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RECORDS 1960, No. 13

A DISCUSSION ON CORRECTIONS FOR WEATHERING AND ELEVATION IN EXPLORATION SEISMIC WORK, 1959

by

K. R. Vale,

and members of the Seismic Group,
Bureau of Mineral Resources, Geology and Geophysics

BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

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Note to accompany Record No. 1960-13.

Since the above Record was prepared it has been found necessary to adopt a new list of symbols for use in exploration seismic work. Many of the changes are only slight ones - e.g. Ve is used in place of V_e.

A list of the new symbols is attached.

ERRATA

The following errors should be corrected in Record 1960-13 :-

Page 5, 2nd line from bottom

in place of	t	insert	Σt

Page 6, line beginning "Case (2).."

in place of	x	insert	Δx

Page 8, lines 12 and 13

in place of	x_1	insert	x_n

Page 9, last equation

in place of	$V_{horizontal}$	insert	V_h

Plate 1

in place of	Δt	insert	ts

Plate 3, near centre

in place of	ds	insert	$\overline{ds}$

STANDARD SYMBOLS IN SEISMIC COMPUTATIONS.

VELOCITY:

v	:	Velocity of longitudinal wave, variable function.
V	:	Velocity of longitudinal wave, constant value, i.e. for a particular horizon or interval.
v_i	:	Interval velocity, variable function - the limiting value of $\frac{\Delta d}{\Delta t}$ at depth d.
Vi	:	Interval velocity, average velocity over discrete interval of depth.
v_a	:	Average velocity, variable function, e.g. $v_a = V_o + a.t.$
Va	:	Average vertical velocity to a particular depth.
V_o	:	Velocity at zero depth, e.g. $v_i = V_o + a.d.$
Vo	:	Average vertical velocity in weathering layer.
Vo'	:	Velocity in "second" weathering layer of "Two Layer Case", i.e. velocity recorded on near geophones of reflection spread when two velocities are recorded.
Vo_1, Vo_2, etc.	:	Velocity in successive weathering layers compounded in Vo.
Ve	:	Vertical velocity in sub-weathering layer or elevation correction velocity.
Vh	:	Horizontal velocity in sub-weathering layer, generally equals Ve, but not necessarily.
V_1	:	Velocity in first layer of layered section, should equal Vh and sometimes Ve.
V_2	:	Velocity in second layer of layered section.
V_n	:	Velocity in n'th layer, generally refractor under consideration.
V_m	:	Velocity in m'th layer, but not refractor under consideration, :- $m < n$.
V_{2U}, V_{2D}	:	Apparent velocities shooting up-dip and down-dip for refraction through second layer of velocity V_2.
V_{nU}, V_{nD}	:	Apparent velocities shooting up-dip and down-dip for refraction through n'th layer of velocity V_n.

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Va_n :	Average velocity of overburden above the n'th layer of velocity V_n.
Vcab :	Velocity in well-logging cable.

<u>TIME</u>:

t :	General symbol for time as a variable function. In reflection calculations, the vertical time of travel from the datum to the reflecting horizon at depth d and return to datum.
t_x :	Travel time of reflection or refraction from the shot point to a geophone at distance x.
t_n :	Recorded (i.e. uncorrected) reflection time at n'th geophone.
t_o :	(i) Recorded (i.e. uncorrected) reflection time at shot point. (ii) Accepted time of travel from shot to well geophone. Ideally equals tv_1, tha_1, and thb_1.
tc :	(i) General symbol for reflection time corrected to datum, i.e. reflection time to any geophone corrected for elevation, weathering and spread delays. (ii) Vertical time from datum plane to well geophone.
tr :	General symbol for refraction time from shot to geophone (i.e. first break time) on reflection spread. Commonly used for refraction time to geophone adjacent to shot point.
t_Ar_n :	Refraction time (first break time) from shot point "A" to geophone "n" on reflection spread.
t_h :	Horizontal travel time in sub-weathering layer between shot points.
[illegible] :	Horizontal travel time in sub-weathering layer between adjacent geophones.
ts :	Uphole time.
$\overline{ts}$:	Equivalent uphole time below geophone adjacent to shot point.
tw :	Vertical time in weathering layer (weathering time), commonly at shot point.
tw_n :	Weathering time at n'th geophone.
tw_1 :	Weathering time at geophone adjacent to shot point.

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tw'	:	First estimate of weathering time in graphic solution of weathering problems.
Wc	:	General symbol for weathering correction, but commonly used for weathering correction at shot point. Weathering correction is time required to replace weathering layer by sub-weathering layer.
Wc_g	:	Weathering correction at geophone.
Ec	:	General symbol for elevation correction, but commonly used for elevation correction at shot point. Elevation correction is time required to reduce recorded times to equivalent datum level times.
Ec_g	:	Elevation correction at geophone.
Σt	:	Sum of weathering and elevation corrections.
t_{sd}	:	Vertical time from shot to datum.
t_{wd}	:	Vertical time from base of weathering to datum.
Δt	:	General symbol for time increments or variations caused by changes in depths or distances.
Δt_n	:	Difference between recorded reflection times at n'th geophone and shot point.
$Ls\,\Delta t_n$	:	The least square value of the Δt_n's for ten geophone intervals. Equal to the least square of redorded reflection times t_n.
Δt_x	:	The spread correction at a distance x from shot point. Spread correction is the increase in reflection time due to the distance of the geophone from the shot point for a horizontal reflecting interface.
$Ls\,\Delta t_x$	:	The least square value of the spread corrections involved in a reflection for ten geophone intervals.
Δtc	:	(i) General symbol for change in corrected reflection or refraction times due to the change in depth of the reflecting or refracting interface. (ii) Change in vertical time (tc) from datum to well geophone for change in well geophone depth, ΔD.
$Ls\ \Delta tc$	:	The least square value of the Δtc's of a reflection for ten geophone intervals. Equal to the least square of the corrected reflection times tc.

t_{xU}, t_{xD}	:	Refraction travel times shooting up-dip and down-dip.
T_n	:	Intercept time at shot point for n'th layer.
T_{n_7}	:	Intercept time for n'th layer at shot point 7.
T_{nU}, T_{nD}	:	Intercept times for n'th layer shooting up-dip and down-dip.
$T(2-58)_n$	:	Reciprocal time for n'th layer at shot point 58 shooting from shot point 2.
tv_1	:	First break time from shot to well-geophone on vertical component phone.
tv_2	:	First trough time from shot to well-geophone on vertical component phone.
tha_1	:	First break time from shot to well-geophone on horizontal "a" component phone.
tha_2	:	First trough time from shot to well-geophone on horizontal "a" component phone.
thb_1	:	First break time from shot to well-geophone on horizontal "b" component phone.
thb_2	:	First trough time from shot to well-geophone on horizontal "b" component phone.
t_{RG}	:	Travel time to reference geophone in well survey.
to_R	:	Reference reflection time in well survey.
t_{cab}	:	Calculated cable break time in well survey.
to_{cab}	:	Observed cable break time in well survey.

DISTANCE:

x	:	Distance from shot point.
x_n	:	Distance from shot point to n'th geophone.
Δx	:	(i) Interval between geophones of reflection or refraction spread.
		(ii) Distance from shot point to adjacent geophones of reflection spread.
x_c	:	Critical distance, i.e. the distance at which a refraction first becomes the first arrival.
x_{cn}	:	The critical distance for the n'th refractor.

S	:	Offset distance, i.e. the horizontal displacement of the refraction point from the geophone position or the shot point.
S_n	:	Offset distance for n'th layer.
S_{nU}, S_{nD}	:	Offset distances shooting up-dip and down-dip.
L	:	Length of geophone spread.
X	:	Distance from shot point to well.

DEPTH:

d	:	Depth below datum - variable function.
Do	:	Elevation of datum plane relative to sea level.
E	:	General symbol for elevation relative to datum.
Es	:	Elevation of shot point relative to datum.
Eg	:	Elevation of geophone relative to datum.
ds	:	Depth to shot below surface.
$\overline{ds}$	:	Equivalent depth of shot below geophone adjacent to shot point.
dw	:	Depth of weathering layer, i.e. thickness of weathering layer, commonly at shot point.
dw_n	:	Depth of weathering at n'th geophone.
dw_1	:	Depth of weathering at geophone adjacent to shot point.
D	:	(i) Depth below datum of a particular horizon. (ii) Depth below datum of well geophone.
D_n	:	Depth below datum of n'th layer of velocity V_n.
D_{nU}, D_{nD}	:	Depth to n'th layer vertically below shot point, shooting up-dip and down-dip.
H_m	:	Thickness of m'th layer of velocity V_m.
Δd	:	General symbol for variations in the depth d.

ΔD : (i) Change in depth of reflecting or refracting interface related to change (Δtc) in corrected time.

(ii) Difference in depths to well-geophone for adjacent positions.

ANGLES:

θ : Angle of dip of interface (reflecting or refracting).

i : General symbol for angle that a ray makes with vertical and/or normal, or, at a point of discontinuity, for the angle of incidence.

r : Angle of refraction.

i_{mn} : In cases of horizontal layering, critical angle of incidence for ray in layer of velocity V_m incident on layer of velocity V_n. Also angle ray makes with normal in m'th layer for critical refraction along the n'th layer.

Note: $\sin i_{mn} = \frac{V_m}{V_n}$.

i_{on} : Angle ray makes with normal in weathering layer for refraction along n'th layer.

i_{1n} : Angle ray makes with normal in first layer for refraction along n'th layer.

i_{in} : Critical angle of incidence on refractor of velocity V_n, where velocity immediately above refractor is v_i.

α : Vertical angle subtended at well geophone by straight line from shot to well.

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FOREWORD

The following discussion is not attributable to any particular author. It discusses the methods currently used by the Seismic Group of the Bureau of Mineral Resources, Geology and Geophysics, for the calculation of weathering and elevation corrections to be applied to reflection seismograms when transferring data from a seismogram to a cross-section. Most of the methods were introduced by me; they are based on methods used by two overseas contractors with whom I was associated in 1946-49.

Mr. T.E. Edwards introduced the "Graphical Method using Mean Velocity Times and Differentials". Mr. M.J. Goodspeed developed the charts relating V_o/V_e and $\overline{ts}/tr$ to $\overline{ds}/\Delta x$ and $dw_1/\Delta x$. The principles involved in the various methods are well covered in text books such as :

HEILAND, C.A.,	1946	GEOPHYSICAL EXPLORATION. Prentice-Hall, New York.
JAKOSKY, J.J.,	1950	EXPLORATION GEOPHYSICS. Trija, Los Angeles.
NETTLETON, L.L.,	1940	GEOPHYSICAL PROSPECTING FOR OIL. McGraw Hill, New York.
DOBRIN, M.B.,	1952	INTRODUCTION TO GEOPHYSICAL PROSPECTING. McGraw Hill, New York.
DIX, C.H.,	1952	SEISMIC PROSPECTING FOR OIL. Harper, New York.

but the presentation in this Record is more suited to the needs of staff working in the Seismic Group of the Bureau of Mineral Resources.

Because it is a practical guide in current use, it may also be of interest to others.

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INTRODUCTION.

The term "weathered layer", as used in seismic work, is a loose term which seldom correlates with the geological use of the term. It is used here to mean the complete set of strata above the deepest point penetrated by the refraction wave we record at a maximum distance of 1760 ft from the shot-point. (1760 ft is the longest spread commonly used for reflection seismic surveys). The highest velocity recorded is usually known as the sub-weathering velocity (V_e).

The weathered layer presents problems on every seismic survey because :

(1) It influences the way in which energy is transferred from the explosive charge to the ground, and

(2) allowance must be made for the increased travel-time of the reflected or refracted energy, owing to its relatively low velocity in the weathered layer (V_o).

In ordinary reflection-shooting, most weathering conditions may be classed as either :

the single-layer case, or

the two-layer case,

depending on whether one or two velocities are recorded. Generally, there will also be other layers whose velocities are not recorded. In the single-layer case the shot is fired below the weathered layer, and the velocity calculated from the refraction breaks is the sub-weathering velocity. In the two-layer case, the shot is assumed to be fired below all but one of the low-velocity layers; the velocity of the deepest section of the weathered zone is recorded on the near geophones and the sub-weathering velocity on the farther geophones (Fig.1). Both cases are solved by assuming an average velocity for the weathered layer above the layer recorded on the near geophones.

In the single-layer case, the time in the weathered layer can be accurately calculated for each geophone, and the weathering correction found for each trace, by either the graphical method or the reciprocal-time method (both described in a later Chapter). To calculate a correction for each geophone in the two-layer case, only the graphical method can be used unless special weathering shots are fired. Alternatively, if the variations in weathering thickness are not too erratic, reasonable average values of thickness and depth across the spread can be calculated by simple refraction techniques such as the intercept-time method.

During ordinary reflection-shooting the velocity in the first layer of weathering is not recorded, and a value must be assumed in order to make appropriate corrections. A constant check on this value - which is the mean of velocities in all the component layers of the so-called first layer - is made by calculating the depth of weathering (dw) both from the up-hole time at the shot-point and from the first break (refraction) times at the geophones nearest to the shot-point. Any persistent discrepancy indicates that it is necessary to revise the average weathering velocity. A thorough investigation of weathering velocities requires :

(a) Surface shots with close spacing of geophones; the spread is shot from each end in opposite directions, to eliminate misleading values due to variations in layer thickness. The thicknesses and velocities of the various layers are calculated by standard refraction procedures.

(b) Hole shots at intervals of five to ten feet within and below the weathered layer; the arrival times are recorded by an up-hole geophone.

(c) A plot of up-hole times against depth, for all shots fired in the weathered layer over the area of interest. If the points lie reasonably close to a straight line it may be assumed that the weathering velocity is uniform over the area, and the slope of the line provides a check on the magnitude of the velocity.

More detailed information can be obtained by making additional shots and obtaining reciprocal times at a few geophone positions for all layers, as is commonly done in engineering refraction work. The principle is the same as that on which the reciprocal-time method for weathering corrections is based, except that the subtractor is a surface-to-surface time instead of a horizontal sub-weathering time between shot-points.

When the final decision is being made on what velocity values to adopt, it must be remembered that horizontal velocities are not always the same as vertical velocities; this is a common feature of shale, for example.

In addition to finding the depth and nature of the weathered layer at every geophone point by the methods to be discussed, it is necessary to find the elevation of every geophone point. This is usually done by normal surveyor's levelling technique, and is required for two reasons :

(1) Variations in the elevation of the geophones affect the recorded step-out of reflection times, even if the weathered layer is of constant thickness across the spread; reflection times are therefore corrected to a common elevation (referred to as the "datum plane").

(2) It is often necessary to collate the results of a seismic survey with those of other seismic surveys and with bore-hole information. This is possible only if all the results can be reduced to a common reference level.

Having found the variations of weathering and elevation, corrections are applied to reflection times. The corrections have the equivalent effect of :

(a) replacing the weathered layer with material having the sub-weathering velocity,

(b) "filling up" or "planing off" the surface to make it coincide with the datum plane, and

(c) placing the shot and geophone positions at the datum level, vertically above or below their actual positions.

In practice, the datum plane may be chosen at any convenient level above or below the physical surface. The adjustments just described are termed "Weathering and Elevation Corrections".

<u>Definitions of Symbols</u>

D	datum plane
E_s	elevation of shot-point referred to datum plane
E_g	elevation of geophone referred to datum plane
ds	depth of shot
dw	depth of weathering at shot-point
dw_1	depth of weathering at adjacent geophone
Δt	time from shot to datum level
Δt_g	time from datum level to base of weathered layer below geophone

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Definition of Symbols (continued)

tw	vertical weathered layer time at shot-point; also general symbol for time in the weathered layer
tw_1	vertical weathered layer time at adjacent geophone
t_o	recorded reflection time
t_c	corrected reflection time. This symbol normally signifies the reflection time corrected for weathering, elevation, and spread, but spread is not considered in this discussion.
ts	up-hole time
tr	recorded first-break (refraction) time at the geophone nearest the shot
W_c	weathering correction at the shot-point
Σt	($= t_o - t_c$) total weathering and elevation correction

Most of these symbols are illustrated in Fig. 2.

When calculating elevation and weathering corrections, it is assumed that the energy has travelled vertically through the near-surface layers at the shot-point and geophone positions.

The recorded reflection time t_o is the time from the shot S to the reflection interface and back to the geophone G. The corrected reflection time t_c is the time from A, a point on the datum vertically below the shot, to B, a point on the datum vertically below the geophone. From Fig. 2,

$$
\begin{aligned}
\Sigma t &= t_o - t_c \\
&= \Delta t + \Delta t_g + tw_1 \quad \ldots\ldots(1) \\
&= (E_s - ds)/V_e + (E_g - dw_1)/V_e + dw_1/V_o \quad \ldots\ldots(2) \\
&= (E_s - ds)/V_e + E_g/V_e + dw_1\ (1/V_o - 1/V_e) \quad \ldots\ldots(3)
\end{aligned}
$$

The terms on the right hand side of equation (3) are referred to, in order, as the elevation correction at the shot-point, the elevation correction at the geophone, and the weathering correction. The weathering correction can be written :

$$
\begin{aligned}
dw_1/V_o - dw_1/V_e &= (dw_1/V_o)\ (1 - V_o/V_e) \\
&= f.tw_1 \qquad \text{where } f = 1 - V_o/V_e
\end{aligned}
$$

Hence the total correction at the first geophone is :

$$\Sigma t = (E_s - ds)/V_e + E_g/V_e + f.tw_1 \quad \ldots\ldots(4)$$

It is convenient to write :

$$\Delta t_g + tw_1 = \Delta t + \overline{ts}$$

where $\overline{ts}$ is the value of the up-hole time if the shot were fired at the same level under the nearest geophone and recorded on that geophone.
Equation (1) then becomes :

$$\Sigma t = 2\,\Delta t + \overline{ts} \quad \ldots\ldots(5)$$

$\overline{ts}$ is found from a weathering chart (to be described later) by using the observed value of tr together with $\overline{ds}$, the effective depth of shot if fired at the same level under the nearest geophone. The weathering correction at the shot-point (W_c) may be obtained from the up-hole geophone time ts.

Up-hole time = travel time in weathered layer, plus travel time in sub-weathered layer;

$$\text{or} \quad ts = (ds - dw)/V_e + dw/V_o \quad \ldots\ldots (6)$$

$$= (dw/V_o - dw/V_e) + ds/V_e$$

$$= W_c + ds/V_e$$

$$\therefore \quad W_c = ts - ds/V_e \quad \ldots\ldots (7)$$

DEPTH OF WEATHERING AT THE SHOT-POINT AND AT AN ADJACENT GEOPHONE

Preparation of Weathering-correction Charts

Having obtained values for the weathering velocity (V_o) and the sub-weathering velocity (V_e), a chart may be constructed relating the four quantities :

ds = depth of shot

dw = depth of weathering

ts = up-hole time

tr = time to adjacent geophone

Using this chart and the known values of ds, ts and tr, we may find dw. Similarly ts may be found by using known values for $\overline{ds}$ and tr, and dw_1 may be found from $\overline{ds}$ and tr.

Construction of the chart proceeds in three steps :

(1) Construction of chart relating ts, ds, and dw.

(2) Construction of chart relating tr, $\overline{ds}$, and dw_1.

(3) Construction of final chart from the first two.

Step (1) A chart relating ts, ds, and dw may be readily constructed; it is based on the equation :

$$ts = (ds - dw)/V_e + dw/V_o$$

N.B. The relation applies only if the shot is at or below the base of the weathered layer; i.e. if ds is not less than dw.

ds is set out in the X-direction, ts in the Y-direction. A line with slope $1/V_o$ is drawn through the origin. This line would give the value of ts if dw were equal to ds. Lines of slope $1/V_e$ are drawn to intersect the V_o line at values of ds = 0, 10, 20, 30 etc., and these lines are labelled dw = 0, 10, 20, 30 etc. (see Plate 1). It is readily seen by considering the up-hole ray travelling in reverse from the up-hole geophone to the shot, that in the case where dw = 20 say, the first 20 ft are covered at velocity V_o and the remainder at velocity V_e. This is exactly the relation given by the line labelled dw = 20.

Step (2) A chart relating tr, $\overline{ds}$ and dw_1 may be constructed with the aid of a slide rule which gives trigonometrical ratios in addition to the normal multiplying scales (Plate 2). In the calculations the normal value of 110 ft is used for the horizontal distance from the shot-point to the adjacent geophone (Fig.3).

The maximum value of r, that is, the critical angle, is first obtained.

$$\sin r/\sin i \;=\; V_o/V_e \quad \text{i.e.} \quad \sin r \;=\; (V_o/V_e)\sin i$$

$$\sin r \ngtr V_o/V_e$$

$$\text{i.e.} \quad r \ngtr \sin^{-1}(V_o/V_e)$$

A range of values for r is now taken. It is convenient to take the nearest integral number of degrees less than $r_{\underline{crit}}$ and about four other values at two-degree intervals less than this. A range of values for dw_1 is also taken at 5ft or 10ft intervals up to about 100ft. The value $dw_1 = 0$ is omitted at this stage.

The quantities ∂x, m, $\overline{ds} - dw_1$, t_e, and t'w shown on Fig. 3 are now calculated from the following equations:

$$\partial x = dw_1 . \tan r$$

$$m = 110 - \partial x$$

$$t'w = dw_1/(V_o \cos r)$$

$$\sin i = (V_e/V_o)\sin r$$

$$t_e = m/(V_e \sin i)$$

$$\overline{ds} - dw_1 = m/\tan i$$

$$tr = t'w + t_e$$

The calculations are set out in tabular form. It is most convenient to calculate the values of sin r, cos r, sin i, and tan i first; then the values of m; then the values of t'w for each value of dw_1 in turn for the various values of r (plates 4 and 5).

The results are plotted (Plate 2); $\overline{ds}$ is drawn along the X-axis, tr is drawn along the Y-axis, and a family of curves represent the various values of dw_1.

Values for the ($dw_1 = 0$) curve are most easily calculated from the equation:

$$tr = \frac{(110^2 + \overline{ds}^2)^{\frac{1}{2}}}{V_e}$$

<u>Step (3)</u> The values for the final chart are read from charts (1) and (2). The same range of values chosen for dw_1 is now used for ds. For each of these values in turn we read the values of ts and tr corresponding to every one of the plotted values of dw_1 less than or equal to $\overline{ds}$. The results are put in tabular form and then plotted on a chart; tr is drawn along the X-axis and ts along the Y-axis. Two families of curves are drawn; one joining points of equal $\overline{ds}$, the other joining points of equal dw_1 (Plate 3).

Once a weathering correction chart has been constructed, the terms on the right hand side of equation (5) may be calculated. This is one of the easiest and most accurate methods of calculating t for the geophones adjacent to the shot-point.

Use of Weathering Correction Charts in Various Non-Standard Cases.

The weathering correction chart constructed for the standard adjacent geophone distance of 110 ft and for given values of V_o and V_e can also be used in the following cases :

(1) Areas where V_o and V_e differ from the values used in the chart by the <u>same</u> factor f.

(2) Short spreads (Δx less than 110 ft); <u>or</u> offset holes where the effective horizontal distance to the adjacent geophone is greater than 110 ft.

(3) For adjustment of first-break times for use in the graphical method of determining the differential weathering depths, in cases where shots at widely differing depths must be used.

All these applications depend on the geometry of the arrangement shown in Fig. 3.

Firstly, if V_o and V_e are <u>both</u> changed by a factor **f** and no other changes are made, it is clear that the angles i and r are unchanged; consequently the ray paths are unchanged and the only result is to change both t_e and t'w by the factor 1/f.

<u>Case (1)</u> If, for example, the chart is computed for values $V_o = 2000$, $V_e = 6000$ and it is desired to use it in an area where $V_o = 1500$, $V_e = 4500$, the calculation of a new chart for these values would only involve multiplying the values of $\overline{ts}$ and tr by $1/f = 2000/1500 = 4/3$. The same result is obtained by multiplying observed values of $\overline{ts}$ and tr by 3/4 for use in determining dw and dw_1 from the original chart.

Referring again to Fig. 3, it is also clear that if <u>all</u> the distances in the figure, viz.: ds, $\overline{ds}$, dw, dw_1, and Δx are altered by the <u>same</u> factor, this again amounts merely to a change of scale, angles are unaltered, and the only effect is to alter t_e and t'w by the same factor.

<u>Case (2)</u> If it is desired to use the weathering chart in a case where x is different from 110 ft by a factor f ($f > 1$ for offset holes, $f < 1$ for short spreads) it is only necessary to proceed as follows :-

(a) Multiply observed values of $\overline{ds}$, $\overline{ts}$, and tr by the factor 1/f. This brings Δx to the standard value 110 ft for which the chart is computed, but does not alter any angles.

(b) Use the new values to find a value of dw_1 from the chart.

(c) Multiply this value by f to return to the original scale.

<u>Case (3)</u> To adjust first-break times for varying shot depths to a standard shot depth, dw is found for the first geophone in the usual way, and the adjusted tr is obtained by using this value of dw and the standard value of ds.

The same is done for the second and, if necessary, the third nearest geophone, using the scale conversion detailed in Case (2) with f = 2 and 3. It is rarely necessary to proceed beyond the third nearest geophone with this adjustment.

Any combination of the above applications can also be used; e.g., shots at different depths, offset from varying short spreads.

Consideration of these scale conversions suggests that there are really only four quantities basically involved, viz. :

$$V_e/V_o, \quad \overline{ts}/tr, \quad \overline{ds}/\Delta x, \quad dw_1/\Delta x$$

A series of general charts of type (3) has been drawn for six different values of V_e/V_o (= 1.5, 2.0, 2.5, 3.0, 4.0, 5.0). These are shown as Plates 9 to 14; V_o.ts/Δx has been plotted as ordinate and V_o.tr/Δx as abscissa. On each chart there are two sets of curves, for constant values of dw/Δx and ds/Δx.

The general charts may be used in their present form to determine $\overline{ts}$ or dw, and tw (knowing V_e/V_o, Δx, and tr). Alternatively, if many computations are required in which V_e/V_o and Δx remain constant, it will be convenient to use one of the general charts to construct a particular chart such as the one on Plate 3.

WEATHERING CORRECTIONS AT INDIVIDUAL GEOPHONES

Determination of weathering corrections at individual geophones is one of the most difficult problems in reflection work, but it is important that it should be solved satisfactorily, because these corrections control the accuracy of correlation and dip determination.

There is no unique method of solution, because of the widely varying conditions found in the surface and near-surface layers, but one of several methods, including those described below, will generally prove satisfactory. If not, it may be necessary to shoot shallow refraction weathering shots, using the ordinary refraction technique.

Graphical Method Using Mean Velocity Times and Differentials.

Consider a section AB of a continuous profiling traverse in which A and B are adjacent shot-points, and A is the north or east of B.

The times of refraction breaks for the 12 geophones between A and B when shooting from A are plotted against the distances of the geophones from shot-point A. In the single-layer case these points will lie approximately on a straight line (Plate 6). Next, the times of refraction breaks when shooting from B are plotted on the same graph, so that the distance from the origin of each point represents the distance of the geophone from the shot-point. If the weathered layer between A and B is fairly uniform, the second set of points will lie close to the set from shot-point A. If the weathered layer thickens towards one shot-point, the two sets of points will lie approximately on straight lines which intersect. The best-fitting straight line is drawn through the 24 plotted points, and the slope of this line is a measure of the mean sub-weathering velocity.

If there is a second, higher velocity indicated on the time-distance curve for the farther geophones, the same principles are applied; i.e., finding deviations from each mean velocity line of the points to which the line is fitted. It is assumed here that no allowance need be made for the first of the high-velocity layers. In other words the weathering corrections which must be applied to the reflection times will be determined solely by the upper low-velocity layers.

Under some circumstances this method will not work because the actual travel paths do not agree with the assumed paths; further investigation is then necessary. In every case the test to be outlined under "Reciprocal Time Method" (below) should be applied for indications that the shot may have been fired in the weathered layer. However, for the test to be significant, neither shot should be far below the base of the weathered layer.

The next step is to measure the "differentials"; the "differential" at a particular geophone point is the difference between the plotted refraction time and the mean velocity time, and is measured from the vertical distance between the plotted point and the straight line. The differentials are positive if the points are above the line and negative if below. Since the same eleven geophones are used between A and B in both shots, two values of the differentials are obtained for each geophone, and these are averaged. The differentials to be averaged are those which refer to the same geophone; not to geophones which have approximately the same refraction times. There will be only one differential for each of the geophones placed at the shot-point at the far end of each spread.

The differentials so obtained are a measure of the advancement or retardation of the shock waves in the weathered layer under each geophone, relative to the mean times.

A method for determining the absolute weathered-layer times is available from the graphical plot. Consider the case where the weathered layer is of constant depth across the spread; if the shot level is at the base of the weathered layer then the time to geophone "n" will be of the form

$$tr_n = tw_n + x_1/V_e$$

where tw is the vertical time of travel in the weathered layer and x_1/V_e is the time of (horizontal) travel in the layer below the weathered layer. A graph of tr_n against distance will therefore intersect the time axis at

$$tr_o = tw_o \text{ (strictly } tw_o . \cos i_c \text{, where } i_c = \text{ critical angle)}$$

hence the intercept time gives the value for the weathered-layer time.

In the case under consideration the intercept time indicated by the best-fitting straight line is a measure of the average time in the weathered layer between the two shot-points. In the column headed tw' (Plate 6) the intercept time is applied to the geophone point half way between the shot-points. Weathered-layer times for the other geophone points can then be written in, maintaining the same relativity in values as indicated by the differentials.

In practice a second and more reliable method is used for determining the absolute times in the weathered layer. Times tw_1 at the geophone points adjacent to the shot-points are determined from the first-break refraction times tr. This can be done from a chart of type (2) modified to give tw_1 rather than dw_1.

The weathered-layer times finally used (column tw on Plate 6) have the same relativity to each other as the differentials, but their absolute values are determined by tw_1 times at the geophone points adjacent to the shot-points. The difference between the tw_1 times at these two geophone points, and the difference between their differentials, should be equal. But in practice they may differ by up to a few milliseconds; if so, the two tw times will differ from the tw_1 times, but the average of the two tw times should equal the average of the tw_1 times. The weathering corrections for the individual geophones are obtained by multiplying weathered-layer times by the factor

$$f = 1 - V_o/V_e$$

As an additional check the weathering corrections at the shot-points are calculated from the up-hole times.

$$W_c = ts - ds/V_e$$

It is seen that there are three independent methods for determining absolute values of weathering corrections. The method involving the refraction breaks on the near geophone is generally preferred as it derives the corrections directly from the geophones to which they are to be applied; this becomes very important in areas where there are sharp changes in weathering.

It should be noted that, following the procedure above, the weathering correction f.tw for each shot-point will be determined twice - once for the spread to the north or east of the shot-point and again for the spread to the south or west. For the final result the two values should be averaged.

When determining the absolute tw' time for geophone No. 1 (farthest from shot at B and placed at A) there is only one differential time, as this geophone does not record shot A. Use the difference between this differential and the one for No. 2 (shot from B), to determine the tw' time. The same procedure is followed for geophone No. 24.

Reciprocal Time Method (Fig. 4)

As in the case of the graphical method, interlocking spreads are used. At each geophone the two refraction times t_1r_n from shot-point 1 and t_2r_n from shot-point 2 are added, and the horizontal time t_h from shot-point to shot-point subtracted. (the error due to the angle of refraction is small)

$$t_1r_n + t_2r_n - t_h = 2\ tw_n \quad \text{.................................}(8)$$

Horizontal time t_h is given by

$$t_h/x_{12} = \frac{(t_1r_{11} - t_1r_1) + (t_2r_1 - t_2r_{11})}{2(x_{11} - x_1)} \quad \text{................}(9)$$

or $$t_h = 0.6\ (t_1r_{11} - t_1r_1) + (t_2r_1 - t_2r_{11})$$

where $x_{12} = 1320$ ft

$x_{11} - x_1 = 1100$ ft

Horizontal time t_a between adjacent geophones is given by

$$t_a = \tfrac{1}{2}\left[(t_1r_n - t_1r_{n-1}) + (t_2r_{n-1} - t_2r_n)\right] \quad \text{.........}(10)$$

For evenly spaced geophones the horizontal time between adjacent geophones should not vary by more than 2 milliseconds. Greater variations or systematic changes indicate variations in horizontal velocity, incorrect placement of geophones, faulty surveying, creek crossings, or deep penetration (indicated by small values for the central geophones).

The difference in tw at adjacent geophone points is given by

$$tw_n - tw_{n-1} = t_1r_n - t_1r_{n-1} - t_a$$

$$= t_1r_n - t_1r_{n-1} - \tfrac{1}{2}(t_1r_n - t_1r_{n-1}) - \tfrac{1}{2}(t_2r_{n-1} - t_2r_n)$$

$$= \frac{(t_1r_n - t_1r_{n-1}) - (t_2r_{n-1} - t_2r_n)}{2} \quad \text{...................}(11)$$

Usually equations (8) and (9) are used to find tw times only for the geophones nearest shot-points. The other tw times are calculated by differences, and this gives a check on the accuracy.

$$x_{12}/t_h = V_{horizontal}$$

If $t_1r_{11} + t_1r_1$ does not equal $t_2r_{11} + t_2r_1$ it may indicate that one shot has been fired in the weathered layer. If one or both of the shots are fired in the weathered layer the individual tw_1 can be found by using a surface-to-surface subtractor, i.e. the time between adjacent shot-points. This subtractor is obtained from up-hole times and refraction times from each shot to the adjacent shot-point.

Plate 7 shows the procedure for calculating tw times by the reciprocal- time method. The example used is the same spread as that on Plate 6 illustrating the graphical method. The results given by the two methods agree within 1 or 2 milliseconds. It is convenient to do the computations for the reciprocal-time method on the first part of each record, as shown.

Explanation of Plate 7

Figures in column I on the record for shot-point 456 represent first-break time differences (in milliseconds) between the adjacent geophones for that record. Column II shows time differences between the same pairs of geophones, as indicated by the adjacent record for shot-point 455. Figures in column III represent the sums of the figure in the first two columns.

First-break times t_1r_1, t_2r_1 and t_1r_{11}, t_2r_{11} are written down, and the sum and difference for each pair obtained. Adding the two differences (191 + 194) gives twice the horizontal travel time over 10 geophone intervals (385). This last figure may also be obtained by adding up the figures in column III. The subtractor t_h is then calculated from

$$t_h/1320 = 385/(2 \times 1100)$$

By subtracting t_h from each of the sums of t_1r_1, t_2r_1 and t_1r_{11}, t_2r_{11}, 2tw is found for each of the two geophones adjacent to the shot-points, as shown by equation (8).

e.g. $40 + 231 - 231 = 40$ i.e. $tw_1 = 20$

Now, the mean horizontal travel time between geophones is

$$385/(2 \times 10) = 19 \text{ (approx.)}$$

Subtracting this value from the first-break times at the geophones adjacent to the shot-points will give a check on the tw times for these geophones,

e.g. $40 - 19 = 21$

$= tw_1$ (approx.)

tw values for the other geophones are found by the use of equation (11).

In practice, the differences between the tw values are found by halving the differences between columns I and II.

e.g. $17 - 20 = -3$

$t_1w_3 - t_1w_2 = -1.5$ $t_1w_3 = 20 - 1.5 = 18$ (approx.)

To find the tw time for the geophone at shot-point 455, the mean horizontal travel time between geophones (19 milliseconds) is added to the first-break time t_1r_{11} at the adjacent geophone. Suppose this sum is greater than t_1r_{12} by an amount t :

$$t_1w_{12} = t_1w_{11} - t$$

e.g. $223 + 19 = 242$ $t_1w_{12} = 11 - (242 - 241)$

$= 10$

A second method for determining tw at the adjacent shot-point is to subtract t_h from the first-break time t_1r_{12}.

e.g. $241 - 231 = 10 = t_1w_{12}$

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Note: The differences $t_2r_1 - t_1r_1$ (=191) and $t_1r_{11} - t_2r_{11}$ (=194) should be equal provided :

(1) neither shot has been fired in the weathered layer.

(2) both shots are at about the same depth.

(3) the horizontal velocity between each shot and its adjacent geophone (on common spread) is the same.

(4) first-breaks have been picked correctly.

The same conditions apply also to the sums -

$t_1r_1 + t_1r_{11}$ (=263) and $t_2r_{11} + t_2r_1$ (=260).

If these differences or sums do not agree closely, check the up-hole times to determine whether one shot was fired in the weathered layer. Check also the computations on the relevant adjoining record; this should confirm whether the shot was in the weathered layer.

The values of first-break times scaled from the record (usually known as the first-break time "picks") should also be checked. A discrepancy due to incorrect picks may be discovered by comparing the sums $t_1r_2 + t_1r_{10}$ and $t_2r_{10} + t_2r_2$ for the next pair of traces (both 262 in this case). If one shot is fired in the weathered layer the time from the shot to the layer below the weathered layer is one half the difference between the sums $t_1r_1 + t_1r_{11}$ and $t_2r_{11} + t_2r_1$. Allowance must be made for this additional travel time through the weathered layer when calculating the total corrections to apply to the reflections.

In the cases where some of the figures in column III differ considerably from the mean value (e.g. 42, 43, 35) the relevant time picks should be checked. If the discrepancies are real, look for indications that geophones are misplaced. If so, one would expect large and small intervals to be adjacent to one another, but this may not happen if an incorrect pick has been made also. It should be noted that abnormal values in column III cannot be caused by variations in weathering depth.

If it is indicated that variations in the figures of column III do represent actual changes in horizontal velocity, the cause should be investigated. Presumably there is a physiographical or geological reason. Creeks frequently give rise to large intervals, but they are usually also associated with deep weathering.

Plate 8 is a graphical proof that the weathered-layer times have been correctly computed. Here the observed first-break times tr for the spread 455 - 456 have been plotted against distance from the shot. The individual tw times have been subtracted and the (tr - tw) times plotted. The latter times lie close to a straight line through the origin and through the subtractor time (231) at the adjacent shot-point.

If one of the shots had been fired in the weathered layer the line would not pass through the origin and the subtractor, but would have an intercept-time at the shot-point, equal to the additional weathered layer travel-time. If some of the corrected times do not fall on the line, discrepancies in horizontal travel-times or errors are indicated.

APPLICATION OF WEATHERING AND ELEVATION CORRECTIONS TO REFLECTION STEP-OUT.

The procedure for applying weathering and elevation corrections depends on the type of cross-section to be produced from the records. Cross-sections may be divided into three main types :-

(Facing Page 12)

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SEISMIC SURVEY

Area ......

S.P. .... Trav. ..... Date ..

Shot .. Charge .. Depth ..

Spread ..

Geos. ..... Amp. .. Cam ..

Orig'L Recording / Play Back

Filters

Gains

Mixing

A.G.C

Presupp

Pattern Geophones

No. .... Spacing ....

Layout

Pattern Holes

No ..... Spacing ...

Layout

Remarks.

ELEVATION AND WEATHERING CORRECTIONS

D = V_o= .... V_e= .... ds = $\frac{E - ds}{V_e}$ =

SP		Dist.	Elev.	t_w	$f_e t_w$	E/V_e	Σt
	1						
	2						
	3						
	4						
	5						
	6						
	7						
	8						
	9						
	10						
	11						
SP	12						
	00						
	13						
	14						
	15						
	16						
	17						
	18						
	19						
	20						
	21						
	22						
SP	23						
	24						

	LS. Elev.	LS. t_w	LS $f_e t_w$	LS E/V_e	LS. Σt
Traces 1-12					
13-24					
1-24					

G 85-55

FIG. 5

(a) Hand-plotted correlation cross-sections.

(b) Hand-plotted dip or migrated cross-sections.

(c) Electronically produced, fully corrected record cross-sections employing variable intensity, variable area, or other form of trace display.

(a) Correlation Cross-sections.

In the case of correlation cross-sections the only reflection times plotted are those on the centre traces and on the outside traces of a record. Consequently weathering corrections need be calculated only for the shot-point (or average correction for the two geophones adjacent to the shot-point) and for the two most distant geophones, which are located near the adjacent shot-points.

The weathering and elevation correction at the shot-point is generally found from equation (5) and chart type 3 as it is based on the first-break times tr at the nearest geophones. If for any reason the tr times are considered unreliable (see GENERAL NOTE below), ts may be derived directly from the recorded up-hole time ts.

For the outside traces on the record, the corrections at the adjacent shot-points are used after adjustment for difference in shot depths between the record under consideration and the adjacent record. This adjustment amounts to the difference between values of $(E_s - ds)/V_e$ for the two shots.

(b) Dip Cross-sections.

In the case of dip cross-sections the reflection time at the shot-point and the tangent of the reflection dip angle are plotted. After this the reflection dip is determined from the "least square" slope of the reflection times on individual traces. In this method it is necessary to determine weathering and elevation corrections for each trace, and hence the "least square" corrections across the spread. The weathered layer times for individual geophones are determined as described in section (a) above, usually by means of the graphical method.

The individual weathered layer times are entered in the column labelled "tw" on the Elevation and Weathering Correction sheet at the beginning of the seismic record (Fig.5). In the next column the weathering correction f.tw for each geophone is entered (see Introduction). The elevation correction E/V_e for each geophone is entered in the next column. The elevation correction at the shot-point $(E - ds)/V_e$ is common to all traces, but must in each case be added to f.tw and E/V_e when deriving the total correction $\sum t$ (equation 4).

The resulting figures in the $\sum t$ column are then "least-squared"; the top and bottom groups as separate 12-trace groups, then the whole column as a 25-trace group. (An imaginary trace of zero weight is assumed at the shot-point, i.e., the centre of the record). The three resulting "least-square" values for each quantity are written in the spaces provided.

The least-square operation is equivalent to fitting a straight line to graph points representing the values of $\sum t$, and determining the slope of this line in milliseconds per 10 geophone intervals. The operation can be quickly carried out by means of a special least-square slide rule.

The sign of least-square $\sum t$ or least-square of the reflection times is found by assigning the greatest positive weight to the figure uppermost on the correction sheet of a 12- or 25-trace group and successively decreasing the weight going down the group so that if there is a middle figure it carries zero weight and so that the bottom figure carries a negative weight equal in magnitude to that of the top figure. For a 12-trace group, the value for trace 1 has a weight of +0.55; for trace 2, +0.45 .... for trace 12, -0.55. For a 25-trace group, trace 1 has a weight of +1.2; trace 2, +1.1; .... trace 25; -1.2. Least-square $\sum t$ is subtracted algebraically from the least-square of the reflection trough times on the record. The weight figure (0.55 or 1.2) is derived from the expression

$$\frac{(\text{number of traces minus 1})}{10 \times 2}$$

where 10 is the 10 geophone intervals mentioned in the previous paragraph.

The resultant sign is in accordance with the convention that the sign of the corrected reflection step-out LS Δt_c (where LS stands for "Least Square") indicates the direction of the dip of the surface; e.g. over an east-west traverse LS Δt_c greater than zero indicates an easterly dipping interface, LS Δt_c less than zero indicates a westerly dip.

As an alternate method of deriving the $\sum t$ values, the various terms making up $\sum t$ may be least-squared separately and the least-square values added; viz.

$$\text{LS} \sum t = \text{LS} \left\{ f.tw + E_g/V_e + (E_s - ds)/V_e \right\}$$

For a particular shot the values f, $1/V_e$ and $(E_s - ds)/V_e$ are constants.

$$\therefore \quad \text{LS} \sum t = f.\text{LS } tw + (1/V_e).\text{LS } E_g$$

(c) Electronically produced Cross-sections.

In the case of cross-sections produced electronically, each individual trace appears on the final cross-section. Individual elevation and weathering corrections must therefore be applied to the traces (e.g. by moving magnetic heads relative to each other) in order that the reflections should line up from trace to trace.

The weathering and elevation corrections may be determined as in (b) and entered on the record label. In this case least-squaring is not necessary.

GENERAL NOTE

The types of weathering conditions described above are the simplest, and fortunately the most common. Other conditions which occur and must be recognised are :

(1) A gradual lateral change of horizontal velocity along the spread.

(2) Erratic changes of velocity from geophone to geophone.

(3) Unreliable refraction breaks.

(4) More than two weathered layers.

The presence of conditions (1) and (2) should be indicated by application of the reciprocal-time method. Condition (3) is generally caused by "stringers", i.e. lenses of high-velocity rock (often caliche) within the weathered layer. Condition (4) can be solved only by multi-layer refraction methods.

In a new area the normal procedure is to drill test shot-holes at representative places to include the various conditions likely to be encountered. The area to be surveyed should be reasonably well covered in this way, and the holes should be placed in situations where there are, as far as can be determined, no structural complications.

Test holes are usually fairly deep (about 250 ft) but may be shallower if conditions suggest that deeper drilling is not warranted. Travel times through the weathered layers may be determined by a down-hole geophone survey i.e., firing small shots at the surface and recording on geophones placed down the hole at intervals of ten to twenty feet from bottom to surface.

Shots are then fired at about every 20 ft in the hole to determine the best shooting-depth, filter setting, etc. It is important that good up-hole breaks should be recorded, in order to check the time-depth curve obtained from the down-hole geophone survey. If a down-hole survey is not possible, additional shots for more up-hole times may be necessary. During these operations the horizontal and vertical velocities required for computation of weathering corrections, are also determined. This information should be supplemented by special refraction shots for near-surface data.

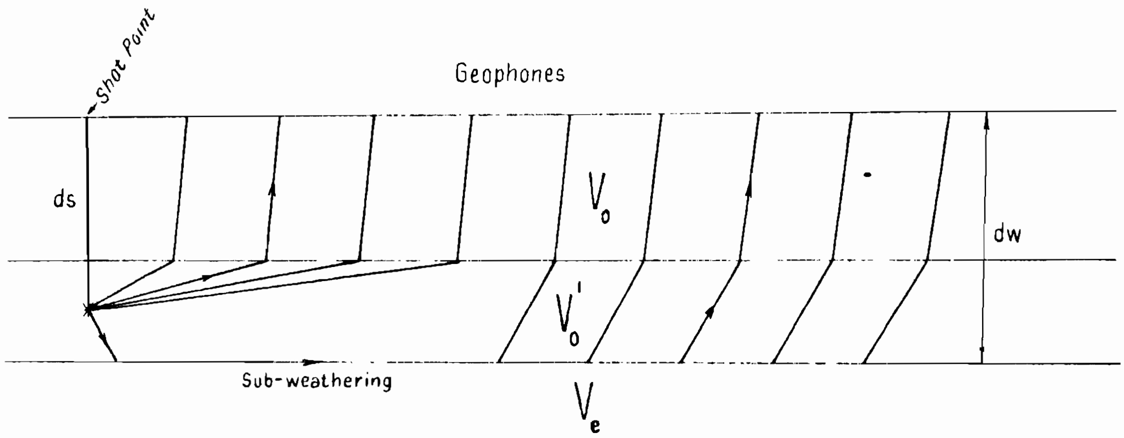

FIG. 1

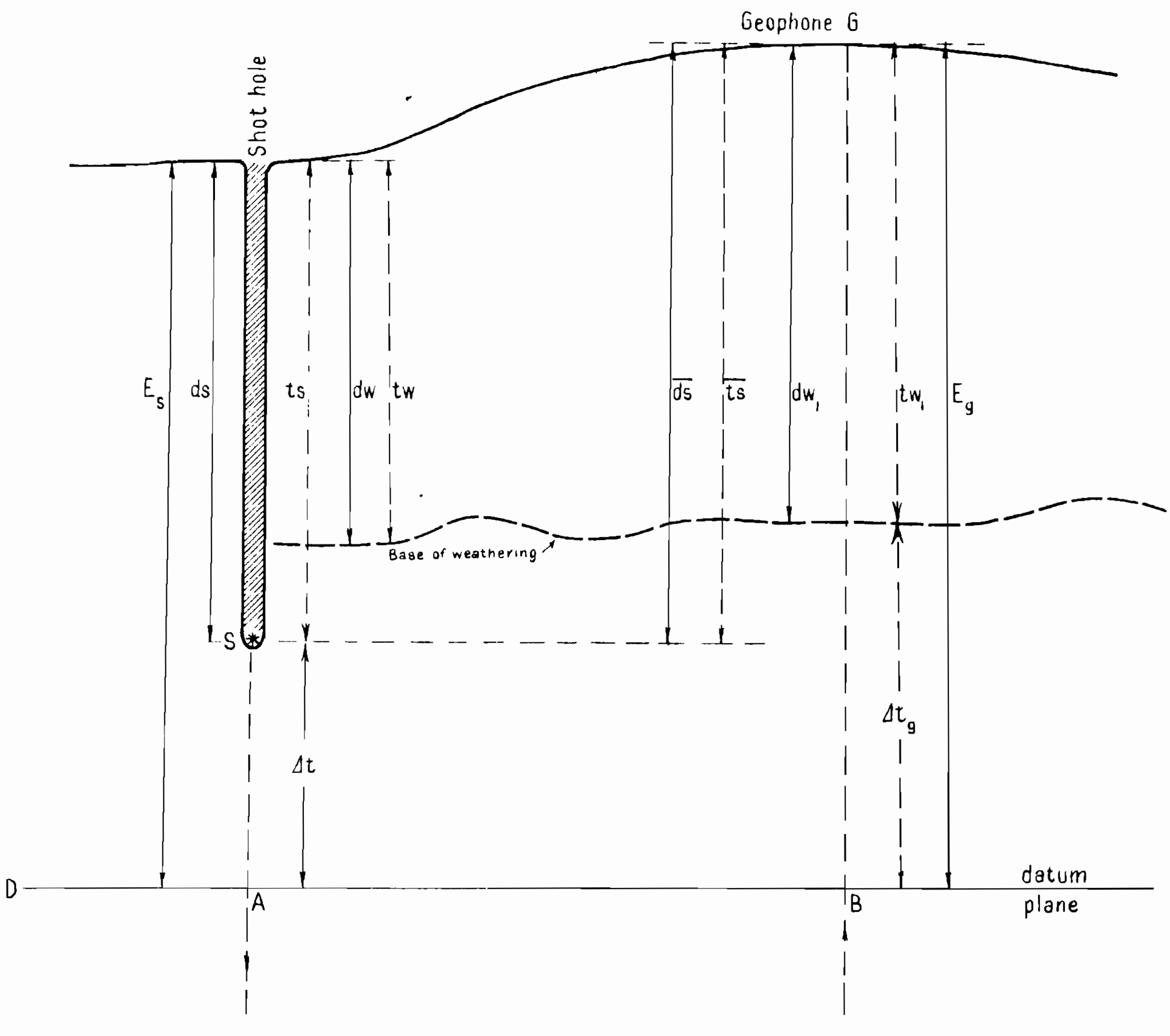

FIG. 2

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TO ACCOMPANY RECORDS 1960, No 13

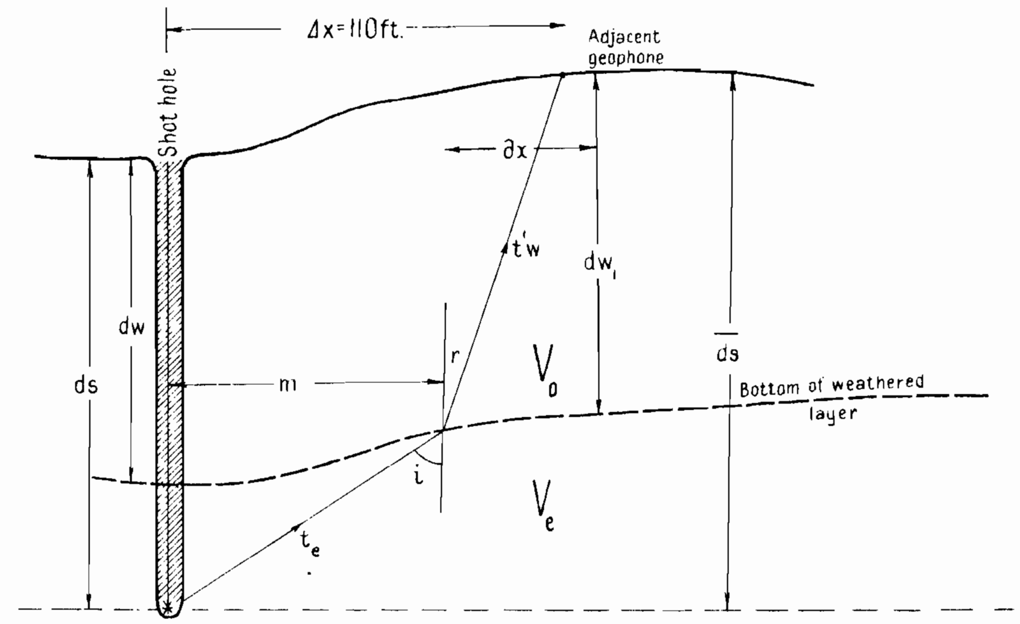
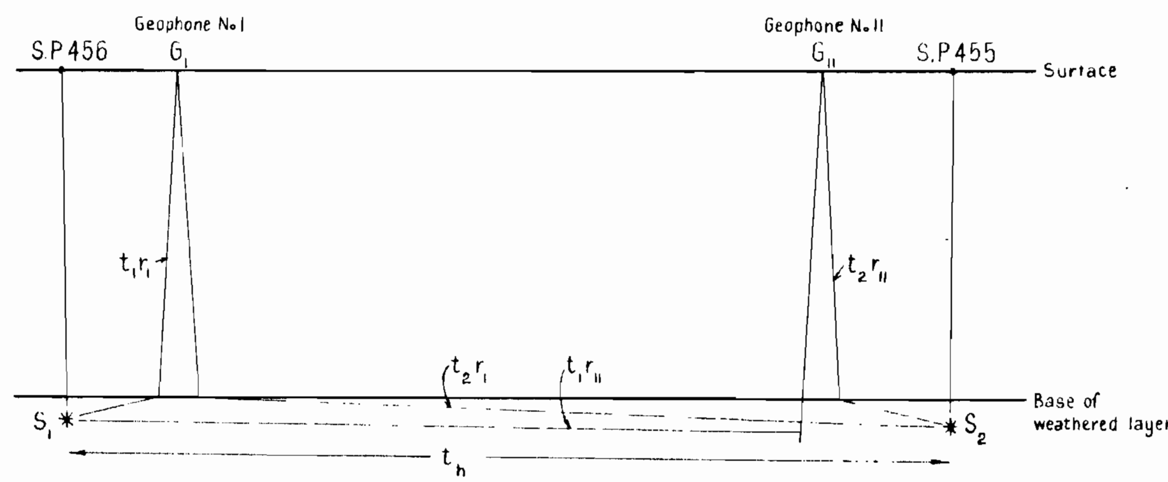


FIG. 3

Reciprocal Time Method.



Code to symbols: t_2r_{11} means refraction time from Shot No. 2 to geophone No.11.

FIG. 4

Corrections for Weathering and Elevation.

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TO ACCOMPANY RECORDS 1960, No 13

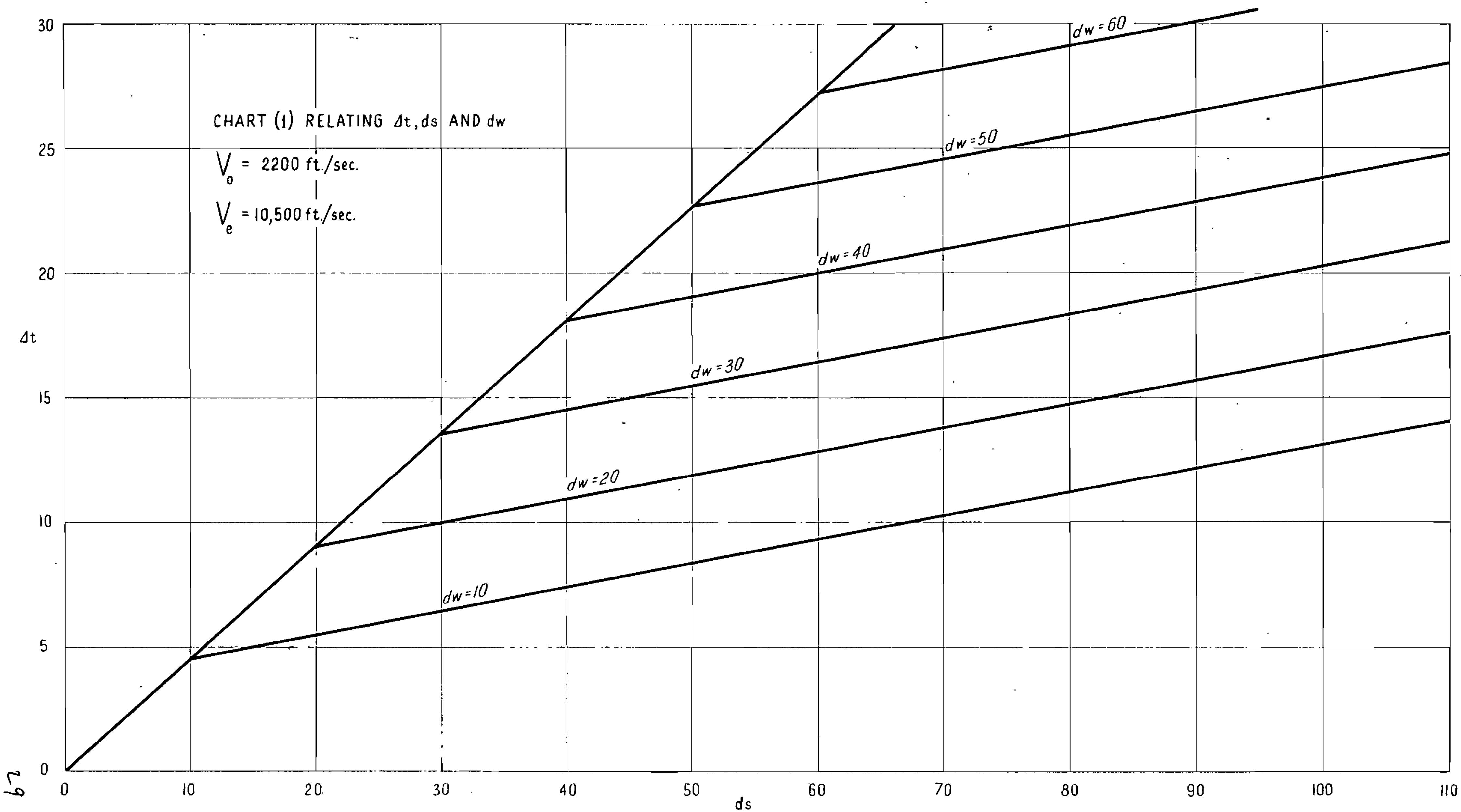

PLATE I

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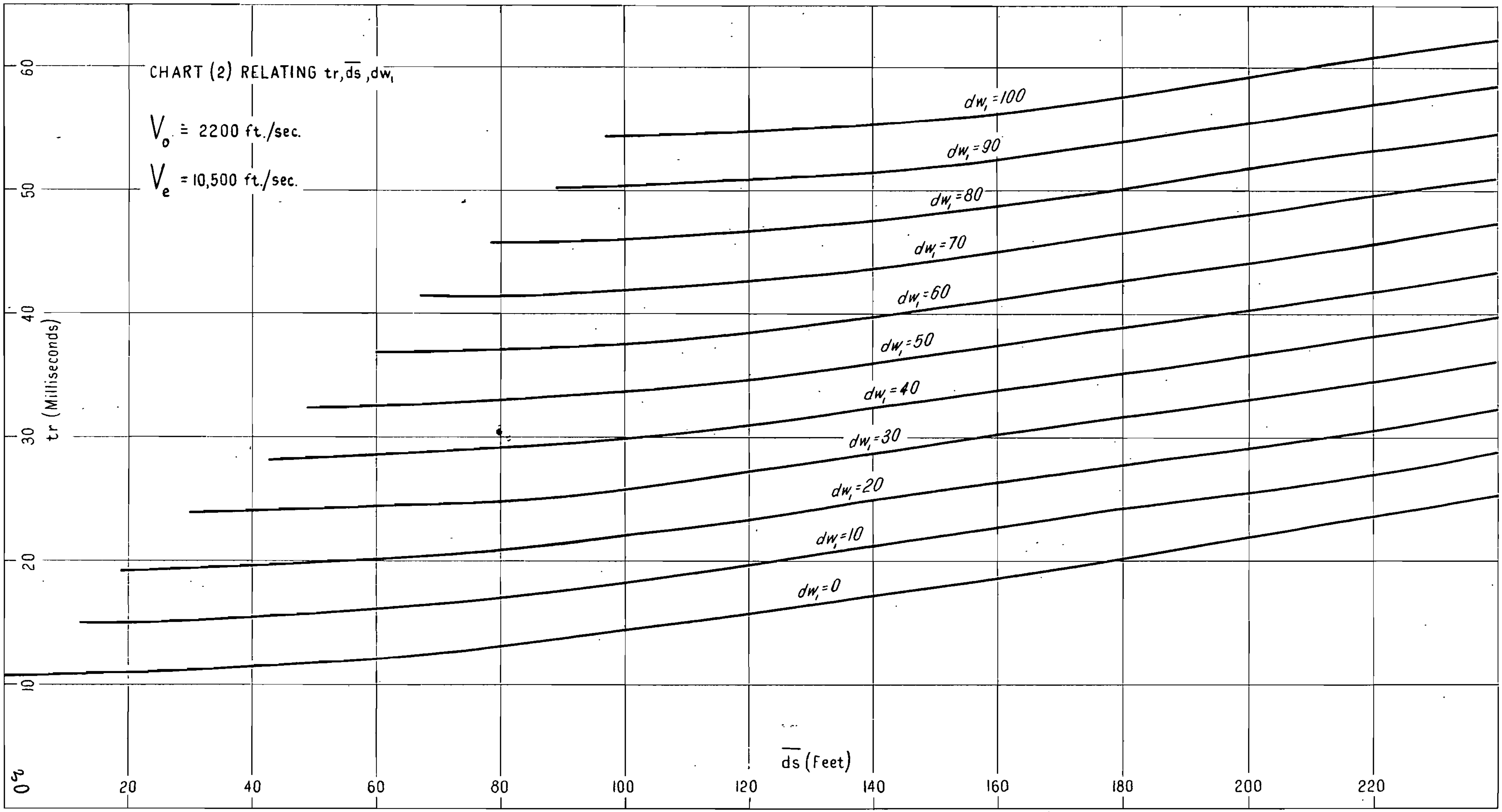
G85-102

PLATE 2



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TO ACCOMPANY RECORDS 1960, No. 18

G85-106

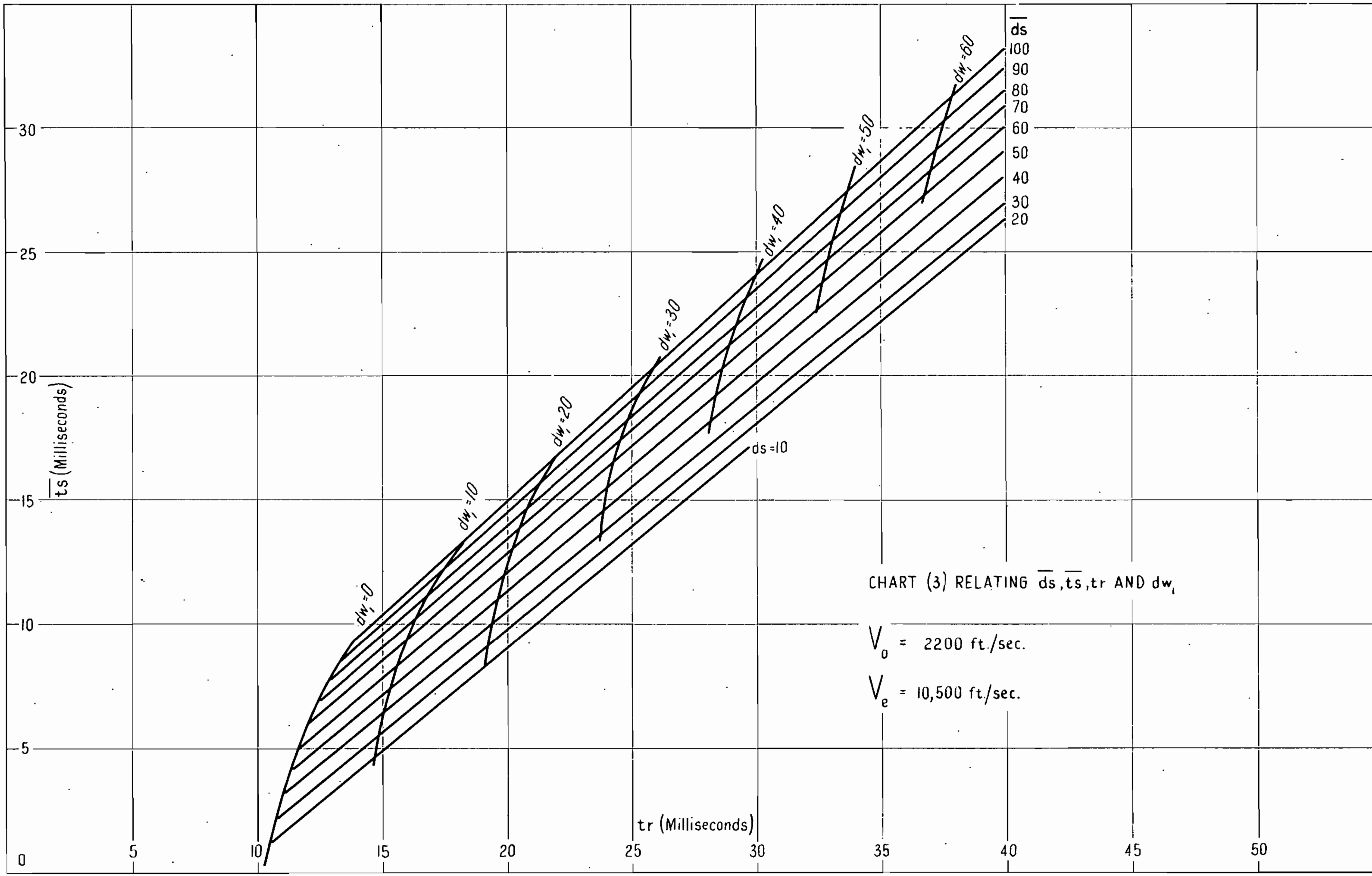

PLATE 3

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COMPUTATIONS - Chart (2)

r°	cos r	sin r	tan r	sin i	tan i	dw_1	∂x (= dw_1 tan r)
12°	.9782	.2079	.2126	.992	7.86	10	2.126
						20	4.251
						30	6.377
						40	8.51
						50	10.63
						etc.	
11°	.9816	.1908	.1944	.911	2.209	10	1.944
						20	3.888
						30	5.83
						40	7.78
						50	9.72
						etc.	
10°	.9848	.1737	.1763	.828	1.477	10	1.763
						20	3.527
						30	5.29
						40	7.05
						50	8.82
						etc.	
8°	.9903	.1392	.1405	.664	.888	10	1.405
						20	2.811
						30	4.20
						40	5.61
						50	7.01
						etc.	
6°	.9945	.1045	.1051	.498	.574	10	1.051
						20	2.102
						30	3.153
						40	4.206
						50	5.25
						etc.	

For additional columns see second sheet.

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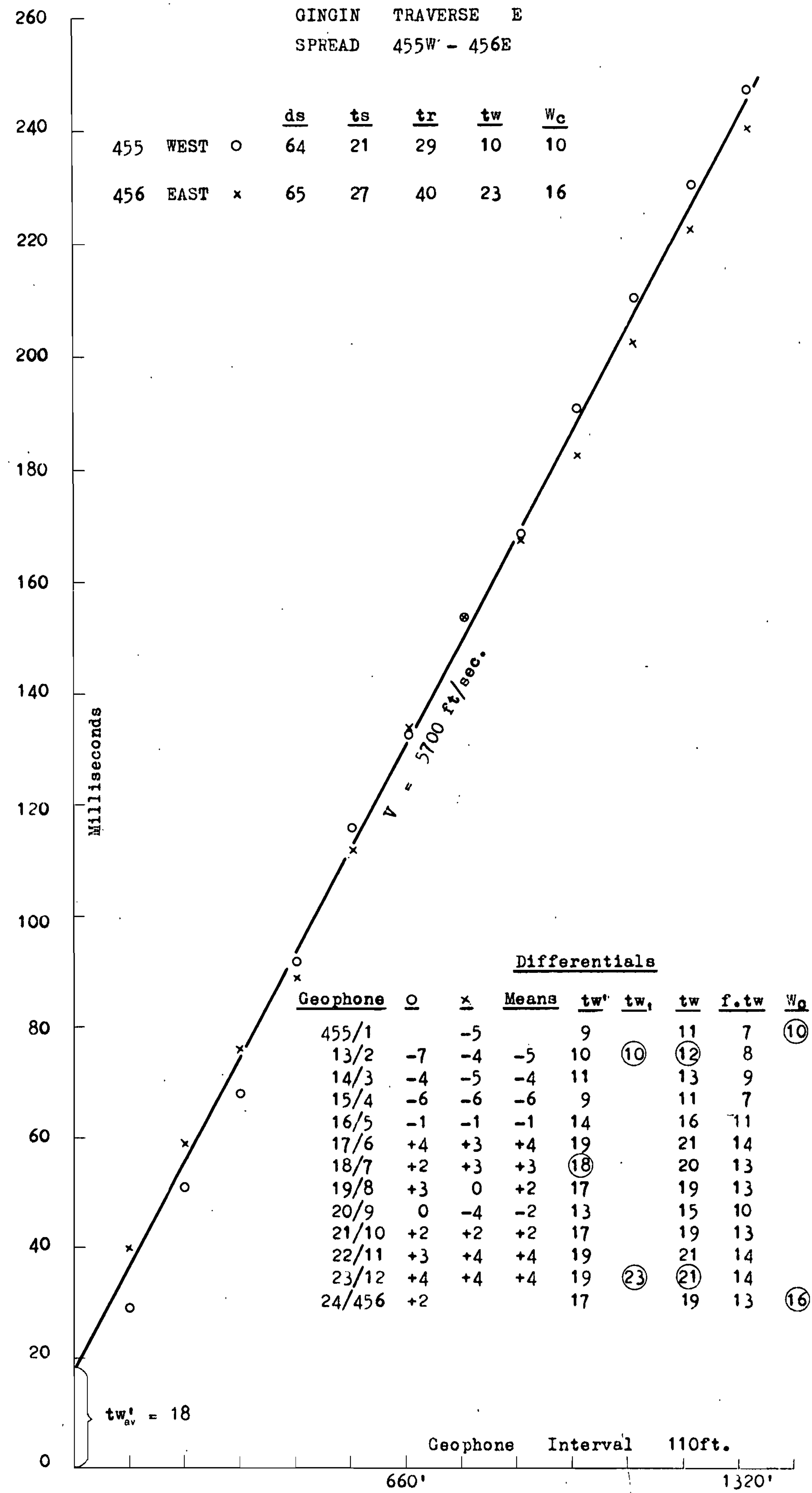
m ($= 110 - \partial x$)	$t'w$ $\left(\frac{dw_1}{V_0 \cos r}\right)$	te $\left(\frac{m}{V_e \sin i}\right)$	tr ($t'w + te$)	$\overline{ds} - dw_1$ $\left(= m/\tan i\right)$	$\overline{ds}$ $\left(dw_1 + \frac{m}{\tan i}\right)$
107.87	4.64	10.35	14.99	13.71	23.71
105.75	9.28	10.16	19.44	13.44	33.44
103.62	13.92	9.94	23.86	13.16	43.16
101.49	18.58	9.74	28.32	12.90	52.90
99.37	23.22	9.54	32.76	12.62	62.62
108.06	4.63	11.30	15.93	48.85	58.9
106.11	9.26	11.09	20.35	48.05	68.0
104.17	13.89	10.89	24.78	47.15	77.2
102.22	18.52	10.69	29.21	46.25	86.3
100.28	23.15	10.48	33.63	45.40	95.4
108.24	4.62	12.43	17.05	73.3	83.3
106.47	9.24	12.23	21.47	72.1	92.1
104.71	13.83	12.02	25.85	70.9	100.9
102.95	18.47	11.83	30.30	69.7	109.7
101.18	23.08	11.62	34.70	68.5	118.5
108.60	4.58	16.14	20.72	122.0	132.0
107.19	9.16	15.94	25.10	120.5	140.5
105.80	13.76	15.73	29.49	119.0	149.0
104.39	18.35	15.53	33.88	117.4	157.4
102.99	22.94	15.30	38.24	115.7	165.7
108.95	4.57	20.80	25.37	188.7	198.7
107.95	9.14	20.60	29.74	186.9	206.9
106.85	13.71	20.40	34.11	185.0	215.0
105.79	18.28	20.20	38.48	183.1	223.1
104.75	22.86	20.00	42.86	181.3	231.3

Plate 6



			ds	ts	tr	tw	W_c
455	WEST	o	64	21	29	10	10
456	EAST	×	65	27	40	23	16

Differentials

Geophone	o	×	Means	tw'	tw_1	tw	f.tw	W_c
455/1		-5		9		11	7	10
13/2	-7	-4	-5	10	10	12	8	
14/3	-4	-5	-4	11		13	9	
15/4	-6	-6	-6	9		11	7	
16/5	-1	-1	-1	14		16	11	
17/6	+4	+3	+4	19		21	14	
18/7	+2	+3	+3	18		20	13	
19/8	+3	0	+2	17		19	13	
20/9	0	-4	-2	13		15	10	
21/10	+2	+2	+2	17		19	13	
22/11	+3	+4	+4	19		21	14	
23/12	+4	+4	+4	19	23	21	14	
24/456	+2			17		19	13	16

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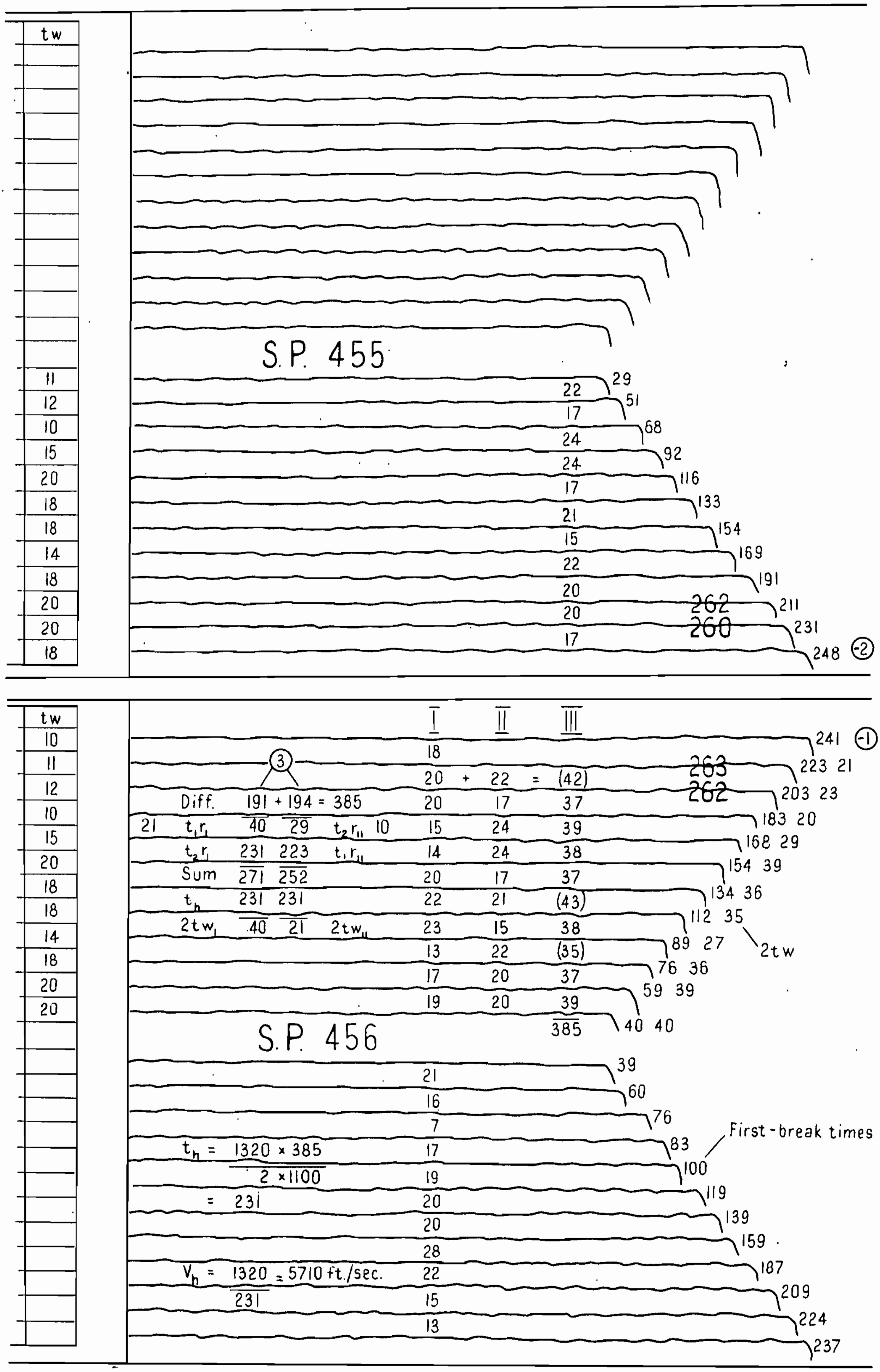
TO ACCOMPANY RECORDS 1960, No. 13



DIAGRAMS SHOWING PROCEDURE OF APPLYING RECIPROCAL-TIME METHOD ON FIRST PART OF SEISMIC RECORDS.

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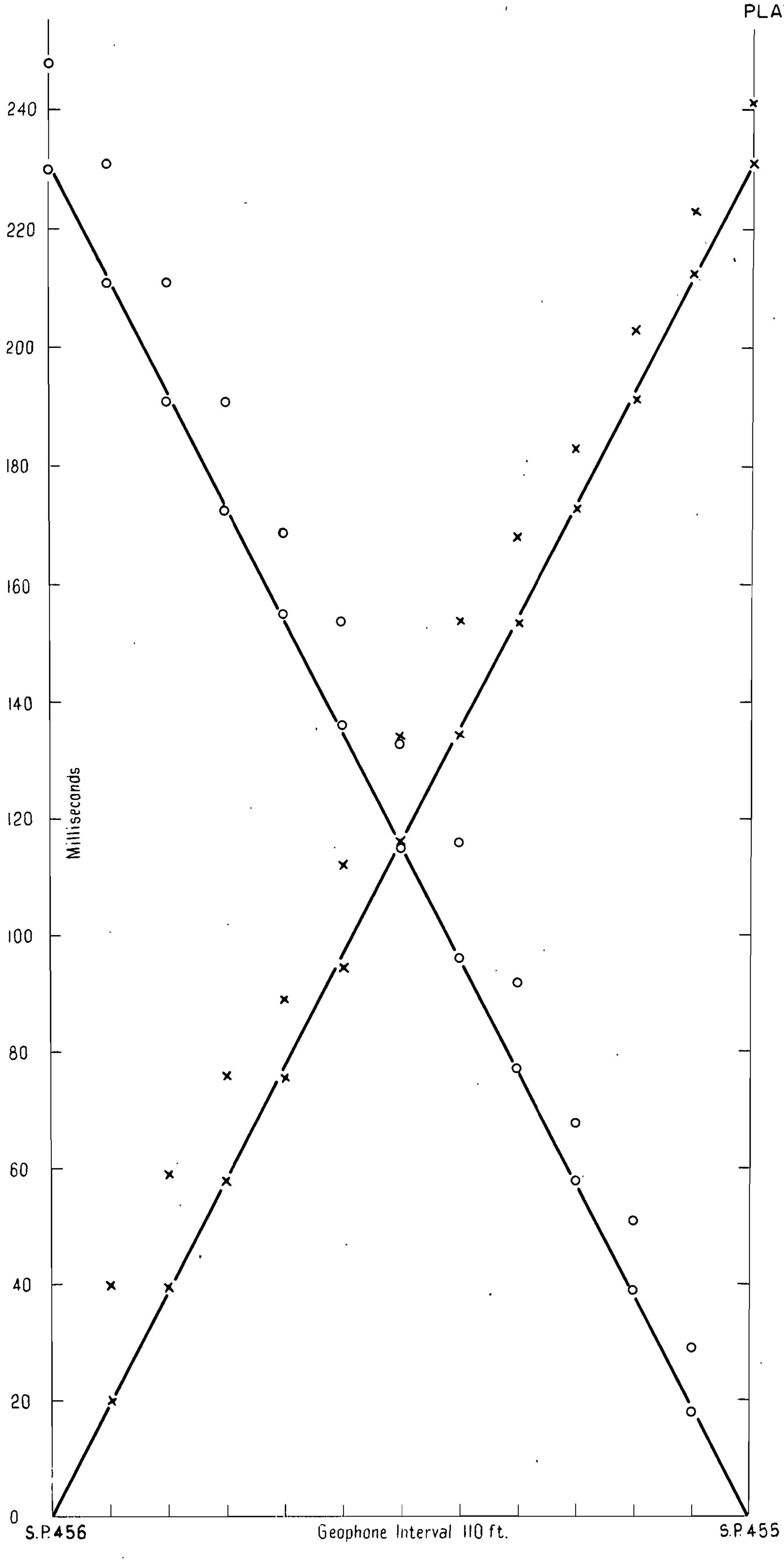
TO ACCOMPANY RECORDS 1960, No 13



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TO ACCOMPANY RECORDS 1960, No. 13

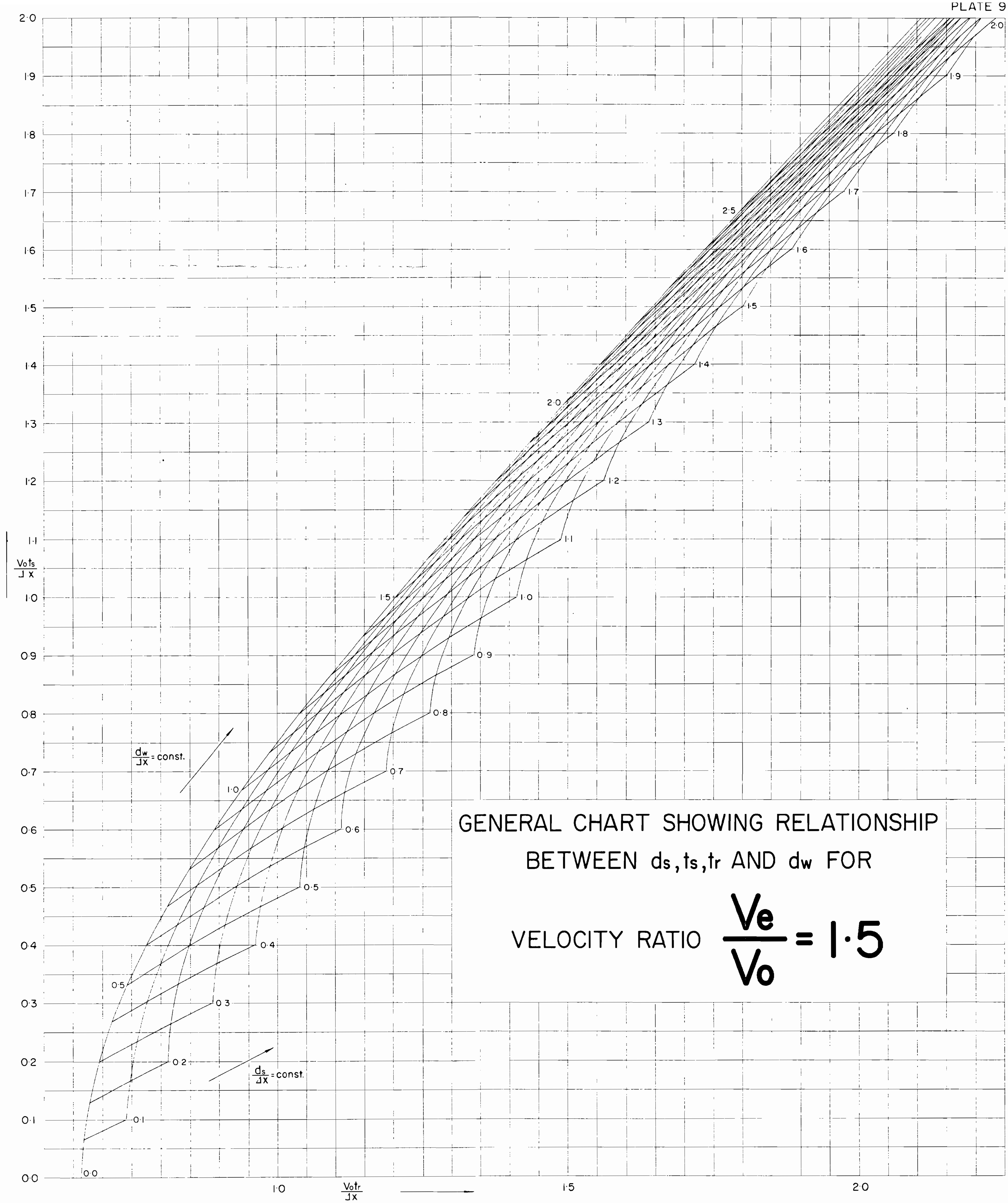
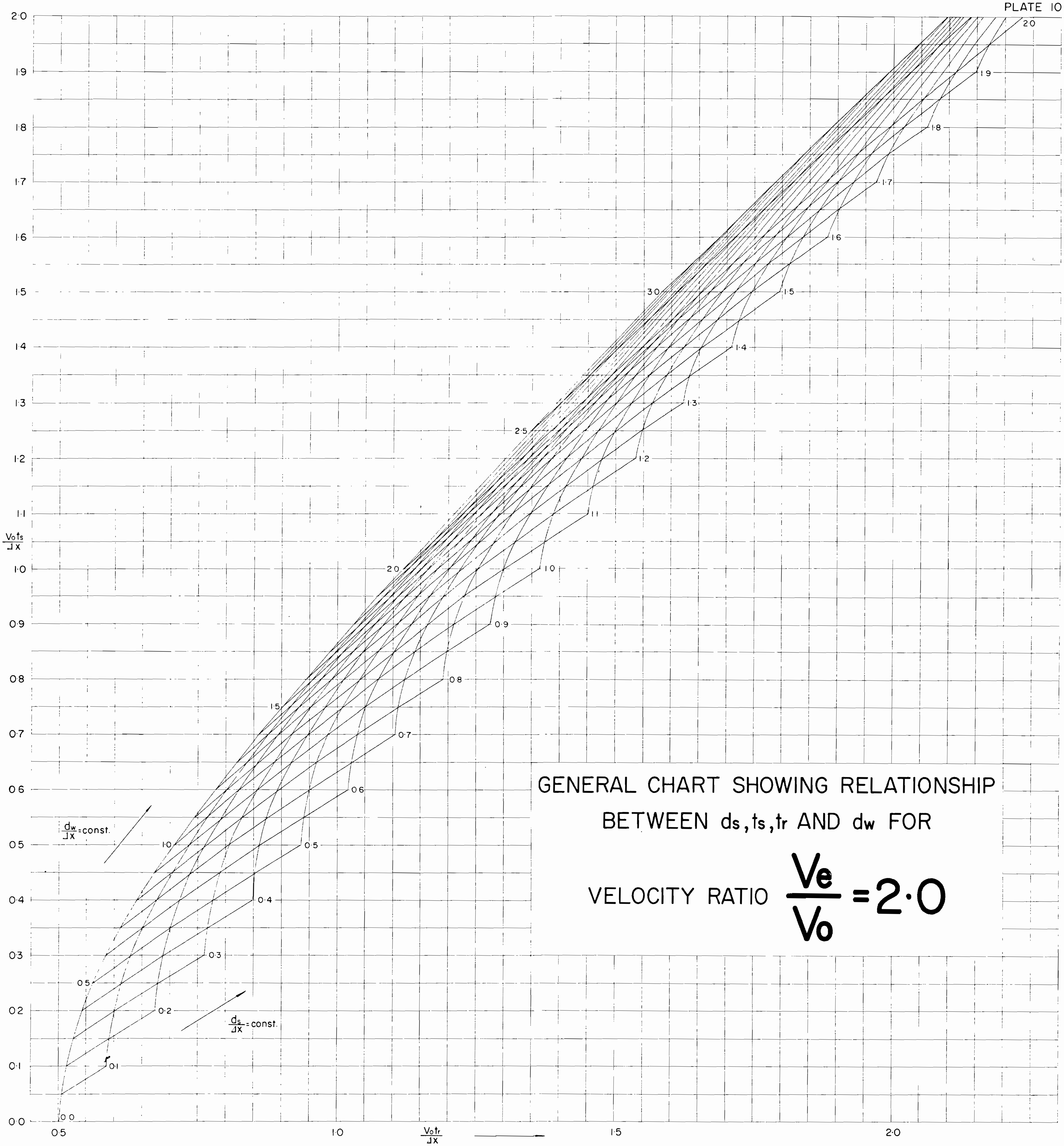

GENERAL CHART SHOWING RELATIONSHIP
BETWEEN ds, ts, tr AND dw FOR
VELOCITY RATIO $\frac{Ve}{Vo} = 1{\cdot}5$
$\frac{Vo\,ts}{\Delta x}$
$\frac{Vo\,tr}{\Delta x}$
$\frac{dw}{\Delta x}$ = const.
$\frac{ds}{\Delta x}$ = const.
0·0
0·1
0·2
0·3
0·4
0·5
0·6
0·7
0·8
0·9
1·0
1·1
1·2
1·3
1·4
1·5
1·6
1·7
1·8
1·9
2·0
2·5

PLATE 10



GENERAL CHART SHOWING RELATIONSHIP BETWEEN d_s, t_s, t_r AND d_w FOR VELOCITY RATIO $\frac{V_e}{V_o} = 2{\cdot}0$

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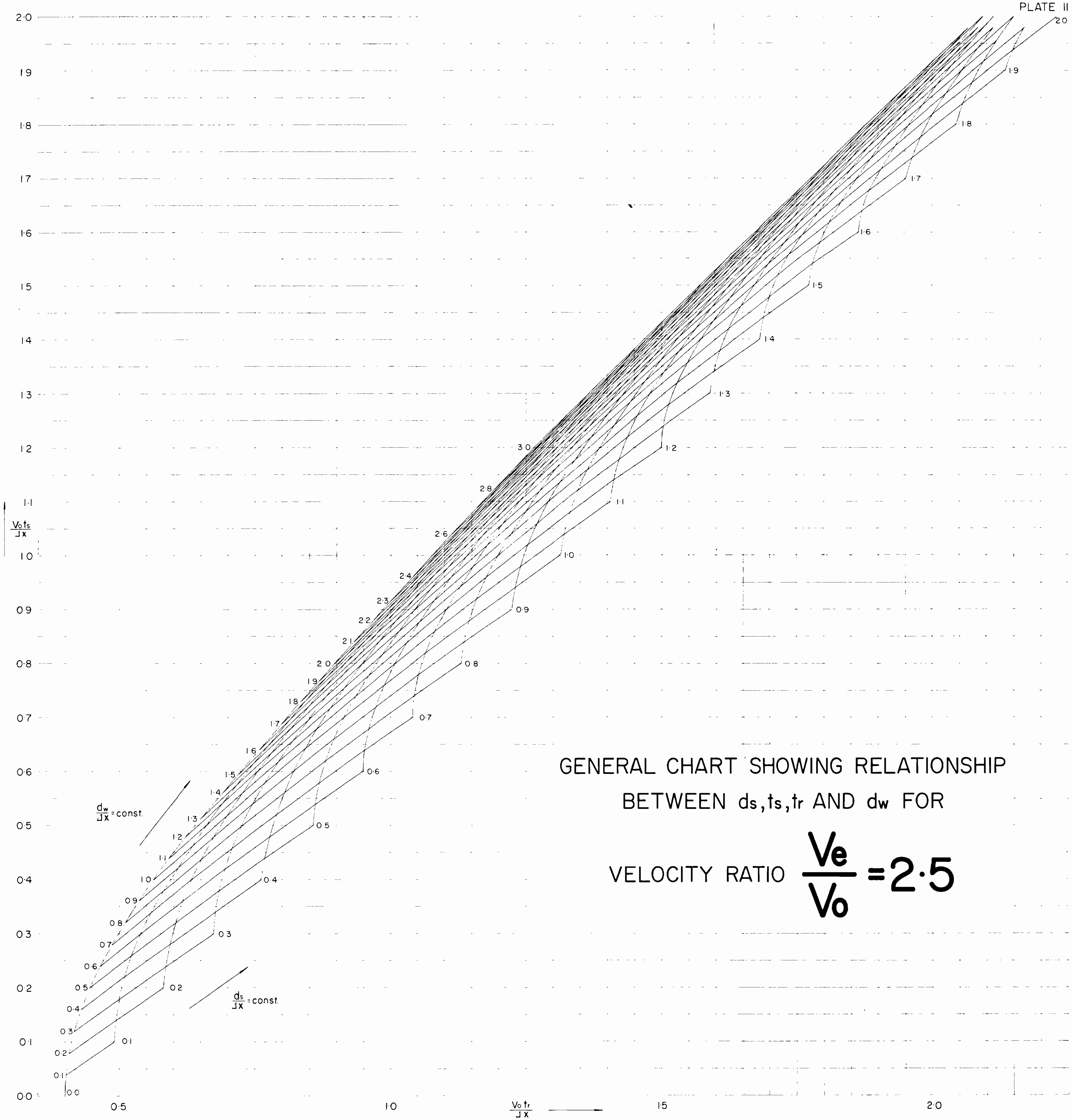
TO ACCOMPANY RECORDS 1960, No.13

PLATE II



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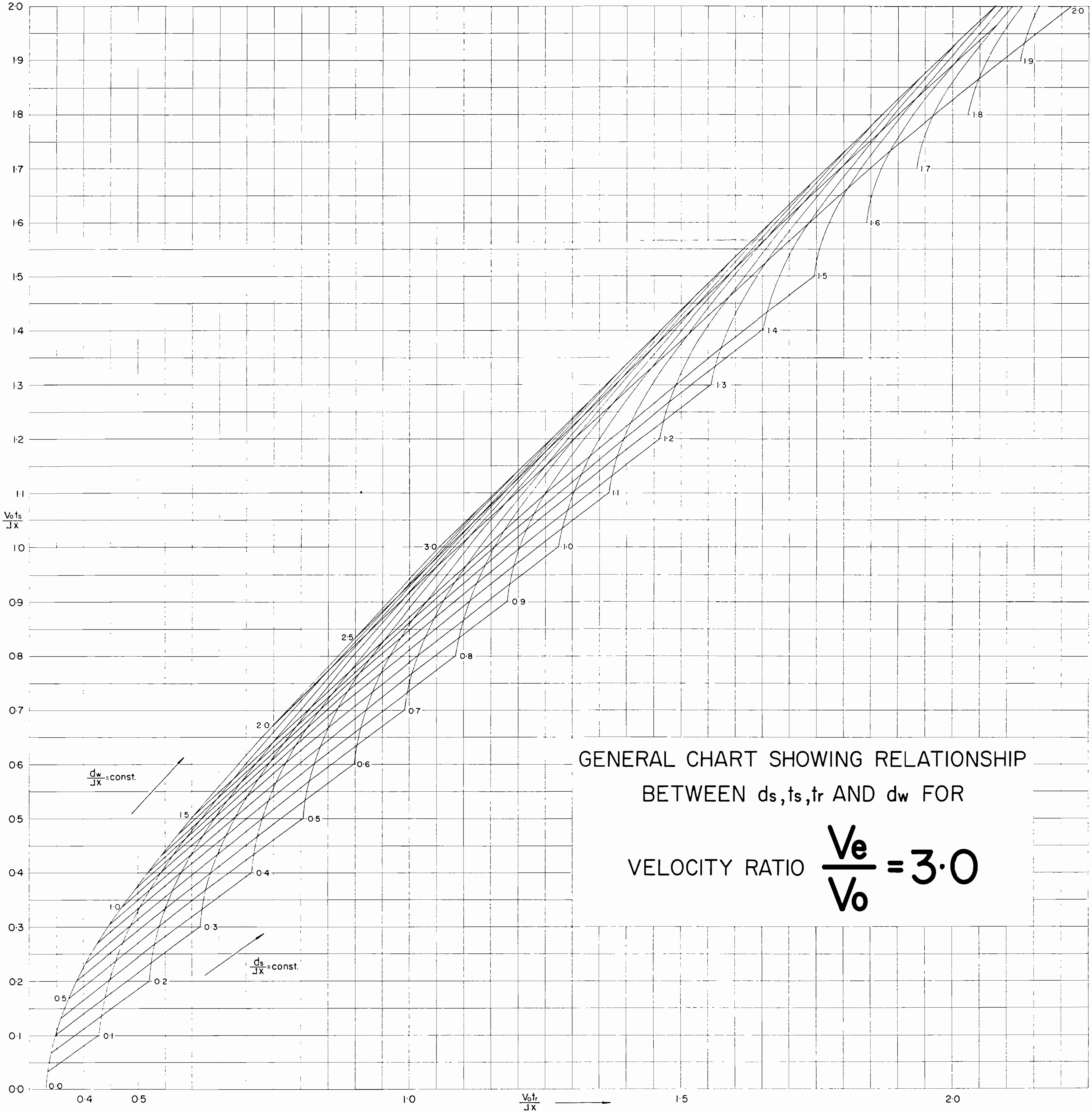
TO ACCOMPANY RECORDS 1960, N-13



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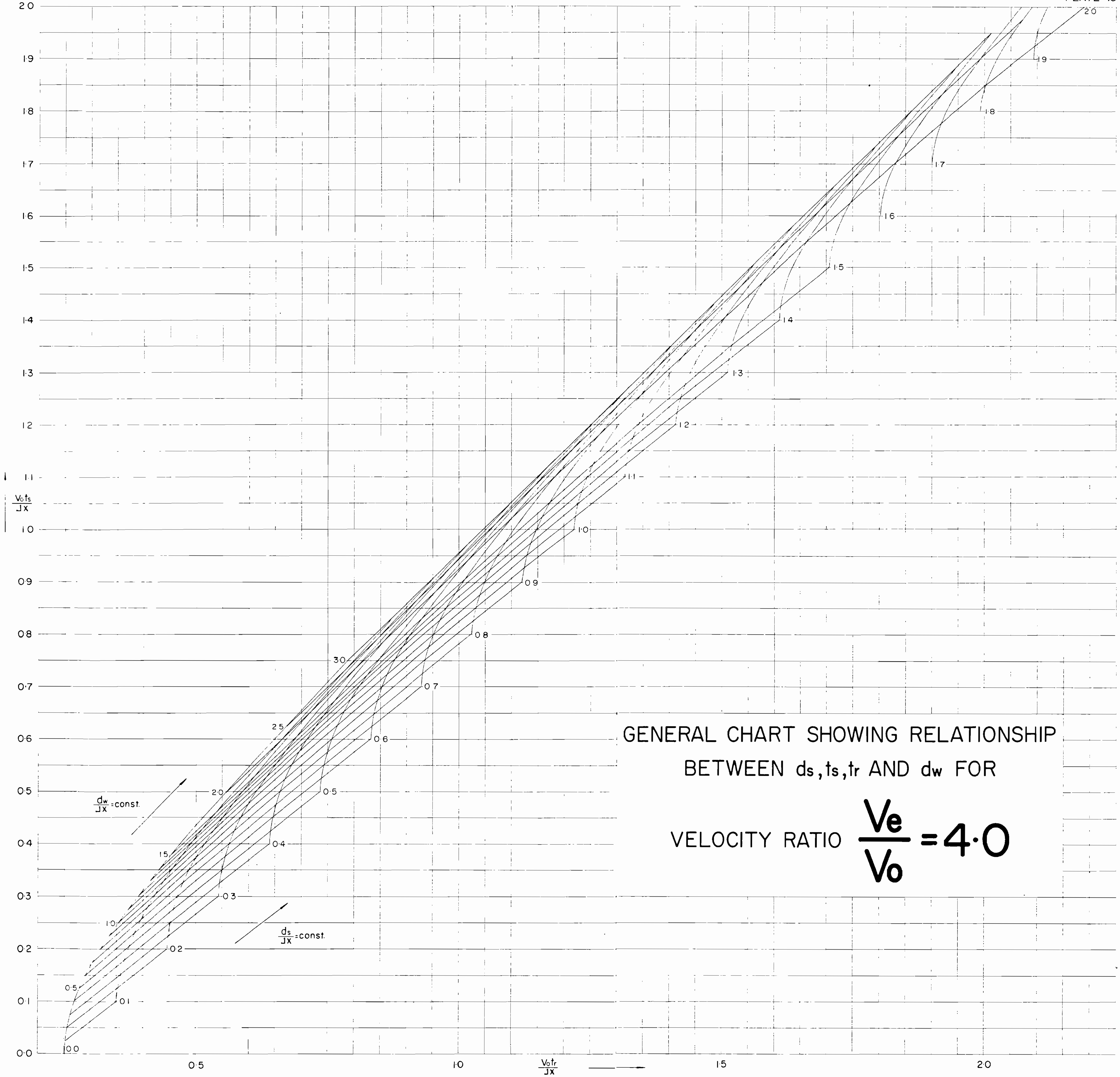
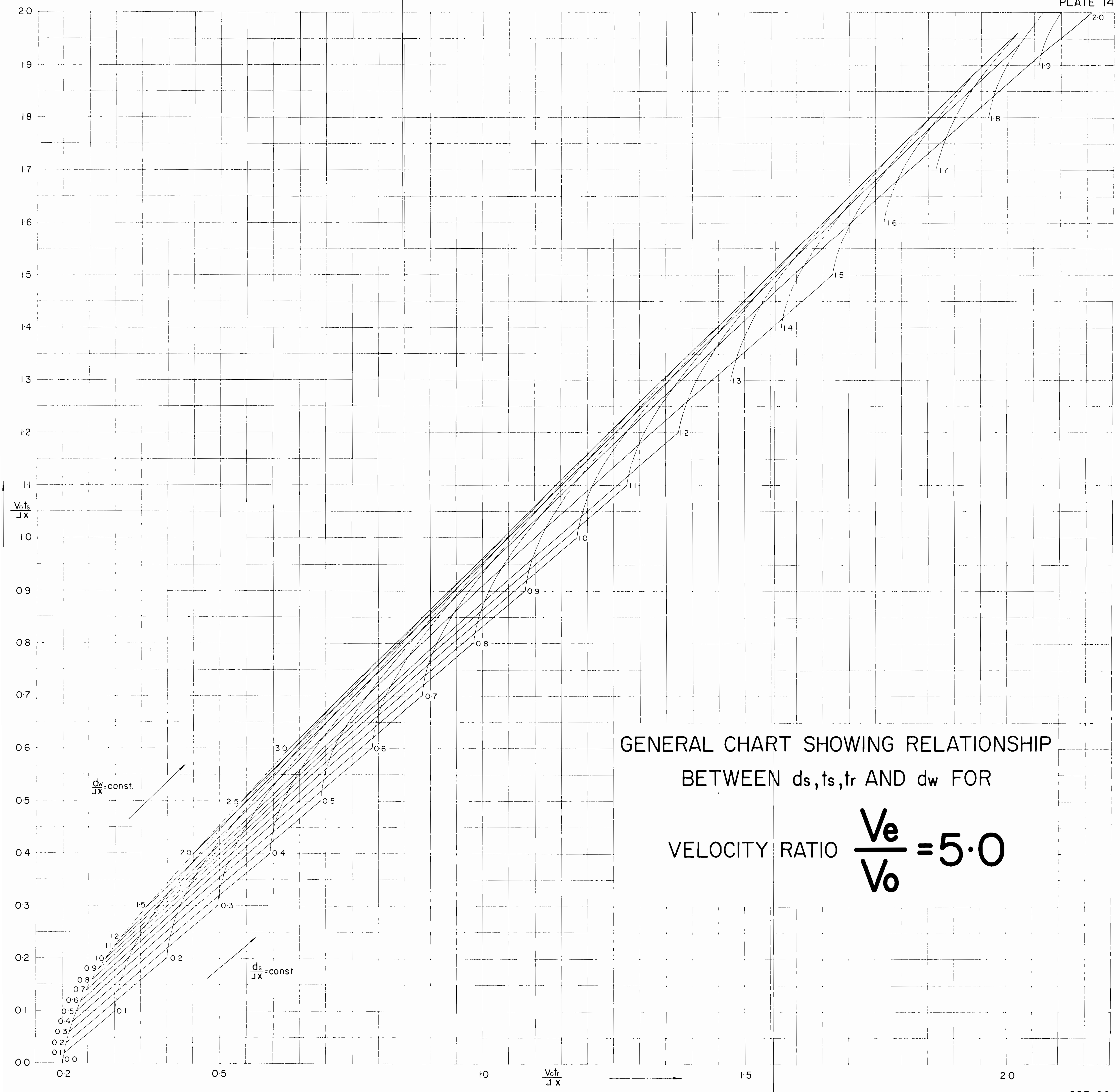
TO ACCOMPANY RECORDS 1960, No 13



GENERAL CHART SHOWING RELATIONSHIP BETWEEN d_s, t_s, t_r AND d_w FOR

VELOCITY RATIO $\frac{V_e}{V_o} = 4·0$

PLATE 14



GENERAL CHART SHOWING RELATIONSHIP BETWEEN d_s, t_s, t_r AND d_w FOR

VELOCITY RATIO $\frac{V_e}{V_o} = 5 \cdot 0$

Geophysical Branch, Bureau of Mineral Resources, Geology and Geophysics. G85-99
TO ACCOMPANY RECORDS 1960, No.13