2 shown in Figure 2.

COMPUTE SA

DO and IF statements start an iterative procedure which varies SEST and $\theta_3$ by + or - increments until $|DEL| < 1X10^{-6}$ while insuring $TIR \leq SA \leq \theta_{rc}$. When convergence is completed, the error VAL between $R'$ and R will be very small and the smallest bottom grazing angle SA for which a ray refracted in the sediment can travel from source to receiver is found. If convergence does not occur after 500 iterations, the statement is printed "SMALL BOTTOM REFRACTION ANGLE DOES NOT CONVERGE," and the procedure stops.

SA3=T3 gives the angle of the ray at the top of the sediment corresponding to the bottom grazing angle SA.

BA INITIALIZATION

$T3 = \theta_3 = \cos^{-1} \frac{C_3}{C_1} \cos$ BEST is the angle at the top of the sediment for bottom grazing angle BEST (with initial value $\theta_{rc}$).

VAL has the same significance as in COMPUTE SA with SEST replaced by BEST.

COMPUTE BA

DO and IF statements generate an iterative procedure which varies BEST and $\theta_3$ by + or - increments as needed until $|DEL| < 1 X 10^{-6}$ while insuring $SA \leq BA \leq \theta_{rc}$.

The procedure is similar to the one for COMPUTE SA. Upon convergence the biggest bottom grazing angle BA for which a ray refracted in the sediment can travel from source to receiver is found. If convergence does not occur after 500 iterations, the statement is printed "LARGE BOTTOM REFRACTION ANGLE DOES NOT CONVERGE," and computation stops.

BA3=T3= $\theta_3$ gives the angle of the ray at the top of the sediment corresponding to the bottom grazing angle BA.

RETURN

END (of subroutine REFRANG). Now we go back to SUBROUTINE REFR.

IF (BA>THIB) go to 998. THIB=$\cos^{-1}\frac{C_1}{C_B}$ so for BA>THIB the ray hits the basement. (173)

Otherwise, compute the sines of grazing angles BA and corresponding angles for the same ray in the layer and sediment.

BC1 = cosBA (174)

BS1 = sinBA = $\sqrt{1-\cos^2 BA}$ (175)

BC2 = $\frac{C_2}{C_1}$ cosBA (Snell's law) (176)

BS2 = $\sqrt{1-(BC2)^2}$ = $\sin\theta_2$ (in layer) (177)

BC3 = $\frac{C_3}{C_1} BC1 = \frac{C_3}{C_1}\cos BA = \cos\theta_3$ (178)

BS3 = $\sin\theta_3$ (in sediment) (179)

BIG ANGLE REFLECTION COEFFICIENT

$A_1 = Z_1/\sin BA$ (180)

$A_2 = Z_2/\sin\theta_2$ } Acoustic impedances used to compute reflection coefficients. (181)

$A_3 = Z_3/\sin\theta_3$ (182)

BV32(J) = (A3-A2)/(A3+A2) } Big angle reflection coefficients for boundries (183)

BV21(J) = (A2-A1)(A2+A1) } designated by the subscripts. (184)

Big angle transmission coefficient factor (two-way)

$$BTRF = 16A_1A_3\left(\frac{A_2}{(A_3+A_2)(A_2+A_1)}\right)^2 \quad (185)$$

similar to the one in Subroutine GEOPHYS.

BSIN2(J) = $\sin\theta_2$ (in layer) (186)

GEOMETRIC AMPLITUDE

The geometric spreading loss factor, equation (38) of Spofford et al.(1982) is

$$\frac{I}{I_0} = \frac{1}{R\tan\theta_b\left|\frac{dR}{d\theta}\right|_{\theta=\theta_b}} . \quad (187)$$

We are dealing with the amplitude or pressure ratio so let

$$BGI(J) = \sqrt{\frac{1}{R\tan BA\left|\frac{dR}{dBA}\right|}} = P/P_0 . \quad (188)$$

We need the derivative $\frac{dR}{dBA}$. Taking the range formula from Subroutine GCOMP or equations (16) and (21) of Spofford et al. (1982) with appropriate substitutions of angles gives

$$R = \frac{D1}{\tan\theta_1} + \frac{F_1}{g_o} F_2 \tan\theta_3 \quad (189)$$

where

$$F_1 = \frac{2BC_3}{(1+B)} \quad \text{and} \quad F_2 = \left[1 + \frac{1}{2B}\left(1 + \frac{\theta_3}{\sin\theta_3\cos\theta_3}\right)\right]. \quad (190)$$

$$\frac{dR}{d\theta_1} = -\frac{D1}{\sin^2\theta_1} + \frac{F_1}{g_o}\left[\frac{dF_2}{d\theta_1}\tan\theta_3 + F_2\sec^2\theta_3\frac{d\theta_3}{d\theta_1}\right]. \quad (191)$$

$$\frac{dF_2}{d\theta_1} = \frac{dF_2}{d\theta_3}\frac{d\theta_3}{d\theta_1}. \quad (192)$$

From Snell's law $\cos\theta_1 = \frac{C_1}{C_3}\cos\theta_3$ and differentiating gives (193)

$$-\sin\theta_1 = -\frac{C_1}{C_3}\sin\theta_3\frac{d\theta_3}{d\theta_1}, \quad (194)$$

$$\frac{d\theta_3}{d\theta_1} = \frac{C_3}{C_1}\frac{\sin\theta_1}{\sin\theta_3}, \quad (195)$$

$$\frac{dF_2}{d\theta_1} = \frac{1}{2B\sin\theta_3\cos\theta_3}\left[1 + \theta_3\left(\frac{\sin^2\theta_3 - \cos^2\theta_3}{\sin\theta_3\cos\theta_3}\right)\right]\left(\frac{C_3}{C_1}\right)\frac{\sin\theta_1}{\sin\theta_3} \quad (19$$

$$\frac{dR}{d\theta_1} = -\frac{D1}{\sin^2\theta_1} + \frac{F_1}{g_o}\left\{\frac{C_3\sin\theta_1}{2BC_1\sin\theta_3\cos^2\theta_3}\left[1 + \theta_3\left(\frac{\sin^2\theta_3 - \cos^2\theta_3}{\sin\theta_3\cos\theta_3}\right)\right] + F_2\frac{C_3\sin\theta_1}{C_1\sin\theta_3\cos^2\theta_3}\right\} \quad (19$$

$$\frac{dR}{d\theta_1} = -\frac{D1}{\sin^2\theta_1} + \frac{F_1}{g_o}\left(\frac{C_3\sin\theta_1}{C_1\sin\theta_3\cos^2\theta_3}\right)\left\{\frac{1}{2B}\left[1 + \theta_3\left(\frac{\sin^2\theta_3 - \cos^2\theta_3}{\sin\theta_3\cos\theta_3}\right)\right] + F_2\right\} \quad ($$

$$\frac{dR}{d\theta_1} = -\frac{D1}{\sin^2\theta_1} + \frac{F_1}{g_o}\left(\frac{C_3\sin\theta_1}{C_1\sin\theta_3\cos^2\theta_3}\right) \times \left[\frac{1}{2B} - \frac{1}{2B}\frac{\theta_3(2\cos^2\theta_3 - 1)}{\sin\theta_3\cos\theta_3} + \frac{2B}{2B} + \frac{1}{2B} + \frac{\theta_3}{2B\sin\theta_3\cos\theta_3}\right] \quad (199)$$

$$\frac{dR}{d\theta_1} = -\frac{D1}{\sin^2\theta_1} + \frac{F_1}{g_o(2B)}\left(\frac{C_3\sin\theta_1}{C_1\sin\theta_3\cos^2\theta_3}\right) \times \left[1 - \frac{2\theta_3\cos^2\theta_3}{\sin\theta_3\cos\theta_3} + \frac{\theta_3}{\sin\theta_3\cos\theta_3} + (2B+1) + \frac{\theta_3}{\sin\theta_3\cos\theta_3}\right] \quad (200$$

$$\frac{dR}{d\theta_1} = -\frac{D1}{\sin^2\theta_1} + \frac{F_1}{Bg_0}\left(\frac{C_3 \sin\theta_1}{C_1 \sin\theta_3 \cos^2\theta_3}\right) \tag{201}$$

$$\times\left[(1+B) + \frac{\theta_3}{\sin\theta_3\cos\theta_3}\left(1-\cos^2\theta_3\right)\right],$$

$$\frac{dR}{d\theta_1} = -\frac{D1}{\sin^2\theta_1} + \frac{F_1}{Bg_0}\left(\frac{C_3 \sin\theta_1}{C_1 \sin\theta_3 \cos^2\theta_3}\right)\left[1 + B + \theta_3 \tan\theta_3\right], \tag{202}$$

$$\frac{dR}{d\theta_1} = -\frac{D1}{\sin^2\theta_1} + \frac{(1+B)}{B}\left(\frac{F_1}{g_0}\right)\left(\frac{C_3 \sin\theta_1}{C_1 \sin\theta_3 \cos^2\theta_3}\right)\left(1 + \frac{\theta_3\tan\theta_3}{1+B}\right), \tag{203}$$

Substituting the expression for $F_1$ gives

$$\frac{dR}{d\theta_1} = -\frac{D1}{\sin^2\theta_1} + \left(\frac{1+B}{B}\right)\left(\frac{2BC_3}{1+B}\right)\left(\frac{C_3 \sin\theta_1}{C_1 \sin\theta_3 \cos^2\theta_3}\right)\left(1 + \frac{\theta_3\tan\theta_3}{1+B}\right) \tag{204}$$

and substituting in the factors

$$D2 = \frac{2C_3^2}{C_1 g_0}, \quad D7 = (1+B), \; \theta_1 = BA, \; \sin\theta_1 = BS1, \tag{205}$$

$$\sin\theta_3 = BS3, \; \cos\theta_3 = BC3, \; \theta_3 = BA3, \; \tan\theta_3 = \tan BA3 \tag{206}$$

gives the equation

$$DRDT = -\frac{D1}{\sin^2 BA} + \frac{D2 \sin BA}{\sin BA3 \cos^2 BA3}\left(1 + \frac{BA3 \tan BA3}{D7}\right) \tag{207}$$

as in the SUBROUTINE REFR.

This is the derivative of the range with respect to the bottom grazing angle evaluated at the Big Angle in the water. With this derivative DRDT we compute BGI(J) as in the subroutine for the Big Angle.

ARC LENGTH

Our model assumes that loss mechanisms in sediments behave linearly, e.g. loss

$L = K \cdot S \cdot f$ by equation (13) of Spofford et al.(1982), or in terms of symbols used in our program $DL = \alpha o S F_K$, so in the program it is assumed the frequency averaged or effective value of the sound path, ARC LENGTH, in the sediment is given by

$$S = \frac{DL}{\alpha o F_K} \quad (208)$$

where DL is dissipation loss in the sediment given by equation (23) of Spofford et al.(1982), or as shown in Subroutine GEOPHYS, $\alpha o$ is the average value of attenuation constant for this path length, and $F_K$ denotes the center frequency of a one-octave measured bandwidth. Thus, let

$$BLS = \frac{DL}{\alpha o F_K} \quad (209)$$

and in terms of the equation for DL with lower limit $\Theta^1 = 0$, upper limit $\Theta o = \Theta_3$ and the factors from this subroutine, D8 through D14, we get

$$BLS = \frac{2C_3}{\alpha_0 g_0 (1+B)\cos\Theta_3}\left[-\frac{\gamma C_3^2}{6\sigma}\left(\frac{\sin\Theta_3}{\cos\Theta_3}\right)^3 - \frac{(B\gamma C_3^2 + 2\gamma\nu C_3)\sin\Theta_3}{4\sigma\cos\Theta_3} + \frac{\gamma C_3^2 \sin\Theta_3}{2\sigma\cos^3\Theta_3} + \frac{(\gamma(\nu^2-\mu) + 2\alpha_0\sigma + 2B\nu C_3\gamma)\sin\Theta_3}{2\sigma\cos\Theta_3} + \frac{(B\gamma C_3^2 + 2\gamma\nu C_3)\Theta_3}{4\sigma\cos^2\Theta_3} + \left(\frac{B\gamma(\nu^2-\mu)}{2\sigma} + \alpha_0 B\right)\Theta_3\right] \quad (210)$$

as in the subroutine statement for the ARC LENGTH

TRAVEL TIME

We need the total travel time of a path with bottom grazing angle BA (Big Angle). We first find the travel time in the sediment. By definition $C(Z) = \frac{dS}{dt}$ where S is an element of path length. The vertical component of dS is

$dz = \sin\Theta\, dS$ so $dS = dz/\sin\Theta$, and, noting that $\Theta = \Theta(z)$, we have

$$dt = \frac{dS}{c(z)} = \frac{dz}{C(z)\sin\Theta(z)} \quad \text{from which} \quad (211)$$

$$Ts = 2\int_0^{\tilde{z}} \frac{dz}{c(z)\sin\Theta(z)} . \quad (212)$$

This is equation (19) of Spofford et al.(1982) where $\tilde{z}$ represents the turning point depth or basement depth for rays which reflect from the basement.

Snell's law gives $C(z) = c_0 \frac{\cos\theta(z)}{\cos\theta_0}$ where $c_0$ is the sound speed at the top (213) of the sediment and $\theta_0$ is the angle at the top of the sediment. Differentiate this with respect to z.

$$-\sin\theta \frac{d\theta}{dz} = \frac{\cos\theta_0}{C_0}\frac{dC(z)}{dz} = \frac{\cos\theta_0}{C_0} g(z) \tag{214}$$

$$\frac{1}{\sin\theta} = -\frac{C_0}{g(z)\cos\theta_0}\frac{d\theta}{dz} \tag{215}$$

$$T_s = 2\int_0^{\tilde{z}} - \frac{C_0 \frac{d\theta}{dz}\, dz}{g(z)\, C(z)\cos\theta_0} \tag{216}$$

$$T_s = -\frac{2C_0}{\cos\theta_0}\int_{\theta_0}^{\theta'} \frac{d\theta}{g(z)\, c(z)} \tag{217}$$

$$T_s = -\frac{2C_0}{\cos\theta_0}\int_{\theta_0}^{\theta'} \frac{d\theta}{\frac{g_0(1+B)C_0}{C(z)+BC_0} C(z)} \tag{218}$$

$$T_s = -\frac{2}{\cos\theta_0}\int_{\theta_0}^{\theta'} \frac{(C(z)+BC_0)\, d\theta}{g_0(1+B)C(z)} \tag{219}$$

$$T_s = -\frac{2}{g_0(1+B)\cos\theta_0}\int_{\theta_0}^{\theta'} \left(1 + \frac{BC_0}{C(z)}\right) d\theta \tag{220}$$

$$T_s = -\frac{2}{g_0(1+B)}\int_{\theta_0}^{\theta'} \left(\frac{1}{\cos\theta_0} + \frac{B}{\cos\theta}\right) d\theta \tag{221}$$

$$T_s = -\frac{2}{g_0(1+B)}\left[\frac{\theta}{\cos\theta_0} + B\ln(\sec\theta + \tan\theta)\right]_{\theta_0}^{\theta'} \tag{222}$$

Using a trig identity and interchanging the limits gives

$$T_s = \frac{2}{g_0(1+B)}\left[\frac{\theta}{\cos\theta_0} + B\ln\left(\frac{\cos\theta}{1-\sin\theta}\right)\right]_{\theta=\theta'}^{\theta=\theta_0} \tag{223}$$

This is equation (22) of Spofford et al.(1982). The time for travel in the water is the slant range divided by the sound speed in the water, i.e. $D1/C_1 \sin BA$. Adding this to Ts where we substitute $\theta'=0$ for a path refracted in the sediment, $\theta_0 = BA3$, and $\sin BA = BS1$ yields

$$T = \frac{D1}{C_1 BS1} + \frac{2}{g_0(1+B)}\left[\frac{BA3}{\cos BA3} + B\ln\left(\frac{\cos BA3}{1-\sin BA3}\right)\right] \qquad (224)$$

Now $\frac{\cos\theta}{1-\sin\theta} = \left(\frac{1+\sin\theta}{1-\sin\theta}\right)^{1/2}$ so

$$T = \frac{D1}{C_1 BS1} + \frac{2B}{g_0(1+B)}\left[\frac{BA3}{B\cos BA3} + \frac{1}{2}\ln\left(\frac{1+BS3}{1-BS3}\right)\right]$$

$$T = \frac{D1}{C_1 BS1} + \frac{B}{g_0(1+B)}\left[\frac{2BA3}{B(BC3)} + \ln\left(\frac{1+BS3}{1-BS3}\right)\right] = BT(J) \qquad (225)$$

$$BT(J) = \frac{D5}{BS1} + D4\left[\ln\left(\frac{1+BS3}{1-BS3}\right) + \frac{2}{B}\left(\frac{BA3}{BC3}\right)\right] \qquad (226)$$

which is the expression for the travel time in Subroutine REFR.

DELTA T SOURCE RECEIVER (for Big Angle)

$$BSS = \sqrt{1-\left(\frac{C_S}{C_1}BC1\right)^2} = \sqrt{1-\cos^2\theta_S} \qquad (227)$$

Snell's law with $BC1 = \cos BA$ yields $\frac{CS}{C1}\cos BA = \cos\theta s$ so (228)

$BSS = \sin\theta s$ where $\theta s$ is ray angle at source (or receiver) (229)

$BDTR(J) = D6(ZR)\sin\theta s = 2\left(\frac{ZR}{CS}\right)\sin\theta s$ is the travel time difference for the (230) Big Angle path from source to bottom to surface to receiver.

Similarly $BDTS(J) = 2\left(\frac{ZS}{CS}\right)\sin\theta s$ is the travel time difference for the Big (231) Angle path from source to surface to bottom to receiver.

We want to deal with rays not hitting the basement - refracted in sediment only, so the statement IF SA>THIB($=\cos^{-1}\frac{C_1}{CB}$) go to 999 stops computation. Sound (232) speed in sediment at basement level is CB and THIB is the bottom grazing angle of the refracted ray which reaches the bottom of sediment at basement level.

AUX = FACS*SC1 (233)

$= \frac{C_S}{C_1}\cos SA = \cos\theta s$ where $\theta s$ is angle at source (or receiver) for a ray with bottom grazing angle SA. (234)

IF RAY DOES NOT REACH SURFACE NOT COMPUTED

IF AUX>1 go to 999 stops computation if $\cos\theta_s > 1$ which is not physically realistic.

DELTA T SOURCE RECEIVER (for Small Angle)

$$SSS = \sqrt{1-(AUX)^2} = \sin\theta_s \text{ for bottom grazing angle SA.} \qquad (235)$$

$$SDTR(J) = 2\left(\frac{ZR}{CS}\right)\sin\theta_s \qquad (236)$$

$$SDTS(J) = 2\left(\frac{ZS}{CS}\right)\sin\theta_s \qquad (237)$$

Travel time difference for indirect path for surface reflections at receiver and source.

Use of Snell's law and trig identity is made to define the following:

$$SS1 = \sqrt{1-(SC1)^2} = \sin SA \qquad (238)$$

$$SC2 = \frac{C_2}{C_1}\cos SA = \cos\theta_2 \qquad (239)$$

where $\theta_2$ is the angle in the layer for ray with bottom grazing angle SA,

$$SS2 = \sqrt{1-(SC2)^2} = \sin\theta_2, \qquad (240)$$

$$SC3 = \frac{C_3}{C_1}(SC1) = \frac{C_3}{C_1}\cos SA = \cos\theta_3 \qquad (241)$$

where $\theta_3$ is angle at top of sediment for bottom grazing angle SA,

$$SS3 = \sqrt{1-(SC3)^2} = \sqrt{1-\cos^2\theta_3} = \sin\theta_3 \qquad (242)$$

SMALL ANGLE REFLECTION COEFFICIENT

$$A_1 = Z_1/\sin SA, \quad A_2 = Z_2/\sin\theta_2, \quad A_3 = Z_3/\sin\theta_3 \qquad (243)$$

Impedances corresponding to Small Angle ray.

$$SV32(J) = (A3-A2)/(A3+A2)$$

$$SV21(J) = (A2-A1)/(A2+A1) \qquad (244)$$

Reflection coefficients for boundaries designated by subscripts.

$$STRF(J) = 16A_1A_3\left(\frac{A_2}{(A_3+A_2)(A_2+A_1)}\right)^2 \qquad (245)$$

Two-way travel layer transmission coefficient factor.

$SSIN2 = \sin\theta_2$ for small angle ray. (246)

GEOMETRIC AMPLITUDE (for Small Angle)

DRDT - same as DRDT for Big Angle case with BA,BA3 changed to SA,SA3 etc. This is the derivative of the range with respect to the bottom grazing angle evaluated at SA.

$$SGI(J) = \sqrt{\frac{\cos SA}{R \sin SA \left|\frac{dR}{dSA}\right|}} = \frac{P}{P_o}$$ the pressure ratio for the Small Angle path. (247)

This is the geometric spreading loss factor.

ARC LENGTH

SLS(J) is the same as BLS(J) with angles changed to those appropriate to the Small Angle path.

TRAVEL TIME

ST(J) is the same as BT(J) with angles changed to those appropriate to the Small Angle case.

999 TH=TH-DEL increments the angle. The computations are made in steps of 1 degree for all applicable angles.

RETURN

END (of Subroutine REFR) (Go back to the main program.) CALL BASE

SUBROUTINE BASE

The statements NTIR, DEL, TH, N=90-MAXθ(N,NTIR), and DO 10 I=1,90 cause calculations to be made in steps of 1 degree for angles from the angle of total internal reflection or the apparent bottom angle for a ray vertexing at the bottom of the sediment, whichever is larger, to $90^o$. This insures reflections at the basement are accounted for. The Z's and FAC's are the same as used before.

$$CB = \sqrt{2 g_o (1+B)(C_3) BZ + C_3^2 (1+B)^2} - B C_3 \qquad (248)$$

gives the sound speed in the sediment at the basement level.

D1 through D14 are factors used later.

$BSA = \pi/2 - 1 \times 10^{-8}$ (used in Subroutine BASANG) (249)

$TH3 = \cos^{-1}\frac{C_3}{C_1}\cos\theta_{1B} = \theta_3$ is angle at top of sediment corresponding to bottom (250) grazing angle $\theta_{1B}$ for a ray which reaches the bottom of the sediment.

R is the range for a ray refracted in the sediment with vertex at the basement. This expression is found by substituting $\theta_o = \theta_3$, $\theta' = 0$ into the equation for Rs giving

$$R_s = \frac{C_3}{g_0(1+B)\cos\theta_3}\left[\frac{\theta_3}{\cos\theta_3} + \sin\theta_3(1+2B)\right]$$

$$= \frac{C_3}{g_0(1+B)\cos\theta_3}\left[\frac{\theta_3}{\cos\theta_3} + \sin\theta_3 + 2B\sin\theta_3\right]$$

$$= \frac{C_3}{g_0(1+B)\cos\theta_3}\left[\theta_3 + \frac{2\sin\theta_3\cos\theta_3}{2} + 2B\sin\theta_3\cos\theta_3\right]$$

$$= \frac{C_3}{g_0(1+B)\cos^2\theta_3}\left[\theta_3 + \frac{\sin 2\theta_3}{2} + B\sin 2\theta_3\right]$$

$$= \frac{2C_3}{g_0(1+B)\cos^2\theta_3}\left[\frac{\theta_3}{2} + \sin 2\theta_3\left(\tfrac{1}{2}+B\right)\left(\tfrac{1}{2}\right)\right] \qquad (251)$$

$$R = \frac{D1}{\tan\theta_{1B}} + \frac{D3}{\cos^2\theta_3}\left[\frac{\theta_3}{2} + \left(0.25 + \frac{B}{2}\right)\sin 2\theta_3\right]. \qquad (252)$$

$AUX = \tan^{-1} \frac{D1}{R}$ This is the apparent angle for a ray tangent at the bottom (253)

of the sediment as shown in Figure 16.

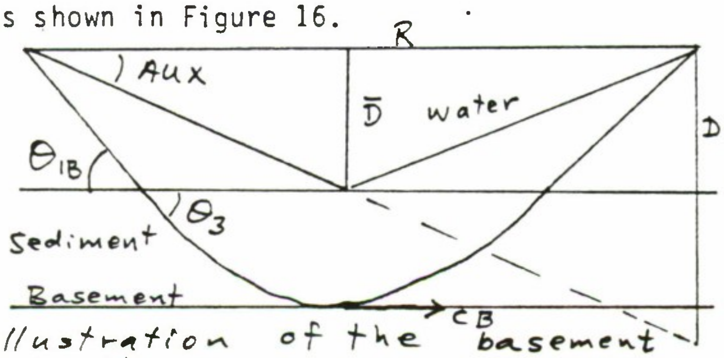



Figure 16. Illustration of the basement grazing ray path.

```
DO 10 I=1,90
BSS/N2(I)=0.0
BSV32(I) =0.0
BSV21(I) =0.0
BSGI(I)  =0.0
```

Program modified by addition of these statements to insure completion of a run.

```
10 BSTRF(I)=0
```

clears registers

```
DO 100 I = 1,N
J=90-I
```

orders computations for angles in the range mentioned.

TH=TH-DEL increments angles

CALL BASANG

SUBROUTINE BASANG

IF TH>TIR GO TO 100 allows computations to proceed for angles greater than TIR. Otherwise print "SPECULAR ANGLE OF BASEMENT RAY LESS THAN TIR" and computation stops. CB is same as in Subroutine BASE--sound speed at basement level of sediment. The next several factors are like ones used before.

BEST = BSA is estimate of basement reflected ray angle in water.

AUX = cosBSA (254)

THB = $\cos^{-1}\left(\frac{CB}{C1}\right)\cos BSA = \theta_B$ angle of ray at basement. (255)

TH3=$\cos^{-1}\left(\frac{C3}{C1}\right)\cos BSA = \theta_3$ angle of ray at top of sediment. (256)

Now find the range in terms of $\theta_B$ and $\theta_3$ as limits from previous equations for R and Rs.

$$R_s = \frac{C_3}{g_o(1+B)\cos\theta_3}\left[\frac{\theta_3}{\cos\theta_3} + \frac{\sin\theta_3\cos\theta_3}{\cos\theta_3} + 2B\sin\theta_3 - \frac{\theta_B}{\cos\theta_3} - \frac{\sin\theta_B\cos\theta_B}{\cos\theta_3} - 2B\sin\theta_B\right], \tag{257}$$

where $\theta_o = \theta_3$ and $\theta' = \theta_B$.

$$R_s = \frac{D2}{\cos^2\theta_3}\left[\frac{\theta_3-\theta_B}{\cos\theta_3} + \frac{\sin\theta_3\cos\theta_3 - \sin\theta_B\cos\theta_B}{2} + B\frac{C_3}{C_1}\cos BSA(\sin\theta_3 - \sin\theta_B)\right] \tag{258}$$

$$R_s = \frac{D2}{\left(\frac{C_3}{C_1}\cos BSA\right)^2}\left[\frac{\theta_3-\theta_B}{2} + \frac{\sin 2\theta_3 - \sin 2\theta_B}{4} + B\left(\frac{C_3}{C_1}\right)\cos BSA(\sin\theta_3 - \sin\theta_B)\right]. \tag{259}$$

This is the second term in VAL. From the formula for R we see

$$VAL = \frac{D1}{\tan BEST} + \frac{D2}{\left(\frac{C_3}{C_1}\cos BSA\right)^2}\left[\frac{\theta_3-\theta_B}{2} + \frac{\sin 2\theta_3 - \sin 2\theta_B}{4} + \frac{BC_3}{C_1}\cos BSA(\sin\theta_3 - \sin\theta_B)\right] - \frac{D1}{\tan TH}, \tag{260}$$

where TH is the apparent bottom angle. This VAL is similar to the one used in SUBROUTINE REFRANG except basement reflection occurs. See Figure 15.

Now the IF and DO statements start iterations which adjust the angles to make VAL approach zero until convergence is obtained when $|DEL| < 1X10^{-6}$ whereupon BEST=BSA. If convergence does not occur, print "BASEMENT ANGLE DOES NOT CONVERGE." and stop computation.

The basement reflected ray angle at the top of the sediment is BSA3=TH3= $\theta_3$ and BSA is the basement reflected ray angle in the water. We use BSA and BSA3 in SUBROUTINE BASE. (261)

RETURN

END (of subroutine BASANG) Go back to SUBROUTINE BASE.

IF (BSA3.EQ.0.0) GO TO 100-added to insure completion of run.

BC1 = cos BSA (262)

BS1 = sin BSA (263)

BC2 = $\frac{C2}{C1}$ cos BSA = cos $\theta_2$ , $\theta_2$ is in the layer. (264)

BS2 = sin $\theta_2$ in layer (265)

BC3 = $\frac{C3}{C1}$ cos BSA = cos $\theta_3$ , $\theta_3$ is at top of sediment. (266)

BS3 = sin $\theta_3$ (267)

BCB = $\frac{CB}{C1}$ cos BSA = cos $\theta_B$, $\theta_B$ is basement grazing angle in the sediment. (268)

BSB = sin $\theta_B$ (269)

DELTA T SOURCE RECEIVER

AUX = $\frac{Cs}{C1}$ cos BSA = cos $\theta_s$ where $\theta_s$ is angle at the source for the basement reflected ray. (270)

IF RAY DOES NOT REACH SURFACE NOT COMPUTED.

IF AUX>1 go to 999 stops computation if cos $\theta_s$ > 1 which is not realistic in nature.

$$SS = \sqrt{1-(AUX)^2} = \sqrt{1-\cos^2\theta_s} = \sin\theta_s \quad (271)$$

$$\left.\begin{aligned} BSDTR(J) &= 2\left(\frac{ZR}{CS}\right)\sin\theta_s \\ BSDTS(J) &= 2\left(\frac{ZS}{CS}\right)\sin\theta_s \end{aligned}\right\}$$

Travel time differences for receiver and source respectively. (272)

LAYER REFLECTION COEFFICIENTS

$$\left.\begin{aligned} A_1 &= Z_1/\sin BSA \\ A_2 &= Z_2/\sin\theta_2 \\ A_3 &= Z_3/\sin\theta_3 \end{aligned}\right\}$$

Acoustic impedances, medium designated by subscripts. (273)

$BSV32(J)=(A_3-A_2)/(A_3+A_2)$ Reflection coefficients for (274)

$BSV21(J)=(A_2-A_1)/(A_2+A_1)$ boundaries designated by subscripts.

$$BSTRF(J) = 16\, A_1 A_3 \left(\frac{A_2}{(A_3+A_2)(A_2+A_1)}\right)^2 \quad (275)$$

This is a two-way layer transmission coefficient factor for basement reflected ray.

BSSIN2(J) = $\sin\theta_2$, $\theta_2$ is angle in layer. (276)

GEOMETRIC AMPLITUDE

BSAB = $\cos^{-1}(\cos\theta_B) = \theta_B$ basement reflection angle in sediment at basement.

We now find the derivative of the range with respect to the bottom-grazing angle, $\theta_1$.

$$R = \frac{DI}{\tan\theta_1} + \frac{DA}{2\cos^2\theta_3}\left[\theta_3 - \theta_B + \sin\theta_3\cos\theta_3 - \sin\theta_B\cos\theta_B\right] \quad (277)$$

$$+ \frac{DB}{\cos^2\theta_3}\left[\sin\theta_3\cos\theta_3 - \sin\theta_B\cos\theta_3\right].$$

$$\frac{dR}{d\theta_1} = \frac{-DI}{\sin^2\theta_1} + \frac{DA(-2)(-\sin\theta_3)}{2\cos^3\theta_3}\left(\frac{d\theta_3}{d\theta_1}\right)\left[\theta_3 - \theta_B + \sin\theta_3\cos\theta_3 - \sin\theta_B\cos\theta_B\right]$$

$$+ \frac{DA}{2\cos^2\theta_3}\left[\frac{d\theta_3}{d\theta_1} - \frac{d\theta_B}{d\theta_3}\frac{d\theta_3}{d\theta_1} + (\cos^2\theta_3 - \sin^2\theta_3)\frac{d\theta_3}{d\theta_1} - (\cos^2\theta_B - \sin^2\theta_B)\frac{d\theta_B}{d\theta_3}\frac{d\theta_3}{d\theta_1}\right]$$

$$+ \frac{DB(2)\sin\theta_3}{\cos^3\theta_3}\left(\frac{d\theta_3}{d\theta_1}\right)\left[\sin\theta_3\cos\theta_3 - \sin\theta_B\cos\theta_3\right]$$

$$+ \frac{DB}{\cos^2\theta_3}\left[(\cos^2\theta_3 - \sin^2\theta_3)\frac{d\theta_3}{d\theta_1} - \cos\theta_B\cos\theta_3\frac{d\theta_B}{d\theta_3}\frac{d\theta_3}{d\theta_1} + \sin\theta_B\sin\theta_3\frac{d\theta_3}{d\theta_1}\right].$$

Snell's law: $\frac{\cos\theta_3}{C_3} = \frac{\cos\theta_1}{C_1}$. Differentiating gives (278)

$$-\frac{\sin\theta_3}{C_3}\frac{d\theta_3}{d\theta_1} = -\frac{\sin\theta_1}{C_1},$$

$$\frac{d\theta_3}{d\theta_1} = \frac{C_3\sin\theta_1}{C_1\sin\theta_3}. \quad \text{Similarly,}$$

$$\frac{d\theta_B}{d\theta_3} = \frac{C_B\sin\theta_3}{C_3\sin\theta_B}$$, and substituting these gives

$$\frac{dR}{d\theta_1} = -\frac{D1}{\sin^2\theta_1} + \frac{DA\sin\theta_3}{\cos^3\theta_3}\left(\frac{C_3\sin\theta_1}{C_1\sin\theta_3}\right)\Big[\theta_3 - \theta_B + \sin\theta_3\cos\theta_3$$
$$- \sin\theta_B\cos\theta_B\Big]$$
$$+ \frac{DA}{2\cos^2\theta_3}\left(\frac{C_3\sin\theta_1}{C_1\sin\theta_3}\right)\Big[1 - \frac{C_B\sin\theta_3}{C_3\sin\theta_B} + \cos^2\theta_3 - \sin^2\theta_3$$
$$-(\cos^2\theta_B - \sin^2\theta_B)\frac{C_B\sin\theta_3}{C_3\sin\theta_B}\Big]$$
$$+ \frac{DB(2)\sin\theta_3}{\cos^3\theta_3}\left(\frac{C_3\sin\theta_1}{C_1\sin\theta_3}\right)\Big[\sin\theta_3\cos\theta_3 - \sin\theta_B\cos\theta_3\Big]$$
$$+ \frac{DB}{\cos^2\theta_3}\left(\frac{C_3\sin\theta_1}{C_1\sin\theta_3}\right)\Big[\cos^2\theta_3 - \sin^2\theta_3 - (\cos\theta_B\cos\theta_3)\frac{C_B\sin\theta_3}{C_3\sin\theta_B}$$
$$+ \sin\theta_B\sin\theta_3\Big] . \quad (279)$$

$$\frac{dR}{d\theta_1} = -\frac{D1}{\sin^2\theta_1} + \frac{DAC_3\sin\theta_1}{C_1\sin\theta_3}\left(\frac{\sin\theta_3}{\cos^3\theta_3}\right)\Big[\theta_3 - \theta_B + \sin\theta_3\cos\theta_3$$
$$- \sin\theta_B\cos\theta_B\Big]$$
$$+ \frac{DAC_3\sin\theta_1}{2C_1\sin\theta_3}\Big[2 - \frac{C_B\sin\theta_3}{C_3\sin\theta_B\cos^2\theta_3} - \left(\frac{C_B}{C_3}\right)^3\frac{\sin\theta_3}{\sin\theta_B}$$
$$+ \frac{C_B\sin\theta_3\sin^2\theta_B}{C_3\sin\theta_B\cos^2\theta_3}\Big]$$
$$+ \frac{DBC_3\sin\theta_1}{C_1\sin\theta_3\cos\theta_3}\Big[\frac{2\sin^2\theta_3}{\cos\theta_3} - \frac{2\sin\theta_3\sin\theta_B}{\cos\theta_3}$$
$$+ \frac{\cos^2\theta_3 - \sin^2\theta_3}{\cos\theta_3} - \frac{C_B\sin\theta_3\cos\theta_B}{C_3\sin\theta_B} + \frac{\sin\theta_B\sin\theta_3}{\cos\theta_3}\Big] .$$

(280)

$$\frac{dR}{d\theta_1} = \frac{-DI}{\sin^2\theta_1} + \frac{DAC_3\sin\theta_1}{C_1\sin\theta_3}\left(\frac{\sin\theta_3}{\cos^3\theta_3}\right)\left[\theta_3-\theta_B+\sin\theta_3\cos\theta_3-\sin\theta_B\cos\theta_B\right]$$
$$+\frac{DAC_3\sin\theta_1}{2C_1\sin\theta_3}\left[2-\frac{C_B\sin\theta_3}{C_3\sin\theta_B}\left(\frac{\sin^2\theta_B-1}{\cos^2\theta_3}\right)-\left(\frac{C_B}{C_3}\right)^3\frac{\sin\theta_3}{\sin\theta_B}\right]$$
$$+\frac{DBC_3\sin\theta_1}{C_1\sin\theta_3\cos\theta_3}\left[\frac{1-\sin\theta_3\sin\theta_B}{\cos\theta_3}-\frac{C_B}{C_3}\frac{\sin\theta_3\cos\theta_B}{\sin\theta_B}\right]. \quad (281)$$

$$\frac{dR}{d\theta_1} = \frac{-DI}{\sin^2\theta_1} + \frac{DAC_3\sin\theta_1}{C_1\sin\theta_3}\left(\frac{\sin\theta_3}{\cos^3\theta_3}\right)\left[\theta_3-\theta_B+\sin\theta_3\cos\theta_3-\sin\theta_B\cos\theta_B\right]$$
$$+\frac{DAC_3\sin\theta_1}{C_1\sin\theta_3}\left[1+\frac{C_B\sin\theta_3}{2C_3\sin\theta_B}\left(\frac{-\cos^2\theta_B}{\cos^2\theta_3}\right)-\left(\frac{C_B}{C_3}\right)^3\frac{\sin\theta_3}{2\sin\theta_B}\right]$$
$$+\frac{DBC_3\sin\theta_1}{C_1\sin\theta_3\cos\theta_3}\left[\frac{1}{\cos\theta_3}-\sin\theta_3\left(\frac{\sin\theta_B}{\cos\theta_3}+\left(\frac{C_B}{C_3}\right)^2\frac{\cos\theta_3}{\sin\theta_B}\right)\right]. \quad (282)$$

$$\frac{dR}{d\theta_1} = \frac{-DI}{\sin^2\theta_1} + \frac{C_3\sin\theta_1}{C_1\sin\theta_3}\left\{DA\left[\frac{\sin\theta_3}{\cos^3\theta_3}\left(\theta_3-\theta_B+\sin\theta_3\cos\theta_3-\sin\theta_B\cos\theta_B\right)\right.\right.$$
$$\left.+\left(1-\left(\frac{C_B}{C_3}\right)^3\frac{\sin\theta_3}{\sin\theta_B}\right)\right]$$
$$\left.+\frac{DB}{\cos\theta_3}\left[\frac{1}{\cos\theta_3}-\sin\theta_3\left(\frac{\sin\theta_B}{\cos\theta_3}+\left(\frac{C_B}{C_3}\right)^2\frac{\cos\theta_3}{\sin\theta_B}\right)\right]\right\}. \quad (283)$$

This is the expression in Subroutine Base for DRDT where the quantity inside braces is DRDT3, $\theta_1$ = BSA and other angles and their functions are as mentioned above in discussing this subroutine.

R = D1/tanTH gives the range in terms of TH.

$$BSGI(J) = \sqrt{\frac{\cos\theta_1}{R\sin\theta_1\left|\frac{dR}{d\theta_1}\right|}} \quad (284)$$

is the geometric spreading loss factor.

ARC LENGTH

is found in a manner similar to that in Subroutine REFR but with use of $\theta_B$ for the lower limit in equation (23) of Spofford et al.(1982) corresponding to the basement reflection angle. This gives

$$BSLS = \frac{DL}{\alpha_0 FK} = \frac{2C_3}{\alpha_0 g_0(1+B)\cos\theta_3}\left[\frac{-\gamma C_3^2}{6\sigma\cos^3\theta_3}\left(\sin^3\theta_3-\sin^3\theta_B\right) + \frac{B\gamma C_3^2+2\gamma\nu C_3}{4\sigma\cos^2\theta_3}\left(\sin\theta_3\cos\theta_3-\sin\theta_B\cos\theta_B\right) + \left(\frac{\gamma C_3^2}{2\sigma\cos^3\theta_3}+\frac{\gamma(\nu^2-\mu)+2\alpha_0\sigma+B\nu C_3\gamma}{2\sigma\cos\theta_3}\right)\left(\sin\theta_3-\sin\theta_B\right) + \left(\frac{B\gamma C_3^2+2\gamma\nu C_3}{4\sigma\cos^2\theta_3}+\frac{B\gamma(\nu^2-\mu)}{2\sigma}+B\alpha_0\right)\left(\theta_3-\theta_B\right)\right] \quad (285)$$

TRAVEL TIME

is found as in Subroutine REFR with $\theta_B$ substituted as the lower limit in the equation for TS, equation (22) of Spofford et al.(1982).

$$T = \frac{D1}{C_1\sin\theta_1} + \frac{2}{g_0(1+B)}\left[\frac{\sin\theta_3-\sin\theta_B}{\cos\theta_3} + B\ln\left(\frac{\cos\theta_3}{1-\sin\theta_3}\right) - B\ln\left(\frac{\cos\theta_B}{1-\sin\theta_B}\right)\right] \quad (286)$$

and by the identity mentioned in Subroutine REFR

$$BST(J) = \frac{D5}{\sin\theta_1} + D4\left[\frac{\sin\theta_3-\sin\theta_B}{\cos\theta_3} + \frac{B}{2}\ln\left(\frac{1+\sin\theta_3}{1-\sin\theta_3}\right)\left(\frac{1-\sin\theta_B}{1+\sin\theta_B}\right)\right] \quad (287)$$

The computations in this subroutine are made in 1 degree steps for all applicable angles.

RETURN

END (of SUBROUTINE BASE) (Go back to main program.)

SUBROUTINE LOSS (JJ)

Discussion. This supplements section III.C. Simulated Bottom Loss, as set forth in Spofford et al.(1982).

Other subroutines provide for computations of travel time for base path, angles, reflection and transmission coefficient factors, surface scattering travel time differences, etc. which are needed in this subroutine.

For a base path travel time of $T_{K,1}$ the three other paths have travel times

$$T_{K,2} = T_{K,1} + (2ZS/CS)\sin\theta_S \tag{288}$$

$$T_{K,3} = T_{K,1} + (2ZR/CS)\sin\theta_S \tag{289}$$

$$T_{K,4} = T_{K,1} + (2ZS/CS)\sin\theta_S + (2ZR/CS)\sin\theta_S \tag{290}$$

The travel time differences are converted to phase shifts, and the paths acquire additional phase shifts for surface reflections of $\pi$, $\pi$, and $2\pi$ radians respectively. The subroutine accounts for all these effects by treating the surface scattering travel time interference "artifact" as a separate factor.

It is assumed the frequency averaged intensity ratio is given by

$$\left\langle \frac{I}{I_0} \right\rangle = \frac{1}{F_2 - F_1}\int_{F_1}^{F_2} P^* P \, dF \tag{291}$$

where P represents the sound pressure and F is the frequency.

Ordinarily one assumes a superposition of waves results in pressure $P = \sum_K A_K e^{i\phi_K}$ so one would write $P^*P = \left(\sum_K A_K^* e^{-i\phi_K}\right)\left(\sum_L A_L e^{i\phi_L}\right)$, (292)

but in this model it is assumed $P = \sum_K A_K \sum_j e^{i\phi_{K,j}}$ (293)

where some justification is by Spofford et al.(1982).

If we include the frequency dependence in $\phi_{K,j}$ so this represents phase per unit frequency we get

$$p^*p = \sum_{K,L} A_L^* A_K \sum_j e^{-i\phi_{Lj}^* F} e^{+i\phi_{K,j} F} \qquad (294)$$

and

$$\left\langle \frac{I}{I_0} \right\rangle = \frac{1}{F_2 - F_1} \int_{F_1}^{F_2} \sum_{K,L} A_L^* A_K \sum_j e^{i(\phi_{Kj} - \phi_{Lj}^*)F} dF . \qquad (295)$$

Now let $\langle A_L^* A_K \rangle$ be the frequency averaged products of amplitudes; they can be factored out of the integral, and note $F_2 - F_1 = F_1$ for 1 octave bandwidth, so

$$\left\langle \frac{I}{I_0} \right\rangle = \frac{1}{F_1} \sum_{K,L} \langle A_L^* A_K \rangle \sum_j \int_{F_1}^{F_2} e^{i(\phi_{Kj} - \phi_{Lj}^*)F} dF , \qquad (296)$$

$$\left\langle \frac{I}{I_0} \right\rangle \doteq \frac{1}{F_1} \sum_{K,L} \langle A_L^* A_K \rangle \sum_j \left[ \frac{e^{i(\phi_{Kj} - \phi_{Lj}^*)F_2} - e^{i(\phi_{Kj} - \phi_{Lj}^*)F_1}}{i(\phi_{Kj} - \phi_{Lj}^*)} \right] . \qquad (297)$$

For paths in the sediment the phases are assumed to be complex and written $\phi_K = 2\pi(t + i\alpha_0 S)$ with t the time in the sediment (plus surface scattering travel (298) time difference), $\alpha_0$ the absorption coefficient, and S the effective path length in the sediment. The exponential terms account for absorption in the sediment. But for layer-reflected paths it is assumed there is no absoption and the imaginary part is zero. Thus the phases are real and contributions from these paths are

$$\frac{1}{F_1} \sum_{K,L} \langle A_L^* A_K \rangle \sum_j \left[ \frac{\sin(\phi_{Kj} - \phi_{Lj})F_2 - \sin(\phi_{Kj} - \phi_{Lj})F_1}{\phi_{Kj} - \phi_{Lj}} \right] . \qquad (299)$$

Consider the first sum. For layer-reflected rays of unit incident amplitude, the reflected amplitude is simply taken to be the reflection coefficient, V, and intensity is V*V. The frequency averaged value of V*V is desired. It is obtained by computing the values of V*V at eight different frequencies over a one octave range and finding the numerical average. The number of values used in the average evidently is arbitrarily chosen to be eight.

Consider the second sum. Four bottom interacting reflected pulses reach the receiver from the source in some order arbitrarily chosen, for example, on a time scale as illustrated.


The sum includes all combinations of travel time differences such as:

| K,L | Phase Shift/F | Surface reflection at |
|---|---|---|
| 1-2 | DR | receiver |
| 1-3 | DS | source |
| 1-4 | DS + DR | source and receiver |
| 2-3 | DS - DR | source and receiver |
| 2-4 | DS | source |
| 3-4 | DR | receiver |

The frequency averaged sum is

$$\frac{4}{2F_1}\left[\frac{\sin F_2(DR+DS)-\sin F_1(DR+DS)}{DR+DS}+\frac{\sin F_2(DS-DR)-\sin F_1(DS-DR)}{DS-DR} - 2\,\frac{\sin F_2 DS-\sin F_1 DS}{DS} - 2\,\frac{\sin F_2 DR-\sin F_1 DR}{DR}\right] \qquad (300)$$

for the layer reflected paths. The terms corresponding to only one surface reflection are given negative signs to account for a phase shift of $\pi$ radians while those corresponding to two reflections have positive signs to account for a phase shift of $2\pi$ radians. The terms corresponding to no phase shift are accounted for by adding the numeral 4 to this sum. The sum just mentioned is multiplied by the frequency averaged value of V*V. This accounts for the layer reflected ray intensities.

Next the layer transmitted rays are accounted for by computing the layer two-way transmission coefficient at the center frequency of the octave wide band and multiplying by the basement reflection coefficient (where appropriate) and the geometrical spreading loss factor. This gives the amplitude of the transmitted rays. No further frequency averaging is done for transmitted path amplitudes.

The phases of the four layer-transmitted signals are accounted for by changing the signs of two of the amplitudes which is equivalent to changing the phases by $\pi$ radians to account for one surface reflection each and no change of the other two to account for phase change of zero for the bottom-reflected-only path and phase change of $2\pi$ for the twice-surface-reflected path. In addition, phase shifts and attenuation in the sediment are accounted for by forming complex frequency dependent phases as follows:

$$\phi_1 = 2\pi(t + i\alpha_0 S) , \qquad (301)$$

$$\phi_2 = 2\pi(t + t_S + i\alpha_0 S), \qquad (302)$$

$$\phi_3 = 2\pi(t + t_R + i\alpha_0 S), \qquad (303)$$

$$\phi_4 = 2\pi(t + t_S + t_R + i\alpha_0 S), \qquad (304)$$

where t is base ray travel time, $t_R$ and $t_S$ are surface scattering travel time differences, $\alpha_0$ is the sediment attentuation coefficient, and S is the sediment path length. These phase factors account for attenuation in the sediment. Products of amplitudes are formed as are the exponential phase factors and their integrals are summed as needed to produce the transmitted ray portion of $\left\langle \frac{I}{I_0} \right\rangle$.

The reflected and transmitted frequency averaged intensities are combined incoherently to find the total loss which would be measured, $L = -10 \log \langle I/I_0 \rangle$, (305) equation (43) of Spofford et al.(1982).

The computed spreading loss is given most simply by

$$L_o = -10 \log_{10} \frac{4}{(\text{slant range})^2} = -10 \log_{10} \frac{4}{\left(\frac{R}{\cos\theta}\right)^2} \quad (306)$$

which represents a sum of 4 unit initial intensity rays.

Therefore, bottom loss is found by subtraction

$$BL = L - L_o,$$

$$= -10 \log \left\langle \frac{I}{I_o} \right\rangle - \left[ -10 \log \frac{4}{\left(\frac{R}{\cos\theta}\right)^2} \right] \quad (307)$$

$$= -10 \log \left[ \frac{\left\langle \frac{I}{I_o} \right\rangle}{4\left(\frac{\cos\theta}{R}\right)^2} \right] = ALOSS. \quad (308)$$

Suitable variations in computational procedures are made in order to suit the various domains to be accounted for.

Now consider SUBROUTINE LOSS(JJ).

ALPHØ= $\frac{\ln 10}{4\pi(10000)}$ ALPH9 is used to convert the usual logarithmic expression in dB/m/kHz from the COMMON block to suitable units for use in an exponential form.

EX= $\log_{10} e$ is defined.

Aim=(o+i) used to provide imaginary quantities.

$F_1 = F/\sqrt{2}$ is the lower limit and (309)

$F_2 = F\sqrt{2}$ is the upper limit of a one octave bandwidth centered at F. (310)

FPI2D = $\frac{4\pi FD}{C_2}$ Thickness of the layer is D and sound speed in the layer is $C_2$. (311)

NAV1=8 is defined.

$$FPIINC = \frac{FPI2D(\sqrt{2} - 1/\sqrt{2})}{NAVI} = \frac{4\pi D}{C_2} \frac{(F_2 - F_1)}{8} \text{ is an increment} \quad (312)$$

$$FPIIN = \frac{4\pi D}{C_2} F - \frac{(8-1)}{2} \frac{4\pi D}{8C_2} (F_2 - F_1) \quad (313)$$

$$= \frac{4\pi D}{C_2} \left(F - \frac{7}{16} (F_2 - F_1)\right) \quad (314)$$

This is an increment to be used in computing frequency dependent phases for reflection and transmission coefficients. Consider a one octave bandwidth centered at frequency F(JJ)=F with lower and upper limits $F_1$ and $F_2$. The term FPIIN is used to compute a quantity at the frequency $Fc = F - \frac{7}{16}(F_2 - F_1)$ (315)

as illustrated in figure 17.

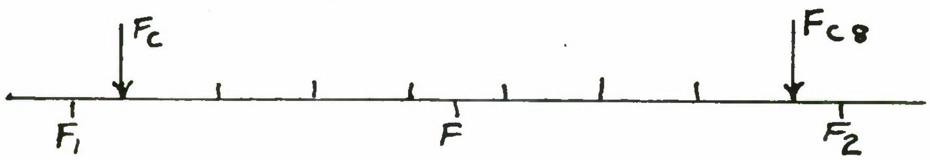



Figure 17. Frequencies for computation of average in a one-octave wide band.

This is the starting frequency for computing frequency averaged reflection and transmission coefficients.

NTHC = $\theta_c$ the caustic angle in degrees

N = 90 - $\theta_c$

COMPUTE LOSS FOR ANGLES ABOVE CRITICAL

(the caustic angle). These calculations apply to the domain of range $R_3$ as shown in figure 2.

DO 1Ø I = 1,90

10 ALOSS(JJ,I)=25 This puts in an assumed value.

DO 1ØØ,I=1,N

J = 91-I Computations are made for angles in steps of 1 degree from $\theta_c$ to $90^o$.

FPIAUX=FPIIN Use in starting the frequency average calculation.

DO 2Ø NAV=1,NAV1 Calculation is made for 8 frequencies within the one octave bandwidth.

ALPH2= $\alpha_2 = \frac{4\pi D}{C_2}\left[F - \frac{7}{16}(F_2 - F_1)\right] \sin\theta_2$ (316)

is a frequency and path dependent phase angle for the layer.

$C=\cos\alpha_2$
$S=\sin\alpha_2$ } Used in computing the square of the layer reflection coefficients.

The square of the layer reflection coefficient is needed because we want the intensity of the reflected wave which is proportional to the layer reflection coefficient, or equal to it for an incident wave of unit intensity.

The layer reflection coefficient, equation (30) of Spofford et al.(1982) is

$$R = \frac{V_{12} + V_{23}e^{2i\alpha d}}{1 + V_{12}V_{23}e^{2i\alpha d}} \quad \text{and if we let } \alpha_2 = 2\alpha d \qquad (317)$$

$$R^*R = \left(\frac{V_{12}+V_{23}e^{-i\alpha_2}}{1+V_{12}V_{23}e^{-i\alpha_2}}\right)\left(\frac{V_{12} + V_{23}e^{i\alpha_2}}{1+V_{12}V_{23}e^{i\alpha_2}}\right)$$

$$= \frac{V_{12}^2 + V_{23}^2 + V_{32}V_{12}\left(e^{i\alpha_2} + e^{-i\alpha_2}\right)}{1 + V_{12}^2V_{23}^2 + V_{12}V_{23}\left(e^{i\alpha_2} + e^{-i\alpha_2}\right)}$$

$$= \frac{V_{12}^2 + 2V_{32}V_{12}\cos\alpha_2 + V_{23}^2}{1 + V_{12}^2V_{23}^2 + 2V_{12}V_{23}\cos\alpha_2}$$

$$= \frac{(V_{12} + V_{23}\cos\alpha_2)^2 + (V_{23}\sin\alpha_2)^2}{(1+V_{12}V_{23}\cos\alpha_2)^2 + (V_{12}V_{23}\sin\alpha_2)^2} \qquad (318)$$

Interchanging subscripts changes signs of the factors but has no effect on the value of R*R so doing this and introducing prefix R we find

$$VV=R^*R= \frac{(RV21 + RV32\cos\alpha_2)^2 + (RV32\sin\alpha_2)^2}{(1+RV21\,RV23\cos\alpha_2)^2 + (RV21\,RV32\sin\alpha_2)^2} \qquad (319)$$

as in Subroutine LOSS. The boundary reflection coefficients RV21, RV32 are computed in Subroutine REFL.

AUX=AUX+VV     The value of VV is computed and the results summed.

FPIAUX = FPIAUX + FPIINC causes increment in frequency to the next step shown in figure 17 and computation of VV again.

20 CONTINUE. Procedure is completed 8 times yielding a sum of 8 values of VV.

VV = AUX/NAV1 = $\frac{VV(Fc)+\text{---}+VV(Fc8)}{8}$ gives an average value of VV, the squared reflection coefficient, over the 1 octave frequency band as illustrated in figure 17.

DR = $2\pi$RDTR(J), DS = $2\pi$RDTS(J) } converts surface scattering travel time differences so when multiplied by frequency gives phase shift in radians. (320)

DT The first four consecutive DT statements provide the sum of frequency averaged phases for the layer reflected waves as described in the Discussion. The fifth DT statement provides the sum multiplied by the frequency averaged reflection coefficient to obtain the intensity of the layer-reflected rays. For basement reflected paths the separate ray contributions are summed incoherently on the assumption that the time delays between layer and basement reflected paths results in incoherent arrivals at the receiver.

ALPH2=FPI2D*BSSIN2(J)/2=$\frac{4\pi F(JJ)}{C_2}\frac{\sin\theta_2}{2} = \alpha_2$ gives phase shift for 1 way travel in the layer. (321)

C = $\cos\alpha_2$

S = $\sin\alpha_2$

The two-way travel layer-transmission coefficient can be obtained as shown for SUBROUTINE GEOPHYS:

$$T = \frac{16 A_1 A_3 \left(\frac{A_2}{(A_3+A_2)(A_2+A_1)}\right)^2}{1+2V_{32}V_{21}\cos 2\alpha_2 + (V_{32}V_{21})^2} \qquad (322)$$

where we have in the numerator the expression for BSTRF. Consider the denominator of this expression. It has the form $1 + 2M\cos 2\alpha_2 + M^2$, where (323)

M = V32V21, so by using identities we can write:

$$\sin^2\alpha_2 + \cos^2\alpha_2 + 2M(\cos^2\alpha_2 - \sin^2\alpha_2) + M^2(\sin^2\alpha_2 + \cos^2\alpha_2) \qquad (324)$$

$$= \cos^2\alpha_2(1+2M+M^2) + \sin^2\alpha_2(1-2M+M^2) \qquad (325)$$

$$= (1+M)^2\cos^2\alpha_2 + (M-1)^2\sin^2\alpha_2 \qquad (326)$$

$$= [(1+M)\cos\alpha_2 + i(M-1)\sin\alpha_2] \qquad (327)$$

Substitution of this expression for the denominator gives

$$V = \frac{BSTRF}{[(1+BSV32\,BSV21)\cos\alpha_2 + i(BSV32\,BSV21-1)]^2} \quad (328)$$

The quantities with prefix BS come from SUBROUTINE BASE.

The amplitude of a ray reflected by the basement after passing through the layer into the water is given by $VV = |V|\sqrt{\frac{\cos\theta_1}{R\sin\theta_1\left|\frac{dR}{d\theta_1}\right|}}\,(REF)$ (329)

where $BSG1(J) = \sqrt{\frac{\cos\theta_1}{R\sin\theta_1\left|\frac{dR}{d\theta_1}\right|}}$ is the geometric spreading factor and (REF) (330) is a numerical basement pressure reflection coefficient.

AUX = 0 is defined.

IF VV=0 GO TO 120 accounts for the case of no basement reflection.

The amplitudes of the basement reflected waves are designated

BR(1)=VV

BR(@)=-VV

BR(3)=-VV

BR(4)=VV

The negative signs are to augment phases by $\pi$ radians for 1 surface reflection and the positive signs account for zero and $2\pi$ radian phase shifts for no surface and two surface reflections respectively.

$V=(BST(J) + i\alpha_o BSLS(J))=(t+i\alpha_o S)$ (331) is used to form the complex frequency dependent phases mentioned in the Discussion as follows:

PH(1) = $\phi_1 = 2\pi(t+i\alpha_o S)$ (332)

PH(2) = $\phi_2 = 2\pi(t+t_s+i\alpha_o S)$ (333)

PH(3) = $\phi_3 = 2\pi(t+t_R+i\alpha_o S)$ (334)

PH(4) = $\phi_4 = 2\pi(t+t_R+t_s+i\alpha_o S)$ (335)

Here BST(J) = t is the travel time in water plus time in the sediment, $t_R$ and $t_S$ are surface scattering travel time differences, and ALPHØ* BSLS(J) is the attenuation loss per unit frequency in the sediment = $\alpha_o S$ where S is the "effective" path length. These are complex phase factors.

V = 0 is defined.

DO11Ø K=1,3 to 11Ø CONTINUE produces AUX=BR(K)*BR(L) i.e. cross products of the amplitudes of the transmitted rays for all permitted combinations and

AUX1=(PH(K)-CONJG(PH(L))*AIM

$=i(\phi_K-\phi_L^*)$ the corresponding complex phase differences.

IF (REAL(AUX1)*F2<-40) GO TO 11Ø causes terms like $4\pi\alpha_o SF_2$ to be ignored unless greater than -40 (Note that $e^{-40} \approx 10^{-17}$) in which case

$$V = V+BR(K)*BR(L)\ \frac{e^{iF_2(\Phi_K-\Phi_L^*)} - e^{iF_1(\Phi_K-\Phi_L^*)}}{i(\Phi_K-\Phi_L^*)} \qquad (336)$$

Here we have terms applicable to the transmitted rays like those in the formula for the frequency averaged intensity ratio shown in the Discussion of this subroutine. Terms of this kind are generated and summed.

AUX = 2*REAL(V)=2ReV gives the effective value of the intensity of the cross product terms for the four contributing paths.

$AUX2= -2(2\pi)\alpha_o S$

IF $AUX2*F2 = -4\pi\alpha_o SF2 < -40$ go to 12Ø causes terms like $-4\pi\alpha_o SF2$ to be ignored unless greater than -40 in which case

$$AUX = 2ReV + \frac{4(e^{-4\pi\alpha_o SF_2} - e^{-4\pi\alpha_o SF_1})}{-4\pi\alpha_o S}\left[BR(1)\right]^2 \qquad (337)$$

The last term accounts for dissipation loss along the path in the sediment for four rays with initial intensities of the same amount, $[BR(1)]^2 = (VV)^2$, combined incoherently.

$$120\quad DT = DT + \frac{\left[2ReV + \frac{4(e^{-4\pi\alpha_o SF_2} - e^{-4\pi\alpha_o SF_1})(VV)^2}{-4\pi\alpha_o S}\right]}{F_1\left[4\left(\frac{\cos\theta}{R}\right)^2\right]} \qquad (338)$$

On the right-hand side of the last equation DT represents the frequency averaged effects of the layer-reflected rays and in the second term 2ReV gives the effects of the cross product terms for the transmitted rays while the last term gives the effects of the frequency averaged attenuation in the sediment on the 4 rays with intensities $(VV)^2$. In the denominators the factors F1 and $4\pi\alpha_0 S$ are needed for the frequency averaging and the 4 $(\cos\theta/R)^2$ is the geometric intensity sum for 4 rays with $R/\cos\theta$ as the slant range. The last step gives the bottom loss for angles above the caustic:

ALOSS(JJ,J)=-10 $\log_{10}$(DT).

CONTINUE

NMAX=91-N is definition.

COMPUTE LOSS FOR ANGLES BETWEEN TIR AND THS.

This applies to the domain designated by $R_1$ in figure 2, i.e. for angles between THS=SAP the smallest bottom grazing angle or TIR the angle of total internal reflection, whichever is greater, and the basement limiting angle.

Previously we had N=90-NTHC

NMAX=91-90+NTHC=1+NTHC

NTIR=TIR+1 gives angle in degrees.

N=NMAX-NTIR

N=1+NTHC-NTIR-1=NTHC-NTIR redefines N

DO 2ØØ I=1,N=1,NTHC-NTIR

J=NMAX-1=NTHC is maximum value of J while the minimum value is 1+NTIR or NSAP.

IF (J<NSAP) go to 800 causes computation for angles between TIR and THS as stated. Otherwise, for rays in domain R2 shown in figure 2, the following is done:

COMPUTE REFLECTION COEFFICIENT

COMPUTE FREQ AVERAGE ABSOLUTE REFLECTION

From here to the statement VV=AUX/NAV1 the frequency averaged squared reflection coefficient VV is computed as for the case of angles above the caustic in this subroutine.

ALPH2=FPI2D*RSIN2(J)= $\frac{4\pi DF(JJ)\sin\theta_2}{C_2} = \alpha_2$

Compute new $\alpha_2$, using the band center frequency to find a new V.

C=cos $\alpha_2$

S=sin $\alpha_2$

$$V = \frac{\dfrac{RV21+RV32\cos\alpha_2+i\ RV32\sin\alpha_2}{(1+RV21\,RV32\cos\alpha_2+i\,RV21\,RV32\sin\alpha_2)}}{\left|\dfrac{RV21+RV32\cos\alpha_2+i\,RV32\sin\alpha_2}{1+RV21\,RV32\cos\alpha_2+i\,RV21\,RV32\sin\alpha_2}\right|}\sqrt{VV}\left(\frac{\cos\theta_1}{R_1}\right) \quad (339)$$

Here the first term contains the new $\alpha_2$ calculated for the band center frequency, and it gives proportional values of real and imaginary parts of the complex layer reflection coefficient while the second term, $\sqrt{VV}$, gives the magnitude, and the last term is the geometric amplitude factor. Thus V is the complex amplitude of the layer reflected ray. This is used to obtain a coherent sum of contributions from the 4 paths for this angular domain.

AR(1)=V
AR(2)=-V
AR(3)=-V
AR(4)=V

These give amplitudes of the four layer reflected paths including effects of phase shifts upon surface reflection.

PH(1) = $2\pi t$
PH(2)=$2\pi(t+t_S)$
PH(3)=$2\pi(t+t_R)$
PH(4)=$2\pi(t+t_R+t_S)$

Here RT(S)=t is travel time in the water for the reflection path, RDTS(J)=ts, RDTR(J)=tr appropriate to this path.

COMPUTE BIG TRANSMISSION COEFFICIENT

This applies to path R2.C. of figure 2.

AR(5)=0
AR(6)=0
AR(7)=0
AR(8)=0

} Sets array = 0

The layer transmission coefficient factor BTRF for the Big Angle ray is needed as computed in SUBROUTINE REFR.

IF BTRF=0 GO TO 205
IF BT(S) RT(J) GO TO 205

} Skips Big Angle computation for physically unrealistic cases.

Here BT is total travel time and RT is travel time in water.

ALPH2= $\alpha_2 = \frac{4\pi DF(JJ)}{C_2} \frac{\sin\theta_2}{2}$ where $\theta_2$ is the angle in the layer for the big angle case and $\alpha_2$ is the phase factor for transmission one way through the layer.

$$V = \frac{16A_1A_3\left(\frac{A_2}{(A_3+A_2)(A_2+A_1)}\right)^2\sqrt{\frac{\cos BA}{\sin BA\left|\frac{dR}{dBA}\right|}}}{[(1+BV32BV21)\cos\alpha_2 + i(BV32BV21-1)\sin\alpha_2]^2} \qquad (340)$$

This is the two-way transmission coefficient for paths refracted in the sediment multiplied by the geometric spreading factor.

AR(5)=V
AR(6)=-V
AR(7)=-V
AR(8)=V

} These are amplitudes for sediment refracted paths including effects of surface reflections on phases.

$V=BT(J)+i\alpha_0 BLS(J)$ (341)

$V=t+i\alpha_0 S_c$ the total travel time for path with bottom grazing angle BA = Big Angle plus dissipation loss per unit frequency in sediment. (342)

$$PH(5) = 2\pi(t+i\alpha_0 S_c) \qquad (343)$$

$$PH(6) = 2\pi(t+t_S+i\alpha_0 S_c) \qquad (344)$$

$$PH(7) = 2\pi(t+t_R+i\alpha_0 S_c) \qquad (345)$$

$$PH(8) = 2\pi(t+t_S+t_R+i\alpha_0 S_c) \qquad (346)$$

These are the complex phase factors including effects of surface scattering travel times and dissipation loss factors for this case.

CONTINUE

COMPUTE SMALL TRANSMISSION COEFFICIENT

This applies to path R2.b. of figure 2. Here the computation is exactly the same as for the Big Angle case but using appropriate factors for the Small Angle case. One exception occurs. The transmission coefficient is made negative imaginary:

$$V=-V*SGI(J)*AIM=-iV\sqrt{\frac{\cos SA}{R\sin SA\left|\frac{dR}{dSA}\right|}} \qquad (347)$$

This should account for a (controversial) phase change due to the caustic in the sediment shown in figure 2 for ray R2.b. and mentioned on page 56 of Spofford et al.(1982).

The amplitudes and phases are computed as in the Big Angle case.

COMPUTE BASEMENT RAY TRANSMISSION COEFFICIENT.

This applies to path R2.d. of figure 2.

The same procedure is used as for the Big and Small Angle coefficients. We get the amplitudes of the transmitted rays by multiplying the transmission coefficients by the geometric spreading factor and the basement reflection coefficient REF. This accounts for ray R2.d. in figure 2.

Amplitudes and phase factors are computed as before in this subroutine.

The rest of the computations are done in a similar manner as before except for differences in notation.

DO 21Ø,K=1,15

NA=K+1

DO 210,L=NA,16

AUX 99=AR(K)*CONJG(AR(L))

$=AR(K)\ AR^{*}(L)$ computes cross products of complex amplitudes for all three cases of angles from caustic to basement limiting.

IF $|AUX99| = 0$ GO TO 210

AUX $1=i(\phi_K - \phi_L^*)$ computes complex phase differences.

IF REAL (AUX1)*F2 $<-40$ GO TO 210 causes terms like $4\pi\alpha_o SF_2$ to be ignored unless greater than -40 in which case the sum is computed.

$$V = V + AR(K)AR^*(L)\ \frac{e^{iF_2(\phi_K-\phi_L^*)} - e^{iF_1(\phi_K-\phi_L^*)}}{i(\phi_K-\phi_L^*)} \qquad (348)$$

This makes a sum of contributions from the Small Angle path, Big Angle path and basement reflected path.

CONTINUE to 209.

AUX=2*REAL(V) gives the average value of a complex quantity representing the sum of contributions from the four paths.

IF $|AR(13)| = 0$ go to 209 Skip next computation unless transmitted contribution of basement ray intensity $> 0$.

AUX $2=-4\pi\alpha_o S_d$ is effective path length for basement reflected ray in sediment.

IF $-4\pi\alpha_o S_d F_2 < -40$ GO TO 209 Ignore contributions $< -40$.

$$AUX=2ReV+(4)\frac{e^{-4\pi\alpha_o S_d F_2} - e^{-4\pi\alpha_o S_d F_1}}{-4\pi\alpha_o S_d}|V|^2 \qquad (349)$$

gives contributions for basement reflected paths.

AUX2=$-4\pi\alpha_o S_c$, $S_c$ is effective path length in sediment for Big Angle path.

IF $-4\pi\alpha_o S_c F_2 < -40$ TO TO 211 } Ignore contributions too small to be

IF AR(5) = 0 GO TO 211 } physically realistic. (350)

$$AUX = 2\,\mathrm{Re}\,V + (4)\frac{e^{-4\pi\alpha_o S_d F_2} - e^{-4\pi\alpha_o S_d F_1}}{-4\pi\alpha_o S_d} + (4)\frac{e^{-4\pi\alpha_o S_c F_2} - e^{-4\pi\alpha_o S_c F_1}}{-4\pi\alpha_o S_c} \qquad (351)$$

adds contributions for ray along Big Angle path.

AUX2= $-4\pi\alpha_o S_b$, $S_b$ is effective path length in sediment for Small Angle path.

IF $-4\pi\alpha_o S_b F_3 < -40$ GO TO 212. } Ignore contributions that are not

IF AR(9) =0 GO TO 212. } physically realistic. (352)

$$AUX=2ReV+(4)\frac{e^{-4\pi\alpha_o S_d F_2}-e^{-4\pi\alpha_o S_d F_1}}{-4\pi\alpha_o S_d}+(4)\frac{e^{-4\pi\alpha_o S_c F_2}-e^{-4\pi\alpha_o S_c F_1}}{-4\pi\alpha_o S_c}+(4)\frac{e^{-4\pi\alpha_o S_b F_2}-e^{-4\pi\alpha_o S_b F_1}}{-4\pi\alpha_o S_b} \quad (353)$$

adds contributions for ray along Small Angle path.

$$AUX=\frac{AUX}{F_1}+4\,|AR(1)|^2 \quad (354)$$

The first term, $\frac{AUX}{F_1}$ is needed as part of the frequency averaging and the second term $4|AR(1)|^2$ adds the sum of intensities of the 4 layer reflected rays.

IF AUX>0 GO TO 213 where the computation is completed. Otherwise set the value ALOSS(JJ,J)=25. This is an assumed value.

GO TO 200 allows continuation of computations.

$$ALOSS(JJ,J)=-10\log_{10}\frac{AUX}{4(\cos\theta/R)^2} \quad (355)$$

This completes the computations for the domain where Big Angle, Small Angle, and basement reflected paths can all contribute. The 4 in the denominator represents the sum of 4 unit intensities and $(\cos\theta/R)^2$ is the inverse squared slant range factor.

CONTINUE

N=J-1

NA=J

DO 701 I=1,N

J=NA-I

IF J<NSAP GO TO 999 Stops computations for bottom angles too small for ray to travel from source or to receiver.

Statements from DR to last DT compute same quantities as in case for angles above critical (caustic) near the beginning of this subroutine, but for angles greater than NSAP.

ALOSS(JJ,J)=$-10 \log_{10}$DT gives loss for angles between SAP and TIR. For this case, total internal reflection occurs, no paths penetrate the layer, and it is assumed no losses occur in the sediment.

CONTINUE

GO TO 999 Stops the subroutine. You will remember

IF J<NSAP the routine goes to 800.

N=J-1

NA=J

DO 801 I=1,N

J=NA-I

IF J<NTIR GO TO 999 Computations are done for angles between TIR and basement limiting ray angle, e.g. ray R1.b. shown in figure 2

COMPUTE BIG TRANSMISSION COEFFICIENT

ALOSS(JJ,J)=25 Loss value is assumed.

ALPH2=$\alpha_2 = \frac{4\pi DF(JJ)\sin BA}{C_2}$ Uses Big Angle.

V=V*BGI(J) gives the two-way transmission coefficient multiplied by the geometric amplitude as done before using Big Angle.

AUX3=$|V|^2$ gives intensity of two-way transmitted ray.

IF AUX3=0 GO TO 801 Skip rest of computation.

Otherwise compute

DR to last DT statement as done before in this subroutine.

AUX2=$-4\pi\alpha_0 S \log_{10} e$ where S represents the effective Big Angle path in the sediment.

IF AUX2*F2 $<$ -40 GO TO 801. causes this calculation to be skipped if $-4\pi\alpha_0 S \log_{10} e < -40$.

Otherwise compute

$$\text{ALOSS(JJ,J)}=-10\left\{-4\pi\alpha_0 S \log_{10} e + \log_{10}\left[\frac{|V|^2 DT}{\left(\frac{\cos\theta}{R}\right)^2}\right]\right\} \qquad (356)$$

$$= -10 \log_{10}\left[\frac{|V|^2 (DT)\, e^{-4\pi\alpha_0 S}}{\left(\frac{\cos\theta}{R}\right)^2}\right].$$

Here only sediment refracted paths are considered--no layer reflection.

IF ALOSS(JJ,J)$>$25 ALOSS(JJ,J)=25

This replaces the computed value when greater than 25 with the value 25 on the assumption that the greater value is unrealistic.

CONTINUE Computations are made in steps of 1 degree for the allowable values.

RETURN

END Stops SUBROUTINE LOSS(JJ)

## III. ANALYSIS OF DATA AND SELECTION OF VALUES FOR INPUT TO COMPUTER

Program BTLS has two input options. The choice of the option desired provides for the computation of either Geo-parameters or simulated bottom loss. In either case the environmental geometry is important and the following inputs are required.

1. T = thickness of the sediment (from the bottom of the water to the interface with the basement) is characterized, not by units of length, but by the two-way travel time for sound to travel from top of the sediment to the basement and return. This time should be entered in units of tenths of seconds. Two decimal places should be used (e.g., if the two-way travel time is, say, 1.7 seconds, it would be entered as 17.00.). The time may be obtained from sediment thickness charts or other source.

2. NNFILE = Arbitrary file number--a number which designates the geographical site of the measurements or predictions.

3. IOPT = input option, Ø for Geo-Parameters
   1 for Inversion Parameters

IOPT=Ø causes computation (and plotting) of simulated bottom loss.

IOPT=1 causes computation and printout of geo-parameters.

4. The data listed next is required for all computations, and it should not be controversial in nature.

   ZB = water depth (of bottom below surface). Units are meters. Entry should contain two decimal places, e.g. ZB=4800.00.

ZS = depth of sound source below surface of water (Standard depth is 244 meters.) Units are meters. Entry should contain two decimal places, e.g. ZS = 244.00.

ZR = depth of receiver of sound below surface of water. Units are meters. Entry should contain two decimal places, e.g. ZR=305.00.

CS = Speed of sound in water at the depth ZR or ZS, whichever is smaller. Units are meters/second. Entry should contain two decimal places, e.g. CS=1507.00.

C1 = Speed of sound in water at bottom of water column. Units are meters/second. Entry should contain two decimal places, e.g. C1=1543.70.

## GEOPHYSICAL PARAMETER COMPUTATION

For IOPT = 1 the INPUT INVERSION PARAMETERS required are listed below. INPUT is format free. The following are required inputs.

1. DBLOSS
2. FREQ
3. THETA
4. ALOSSØ
5. ALOSSM
6. FM
7. TIR
8. THC
9. RATIO
10. G
11. BETA
12. GAM
13. REF

The statements which follow are intended to be used for guidance in determining the rest of the necessary input data for computer runs of Program BTLS. Data, tables, and articles referred to are meant to be used as examples only. They may not represent true values for a given situation. As bottom loss work progresses, it is expected that much data will accumulate, and the techniques and "art" used in interpretation will become highly sophisticated. Therefore, it is essential to use all evidence at one's disposal, and take great care in choosing assigned or estimated values. Otherwise, large errors in output results should be expected. With this caveat in mind we proceed to a discussion of ways and means to arrive at input data.

For the measurement location, the bulk sediment type is to be obtained from measured core data, core data summaries, or other source. The type of sediment must be known in order to choose properly some assigned values.

The quantities DBLOSS, FREQ, and THETA are used to compute ALPHØ, the logarithmic attenuation coefficient of the sediment in dB/m/kHz.

DBLOSS is a value found by inspection of a graph (or possibly a table of data) of measured bottom loss as a function of apparent grazing angle. Consider Figure 18 as an example. Look on the curve for the frequency 400 Hz. Find a reasonably smooth portion of the curve which seems to be as nearly linear as possible. Read the graph and determine the bottom loss in DB and the apparent bottom grazing angle for a point on the smooth linear portion of the curve. For example DBLOSS = 3.5 dB, FREQ = 400 Hz, THETA = 20 degrees. Entry should contain two decimal places, e.g. DBLOSS = 3.50.

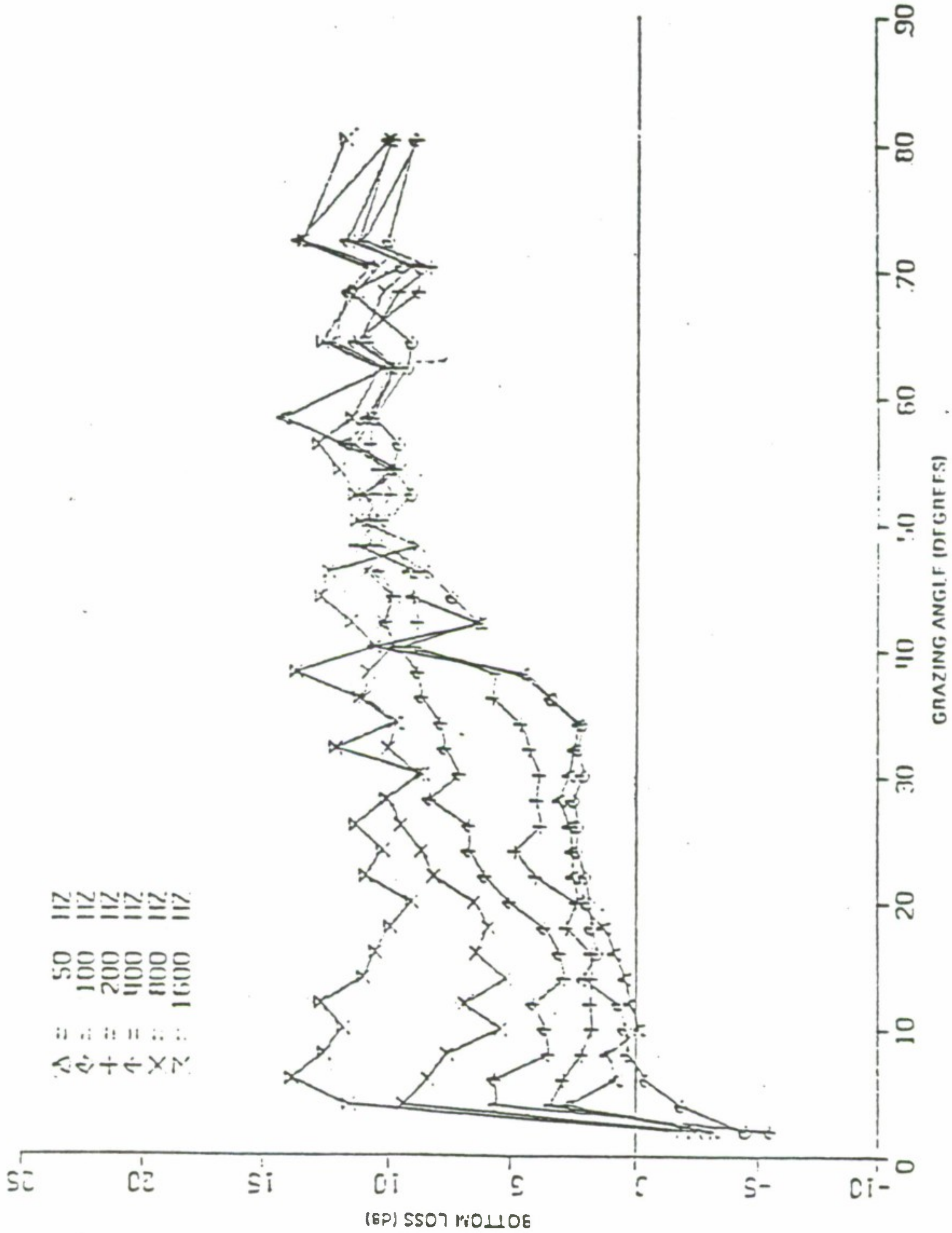



Figure 18. Bottom loss versus grazing angle measured in six one-octave bands at indicated center frequencies: zero high-angle frequency dependence.

After Spofford et al. (1982)

For other examples consider Figure 19 where DBLOSS = 4dB, FREQ = 400 Hz, THETA = $20^o$ while Figure 20 indicates DBLOSS = 8.5 dB, FREQ = 400 Hz, THETA = $20^o$. Note that usually one should choose mid-frequencies and modest grazing angles to obtain values of DBLOSS, FREQ, and THETA.

ALOSSØ, ALOSSM, and FM are used to compute the density of the layer above the sediment, $\rho_2$ = RH2, the density of the sediment, $\rho_3$ = RH3, and the thickness D of the layer. To find these input quantities look at the bottom loss curves. Look at the portions of the curves for large angles. Find the frequency at which the loss is smallest. This frequency is the value FM. The units to be used for this quantity are Hertz (Hz). Now read the minimum value of bottom loss for the curve just selected. This minimum value of bottom loss is ALOSSM in units of dB and usually occurs at relatively high frequency. This quantity is characteristic of the thin layer and of frequencies greater than 300 to 400 Hz, therefore data for frequencies lower than 300-400 Hz should not be used here. The value of ALOSSØ is the amount of bottom loss where the curve has a maximum at low frequency (say, less than 300-400 Hz). These entries should all contain two decimal places, e.g. ALOSSØ = 9.00, ALOSSM = 7.00, FM = 1600.00.

The angle of total internal reflection, TIR, is the largest grazing angle where no sound energy penetrates into the layer or sediment. All the sound is reflected from the bottom for bottom grazing angles less than this angle. This phenomenon can occur for sediments (or the top layer) in which the speed of sound is greater than the speed of sound at the bottom of the water column. For the angle TIR and smaller angles there is no bottom loss.

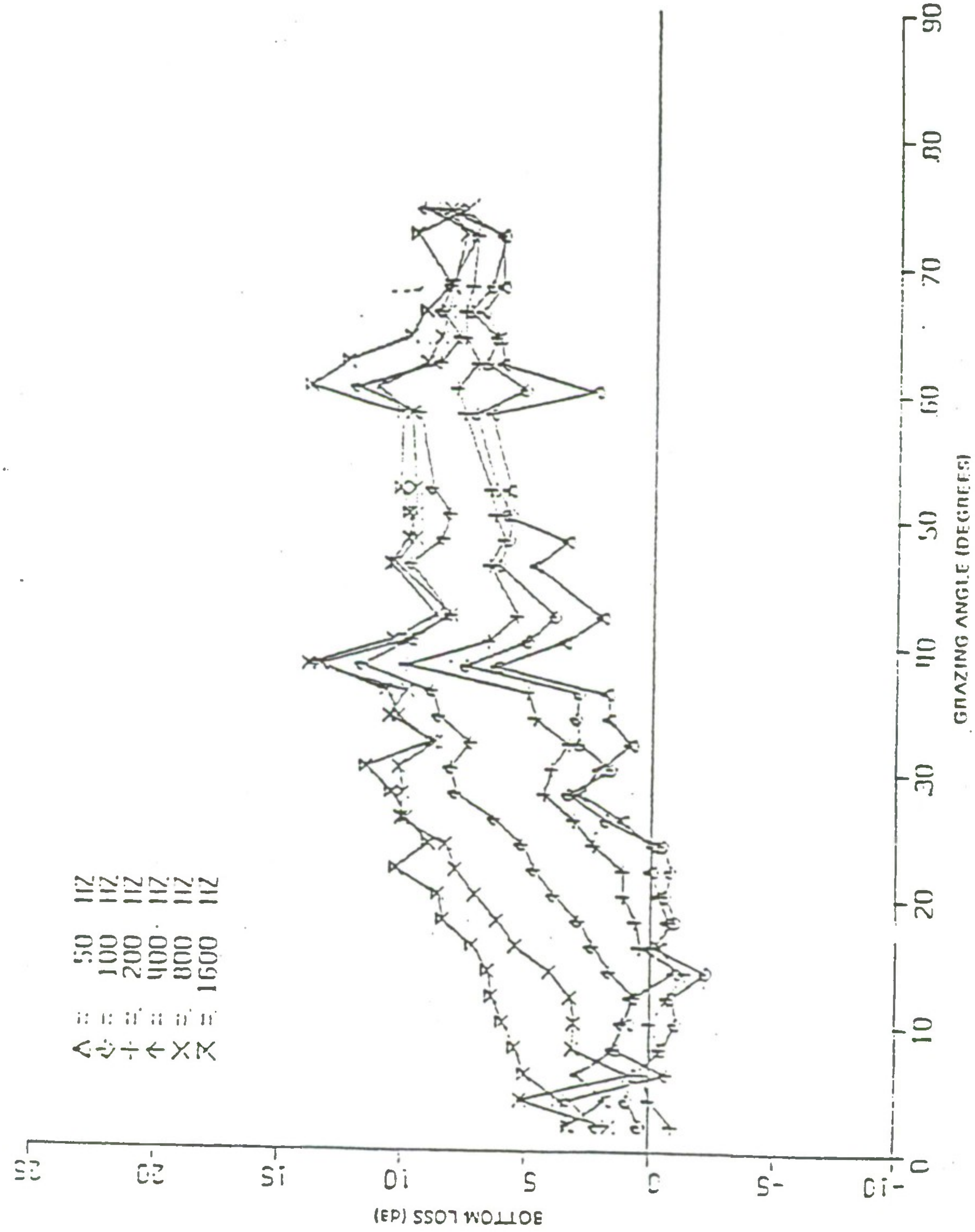



Figure 19. Bottom loss versus grazing angle measured in six one-octave bands at indicated center frequencies: positive high-angle frequency dependence.

After Spofford et al. (1982)

Spofford, Greene, and Hersey
J. Acoust. Soc. Am.

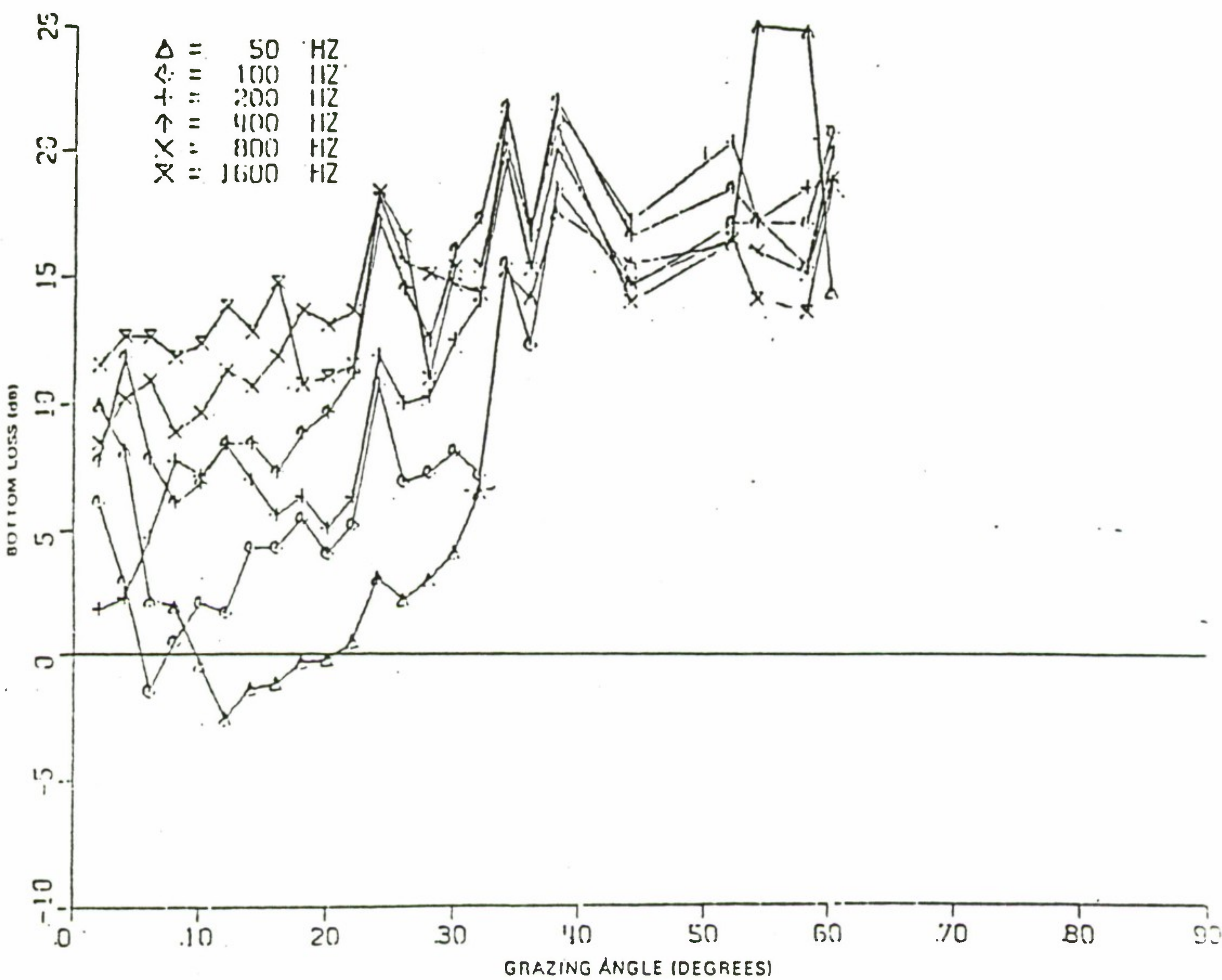



Figure 20. Bottom loss versus grazing angle measured in six one-octave bands at indicated center frequencies: negative high-angle frequency dependence.

After Spofford et al. (1982)

Consequently, you should inspect the bottom loss curves and find the greatest angle for which there is a zero value of bottom loss. This angle is TIR and the units are degrees. Entry should have two decimal places, e.g. TIR = 10.00.

The caustic angle, THC, is the apparent bottom grazing angle, at which there is a marked increase in bottom loss. For example, in Figure 18 the caustic angle THC = $40^{o}$ as indicated by spikes in the curves. Notice Figure 19; no caustic effect can be found here. The sediments are not thick enough to allow the caustic to form. The basement grazing ray appears to correspond to the bottom grazing angle of about 25 degrees. This figure is discussed further under High Angle Losses, Type 2. In Figure 20 the caustic angle is at $34^{o}$. Use degrees as the proper units for THC. This angle is interpreted as the boundary separating strong sediment refracting paths from weak reflected paths. Entry should have two decimal places, e.g. THC = 39.00.

The quantity RATIO is the value of the speed of sound in the top layer of the sediment, C2, divided by the speed of sound in the water at the bottom of the water column. It is computed by use of Snell's law from the angle TIR. Alternately, if desired, it can be an assigned value. It is a number without units. Hamilton's value of sound-speed ratio by sediment type from Table 1, reproduced here from Spofford et al.(1982), has been used directly and given satisfactory results in some cases. In some instances it should be adjusted to account for unusually low or high-speed bottoms which manifest themselves in the data by either a finite loss at zero or minimal grazing angle, or zero loss at a finite grazing angle, respectively. The entry should have four decimal places, e.g. RATIO = 1.0040.

Table I. Sound Speed profile parameters from Hamilton[10] by sediment type and corresponding values of $\beta$ for $c(z)$ given by Equation (15). (units - km, sec)

| Sediment Type | $c_o$ | $g_o$ | $\gamma$ | $\delta$ | Values at 500 m $c$ | $g$ | Fitted $\beta$ $\beta_c$ | $\beta_g$ |
|---|---|---|---|---|---|---|---|---|
| Turbidites | 1.511 | 1.304 | -0.741 | 0.257 | 2.010 | 0.756 | -0.46 | -0.56 |
| Siliceous | 1.509 | 0.869 | -0.267 | 0 | 1.877 | 0.602 | -0.33 | -0.47 |
| Calcareous | 1.559 | 1.713 | -0.374 | 0 | 2.322 | 1.339 | 0.99 | 0.73 |

After Spofford et al.(1982)

Spofford, Greene, and Hersey - J. Acoust. Soc. Am.

The gradient of the speed of sound in the sediment at the top of the sediment is designated G. This quantity is computed from input data including the apparent caustic grazing angle, THC, especially. If desired, an assigned value can be used for input data. Units are 1/second. Hamilton's tabulated values are suggested as a source of numerical values when it is desired to assign a value. Table 1 may be used as a source of possible values with the caution that these values are to be considered as examples only. Entry should have two decimal places, e.g. G = 1.79.

The parameter BETA=B controls the rate of decrease of the sound speed gradient in the sediment with increasing depth and increasing sound speed. It controls the shape of the sound speed profile. Its values lie between -1 and + infinity. This parameter is a pure number with no units. The value of B must be assigned. Some typical values of B are given in Table 1. As illustrated in the table, the value of B is based upon the type of sediment at the site under consideration. Values given in Table 1 are typical values only and may not be characteristic of a particular site (NNFILE number). Entry should show a sign and two decimal places, e.g. BET=-.50.

The quantity GAM=$\gamma$ is the gradient of the logarithmic attenuation coefficient of the sediment and has units $dB/m^2/kHz$. The value of this quantity must be assigned. The value of GAM ranges from 0 to 0.00040 and, as mentioned in "Documentation of Bottom Loss Upgrade Parameters," increments may be typically 0.00005. Roughly the value GAM = 0.00005 corresponds to terrigenous abyssal plain sediments, GAM = 0.00010 to terrigenous continental rise sediments, and GAM = 0.00020 to calcareous sediments. The non-linear loss at higher angles and lower frequencies may help in estimating GAM. The entry should show 5 decimal places, e.g. GAM = 0.00010.

The basement reflection coefficient REF is a pure number used to represent the sound pressure reflection coefficient for sound penetrating the sediment, reflecting from the basement, and returning through the sediment to the water. The value must be assigned. This is a pure number with no units, and its value is in the range from 0 to 1. Basement reflected paths may make important contributions to the sound level after a bottom interaction occurs. Sometimes this effect is observable in bottom loss curves. For example, a look at Figure 19 shows a rise in the curves at a bottom grazing angle of 28°. This has been interpreted as the effect of reflection of the sound from the basement, the onset of basement reflection taking place at 28°. Basement reflection coefficients, REF, of 0.4 to 0.5 independent of frequency and grazing angle appear to be quite common. The entry should contain two decimal places, e.g. REF = 0.50.

High angle losses are discussed by Spofford et al. (1982) as follows:

*D. High Angle Losses*

*At the higher angles the bottom-loss data show several characteristic patterns. Very little significant angle dependence is apparent; however, four types of frequency dependence have been identified:*

*Type 1. Zero (0) Frequency Dependence*

*This is the simplest behavior and represents the frequency and angle-independent loss characteristic of a two-fluid interface. Figure 18 is a good example of this type where the loss of approximately 10 dB corresponds to an impedance of 3.2 or a sediment density of 2.0 g/cm*$^3$*, characteristic of sandy-silt found on continental terraces.*

*Type 2. Positive (+) Frequency Dependence*

*When the sediments are not so thick, at the high angles the interface-reflected path is augmented by a basement-reflected path which can carry significant energy, especially at the lower frequencies where volume attenuation in the sediment is diminished. Figure 19 illustrates such a case. The sediments are not thick enough to allow the caustic to form. In fact the basement grazing ray appears to correspond to the bottom-grazing angle of about 25* *degrees consistent with the known sediment thickness at this location of approximately 90 meters and the gradient appropriate to this type of calcareous sediment of 1.7 sec$^{-1}$. The higher frequency losses, dominated by the interface-reflected wave, tend to cluster around 10 dB. As the frequency decreases, the amplitude of the basement-reflected path increases until the two paths have comparable amplitude at 200 Hz (thereby reducing the loss by 3 dB). At 50 and 100 Hz the basement return dominates and attenuation effects are nearly negligible. Basement reflection coefficients of 6-8 dB corresponding to REF = 0.4-0.5 independent of frequency and grazing angle appear to be quite common.*

*Type 3. Negative (-) Frequency Dependence*

*A third type of frequency dependence at high angles is illustrated in Figure 20. Here the high frequencies show less loss than the low frequencies. This appears to be modelable as a thin high-impedance layer at the top of the sediment. The shorter wavelengths respond to this impedance while longer wavelengths tend to "see" through the layer, responding more strongly to the lower impedance characteristic of the bulk of the sediment as the frequeny decreases. In this case, it would appear that the thin layer has an effective impedance ratio of 1.50, whereas the bulk of the sediments has a near-surface ratio of 1.29. The higher impedance is characteristic of sandy silt, whereas the bulk of the sediment might be clayey silt.*

*Type 4. Reversing (±) Frequency Dependence*

*A fourth type of behavior is occasionally observed when the thin-layer (Type 3) effect appears to peak at a particular frequency. In Figure 21 the loss decreases at high angles until 200 Hz, where it reaches a minimum and then increases. This strongly suggests a high-impedance layer (or set of layers) which acoustically resonates at 200 Hz. If, in fact, this is a single layer it would then have to be about 2 meters thick with a well defined lower interface with the sediment.*

## RESULTS OF GEO-PARAMETER COMPUTATION

The inversion computation yields results as follows:

$$RATIO = \frac{C2}{C1}$$

RH2 = density of top layer of sediment in gram/cm$^3$.

RH3 = density of sediment below the layer in gram/cm$^3$.

D = thickness of the top layer in meters.

G = sound speed gradient at the top of the sediment in units sec$^{-1}$.

B = sound speed profile parameter, no units.

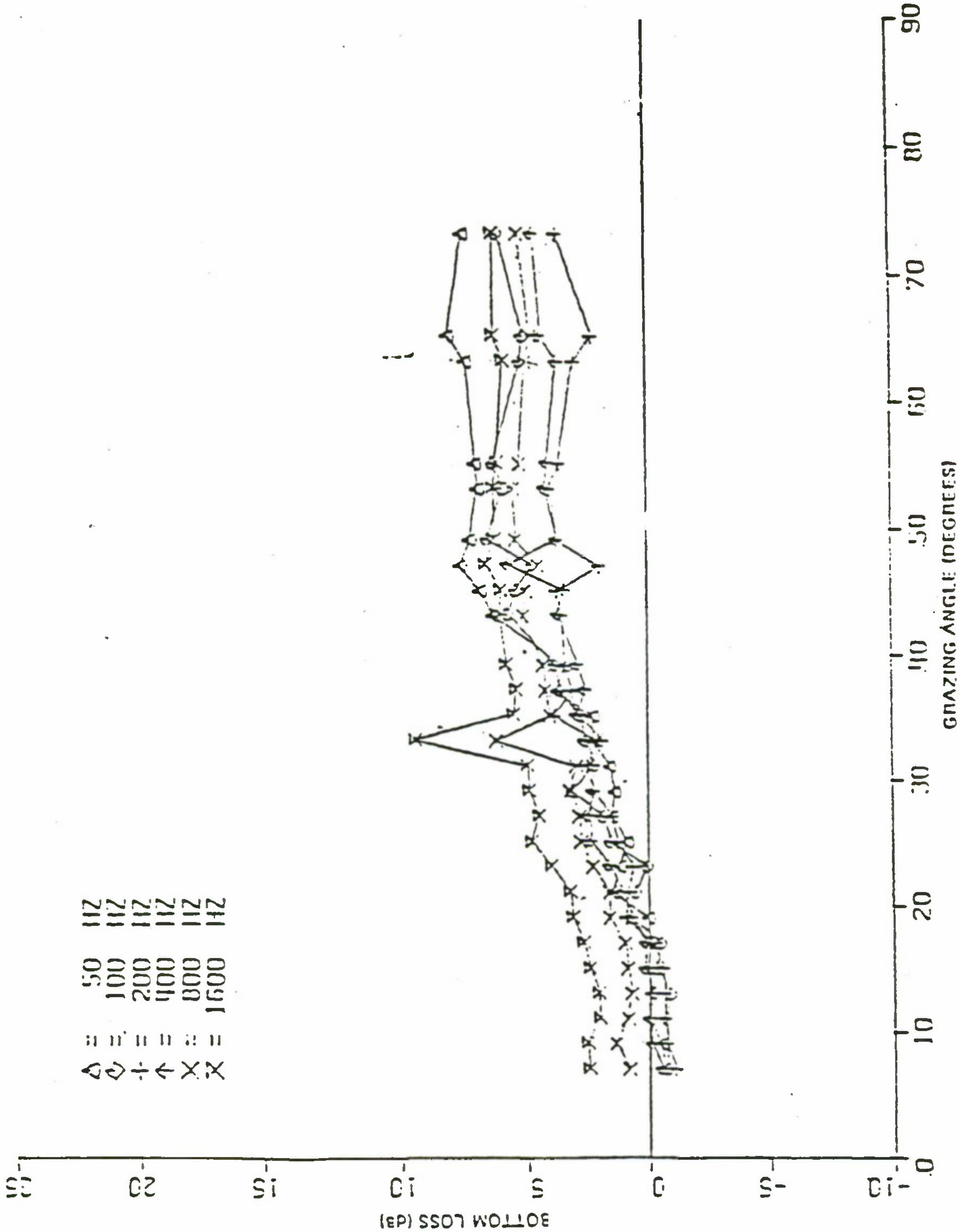



Figure 21. Bottom loss versus grazing angle measured in six one-octave bands at indicated center frequencies: reversing high-angle frequency dependence.

After Spofford et al.(1982)

ALPHØ = logarithmic sound attenuation coefficient for sound in sediment, units DB/m/kHz.

GAM = attenuation coefficient gradient in units of $dB/m^2/kHz$.

BZ = depth of the sediment in meters.

REF = basement reflection coefficient, no units.

## BOTTOM LOSS COMPUTATION

If bottom loss is the desired result, use input option statement.

IOPT = 0.

The required input data is listed below.

This example illustrates the number of decimal places needed for each entry:

1. RATIO = 1.0040
2. G = 1.79
3. BETA = -.50
4. RH2 = 2.33
5. RH3 = 2.09
6. D = .24
7. ALPHØ = .029
8. GAM = .00010
9. REF = .50
10. BZ = 1067.78

These quantities mentioned before have the same definitions given before.

The computation yields values of bottom loss in dB in steps of 1 degree for all applicable apparent bottom grazing angles from 0 to 90°. Computations are done for the following frequencies (in Hz): 50, 100, 200, 400, 800, and 1600, or others as specified. Frequencies mentioned are the frequencies of the centers of bands one-octave wide, and the computed bottom loss is a frequency-averaged value for the one octave bandwidth. The results are plotted in graphical form.

For runs involving a basement reflection, if 90 degrees is reached on the loss plot, the loss value increases to the value one would have if no basement return were present. This may be helpful to the user in evaluating the effects of basement reflection and in adjusting the value of the basement reflection coefficient REF.

Computed bottom loss values of 25dB should be treated suspiciously because they may be the result of computations which result in loss values of greater than 25dB. These are thought to be physically unrealistic so are set arbitrarily at 25dB by the computer. See statement in Subroutine LOSS:

ALOSS(JJ,I)=25.

See also similar statements between 212 and 213 and between 800 and 801 of Subroutine LOSS.

## IV. CONCLUSIONS

The computer program directs computations of geo-acoustic ocean bottom parameters and simulated bottom loss, generally in accordance with the criteria outlined in the description of the model of Spofford et al.(1982). The program has been implemented on HP 1000 computers inhouse at the Naval Oceanographic Office and aboard ship at sea. At present, new bottom loss data is being acquired by experiments at sea, and results are being computed by use of PROGRAM BTLS. Some initial problems with use of the program have been overcome, and use and evaluation are continuing. Some problems associated with the program are discussed in the section containing recommendations.

## V. RECOMMENDATIONS

It is recommended that changes be made to the program as follows:

In SUBROUTINE GEOPHYS change line D=C1/FM/4 to read D=C2/FM/4. Change line AUX=4*D*PI*FREQ/C1*SIN(THETA to read AUX=4*D*PI*FREQ/C2*SIN(THETA). These change the speed of sound in the layer at the top of the sediment to the correct value C2. Change AUX=AUX/T to read AUX=AUX/T**2 in order to compute the square of the two-way layer transmission coefficient.

Once these changes are carried out, the program should be run again with data used for previous computations done before making these changes. A careful evaluation of the old and new results should be made to determine the effects of these changes.

The program computations are based upon an assumed bandwidth of 1 octave. This is important in the calculation of simulated bottom loss. The actual bandwidth used in processing measured signals to provide input data for computing geo-parameters does not seem to be important, because only the band center frequency is designated, and the bandwidth does not enter into the calculations. Nevertheless, when comparing simulated bottom loss plots with actual measured bottom loss data, the bandwidth used for the simulation should be the same as the bandwidth used to obtain the measured data. It seems that all recent measured data is processed with a 1/3 octave bandwidth. Therefore, discrepancies should be expected in a comparison of simulated bottom loss with 1/3 octave bandwidth measured loss. It is recommended that the same bandwidth be used in computing simulated bottom loss and for processing measurements of bottom loss.

# VI. REFERENCES

SPOFFORD, C. W.; GREENE, R. R.; and HERSEY, J. B., "The Estimation of Geo-Acoustic Ocean Sediment Parameters from Measured Bottom-Loss Data," (1982) to be published in the Journal of the Acoustical Society of America.

Documentation of Bottom Loss Upgrade Parameters, anon. (1982).

BREKHOVSKHIK, L.M., Waves in Layered Media, 2nd Edition (Academic Press, New York 1980).

# APPENDIX A

## PROGRAM BTLS

```
&BTL10 T=00003 IS ON CR00032 USING 00371 BLKS R=0000

FTN4X,L
      PROGRAM BTL10
C                                                                       BTLS
C   THIS PROGRAM SIMULATES MEASURED BOTTOM LOSS DATA                    MAY82
C        INCLUDING MEASUREMENT ARTIFACTS                                MAY82
C                                                                       MAY82
C   BLANK COMMON CONTAINS GEOACOUSTIC PARAMETERS                        MAY82
C                                                                       MAY82
C                                                                       BTLS
      COMMON ZB,ZR,ZS,C1,C2,C3,RH1,RH2,RH3,G,D,ALPN0,CS,BZ,REF,HEAD(20) BTLS
      COMMON /ALPH/GAM                                                  MAY82
      COMMON /T/T                                                       MAY82
C                                                                       MAY82
C   COMMON BLOCK AL CONTAINS THE SIX FREQUENCIES DEFINED                MAY82
C        IN THE FOLLOWING DATA STATEMENT IN F, AND CORRESPONDING        MAY82
C        BOTTOM LOSS FOR THE SIX FREQUENCIES AND 90 ANGLES IN           MAY82
C        ALOSS.  THE VALUSE IN ALOSS ARE CALCULATED IN SUBROUTINE LOSS. MAY82
C        NOTE !                                                         MAY82
C             ALL VALUES OF ALOSS ARE RETAINED, WHICH IS                MAY82
C             NOT NECESSARY IN THIS VERSION OF THE PROGRAM.             MAY82
C                                                                       MAY82
      COMMON/AL/F(6),ALOSS(6,90)                                        BTLS
      DIMENSION BRAY(600)
      EQUIVALENCE (BRAY(1),F(1)),(BRAY(7),ALOSS(1,1))
C                                                                       MAY82
C         LOOP 500 READS A SET OF INPUT DATA AND GENERATES A SET        MAY82
C              OF BOTTOM LOSS DATA ON EACH PASS UP TO A MAXIMUM         MAY82
C              OF 10 CASES                                              MAY82
C                                                                       MAY82
C                                                                       MAY82
C         SUBROUTINE LOS2 CALCULATES ALL FREQUENCEY INDEPENDENT         MAY82
C              INTERMEDIATE VARIABLES                                   MAY82
C                                                                       MAY82
      CALL LOS2                                                         BTLS
       IF(T.EQ.999) GO TO 999                                           MAY82
C                                                                       MAY82
C         LOOP 41 CALCULATES BOTTOM LOSS AT A PARTICULAR                MAY82
C              FREQUENCY IN SUBROUTINE LOSS AND PRINTS IT               MAY82
C              OUT ON EACH PASS.                                        MAY82
C                                                                       MAY82
      DO 41 J=1,6                                                       BTLS
      CALL LOSS(J)                                                      BTLS
       WRITE(6,2)(ALOSS(J,I),I=1,90)                                    MAY82
    2 FORMAT(1X,8F8.2)                                                  BTLS
   41 CONTINUE                                                          BTLS
      CALL EXEC(14,2,BRAY,1200)
      WRITE(1,69)
69    FORMAT(' NORMAL TERMINATION -- BOTTOM LOSS MODEL')
 999   STOP                                                             MAY82
      END                                                               BTLS
      SUBROUTINE LOS2                                                   LOS2
      COMMON ZB,ZR,ZS,C1,C2,C3,RH1,RH2,RH3,G,D,ALPN0,CS,BZ,REF,HEAD(20) LOS2
       COMMON /DATA/ LZERO,FZERO,L70,F70,TH70,L71,F71,DBLOSS,FREQ,THETA, MAY82
     1 ALOSS0,ALOSSM,FM,T1R,THC,THRC,TN1B,BETA                          MAY82
C                                                                       MAY82
      COMMON /ALPH/GAM                                                  LOS2
      COMMON/T/T                                                        LOS2
      REAL LZERO,L70,L71                                                LOS2
```

```
      DATA PI/3.141592655/                                              MAY82
      RN1=1                                                             MAY82
C                                                                       MAY82
C    INPUTS                                                             MAY82
C         1)  T=TWO WAY TRAVEL TIME THICKNESS OF SEDIMENT               MAY82
C                   IN TENTHS OF SECONDS                                MAY82
C                                                                       MAY82
C         2)  NNFILE = ARBITRARY FILE NUMBER                            MAY82
C                                                                       MAY82
C         3)  IOPT= INPUT OPTION, 0 FOR GEO-PARAMETERS,                 MAY82
C                                 1 FOR INVERSION PARAMETERS            MAY82
C                                                                       MAY82
      WRITE(1,701)
701   FORMAT(' INPUT OPTIONS ARE:  0 = INPUT GEO-PARAMETERS',/,
     *     '                       1 = INPUT BOTTOM LOSS',/,
     *     '                       2 = END PROGRAM',//,
     *     ' ENTER STATION NUMBER AND INPUT OPTION:')
      READ(1,*)  NNFILE,IOPT                                            MAY82
      IF(IOPT.EQ.2) GO TO 999
      WRITE(1,702)
702   FORMAT(' ENTER THE TWO-WAY TRAVEL TIME THICKNESS IN 10THS OF SECON
     *DS:')
      READ(1,*) T
C                                                                       MAY82
C     BRANCH TO EXIT                                                    MAY82
C                                                                       MAY82
      T=T/20.                                                           MAY82
C                                                                       MAY82
C      INPUT EXPERIMENTAL GEOMETERY PARAMETERS                          MAY82
C                                                                       MAY82
      WRITE(1,705)
705   FORMAT(' ENTER THE WATER DEPTH:')
      READ(1,*) ZB
      WRITE(1,706)
706   FORMAT(' ENTER SOURCE DEPTH AND RECEIVER DEPTH:')
      READ(1,*) ZS,ZR
      WRITE(1,707)
707   FORMAT(' ENTER SOUND SPEED AT SOURCE OR RECEIVER - WHICHEVER IS SH
     *ALLOWER:')
      READ(1,*) CS
      WRITE(1,708)
708   FORMAT(' ENTER SOUND SPEED AT THE BOTTOM OF THE WATER:')
      READ(1,*) C1
C                                                                       MAY82
C                                                                       MAY82
C     BRANCH TO INPUT OPTION                                            MAY82
C                                                                       MAY82
      IF(IOPT.EQ.0) GO TO 500                                           MAY82
C                                                                       MAY82
C     INPUT INVERSION PARAMETERS                                        MAY82
C                                                                       MAY82
      WRITE(1,709)
709   FORMAT('                     ATTENUATION CALCULATION',//,
     *' FOR A POINT BELOW THE CAUSTIC WHERE BL CURVE IS NEARLY LINEAR,'/
     *,' ENTER A LOSS, FREQUENCY AND ANGLE: (ANG=APPROX 20, FREQ = APPRO
     *X 200)')
      READ(1,*) DBLOSS,FREQ,THETA
      WRITE(1,710)
710   FORMAT(' ENTER LOW FREQ LOSS LEVEL AT HIGH ANGLES.',/,
     *        ' THE MINIMUM LOSS LEVEL AT HIGH ANGLES',/,
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```
     *        ' AND THE FREQUENCY OF THE MINIMUM LOSS:')
      READ(1,*) ALOSS0,ALOSSM,FM
      WRITE(1,711)
711   FORMAT(' ENTER ANGLE OF TOTAL INTERNAL REFLECTION,',/,
     *        ' ANGLE OF CAUSTIC,',/,
     *        ' RATIO OF SPEED IN SEDIMENT TO SPEED AT BOTTOM OF WATER:')
      READ(1,*)TIR,THC,RATIO                                            MAY82
      IF(THC.EQ.0.0) THEN
        WRITE(1,712)
712     FORMAT(' ENTER GRADIENT AT TOP OF SEDIMENT:')
        READ(1,*) G
      ENDIF
      WRITE(1,713)
713   FORMAT(' ENTER CANONICAL CURVE TYPE AND ATTENUATION PROFILE GRADIE
     *NT:')
      READ(1,*)  BETA,GAM
      WRITE(1,714)
714   FORMAT(' ENTER BASEMENT REFLECTION COEFFICIENT IN PRESSURE UNITS:'
     *)
      READ(1,*)REF                                                      MAY82
C                                                                       MAY82
C        OPTIONS AND ERROR CHECKING                                     MAY82
C                                                                       MAY82
      IF(TIR.GT.0.  .OR. RATIO .LE. 0.) RATIO=1./COS(TIR*PI/180.)       MAY82
      C2=C1*RATIO                                                       MAY82
      C3=C2                                                             MAY82
C                                                                       MAY82
C        IF GRADIENT G IS NOT SPECIFIED CALCULATE IT FROM THE           MAY82
C             CAUSTIC ANGLE, THC                                        MAY82
C                                                                       MAY82
       IF(G.NE.0.) GO TO 300                                            MAY82
       IF(THC.LE.0.) THC=30                                             MAY82
       CALL GCOMP                                                       MAY82
 300   CONTINUE                                                         MAY82
      WRITE(6,140)                                                      LOS2
 140  FORMAT(//," INPUT DATA",/)                                        LOS2
      WRITE(6,210)NNFILE,T                                              LOS2
 210  FORMAT(1X,I4,/," T =",F8.2)                                       LOS2
      WRITE(6,220)ZB,ZS,ZR,CS,C1                                        LOS2
 220  FORMAT(" ZB=",F8.2," ZS=",F8.2," ZR=",F8.2," CS=",F8.2," C1=",F8.2 LOS2
     1)                                                                 LOS2
      WRITE(6,141)DBLOSS,FREQ,THETA                                     LOS2
 141  FORMAT(" DBLOSS=",F8.2," FREQ  =",F8.2," THETA =",F8.2)           LOS2
      WRITE(6,142)ALOSS0,ALOSSM,FM                                      LOS2
 142  FORMAT(" ALOSS0=",F8.2," ALOSSM=",F8.2," FM    =",F8.2)           LOS2
      WRITE(6,143)TIR,THC,RATIO                                         LOS2
  143 FORMAT(" TIR   =",F8.2," THC   =",F8.2," RATIO =",F8.4)           RUNINT
C                                                                       MAY82
C      CHANGE DEGREES TO RADIANS                                        MAY82
C                                                                       MAY82
      THETA = THETA*PI/180.                                             MAY82
      THC=THC*PI/180.                                                   MAY82
      TIR=TIR*PI/180.                                                   MAY82
C                                                                       MAY82
C       CALL ROUTINE WHICH CALCULATES THE REMAINING                     MAY82
C            GEOPHYSICAL PARAMETERS FROM THE INVERSION INPUTS           MAY82
C                                                                       MAY82
      CALL GEOPY
      GO TO 499                                                         MAY82
C                                                                       MAY82
```

```
C     OPTIONAL BRANCH TO INPUT GEO-PARAMETERS DIRECTLY                    MAY82
C                                                                         MAY82
  500 CONTINUE                                                            MAY82
      WRITE(1,715)
 715  FORMAT(' ENTER RATIO OF SPEED IN SEDIMENT TO SPEED AT BOTTOM OF WA
     *TER:')
      READ(1,*) RATIO
      WRITE(1,716)
 716  FORMAT(' ENTER GRADIENT AT TOP OF SEDIMENT AND CANONICAL CURVE TYP
     *E:')
      READ(1,*) G,BETA
      WRITE(1,717)
 717  FORMAT(' ENTER THIN LAYER DENSITY, SEDIMENT DENSITY AND THIN LAYER
     * THICKNESS IN METERS:')
      READ(1,*) RN2,RH3,D
      WRITE(1,718)
 718  FORMAT(' ENTER SURFACE ATTENUATION IN DB/M/KHZ:')
      READ(1,*) ALPN0
      WRITE(1,719)
 719  FORMAT(' ENTER ATTENUATION PROFILE GRADIENT AND BASEMENT REFLECTIO
     *N COEFFICIENT IN PRESSURE:')
      READ(1,*) GAM,REF
C
       C2=C1*RATIO                                                        MAY82
       C3=C2                                                              MAY82
C                                                                         MAY82
C      CALL A SUBRUUTINE WNICN CALCULATES AND PRINTS VARIOUS              MAY82
C            CRITICAL ANGLES CHARACTERISTIC OF THE MEASUREMENT            MAY82
C            GEOMETRY                                                     MAY82
C                                                                         MAY82
  499  CALL CANGLE                                                        MAY82
C                                                                         MAY82
C          PRINT GEO-PARAMETERS                                           MAY82
C                                                                         MAY82
      WRITE(6,145)                                                        MAY82
  145   FORMAT(//,"  GEO-PARAMETERS ",//)                                 MAY82
      WRITE(6,146)RATIO,RN2,RN3,D,G,BETA,ALPH0,GAM,BZ,REF                 LOS2
   146 FORMAT(" RAT=",F8.4,/," RN2=",F8.2," RN3=",F8.2,/,                 RUNINT
     1" D  =",F8.2,/," G  =",F8.2," BET=",F8.2,/,                         LOS2
     2" AL0=",F9.3,"GAM=",F11.5,/," BZ =",F8.2," REF=",F8.2,//)           LOS2
C                                                                         MAY82
C          CALL ROUTINES FOR FREQUENCY-INDEPENDENT INTERMEDIATE           MAY82
C                  VARIABLE                                               MAY82
C                                                                         MAY82
      CALL REFL                                                           MAY82
      CALL REFR                                                           MAY82
      CALL BASE                                                           MAY82
C                                                                         MAY82
  999  RETURN                                                             MAY82
       END                                                                MAY82
      SUBROUTINE GEOPY
      COMMON ZB,ZR,ZS,C1,C2,C3,RN1,RN2,RN3,G,D,ALPN0,CS,BZ,RE,NEAD(20)    GEOPHY
      COMMON/DATA/LZERO,FZERO,L70,F70,TN70,L71,F71,DBLOSS,                GEOPHY
     1FREQ,THETA,ALOSS0,ALOSSM,FM,TIR,TNC,TNRC,TN1B,BETA                  GEOPHY
      COMMON /ALPH/GAM                                                    GEOPHY
      REAL LZERO,L70,L71                                                  GEOPHY
      DATA PI/3.141592655/                                                GEOPHY
COMPUTE DENSITIES RH2,RH3                                                 GEOPHY
      Z1=C1*RH1                                                           GEOPHY
      D=C1/FM/4                                                           GEOPHY
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```
      R=EXP(-ALOG(10.)*ALOSS0/20)                                       GEOPHY
      Z3=(1+R)/(1-R)*Z1                                                 GEOPHY
      R=EXP(-ALOG(10.)*ALOSSM/20)                                       GEOPHY
      Z2=(1+R)/(1-R)*Z1*Z3                                              GEOPHY
      Z2=SQRT(Z2)                                                       GEOPHY
      SPRAT=C3/C1                                                       GEOPHY
      RN2=Z2/C2                                                         GEOPHY
      RN3=Z3/C3                                                         GEOPHY
COMPUTE DISSIPATION CONSTANT ALPH0                                      GEOPHY
      THETA=ACOS(C2/C1*COS(THETA))                                      GEOPHY
      BS=SIN(THETA)                                                     GEOPHY
      BC=COS(THETA)                                                     GEOPHY
      V32=(Z3-Z2)/(Z3+Z2)                                               GEOPHY
      V21=(Z2-Z1)/(Z2+Z1)                                               GEOPHY
      AUX=4*D*PI*FREQ/C1*SIN(THETA)                                     GEOPHY
      V=CABS((V21+V32*CMPLX(COS(AUX),SIN(AUX)))/(1+V21*V32*             GEOPHY
     1CMPLX(COS(AUX),SIN(AUX))))                                        GEOPHY
      T=CABS(1/(1+V21*V32*CMPLX(COS(AUX),SIN(AUX))))**2                 GEOPHY
     1*16*Z1*Z3*(Z2/(Z1+Z2)/(Z2+Z3))**2                                 GEOPHY
      AUX=10.**(-DBLOSS/10.)-V**2                                       GEOPHY
      AUX=AUX/T                                                         GEOPHY
      ALS=-ALOG10(AUX)*10                                               GEOPHY
      FK=FREQ/1000                                                      GEOPHY
      SIG=G*(1+BETA)*C2                                                 GEOPHY
      AMU=(C2*(1+BETA))**2                                              GEOPHY
      ANU=BETA*C2                                                       GEOPHY
      ALPH0=ALS/FK-2*C2/G/(1+BETA)/BC*                                  GEOPHY
     1(GAM*C2**2/2/SIG/BC**3*(BS-BS**3/3)+                              GEOPHY
     2(BETA*GAM*C2**2+2*GAM*ANU*C2)/4/SIG/BC**2*                        GEOPHY
     3(THETA+BS*BC)+                                                    GEOPHY
     4(GAM*(ANU**2-AMU)+2*BETA*GAM*ANU*C2)/2/SIG/BC*BS+                 GEOPHY
     5BETA*GAM*(ANU**2-AMU)/2/SIG*THETA)                                GEOPHY
      ALPN0=ALPH0/(BS/BC+BETA*THETA)*G*(1+BETA)*BC/2/C2                 GEOPHY
      RETURN                                                            MAY82
      END                                                               MAY82
      SUBROUTINE CANGLE                                                 MAY82
C                                                                       MAY82
      COMMON ZB,ZR,ZS,C1,C2,C3,RN1,RN2,RN3,G,D,ALPN0,CS,BZ,RE,HEAD(20)  MAY82
      COMMON /ALPH/GAM                                                  MAY82
      COMMON /T/T                                                       MAY82
C                                                                       MAY82
      COMMON /DATA/ LZERO,FZERO,L70,F70,TN70,L71,F71,DBLOSS,FREQ,       MAY82
     1THETA,ALOSS0,ALOSSM,FM,TIR,TNC,THRC,THIB,BETA                     MAY82
C                                                                       MAY82
      REAL LZERO,L70,L71                                                MAY82
C                                                                       MAY82
      DATA PI/3.14159264/                                               MAY82
C                                                                       MAY82
       DI=2.*ZB-ZR-ZS                                                   MAY82
C                                                                       MAY82
C             CALCULATE SEDIMENT THICKNESS                              MAY82
C                                                                       MAY82
      B=BETA                                                            MAY82
      CZP=2000                                                          MAY82
      A=C2*(G*(1.+B)*T+1.+B*ALOG(C2))                                   MAY82
 60   CZ=CZP+(A-CZP-B*C2*ALOG(CZP))/(1.+B*C2/CZP)                       MAY82
      IF(ABS(CZ-CZP).LT..01) GO TO 70                                   MAY82
      CZP=CZ                                                            MAY82
      GO TO 60                                                          MAY82
 70   BZ=((CZ+B*C2)**2-C2**2*(1+B)**2)/(2*G*(1+B)*C2)                   MAY82
```

```
C                                                                       MAY82
C          COMPUTE REFINED CRITICAL ANGLE                               MAY82
C                                                                       MAY82
      THRC=PI/4                                                         MAY82
      CALL TOTCI
C                                                                       MAY82
C          COMPUTE CRITICAL RAY DEPTH CRD                               MAY82
      CAUX=C1/COS(THRC)                                                 MAY82
      CRD=((CAUX+BETA*C3)**2-(C3*(1+BETA))**2)/2/G/(1+BETA)/C3          MAY82
C                                                                       MAY82
C          CALCULATE VELOCITY, VELOCITY GRADIENT, AND ATTENUATION       MAY82
C                 CONSTANT AT DEPTH OF 500 METERS                       MAY82
C                                                                       MAY82
      BSPD=SQRT(2*G*(1+BETA)*C3*500+C3**2*(1+BETA)**2)-BETA*C3          MAY82
      BGRAD=G*(1+BETA)/(BSPD/C3+BETA)                                   MAY82
      ALBOT=ALPHO+GAM*500                                               MAY82
C                                                                       MAY82
C          COMPUTE TWO WAY TRAVEL TIME IN SECONDS                       MAY82
C                                                                       MAY82
      TWTT=2*T                                                          MAY82
      SPRAT=C2/C1                                                       MAY82
C                                                                       MAY82
C          COMPUTE BASEMENT CRITICAL ANGLES TH18,TH38                   MAY82
C                                                                       MAY82
     C8=SQRT(2*G*(1+BETA)*C3*BZ+C3**2*(1+BETA)**2)-BETA*C3              MAY82
      TH18=ACOS(C1/C8)                                                  MAY82
      TH38=ACOS(C3/C8)                                                  MAY82
      R=DI/TAN(TH18)+2*C3*TAN(TH38)/G*(BETA/(1+BETA))*                  MAY82
     1(1+(1+TH3B/SIN(TH38)/COS(TH38))/2/BETA)                           MAY82
C                                                                       MAY82
C           COMPUTE SMALLEST APPARENT ANGLE FOR BASEMENT REFLECTION     MAY82
C                                                                       MAY82
      TH8=ATAN(DI/R)                                                    MAY82
C                                                                       MAY82
C            CHANGE RADIANS TO DEGREES                                  MAY82
C                                                                       MAY82
      TH8=TH8*180/PI                                                    MAY82
       A=TIR*180/PI                                                     MAY82
       A1=THC*180/PI                                                    MAY82
       A2=THRC*180/PI                                                   MAY82
       A3=TH18*180/PI                                                   MAY82
C                                                                       MAY82
C            PRINT OUT CRITICAL ANGLES                                  MAY82
C                                                                       MAY82
        WRITE(6,1)                                                      MAY82
 1    FORMAT(1X,//," CRITICAL ANGLES",/)                                MAY82
      WRITE(6,11)A,SPRAT,A1,A2,THB,A3,TWTT,BZ,CRD,BGRAD,BSPD,ALBOT,GAM  MAY82
 11   FORMAT(" TIR =",F8.2," RAT =",F8.4," THC =",F8.2," THRC =",F8.2,  MAY82
     1/," TH8 =",F8.2," THR8 =",F8.2,                                   MAY82
     2/," TWTT =",F8.2," BZ =",F8.2," CRD =",F8.2,/,                    MAY82
     3" G500 =",F8.2," C500 =",F8.2," A500 =",F9.3," GAM =",F11.5)      MAY82
 999    RETURN                                                          MAY82
         END                                                            MAY82
      SUBROUTINE TOTCI
      COMMON ZB,ZR,ZS,C1,C2,C3,RH1,RH2,RH3,G,D,ALPHO,CS,BZ,REF,HEAD(20) TOTCRT
      COMMON/DATA/LZERO,FZERO,L70,F70,TH70,L71,F71,DBLOSS,              TOTCRT
     1FREQ,THETA,ALOSS0,ALOSSM,FM,TIR,THC,THRC,TH18,BETA                TOTCRT
      REAL LZERO,L70,L71                                                TOTCRT
C  CHECK THAT C3 LESS THAN C2                                           TOTCRT
      IF(C3.LE.C2)GO TO 10                                              TOTCRT
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```
      WRITE(1,11)
   11 FORMAT(" C3 MUST BE LESS THAN OR EQUAL TO C2")                      TOTCRT
      STOP                                                                TOTCRT
   10 PI=3.141592654                                                      TOTCRT
C  COMPUTE TIR=ANGLE OF TOTAL INTERNAL REFLECTION                         TOTCRT
      TIR=0                                                               TOTCRT
      IF(C2.LE.C1)GO TO 100                                               TOTCRT
      TIR=ACOS(C1/C2)                                                     TOTCRT
  100 CONTINUE                                                            TOTCRT
C  COMPUTE TNC=CRITICAL ANGLE (CAUSTIC)                                   TOTCRT
      PI=3.141592654                                                      TOTCRT
      PI2=PI/2                                                            TOTCRT
      DELT=PI/180                                                         TOTCRT
      D1=2*ZB-ZR-ZS                                                       TOTCRT
      D2=2*C3/G                                                           TOTCRT
      D2=D2*BETA/(1+BETA)                                                 TOTCRT
      FAC=C3/C1                                                           TOTCRT
      TN3=ACOS(FAC*COS(TNRC))                                             TOTCRT
      R=D1/TAN(THRC)+D2*TAN(TN3)*(1+(1+TN3/SIN(TH3)/COS(TN3))/2/BETA)     TOTCRT
C  MINIMIZE EXPRESSION FOR RANGE BY CONJUGATE DIRECTIONS                  TOTCRT
      DO 200 I=1,1000                                                     TOTCRT
      AUX=THRC+DELT                                                       TOTCRT
      IF(AUX.GE.PI2)GO TO 500                                             TOTCRT
      IF(AUX.LE.TIR)GO TO 500                                             TOTCRT
      THRC=AUX                                                            TOTCRT
      TN3=ACOS(FAC*COS(TNRC))                                             TOTCRT
      RAUX=D1/TAN(THRC)+D2*TAN(TN3)*(1+(1+TH3/SIN(TH3)/COS(TH3))/2/BETA) TOTCRT
      IF(RAUX.GT.R)GO TO 500                                              TOTCRT
      R=RAUX                                                              TOTCRT
      GO TO 200                                                           TOTCRT
  500 R=RAUX                                                              TOTCRT
      DELT=-DELT/3                                                        TOTCRT
       IF(ABS(DELT).LE.1.E-6) GO TO 999                                   MAY82
  200 CONTINUE                                                            TOTCRT
      WRITE(1,1)
    1 FORMAT(" CRITICAL ANGLE FAILED TO CONVERGE")                        TOTCRT
      STOP                                                                TOTCRT
C   BOTTOM ANGLE OF REFRACTED RAY AT CRITICAL ANGLE                       MAY82
  999 THC=ATAN(D1/R)                                                      TOTCRT
      CB=SQRT(2*G*(1+BETA)*C3*BZ+(C3*(1+BETA))**2)-BETA*C3                TOTCRT
      TH18=ACOS(C1/CB)                                                    TOTCRT
      RETURN                                                              TOTCRT
      END                                                                 TOTCRT
      SUBROUTINE REFL                                                     REFL
      COMMON ZB,ZR,ZS,C1,C2,C3,RH1,RH2,RH3,G,D,ALPN0,CS,BZ,REF,NEAD(20)   REFL
      COMMON/DATA/LZERO,FZERO,L70,F70,TH70,L71,F71,DBLOSS,                REFL
     1FREQ,THETA,ALOSS0,ALOSSM,FM,TIR,THC,THRC,TH18,BETA                  REFL
      REAL LZERO,L70,L71                                                  REFL
      COMMON /R/NSAP,RV21,RV32,RSIN2,RDTS,RDTR,RT,RGI                     REFL
      DIMENSION RV21(90),RV32(90),RSIN2(90),RDTS(90),RDTR(90),RT(90),     REFL
     1RGI(90)                                                             REFL
C*********************************************************************** REFL
C  RETURNS IN COMMON                                                      REFL
C   NSAP=NSAP=SMALLEST ANGLE(DEG) TO REACH SURFACE DUE TO SOUND PROFILE  REFL
C   RV21,RV32=REFLECTION COEFFICIENTS FOR RESPECTIVE INTERFACE            REFL
C   RSIN2=SIN OF GRAZING ANGLE IN HIGH SPEED LAYER                        REFL
C  RDTS,RDTR=REFLECTION PATH DELTA T FOR SOURCE,RECEIVER RESP.            REFL
C   RT=TRAVEL TIME FOR REFLECTION PATH                                    REFL
C   RGI=GEOMETRIC INTENSITY OF REFLECTION PATH                            REFL
C*********************************************************************** REFL
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C   COMPUTE HSAP                                                           REFL
        PI=3.141592654                                                     REFL
        NSAP=1                                                             REFL
        IF(C1.GE.CS)GO TO 100                                              REFL
        SAP=ACOS(C1/CS)*180/PI                                             REFL
        NSAP=SAP+1                                                         REFL
        WRITE(1,1) SAP
      1 FORMAT(" SMALLEST AHGLE TO REACN SURFACE=",F8.2)                   REFL
  100   CONTIHUE                                                           REFL
C   COMPUTE REFLECTION COEFFICIEHTS FOR ANGLES GREATER THAH TIR,SAP        REFL
        NTIR=TIR*180/PI+1                                                  REFL
        N=MAX0(HTIR,HSAP)                                                  REFL
        Z1=RN1*C1                                                          REFL
        Z2=RH2*C2                                                          REFL
        Z3=RH3*C3                                                          REFL
        DELT=PI/180                                                        REFL
        TH=(HSAP-1)*DELT                                                   REFL
        FAC2=C2/C1                                                         REFL
        FAC3=C3/C1                                                         REFL
        FACS=CS/C1                                                         REFL
        AR=2*ZR/CS                                                         REFL
        AS=2*ZS/CS                                                         REFL
        D1=2*ZB-ZR-ZS                                                      REFL
        DO 200 I=NSAP,90                                                   REFL
        TH=TN+DELT                                                         REFL
        CTN=COS(TH)                                                        REFL
C   SURFACE SCATTERING TRAVEL TIME DIFFERENCES                             REFL
        S=SQRT(1-(FACS*CTH)**2)                                            REFL
        RDTS(I)=AS*S                                                       REFL
        RDTR(I)=AR*S                                                       REFL
        IF(I.LT.H)GO TO 200                                                REFL
C   SIN2                                                                   REFL
        RSIH2(I)=SQRT(1-(FAC2*CTN)**2)                                     REFL
C   REFLECTION COEFFICIEHTS                                                REFL
        A1=Z1/SIH(TH)                                                      REFL
        A2=Z2/RSIH2(I)                                                     REFL
        A3=Z3/SQRT(1-(FAC3*CTN)**2)                                        REFL
        RV32(I)=(A3-A2)/(A3+A2)                                            REFL
        RV21(I)=(A2-A1)/(A2+A1)                                            REFL
C   TRAVEL TIME                                                            REFL
        R=D1/TAH(TH)                                                       REFL
        RT(I)=R/(CTH*C1)                                                   REFL
C   GEOMETRIC IHTENSITY(AMPLITUDE)                                         REFL
        RGI(I)=CTH/R                                                       REFL
  200   CONTINUE                                                           REFL
        RETURN                                                             REFL
        EHD                                                                REFL
        SUBROUTINE REFR                                                    REFR
        COMMON ZB,ZR,ZS,C1,C2,C3,RN1,RN2,RN3,G,D,ALPH0,CS,BZ,REF,HEAD(20)  REFR
        COMMON/DATA/LZERO,FZERO,L70,F70,TH70,L71,F71,DBLOSS,               REFR
       1FREQ,THETA,ALOSS0,ALOSSM,FM,TIR,TNC,TNRC,TN18,BETA                 REFR
        COMMON /ALPN/GAM                                                   REFR
        REAL LZERO,L70,L71                                                 REFR
        COMMON /B/BV21,BV32,BSIH2,BTRF,BGI,BLS,BT,BDTS,BDTR                REFR
        COMMON /S/SV21,SV32,SSIN2,STRF,SGI,SLS,ST,SDTS,SDTR                REFR
        DIMEHSION BV21(90),BV32(90),BSIH2(90),BTRF(90),BGI(90),            REFR
       1BLS(90),BT(90),BDTS(90),BDTR(90)                                   REFR
        DIMENSION SV21(90),SV32(90),SSIN2(90),STRF(90),SGI(90),            REFR
       1SLS(90),ST(90),SDTS(90),SDTR(90)                                   REFR
C**********************************************************************    REFR
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C  FOR EACH SPECULAR BOTTOM ANGLE BETWEEN THE ANGLE OF TOTAL INTERNAL    REFR
C  REFLECTION AND THE CRITICAL ANGLE THIS SUBROUTINE RETURNS             REFR
C  (SMALL BOTTOM ANGLE PREFIX S,BIG BOTTOM ANGLE PREFIX B)               REFR
C   V21,V32=REFLECTION COEFFICIENTS AT INTERFACE                         REFR
C  SIN2=SIN OF GRAZING ANGLE IN HIGH SPEED LAYER                         REFR
C  TRF=TRANSMISSION COEFFICIENT FACTOR                                   REFR
C  GI=GEOMETRIC INTENSITY                                                REFR
C   LS=ARC LENGTH OF RAY IN THE BOTTOM                                   REFR
C   T=TRAVEL TIME                                                        REFR
C   DTS,DTR=DELTA T FOR SURFACE REFLECTION FOR SOURCE,RECEIVER RESP.     REFR
C*********************************************************************    REFR
      PI=3.141592654                                                     REFR
      NTIR=TIR*180/PI+1                                                  REFR
      NTHC=THC*180/PI+1                                                  REFR
      N=NTHC-NTIR                                                        REFR
      DEL=PI/180                                                         REFR
      TN=(NTHC-1)*DEL                                                    REFR
      Z1=RN1*C1                                                          REFR
      Z2=RN2*C2                                                          REFR
      Z3=RN3*C3                                                          REFR
      FAC2=C2/C1                                                         REFR
      FAC3=C3/C1                                                         REFR
      FACS=CS/C1                                                         REFR
      SEST=THRC                                                          REFR
      BEST=THRC                                                          REFR
      D1=2*ZB-ZR-ZS                                                      REFR
      D2=2*C3**2/G/C1                                                    REFR
      D3=2*C3/G*BETA/(1+BETA)                                            REFR
      D4=BETA/(1+BETA)/G                                                 REFR
      D7=1+BETA                                                          REFR
      D5=D1/C1                                                           REFR
      D6=2/CS                                                            REFR
      ANU=BETA*C3                                                        REFR
      SIG=G*(1+BETA)*C3                                                  REFR
      AMU=C3**2*(1+BETA)**2                                              REFR
      D8=2*C3/G/(1+BETA)/ALPH0                                           REFR
      D9=-GAM*C3**2/SIG/6                                                REFR
      D10=(BETA*GAM*C3**2+GAM*ANU*C3*2)/4/SIG                            REFR
      D11=-3*D9                                                          REFR
      D12=(GAM*(ANU**2-AMU)+2*ALPH0*SIG+2*BETA*ANU*C3*GAM)/2/SIG         REFR
      D14=BETA*GAM*(ANU**2-AMU)/2/SIG+BETA*ALPH0                         REFR
      DO 10 I=1,90                                                       REFR
      BTRF(I)=0                                                          REFR
   10 STRF(I)=0                                                          REFR
      DO 100 I=1,N                                                       REFR
      J=NTHC-I                                                           REFR
      R=D1/TAN(TN)                                                       REFR
      CALL REFRN(TN,SEST,BEST,SA,SA3,BA,BA3)
      IF(BA.GT.TH1B)GO TO 998                                            REFR
      BC1=COS(BA)                                                        REFR
      BS1=SQRT(1-BC1**2)                                                 REFR
      BC2=FAC2*BC1                                                       REFR
      BS2=SQRT(1-BC2**2)                                                 REFR
      BC3=FAC3*BC1                                                       REFR
      BS3=SQRT(1-BC3**2)                                                 REFR
C  BIG ANGLE REFLECTION COEFFICIENT                                      REFR
      A1=Z1/BS1                                                          REFR
      A2=Z2/BS2                                                          REFR
      A3=Z3/BS3                                                          REFR
      BV32(J)=(A3-A2)/(A3+A2)                                            REFR
```

```
      BV21(J)=(A2-A1)/(A2+A1)                                           REFR
      BTRF(J)=16*A1*A3*(A2/(A3+A2)/(A2+A1))**2                          REFR
      BSIN2(J)=BS2                                                      REFR
C  GEOMETRIC AMPLITUDE                                                  REFR
      DRDT=-D1/BS1**2+D2*(BS1/BS3/BC3**2)*(1.+BA3*                      REFR
     1TAN(BA3)/D7)                                                      REFR
      BGI(J)=BC1/(R*BS1*ABS(DRDT))                                      REFR
      BGI(J)=SQRT(BGI(J))                                               REFR
C  ARC LENGTH                                                           REFR
      BLS(J)=D8/BC3*(D9/BC3**3*BS3**3+D10/BC3*BS3                       REFR
     1+(D11/BC3**3+D12/BC3)*BS3+(D10/BC3**2+D14)*BA3)                   REFR
C  TRAVEL TIME                                                          REFR
      BT(J)=D5/BS1+D4*(ALOG((1+BS3)/(1-BS3))+2*BA3/BC3/BETA)            REFR
C  DELTA T SOURCE RECEIVER                                              REFR
      BSS=SQRT(1-(FACS*BC1)**2)                                         REFR
      BDTR(J)=D6*ZR*BSS                                                 REFR
      BDTS(J)=D6*ZS*BSS                                                 REFR
  998 SC1=COS(SA)                                                       REFR
      IF(SA.GT.TN1B)GO TO 999                                           REFR
      AUX=FACS*SC1                                                      REFR
C  IF RAY DOES NOT REACH SURFACE NOT COMPUTED                           REFR
      IF(AUX.GT.1.)GO TO 999                                            REFR
C  DELTA T SOURCE RECEIVER                                              REFR
      SSS=SQRT(1-AUX**2)                                                REFR
      SDTR(J)=D6*ZR*SSS                                                 REFR
      SDTS(J)=D6*ZS*SSS                                                 REFR
      SS1=SQRT(1-SC1**2)                                                REFR
      SC2=FAC2*SC1                                                      REFR
      SS2=SQRT(1-SC2**2)                                                REFR
      SC3=FAC3*SC1                                                      REFR
      SS3=SQRT(1-SC3**2)                                                REFR
C  SMALL ANGLE REFLECTION COEFFICIENT                                   REFR
      A1=Z1/SS1                                                         REFR
      A2=Z2/SS2                                                         REFR
      A3=Z3/SS3                                                         REFR
      SV32(J)=(A3-A2)/(A3+A2)                                           REFR
      SV21(J)=(A2-A1)/(A2+A1)                                           REFR
      STRF(J)=16*A1*A3*(A2/(A3+A2)/(A2+A1))**2                          REFR
      SSIN2(J)=SS2                                                      REFR
C  GEOMETRIC AMPLITUDE                                                  REFR
      DRDT=-D1/SS1**2+D2*(SS1/SS3/SC3**2)*(1+SA3*TAN(SA3)/D7)           REFR
      SGI(J)=SC1/(R*SS1*ABS(DRDT))                                      REFR
      SGI(J)=SQRT(SGI(J))                                               REFR
C  ARC LENGTH                                                           REFR
      SLS(J)=D8/SC3*(D9/SC3**3*SS3**3+D10/SC3*SS3                       REFR
     1+(D11/SC3**3+D12/SC3)*SS3+(D10/SC3**2+D14)*SA3)                   REFR
C  TRAVEL TIME                                                          REFR
      ST(J)=D5/SS1+D4*(ALOG((1+SS3)/(1-SS3))+2*SA3/SC3/BETA)            REFR
  999 TH=TH-DEL                                                         REFR
  100 CONTINUE                                                          REFR
      RETURN                                                            REFR
      END                                                               REFR
      SUBROUTINE BASE                                                   BASE
C*********************************************************************** BASE
C  FOR EACH SPECULAR BOTTOM ANGLE SUB RETURNS                           BASE
C   BSV21,BSV32=REFLECTION COEFFICIENTS AT INTERFACE                    BASE
C   BSSIN2=SIN OF GRAZING ANGLE IN HIGH SPEED LAYER                     BASE
C   BSTPF=TRANSMISSION COEFFICIENT FACTOR                               BASE
C  BSGI=GEOMETRIC AMPLITUDE                                             BASE
C   BSLS=ARC LENGTH OF RAY IN BOTTOM                                    BASE
```

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C   BST=TRAVEL TIME                                                       BASE
C   BSDTS,BSDTR=DELTA T FOR SURFACE REFLECTIOH FOR SOURCE RECEIVER        BASE
C*********************************************************************    BASE
      COMMOH ZB,ZR,ZS,C1,C2,C3,RN1,RN2,RN3,G,D,ALPH0,CS,BZ,REF,HEAD(20)  BASE
      COMMON /DATA/LZERO,FZERO,L70,F70,TN70,L71,F71,DBLOSS,FREQ,THETA,   BASE
     1ALOSS0,ALOSSM,FM,TIR,THC,TNRC,TH1B,BETA                            BASE
      COMMON /BS/BSV21,BSV32,BSSIN2,BSTRF,BSGI,BSLS,BST,BSDTS,BSDTR      BASE
      DIMENSIOH BSV21(90),BSV32(90),BSSIN2(90),BSTRF(90),BSGI(90),       BASE
     1BSLS(90),BST(90),BSDTS(90),BSDTR(90)                               BASE
      COMMON /ALPN/GAM                                                   BASE
      REAL LZERO,L70,L71                                                 BASE
      PI=3.141592654                                                     BASE
      HTIR=TIR*180/PI+1                                                  BASE
      DEL=PI/180                                                         BASE
      TH=PI/2                                                            BASE
      Z1=RH1*C1                                                          BASE
      Z2=RH2*C2                                                          BASE
      Z3=RH3*C3                                                          BASE
      FAC2=C2/C1                                                         BASE
      FAC3=C3/C1                                                         BASE
      FACS=CS/C1                                                         BASE
      CB=SQRT(2*G*(1+BETA)*C3*BZ+(C3*(1+BETA))**2)-BETA*C3               BASE
      FACB=CB/C1                                                         BASE
      D1=2*ZB-ZR-ZS                                                      BASE
      D2=2*C3**2/C1/G/(1+BETA)                                           BASE
      D3=2*C3/G/(1+BETA)                                                 BASE
      D4=2/G/(1+BETA)                                                    BASE
      D5=D1/C1                                                           BASE
      D6=2/CS                                                            BASE
      D7=2*C3*BETA/G/(1+BETA)/C1                                         BASE
C     THE FOLLOWING 2 LINES ADDED 5/29/79                                BASE
      DA=2.*C3/G/(1.+BETA)                                               BASE
      DB=DA*BETA                                                         BASE
      ANU=BETA*C3                                                        BASE
      SIG=G*(1+BETA)*C3                                                  BASE
      AMU=C3**2*(1+BETA)**2                                              BASE
      D8=2*C3/G/(1+BETA)/ALPH0                                           BASE
      D9=-GAM*C3**2/SIG/6                                                BASE
      D10=(BETA*GAM*C3**2+GAM*ANU*C3*2)/4/SIG                            BASE
      D11=-3*D9                                                          BASE
      D12=(GAM*(ANU**2-AMU)+2*ALPH0*SIG+2*BETA*AHU*C3*GAM)/2/SIG         BASE
      D14=BETA*GAM*(ANU**2-AMU)/2/SIG+BETA*ALPN0                         BASE
      BSA=TH-1.E-6                                                       BASE
      TN3=ACOS(FAC3*COS(TH1B))                                           BASE
      R=D1/TAN(TN1B)+D3/COS(TH3)**2*(TH3/2+(.25+BETA/2)*SIN(2*TH3))      BASE
      AUX=ATAH(D1/R)                                                     BASE
      N=AUX*180/PI+1                                                     BASE
      N=90-MAX0(H,HTIR)                                                  BASE
      DO 10 I=1,90                                                       BASE
      BSSIH2(I)=0.0
      BSV32(I)=0.0
      BSV21(I)=0.0
      BSGI(I)=0.0
   10 BSTRF(I)=0                                                         BASE
      DO 100 I=1,N                                                       BASE
      J=90-I                                                             BASE
      TH=TH-DEL                                                          BASE
      CALL BASANG(TH,BSA,BSA3)                                           BASE
      IF(BSA3.EQ.0.0) GO TO 100
      BC1=COS(BSA)                                                       BASE
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```
      BS1=SQRT(1-BC1**2)                                                BASE
      BC2=FAC2*BC1                                                      BASE
      BS2=SQRT(1-BC2**2)                                                BASE
      BC3=FAC3*BC1                                                      BASE
      BS3=SQRT(1-BC3**2)                                                BASE
      BCB=FACB*BC1                                                      BASE
      BSB=SQRT(1-BCB**2)                                                BASE
C  DELTA T SOURCE RECEIVER                                              BASE
      AUX=FACS*BC1                                                      BASE
C  IF RAY DOES NOT REACH SURFACE NOT COMPUTED                           BASE
      IF(AUX.GT.1.)GO TO 999                                            BASE
      SS=SQRT(1-AUX**2)                                                 BASE
      BSDTR(J)=D6*ZR*SS                                                 BASE
      BSDTS(J)=D6*ZS*SS                                                 BASE
C  LAYER REFLECTION COEFFICIENTS                                        BASE
      A1=Z1/BS1                                                         BASE
      A2=Z2/BS2                                                         BASE
      A3=Z3/BS3                                                         BASE
      BSV32(J)=(A3-A2)/(A3+A2)                                          BASE
      BSV21(J)=(A2-A1)/(A2+A1)                                          BASE
      BSTRF(J)=16*A1*A3*(A2/(A3+A2)/(A2+A1))**2                         BASE
      BSSIN2(J)=BS2                                                     BASE
C  GEOMETRIC AMPLITUDE                                                  BASE
      BSAB=ACOS(BCB)                                                    BASE
C     FOLLOWING 4 CARDS ADDED 5/59/79                                   BASE
      DRDT3=DA*(BS3/BC3**3*(BSA3-BSAB+BS3*BC3-BSB*BCB)                  BASE
     1+(1.-(CB/C3)**3*BS3/BSB))+DB/BC3*(1./BC3-BS3*(BSB/BC3+(CB/C3)**2  BASE
     2*BC3/BSB))                                                        BASE
      DRDT=-D1/BS1**2+(C3/C1)*BS1/BS3*DRDT3                             BASE
      R=D1/TAN(TH)                                                      BASE
      BSGI(J)=BC1/(R*BS1*ABS(DRDT))                                     BASE
      BSGI(J)=SQRT(BSGI(J))                                             BASE
C  ARC LENGTH                                                           BASE
      BSLS(J)=DB/BC3*(D9/BC3**3*(BS3**3-BSB**3)                         BASE
     1+D10/BC3**2*(BS3*BC3-BSB*BCB)+(D11/BC3**3+D12/BC3)*(BS3-BSB)      BASE
     1+(D10/BC3**2+D14)*(BSA3-BSAB))                                    BASE
C  TRAVEL TIME                                                          BASE
      BST(J)=D5/BS1+D4*((BSA3-BSAB)/BC3+BETA*ALOG((1+BS3)/              BASE
     1(1-BS3)*(1-BSB)/(1+BSB))/2)                                       BASE
 100  CONTINUE                                                          BASE
 999  RETURN                                                            BASE
      END                                                               BASE
      SUBROUTINE REFRN(TH,SEST,BEST,SA,SA3,BA,BA3)
      COMMON ZB,ZR,ZS,C1,C2,C3,RH1,RH2,RH3,G,D,ALPH0,CS,BZ,REF,HEAD(20) RFRANG
      COMMON /DATA/LZERO,FZERO,L70,F70,TH70,L71,F71,DBLOSS,FREQ,THETA,  RFRANG
     1ALOSS0,ALOSSM,FM,TIR,THC,THRC,TH1B,BETA                           RFRANG
      REAL LZERO,L70,L71                                                RFRANG
C********************************************************************** RFRANG
C  GIVEN                                                                RFRANG
C   TIR=ANGLE OF TOTAL INTERNAL REFLECTION                              RFRANG
C   TH=GRAZING ANGLE                                                    RFRANG
C   SEST=ESTIMATE SMALL ANGLE                                           RFRANG
C   BEST=ESTIMATE BIG ANGLE                                             RFRANG
C  RETURNS                                                              RFRANG
C   SA=SMALL ANGLE REFRACTED RAY                                        RFRANG
C   BA=BIG ANGLE REFRACTED RAY                                          RFRANG
C********************************************************************** RFRANG
      IF(TH.GT.TIR)GO TO 100                                            RFRANG
      WRITE(1,1)
    1 FORMAT(" SPECULAR ANGLE OF REFRACTED RAY LESS THAN TIR")          RFRANG
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      STOP                                                              RFRANG
  100 D1=2*ZB-ZR-ZS                                                     RFRANG
      PI2=3.141592654                                                   RFRANG
      PI2=PI2/2                                                         RFRANG
      D2=2*C3/G*(BETA/(1+BETA))                                         RFRANG
      D3=1/(2*BETA)                                                     RFRANG
      FAC3=C3/C1                                                        RFRANG
      R=D1/TAN(TH)                                                      RFRANG
      T3=ACOS(FAC3*COS(SEST))                                           RFRANG
      VAL =D1/TAN(SEST)+D2*TAN(T3)*(1+(1+T3/SIN(T3)/COS(T3))*D3)-R      RFRANG
      DEL=(SEST-TIR)/10.0001                                            RFRANG
C  COMPUTE SA                                                           RFRANG
  102 DO 200 I=1,500                                                    RFRANG
        IF(ABS(DEL).LT.1.E-6) GO TO 201                                 MAY82
      SA=SEST-DEL                                                       RFRANG
      IF(SA.LE.TIR)GO TO 211                                            RFRANG
      IF(SA.GE.THRC)GO TO 211                                           RFRANG
      T3=ACOS(FAC3*COS(SA))                                             RFRANG
      VALP=D1/TAN(SA   )+D2*TAN(T3)*(1+(1+T3/SIN(T3)/COS(T3))*D3)-R     RFRANG
      AUX=VAL*VALP                                                      RFRANG
      SEST=SA                                                           RFRANG
      VAL=VALP                                                          RFRANG
      IF(AUX.GT.0.)GO TO 200                                            RFRANG
  210 DEL=-DEL/3                                                        RFRANG
      GO TO 200                                                         RFRANG
  211 DEL=DEL/3                                                         RFRANG
  200 CONTINUE                                                          RFRANG
      WRITE(1,2)
    2 FORMAT(" SMALL BOTTOM REFRACTION ANGLE DOES NOT CONVERGE")        RFRANG
      STOP                                                              RFRANG
  201 SA3=T3                                                            RFRANG
C  BA INITIALIZATION                                                    RFRANG
      T3=ACOS(FAC3*COS(BEST))                                           RFRANG
      VAL =D1/TAN(BEST)+D2*TAN(T3)*(1+(1+T3/SIN(T3)/COS(T3))*D3)-R      RFRANG
      DEL=(PI2-BEST)/10.0001                                            RFRANG
C  COMPUTE BA                                                           RFRANG
  302 DO 400 I=1,500                                                    RFRANG
        IF(ABS(DEL).LT.1.E-6) GO TO 401                                 MAY82
      BA=BEST+DEL                                                       RFRANG
      IF(BA.LE.THRC)GO TO 411                                           RFRANG
      IF(BA.GE.PI2)GO TO 411                                            RFRANG
      T3=ACOS(FAC3*COS(BA))                                             RFRANG
      VALP=D1/TAN(BA   )+D2*TAN(T3)*(1+(1+T3/SIN(T3)/COS(T3))*D3)-R     RFRANG
      AUX=VAL*VALP                                                      RFRANG
      BEST=BA                                                           RFRANG
      VAL=VALP                                                          RFRANG
      IF(AUX.GT.0.)GO TO 400                                            RFRANG
  410 DEL=-DEL/3                                                        RFRANG
      GO TO 400                                                         RFRANG
  411 DEL=DEL/3                                                         RFRANG
  400 CONTINUE                                                          RFRANG
      WRITE(1,3)
    3 FORMAT(" LARGE BOTTOM REFRACTION ANGLE DOES NOT CONVERGE")        RFRANG
      STOP                                                              RFRANG
  401 BA3=T3                                                            RFRANG
      RETURN                                                            RFRANG
      END                                                               RFRANG
      SUBROUTINE BASANG(TH,BSA,BSA3)                                    BASANG
      COMMON ZB,ZR,ZS,C1,C2,C3,RH1,RH2,RH3,G,D,ALPH0,CS,BZ,REF,HEAD(20) BASANG
      COMMON /DATA/LZERO,FZERO,L70,F70,TH70,L71,F71,DBLOSS,FREQ,THETA,   BASANG
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     1ALOSSO,ALOSSM,FM,TIR,TNC,THRC,TN1B,BETA                          BASANG
      REAL LZERO,L70,L71                                                BASANG
C**********************************************************************  BASANG
C  GIVEN                                                                BASANG
C    BZ=SEDIMENT DEPTH                                                  BASANG
C    TH1B=BASEMENT CRITICAL ANGLE                                       BASANG
C    TIR=ANGLE OF TOTAL INTERNAL REFLECTION                             BASANG
C    TH=GRAZING ANGLE                                                   BASANG
C  RETURNS                                                              BASANG
C    BSA=BASEMENT REFLECTED RAY ANGLE IN WATER                          BASANG
C    BSA3=BASEMENT REFLECTED RAY ANGLE IN SEDIMENT                      BASANG
C**********************************************************************  BASANG
      IF(TH.GT.TIR)GO TO 100                                            BASANG
      WRITE(1,1)
    1 FORMAT(" SPECULAR ANGLE OF BASEMENT RAY LESS THAN TIR")           BASANG
      STOP                                                              BASANG
  100 D1=2*ZB-ZR-ZS                                                     BASANG
      PI=3.141592654                                                    BASANG
      PI2=PI/2                                                          BASANG
      D2=2*C3/G/(1+BETA)                                                BASANG
      FAC3=C3/C1                                                        BASANG
      CB=SQRT(2*G*(1+BETA)*C3*BZ+(C3*(1+BETA))**2)-BETA*C3              BASANG
      FACB=CB/C1                                                        BASANG
      R=D1/TAN(TN)                                                      BASANG
      BEST=BSA                                                          BASANG
      AUX=COS(BEST)                                                     BASANG
      TNB=ACOS(FACB*AUX)                                                BASANG
      TN3=ACOS(FAC3*AUX)                                                BASANG
      VAL=D1/TAN(BEST)+D2/(FAC3*AUX)**2*((TN3-TNB)/2+                   BASANG
     1(SIN(2*TN3)-SIN(2*THB))/4+BETA*(FAC3*AUX)*(SIN(TN3)-SIN(THB)))-R  BASANG
      DEL=PI/180                                                        BASANG
      AUX=TIR                                                           BASANG
      IF(TN1B.GT.TIR)AUX=TN1B                                           BASANG
  101 IF((BEST-DEL).GT.AUX)GO TO 102                                    BASANG
      DEL=DEL*.9                                                        BASANG
      GO TO 101                                                         BASANG
C  COMPUTE BSA                                                          BASANG
  102 DO 200 I=1,500                                                    BASANG
      BSA=BEST-DEL                                                      BASANG
      IF(BSA.LE.AUX)GO TO 211                                           BASANG
      IF(BSA.GE.PI2)GO TO 211                                           BASANG
      AUX1=COS(BSA)                                                     BASANG
      THB=ACOS(FACB*AUX1)                                               BASANG
      TH3=ACOS(FAC3*AUX1)                                               BASANG
      VALP=D1/TAN(BSA)+D2/(FAC3*AUX1)**2*((TN3-TNB)/2+                  BASANG
     1(SIN(2*TN3)-SIN(2*TNB))/4+BETA*(FAC3*AUX1)*(SIN(TN3)-SIN(TNB)))-R BASANG
      BAUX=VAL*VALP                                                     BASANG
      BEST=BSA                                                          BASANG
      VAL=VALP                                                          BASANG
      IF(BAUX.GT.0.)GO TO 200                                           BASANG
  210 DEL=-DEL/3                                                        BASANG
       IF(ABS(DEL).LT.1.E-6) GO TO 201                                  MAY82
      GO TO 200                                                         BASANG
  211 DEL=DEL/3                                                         BASANG
  200 CONTINUE                                                          BASANG
      BSA=PI/2.0-1.0E-6
      TH3=0.0
      WRITE(1,2)
    2 FORMAT(" BASEMENT ANGLE DOES NOT CONVERGE")                       BASANG
  201 BSA3=TH3                                                          BASANG
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```
      RETURN                                                               BABANG
      END                                                                  BABANG
      SUBROUTINE LOSS(JJ)                                                  LOSS
      COMMON Z8,ZR,ZS,C1,C2,C3,RN1,RN2,RN3,G,D,ALPN9,CS,BZ,REF,HEAD(20)   LOSS
      COMMON /DATA/LZERO,FZERO,L70,F70,TH70,L71,F71,DBLOSS,FREQ,TNETA,    LOSS
     1ALOSS0,ALOSSM,FM,TIR,TNC,TNRC,TN18,BETA                             LOSS
      COMMON/AL/F(6),ALOSS(6,90)                                           LOSS
      COMMON /R/NSAP,RV21,RV32,RSIN2,RDTS,RDTR,RT,RGI                      LOSS
      DIMENSION RV21(90),RV32(90),RSIN2(90),RDTS(90),RDTR(90),RT(90),     LOSS
     1RGI(90)                                                              LOSS
      COMMON /B/BV21,BV32,BSIN2,BTRF,BGI,BLS,BT,BDTS,BDTR                  LOSS
      COMMON /S/SV21,SV32,SSIN2,STRF,SGI,SLS,ST,SDTS,SDTR                  LOSS
      DIMENSION BV21(90),BV32(90),BSIN2(90),BTRF(90),BGI(90),             LOSS
     1BLS(90),BT(90),BDTS(90),BDTR(90)                                     LOSS
      DIMENSION SV21(90),SV32(90),SSIN2(90),STRF(90),SGI(90),             LOSS
     1SLS(90),ST(90),SDTS(90),SDTR(90)                                     LOSS
      COMMON /BS/BSV21,BSV32,BSSIN2,BSTRF,BSGI,BSLS,BST,BSDTS,BSDTR        LOSS
      DIMENSION BSV21(90),BSV32(90),BSSIN2(90),BSTRF(90),BSGI(90),        LOSS
     1BSLS(90),BST(90),BSDTS(90),BSDTR(90)                                 LOSS
      COMPLEX AUX99,V,AIM,AUX1,AR(16),PN(16)                               LOSS
      DIMENSION BR(4)                                                      LOSS
      REAL LZERO,L70,L71                                                   LOSS
C***********************************************************************   LOSS
C  THIS SUBROUTINE COMPUTES APPARENT LOSS DUE TO PROPAGATION               LOSS
C***********************************************************************   LOSS
      PI=3.141592654                                                       LOSS
      ALPH0=ALOG(10.)/4/PI/10000*ALPN9                                     LOSS
      EX=ALOG10(EXP(1.))                                                   LOSS
      PI2=2*PI                                                             LOSS
      AIM=CMPLX(0.,1.)                                                     LOSS
      SQRT2=SQRT(2.)                                                       LOSS
      F1=F(JJ)/SQRT2                                                       LOSS
      F2=F(JJ)*SQRT2                                                       LOSS
      FPI2D=4.*PI*F(JJ)*D/C2                                               LOSS
      NAV1=8                                                               LOSS
      FPIINC = FPI2D*(SQRT2-1.0/SQRT2)/NAV1                                REFFIX
      FPIIN=FPI2D-(NAV1-1)*FPIINC/2.                                       LOSS
      NTNC=TNC*180/PI                                                      LOSS
      N=90-NTHC                                                            LOSS
C  COMPUTE LOSS FOR ANGLES ABOVE CRITICAL (CAUSTIC)                        LOSS
      DO 10 I=1,90                                                         LOSS
   10 ALOSS(JJ,I)=25.                                                      LOSS
      DO 100 I=1,N                                                         LOSS
      J=91-I                                                               LOSS
      FPIAUX=FPIIN                                                         LOSS
      AUX=0.                                                               LOSS
      DO 20 NAV=1,NAV1                                                     LOSS
      ALPN2=FPIAUX*RSIN2(J)                                                LOSS
      C=COS(ALPH2)                                                         LOSS
      S=SIN(ALPH2)                                                         LOSS
      VV=(RV21(J)+RV32(J)*C)**2+(RV32(J)*S)**2                             LOSS
      VV=VV/((1+RV21(J)*RV32(J)*C)**2+(RV21(J)*RV32(J)*S)**2)              LOSS
      AUX=AUX+VV                                                           LOSS
      FPIAUX=FPIAUX+FPIINC                                                 LOSS
   20 CONTINUE                                                             LOSS
      VV=AUX/NAV1                                                          LOSS
      DR=PI2*RDTR(J)                                                       LOSS
      DS=PI2*RDTS(J)                                                       LOSS
      AUX=DR+DS                                                            LOSS
      DT=SIN(F2*AUX)-SIN(F1*AUX)                                           LOSS
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      DT=DT/AUX                                                          LOSS
      AUX=DS-DR                                                          LOSS
      DT=DT+SIN(F2*AUX)/AUX-SIN(F1*AUX)/AUX                              LOSS
      DT=DT-2*(SIN(F2*DS)-SIN(F1*DS))/DS                                 LOSS
      DT=DT-2*(SIN(F2*DR)-SIN(F1*DR))/DR                                 LOSS
      DT=DT/2/F1+1                                                       LOSS
      DT=VV*DT                                                           LOSS
      ALPH2=FPI2D*BSSIN2(J)/2                                            LOSS
      C=COS(ALPH2)                                                       LOSS
      S=SIN(ALPH2)                                                       LOSS
      V=BSTRF(J)/CMPLX((1+BSV32(J)*BSV21(J))*C,                          LOSS
     1(BSV32(J)*BSV21(J)-1)*S)**2                                        LOSS
      VV=CABS(V)*BSGI(J)*REF                                             LOSS
      AUX=0                                                              LOSS
      IF(VV.EQ.0.)GO TO 120                                              LOSS
      BR(1)=VV                                                           LOSS
      BR(2)=-VV                                                          LOSS
      BR(3)=-VV                                                          LOSS
      BR(4)=VV                                                           LOSS
      V=CMPLX(BST(J),ALPH0*BSLS(J))                                      LOSS
      PH(1)=PI2*V                                                        LOSS
      PH(2)=PI2*(V+BSDTS(J))                                             LOSS
      PH(3)=PI2*(V+BSDTR(J))                                             LOSS
      PH(4)=PI2*(V+BSDTR(J)+BSDTS(J))                                    LOSS
      V=0                                                                LOSS
      DO 110 K=1,3                                                       LOSS
      NA=K+1                                                             LOSS
      DO 110 L=NA,4                                                      LOSS
      AUX=BR(K)*BR(L)                                                    LOSS
      AUX1=(PH(K)-CONJG(PH(L)))*AIM                                      LOSS
      IF(REAL(AUX1)*F2.LT.-40.)GO TO 110                                 LOSS
      V=V+AUX*(CEXP(F2*AUX1)-CEXP(F1*AUX1))/AUX1                         LOSS
  110 CONTINUE                                                           LOSS
      AUX=2*REAL(V)                                                      LOSS
      AUX2=-2*PI2*ALPH0*BSLS(J)                                          LOSS
      IF(AUX2*F2.LT.-40.)GO TO 120                                       LOSS
      AUX=AUX+4*(EXP(F2*AUX2)-EXP(F1*AUX2))/AUX2*BR(1)**2                LOSS
  120 DT=DT+AUX/(2*RGI(J))**2/F1                                         LOSS
      ALOSS(JJ,J)=-10.*ALOG10(DT)                                        LOSS
  100 CONTINUE                                                           LOSS
      NMAX=91-N                                                          LOSS
C   COMPUTE LOSS FOR ANGLES BETWEEN TIR AND TNS                          LOSS
      NTIR=TIR*180/PI+1                                                  LOSS
      N=NMAX-NTIR                                                        LOSS
      DO 200 I=1,N                                                       LOSS
      J=NMAX-I                                                           LOSS
      IF(J.LT.NSAP)GO TO 800                                             LOSS
C   COMPUTE REFLECTION COEFFICIENT                                       LOSS
C                                                                        LOSS
COMPUTE FREQ AVERAGE ABSOLUTE REFLECTION                                 LOSS
      FPIAUX=FPIIN                                                       LOSS
      AUX=0                                                              LOSS
      DO 130 NAV=1,NAV1                                                  LOSS
      ALPH2=FPIAUX*RSIN2(J)                                              LOSS
      C=COS(ALPH2)                                                       LOSS
      S=SIN(ALPH2)                                                       LOSS
      VV=(RV21(J)+RV32(J)*C)**2+(RV32(J)*S)**2                           LOSS
      VV=VV/((1+RV21(J)+RV32(J)*C)**2+(RV21(J)*RV32(J)*S)**2)            LOSS
      AUX=AUX+VV                                                         LOSS
      FPIAUX=FPIAUX+FPIINC                                               LOSS
```

```
  130 CONTINUE                                                        LOSS
      VV=AUX/NAV1                                                     LOSS
      ALPH2=FPI2D*RSIN2(J)                                            LOSS
      C=COS(ALPH2)                                                    LOSS
      S=SIN(ALPH2)                                                    LOSS
      V=CMPLX(RV21(J)+RV32(J)*C,RV32(J)*S)                            LOSS
      V=V/CMPLX(1+RV21(J)*RV32(J)*C,RV21(J)*RV32(J)*S)                LOSS
      V=V/CABS(V)*RGI(J)*SQRT(VV)                                     LOSS
      AR(1)=V                                                         LOSS
      AR(2)=-V                                                        LOSS
      AR(3)=-V                                                        LOSS
      AR(4)=V                                                         LOSS
      PH(1)=PI2*RT(J)                                                 LOSS
      PH(2)=PI2*(RT(J)+RDTS(J))                                       LOSS
      PH(3)=PI2*(RT(J)+RDTR(J))                                       LOSS
      PH(4)=PI2*(RT(J)+RDTR(J)+RDTS(J))                               LOSS
C  COMPUTE BIG TRANSMISSION COEFFICIENT                               LOSS
      AR(5)=0                                                         LOSS
      AR(6)=0                                                         LOSS
      AR(7)=0                                                         LOSS
      AR(8)=0                                                         LOSS
      IF(BTRF(J).EQ.0.)GO TO 205                                      LOSS
      IF(BT(J).LT.RT(J))GO TO 205                                     LOSS
      ALPH2=FPI2D*BSIN2(J)/2                                          LOSS
      C=COS(ALPH2)                                                    LOSS
      S=SIN(ALPH2)                                                    LOSS
      V=BTRF(J)/CMPLX((1+BV32(J)*BV21(J))*C,(BV32(J)*BV21(J)-1)*S)**2 LOSS
      V=V*BGI(J)                                                      LOSS
      AR(5)=V                                                         LOSS
      AR(6)=-V                                                        LOSS
      AR(7)=-V                                                        LOSS
      AR(8)=V                                                         LOSS
      V=CMPLX(BT(J),ALPH0*BLS(J))                                     LOSS
      PH(5)=PI2*V                                                     LOSS
      PH(6)=PI2*(V+BDTS(J))                                           LOSS
      PH(7)=PI2*(V+BDTR(J))                                           LOSS
      PH(8)=PI2*(V+BDTS(J)+BDTR(J))                                   LOSS
  205 CONTINUE                                                        LOSS
C  COMPUTE SMALL TRANSMISSION COEFFICIENT                             LOSS
      ALPH2=FPI2D*SSIN2(J)/2                                          LOSS
      C=COS(ALPH2)                                                    LOSS
      S=SIN(ALPH2)                                                    LOSS
      V=STRF(J)/CMPLX((1+SV32(J)*SV21(J))*C,(SV32(J)*SV21(J)-1)*S)**2 LOSS
      V=-V*SGI(J)*AIM                                                 LOSS
      AR(9)=V                                                         LOSS
      AR(10)=-V                                                       LOSS
      AR(11)=-V                                                       LOSS
      AR(12)=V                                                        LOSS
      V=CMPLX(ST(J),ALPH0*SLS(J))                                     LOSS
      PH(9)=PI2*V                                                     LOSS
      PH(10)=PI2*(V+SDTS(J))                                          LOSS
      PH(11)=PI2*(V+SDTR(J))                                          LOSS
      PH(12)=PI2*(V+SDTS(J)+SDTR(J))                                  LOSS
C  COMPUTE BASEMENT RAY TRANSMISSION COEFFICIENT                      LOSS
      ALPH2=FPI2D*BSSIN2(J)/2                                         LOSS
      C=COS(ALPH2)                                                    LOSS
      S=SIN(ALPH2)                                                    LOSS
      V=BSTRF(J)/CMPLX((1+BSV32(J)*BSV21(J))*C,                       LOSS
     1(BSV32(J)*BSV21(J)-1)*S)**2                                     LOSS
      V=V*BSGI(J)*REF                                                 LOSS
```

```
      AR(13)=V                                                          LOSS
      AR(14)=-V                                                         LOSS
      AR(15)=-V                                                         LOSS
      AR(16)=V                                                          LOSS
      V=CMPLX(BST(J),ALPH0*BSLS(J))                                     LOSS
      PH(13)=PI2*V                                                      LOSS
      PH(14)=PI2*(V+BSDTS(J))                                           LOSS
      PH(15)=PI2*(V+BSDTR(J))                                           LOSS
      PH(16)=PI2*(V+BSDTS(J)+BSDTR(J))                                  LOSS
      V=0                                                               LOSS
      DO 210 K=1,15                                                     LOSS
      NA=K+1                                                            LOSS
      DO 210 L=NA,16                                                    LOSS
      AUX99=AR(K)*CONJG(AR(L))                                          LOSS
      IF(CABS(AUX99).EQ.0.)GO TO 210                                    LOSS
      AUX1=(PH(K)-CONJG(PH(L)))*AIM                                     LOSS
      IF(REAL(AUX1)*F2.LT.-40)GO TO 210                                 LOSS
      V=V+AUX99*(CEXP(F2*AUX1)-CEXP(F1*AUX1))/AUX1                      LOSS
 210  CONTINUE                                                          LOSS
      AUX=2*REAL(V)                                                     LOSS
      IF(CABS(AR(13)).EQ.0.)GO TO 209                                   LOSS
      AUX2=-2*PI2*ALPH0*BSLS(J)                                         LOSS
      IF(AUX2*F2.LT.-40)GO TO 209                                       LOSS
      AUX=AUX+4*(EXP(F2*AUX2)-EXP(F1*AUX2))/AUX2*CABS(AR(13))**2        LOSS
 209  AUX2=-2*PI2*ALPH0*BLS(J)                                          LOSS
      AUX2=-2*PI2*ALPH0*BLS(J)                                          LOSS
      IF(AUX2*F2.LT.-40)GO TO 211                                       LOSS
      IF(CABS(AR(5)).EQ.0.)GO TO 211                                    LOSS
      AUX=AUX+4*(EXP(F2*AUX2)-EXP(F1*AUX2))/AUX2*CABS(AR(5))**2         LOSS
 211  AUX2=-2*PI2*ALPH0*SLS(J)                                          LOSS
      IF(AUX2*F2.LT.-40)GO TO 212                                       LOSS
      IF(CABS(AR(9)).EQ.0.)GO TO 212                                    LOSS
      AUX=AUX+4*(EXP(F2*AUX2)-EXP(F1*AUX2))/AUX2*CABS(AR(9))**2         LOSS
 212  AUX=AUX/F1+4*CABS(AR(1))**2                                       LOSS
      IF(AUX.GT.0.)GO TO 213                                            LOSS
      ALOSS(JJ,J)=25.                                                   LOSS
      GO TO 200                                                         LOSS
  213 ALOSS(JJ,J)=-10.*ALOG10(AUX/(2.*RGI(J))**2)                       LOSS
 200  CONTINUE                                                          LOSS
 700  N=J-1                                                             LOSS
      NA=J                                                              LOSS
      DO 701 I=1,N                                                      LOSS
      J=NA-I                                                            LOSS
      IF(J.LT.NSAP)GO TO 999                                            LOSS
      DR=PI2*RDTR(J)                                                    LOSS
      DS=PI2*RDTS(J)                                                    LOSS
      AUX=DR+DS                                                         LOSS
      DT=SIN(F2*AUX)-SIN(F1*AUX)                                        LOSS
      DT=DT/AUX                                                         LOSS
      AUX=DS-DR                                                         LOSS
      DT=DT+SIN(F2*AUX)/AUX-SIN(F1*AUX)/AUX                             LOSS
      DT=DT-2*(SIN(F2*DS)-SIN(F1*DS))/DS                                LOSS
      DT=DT-2*(SIN(F2*DR)-SIN(F1*DR))/DR                                LOSS
      DT=DT/2/F1+1                                                      LOSS
      ALOSS(JJ,J)=-10.*ALOG10(DT)                                       LOSS
 701  CONTINUE                                                          LOSS
      GO TO 999                                                         LOSS
 800  N=J-1                                                             LOSS
      NA=J                                                              LOSS
      DO 801  I=1,N                                                     LOSS
```

```
      J=NA-I                                                            LOSS
      IF(J.LT.NTIR)GO TO 999                                            LOSS
C  COMPUTE BIG TRANSMISSION COEFFICIENT                                 LOSS
      ALOSS(JJ,J)=25.                                                   LOSS
      ALPH2=FPI2D*BSIH2(J)                                              LOSS
      C=COS(ALPH2)                                                      LOSS
      S=SIH(ALPH2)                                                      LOSS
      V=BTRF(J)/CMPLX((I+BV32(J)*BV21(J))*C,(BV32(J)*BV21(J)-1)*S)**2   LOSS
      V=V*BGI(J)                                                        LOSS
      AUX3=CABS(V)**2                                                   LOSS
      IF(AUX3.EQ.0)GO TO 801                                            LOSS
      DR=PI2*BDTR(J)                                                    LOSS
      DS=PI2*BDTS(J)                                                    LOSS
      AUX=DR+DS                                                         LOSS
      DT=SIH(F2*AUX)-SIH(F1*AUX)                                        LOSS
      DT=DT/AUX                                                         LOSS
      AUX=DS-DR                                                         LOSS
      DT=DT+SIN(F2*AUX)/AUX-SIH(F1*AUX)/AUX                             LOSS
      DT=DT-2*(SIN(F2*DS)-SIN(F1*DS))/DS                                LOSS
      DT=DT-2*(SIH(F2*DR)-SIN(F1*DR))/DR                                LOSS
      DT=DT/2/F1+I                                                      LOSS
      AUX2=-2*PI2*ALPH0*BLS(J)*EX                                       LOSS
      IF(AUX2*F2.LT.-40.)GO TO 801                                      LOSS
      ALOSS(JJ,J)=-10*(AUX2+ALOG10(AUX3*DT/RGI(J)**2))                  LOSS
      IF(ALOSS(JJ,J).GT.25.)ALOSS(JJ,J)=25                              LOSS
  801 CONTIHUE                                                          LOSS
  999 RETURH                                                            LOSS
      EHD                                                               LOSS
      SUBROUTIHE GCOMP                                                  GCOMP
C                                                                       GCOMP
C          THIS SUBROUTINE COMPUTES THE GRADIENT (G)                    GCOMP
C          AND ITERATES TO FIND THE ACTUAL CRITICAL                     GCOMP
C          ANGLE (THC). BOTH ARE THEH RETURNED TO THE                   GCOMP
C          MAIN PROGRAM.                                                GCOMP
C                                                                       GCOMP
      COMMOH ZB,ZR,ZS,CI,C2,C3,RHI,RH2,RH3,G,D,ALPH0,CS,BZ,REF,HEAD(20) GCOMP
      COMMON /DATA/LZERO,FZERO,L70,F70,TH70,L71,F71,DBLOSS,FREQ,THETA,  GCOMP
     1    ALOSS0,ALOSSM,FM,TIR,THC,THRC,TH18,BETA                       GCOMP
       REAL LZERO,L70,L71                                               MAY82
      PI=3.14159265                                                     GCOMP
      THRC=30.                                                          GCOMP
      THC0=THC                                                          GCOMP
      B=BETA                                                            GCOMP
      THRC=THRC*(PI/180.)                                               GCOMP
      THINC=1.                                                          GCOMP
      DI=2*ZB-ZR-ZS                                                     GCOMP
      TH3=ACOS((C3/C1)*COS(THRC))                                       GCOMP
      FACT1=(2.*C3*B)/(1.+B)                                            GCOMP
      SIN3=SIN(TH3)                                                     GCOMP
      COS3=COS(TH3)                                                     GCOMP
      SIH3SQ=SIN3*SIN3                                                  GCOMP
      COS3SQ=COS3*COS3                                                  GCOMP
      FACT2=1.+(1./(2.*B))*(1.+(TH3/(SIN3*COS3)))                       GCOMP
      GZERO=(FACT1*(1./COS3SQ)*FACT2+(C3/(1.+B))                        GCOMP
     1    *(1./COS3SQ)*(1.-((TH3*(COS3SQ-SIN3SQ))/(SIN3*COS3))))        GCOMP
     2    *((C3/C1)*(SIN(THRC)/SIN3))/(D1/SIN(THRC)**2)                 GCOMP
      R=(D1/TAN(THRC))+(FACT1*TAN(TH3)/GZERO)*FACT2                     GCOMP
      THC1=ATAN(D1/R)                                                   GCOMP
      THC1=THC1*(180./PI)                                               GCOMP
      MAXIT=100                                                         GCOMP
```

```
  100 DO 600 IT=1,MAXIT                                                   GCOMP
      THRC=THRC*(180./PI)                                                 GCOMP
      THRC=THRC+THINC                                                     GCOMP
      THRC=THRC*(PI/180.)                                                 GCOMP
      TH3=ACOS((C3/C1)*COS(THRC))                                         GCOMP
      FACT1=(2.*C3*B)/(1.+B)                                              GCOMP
      SIN3=SIN(TH3)                                                       GCOMP
      COS3=COS(TH3)                                                       GCOMP
      SIN3SQ=SIN3*SIN3                                                    GCOMP
      COS3SQ=COS3*COS3                                                    GCOMP
      FACT2=1.+(1./(2.*B))*(1.+(TH3/(SIN3*COS3)))                         GCOMP
      GZERO=(FACT1*(1./COS3SQ)*FACT2+(C3/(1.+B))                          GCOMP
     1    *(1./COS3SQ)*(1.-((TH3*(COS3SQ-SIN3SQ))/(SIN3*COS3))))          GCOMP
     2    *((C3/C1)*(SIN(THRC)/SIN3))/(D1/SIN(THRC)**2)                   GCOMP
      R=(D1/TAN(THRC))+(FACT1*TAN(TH3)/GZERO)*FACT2                       GCOMP
      THC2=ATAN(D1/R)                                                     GCOMP
      THC2=THC2*(180./PI)                                                 GCOMP
       IF(ABS(THC0-THC1).LE. 1.E-4) GO TO 700                             MAY82
      IF(((THC0-THC1)*(THC0-THC2)) .GE. 0.) GO TO 500                     GCOMP
      THINC= -THINC/2.                                                    GCOMP
  500 THC1=THC2                                                           GCOMP
  600 CONTINUE                                                            GCOMP
      WRITE(1,650) MAXIT,THC0,THC2
  650 FORMAT(1X,I5,2X,"ITERATIONS AND STILL NO SOLUTION",/,               GCOMP
     1    1X,"THC0=",F10.6,5X,"THC2=",F10.6)                              GCOMP
      GO TO 800                                                           GCOMP
  700 THC=THC2                                                            GCOMP
      G=GZERO                                                             GCOMP
  800 RETURN                                                              GCOMP
      END                                                                 GCOMP
      BLOCK DATA NULL
      COMMON /DATA/ALZERO,FZERO,AL70,F70,TN70,AL71,F71,DBLOSS,FREQ,
     1 THETA,ALOSS0,ALOSSM,FM,TIR,THC,THRC,TH1B,BETA
      COMMON /ALPH/GAM                                                    REFR
      COMMON /T/T                                                         MAY82
      COMMON /R/NSAP,RV21(90),RV32(90),RSIN2(90),RDTS(90),RDTR(90),
     * RT(90),RGI(90)
      COMMON /B/BV21(90),BV32(90),BSIN2(90),BTRF(90),BGI(90),BLS(90),
     * BT(90),BDTS(90),BDTR(90)
      COMMON /S/SV21(90),SV32(90),SSIN2(90),STRF(90),SGI(90),SLS(90),
     * ST(90),SDTS(90),SDTR(90)
      COMMON /BS/BSV21(90),BSV32(90),BSSIN2(90),BSTRF(90),BSGI(90),
     * BSLS(90),BST(90),BSDTS(90),BSDTR(90)
      COMMON/AL/F(6),ALOSS(6,90)                                          LOSS
      DATA F/50.,100.,200.,400.,800.,1600./
      END
      END$
```

APPENDIX B

Flow Chart of PROGRAM BTLS

```
                  /'''''''''''''''''''\
                 :       BEGIN         :
                  \.................../
                           I
                           I
..............................................
:                          L                 :
:                 PROGRAM BTLS9              :
:............................................:
                           I
                           I---[ THIS PROGRAM SIMULATES MEASURED]
                           I   [BOTTOM LOSS DATA                ]
                           I   [ INCLUDING MEASUREMENT ARTIFACTS]
                           I
                           I---[ BLANK COMMON CONTAINS GEOACOUST]
                           I   [C PARAMETERS                    ]
                           I
                           I
..............................................
: COMMON ZB,ZR,ZS,C1,C2,C3,RH1,RH2,RH3,G,D,  :
: ALPHO,CS,BZ,REF                            :
:              COMMON /ALPH/GAM              :
:                COMMON /T/T                 :
:............................................:
                           I
                           I---[ COMMON BLOCK AL CONTAINS THE   ]
                           I   [SIX FREQUENCIES DEFINED         ]
                           I   [ IN THE FOLLOWING DATA STATEMENT]
                           I   [IN F, AND CORRESPONDING         ]
                           I   [ BOTTOM LOSS FOR THE SIX        ]
                           I   [FREQUENCIES AND 90 ANGLES IN    ]
                           I   [ ALOSS. THE VALUSE IN ALOSS ARE ]
                           I   [CALCULATED IN SUBROUTINE LOSS.  ]
                           I
                           I---[ ALL VALUES OF ALOSS ARE        ]
                           I   [RETAINED, WHICH IS              ]
                           I   [ NOT NECESSARY IN THIS VERSION  ]
                           I   [OF THE PROGRAM.                 ]
                           I
                           I
..............................................
:          COMMON/AL/F(6),ALOSS(6,90)        :
:             DIMENSION BRAY(546)            :
: EQUIVALENCE (BRAY(1).F(1)),(BRAY(7),       :
: ALOSS(1,1))                                :
:............................................:
                           I
                           I---[ LOOP 500 READS A SET OF INPUT  ]
                           I   [DATA AND GENERATES A SET        ]
                           I   [ OF BOTTOM LOSS DATA ON EACH    ]
                           I   [PASS UP TO A MAXIMUM            ]
                           I
                           I---[ SUBROUTINE LOS2 CALCULATES ALL ]
                           I   [FREQUENCFY INDEPENDENT          ]
                           I   [ INTERMEDIATE VARIABLES         ]
                           I
                           I
```

```
.............................................
: :                 CALL LOS2              : :
:.:........................................:.:
                        I
                        I
 /''''''''''''''''''''''''''''''''''''''''''\  TRUE
<              IF(T.EQ.999) GO TO 999        >------------------0
 \........................................../                   Z
                        I  FALSE                                Z
                        I                                       Z
                        I---[ LOOP 41 CALCULATES BOTTOM LOSS ]  Z
                        I   [AT A PARTICULAR                 ]  Z
                        I   [ FREQUENCY IN SUBROUTINE LOSS   ]  Z
                        I   [AND PRINTS IT                   ]  Z
                        I   [ OUT ON EACH PASS.              ]  Z
                        I                                       Z
                        I                                       Z
.............................................                  Z
A---->:                 DO 41 J=1,6                :            Z
A     :............................................:            Z
A                       I                                       Z
A                       I                                       Z
A     .............................................             Z
A     : :               CALL LOSS(J)               : :          Z
A     :.:..........................................:.:          Z
A                       I                                       Z
A                       I                                       Z
A       /''''''''''''''''''''''''''''''''''''''''''/            Z
A      /        WRITE(6,2)(ALOSS(J,I),I=1,90)     /             Z
A     /........................................../              Z
A                       I                                       Z
A                       I---[ 2 FORMAT(1X,8F8.2)             ]  Z
A                       I                                       Z
A       [   41]         I                                       Z
A     .............................................             Z
------:                 CONTINUE                   :            Z
      :............................................:            Z
                        I                                       Z
                        I                                       Z
      .............................................             Z
      : :       CALL EXEC(14,2,BRAY,1092)          : :          Z
      :.:..........................................:.:          Z
                        I                                       Z
                        I                                       Z
        /''''''''''''''''''''''''''''''''''''''''''/            Z
       /                WRITE(1,69)               /             Z
      /........................................../              Z
                        I                                       Z
                        I---[69 FORMAT(' NORMAL TERMINATION -]  Z
                        I   [ BOTTOM LOSS MODEL')            ]  Z
                        I                                       Z
                        0<--------------------------------------0
        [  999]         I
                /''''''''''''''''''''\
               :         STOP         :
                \..................../
```

```
.............................................
\              SUBROUTINE LOS2             /
 \........................................../
                      I
                      I
............................................
: COMMON ZB,ZR,ZS,C1,C2,C3,RH1,RH2,RH3,G,D, :
: ALPHO,CS,BZ,REF                           :
:  COMMON /DATA/ LZERO,FZERO,L70,F70,TH70,  :
: L71,F71,DBLOSS,FREQ,THETA, ALOSSD,ALOSSM, :
: FM,TIP,THC,THPC,TH1B,BETA                 :
:...........................................:
                      I
                      I
............................................
:             COMMON /ALPH/GAM              :
:               COMMON/T/T                  :
:            REAL LZERO,L70,L71             :
:          DATA PI/3.141592655/             :
:                 RH1=1                     :
:...........................................:
                      I
                      I---[ INPUTS                          ]
                      I   [ 1) T=TWO WAY TRAVEL TIME        ]
                      I   [THICKNESS OF SEDIMENT            ]
                      I
                      I---[ 2) NNFILE = ARBITRARY FILE      ]
                      I   [NUMBER                           ]
                      I
                      I---[ 3) IOPT= INPUT OPTION, 0 FOR    ]
                      I   [GEO-PARAMETERS,                  ]
                      I
                      I
  /'''''''''''''''''''''''''''''''''''''''''/
 /              WRITE(1,701)               /
/........................................./
                      I
                      I---[701 FORMAT(' INPUT OPTIONS ARE: ]
                      I   [0 = INPUT GEO-PARAMETERS',/, ' ]
                      I   [1 = INPUT BOTTOM LOSS',/, ' 2 ]
                      I   [ END PROGRAM',//, ' ENTER      ]
                      I   [STATION NUMBER AND INPUT OPTION:]
                      I   [)                                ]
                      I
                      I
  /'''''''''''''''''''''''''''''''''''''''''/
 /           READ(1,*) NNFILE,IOPT         /
/........................................./
                      I
                      I
```

```
 /'''''''''''''''''''''''''''''''''''''''''\  TRUE
<          IF(IOPT.EQ.2) GO TO 999          >-----------------0
 \........................................./                  Z
                     I  FALSE                                 Z
                     I                                        Z
                     I                                        Z
  /''''''''''''''''''''''''''''''''''''''''/                  Z
 /              WRITE(1,702)              /                   Z
/........................................./                   Z
                     I                                        Z
                     I---[702 FORMAT(' ENTER THE TWO-WAY  ]   Z
                     I   [TRAVEL TIME THICKNESS IN 10THS  ]   Z
                     I   [OF SECON *DS:')                 ]   Z
                     I                                        Z
                     I                                        Z
  /''''''''''''''''''''''''''''''''''''''''/                  Z
 /              READ(1,*) T               /                   Z
/........................................./                   Z
                     I                                        Z
                     I---[ BRANCH TO EXIT                 ]   Z
                     I                                        Z
                     I                                        Z
...........................................                   Z
:               T=T/20.                   :                   Z
:.........................................:                   Z
                     I                                        Z
                     I---[ INPUT EXPERIMENTAL GEOMETERY   ]   Z
                     I   [PARAMETERS                      ]   Z
                     I                                        Z
                     I                                        Z
  /''''''''''''''''''''''''''''''''''''''''/                  Z
 /              WRITE(1,705)              /                   Z
/........................................./                   Z
                     I                                        Z
                     I---[705 FORMAT(' ENTER THE WATER    ]   Z
                     I   [DEPTH:')                        ]   Z
                     I                                        Z
                     I                                        Z
  /''''''''''''''''''''''''''''''''''''''''/                  Z
 /              READ(1,*) ZB              /                   Z
/........................................./                   Z
                     I                                        Z
                     I                                        Z
  /''''''''''''''''''''''''''''''''''''''''/                  Z
 /              WRITE(1,706)              /                   Z
/........................................./                   Z
                     I                                        Z
                     I---[706 FORMAT(' ENTER SOURCE DEPTH ]   Z
                     I   [AND RECEIVER DEPTH:')           ]   Z
                     I                                        Z
                     I                                        Z
  /''''''''''''''''''''''''''''''''''''''''/                  Z
 /            READ(1,*) ZS,ZR             /                   Z
/........................................./                   Z
                     I                                        Z
                     I
```

```
   /'''''''''''''''''''''''''''''''''''''''''''''''/
  /                WRITE(1,707)                  /
 /................................................/
                        I
                        I---[707 FORMAT(' ENTER SOUND SPEED  ]
                        I   [AT SOURCE OR RECEIVER -         ]
                        I   [WHICHEVER IS SH *ALLOWER:')     ]
                        I
                        I
   /'''''''''''''''''''''''''''''''''''''''''''''''/
  /                READ(1,*) CS                  /
 /................................................/
                        I
                        I
   /'''''''''''''''''''''''''''''''''''''''''''''''/
  /                WRITE(1,708)                  /
 /................................................/
                        I
                        I---[708 FORMAT(' ENTER SOUND SPEED  ]
                        I   [AT THE BOTTOM OF THE WATER:')   ]
                        I
                        I
   /'''''''''''''''''''''''''''''''''''''''''''''''/
  /                READ(1,*) C1                  /
 /................................................/
                        I
                        I---[ BRANCH TO INPUT OPTION         ]
                        I
                        I
  /'''''''''''''''''''''''''''''''''''''''''''''''\  TRUE
 <          IF(IOPT.EQ.0) GO TO 500                >----------------O
  \.............................................../                 X
                        I  FALSE                                    X
                        I                                           X
                        I---[ INPUT INVERSION PARAMETERS      ]     X
                        I                                           X
                        I                                           X
   /'''''''''''''''''''''''''''''''''''''''''''''''/                X
  /                WRITE(1,709)                  /                  X
 /................................................/                 X
                        I                                           X
                        I---[709 FORMAT(' ATTENUATION        ]      X
                        I   [CALCULATION',//, *' FOR A POINT ]      X
                        I   [BELOW THE CAUSTIC WHERE BL CURVE]      X
                        I   [IS NEARLY LINEAR,'/ *,' ENTER A ]      X
                        I   [LOSS, FREQUENCY AND ANGLE: (ANG=]      X
                        I   [APPROX 20, FREQ = APPRO *X 200)']      X
                        I                                           X
                        I                                           X
   /'''''''''''''''''''''''''''''''''''''''''''''''/                X
  /        READ(1,*) DBLOSS,FREQ,THETA           /                  X
 /................................................/                 X
                        I                                           X
                        I                                           X
```

```
      /'''''''''''''''''''''''''''''''''''''''''''/                    X   Z
     /              WRITE(1,710)              /                      X   Z
    /.........................................../                       X   Z
                           I                                          X   Z
                           I---[710 FORMAT(' ENTER LOW FREQ LOSS]     X   Z
                           I    [LEVEL AT HIGH ANGLES,',/, * '   ]    X   Z
                           I    [THE MINIMUM LOSS LEVEL AT HIGH  ]    X   Z
                           I    [ANGLES',/, * ' AND THE FREQUENCY]    X   Z
                           I    [OF THE MINIMUM LOSS:')          ]    X   Z
                           I                                          X   Z
                           I                                          X   Z
      /'''''''''''''''''''''''''''''''''''''''''''/                    X   Z
     /       READ(1,*) ALOSSO,ALOSSM,FM        /                      X   Z
    /.........................................../                       X   Z
                           I                                          X   Z
                           I                                          X   Z
      /'''''''''''''''''''''''''''''''''''''''''''/                    X   Z
     /              WRITE(1,711)              /                      X   Z
    /.........................................../                       X   Z
                           I                                          X   Z
                           I---[711 FORMAT(' ENTER ANGLE OF      ]    X   Z
                           I    [TOTAL INTERNAL REFLECTION,',/, *]    X   Z
                           I    [' ANGLE OF CAUSTIC,',/, * '     ]    X   Z
                           I    [RATIO OF SPEED IN SEDIMENT TO   ]    X   Z
                           I    [SPEED AT BOTTOM OF WATER:')     ]    X   Z
                           I                                          X   Z
                           I                                          X   Z
      /'''''''''''''''''''''''''''''''''''''''''''/                    X   Z
     /         READ(1,*)TIR,THC,RATIO         /                      X   Z
    /.........................................../                       X   Z
                           I                                          X   Z
                           I                                          X   Z
     /'''''''''''''''''''''''''''''''''''''''''''\                     X   Z
    <          IF(THC.EQ.0.0) THEN              >----     ------0--+   X   Z
     \.........................................../                 |   X   Z
                      @@@@ I                                       |   X   Z
                           I                                       |   X   Z
                           I                                       |   X   Z
      /'''''''''''''''''''''''''''''''''''''''''''/                 |   X   Z
     /              WRITE(1,712)              /                   |   X   Z
    /.........................................../                    |   X   Z
                           I                                       |   X   Z
                           I---[712 FORMAT(' ENTER GRADIENT AT  ]  |   X   Z
                           I    [TOP OF SEDIMENT:')             ]  |   X   Z
                           I                                       |   X   Z
                           I                                       |   X   Z
      /'''''''''''''''''''''''''''''''''''''''''''/                 |   X   Z
     /              READ(1,*) G               /                   |   X   Z
    /.........................................../                    |   X   Z
                           I                                       |   X   Z
                           I                                       |   X   Z
    .............................................                  |   X   Z
    :                 ENDIF                     :  <---------------+   X   Z
    :...........................................:                      X   Z
                           I                                          X   Z
                           I                                          X   Z
```

```
  /''''''''''''''''''''''''''''''''''''''''''/
 /                WRITE(1,713)              /
/........................................../
                    I
                    I---[713 FORMAT(' ENTER CANONICAL     ]
                    I   [CURVE TYPE AND ATTENUATION       ]
                    I   [PROFILE GRADIE *NT:')            ]
                    I
                    I
  /''''''''''''''''''''''''''''''''''''''''''/
 /              READ(1,*) BETA,GAM          /
/........................................../
                    I
                    I
  /''''''''''''''''''''''''''''''''''''''''''/
 /                WRITE(1,714)              /
/........................................../
                    I
                    I---[714 FORMAT(' ENTER BASEMENT      ]
                    I   [REFLECTION COEFFICIENT IN        ]
                    I   [PRESSURE UNITS:' *)              ]
                    I
                    I
  /''''''''''''''''''''''''''''''''''''''''''/
 /                READ(1,*)REF              /
/........................................../
                    I
                    I---[ OPTIONS AND ERROR CHECKING      ]
                    I
                    I
 /''''''''''''''''''''''''''''''''''''''''''\  FALSE
<     IF(TIR.GT.0. .OR. RATIO .LE. 0.)       >--------------I
 \........................................../               I
                    I  TRUE                                 I
                    I                                       I
............................................                I
:   RATIO=1./COS(TIR*PI/180.)              :                I
:..........................................:                I
                    I                                       I
                    O<--------------------------------------
                    I
............................................
:              C2=C1*RATIO                 :
:                C3=C2                     :
:..........................................:
                    I
                    I---[ IF GRADIENT G IS NOT SPECIFIED ]
                    I   [CALCULATE IT FROM THE           ]
                    I   [ CAUSTIC ANGLE, THC             ]
                    I
                    I
```

```
 /''''''''''''''''''''''''''''''''''''''''''''\  TRUE                 X   Z
<          IF(G.NE.0.) GO TO 300                >-------------------0  X   Z
 \............................................/                     U  X   Z
                       I  FALSE                                    U  X   Z
                       I                                           U  X   Z
                       I                                           U  X   Z
 /''''''''''''''''''''''''''''''''''''''''''''\  FALSE              U  X   Z
<            IF(THC.LE.0.)                      >---------------I  U  X   Z
 \............................................/                I  U  X   Z
                       I  TRUE                                 I  U  X   Z
                       I                                       I  U  X   Z
..............................................                 I  U  X   Z
:                THC=30                      :                 I  U  X   Z
:............................................:                 I  U  X   Z
                       I                                       I  U  X   Z
                       0<--------------------------------------   U  X   Z
                       I                                          U  X   Z
..............................................                    U  X   Z
: :            CALL GCOMP                  : :                    U  X   Z
:.:........................................:.:                    U  X   Z
                       I                                          U  X   Z
                       0<-----------------------------------------0  X   Z
  [  300]              I                                             X   Z
..............................................                       X   Z
:               CONTINUE                     :                       X   Z
:............................................:                       X   Z
                       I                                             X   Z
                       I                                             X   Z
  /''''''''''''''''''''''''''''''''''''''''''/                       X   Z
 /           WRITE(6,140)                   /                        X   Z
/..........................................  /                       X   Z
                       I                                             X   Z
                       I---[ 140 FORMAT(//,¤ INPUT DATA¤,/) ]        X   Z
                       I                                             X   Z
                       I                                             X   Z
  /''''''''''''''''''''''''''''''''''''''''''/                       X   Z
 /        WRITE(6,210)NNFILE,T              /                        X   Z
/..........................................  /                       X   Z
                       I                                             X   Z
                       I---[ 210 FORMAT(1X,I4,/,¤ T =¤,F8.2)]        X   Z
                       I                                             X   Z
                       I                                             X   Z
  /''''''''''''''''''''''''''''''''''''''''''/                       X   Z
 /     WRITE(6,220)ZB,ZS,ZR,CS,C1           /                        X   Z
/..........................................  /                       X   Z
                       I                                             X   Z
                       I---[ 220 FORMAT(¤ ZB=¤,F8.2,¤ ZS=¤, ]        X   Z
                       I   [F8.2,¤ ZR=¤,F8.2,¤ CS=¤,F8.2,¤  ]        X   Z
                       I   [C1=¤,F8.2 1)                    ]        X   Z
                       I                                             X   Z
                       I                                             X   Z
  /''''''''''''''''''''''''''''''''''''''''''/                       X   Z
 /   WRITE(6,141)DBLOSS,FREG,THETA          /                        X   Z
/..........................................  /                       X   Z
                                                                     X   Z
```

```
                              I
                              I---[ 141 FORMAT(¤ DBLOSS=¤,F8.2,¤    ]          X    Z
                              I    [FREQ =¤,F8.2,¤ THETA =¤,F8.2)    ]          X    Z
                              I                                                 X    Z
                              I                                                 X    Z
     /'''''''''''''''''''''''''''''''''''''''''''''''/                          X    Z
    /          WRITE(6,142)ALOSSO,ALOSSM,FM         /                           X    Z
   /.............................................../                            X    Z
                              I                                                 X    Z
                              I---[ 142 FORMAT(¤ ALOSSO=¤,F8.2,¤    ]          X    Z
                              I    [ALOSSM=¤,F8.2,¤ FM =¤,F8.2)      ]          X    Z
                              I                                                 X    Z
                              I                                                 X    Z
     /'''''''''''''''''''''''''''''''''''''''''''''''/                          X    Z
    /          WRITE(6,143)TIR,THC,RATIO            /                           X    Z
   /.............................................../                            X    Z
                              I                                                 X    Z
                              I---[ 143 FORMAT(¤ TIR =¤,F8.2,¤ THC ]          X    Z
                              I    [¤,F8.2,¤ RATIO =¤,F8.4)          ]          X    Z
                              I                                                 X    Z
                              I---[ CHANGE DEGREES TO RADIANS        ]          X    Z
                              I                                                 X    Z
                              I                                                 X    Z
   ...............................................                              X    Z
   :          THETA = THETA*PI/180.               :                             X    Z
   :             THC=THC*PI/180.                  :                             X    Z
   :             TIR=TIR*PI/180.                  :                             X    Z
   :..............................................:                             X    Z
                              I                                                 X    Z
                              I---[ CALL ROUTINE WHICH CALCULATES    ]          X    Z
                              I    [THE REMAINING                    ]          X    Z
                              I    [ GEOPHYSICAL PARAMETERS FROM THE]          X    Z
                              I    [INVERSION INPUTS                 ]          X    Z
                              I                                                 X    Z
                              I                                                 X    Z
   ...............................................                              X    Z
   : :                 CALL GEOPY               : :                             X    Z
   :.:..........................................:.:                             X    Z
                              I                                                 X    Z
                              I                                                 X    Z
               /''''''''''''''''''''\                                           X    Z
              :      GO TO 499       :-------------------------------O          X    Z
               \..................../                                 U         X    Z
                                                                      U         X    Z
                              I                                       U         X    Z
                              I---[ OPTIONAL BRANCH TO INPUT GEO-    ]  U         X    Z
                              I    [PARAMETERS DIRECTLY              ]  U         X    Z
                              I                                       U         X    Z
                              O<------------------------------------------------O    Z
     [  500]                  I                                       U              Z
   ...............................................                    U              Z
   :                   CONTINUE                   :                   U              Z
   :..............................................:                   U              Z
                              I                                       U              Z
                              I
```

```
                                                                  U     Z
  /''''''''''''''''''''''''''''''''''''''''''/                    U     Z
 /               WRITE(1,715)               /                     U     Z
/..........................................  /                    U     Z
                    I                                             U     Z
                    I---[715 FORMAT(' ENTER RATIO OF       ]      U     Z
                    I   [SPEED IN SEDIMENT TO SPEED AT     ]      U     Z
                    I   [BOTTOM OF WA *TER:')              ]      U     Z
                    I                                             U     Z
                    I                                             U     Z
  /''''''''''''''''''''''''''''''''''''''''''/                    U     Z
 /           READ(1,*) RATIO                /                     U     Z
/.........................................../                     U     Z
                    I                                             U     Z
                    I                                             U     Z
  /''''''''''''''''''''''''''''''''''''''''''/                    U     Z
 /               WRITE(1,716)               /                     U     Z
/.........................................../                     U     Z
                    I                                             U     Z
                    I---[716 FORMAT(' ENTER GRADIENT AT    ]      U     Z
                    I   [TOP OF SEDIMENT AND CANONICAL     ]      U     Z
                    I   [CURVE TYP *E:')                   ]      U     Z
                    I                                             U     Z
                    I                                             U     Z
  /''''''''''''''''''''''''''''''''''''''''''/                    U     Z
 /           READ(1,*) G,BETA               /                     U     Z
/.........................................../                     U     Z
                    I                                             U     Z
                    I                                             U     Z
  /''''''''''''''''''''''''''''''''''''''''''/                    U     Z
 /               WRITE(1,717)               /                     U     Z
/.........................................../                     U     Z
                    I                                             U     Z
                    I---[717 FORMAT(' ENTER THIN LAYER     ]      U     Z
                    I   [DENSITY, SEDIMENT DENSITY AND     ]      U     Z
                    I   [THIN LAYER * THICKNESS IN METERS]        U     Z
                    I   [')                                ]      U     Z
                    I                                             U     Z
                    I                                             U     Z
  /''''''''''''''''''''''''''''''''''''''''''/                    U     Z
 /         READ(1,*) RH2,RH3,D              /                     U     Z
/.........................................../                     U     Z
                    I                                             U     Z
                    I                                             U     Z
  /''''''''''''''''''''''''''''''''''''''''''/                    U     Z
 /               WRITE(1,718)               /                     U     Z
/.........................................../                     U     Z
                    I                                             U     Z
                    I---[718 FORMAT(' ENTER SURFACE        ]      U     Z
                    I   [ATTENUATION IN DB/M/KHZ:')        ]      U     Z
                    I                                             U     Z
                    I                                             U     Z
  /''''''''''''''''''''''''''''''''''''''''''/                    U     Z
 /           READ(1,*) ALPHO                /                     U     Z
/.........................................../                     U     Z
```

```
                               I                                               U         Z
                               I                                               U         Z
   /'''''''''''''''''''''''''''''''''''''''''''/                               U         Z
  /                WRITE(1,719)               /                                U         Z
 /.........................................../                                 U         Z
                               I                                               U         Z
                               I---[719 FORMAT(' ENTER ATTENUATION  ]          U         Z
                               I    [PROFILE GRADIENT AND BASEMENT   ]         U         Z
                               I    [REFLECTIO *N COEFFICIENT IN     ]         U         Z
                               I    [PRESSURE:')                     ]         U         Z
                               I                                               U         Z
                               I                                               U         Z
   /'''''''''''''''''''''''''''''''''''''''''''/                               U         Z
  /             READ(1,*) GAM,REF             /                                U         Z
 /.........................................../                                 U         Z
                               I                                               U         Z
                               I                                               U         Z
 .............................................                                 U         Z
 :                  C2=C1*RATIO              :                                 U         Z
 :                     C3=C2                 :                                 U         Z
 :...........................................:                                 U         Z
                               I                                               U         Z
                               I---[ CALL A SUBRUUTINE WHICH        ]          U         Z
                               I    [CALCULATES AND PRINTS VARIOUS   ]         U         Z
                               I    [ CRITICAL ANGLES CHARACTERISTIC ]         U         Z
                               I    [OF THE MEASUREMENT              ]         U         Z
                               I                                               U         Z
                               O<----------------------------------------------O         Z
   [   490]                    I                                                         Z
 .............................................                                           Z
 : :                CALL CANGLE            : :                                           Z
 :.:.......................................:.:                                           Z
                               I                                                         Z
                               I---[ PRINT GEO-PARAMETERS           ]                    Z
                               I                                                         Z
                               I                                                         Z
   /'''''''''''''''''''''''''''''''''''''''''''/                                         Z
  /                WRITE(6,145)               /                                          Z
 /.........................................../                                           Z
                               I                                                         Z
                               I---[ 145 FORMAT(//,¤ GEO-PARAMETERS ]                    Z
                               I    [,//)                            ]                   Z
                               I                                                         Z
                               I                                                         Z
   /'''''''''''''''''''''''''''''''''''''''''''/                                         Z
  /    WRITE(6,146)RATIO,RH2,RH3,D,G,BETA,    /                                          Z
 /    ALPHO,GAM,BZ,REF                       /                                           Z
 ............................................/                                           Z
                               I                                                         Z
                               I---[ 146 FORMAT(¤ RAT=¤,F8.4,/,¤ RH2]                    Z
                               I    [¤,F8.2,¤ RH3=¤,F8.2,/, 1¤ D =¤, ]                   Z
                               I    [F8.2,/,¤ G =¤,F8.2,¤ BET=¤,F8.2,]                   Z
                               I    [, 2¤ ALO=¤,F9.3,¤GAM=¤,F11.5,/,¤]                   Z
                               I    [BZ =¤,F8.2,¤ REF=¤,F8.2)         ]                  Z
                               I                                                         Z
                               I---[ CALL ROUTINES FOR FREQUENCY-   ]                    Z
                               I    [INDEPENDENT INTERMEDIATE        ]                   Z
                               I                                                         Z
                               I                                                         Z
```

```
.............................................                Z
: :                 CALL REFL                  : :           Z
:.:............................................:.:           Z
                        I                                    Z
                        I                                    Z
.............................................                Z
: :                 CALL REFR                  : :           Z
:.:............................................:.:           Z
                        I                                    Z
                        I                                    Z
.............................................                Z
: :                 CALL BASE                  : :           Z
:.:............................................:.:           Z
                        I                                    Z
                        0<-----------------------------------0
  [  999]               I
               /''''''''''''''''''''\
              :        RETURN        :
               \..................../
```

```
.............................................
\               SUBROUTINE GEOPY            /
 \.........................................../
                      I
                      I
............................................
: COMMON ZB,ZR,ZS,C1,C2,C3,RH1,RH2,RH3,G,D,  :
: ALPHO,CS,BZ,REF                            :
: COMMON/DATA/LZERO,FZERO,L70,F70,TH70,L71,  :
: F71,DBLOSS,FREQ,THETA,ALOSSO,ALOSSM,FM,    :
: TIR,THC,THRC,TH1B,BETA                     :
:            COMMON /ALPH/GAM                :
:           REAL LZERO,L70,L71               :
:          DATA PI/3.141592655/              :
:............................................:
                      I
                      I---[OMPUTE DENSITIES RH2,RH3          ]
                      I
                      I
............................................
:                Z1=C1*RH1                   :
:                D=C1/FM/4                   :
:       R=EXP(-ALOG(10.)*ALOSSO/20)          :
:            Z3=(1+R)/(1-R)*Z1               :
:       R=EXP(-ALOG(10.)*ALOSSM/20)          :
:           Z2=(1+R)/(1-R)*Z1*Z3             :
:               Z2=SQRT(Z2)                  :
:               SPRAT=C3/C1                  :
:                RH2=Z2/C2                   :
:                RH3=Z3/C3                   :
:............................................:
                      I
                      I---[OMPUTE DISSIPATION CONSTANT       ]
                      I    [ALPHO                            ]
                      I
                      I
```

```
.............................................
:       THETA=ACOS(C2/C1*COS(THETA))        :
:              BS=SIN(THETA)                :
:              BC=COS(THETA)                :
:           V32=(Z3-Z2)/(Z3+Z2)             :
:           V21=(Z2-Z1)/(Z2+Z1)             :
:      AUX=4*D*PI*FREQ/C1*SIN(THETA)        :
: V=CABS((V21+V32*CMPLX(COS(AUX),SIN(AUX))) :
: /(1+V21*V32*CMPLX(COS(AUX),SIN(AUX))))    :
: T=CABS(1/(1+V21*V32*CMPLX(COS(AUX),SIN(   :
: AUX))))**2*16*Z1*Z3*(Z2/(Z1+Z2)/(Z2+Z3))* :
: *2                                        :
:       AUX=10.**(-DBLOSS/10.)-V**2         :
:               AUX=AUX/T                   :
:           ALS=-ALOG10(AUX)*10             :
:              FK=FREQ/1000                 :
:            SIG=G*(1+BETA)*C2              :
:           AMU=(C2*(1+BETA))**2            :
:              ANU=BETA*C2                  :
: ALPHO=ALS/FK-2*C2/G/(1+BETA)/BC*(GAM*C2** :
: 2/2/SIG/BC**3*(BS-BS**3/3)+(BETA*GAM*C2** :
: 2+2*GAM*ANU*C2)/4/SIG/BC**2*(THETA+BS*BC) :
: +(GAM*(ANU**2-AMU)+2*BETA*GAM*ANU*C2)/2/  :
: SIG/BC*BS+BETA*GAM*(ANU**2-AMU)/2/SIG*    :
: THETA)                                    :
: ALPHO=ALPHO/(BS/BC+BETA*THETA)*G*(1+BETA) :
: *BC/2/C2                                  :
:...........................................:
                     I
                     I
           /''''''''''''''''''''\
          :       RETURN         :
           \..................../
```

```
.................................................
 \             SUBROUTINE CANGLE               /
  \...........................................//
                       I
                       I
 ...............................................
 : COMMON ZB,ZR,ZS,C1,C2,C3,RH1,RH2,RH3,G,D,   :
 : ALPHO,CS,BZ,REF                             :
 :              COMMON /ALPH/GAM               :
 :                COMMON /T/T                  :
 :.............................................:
                       I
                       I
 ...............................................
 : COMMON /DATA/ LZERO,FZERO,L70,F70,TH70,     :
 : L71,F71,DBLOSS,FREQ,THETA,ALOSSO,ALOSSM,    :
 : FM,TIR,THC,THRC,TH1B,BETA                   :
 :.............................................:
                       I
                       I
 ...............................................
 :             REAL LZERO,L70,L71              :
 :.............................................:
                       I
                       I
 ...............................................
 :           DATA PI/3.14159264/               :
 :.............................................:
                       I
                       I
 ...............................................
 :              DI=2.*ZB-ZR-ZS                 :
 :.............................................:
                       I
                       I---[ CALCULATE SEDIMENT THICKNESS   ]
                       I
                       I
 ...............................................
 :                  B=BETA                     :
 :                 CZP=2000                    :
 :     A=C2*(G*(1.+B)*T+1.+B*ALOG(C2))         :
 :.............................................:
                       I
                       0<-------------------------------------0
  [    60]             I                                      Z
 ...............................................              Z
 : CZ=CZP+(A-CZP-B*C2*ALOG(CZP))/(1.+B*C2/     :              Z
 : CZP)                                        :              Z
 :.............................................:              Z
                       I                                      Z
                       I                                      Z
  /''''''''''''''''''''''''''''''''''''''''''''\  TRUE        Z
 <     IF(ABS(CZ-CZP).LT..01) GO TO 70         >--------------0  Z
  \............................................/              X  Z
                       I  FALSE                               X  Z
                       I                                      X  Z
                       I                                      X  Z
```

```
 .............................................                                  X    Z
 :                  CZP=CZ                   :                                  X    Z
 :...........................................:                                  X    Z
                       I                                                        X    Z
                       I                                                        X    Z
           /''''''''''''''''''''''\                                             X    Z
          :      GO TO 60          :--------------------------------------------------O
           \......................./                                            X
                                                                                X
                                                                                X
                       O<-------------------------------------------------------O
   [    70]            I
 .............................................
 : BZ=((CZ+B*C2)**2-C2**2*(1+B)**2)/(2*G*(1+ :
 : B)*C2)                                    :
 :...........................................:
                       I
                       I---[ COMPUTE REFINED CRITICAL ANGLE ]
                       I
                       I
 .............................................
 :                THRC=PI/4                  :
 :...........................................:
                       I
                       I
 .............................................
 : :              CALL TOTCI               : :
 :.:.......................................:.:
                       I
                       I---[ COMPUTE CRITICAL RAY DEPTH CRD ]
                       I
                       I
 .............................................
 :             CAUX=C1/COS(THRC)             :
 :  CRD=((CAUX+BETA*C3)**2-(C3*(1+BETA))**2) :
 : /2/G/(1+BETA)/C3                          :
 :...........................................:
                       I
                       I---[ CALCULATE VELOCITY, VELOCITY   ]
                       I   [GRADIENT, AND ATTENUATION       ]
                       I   [ CONSTANT AT DEPTH OF 500 METERS]
                       I
                       I
 .............................................
 :  BSPD=SQRT(2*G*(1+BETA)*C3*500+C3**2*(1+  :
 : BETA)**2)-BETA*C3                         :
 :      BGRAD=G*(1+BETA)/(BSPD/C3+BETA)      :
 :            ALBOT=ALPHO+GAM*500            :
 :...........................................:
                       I
                       I---[ COMPUTE TWO WAY TRAVEL TIME IN ]
                       I   [SECONDS                         ]
                       I
                       I
```

```
••••••••••••••••••••••••••••••••••••••••••••••••
:                 TWTT=2*T                      :
:                 SPRAT=C2/C1                   :
:•••••••••••••••••••••••••••••••••••••••••••••••:
                        I
                        I---[ COMPUTE BASEMENT CRITICAL          ]
                        I    [ANGLES TH1B,TH3B                   ]
                        I
                        I
••••••••••••••••••••••••••••••••••••••••••••••••
: CB=SQRT(2*G*(1+BETA)*C3*BZ+C3**2*(1+BETA)    :
: **2)-BETA*C3                                  :
:              TH1B=ACOS(C1/CB)                 :
:              TH3B=ACOS(C3/CB)                 :
:  R=DI/TAN(TH1B)+2*C3*TAN(TH3B)/G*(BETA/(      :
: 1+BETA))*(1+(1+TH3B/SIN(TH3B)/COS(TH3B))/    :
: 2/BETA)                                       :
:•••••••••••••••••••••••••••••••••••••••••••••••:
                        I
                        I---[ COMPUTE SMALLEST APPARENT ANGLE]
                        I    [FOR BASEMENT REFLECTION            ]
                        I
                        I
••••••••••••••••••••••••••••••••••••••••••••••••
:               THB=ATAN(DI/R)                  :
:•••••••••••••••••••••••••••••••••••••••••••••••:
                        I
                        I---[ CHANGE RADIANS TO DEGREES          ]
                        I
                        I
••••••••••••••••••••••••••••••••••••••••••••••••
:               THB=THB*180/PI                  :
:                A=TIR*180/PI                   :
:                A1=THC*180/PI                  :
:               A2=THRC*180/PI                  :
:               A3=TH1B*180/PI                  :
:•••••••••••••••••••••••••••••••••••••••••••••••:
                        I
                        I---[ PRINT OUT CRITICAL ANGLES          ]
                        I
                        I
  /''''''''''''''''''''''''''''''''''''''''''''/
 /                 WRITE(6,1)                 /
/•••••••••••••••••••••••••••••••••••••••••••••/
                        I
                        I---[ 1 FORMAT(1X,//,¤ CRITICAL          ]
                        I    [ANGLES¤,/)                         ]
                        I
                        I
  /''''''''''''''''''''''''''''''''''''''''''''/
 /    WRITE(6,11)A,SPRAT,A1,A2,THB,A3,TWTT,/  /
/   BZ,CRD,BGRAD,BSPD,ALBOT,GAM              /
/•••••••••••••••••••••••••••••••••••••••••••••/
```

```
                        I
                        I---[ 11 FORMAT(¤ TIR =¤,F8.2,¤ RAT =]
                        I    [,F8.4,¤ THC =¤,F8.2,¤ THRC =¤,F8]
                        I    [2, 1/,¤ THB =¤,F8.2,¤ THRB =¤,F8]
                        I    [2, 2/,¤ TWTT =¤,F8.2,¤ BZ =¤,F8.]
                        I    [2,¤ CRD =¤,F8.2,/, 3¤ G500 =¤,F8]
                        I    [2,¤ C500 =¤,F8.2,¤ A500 =¤,F9.3,]
                        I    [ GAM =¤,F11.5)                  ]
                        I
[  999]                 I
                 /''''''''''''''''''''''\
                :        RETURN          :
                 \....................../
```

```
.............................................
\             SUBROUTINE TOTCI             /
 \.........................................\/
                    I
                    I
...........................................
: COMMON ZB,ZR,ZS,C1,C2,C3,RH1,RH2,RH3,G,D, :
: ALPHO,CS,BZ,REF                           :
: COMMON/DATA/LZERO,FZERO,L70,F70,TH70,L71, :
: F71,DBLOSS,FREQ,THETA,ALOSSO,ALOSSM,FM,   :
: TIR,THC,THRC,TH1B,BETA                    :
:            REAL LZERO,L70,L71             :
:...........................................:
                    I
                    I---[ CHECK THAT C3 LESS THAN C2      ]
                    I
                    I
 /''''''''''''''''''''''''''''''''''''''''''\  TRUE
<          IF(C3.LE.C2)GO TO 10              >-----------------0
 \..........................................\/                 Z
                    I  FALSE                                   Z
                    I                                          Z
                    I                                          Z
  /'''''''''''''''''''''''''''''''''''''''''/                  Z
 /                WRITE(1,11)              /                   Z
/.........................................\/                   Z
                    I                                          Z
                    I---[ 11 FORMAT(¤ C3 MUST BE LESS      ]   Z
                    I   [THAN OR EQUAL TO C2¤)             ]   Z
                    I                                          Z
                    I                                          Z
             /''''''''''''''''''''\                            Z
            :        STOP          :                           Z
             \..................../                            Z
                                                               Z
                                                               Z
                    0<-----------------------------------------0
 [    10]           I
...........................................
:              PI=3.141592654               :
:...........................................:
                    I
                    I---[ COMPUTE TIR=ANGLE OF TOTAL      ]
                    I   [INTERNAL REFLECTION              ]
                    I
                    I
...........................................
:                  TIR=0                    :
:...........................................:
                    I
                    I
```

```
       /''''''''''''''''''''''''''''''''''''''''''\  TRUE
      <          IF(C2.LE.C1)GO TO 100            >-----------------0
       \........................................./                  Z
                         I  FALSE                                   Z
                         I                                          Z
                         I                                          Z
      ............................................                  Z
      :              TIR=ACOS(C1/C2)             :                  Z
      :..........................................:                  Z
                         I                                          Z
                         O<-----------------------------------------O
   [  100]               I
      ............................................
      :                 CONTINUE                 :
      :..........................................:
                         I
                         I---[ COMPUTE THC=CRITICAL ANGLE (    ]
                         I   [CAUSTIC)                         ]
                         I
                         I
      ............................................
      :             PI=3.141592654               :
      :                PI2=PI/2                  :
      :              DELT=PI/180                 :
      :             D1=2*ZB-ZR-ZS                :
      :               D2=2*C3/G                  :
      :          D2=D2*BETA/(1+BETA)             :
      :               FAC=C3/C1                  :
      :        TH3=ACOS(FAC*COS(THRC))           :
      : R=D1/TAN(THRC)+D2*TAN(TH3)*(1+(1+TH3/SIN( :
      : TH3)/COS(TH3))/2/BETA)                   :
      :..........................................:
                         I
                         I---[ MINIMIZE EXPRESSION FOR RANGE   ]
                         I   [BY CONJUGATE DIRECTIONS          ]
                         I
                         I
      ............................................
 A--->:              DO 200 I=1,1000             :
 A    :..........................................:
 A                       I
 A                       I
 A    ............................................
 A    :              AUX=THRC+DELT               :
 A    :..........................................:
 A                       I
 A                       I
 A     /''''''''''''''''''''''''''''''''''''''''''\  TRUE
 A    <          IF(AUX.GE.PI2)GO TO 500          >-----------------O
 A     \........................................./                  Z
 A                       I  FALSE                                   Z
 A                       I                                          Z
 A                       I                                          Z
 A     /''''''''''''''''''''''''''''''''''''''''''\  TRUE           Z
 A    <          IF(AUX.LE.TIR)GO TO 500          >-----------------V
 A     \........................................./                  Z
 A                       I  FALSE                                   Z
 A                       I                                          Z
 A                       I                                          Z
```

```
A   ...............................................            Z
A   :              THRC=AUX                          :          Z
A   :       TH3=ACOS(FAC*COS(THRC))                  :          Z
A   : RAUX=D1/TAN(THRC)+D2*TAN(TH3)*(1+(1+TH3/       :          Z
A   : SIN(TH3)/COS(TH3))/2/BETA)                     :          Z
A   :...............................................:           Z
A                       I                                       Z
A                       I                                       Z
A    /'''''''''''''''''''''''''''''''''''''''''''''\  TRUE      Z
A   <        IF(RAUX.GT.R)GO TO 500                 >-----------V
A    \............................................./            Z
A                       I   FALSE                               Z
A                       I                                       Z
A                       I                                       Z
A   ................................................            Z
A   :                 R=RAUX                         :          Z
A   :...............................................:           Z
A                       I                                       Z
A                       I                                       Z
A                /''''''''''''''''''''\                         Z
A               :      GO TO 200       :------------------0     Z
A                \..................../                   X     Z
A                                                         X     Z
A                                                         X     Z
A                       0<------------------------------------0
A     [   500]          I                                 X
A   ................................................      X
A   :                 R=RAUX                         :    X
A   :               DELT=-DELT/3                     :    X
A   :...............................................:     X
A                       I                                 X
A                       I                                 X
A    /'''''''''''''''''''''''''''''''''''''''''''''\  TRUE  X
A   <     IF(ABS(DELT).LE.1.E-6) GO TO 999          >-----------0
A    \............................................./      X     Z
A                       I   FALSE                         X     Z
A                       I                                 X     Z
A                       0<--------------------------------0     Z
A     [   200]          I                                       Z
A   ................................................            Z
---:                CONTINUE                         :          Z
   :...............................................:            Z
                        I                                       Z
                        I                                       Z
     /'''''''''''''''''''''''''''''''''''''''''''''/            Z
    /                WRITE(1,1)                    /            Z
   /.............................................../            Z
                        I                                       Z
                        I---[ 1 FORMAT(¤ CRITICAL ANGLE    ]    Z
                        I    [FAILED TO CONVERGE¤)         ]    Z
                        I                                       Z
                        I                                       Z
                 /''''''''''''''''''''\                         Z
                :         STOP         :                        Z
                 \..................../                         Z
                                                                Z
```

```
                                              Z
                I---[ BOTTOM ANGLE OF REFRACTED RAY  ]      Z
                I   [AT CRITICAL ANGLE               ]      Z
                I                                           Z
                0<------------------------------------------0
  [   999]      I
.....................................................
:                  THC=ATAN(D1/R)                   :
: CB=SQRT(2*G*(1+BETA)*C3*BZ+(C3*(1+BETA))*        :
: *2)-BETA*C3                                       :
:                 TH1B=ACOS(C1/CB)                  :
:...................................................:
                I
                I
      /''''''''''''''''''''''''\
     :          RETURN          :
      \........................./
```

```
...............................................
 \            SUBROUTINE REFL                /
  \.........................................../
                       I
                       I
.............................................
: COMMON ZB,ZR,ZS,C1,C2,C3,RH1,RH2,RH3,G,D,  :
: ALPHO,CS,BZ,REF                            :
: COMMON/DATA/LZERO,FZERO,L70,F70,TH70,L71,  :
: F71,DBLOSS,FREQ,THETA,ALOSSO,ALOSSM,FM,    :
: TIR,THC,THRC,TH1B,BETA                     :
:           REAL LZERO,L70,L71               :
: COMMON /R/NSAP,RV21,RV32,RSIN2,RDTS,RDTR,  :
: RT,RGI                                     :
: DIMENSION RV21(90),RV32(90),RSIN2(90),     :
: RDTS(90),RDTR(90),RT(90),RGI(90)           :
:...........................................:
                       I
                       I---[*********************************]
                       I   [*********************************]
                       I   [***                              ]
                       I   [ RETURNS IN COMMON               ]
                       I   [ NSAP=NSAP=SMALLEST ANGLE(DEG)   ]
                       I   [TO REACH SURFACE DUE TO SOUND    ]
                       I   [PROFILE                          ]
                       I   [ RV21,RV32=REFLECTION COEFFICIEN]
                       I   [S FOR RESPECTIVE INTERFACE       ]
                       I   [ RSIN2=SIN OF GRAZING ANGLE IN   ]
                       I   [HIGH SPEED LAYER                 ]
                       I   [ RDTS,RDTR=REFLECTION PATH DELTA]
                       I   [T FOR SOURCE,RECEIVER RESP.      ]
                       I   [ RT=TRAVEL TIME FOR REFLECTION   ]
                       I   [PATH                             ]
                       I   [ RGI=GEOMETRIC INTENSITY OF      ]
                       I   [REFLECTION PATH                  ]
                       I   [*********************************]
                       I   [*********************************]
                       I   [***                              ]
                       I   [ COMPUTE NSAP                    ]
                       I
                       I
.............................................
:              PI=3.141592654                :
:                 NSAP=1                     :
:...........................................:
                       I
                       I
  /''''''''''''''''''''''''''''''''''''''''''\  TRUE
 <           IF(C1.GE.CS)GO TO 100            >------------------0
  \........................................../                   Z
                       I   FALSE                                 Z
                       I                                         Z
                       I                                         Z
```

```
        ...........................................           Z
        :         SAP=ACOS(C1/CS)*180/PI          :           Z
        :             NSAP=SAP+1                  :           Z
        :.........................................:           Z
                          I                                   Z
                          I                                   Z
          /''''''''''''''''''''''''''''''''''''''/            Z
         /          WRITE(1,1) SAP              /             Z
        /......................................./             Z
                          I                                   Z
                          I---[ 1 FORMAT(¤ SMALLEST ANGLE TO   ]   Z
                          I   [REACH SURFACE=¤,F8.2)           ]   Z
                          I                                   Z
                          O<----------------------------------O
          [  100]         I
        ...........................................
        :               CONTINUE                  :
        :.........................................:
                          I
                          I---[ COMPUTE REFLECTION COEFFICIENTS]
                          I   [FOR ANGLES GREATER THAN TIR,SAP ]
                          I
                          I
        ...........................................
        :           NTIR=TIR*180/PI+1             :
        :           N=MAX0(NTIR,NSAP)             :
        :               Z1=RH1*C1                 :
        :               Z2=RH2*C2                 :
        :               Z3=RH3*C3                 :
        :             DELT=PI/180                 :
        :           TH=(NSAP-1)*DELT              :
        :               FAC2=C2/C1                :
        :               FAC3=C3/C1                :
        :               FACS=CS/C1                :
        :               AR=2*ZR/CS                :
        :               AS=2*ZS/CS                :
        :             D1=2*ZB-ZR-ZS               :
        :.........................................:
                          I
                          I
        ...........................................
    A-->:            DO 200 I=NSAP,90             :
    A   :.........................................:
    A                     I
    A                     I
    A   ...........................................
    A   :               TH=TH+DELT                :
    A   :              CTH=COS(TH)                :
    A   :.........................................:
    A                     I
    A                     I---[ SURFACE SCATTERING TRAVEL TIME ]
    A                     I   [DIFFERENCES                     ]
    A                     I
    A                     I
```

```
A   ..............................................
A   :          S=SQRT(1-(FACS*CTH)**2)           :
A   :               RDTS(I)=AS*S                 :
A   :               RDTR(I)=AR*S                 :
A   :............................................:
A                       I
A                       I
A    /''''''''''''''''''''''''''''''''''''''''''\  TRUE
A   <           IF(I.LT.N)GO TO 200              >------------------0
A    \........................................../                    Z
A                       I  FALSE                                    Z
A                       I                                           Z
A                       I---[ SIN2                          ]       Z
A                       I                                           Z
A                       I                                           Z
A   ..............................................                  Z
A   :        RSIN2(I)=SQRT(1-(FAC2*CTH)**2)      :                  Z
A   :............................................:                  Z
A                       I                                           Z
A                       I---[ REFLECTION COEFFICIENTS       ]       Z
A                       I                                           Z
A                       I                                           Z
A   ..............................................                  Z
A   :              A1=Z1/SIN(TH)                 :                  Z
A   :              A2=Z2/RSIN2(I)                :                  Z
A   :        A3=Z3/SQRT(1-(FAC3*CTH)**2)         :                  Z
A   :           RV32(I)=(A3-A2)/(A3+A2)          :                  Z
A   :           RV21(I)=(A2-A1)/(A2+A1)          :                  Z
A   :............................................:                  Z
A                       I                                           Z
A                       I---[ TRAVEL TIME                   ]       Z
A                       I                                           Z
A                       I                                           Z
A   ..............................................                  Z
A   :               R=D1/TAN(TH)                 :                  Z
A   :             RT(I)=R/(CTH*C1)               :                  Z
A   :............................................:                  Z
A                       I                                           Z
A                       I---[ GEOMETRIC INTENSITY(AMPLITUDE) ]      Z
A                       I                                           Z
A                       I                                           Z
A   ..............................................                  Z
A   :               RGI(I)=CTH/R                 :                  Z
A   :............................................:                  Z
A                       I                                           Z
A                       0<------------------------------------------0
A     [  200]           I
A   ..............................................
---:                 CONTINUE                    :
   :............................................:
                        I
                        I
              /''''''''''''''''''''\
             :        RETURN        :
              \..................../
```

```
.............................................
\              SUBROUTINE REFR             /
 \........................................./
                      I
                      I
............................................
: COMMON ZB,ZR,ZS,C1,C2,C3,RH1,RH2,RH3,G,D, :
: ALPHO,CS,BZ,REF                           :
: COMMON/DATA/LZERO,FZERO,L70,F70,TH70,L71, :
: F71,DBLOSS,FREQ,THETA,ALOSSO,ALOSSM,FM,   :
: TIR,THC,THRC,TH1B,BETA                    :
:             COMMON /ALPH/GAM              :
:            REAL LZERO,L70,L71             :
: COMMON /B/BV21,BV32,BSIN2,BTRF,BGI,BLS,   :
: BT,BDTS,BDTR                              :
: COMMON /S/SV21,SV32,SSIN2,STRF,SGI,SLS,   :
: ST,SDTS,SDTR                              :
: DIMENSION BV21(90),BV32(90),BSIN2(90),    :
: BTRF(90),BGI(90),BLS(90),BT(90),BDTS(90), :
: BDTR(90)                                  :
: DIMENSION SV21(90),SV32(90),SSIN2(90),    :
: STRF(90),SGI(90),SLS(90),ST(90),SDTS(90), :
: SDTR(90)                                  :
:..........................................:
                      I
                      I---[**********************************]
                      I   [**********************************]
                      I   [***                               ]
                      I   [ FOR EACH SPECULAR BOTTOM ANGLE   ]
                      I   [BETWEEN THE ANGLE OF TOTAL        ]
                      I   [INTERNAL                          ]
                      I   [ REFLECTION AND THE CRITICAL      ]
                      I   [ANGLE THIS SUBROUTINE RETURNS     ]
                      I   [ (SMALL BOTTOM ANGLE PREFIX S,    ]
                      I   [BIG BOTTOM ANGLE PREFIX B)        ]
                      I   [ V21,V32=REFLECTION COEFFICIENTS]
                      I   [AT INTERFACE                      ]
                      I   [ SIN2=SIN OF GRAZING ANGLE IN     ]
                      I   [HIGH SPEED LAYER                  ]
                      I   [ TRF=TRANSMISSION COEFFICIENT     ]
                      I   [FACTOR                            ]
                      I   [ GI=GEOMETRIC INTENSITY           ]
                      I   [ LS=ARC LENGTH OF RAY IN THE      ]
                      I   [BOTTOM                            ]
                      I   [ T=TRAVEL TIME                    ]
                      I   [ DTS,DTR=DELTA T FOR SURFACE      ]
                      I   [REFLECTION FOR SOURCE,RECEIVER    ]
                      I   [RESP.                             ]
                      I   [**********************************]
                      I   [**********************************]
                      I   [***                               ]
                      I
                      I
```

```
                                 ................................................
                                 :              PI=3.141592654                  :
                                 :            NTIR=TIR*180/PI+1                 :
                                 :            NTHC=THC*180/PI+1                 :
                                 :               N=NTHC-NTIR                    :
                                 :                DEL=PI/180                    :
                                 :             TH=(NTHC-1)*DEL                  :
                                 :                Z1=RH1*C1                     :
                                 :                Z2=RH2*C2                     :
                                 :                Z3=RH3*C3                     :
                                 :                FAC2=C2/C1                    :
                                 :                FAC3=C3/C1                    :
                                 :                FACS=CS/C1                    :
                                 :                SEST=THRC                     :
                                 :                BEST=THRC                     :
                                 :              D1=2*ZB-ZR-ZS                   :
                                 :             D2=2*C3**2/G/C1                  :
                                 :        D3=2*C3/G*BETA/(1+BETA)               :
                                 :           D4=BETA/(1+BETA)/G                 :
                                 :                D7=1+BETA                     :
                                 :                 D5=D1/C1                     :
                                 :                 D6=2/CS                      :
                                 :               ANU=BETA*C3                    :
                                 :            SIG=G*(1+BETA)*C3                 :
                                 :         AMU=C3**2*(1+BETA)**2                :
                                 :        D8=2*C3/G/(1+BETA)/ALPHO              :
                                 :           D9=-GAM*C3**2/SIG/6                :
                                 : D10=(BETA*GAM*C3**2+GAM*ANU*C3*2)/4/SIG      :
                                 :                D11=-3*D9                     :
                                 : D12=(GAM*(ANU**2-AMU)+2*ALPHO*SIG+2*BETA*    :
                                 : ANU*C3*GAM)/2/SIG                            :
                                 : D14=BETA*GAM*(ANU**2-AMU)/2/SIG+BETA*        :
                                 : ALPHO                                        :
                                 :..............................................:
                                                       I
                                                       I
                                 ................................................
A-------------------->:                     DO 10 I=1,90                        :
A                                :..............................................:
A                                                      I
A                                                      I
A                                ................................................
A                                :                  BTRF(I)=0                   :
A                                :..............................................:
A                                                      I
A                                  [     10]           I
A                                ................................................
---------------------------------:                  STRF(I)=0                   :
                                 :..............................................:
                                                       I
                                                       I
```

```
     ..................................................
A-->:                 DO 100 I=1,N                    :
A   :.................................................:
A                          I
A                          I
A   ..................................................
A   :                   J=NTHC-I                      :
A   :                 R=D1/TAN(TH)                    :
A   :.................................................:
A                          I
A                          I
A   ..................................................
A   : : CALL REFRN(TH,SEST,BEST,SA,SA3,BA,        : :
A   : : BA3)                                      : :
A   :.:...........................................:.:
A                          I
A                          I
A    /''''''''''''''''''''''''''''''''''''''''''''''\   TRUE
A   <         IF(BA.GT.TH1B)GO TO 998              >--------------------0
A    \............................................./                    Z
A                          I   FALSE                                    Z
A                          I                                            Z
A                          I                                            Z
A   ..................................................                  Z
A   :                 BC1=COS(BA)                     :                 Z
A   :               BS1=SQRT(1-BC1**2)                :                 Z
A   :                 BC2=FAC2*BC1                    :                 Z
A   :               BS2=SQRT(1-BC2**2)                :                 Z
A   :                 BC3=FAC3*BC1                    :                 Z
A   :               BS3=SQRT(1-BC3**2)                :                 Z
A   :.................................................:                 Z
A                          I                                            Z
A                          I---[ BIG ANGLE REFLECTION COEFFICIEN]       Z
A                          I                                            Z
A                          I                                            Z
A   ..................................................                  Z
A   :                   A1=Z1/BS1                     :                 Z
A   :                   A2=Z2/BS2                     :                 Z
A   :                   A3=Z3/BS3                     :                 Z
A   :            BV32(J)=(A3-A2)/(A3+A2)              :                 Z
A   :            BV21(J)=(A2-A1)/(A2+A1)              :                 Z
A   : BTRF(J)=16*A1*A3*(A2/(A3+A2)/(A2+A1))**2        :                 Z
A   :                 BSIN2(J)=BS2                    :                 Z
A   :.................................................:                 Z
A                          I                                            Z
A                          I---[ GEOMETRIC AMPLITUDE              ]     Z
A                          I                                            Z
A                          I                                            Z
A   ..................................................                  Z
A   : DRDT=-D1/BS1**2+D2*(BS1/BS3/BC3**2)*(1.+        :                 Z
A   : BA3*TAN(BA3)/D7)                                :                 Z
A   :           BGI(J)=BC1/(R*BS1*ABS(DRDT))          :                 Z
A   :             BGI(J)=SQRT(BGI(J))                 :                 Z
A   :.................................................:                 Z
```

```
A                                  I                                       Z
A                                  I---[ ARC LENGTH                  ]    Z
A                                  I                                       Z
A                                  I                                       Z
A   ............................................                           Z
A   : BLS(J)=D8/BC3*(D9/BC3**3*BS3**3+D10/BC3*   :                         Z
A   : BS3+(D11/BC3**3+D12/BC3)*BS3+(D10/BC3**2+  :                         Z
A   : D14)*BA3)                                  :                         Z
A   :............................................:                         Z
A                                  I                                       Z
A                                  I---[ TRAVEL TIME                 ]    Z
A                                  I                                       Z
A                                  I                                       Z
A   ............................................                           Z
A   : BT(J)=D5/BS1+D4*(ALOG((1+BS3)/(1-BS3))+2*  :                         Z
A   : BA3/BC3/BETA)                              :                         Z
A   :............................................:                         Z
A                                  I                                       Z
A                                  I---[ DELTA T SOURCE RECEIVER     ]    Z
A                                  I                                       Z
A                                  I                                       Z
A   ............................................                           Z
A   :         BSS=SQRT(1-(FACS*BC1)**2)          :                         Z
A   :             BDTR(J)=D6*ZR*BSS              :                         Z
A   :             BDTS(J)=D6*ZS*BSS              :                         Z
A   :............................................:                         Z
A                                  I                                       Z
A                                  0<--------------------------------------0
A    [  998]                       I
A   ............................................
A   :                SC1=COS(SA)                 :
A   :............................................:
A                                  I
A                                  I
A    /''''''''''''''''''''''''''''''''''''''''''\   TRUE
A   <        IF(SA.GT.TH1B)GO TO 999             >-------------------------0
A    \........................................../                          Z
A                                  I   FALSE                               Z
A                                  I                                       Z
A                                  I                                       Z
A   ............................................                           Z
A   :                AUX=FACS*SC1                :                         Z
A   :............................................:                         Z
A                                  I                                       Z
A                                  I---[ IF RAY DOES NOT REACH SURFACE ]  Z
A                                  I   [NOT COMPUTED                   ]  Z
A                                  I                                       Z
A                                  I                                       Z
A    /''''''''''''''''''''''''''''''''''''''''''\   TRUE                   Z
A   <         IF(AUX.GT.1.)GO TO 999             >-------------------------V
A    \........................................../                          Z
A                                  I   FALSE                               Z
A                                  I                                       Z
A                                  I---[ DELTA T SOURCE RECEIVER     ]    Z
A                                  I                                       Z
A                                  I                                       Z
```

```
A
A   ................................................          Z
A   :            SSS=SQRT(1-AUX**2)                 :          Z
A   :            SDTR(J)=D6*ZR*SSS                  :          Z
A   :            SDTS(J)=D6*ZS*SSS                  :          Z
A   :            SS1=SQRT(1-SC1**2)                 :          Z
A   :              SC2=FAC2*SC1                     :          Z
A   :            SS2=SQRT(1-SC2**2)                 :          Z
A   :              SC3=FAC3*SC1                     :          Z
A   :            SS3=SQRT(1-SC3**2)                 :          Z
A   :...............................................:          Z
A                        I                                     Z
A                        I---[ SMALL ANGLE REFLECTION      ]   Z
A                        I   [COEFFICIENT                  ]   Z
A                        I                                     Z
A                        I                                     Z
A   ................................................          Z
A   :               A1=Z1/SS1                       :          Z
A   :               A2=Z2/SS2                       :          Z
A   :               A3=Z3/SS3                       :          Z
A   :         SV32(J)=(A3-A2)/(A3+A2)               :          Z
A   :         SV21(J)=(A2-A1)/(A2+A1)               :          Z
A   : STRF(J)=16*A1*A3*(A2/(A3+A2)/(A2+A1))**2      :          Z
A   :              SSIN2(J)=SS2                     :          Z
A   :...............................................:          Z
A                        I                                     Z
A                        I---[ GEOMETRIC AMPLITUDE         ]   Z
A                        I                                     Z
A                        I                                     Z
A   ................................................          Z
A   : DRDT=-D1/SS1**2+D2*(SS1/SS3/SC3**2)*(1+       :          Z
A   : SA3*TAN(SA3)/D7)                              :          Z
A   :        SGI(J)=SC1/(R*SS1*ABS(DRDT))           :          Z
A   :           SGI(J)=SQRT(SGI(J))                 :          Z
A   :...............................................:          Z
A                        I                                     Z
A                        I---[ ARC LENGTH                  ]   Z
A                        I                                     Z
A                        I                                     Z
A   ................................................          Z
A   : SLS(J)=D8/SC3*(D9/SC3**3*SS3**3+D10/SC3*      :          Z
A   : SS3+(D11/SC3**3+D12/SC3)*SS3+(D10/SC3**2+     :          Z
A   : D14)*SA3)                                     :          Z
A   :...............................................:          Z
A                        I                                     Z
A                        I---[ TRAVEL TIME                 ]   Z
A                        I                                     Z
A                        I                                     Z
A   ................................................          Z
A   : ST(J)=D5/SS1+D4*(ALOG((1+SS3)/(1-SS3))+2*     :          Z
A   : SA3/SC3/BETA)                                 :          Z
A   :...............................................:          Z
A                        I                                     Z
A                        O<------------------------------------O
A    [   999]            I
```

```
                      ..................................................
        A             :                  TH=TH-DEL                     :
        A             :................................................:
        A                                    I
        A              [   100]              I
        A             ..................................................
        --------------:                  CONTINUE                      :
                      :................................................:
                                             I
                                             I
                                /''''''''''''''''''''\
                               :        RETURN        :
                                \..................../
```

```
.............................................
 \             SUBROUTINE BASE              /
  \........................................./
                      I
                      I---[********************************]
                      I   [********************************]
                      I   [***                             ]
                      I   [ FOR EACH SPECULAR BOTTOM ANGLE ]
                      I   [SUB RETURNS                     ]
                      I   [ BSV21,BSV32=REFLECTION         ]
                      I   [COEFFICIENTS AT INTERFACE       ]
                      I   [ BSSIN2=SIN OF GRAZING ANGLE IN ]
                      I   [HIGH SPEED LAYER                ]
                      I   [ BSTRF=TRANSMISSION COEFFICIENT ]
                      I   [FACTOR                          ]
                      I   [ BSGI=GEOMETRIC AMPLITUDE       ]
                      I   [ BSLS=ARC LENGTH OF RAY IN      ]
                      I   [BOTTOM                          ]
                      I   [ BST=TRAVEL TIME                ]
                      I   [ BSDTS,BSDTR=DELTA T FOR SURFACE]
                      I   [REFLECTION FOR SOURCE RECEIVER  ]
                      I   [********************************]
                      I   [********************************]
                      I   [***                             ]
                      I
                      I
............................................
: COMMON ZB,ZR,ZS,C1,C2,C3,RH1,RH2,RH3,G,D,  :
: ALPHO,CS,BZ,REF                            :
: COMMON /DATA/LZERO,FZERO,L70,F70,TH70,     :
: L71,F71,DBLOSS,FREQ,THETA,ALOSS0,ALOSSM,   :
: FM,TIR,THC,THRC,TH1B,BETA                  :
: COMMON /BS/BSV21,BSV32,BSSIN2,BSTRF,BSGI,  :
: BSLS,BST,BSDTS,BSDTR                       :
: DIMENSION BSV21(90),BSV32(90),BSSIN2(90),  :
: BSTRF(90),BSGI(90),BSLS(90),BST(90),       :
: BSDTS(90),BSDTR(90)                        :
:            COMMON /ALPH/GAM                :
:           REAL LZERO,L70,L71               :
:             PI=3.141592654                 :
:           NTIR=TIR*180/PI+1                :
:               DEL=PI/180                   :
:                TH=PI/2                     :
:               Z1=RH1*C1                    :
:               Z2=RH2*C2                    :
:               Z3=RH3*C3                    :
:               FAC2=C2/C1                   :
:               FAC3=C3/C1                   :
:               FACS=CS/C1                   :
: CB=SQRT(2*G*(1+BETA)*C3*BZ+(C3*(1+BETA))*  :
: *2)-BETA*C3                                :
:               FACB=CB/C1                   :
:             D1=2*ZB-ZR-ZS                  :
:         D2=2*C3**2/C1/G/(1+BETA)           :
:           D3=2*C3/G/(1+BETA)               :
:            D4=2/G/(1+BETA)                 :
:                D5=D1/C1                    :
:                D6=2/CS                     :
:       D7=2*C3*BETA/G/(1+BETA)/C1           :
:............................................:
```

```
                          I
                          I---[ THE FOLLOWING 2 LINES ADDED 5/ ]
                          I    [29/79                          ]
                          I
                          I
             .............................................
             :          DA=2.*C3/G/(1.+BETA)             :
             :               DB=DA*BETA                  :
             :              ANU=BETA*C3                  :
             :          SIG=6*(1+BETA)*C3                :
             :        AMU=C3**2*(1+BETA)**2              :
             :       D8=2*C3/G/(1+BETA)/ALPHO            :
             :          D9=-GAM*C3**2/SIG/6              :
             : D10=(BETA*GAM*C3**2+GAM*ANU*C3*2)/4/SIG   :
             :               D11=-3*D9                   :
             : D12=(GAM*(ANU**2-AMU)+2*ALPHO*SIG+2*BETA* :
             : ANU*C3*GAM)/2/SIG                         :
             : D14=BETA*GAM*(ANU**2-AMU)/2/SIG+BETA*     :
             : ALPHO                                     :
             :              BSA=TH-1.E-6                 :
             :       TH3=ACOS(FAC3*COS(TH1B))            :
             : R=D1/TAN(TH1B)+D3/COS(TH3)**2*(TH3/2+(.   :
             : 25+BETA/2)*SIN(2*TH3))                    :
             :             AUX=ATAN(D1/R)                :
             :             N=AUX*180/PI+1                :
             :           N=90-MAX0(N,NTIR)               :
             :...........................................:
                          I
                          I
             .............................................
        A--->:             DO 10 I=1,90                  :
        A    :...........................................:
        A                 I
        A                 I
        A    .............................................
        A    :            BSSIN2(I)=0.0                  :
        A    :            BSV32(I)=0.0                   :
        A    :            BSV21(I)=0.0                   :
        A    :            BSGI(I)=0.0                    :
        A    :...........................................:
        A                 I
        A      [    10]   I
        A    .............................................
        -----:            BSTRF(I)=0                     :
             :...........................................:
                          I
                          I
             .............................................
        A--->:             DO 100 I=1,N                  :
        A    :...........................................:
        A                 I
        A                 I
        A    .............................................
        A    :               J=90-I                      :
        A    :              TH=TH-DEL                    :
        A    :...........................................:
        A                 I
        A                 I
        A
```

```
A      ..........................................
A      : :       CALL BASANG(TH,BSA,BSA3)       : :
A      :.:......................................:.:
A                          I
A                          I
A       /'''''''''''''''''''''''''''''''''''''''\  TRUE
A      <       IF(BSA3.EQ.0.0) GO TO 100         >----------------------0
A       \......................................./                       Z
A                          I   FALSE                                    Z
A                          I                                            Z
A                          I                                            Z
A      ..........................................                       Z
A      :               BC1=COS(BSA)             :                       Z
A      :           BS1=SQRT(1-BC1**2)           :                       Z
A      :               BC2=FAC2*BC1             :                       Z
A      :           BS2=SQRT(1-BC2**2)           :                       Z
A      :               BC3=FAC3*BC1             :                       Z
A      :           BS3=SQRT(1-BC3**2)           :                       Z
A      :               BCB=FACB*BC1             :                       Z
A      :           BSB=SQRT(1-BCB**2)           :                       Z
A      :........................................:                       Z
A                          I                                            Z
A                          I---[ DELTA T SOURCE RECEIVER        ]       Z
A                          I                                            Z
A                          I                                            Z
A      ..........................................                       Z
A      :               AUX=FACS*BC1             :                       Z
A      :........................................:                       Z
A                          I                                            Z
A                          I---[ IF RAY DOES NOT REACH SURFACE  ]       Z
A                          I   [NOT COMPUTED                    ]       Z
A                          I                                            Z
A                          I                                            Z
A       /'''''''''''''''''''''''''''''''''''''''\  TRUE                 Z
A      <         IF(AUX.GT.1.)GO TO 999          >-----------------0    Z
A       \......................................./                  X    Z
A                          I   FALSE                               X    Z
A                          I                                       X    Z
A                          I                                       X    Z
A      ..........................................                  X    Z
A      :            SS=SQRT(1-AUX**2)           :                  X    Z
A      :            BSDTR(J)=D6*ZR*SS           :                  X    Z
A      :            BSDTS(J)=D6*ZS*SS           :                  X    Z
A      :........................................:                  X    Z
A                          I                                       X    Z
A                          I---[ LAYER REFLECTION COEFFICIENTS  ]  X    Z
A                          I                                       X    Z
A                          I                                       X    Z
A      ..........................................                  X    Z
A      :                A1=Z1/BS1               :                  X    Z
A      :                A2=Z2/BS2               :                  X    Z
A      :                A3=Z3/BS3               :                  X    Z
A      :         BSV32(J)=(A3-A2)/(A3+A2)       :                  X    Z
A      :         BSV21(J)=(A2-A1)/(A2+A1)       :                  X    Z
A      : BSTRF(J)=16*A1*A3*(A2/(A3+A2)/(A2+A1))** :                X    Z
A      : 2                                      :                  X    Z
A      :             BSSIN2(J)=BS2              :                  X    Z
       :........................................:                  X    Z
```

```
A                                   I                                        X    Z
A                                   I---[ GEOMETRIC AMPLITUDE           ]    X    Z
A                                   I                                        X    Z
A                                   I                                        X    Z
A     ..........................................                             X    Z
A     :                BSAB=ACOS(BCB)          :                             X    Z
A     :........................................:                             X    Z
A                                   I                                        X    Z
A                                   I---[ FOLLOWING 4 CARDS ADDED 5/59/79]   X    Z
A                                   I                                        X    Z
A                                   I                                        X    Z
A     ..........................................                             X    Z
A     : DRDT3=DA*(BS3/BC3**3*(BSA3-BSAB+BS3*BC3-   :                         X    Z
A     : BSB*BCB)+(1.-(CB/C3)**3*BS3/BSB))+DB/BC3*  :                         X    Z
A     : (1./BC3-BS3*(BSB/BC3+(CB/C3)**2*BC3/BSB))  :                         X    Z
A     : DRDT=-D1/BS1**2+(C3/C1)*BS1/BS3*DRDT3      :                         X    Z
A     :                 R=D1/TAN(TH)               :                         X    Z
A     :        BSGI(J)=BC1/(R*BS1*ABS(DRDT))       :                         X    Z
A     :            BSGI(J)=SQRT(BSGI(J))           :                         X    Z
A     :............................................:                         X    Z
A                                   I                                        X    Z
A                                   I---[ ARC LENGTH                    ]    X    Z
A                                   I                                        X    Z
A                                   I                                        X    Z
A     ..............................................                         X    Z
A     : BSLS(J)=D8/BC3*(D9/BC3**3*(BS3**3-BSB**3)  :                         X    Z
A     : +D10/BC3**2*(BS3*BC3-BSB*BCB)+(D11/BC3**   :                         X    Z
A     : 3+D12/BC3)*(BS3-BSB)+(D10/BC3**2+D14)*(    :                         X    Z
A     : BSA3-BSAB))                                :                         X    Z
A     :............................................:                         X    Z
A                                   I                                        X    Z
A                                   I---[ TRAVEL TIME                   ]    X    Z
A                                   I                                        X    Z
A                                   I                                        X    Z
A     ..............................................                         X    Z
A     : BST(J)=D5/BS1+D4*((BSA3-BSAB)/BC3+BETA*    :                         X    Z
A     : ALOG((1+BS3)/(1-BS3)*(1-BSB)/(1+BSB))/2)   :                         X    Z
A     :............................................:                         X    Z
A                                   I                                        X    Z
A                                   0<-------------------------------------------0
A       [   100]                    I                                        X
A     ..............................................                         X
----:                   CONTINUE                   :                         X
      :............................................:                         X
                                    I                                        X
                                    0<---------------------------------------0
        [   999]                    I
                      /'''''''''''''''''''''\
                     :        RETURN        :
                      \...................../
```

```
 .........................................
 \   SUBROUTINE REFRN(TH,SEST,BEST,SA,SA3,   /
  \  BA,BA3)                                /
   \......................................./
                    I
                    I
 .........................................
 : COMMON ZB,ZR,ZS,C1,C2,C3,RH1,RH2,RH3,G,D,  :
 : ALPHO,CS,BZ,REF                             :
 : COMMON /DATA/LZERO,FZERO,L70,F70,TH70,      :
 : L71,F71,DBLOSS,FREQ,THETA,ALOSSO,ALOSSM,    :
 : FM,TIR,THC,THRC,TH1B,BETA                   :
 :            REAL LZERO,L70,L71                :
 :.........................................:
                    I
                    I---[*********************************]
                    I   [*********************************]
                    I   [***                              ]
                    I   [ GIVEN                           ]
                    I   [ TIR=ANGLE OF TOTAL INTERNAL     ]
                    I   [REFLECTION                       ]
                    I   [ TH=GRAZING ANGLE                ]
                    I   [ SEST=ESTIMATE SMALL ANGLE       ]
                    I   [ BEST=ESTIMATE BIG ANGLE         ]
                    I   [ RETURNS                         ]
                    I   [ SA=SMALL ANGLE REFRACTED RAY    ]
                    I   [ BA=BIG ANGLE REFRACTED RAY      ]
                    I   [*********************************]
                    I   [*********************************]
                    I   [***                              ]
                    I
                    I
  /''''''''''''''''''''''''''''''''''''''''''\  TRUE
 <           IF(TH.GT.TIR)GO TO 100           >-------------------0
  \........................................../                    Z
                    I  FALSE                                      Z
                    I                                             Z
                    I                                             Z
   /''''''''''''''''''''''''''''''''''''''''/                     Z
  /                WRITE(1,1)              /                      Z
 /......................................../                       Z
                    I                                             Z
                    I---[ 1 FORMAT(¤ SPECULAR ANGLE OF     ]      Z
                    I   [REFRACTED RAY LESS THAN TIR¤)     ]      Z
                    I                                             Z
                    I                                             Z
          /''''''''''''''''''''\                                  Z
         :         STOP          :                                Z
          \..................../                                  Z
                                                                  Z
                                                                  Z
                    0<--------------------------------------------0
    [   100]        I
```

```
                 ......................................
                 :          D1=2*ZB-ZR-ZS             :
                 :        PI2=3.141592654             :
                 :          PI2=PI2/2                 :
                 :   D2=2*C3/G*(BETA/(1+BETA))        :
                 :         D3=1/(2*BETA)              :
                 :          FAC3=C3/C1                :
                 :         R=D1/TAN(TH)               :
                 :     T3=ACOS(FAC3*COS(SEST))        :
                 : VAL =D1/TAN(SEST)+D2*TAN(T3)*(1+(1+T3/  :
                 : SIN(T3)/COS(T3))*D3)-R             :
                 :       DEL=(SEST-TIR)/10.0001       :
                 :....................................:
                                   I
                                   I---[ COMPUTE SA                    ]
                                   I
       [  102]                     I
                 ......................................
A------>:              DO 200 I=1,500                 :
A                :....................................:
A                                  I
A                                  I
A         /''''''''''''''''''''''''''''''''''''''\  TRUE
A        <       IF(ABS(DEL).LT.1.E-6) GO TO 201   >-------------------O
A         \......................................./                    Z
A                                  I  FALSE                            Z
A                                  I                                   Z
A                                  I                                   Z
A                ......................................                Z
A                :           SA=SEST-DEL              :                Z
A                :....................................:                Z
A                                  I                                   Z
A                                  I                                   Z
A         /''''''''''''''''''''''''''''''''''''''\  TRUE               Z
A        <        IF(SA.LE.TIR)GO TO 211            >---------------O  Z
A         \......................................./                X  Z
A                                  I  FALSE                        X  Z
A                                  I                               X  Z
A                                  I                               X  Z
A         /''''''''''''''''''''''''''''''''''''''\  TRUE           X  Z
A        <        IF(SA.GE.THPC)GO TO 211           >---------------V  Z
A         \......................................./                X  Z
A                                  I  FALSE                        X  Z
A                                  I                               X  Z
A                                  I                               X  Z
A                ......................................            X  Z
A                :       T3=ACOS(FAC3*COS(SA))        :            X  Z
A                : VALP=D1/TAN(SA )+D2*TAN(T3)*(1+(1+T3/SIN( :     X  Z
A                : T3)/COS(T3))*D3)-R                 :            X  Z
A                :           AUX=VAL*VALP             :            X  Z
A                :             SEST=SA                :            X  Z
A                :            VAL=VALP                :            X  Z
A                :....................................:            X  Z
A                                  I                               X  Z
A                                  I
```

```
                                                                                   X    7
 A      /''''''''''''''''''''''''''''''''''''''''\  TRUE                           X    7
 A     <         IF(AUX.GT.0.)GO TO 200           >----------------0               X    7
 A      \........................................./                U               X    7
 A                         I  FALSE                                 U               X    7
 A                         I                                        U               X    7
 A       [  210]           I                                        U               X    7
 A     ..........................................                   U               X    7
 A     :                DEL=-DEL/3               :                  U               X    7
 A     :.........................................:                  U               X    7
 A                         I                                        U               X    7
 A                         I                                        U               X    7
 A               /''''''''''''''''''''\                             U               X    7
 A              :      GO TO 200       :----------------------------V               X    7
 A               \..................../                             U               X    7
 A                                                                  U               X    7
 A                                                                  U               X    7
 A                         0<---------------------------------------------------------0    7
 A       [  211]           I                                        U                    7
 A     ..........................................                   U                    7
 A     :                DEL=DEL/3                :                  U                    7
 A     :.........................................:                  U                    7
 A                         I                                        U                    7
 A                         0<---------------------------------------0                    7
 A       [  200]           I                                                             7
 A     ..........................................                                        7
 -----:                 CONTINUE                 :                                       7
       :.........................................:                                       7
                           I                                                             7
                           I                                                             7
        /''''''''''''''''''''''''''''''''''''''''/                                       7
       /                WRITE(1,2)              /                                        7
      /......................................../                                         7
                           I                                                             7
                           I---[ 2 FORMAT(¤ SMALL BOTTOM          ]                      7
                           I   [REFRACTION ANGLE DOES NOT         ]                      7
                           I   [CONVERGE¤)                        ]                      7
                           I                                                             7
                           I                                                             7
                 /''''''''''''''''''''\                                                  7
                :         STOP         :                                                 7
                 \..................../                                                  7
                                                                                         7
                                                                                         7
                           0<-------------------------------------------------------------0
         [  201]           I
       ..........................................
       :                 SA3=T3                  :
       :.........................................:
                           I
                           I---[ BA INITIALIZATION                ]
                           I
                           I
```

```
          ........................................
          :          T3=ACOS(FAC3*COS(BEST))          :
          : VAL  =D1/TAN(BEST)+D2*TAN(T3)*(1+(1+T3/   :
          : SIN(T3)/COS(T3))*D3)-R                    :
          :            DEL=(PI2-BEST)/10.0001         :
          :.......................................:
                               I
                               I---[ COMPUTE BA                          ]
                               I
            [   302]           I
          ........................................
A---->:                DO 400 I=1,500             :
A         :.......................................:
A                              I
A                              I
A          /''''''''''''''''''''''''''''''''''''''\   TRUE
A         <      IF(ABS(DEL).LT.1.E-6) GO TO 401    >---------------O
A          \....................................../                   Z
A                              I  FALSE                               Z
A                              I                                      Z
A                              I                                      Z
A         ........................................                    Z
A         :              BA=BEST+DEL               :                  Z
A         :.......................................:                   Z
A                              I                                      Z
A                              I                                      Z
A          /''''''''''''''''''''''''''''''''''''''\   TRUE            Z
A         <        IF(BA.LE.THRC)GO TO 411          >-----------O     Z
A          \....................................../           X       Z
A                              I  FALSE                       X       Z
A                              I                              X       Z
A                              I                              X       Z
A          /''''''''''''''''''''''''''''''''''''''\   TRUE    X       Z
A         <         IF(BA.GE.PI2)GO TO 411          >-----------V     Z
A          \....................................../           X       Z
A                              I  FALSE                       X       Z
A                              I                              X       Z
A                              I                              X       Z
A         ........................................            X       Z
A         :          T3=ACOS(FAC3*COS(BA))         :          X       Z
A         : VALP=D1/TAN(BA  )+D2*TAN(T3)*(1+(1+T3/SIN( :      X       Z
A         : T3)/COS(T3))*D3)-R                     :          X       Z
A         :               AUX=VAL*VALP             :          X       Z
A         :                 BEST=BA                :          X       Z
A         :                 VAL=VALP               :          X       Z
A         :.......................................:           X       Z
A                              I                              X       Z
A                              I                              X       Z
A          /''''''''''''''''''''''''''''''''''''''\   TRUE    X       Z
A         <        IF(AUX.GT.0.)GO TO 400           >-------O   X     Z
A          \....................................../        U   X     Z
A                              I  FALSE                    U   X     Z
A                              I                           U   X     Z
A           [   410]           I                           U   X     Z
```

```
A    .............................................         U    X    Z
A    :                 DEL=-DEL/3                  :         U    X    Z
A    :.............................................:         U    X    Z
A                          I                                 U    X    Z
A                          I                                 U    X    Z
A                 /''''''''''''''''''''\                     U    X    Z
A                 :     GO TO 400       :--------------------V    X    Z
A                 \..................../                     U    X    Z
A                                                            U    X    Z
A                                                            U    X    Z
A                          O<-----------------------------------O    Z
A    [  411]               I                                 U         Z
A    .............................................         U         Z
A    :                 DEL=DEL/3                   :         U         Z
A    :.............................................:         U         Z
A                          I                                 U         Z
A                          O<--------------------------------O         Z
A    [  400]               I                                           Z
A    .............................................                   Z
---: :                 CONTINUE                    :                   Z
     :.............................................:                   Z
                           I                                           Z
                           I                                           Z
      /''''''''''''''''''''''''''''''''''''''''''/                     Z
     /                 WRITE(1,3)                /                      Z
    /.........................................../                       Z
                           I                                           Z
                           I---[ 3 FORMAT(" LARGE BOTTOM          ]    Z
                           I   [REFRACTION ANGLE DOES NOT         ]    Z
                           I   [CONVERGE")                        ]    Z
                           I                                           Z
                           I                                           Z
                  /''''''''''''''''''''\                               Z
                  :       STOP          :                              Z
                  \..................../                               Z
                                                                       Z
                                                                       Z
                           O<------------------------------------------O
     [  401]               I
     .............................................
     :                 BA3=T3                      :
     :.............................................:
                           I
                           I
                  /''''''''''''''''''''\
                  :      RETURN         :
                  \..................../
```

```
..............................................
\       SUBROUTINE BASANG(TH,BSA,BSA3)       /
 \............................................/
                      I
                      I
.............................................
: COMMON ZB,ZR,ZS,C1,C2,C3,RH1,RH2,RH3,G,D,  :
: ALPHO,CS,BZ,REF                             :
: COMMON /DATA/LZERO,FZERO,L70,F70,TH70,      :
: L71,F71,DBLOSS,FREQ,THETA,ALOSSO,ALOSSM,    :
: FM,TIR,THC,THPC,TH1B,BETA                   :
:            REAL LZERO,L70,L71               :
:.............................................:
                      I
                      I---[**********************************]
                      I   [**********************************]
                      I   [***                               ]
                      I   [ GIVEN                            ]
                      I   [ BZ=SEDIMENT DEPTH                ]
                      I   [ TH1B=BASEMENT CRITICAL ANGLE     ]
                      I   [ TIR=ANGLE OF TOTAL INTERNAL      ]
                      I   [REFLECTION                        ]
                      I   [ TH=GRAZING ANGLE                 ]
                      I   [ RETURNS                          ]
                      I   [ BSA=BASEMENT REFLECTED RAY       ]
                      I   [ANGLE IN WATER                    ]
                      I   [ BSA3=BASEMENT REFLECTED RAY      ]
                      I   [ANGLE IN SEDIMENT                 ]
                      I   [**********************************]
                      I   [**********************************]
                      I   [***                               ]
                      I
                      I
 /''''''''''''''''''''''''''''''''''''''''''\  TRUE
<          IF(TH.GT.TIR)GO TO 100            >------------------------0
 \........................................../                         Z
                      I  FALSE                                        Z
                      I                                               Z
                      I                                               Z
  /''''''''''''''''''''''''''''''''''''''''''/                        Z
 /                 WRITE(1,1)               /                         Z
/........................................../                          Z
                      I                                               Z
                      I---[ 1 FORMAT(¤ SPECULAR ANGLE OF  ]           Z
                      I   [BASEMENT RAY LESS THAN TIR¤)   ]           Z
                      I                                               Z
                      I                                               Z
          /''''''''''''''''''''\                                      Z
         :        STOP          :                                     Z
          \..................../                                      Z
                                                                      Z
                                                                      Z
                      0<----------------------------------------------0
  [   100]            I
```

```
 ..................................................
 :              D1=2*ZB-ZR-ZS                     :
 :              PI=3.141592654                    :
 :                PI2=PI/2                        :
 :           D2=2*C3/G/(1+BETA)                   :
 :               FAC3=C3/C1                       :
 : CB=SQRT(2*G*(1+BETA)*C3*BZ+(C3*(1+BETA))*      :
 :               FACB=CB/C1                       :
 :               R=D1/TAN(TH)                     :
 :                BEST=BSA                        :
 :             AUX=COS(BEST)                      :
 :           THB=ACOS(FACB*AUX)                   :
 :           TH3=ACOS(FAC3*AUX)                   :
 : VAL=D1/TAN(BEST)+D2/(FAC3*AUX)**2*((TH3-       :
 :              DEL=PI/180                        :
 :                AUX=TIR                         :
 :................................................:
                         I
                         I
  /''''''''''''''''''''''''''''''''''''''''''''''\  FALSE
 <            IF(TH1B.GT.TIR)                     >--------------I
  \............................................../               I
                         I  TRUE                                 I
                         I                                       I
 ..................................................              I
 :               AUX=TH1B                         :              I
 :................................................:              I
                         I                                       I
                         O<----------------------------------------------O
   [  101]               I                                               ?
  /''''''''''''''''''''''''''''''''''''''''''''''\  TRUE                 ?
 <      IF((BEST-DEL).GT.AUX)GO TO 102            >------------------O   ?
  \............................................../                   X   ?
                         I  FALSE                                    X   ?
                         I                                           X   ?
                         I                                           X   ?
 ..................................................                  X   ?
 :               DEL=DEL*.9                       :                  X   ?
 :................................................:                  X   ?
                         I                                           X   ?
                         I                                           X   ?
               /''''''''''''''''''''''\                              X   ?
               :      GO TO 101       :------------------------------------O
               \....................../                              X
                                                                     X
                                                                     X
                         I---[ COMPUTE BSA                      ]    X
                         I                                           X
                         O<------------------------------------------O
   [  102]               I
 ..................................................
A-->:             DO 200 I=1,500                  :
A   :.............................................:
A                        I
A                        I
```

```
A
A     .............................................
A     :               BSA=BEST-DEL                :
A     :...........................................:
A                          I
A                          I
A      /'''''''''''''''''''''''''''''''''''''''''\  TRUE
A     <          IF(BSA.LE.AUX)GO TO 211          >---------------0
A      \........................................./                Z
A                          I  FALSE                               Z
A                          I                                      Z
A                          I                                      Z
A      /'''''''''''''''''''''''''''''''''''''''''\  TRUE          Z
A     <          IF(BSA.GE.PI2)GO TO 211          >---------------V
A      \........................................./                Z
A                          I  FALSE                               Z
A                          I                                      Z
A                          I                                      Z
A     .............................................               Z
A     :              AUX1=COS(BSA)                :               Z
A     :           THB=ACOS(FACB*AUX1)             :               Z
A     :           TH3=ACOS(FAC3*AUX1)             :               Z
A     : VALP=D1/TAN(BSA)+D2/(FAC3*AUX1)**2*((TH3- :               Z
A     :              BAUX=VAL*VALP                :               Z
A     :                BEST=BSA                   :               Z
A     :                VAL=VALP                   :               Z
A     :...........................................:               Z
A                          I                                      Z
A                          I                                      Z
A      /'''''''''''''''''''''''''''''''''''''''''\  TRUE          Z
A     <          IF(BAUX.GT.0.)GO TO 200          >-----------0   Z
A      \........................................./            X   Z
A                          I  FALSE                           X   Z
A                          I                                  X   Z
A       [  210]            I                                  X   Z
A     .............................................           X   Z
A     :               DEL=-DEL/3                  :           X   Z
A     :...........................................:           X   Z
A                          I                                  X   Z
A                          I                                  X   Z
A      /'''''''''''''''''''''''''''''''''''''''''\  TRUE      X   Z
A     <      IF(ABS(DEL).LT.1.E-6) GO TO 201      >-------0   X   Z
A      \........................................./        U   X   Z
A                          I  FALSE                       U   X   Z
A                          I                              U   X   Z
A                          I                              U   X   Z
A                /''''''''''''''''''''\                   U   X   Z
A               :      GO TO 200       :------------------V   Z   (see line)
A                \..................../                   U   X   Z
A                                                         U   X   Z
A                                                         U   X   Z
A                          0<---------------------------------------0
A       [  211]            I                              U   X
A     .............................................       U   X
A     :               DEL=DEL/3                   :       U   X
A     :...........................................:       U   X
A                          I                              U   X
A                          0<---------------------------------0
```

```
A    [  200]                  I                                          U
A .........................................                              U
--:                   CONTINUE                  :                        U
  :.........................................:                            U
                              I                                          U
                              I                                          U
  ...........................................                            U
  :                BSA=PI/2.0-1.0E-6            :                        U
  :                   TH3=0.0                   :                        U
  :.........................................:                            U
                              I                                          U
                              I                                          U
    /''''''''''''''''''''''''''''''''''''''''/                           U
   /                 WRITE(1,2)              /                           U
  /......................................../                             U
                              I                                          U
                              I---[ 2 FORMAT(¤ BASEMENT ANGLE DOES ]    U
                              I   [NOT CONVERGE¤)                  ]    U
                              I                                          U
                              O<-----------------------------------------O
    [  201]                   I
  ...........................................
  :                   BSA3=TH3                  :
  :.........................................:
                              I
                              I
               /''''''''''''''''''''\
              :        RETURN        :
               \..................../
```

```
.................................................
\              SUBROUTINE LOSS(JJ)             /
 \............................................../
                        I
                        I
 ...............................................
 : COMMON ZB,ZR,ZS,C1,C2,C3,RH1,RH2,RH3,G,D,   :
 : ALPH9,CS,BZ,REF                             :
 : COMMON /DATA/LZERO,FZERO,L70,F70,TH70,      :
 : L71,F71,DBLOSS,FREQ,THETA,ALOSS0,ALOSSM,    :
 : FM,TIR,THC,THRC,TH1P,BETA                   :
 :        COMMON/AL/F(6),ALOSS(6,90)           :
 : COMMON /R/NSAP,RV21,RV32,RSIN2,RDTS,RDTR,   :
 : RT,RGI                                      :
 : DIMENSION RV21(90),RV32(90),RSIN2(90),      :
 : RDTS(90),RDTR(90),RT(90),RGI(90)            :
 : COMMON /B/BV21,BV32,BSIN2,BTRF,BGI,BLS,     :
 : BT,BDTS,BDTR                                :
 : COMMON /S/SV21,SV32,SSIN2,STRF,SGI,SLS,     :
 : ST,SDTS,SDTR                                :
 : DIMENSION BV21(90),BV32(90),BSIN2(90),      :
 : BTRF(90),BGI(90),BLS(90),BT(90),BDTS(90),   :
 : BDTR(90)                                    :
 : DIMENSION SV21(90),SV32(90),SSIN2(90),      :
 : STRF(90),SGI(90),SLS(90),ST(90),SDTS(90),   :
 : SDTR(90)                                    :
 : COMMON /BS/BSV21,BSV32,BSSIN2,BSTRF,BSGI,   :
 : BSLS,BST,BSDTS,BSDTR                        :
 : DIMENSION BSV21(90),BSV32(90),BSSIN2(90),   :
 : BSTRF(90),BSGI(90),BSLS(90),BST(90),        :
 : BSDTS(90),BSDTR(90)                         :
 : COMPLEX AUX99,V,AIM,AUX1,AR(16),PH(16)      :
 :               DIMENSION BR(4)               :
 :              REAL LZERO,L70,L71             :
 :.............................................:
                        I
                        I---[**********************************]
                        I   [**********************************]
                        I   [***                               ]
                        I   [ THIS SUBROUTINE COMPUTES         ]
                        I   [APPARENT LOSS DUE TO PROPAGATION]
                        I   [**********************************]
                        I   [**********************************]
                        I   [***                               ]
                        I
                        I
```

```
                        ........................................
                        :           PI=3.141592654             :
                        :   ALPHO=ALOG(10.)/4/PI/10000*ALPH9   :
                        :         EX=ALOG10(EXP(1.))           :
                        :             PI2=2*PI                 :
                        :          AIM=CMPLX(0.,1.)            :
                        :          SQRT2=SQRT(2.)              :
                        :          F1=F(JJ)/SQRT2              :
                        :          F2=F(JJ)*SQRT2              :
                        :       FPI2D=4.*PI*F(JJ)*D/C2         :
                        :             NAV1=8                   :
                        : FPIINC = FPI2D*(SQRT2-1.0/SQRT2)/NAV1:
                        :    FPIIN=FPI2D-(NAV1-1)*FPIINC/2.    :
                        :          NTHC=THC*180/PI             :
                        :            N=90-NTHC                 :
                        :......................................:
                                           I
                                           I---[ COMPUTE LOSS FOR ANGLES ABOVE
                                           I   [CRITICAL (CAUSTIC)
                                           I
                                           I
                        ........................................
A---------------------->:           DO 10 I=1,90               :
A                       :......................................:
A                                          I
A    [     10]                             I
A                       ........................................
------------------------:          ALOSS(JJ,I)=25.             :
                        :......................................:
                                           I
                                           I
                        ........................................
A---------------------->:           DO 100 I=1,N               :
A                       :......................................:
A                                          I
A                                          I
A                       ........................................
A                       :             J=91-I                   :
A                       :          FPIAUX=FPIIN                :
A                       :             AUX=0.                   :
A                       :......................................:
A                                          I
A                                          I
A                       ........................................
A  B------------------->:         DO 20 NAV=1,NAV1             :
A  B                    :......................................:
A  B                                       I
A  B                                       I
A  B                    ........................................
A  B                    :       ALPH2=FPIAUX*ASIN2(J)          :
A  B                    :           C=COS(ALPH2)               :
A  B                    :           S=SIN(ALPH2)               :
A  B                    : VV=(RV21(J)+RV32(J)*C)**2+(RV32(J)*S)**2 :
A  B                    : VV=VV/((1+RV21(J)*RV32(J)*C)**2+(RV21(J)* :
A  B                    : RV32(J)*S)**2)                       :
A  B                    :           AUX=AUX+VV                 :
A  B                    :       FPIAUX=FPIAUX+FPIINC           :
A  B                    :......................................:
```

```
A B                                          I
A B                        [    20]          I
A B                    ..........................................
A ---------------------:                 CONTINUE               :
A                      :........................................:
A                                            I
A                                            I
A                      ..........................................
A                      :             VV=AUX/NAV1                :
A                      :            DR=PI2*RDTR(J)              :
A                      :            DS=PI2*RDTS(J)              :
A                      :              AUX=DR+DS                 :
A                      :      DT=SIN(F2*AUX)-SIN(F1*AUX)        :
A                      :              DT=DT/AUX                 :
A                      :              AUX=DS-DR                 :
A                      : DT=DT+SIN(F2*AUX)/AUX-SIN(F1*AUX)/AUX  :
A                      : DT=DT-2*(SIN(F2*DS)-SIN(F1*DS))/DS     :
A                      : DT=DT-2*(SIN(F2*DR)-SIN(F1*DR))/DR     :
A                      :             DT=DT/2/F1+1               :
A                      :               DT=VV*DT                 :
A                      :        ALPH2=FPI2D*BSSIN2(J)/2         :
A                      :             C=COS(ALPH2)               :
A                      :             S=SIN(ALPH2)               :
A                      : V=BSTRF(J)/CMPLX((1+BSV32(J)*BSV21(J))*C, :
A                      : (BSV32(J)*BSV21(J)-1)*S)**2            :
A                      :         VV=CABS(V)*BSGI(J)*REF         :
A                      :                AUX=0                   :
A                      :........................................:
A                                            I
A                                            I
A                       /''''''''''''''''''''''''''''''''''''''\  TRUE
A                      <        IF(VV.EQ.0.)GO TO 120           >-----------O
A                       \....................................../            Z
A                                            I  FALSE                       Z
A                                            I                              Z
A                                            I                              Z
A                      ..........................................           Z
A                      :               BR(1)=VV                 :           Z
A                      :               BR(2)=-VV                :           Z
A                      :               BR(3)=-VV                :           Z
A                      :               BR(4)=VV                 :           Z
A                      :     V=CMPLX(BST(J),ALPH0*BSLS(J))      :           Z
A                      :              PH(1)=PI2*V               :           Z
A                      :        PH(2)=PI2*(V+BSDTS(J))          :           Z
A                      :        PH(3)=PI2*(V+BSDTR(J))          :           Z
A                      :    PH(4)=PI2*(V+BSDTR(J)+BSDTS(J))     :           Z
A                      :                 V=0                    :           Z
A                      :........................................:           Z
A                                            I                              Z
A                                            I                              Z
A                      ..........................................           Z
A B------------------->:              DO 110 K=1,3              :           Z
A B                    :........................................:           Z
A B                                          I                              Z
A B                                          I                              Z
```

```
A B       ............................................          Z
A B       :                 NA=K+1                      :          Z
A B       :............................................:          Z
A B                           I                                     Z
A B                           I                                     Z
A B       ............................................          Z
A B C-->:            DO 110 L=NA,4                      :          Z
A B C     :............................................:          Z
A B C                         I                                     Z
A B C                         I                                     Z
A B C     ............................................          Z
A B C     :           AUX=BR(K)*BR(L)                   :          Z
A B C     :      AUX1=(PH(K)-CONJG(PH(L)))*AIM          :          Z
A B C     :............................................:          Z
A B C                         I                                     Z
A B C                         I                                     Z
A B C      /''''''''''''''''''''''''''''''''''''''''''\  TRUE     Z
A B C     < IF(REAL(AUX1)*F2.LT.-40.)GO TO 110        >-------0   Z
A B C      \........................................../        X   Z
A B C                         I  FALSE                     X   Z
A B C                         I                            X   Z
A B C                         I                            X   Z
A B C     ............................................     X   Z
A B C     : V=V+AUX*(CEXP(F2*AUX1)-CEXP(F1*AUX1))/      :     X   Z
A B C     : AUX1                                        :     X   Z
A B C     :............................................:     X   Z
A B C                         I                            X   Z
A B C                         0<---------------------------0   Z
A B C       [  110]           I                                     Z
A B C     ............................................          Z
A ------:                CONTINUE                       :          Z
A         :............................................:          Z
A                             I                                     Z
A                             I                                     Z
A         ............................................          Z
A         :               AUX=2*REAL(V)                 :          Z
A         :         AUX2=-2*PI2*ALPHO*BSLS(J)           :          Z
A         :............................................:          Z
A                             I                                     Z
A                             I                                     Z
A          /''''''''''''''''''''''''''''''''''''''''''\  TRUE     Z
A         <       IF(AUX2*F2.LT.-40.)GO TO 120        >-----------V
A          \........................................../            Z
A                             I  FALSE                              Z
A                             I                                     Z
A                             I                                     Z
A         ............................................          Z
A         : AUX=AUX+4*(EXP(F2*AUX2)-EXP(F1*AUX2))/      :          Z
A         : AUX2*BF(1)**2                               :          Z
A         :............................................:          Z
A                             I                                     Z
A                             0<--------------------------------0
A           [  120]           I
```

```
A       .............................................
A       :        DT=DT+AUX/(2*RGI(J))**2/F1          :
A       :       ALOSS(JJ,J)=-10.*ALOG10(DT)          :
A       :............................................:
A                             I
A         [  100]             I
A       .............................................
------:                   CONTINUE                   :
        :............................................:
                              I
                              I
        .............................................
        :                  NMAX=91-N                 :
        :............................................:
                              I
                              I---[ COMPUTE LOSS FOP AMGLES BETWEEN]
                              I    [TIR AND THS                    ]
                              I
                              I
        .............................................
        :               NTIR=TIR*180/PI+1            :
        :                 N=NMAX-NTIR                :
        :............................................:
                              I
                              I
        .............................................
A---->:                 DO 200 I=1,N                 :
A       :............................................:
A                             I
A                             I
A       .............................................
A       :                  J=NMAX-I                  :
A       :............................................:
A                             I
A                             I
A        /'''''''''''''''''''''''''''''''''''''''''\  TRUE
A       <        IF(J.LT.NSAP)GO TO 800              >-----------------0
A        \.........................................../                 Z
A                             I  FALSE                                 Z
A                             I                                        Z
A                             I---[ COMPUTE REFLECTION COEFFICIENT ]   Z
A                             I                                        Z
A                             I---[OMPUTE FREQ AVERAGE ABSOLUTE    ]   Z
A                             I    [REFLECTION                     ]   Z
A                             I                                        Z
A                             I                                        Z
A       .............................................                  Z
A       :                FPIAUX=FPIIN                :                 Z
A       :                   AUX=0                    :                 Z
A       :............................................:                 Z
A                             I                                        Z
A                             I                                        Z
A       .............................................                  Z
A B-->:              DO 130 NAV=1,NAV1               :                 Z
A B     :............................................:                 Z
```

```
A B                          I                                                  7
A B                          I                                                  7
A B   ......................................................                   7
A B   :           ALPH2=FPIAUX*RSIN2(J)                      :                  7
A B   :                C=COS(ALPH2)                          :                  7
A B   :                S=SIN(ALPH2)                          :                  7
A B   : VV=(RV21(J)+RV32(J)*C)**2+(RV32(J)*S)**2             :                  7
A B   : VV=VV/((1+RV21(J)*RV32(J)*C)**2+(RV21(J)*            :                  7
A B   : RV32(J)*S)**2)                                       :                  7
A B   :                AUX=AUX+VV                            :                  7
A B   :           FPIAUX=FPIAUX+FPIINC                       :                  7
A B   :......................................................:                  7
A B                          I                                                  7
A B     [   130]             I                                                  7
A B   ......................................................                   7
A ---:                 CONTINUE                              :                  7
A     :......................................................:                  7
A                            I                                                  7
A                            I                                                  7
A     ......................................................                   7
A     :                VV=AUX/NAV1                           :                  7
A     :           ALPH2=FPI2D*RSIN2(J)                       :                  7
A     :                C=COS(ALPH2)                          :                  7
A     :                S=SIN(ALPH2)                          :                  7
A     : V=CMPLX(RV21(J)+RV32(J)*C,RV32(J)*S)                 :                  7
A     : V=V/CMPLX(1+RV21(J)*RV32(J)*C,RV21(J)*               :                  7
A     : RV32(J)*S)                                           :                  7
A     :       V=V/CABS(V)*RGI(J)*SQRT(VV)                    :                  7
A     :                AR(1)=V                               :                  7
A     :                AR(2)=-V                              :                  7
A     :                AR(3)=-V                              :                  7
A     :                AR(4)=V                               :                  7
A     :            PH(1)=PI2*RT(J)                           :                  7
A     :        PH(2)=PI2*(RT(J)+RDTS(J))                     :                  7
A     :        PH(3)=PI2*(RT(J)+RDTR(J))                     :                  7
A     :    PH(4)=PI2*(RT(J)+RDTR(J)+RDTS(J))                 :                  7
A     :......................................................:                  7
A                            I                                                  7
A                            I---[ COMPUTE BIG TRANSMISSION        ]            7
A                            I   [COEFFICIENT                      ]            7
A                            I                                                  7
A                            I                                                  7
A     ......................................................                   7
A     :                AR(5)=0                               :                  7
A     :                AR(6)=0                               :                  7
A     :                AR(7)=0                               :                  7
A     :                AR(8)=0                               :                  7
A     :......................................................:                  7
A                            I                                                  7
A                            I                                                  7
A      /''''''''''''''''''''''''''''''''''''''''''''''''''''\  TRUE            7
A     <      IF(BTRF(J).EQ.0.)GO TO 205                      >-------------------0   7
A      \....................................................../                  X   7
A                            I  FALSE                                        X   7
A                            I                                               X   7
A                            I                                               X   7
```

```
A      /'''''''''''''''''''''''''''''''''''''''''''\  TRUE          X    Z
A     <        IF(BT(J).LT.RT(J))GO TO 205          >---------------V    Z
A      \.........................................../                 X    Z
A                              I   FALSE                             X    Z
A                              I                                     X    Z
A                              I                                     X    Z
A     ............................................                   X    Z
A     :          ALPH2=FPI2D*BSIN2(J)/2           :                  X    Z
A     :               C=COS(ALPH2)                 :                  X    Z
A     :               S=SIN(ALPH2)                 :                  X    Z
A     : V=BTRF(J)/CMPLX((1+BV32(J)*BV21(J))*C,(    :                  X    Z
A     : BV32(J)*BV21(J)-1)*S)**2                   :                  X    Z
A     :                V=V*BGI(J)                  :                  X    Z
A     :                 AR(5)=V                    :                  X    Z
A     :                 AR(6)=-V                   :                  X    Z
A     :                 AR(7)=-V                   :                  X    Z
A     :                 AR(8)=V                    :                  X    Z
A     :        V=CMPLX(BT(J),ALPHO*BLS(J))         :                  X    Z
A     :               PH(5)=PI2*V                  :                  X    Z
A     :          PH(6)=PI2*(V+BDTS(J))             :                  X    Z
A     :          PH(7)=PI2*(V+BDTR(J))             :                  X    Z
A     :      PH(8)=PI2*(V+BDTS(J)+BDTP(J))         :                  X    Z
A     :...........................................:                  X    Z
A                              I                                     X    Z
A                              O<------------------------------------O    Z
A      [  205]                 I                                          Z
A     ............................................                        Z
A     :                 CONTINUE                   :                      Z
A     :...........................................:                       Z
A                              I                                          Z
A                              I---[ COMPUTE SMALL TRANSMISSION     ]     Z
A                              I   [COEFFICIENT                     ]     Z
A                              I                                          Z
A                              I                                          Z
A     ............................................                        Z
A     :          ALPH2=FPI2D*SSIN2(J)/2           :                       Z
A     :               C=COS(ALPH2)                 :                       Z
A     :               S=SIN(ALPH2)                 :                       Z
A     : V=STRF(J)/CMPLX((1+SV32(J)*SV21(J))*C,(    :                       Z
A     : SV32(J)*SV21(J)-1)*S)**2                   :                       Z
A     :            V=-V*SGI(J)*AIM                 :                       Z
A     :                 AR(9)=V                    :                       Z
A     :                AR(10)=-V                   :                       Z
A     :                AR(11)=-V                   :                       Z
A     :                 AR(12)=V                   :                       Z
A     :        V=CMPLX(ST(J),ALPHO*SLS(J))         :                       Z
A     :               PH(9)=PI2*V                  :                       Z
A     :          PH(10)=PI2*(V+SDTS(J))            :                       Z
A     :          PH(11)=PI2*(V+SDTR(J))            :                       Z
A     :      PH(12)=PI2*(V+SDTS(J)+SDTR(J))        :                       Z
A     :...........................................:                       Z
A                              I                                          Z
A                              I---[ COMPUTE BASEMENT RAY TRANSMISSI]     Z
A                              I   [N COEFFICIENT                   ]     Z
A                              I                                          Z
A                              I                                          Z
```

```
A          ..............................................            Z
A          :        ALPH2=FPI2D*BSSIN2(J)/2             :            Z
A          :              C=COS(ALPH2)                  :            Z
A          :              S=SIN(ALPH2)                  :            Z
A          : V=BSTRF(J)/CMPLX((1+BSV32(J)*BSV21(J))*C,  :            Z
A          : (BSV32(J)*BSV21(J)-1)*S)**2                :            Z
A          :            V=V*BSGI(J)*REF                 :            Z
A          :               AR(13)=V                     :            Z
A          :               AR(14)=-V                    :            Z
A          :               AR(15)=-V                    :            Z
A          :               AR(16)=V                     :            Z
A          :     V=CMPLX(BST(J),ALPHD*BSLS(J))          :            Z
A          :              PH(13)=PI2*V                  :            Z
A          :        PH(14)=PI2*(V+BSDTS(J))             :            Z
A          :        PH(15)=PI2*(V+BSDTR(J))             :            Z
A          :    PH(16)=PI2*(V+BSDTS(J)+BSDTR(J))        :            Z
A          :                 V=0                        :            Z
A          :............................................:            Z
A                              I                                     Z
A                              I                                     Z
A          ..............................................            Z
A B------>:            DO 210 K=1,15                    :            Z
A B        :............................................:            Z
A B                            I                                     Z
A B                            I                                     Z
A B        ..............................................            Z
A B        :               NA=K+1                       :            Z
A B        :............................................:            Z
A B                            I                                     Z
A B                            I                                     Z
A B        ..............................................            Z
A B C--->:             DO 210 L=NA,16                   :            Z
A B C      :............................................:            Z
A B C                          I                                     Z
A B C                          I                                     Z
A B C      ..............................................            Z
A B C      :        AUX99=AR(K)*CONJG(AR(L))            :            Z
A B C      :............................................:            Z
A B C                          I                                     Z
A B C                          I                                     Z
A B C       /''''''''''''''''''''''''''''''''''''''''''\  TRUE       Z
A B C      <      IF(CABS(AUX99).EQ.0.)GO TO 210         >---------0  Z
A B C       \............................................/         X  Z
A B C                          I   FALSE                          X  Z
A B C                          I                                  X  Z
A B C                          I                                  X  Z
A B C      ..............................................         X  Z
A B C      :      AUX1=(PH(K)-CONJG(PH(L)))*AIM         :         X  Z
A B C      :............................................:         X  Z
A B C                          I                                  X  Z
A B C                          I                                  X  Z
A B C       /''''''''''''''''''''''''''''''''''''''''''\  TRUE    X  Z
A B C      <    IF(REAL(AUX1)*F2.LT.-40)GO TO 210        >---------V  Z
A B C       \............................................/        X  Z
A B C                          I   FALSE                          X  Z
A B C                          I                                  X  Z
A B C                          I                                  X  Z
```

```
A B C  ...............................................         X    Z
A B C  : V=V+AUX99*(CEXP(F2*AUX1)-CEXP(F1*AUX1))/    :         X    Z
A B C  : AUX1                                         :         X    Z
A B C  :.............................................:         X    Z
A B C                       I                                   X    Z
A B C                       O<----------------------------------O    Z
A B C    [  210]            I                                        Z
A B C  ...............................................              Z
A -----:                 CONTINUE                    :              Z
A      :.............................................:              Z
A                           I                                        Z
A                           I                                        Z
A      ...............................................              Z
A      :               AUX=2*REAL(V)                 :              Z
A      :.............................................:              Z
A                           I                                        Z
A                           I                                        Z
A       /'''''''''''''''''''''''''''''''''''''''''''''\  TRUE         Z
A      <     IF(CABS(AR(13)).EQ.0.)GO TO 209          >-----------O  Z
A       \............................................./           X  Z
A                           I  FALSE                              X  Z
A                           I                                     X  Z
A                           I                                     X  Z
A      ...............................................            X  Z
A      :         AUX2=-2*PI2*ALPHO*BSLS(J)           :            X  Z
A      :.............................................:            X  Z
A                           I                                     X  Z
A                           I                                     X  Z
A       /'''''''''''''''''''''''''''''''''''''''''''''\  TRUE     X  Z
A      <       IF(AUX2*F2.LT.-40)GO TO 209            >-----------V  Z
A       \............................................./           X  Z
A                           I  FALSE                              X  Z
A                           I                                     X  Z
A                           I                                     X  Z
A      ...............................................            X  Z
A      : AUX=AUX+4*(EXP(F2*AUX2)-EXP(F1*AUX2))/      :            X  Z
A      : AUX2*CABS(AR(13))**2                        :            X  Z
A      :.............................................:            X  Z
A                           I                                     X  Z
A                           O<----------------------------------O  Z
A        [  209]            I                                        Z
A      ...............................................              Z
A      :           AUX2=-2*PI2*ALFHO*BLS(J)          :              Z
A      :           AUX2=-2*PI2*ALPHO*BLS(J)          :              Z
A      :.............................................:              Z
A                           I                                        Z
A                           I                                        Z
A       /'''''''''''''''''''''''''''''''''''''''''''''\  TRUE         Z
A      <       IF(AUX2*F2.LT.-40)GO TO 211            >-----------O  Z
A       \............................................./           X  Z
A                           I  FALSE                              X  Z
A                           I                                     X  Z
A                           I                                     X  Z
A       /'''''''''''''''''''''''''''''''''''''''''''''\  TRUE     X  Z
A      <     IF(CABS(AR(5)).EQ.0.)GO TO 211           >-----------V  Z
A       \............................................./           X  Z
A                           I  FALSE                              X  Z
A                           I                                     X  Z
A                           I                                     X  Z
```

```
A         ..................................................           X      Z
A         : AUX=AUX+4*(EXP(F2*AUX2)-EXP(F1*AUX2))/          :           X      Z
A         : AUX2*CABS(AR(5))**2                             :           X      Z
A         :.................................................:           X      Z
A                                 I                                     X      Z
A                                 O<------------------------------------O      Z
A            [  211]              I                                            Z
A         ..................................................                  Z
A         :            AUX2=-2*PI2*ALPHO*SLS(J)             :                  Z
A         :.................................................:                  Z
A                                 I                                            Z
A                                 I                                            Z
A          /''''''''''''''''''''''''''''''''''''''''''''''\   TRUE             Z
A         <       IF(AUX2*F2.LT.-40)GO TO 212              >------------O      Z
A          \................................................/            X      Z
A                                 I   FALSE                             X      Z
A                                 I                                     X      Z
A                                 I                                     X      Z
A          /''''''''''''''''''''''''''''''''''''''''''''''\   TRUE      X      Z
A         <      IF(CABS(AR(9)).EQ.O.)GO TO 212            >------------V      Z
A          \................................................/            X      Z
A                                 I   FALSE                             X      Z
A                                 I                                     X      Z
A                                 I                                     X      Z
A         ..................................................           X      Z
A         : AUX=AUX+4*(EXP(F2*AUX2)-EXP(F1*AUX2))/          :           X      Z
A         : AUX2*CABS(AR(9))**2                             :           X      Z
A         :.................................................:           X      Z
A                                 I                                     X      Z
A                                 O<------------------------------------O      Z
A            [  212]              I                                            Z
A         ..................................................                  Z
A         :           AUX=AUX/F1+4*CABS(AR(1))**2           :                  Z
A         :.................................................:                  Z
A                                 I                                            Z
A                                 I                                            Z
A          /''''''''''''''''''''''''''''''''''''''''''''''\   TRUE             Z
A         <          IF(AUX.GT.O.)GO TO 213                >------------O      Z
A          \................................................/            X      Z
A                                 I   FALSE                             X      Z
A                                 I                                     X      Z
A                                 I                                     X      Z
A         ..................................................           X      Z
A         :               ALOSS(JJ,J)=25.                   :           X      Z
A         :.................................................:           X      Z
A                                 I                                     X      Z
A                                 I                                     X      Z
A                    /''''''''''''''''''''''\                           X      Z
A                    :       GO TO 200      :-------------------O       X      Z
A                    \....................../                   U       X      Z
A                                                               U       X      Z
A                                                               U       X      Z
A                                 O<------------------------------------O      Z
A            [  213]              I                             U              Z
```

```
A                       ...........................................   U      7
A                       : ALOSS(JJ,J)=-10.*ALOG10(AUX/(2.*RGI(J))** :  U      7
A                       : 2)                                        :  U      7
A                       :...........................................:  U      7
A                                            I                         U      7
A                                            O<------------------------O      7
A                        [  200]             I                                7
A                       ...........................................           7
-----------------------:                 CONTINUE                  :          7
                        :...........................................:          7
                                             I                                7
                         [  700]             I                                7
                        ...........................................           7
                        :                  N=J-1                    :          7
                        :                   NA=J                    :          7
                        :...........................................:          7
                                             I                                7
                                             I                                7
                        ...........................................           7
A--------------------->:                DO 701 I=1,N               :          7
A                       :...........................................:          7
A                                            I                                7
A                                            I                                7
A                       ...........................................           7
A                       :                  J=NA-I                   :          7
A                       :...........................................:          7
A                                            I                                7
A                                            I                                7
A                        /'''''''''''''''''''''''''''''''''''''''''\   TRUE   7
A                       <          IF(J.LT.NSAP)GO TO 999           >-------O 7
A                        \.........................................../        X 7
A                                            I   FALSE                      X 7
A                                            I                              X 7
A                                            I                              X 7
A                       ...........................................         X 7
A                       :               DR=PI2*RDTR(J)              :       X 7
A                       :               DS=PI2*RDTS(J)              :       X 7
A                       :                 AUX=DR+DS                 :       X 7
A                       :        DT=SIN(F2*AUX)-SIN(F1*AUX)         :       X 7
A                       :                 DT=DT/AUX                 :       X 7
A                       :                 AUX=DS-DR                 :       X 7
A                       : DT=DT+SIN(F2*AUX)/AUX-SIN(F1*AUX)/AUX     :       X 7
A                       : DT=DT-2*(SIN(F2*DS)-SIN(F1*DS))/DS        :       X 7
A                       : DT=DT-2*(SIN(F2*DR)-SIN(F1*DR))/DR        :       X 7
A                       :               DT=DT/2/F1+1                :       X 7
A                       :          ALOSS(JJ,J)=-10.*ALOG10(DT)      :       X 7
A                       :...........................................:       X 7
A                                            I                              X 7
A                        [  701]             I                              X 7
A                       ...........................................         X 7
-----------------------:                 CONTINUE                  :        X 7
                        :...........................................:       X 7
                                             I                              X 7
                                             I                              X 7
                                 /''''''''''''''''''''''\                   X 7
                                :       GO TO 999         :-----------------V 7
                                 \....................../                   X 7
```

```
                                                                          X    Z
                                                                          X    Z
                                 O<----------------------------------------------O
   [  800]                       I                                        X
 ..........................................                                X
 :                N=J-1                   :                               X
 :                 NA=J                   :                               X
 :........................................:                               X
                                 I                                        X
                                 I                                        X
 ..........................................                                X
A-->:              DO 801  I=1,N          :                               X
A   :.........................................:                           X
A                                I                                        X
A                                I                                        X
A   ..........................................                            X
A   :              J=NA-I                 :                               X
A   :.........................................:                           X
A                                I                                        X
A                                I                                        X
A    /''''''''''''''''''''''''''''''''''''''\   TRUE                      X
A   <       IF(J.LT.NTIR)GO TO 999           >------------------------V
A    \......................................../                            X
A                                I   FALSE                                X
A                                I                                        X
A                                I---[ COMPUTE BIG TRANSMISSION       ]   X
A                                I    [COEFFICIENT                    ]   X
A                                I                                        X
A                                I                                        X
A   ..........................................                            X
A   :          ALOSS(JJ,J)=25.            :                               X
A   :       ALPH2=FPI2D*BSIN2(J)          :                               X
A   :          C=COS(ALPH2)               :                               X
A   :          S=SIN(ALPH2)               :                               X
A   : V=BTRF(J)/CMPLX(((1+BV32(J)*BV21(J))*C,(   :                        X
A   : BV32(J)*BV21(J)-1)*S)**2            :                               X
A   :          V=V*BGI(J)                 :                               X
A   :        AUX3=CABS(V)**2              :                               X
A   :.........................................:                           X
A                                I                                        X
A                                I                                        X
A    /''''''''''''''''''''''''''''''''''''''\   TRUE                      X
A   <       IF(AUX3.EQ.0)GO TO 801           >---------------------------O
A    \......................................../                            X    Z
A                                I   FALSE                                X    Z
A                                I                                        X    Z
A                                I                                        X    Z
A   ..........................................                            X    Z
A   :          DR=PI2*BDTR(J)             :                               X    Z
A   :          DS=PI2*BDTS(J)             :                               X    Z
A   :          AUX=DR+DS                  :                               X    Z
A   :    DT=SIN(F2*AUX)-SIN(F1*AUX)       :                               X    Z
A   :          DT=DT/AUX                  :                               X    Z
A   :          AUX=DS-DR                  :                               X    Z
A   : DT=DT+SIN(F2*AUX)/AUX-SIN(F1*AUX)/AUX  :                            X    Z
A   : DT=DT-2*(SIN(F2*DS)-SIN(F1*DS))/DS  :                               X    Z
A   : DT=DT-2*(SIN(F2*DR)-SIN(F1*DR))/DR  :                               X    Z
A   :          DT=DT/2/F1+1               :                               X    Z
A   :    AUX2=-2*PI2*ALPHJ*BLS(J)*EX      :                               X    Z
A   :.........................................:                           X    Z
```

```
A                              I                                        X   Z
A                              I                                        X   Z
A     /''''''''''''''''''''''''''''''''''''''''\  TRUE                  X   Z
A    <        IF(AUX2*F2.LT.-40.)GO TO 801      >-------------------------------V
A     \......................................../                        X   Z
A                              I   FALSE                                X   Z
A                              I                                        X   Z
A                              I                                        X   Z
A    ..........................................                         X   Z
A    : ALOSS(JJ,J)=-10*(AUX2+ALOG10(AUX3*DT/RGI(  :                      X   Z
A    : J)**2))                                  :                       X   Z
A    :..........................................:                       X   Z
A                              I                                        X   Z
A                              I                                        X   Z
A     /''''''''''''''''''''''''''''''''''''''''\  FALSE                 X   Z
A    <           IF(ALOSS(JJ,J).GT.25.)         >--------------I        X   Z
A     \......................................../               I        X   Z
A                              I   TRUE                        I        X   Z
A                              I                               I        X   Z
A    ..........................................                I        X   Z
A    : ALOSS(JJ,J)=25                           :              I        X   Z
A    :..........................................:              I        X   Z
A                              I                               I        X   Z
A                              O<-----------------------------------------------O
A      [   801]                I                                        X
A    ..........................................                         X
----:                  CONTINUE                 :                       X
    :..........................................:                        X
                               I                                        X
                               O<---------------------------------------O
       [   999]                I
                     /''''''''''''''''''''\
                    :        RETURN        :
                     \..................../
```

```
 .............................................
 \             SUBROUTINE GCOMP              /
  \.........................................../
                      I
                      I---[ THIS SUBROUTINE COMPUTES THE   ]
                      I   [GRADIENT (G)                    ]
                      I   [ AND ITERATES TO FIND THE ACTUAL]
                      I   [CRITICAL                        ]
                      I   [ ANGLE (THC). BOTH ARE THEN     ]
                      I   [RETURNED TO THE                 ]
                      I   [ MAIN PROGRAM.                  ]
                      I
                      I
 ............................................
 : COMMON ZB,ZR,ZS,C1,C2,C3,RH1,RH2,RH3,G,D, :
 : ALPHO,CS,BZ,REF                           :
 : COMMON /DATA/LZERO,FZERO,L70,F70,TH70,    :
 : L71,F71,DBLOSS,FREQ,THETA, ALOSSO,ALOSSM, :
 : FM,TIR,THC,THRC,TH1B,BETA                 :
 :            REAL LZERO,L70,L71             :
 :              PI=3.14159265                :
 :                 THRC=30.                  :
 :                 THC0=THC                  :
 :                  B=BETA                   :
 :           THRC=THRC*(PI/180.)             :
 :                 THINC=1.                  :
 :              D1=2*ZB-ZR-ZS                :
 :       TH3=ACOS((C3/C1)*COS(THRC))         :
 :          FACT1=(2.*C3*B)/(1.+B)           :
 :              SIN3=SIN(TH3)                :
 :              COS3=COS(TH3)                :
 :             SIN3SQ=SIN3*SIN3              :
 :             COS3SQ=COS3*COS3              :
 : FACT2=1.+(1./(2.*B))*(1.+(TH3/(SIN3*COS3) :
 : ))                                        :
 : GZERO=(FACT1*(1./COS3SQ)*FACT2+((C3/(1.+B) :
 : ) *(1./COS3SQ)*(1.-((TH3*(COS3SQ-SIN3SQ)) :
 : /(SIN3*COS3)))) *((C3/C1)*(SIN(THRC)/     :
 : SIN3))/(D1/SIN(THRC)**2)                  :
 : R=(D1/TAN(THRC))+(FACT1*TAN(TH3)/GZERO)*  :
 : FACT2                                     :
 :             THC1=ATAN(D1/R)               :
 :           THC1=THC1*(180./PI)             :
 :               MAXIT=100                   :
 :...........................................:
                      I
   [  100]            I
 ............................................
A---------------->:        DO 600 IT=1,MAXIT                   :
A                 :...........................................:
A                                     I
A                                     I
```

```
A    ..................................................
A    :             THRC=THRC*(180./PI)                :
A    :              THRC=THRC+THINC                   :
A    :             THRC=THRC*(PI/180.)                :
A    :        TH3=ACOS((C3/C1)*COS(THRC))             :
A    :          FACT1=(2.*C3*B)/(1.+B)                :
A    :               SIN3=SIN(TH3)                    :
A    :               COS3=COS(TH3)                    :
A    :             SIN3SQ=SIN3*SIN3                   :
A    :             COS3SQ=COS3*COS3                   :
A    : FACT2=1.+(1./(2.*B))*(1.+(TH3/(SIN3*COS3)     :
A    : ))                                             :
A    : GZERO=(FACT1*(1./COS3SQ)*FACT2+(C3/(1.+B)     :
A    : ) *(1./COS3SQ)*(1.-((TH3*(COS3SQ-SIN3SQ))     :
A    : /(SIN3*COS3)))) *((C3/C1)*(SIN(THRC)/         :
A    : SIN3))/(D1/SIN(THRC)**2)                       :
A    : R=(D1/TAN(THRC))+(FACT1*TAN(TH3)/GZERO)*       :
A    : FACT2                                          :
A    :              THC2=ATAN(D1/R)                   :
A    :            THC2=THC2*(180./PI)                 :
A    :................................................:
A                           I
A                           I
A     /''''''''''''''''''''''''''''''''''''''''''''\  TRUE
A    <  IF(ABS(THC0-THC1).LE. 1.E-4) GO TO 700      >------------0
A     \............................................/            Z
A                           I   FALSE                           Z
A                           I                                   Z
A                           I                                   Z
A     /''''''''''''''''''''''''''''''''''''''''''''\  TRUE      Z
A    < IF(((THC0-THC1)*(THC0-THC2)) .GE. 0.) GO     >--------0   Z
A    < TO 500                                       >        X   Z
A     \............................................/         X   Z
A                           I   FALSE                    X   Z
A                           I                            X   Z
A                           I                            X   Z
A    ..................................................  X   Z
A    :              THINC= -THINC/2.                  :  X   Z
A    :................................................:  X   Z
A                           I                            X   Z
A                           0<---------------------------0   Z
A      [  500]              I                                Z
A    ..................................................      Z
A    :                 THC1=THC2                      :      Z
A    :................................................:      Z
A                           I                                Z
A      [  600]              I                                Z
A    ..................................................      Z
----:                  CONTINUE                       :      Z
     :................................................:      Z
                            I                                Z
                            I                                Z
      /''''''''''''''''''''''''''''''''''''''''''''/         Z
     /        WRITE(1,650) MAXIT,THC0,THC2        /          Z
    /............................................../
```

```
                                                                            Z
                      I                                                     Z
                      I---[ 650 FORMAT(1X,I5,2X,¤ITERATIONS]                Z
                      I    [AND STILL NO SOLUTION¤,/, 1 1X,¤]               Z
                      I    [THC0=¤,F10.6,5X,¤THC2=¤,F10.6)   ]              Z
                      I                                                     Z
                      I                                                     Z
             /''''''''''''''''''''\                                         Z
            :      GO TO 800       :-------------------------------O        Z
             \..................../                                X        Z
                                                                   X        Z
                                                                   X        Z
                      O<-----------------------------------------------------O
   [  700]            I                                            X
 ..................................................                X
 :                    THC=THC2                    :                X
 :                    G=GZERO                     :                X
 :................................................:                X
                      I                                            X
                      O<-------------------------------------------O
   [  800]            I
             /''''''''''''''''''''\
            :       RETURN         :
             \..................../
```

```
                 /''''''''''''''''''''\
                :        BEGIN          :
                 \..................../
                          I
                          I
.........................................................
:              BLOCK DATA NULL                          :
: COMMON /DATA/ALZERO,FZERO,AL70,F70,TH70,              :
: AL71,F71,DBLOSS,FREQ, THETA,ALOSSO,                   :
: ALOSSM,FM,TIR,TMC,THRC,TH1B,BETA                      :
:              COMMON /ALPH/GAM                         :
:                COMMON /T/T                            :
: COMMON /R/NSAP,RV21(90),RV32(90),RSIN2(               :
: 90),RDTS(90),RDTR(90), RT(90),RGI(90)                 :
: COMMON /B/BV21(90),BV32(90),BSIN2(90),                :
: BTRF(90),BGI(90),BLS(90), BT(90),BDTS(90)             :
: ,BDTR(90)                                             :
: COMMON /S/SV21(90),SV32(90),SSIN2(90),                :
: STRF(90),SGI(90),SLS(90), ST(90),SDTS(90)             :
: ,SDTR(90)                                             :
: COMMON /BS/BSV21(90),BSV32(90),BSSIN2(90)             :
: ,BSTRF(90),BSGI(90), BSLS(90),BST(90),                :
: BSDTS(90),BSDTR(90)                                   :
:        COMMON/AL/F(6),ALOSS(6,90)                     :
: DATA F/50.,100.,200.,400.,800.,1600./                 :
:.......................................................:
                          I
                          I
                 /''''''''''''''''''''\
                :          END          :
                 \..................../
```

APPENDIX C

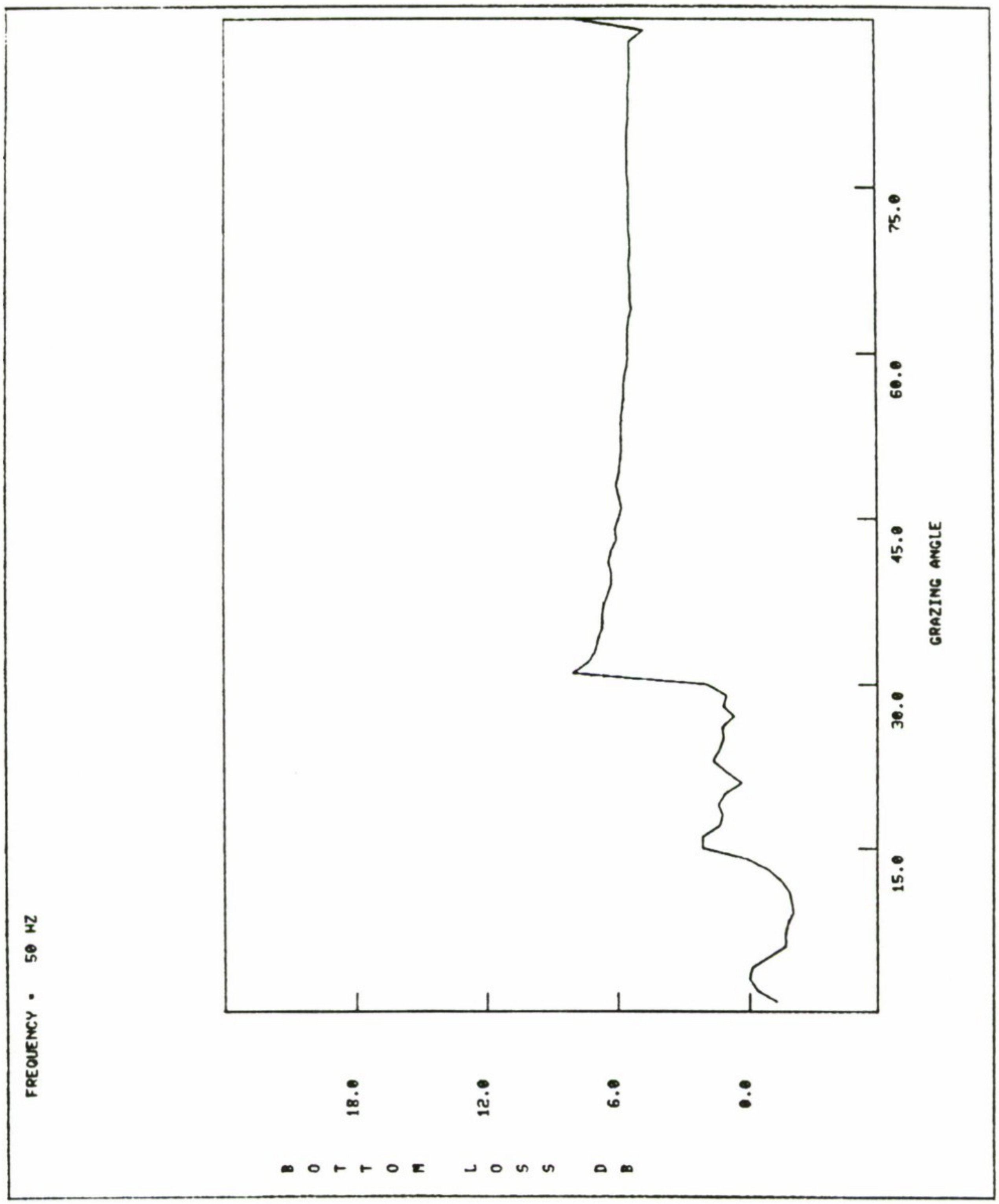
RUN STREAM

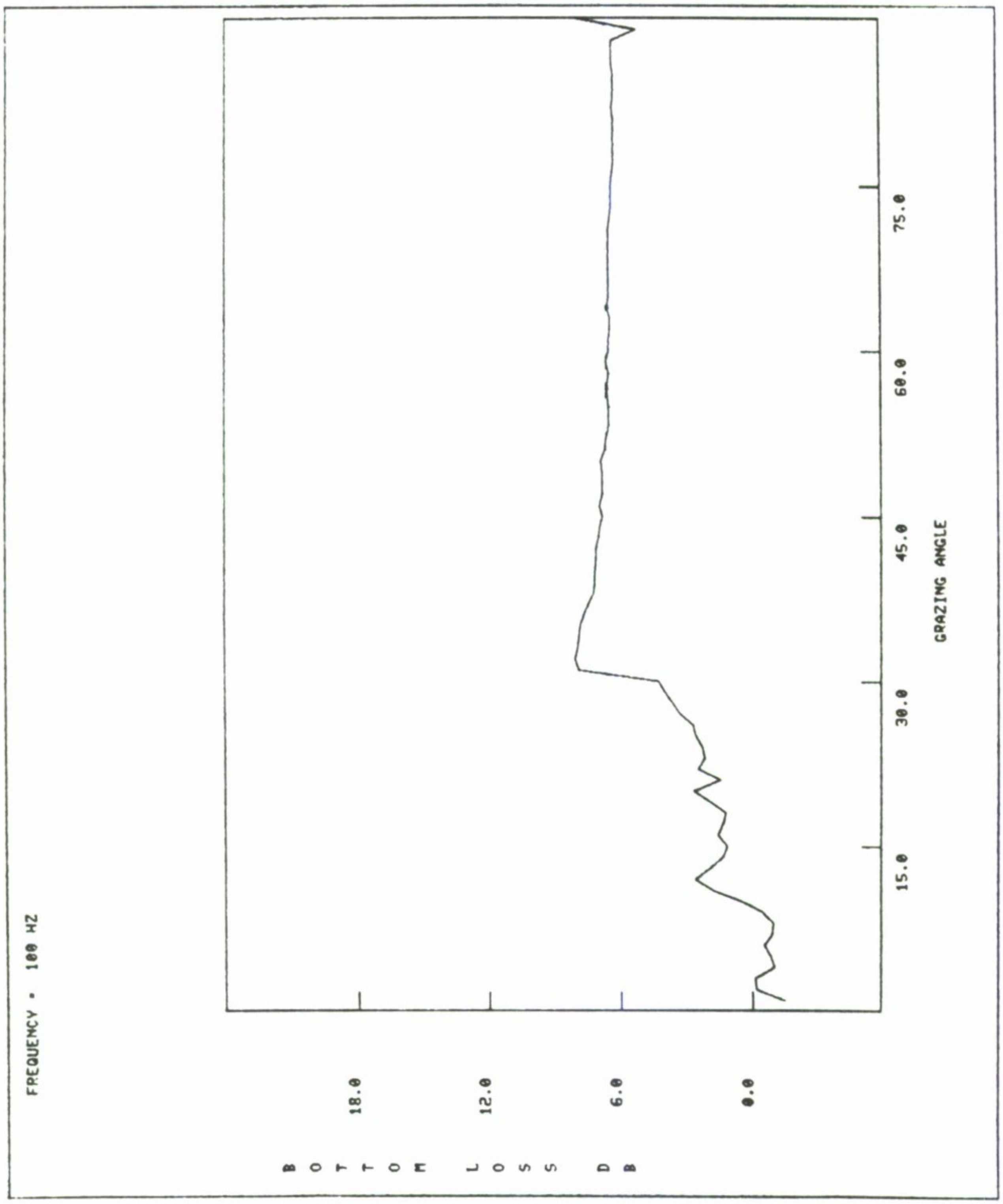
An example of the computer input run stream for each of the two input options follows.

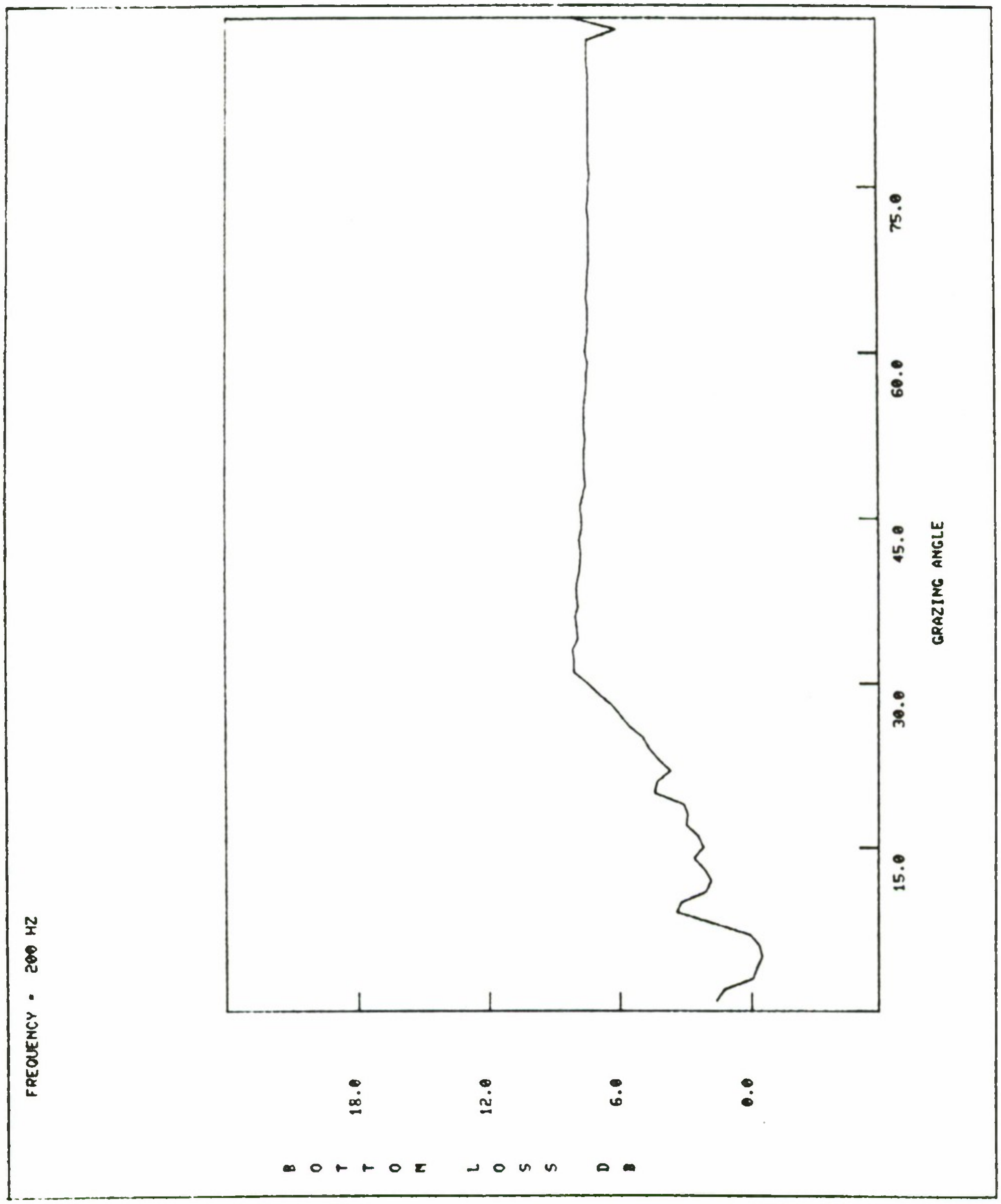
```
:RUN,BTLS9
 INPUT OPTIONS ARE:  Ø = INPUT GEO-PARAMETERS
                     1 = INPUT BOTTOM LOSS
                     2 = END PROGRAM
 ENTER STATION NUMBER AND INPUT OPTION:
8  Ø
 ENTER THE TWO-WAY TRAVEL TIME THICKNESS IN 1ØTHS OF SECONDS:
4.58
 ENTER THE WATER DEPTH:
18ØØ.Ø
 ENTER SOURCE DEPTH AND RECEIVER DEPTH:
244.Ø 3Ø5.Ø
 ENTER SOUND SPEED AT SOURCE OR RECEIVER - WHICHEVER IS SHALLOWER:
1511.72
 ENTER SOUND SPEED AT THE BOTTOM OF THE WATER:
1535.11
 ENTER RATIO OF SPEED IN SEDIMENT TO SPEED AT BOTTOM OF WATER:
.996
 ENTER GRADIENT AT TOP OF SEDIMENT AND CANONICAL CURVE TYPE:
1.7  .86
 ENTER THIN LAYER DENSITY, SEDIMENT DENSITY AND THIN LAYER THICKNESS IN METERS:
2.33 2.33 .Ø4
```

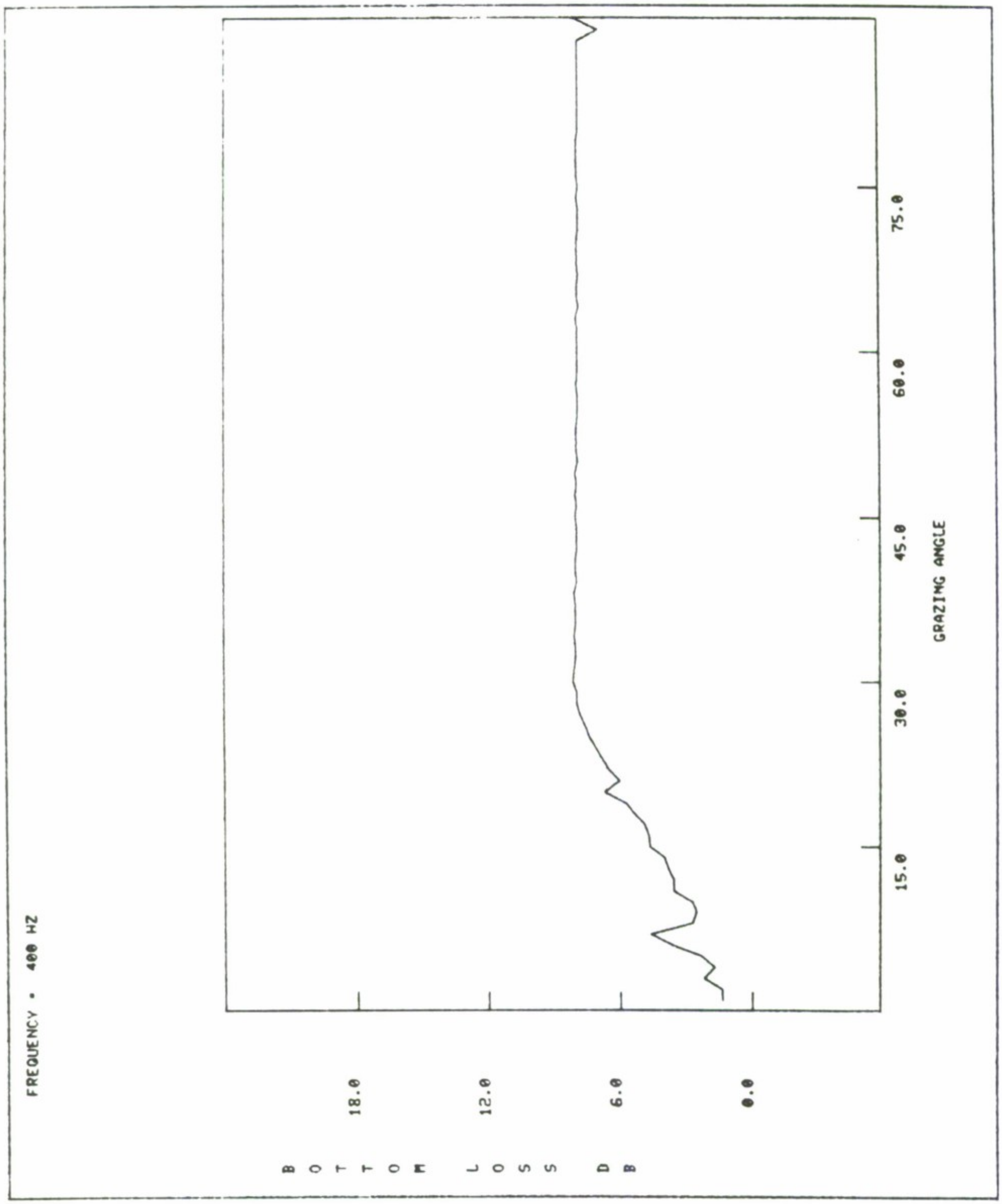
```
 ENTER SURFACE ATTENUATION IN DB/M/KHZ:
.Ø21
 ENTER ATTENUATION PROFILE GRADIENT AND BASEMENT REFLECTION COEFFICIENT IN
PRESSURE:
.ØØØ15  .7Ø8


RUN,BTLS9
 INPUT OPTIONS ARE:  Ø = INPUT GEO-PARAMETERS
                     1 = INPUT BOTTOM LOSS
                     2 = END PROGRAM
 ENTER STATION NUMBER AND INPUT OPTION:
8 1
 ENTER THE TWO-WAY TRAVEL TIME THICKNESS IN 1ØTHS OF SECONDS:
4.58
 ENTER THE WATER DEPTH:
18ØØ.Ø
 ENTER SOURCE DEPTH AND RECEIVER DEPTH:
244.Ø  3Ø5.Ø
 ENTER SOUND SPEED AT SOURCE OR RECEIVER - WHICHEVER IS SHALLOWER:
1511.72
 ENTER SOUND SPEED AT THE BOTTOM OF THE WATER:
1535.11
                         ATTENUATION CALCULATION
 FOR A POINT BELOW THE CAUSTIC WHERE BL CURVE IS NEARLY LINEAR,
 ENTER A LOSS, FREQUENCY AND ANGLE: (ANG=APPROX 2Ø, FREQ = APPROX 2ØØ)
5 2Ø 2ØØ
 ENTER LOW FREQ LOSS LEVEL AT HIGH ANGLES,
```

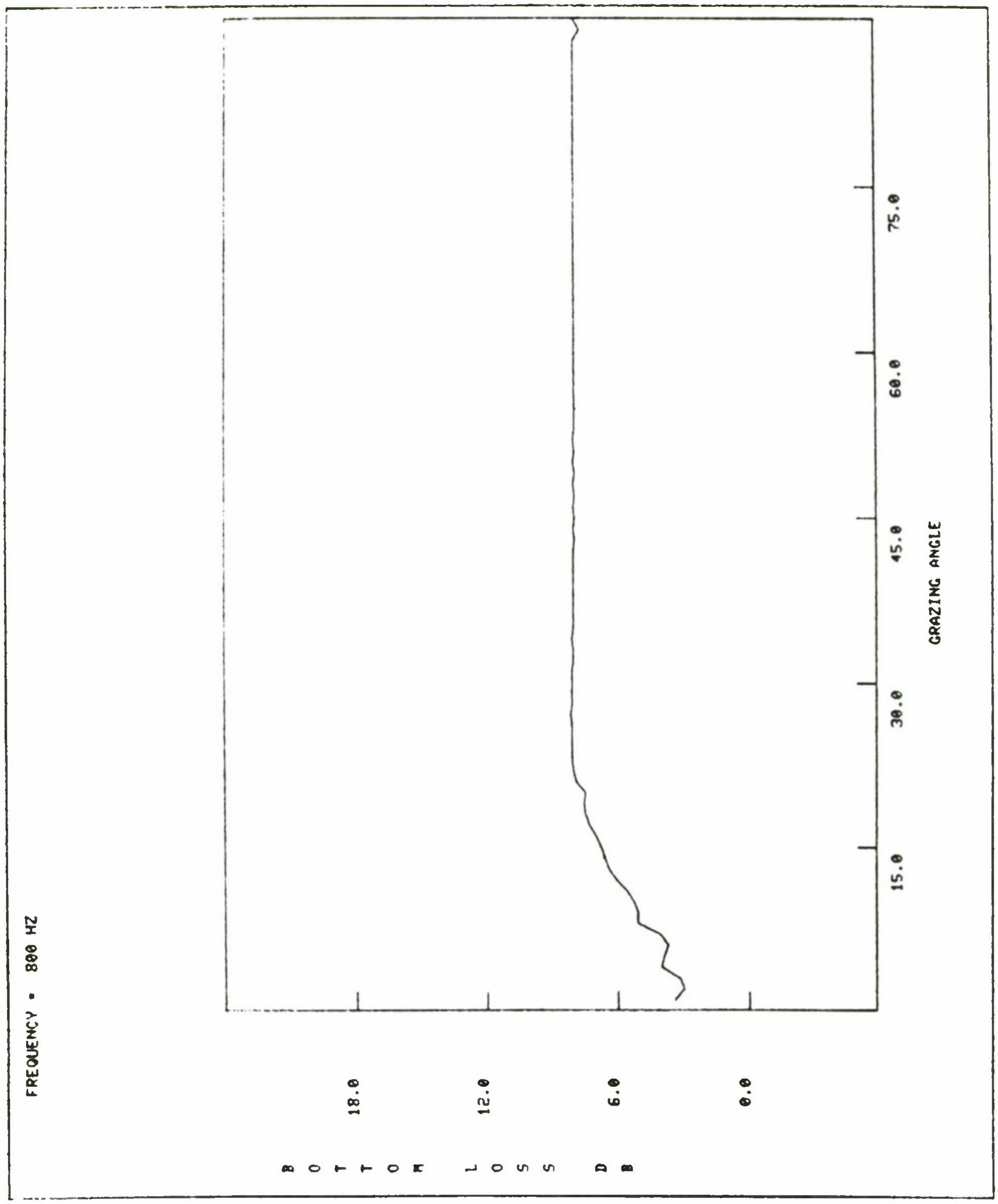
```
THE MINIMUM LOSS LEVEL AT HIGH ANGLES
AND THE FREQUENCY OF THE MINIMUM LOSS:
10 6 80
ENTER ANGLE OF TOTAL INTERNAL REFLECTION,
ANGLE OF CAUSTIC,
RATIO OF SPEED IN SEDIMENT TO SPEED AT BOTTOM OF WATER:
55 34 .996
ENTER CANONICAL CURVE TYPE AND ATTENUATION PROFILE GRADIENT:
.86 1.7
ENTER BASEMENT REFLECTION COEFFICIENT IN PRESSURE UNITS:
.708
/BTL14 *RUNTIME ERROR* 22UN @ 40126
/BTL14 *RUNTIME ERROR* 22UN @ 4022
```


FREQUENCY = 50 HZ
BOTTOM LOSS DB
18.0
12.0
6.0
0.0
15.0
30.0
45.0
60.0
75.0
GRAZING ANGLE

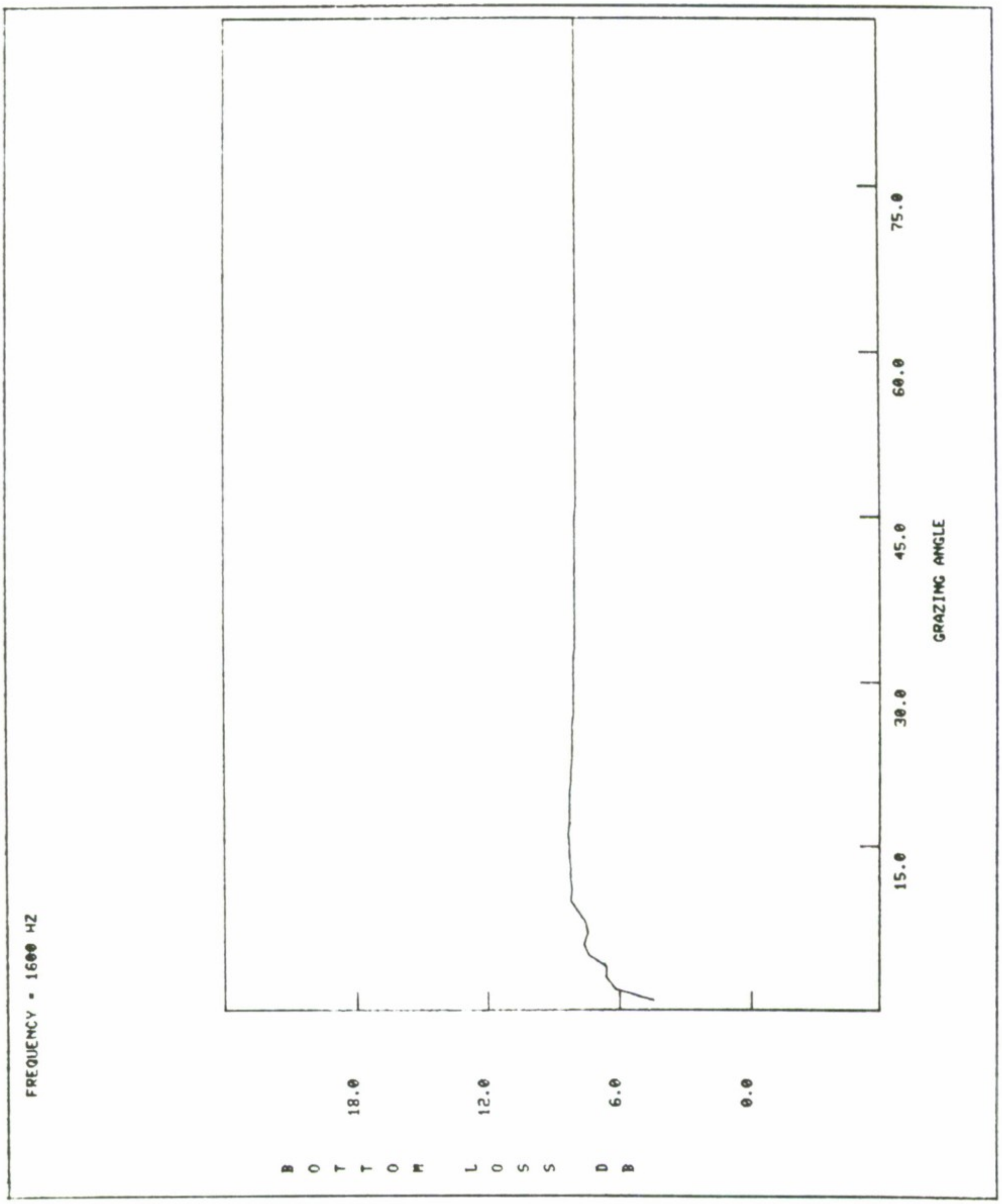

FREQUENCY = 100 HZ
BOTTOM LOSS DB
18.0
12.0
6.0
0.0
15.0
30.0
45.0
60.0
75.0
GRAZING ANGLE


FREQUENCY = 200 HZ
BOTTOM LOSS DB
0.0
6.0
12.0
18.0
15.0
30.0
45.0
60.0
75.0
GRAZING ANGLE


FREQUENCY = 400 HZ
BOTTOM LOSS DB
18.0
12.0
6.0
0.0
15.0
30.0
45.0
60.0
75.0
GRAZING ANGLE



FREQUENCY = 800 HZ
BOTTOM LOSS DB
18.0
12.0
6.0
0.0
15.0
30.0
45.0
60.0
75.0
GRAZING ANGLE


FREQUENCY = 1600 HZ
BOTTOM LOSS DB
18.0
12.0
6.0
0.0
15.0
30.0
45.0
60.0
75.0
GRAZING ANGLE

```
BTL10
 INPUT OPTIONS ARE:  0 • INPUT GEO-PARAMETERS
                     1 • INPUT BOTTOM LOSS
                     2 • END PROGRAM

  ENTER STATION NUMBER AND INPUT OPTION:
3 0
 ENTER THE TWO-WAY TRAVEL TIME THICKNESS IN 10THS OF SECONDS:
4.52
 ENTER THE WATER DEPTH:
1300
 ENTER SOURCE DEPTH AND RECEIVER DEPTH:
244 305
 ENTER SOUND SPEED AT SOURCE OR RECEIVER - WHICHEVER IS SHALLOWER:
1511.7
 ENTER SOUND SPEED AT THE BOTTOM OF THE WATER:
1535.1
 ENTER RATIO OF SPEED IN SEDIMENT TO SPEED AT BOTTOM OF WATER:
.996
 ENTER GRADIENT AT TOP OF SEDIMENT AND CANONICAL CURVE TYPE:
1.7 .86
 ENTER THIN LAYER DENSITY, SEDIMENT DENSITY AND THIN LAYER THICKNESS IN METERS:
2.33 2.33 .04
 ENTER SURFACE ATTENUATION IN DB/M/KHZ:
.021
 ENTER ATTENUATION PROFILE GRADIENT AND BASEMENT REFLECTION COEFFICIENT IN PRESSURE:
.00015 .708
```

CRITICAL ANGLES

TIR = 0.00 RAT = .9960 THC = 30.74 THRC = 46.97
THB = 30.67 THRB = 45.07
TWTT = .46 BZ = 422.13 CRD = 477.57
G500 = 1.34 C500 = 2279.83 A500 = .096 GAM = .00015

GEO-PARAMETERS

RAT= .9960
RH2= 2.33 RH3= 2.33
D = .04
G = 1.70 BET= .86
AL0= .021GAM= .00015
BZ = 422.13 REF= .71

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| -1.25 | -.32 | .05 | -.11 | -.88 | -1.65 | -1.68 | -1.79 |
| -2.02 | -1.97 | -1.81 | -1.45 | -.86 | .15 | 2.22 | 2.21 |
| 1.42 | 1.29 | 1.47 | 1.19 | .37 | 1.09 | 1.71 | 1.42 |
| 1.24 | 1.30 | .77 | 1.20 | 1.11 | 2.03 | 8.07 | 7.35 |
| 7.07 | 6.95 | 6.75 | 6.74 | 6.67 | 6.54 | 6.35 | 6.31 |
| 6.47 | 6.33 | 6.10 | 6.12 | 5.99 | 5.82 | 5.97 | 6.09 |
| 5.98 | 5.89 | 5.82 | 5.82 | 5.83 | 5.86 | 5.79 | 5.76 |
| 5.75 | 5.69 | 5.55 | 5.53 | 5.56 | 5.57 | 5.48 | 5.39 |
| 5.40 | 5.43 | 5.45 | 5.47 | 5.45 | 5.46 | 5.49 | 5.50 |
| 5.50 | 5.51 | 5.52 | 5.52 | 5.52 | 5.52 | 5.52 | 5.52 |
| 5.51 | 5.49 | 5.48 | 5.46 | 5.45 | 5.45 | 5.45 | 5.45 |
| 4.78 | 7.87 | | | | | | |
| -1.47 | -.14 | -.10 | -.97 | -.83 | -.51 | -.85 | -.91 |
| -.39 | .54 | 1.81 | 2.65 | 2.00 | 1.41 | 1.25 | 1.66 |
| 1.41 | 1.30 | 1.96 | 2.71 | 1.52 | 2.57 | 2.26 | 2.36 |
| 2.68 | 2.80 | 3.39 | 3.68 | 4.07 | 4.35 | 7.93 | 8.13 |
| 7.99 | 7.94 | 7.89 | 7.69 | 7.55 | 7.27 | 7.24 | 7.23 |
| 7.16 | 7.16 | 7.06 | 7.00 | 6.85 | 6.97 | 6.89 | 6.87 |
| 6.85 | 6.91 | 6.75 | 6.72 | 6.57 | 6.57 | 6.58 | 6.62 |
| 6.62 | 6.58 | 6.70 | 6.58 | 6.58 | 6.50 | 6.53 | 6.62 |
| 6.57 | 6.57 | 6.55 | 6.56 | 6.56 | 6.56 | 6.58 | 6.53 |
| 6.43 | 6.42 | 6.43 | 6.41 | 6.35 | 6.32 | 6.33 | 6.34 |
| 6.36 | 6.36 | 6.35 | 6.35 | 6.35 | 6.37 | 6.37 | 6.38 |
| 5.28 | 7.95 | | | | | | |
| 1.64 | 1.27 | -.05 | -.20 | -.46 | -.32 | .07 | 1.74 |
| 3.44 | 3.30 | 2.16 | 1.88 | 2.20 | 2.69 | 2.23 | 2.48 |
| 3.00 | 2.99 | 3.13 | 4.45 | 4.38 | 3.74 | 4.26 | 4.71 |
| 5.01 | 5.58 | 6.02 | 6.41 | 7.02 | 7.55 | 8.11 | 8.14 |
| 8.17 | 7.95 | 8.00 | 8.06 | 7.95 | 7.98 | 7.99 | 7.90 |
| 7.81 | 7.82 | 7.91 | 7.76 | 7.80 | 7.82 | 7.74 | 7.62 |
| 7.65 | 7.62 | 7.65 | 7.56 | 7.62 | 7.65 | 7.66 | 7.58 |
| 7.51 | 7.52 | 7.50 | 7.57 | 7.50 | 7.49 | 7.50 | 7.50 |
| 7.51 | 7.45 | 7.45 | 7.39 | 7.39 | 7.41 | 7.41 | 7.40 |
| 7.48 | 7.42 | 7.41 | 7.36 | 7.42 | 7.42 | 7.41 | 7.41 |
| 7.42 | 7.43 | 7.44 | 7.43 | 7.43 | 7.44 | 7.44 | 7.45 |
| 6.08 | 8.08 | | | | | | |
| 1.43 | 1.39 | 2.27 | 1.75 | 2.38 | 3.67 | 4.64 | 2.78 |
| 2.64 | 2.79 | 3.62 | 3.66 | 3.88 | 4.06 | 4.73 | 4.79 |
| 4.94 | 5.45 | 5.76 | 6.77 | 6.06 | 6.60 | 6.84 | 7.18 |
| 7.46 | 7.64 | 7.88 | 8.03 | 8.03 | 8.17 | 8.13 | 8.07 |
| 8.08 | 8.10 | 8.08 | 8.06 | 8.04 | 8.12 | 8.03 | 8.05 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 8.07 | 8.02 | 8.02 | 8.02 | 8.07 | 7.99 | 8.05 | 8.03 |
| 8.05 | 7.97 | 8.03 | 8.02 | 8.03 | 7.95 | 7.96 | 7.96 |
| 7.99 | 7.96 | 7.94 | 7.95 | 7.94 | 7.96 | 7.99 | 7.91 |
| 7.93 | 7.97 | 7.91 | 7.95 | 7.96 | 7.93 | 7.90 | 7.92 |
| 7.91 | 7.92 | 7.89 | 7.93 | 7.93 | 7.94 | 7.95 | 7.91 |
| 7.90 | 7.88 | 7.89 | 7.90 | 7.90 | 7.90 | 7.90 | 7.90 |
| 6.97 | 8.00 | | | | | | |
| 3.44 | 3.01 | 3.18 | 4.06 | 3.94 | 3.73 | 4.08 | 5.13 |
| 5.11 | 5.33 | 5.60 | 6.07 | 6.44 | 6.64 | 6.83 | 7.07 |
| 7.37 | 7.55 | 7.60 | 7.52 | 7.92 | 8.04 | 8.11 | 8.16 |
| 8.11 | 8.16 | 8.16 | 8.12 | 8.13 | 8.10 | 8.11 | 8.10 |
| 8.08 | 8.11 | 8.08 | 8.05 | 8.08 | 8.06 | 8.09 | 8.06 |
| 8.05 | 8.05 | 8.03 | 8.05 | 8.04 | 8.05 | 8.03 | 8.05 |
| 8.02 | 8.05 | 8.03 | 8.04 | 8.02 | 8.03 | 8.01 | 8.02 |
| 8.03 | 8.03 | 8.03 | 8.01 | 8.02 | 8.02 | 8.01 | 8.02 |
| 8.02 | 8.01 | 8.02 | 8.03 | 8.01 | 8.01 | 8.02 | 8.01 |
| 8.00 | 8.02 | 8.02 | 8.02 | 8.01 | 8.00 | 8.00 | 8.01 |
| 8.00 | 8.01 | 8.02 | 8.02 | 8.00 | 8.00 | 7.99 | 7.99 |
| 7.72 | 8.00 | | | | | | |
| 4.49 | 6.21 | 6.63 | 6.65 | 7.42 | 7.63 | 7.45 | 7.59 |
| 7.94 | 8.25 | 8.18 | 8.27 | 8.25 | 8.31 | 8.31 | 8.34 |
| 8.31 | 8.32 | 8.32 | 8.28 | 8.28 | 8.23 | 8.20 | 8.19 |
| 8.18 | 8.16 | 8.15 | 8.13 | 8.14 | 8.11 | 8.11 | 8.11 |
| 8.09 | 8.08 | 8.08 | 8.08 | 8.09 | 8.06 | 8.06 | 8.07 |
| 8.05 | 8.06 | 8.06 | 8.05 | 8.05 | 8.03 | 8.03 | 8.03 |
| 8.03 | 8.03 | 8.03 | 8.02 | 8.03 | 8.03 | 8.03 | 8.03 |
| 8.02 | 8.02 | 8.02 | 8.02 | 8.02 | 8.02 | 8.01 | 8.02 |
| 8.02 | 8.01 | 8.02 | 8.01 | 8.02 | 8.01 | 8.01 | 8.01 |
| 8.02 | 8.01 | 8.01 | 8.00 | 8.01 | 8.02 | 8.00 | 8.01 |
| 8.01 | 8.01 | 8.00 | 8.01 | 8.01 | 8.00 | 8.01 | 8.01 |
| 7.99 | 8.01 | | | | | | |

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