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(54) METHOD AND SYSTEM FOR AUTOMATIC SEISMIC REFLECTION PICKING

(71) We, TEXAS INSTRUMENTS INCORPORATED, a Corporation organised according to the laws of the State of Delaware, United States of America, of 13500 North Central Expressway, Dallas, Texas, United States of America, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

This invention relates to seismic exploration and more particularly to the identification and display of information indicative of character and location of subsurface-reflecting horizons.

In seismic exploration, wiggle-trace seismograms conventionally are produced by recording, as individual traces, the excursions of a spot of light reflected from a galvanometer mirror, deflections of which represent seismic waves detected at a receiving station following generation of seismic waves at a sending station. Collectively, a suite of such traces or undulating lines will indicate the existence of subsurface horizons by time coincidence between traces of waveforms with distinctive character such as like polarity and high amplitude. A seismogram of twenty-four traces or more may represent coverage along a given seismic traverse of a half-mile or more. In order to gain a perspective of subsurface structure, records secured progressively along a traverse are compared one with another. Conventional corrections are generally applied to such seismograms. Weathering, elevation, and moveout corrections are becoming routine. Corrected traces from a plurality of such seismograms, re-recorded in a side-by-side relation, form a seismic record section. Such seismic record sections have been recorded in various forms, the most common forms being wiggle-trace, variable area, and variable density, and combinations of the same. Ten to twenty or more seismograms thus combined form a seismic section record.

Heretofore, record sections have been de-

veloped through the use of correlation methods to produce a section presentation in which small line segments have an inclination equal to the dip of the horizon under observation and a thickness proportional to the correlation coefficient of successive traces along that dip. Such a method is described in Geophysics, Vol. 29, pages 17—37, with a representative section being shown in Figure 13 thereof.

Thus, while it is known to utilize various type of presentations for seismic record sections, there remains a challenging problem of providing methods and systems for production of seismic sections which may be more reliably interpreted in terms of earth structure.

It is an object of the present invention to provide a method or system for producing an improved display of subsurface earth structure.

According to one aspect of the invention there is provided a method of producing a display of subsurface earth structure from a set of seismograms in which adjacent seismic traces represent seismic waves detected at adjacent locations spaced along a traverse, which method comprises: generating respective electrical pulses from said seismograms at the times of peaks of a selected polarity in the traces, generating an electrical control signal when one of said pulses from a first of said traces on a seismogram lies within a time gate which is dependent in width upon mean peak separation in said first trace and centred at the predicted time for one of said pulses from said first trace, and producing a display of time-spaced indicia representative of reflecting horizons on said seismogram only in responsive to said control signal.

According to a second aspect of the invention there is provided a system for producing a display of subsurface earth structure from a set of seismograms in which adjacent seismic traces represent seismic waves detected at adjacent locations spaced along a

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5 traverse, which comprises: means for gener-
ating from said seismograms respective elec-
trical pulses at the times of peaks of a
selected polarity in the traces, means
10 for generating an electrical control sig-
nal when one of said pulses from a
first of said traces on a seismogram
lies within a time gate which is dependent
in width upon the mean separation between
15 peaks in said first trace and centred at the
predicted time for one of said pulses from
said first trace, an X-Y section plotter
adapted to write time-spaced indica-
representative of reflecting horizons on said seismo-
grams, and means for actuating said plotter
only in response to said control signal.

For a more complete understanding of
the present invention and for further objects
and advantages thereof, reference may now be
20 had to the following description taken in
conjunction with the accompanying draw-
ings, in which:—

FIGURE 1 is a schematic diagram portray-
ing a seismic surveying operation embodying
25 the present invention;

FIGURE 2 is a seismic record section of
conventional presentation;

FIGURE 3 is a section display of data
taken from FIGURE 2 but limited to align-
30 ment of relative maxima;

FIGURE 4 is a graded section display of
the reflector segment shown in FIGURE 3
where the grading parameter was numerically
equal to 6.0;

35 FIGURE 5 is the section display of
FIGURE 4 but in which the line segments
are made of varying thicknesses responsive
to the product of the number of peaks in
alignment and the amplitudes of the peaks
40 exceeding predetermined thresholds;

FIGURE 6 is a plot of portions of four
adjacent traces representative of traces from
one of the seismograms of FIGURE 2;

FIGURE 7 is a graph showing a preferred
45 relationship between the average period be-
tween peaks on the traces of FIGURE 6 and
the time gate in which a peak on an adjacent
trace must be found in order to extend an
event;

50 FIGURE 8 is a flow diagram illustrating
event extension operations;

FIGURE 9 illustrates relation between
length and amplitude in order to provide
emphasis on identified events;

55 FIGURE 10 illustrates a simplified opera-
tion for preprocessed data; and

FIGURE 11 is a flow diagram for event
extension operations in a digital computer.

60 In the setting of FIGURE 1, two twenty-
four trace seismograms are produced for in-
clusion in a composite seismic record section.
Additional records will be secured at succes-
sive shot points along the traverse. The sys-
tem has been shown in block form with the

elements thereof in their functional relation-
ship for carrying out the invention.

It will be understood that the operations
involved may be carried out at least in part
by programming a data processor to utilize
70 seismograms which in the field are digitized
and placed in reproducible form on a mag-
netic tape.

In FIGURE 1, a first seismogram is ob-
tained and recorded in a unit 10. The second
seismogram is obtained and recorded at a
75 unit 11. The first seismogram is produced
by detonation of an explosive charge 12.
Seismic waves emanate from the charge and
travel to subsurface reflecting interfaces from
which they are reflected back to the surface,
80 traveling along paths such as the two pairs
of paths 13 and 14. The latter pairs of paths
lead to two geophones on each end of a
spread A. Seismic waves are sensed by de-
tectors preferably uniformly spaced along
85 spread A in a selected seismic traverse hav-
ing the explosive charge 12 in a suitable
shot hole at the spread center. Detector out-
put signals are applied, by way of channels
15, to the input of amplifying-recording-play-
back unit 10. A time break pulse generated
at the instant of detonation of the charge 12
is applied to unit 10 by way of a time break
90 channel 16.

The operations thus far briefly described
95 and the data recorded in unit 10 preferably
will be as described in U.S. Patent No.
3,134,957 to Foote et al., wherein the separate
traces are digitized and multiplexed. For the
purpose of this description, it will be assumed
100 that the separate seismic traces may be trans-
mitted either serially or in parallel as by
channels 17 to a unit 18. In unit 18 the
traces are corrected for weathering, eleva-
tion, and normal moveout and the corrected
105 traces are stored on a storage drum 19. Such
correction operations are well known and will
not be described in detail.

In a similar manner, a charge 20 detonates
at the center of spread B produces seismic
110 waves which are detected and stored as above
described in the unit 11. The traces are
applied by way of channels 21 to a unit 22
which makes the necessary corrections for
weathering, elevation, and normal moveout
115 and then transmits the corrected traces to a
storage drum 23. Drums 19 and 23 are
operated under the control of a motor 24
which also drives a processing drum 25.

The playback channels 26 from drum 19
120 are connected by way of multichannel switch
27 to a processing unit 28 in which signal
spikes are produced representative of extrema,
such as peaks on the sinusoidal or undulating
waveforms. A spike thus produced is located
125 in predetermined time relation to a given
peak. For the purpose of the present de-
scription, it will be assumed that a positive
spike will be recorded on each trace on

drum 25 at a record time corresponding with the peak of each positive excursion on the corresponding trace. The traces thus modified and stored on drum 25 are then employed

5 in connection with a computer-plotter 30 to produce a seismic record section preferably of the type illustrated in FIGURES 4 or 5.

Before considering the operation of the unit 30 and the character of the sections of FIGURES 4 and 5, it will be helpful to consider the conventional seismic record section shown in FIGURE 2. In FIGURE 2, twenty

10 twenty-four trace seismograms have been combined to form the record section 4. The seismograms 40a represents the seismic data obtained by detonation of charge 12 in spread A. The seismogram 40b represents the seismic data obtained through detonation of charge

15 20 in spread B.

20 The additional records 40c—40t represent operations carried out at successive spreads along the traverse which includes the spreads A and B of FIGURE 1. The "reflections" or coherent energy present on the seismograms tends to portray the subsurface structure.

25 Formation of a record section permits the events to be conveniently traced from record to record.

There will now be described a process for automatically deriving, from records that might be used in a conventional record section, events for a seismic picked section only when they satisfy certain lateral continuity requirements.

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35 FIGURE 3 represents the results of a first step in enhancing the record section of FIGURE 2. In FIGURE 3, line segments have been formed where a seismic event is detected and found to extend across a plurality of traces. Detectors are known for detecting elements of an event and may be of the type described and claimed in U.S. Patent No. 2,972,733 to Bucy and U.S. Patent No. 3,018,468 to Jones et al. In such operations,

40 seismic data, such as in FIGURE 2, is employed as input data to an automatic event detector. The output of the detector is applied to an X—Y plotter. In the form shown in FIGURE 3, the events plotted have some similarities to those produced by the present invention. In such prior art, it is not certain that when a segment is plotted, there is actual presence of an element of the event on each trace across which the segment extends.

45 Thus, the seismic record section 41 will differ in a substantive way from seismic picked sections produced by the present operation even though they may have many similarities in appearance. The events portrayed by

50 wigggle-traces on the record section of FIGURE 2 are recorded as line segments in the section of FIGURE 3. Record section 41 was made in an off-line operation by energizing a plotter such as a Digital Incremental

55 Plotter of the type illustrated and described

in the Calcomp (Registered Trade Mark) Instruction Manual for Model No. 564, published by California Computer Products, Inc., 1963.

It is apparent from an inspection of the record section of FIGURE 3, that a large number of events from FIGURE 2 are retained. A seismic picked section produced by the present operation may actually appear identical with a prior art section but only if unique criteria happen to be present in data from which prior art sections are made.

In FIGURE 4, only the most useful events are retained and presented. The section was produced by employing the seismic data from the record section of FIGURE 2 suitably processed to energize an X—Y plotter.

The record section 43 of FIGURE 5 represents a further enhancement of the data shown in FIGURE 3, wherein all of the information is retained but selective emphasis is given to preferred data.

The system for obtaining the improvement represented by the sections 42 and 43 involves the use of automatic seismic event detection operation wherein there is employed a means for picking vents while attempting to eliminate from the ensemble all events whose presence tends to confuse or limit the seismic section interpretability.

Secondarily, the present invention provides event grading, preferably based upon two criteria: (1) In general, useful events will have an average amplitude level greater than the average level of the noise; and (2) useful events will tend to have greater spatial continuity than spurious events. That is, a lineup of a given polarity will extend across a greater number of traces than will spurious events. Spurious events, lineups extending over two, three, or four traces with unacceptable moveout, will give an indication of structure where no structure is present. The present technique is specifically directed to elimination from a record section of the effect of such spurious events.

A further consideration that is taken into account is a change in signal frequency as a function of time. More particularly, during the time interval of from zero to one second on the section of FIGURE 2, the frequency of the seismic reflections will be much higher than in the later section, such as from four seconds to five seconds. This change in frequency may be employed as will hereinafter be indicated in event grading operations.

In the grading operations a grade is assigned to each event once the event has been identified. A basic time-varying threshold signal is established for each time gate into which the record section is divided. Preferably the position of the time gate into which the section is divided is determined during the event detection operation. The time-varying threshold signal is compared with a sig-

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nal which is dependent upon the amplitude of the event and which, in one form, is representative of the product of the length of the event (i.e., the number of traces across which a lineup extends) and the amplitude of the event. The threshold signal is the product of the mean length of all picked events within a specific time gate multiplied by their mean amplitude. The significance of the threshold thus employed lies in the supposition that it will provide a useful reference level against which any individual event can be compared. Events exceeding the threshold level are retained and those which do not are rejected. It is this type of operation on which the unwanted events, retained in section 41, FIGURE 3, are eliminated in production of section 42, FIGURE 4.

The magnitude of the threshold signal for each time gate preferably is adjusted by an appropriate scaling factor of the basic threshold signal. This provides a quantitative basis for obtaining several event-graded seismic picked sections from the same set of original seismograms. FIGURE 5 illustrates such a section. The factors employed in establishing the optimum grading threshold eliminate subjective evaluations of record sections and base the selection of retained events solely upon the physical properties of the record section itself. In practice, several sections may be produced from the data of FIGURE 2. An ungraded section, such as Figure 3, and then several seismic picked sections, of the type shown in FIGURE 4, may be produced. The seismic picked sections will differ one from another in that the reference threshold signal is different in one section from that employed in another so that one seismic picked section will include more data than another.

The data preferably will be conditioned or preprocessed as by filtering to minimize spurious frequencies which might render measurements of periods erroneous. As above noted, the processed data are in a digital format obtained from in-line, equally-spaced groups of seismometers.

In this form, a seismic section may be considered to be an $S \times T$ matrix, M_{st} , where each element is the seismic amplitude of trace s at time t . A seismic reflection is another $S \times T$ matrix, R_{st} , with at least $S \times (T-1)$ zero elements and no more than one non-zero element in any trace. The intersection of the set of all possible reflection matrices constitutes the seismic reflection cross-section matrix C_{st} . The positions of the non-zero elements of C_{st} may be mapped on to a plane. This mapping, together with scale conversions, displays for identifying and grading the various reflectors, and any desired annota-

tion forms the seismic reflection cross-section which is a very important display in any seismic exploration program.

The criteria employed for the detection of the reflections contained in a seismic section, i.e., the definition of the matrix C_{st} , are:

(1) For each trace N in M_{st} , the ordered set of elements is defined which is most likely to contain the non-zero elements of the column vector C_{Nt} . The matrix of these ordered sets will be denoted by $^{(1)}M_{st}$. The information required for this definition is provided by a priori geologic and geophysical experience in the area of interest. For no a priori knowledge each set would include T elements. However, it is possible to restrict consideration of the sets $P_s \leq t \leq Q_s$ where $P_s > 1$ and $Q_s < T$ are integral numbers for $s=1, 2, 3, \dots, S$;

(2) For each trace in $^{(1)}M_{st}$, the ordered set of elements is defined which consists only of relative maxima (peaks) located between P_s and Q_s in trace s . The total number of maxima is, in general, much larger than the total number of restricted elements

$$\sum_{s=1}^S (Q_s - P_s + 1);$$

and

(3) The matrix of relative maxima, $^{(2)}M_{st}$, is tested for the lateral continuity of its elements. If a non-zero element $^{(2)}M_{nm}$ exists and is an element in C_{st} , then a second non-zero element would be expected in the ordered set

$$\{^{(2)}M_{(n+1, m-I)}, ^{(2)}M_{(n+1, m+I)}\}$$

where I is a suitably small integer. Such a procedure may be extended to test all non-zero elements of $^{(2)}M_{st}$ for lateral continuity.

The matrix formed from the non-zero elements of $^{(2)}M_{st}$ which indicated lateral continuity, together with zeros in all other locations, is the required cross-section matrix

C_{st} .

Seismic Detection Based on the Foregoing Criteria

In a particular $S \times T$ seismic-section matrix M_{st} , two numbers P and Q are selected such that $P_s = P$ and $Q_s = Q$, for $s=1, 2, 3, \dots, S$. Applying these two constants to M_{st} , $^{(1)}M_{st}$ is generated. Then the matrix $^{(2)}M_{st}$ of relative maxima is determined. Relative minima (troughs) as well as the relative maxima may be selected, but, in general, one type of extrema is not preferable to the other.

To establish the cross-section matrix C_{st} , the matrix $^{(2)}M_{st}$ is tested for lateral continuity in the following manner.

If $^{(2)}M_{(n-4, t_4)}$, $^{(2)}M_{(n-3, t_3)}$, and $^{(2)}M_{(n-2, t_2)}$

are elements of a particular reflector, the geometric configurations of these three elements is employed in determining the least-squares-fit straight line to the three points. This line is extrapolated to identify the element $^{(2)}M_{(n-1, t_1)}$. Then the elements in the ordered set

$\{^{(2)}M_{(n-1, t_1 + \Delta)}, ^{(2)}M_{(n-1, t_1 - \Delta)}\}$ are searched for the existence of a non-zero element whose time position is closest to t_1 . If a non-zero element $^{(2)}M_{n-1, t_1}$ exists, the procedure is repeated. However, this time the elements

$^{(2)}M_{(n-3, t_3)}$, $^{(2)}M_{(n-2, t_2)}$, and $^{(2)}M_{(n-1, t_1)}$

are used to define the next element $M_{(n, t_0)}$. In this manner, each consecutive element of an individual reflector segment is defined. The procedure is terminated and a new reflector segment search is initiated when a non-zero element is not located within the bounds of the ordered set

$\{^{(2)}M_{(n-i, t_1 + \Delta)}, ^{(2)}M_{(n-i, t_1 - \Delta)}\}$ To initiate a reflector segment, a different procedure is followed since the three points necessary to define a straight line have been established. If $^{(2)}M_{n, t_0}$ is the first element to be tested, a second element is defined as

$^{(2)}M_{n-1, t_0}$ and the ordered set $\{^{(2)}M_{(n-1, t_0 + d)}, ^{(2)}M_{(n-1, t_0 - d)}\}$

is examined for a non-zero element whose time position is closest to t_0 . The parameter d defines the maximum expected dip within the record section and is in general larger in magnitude than the parameter Δ . If $^{(2)}M_{(n-1, t_1)}$

is this non-zero element, a straight line is established with the constraint that it pass through both $^{(2)}M_{n, t_0}$ and $^{(2)}M_{(n-1, t_1)}$. The intersection of this line with the next consecutive trace defines the third element

$^{(2)}M_{(n-2, t_2)}$ and the ordered set $\{^{(2)}M_{n-1, t_2 + \Delta}, ^{(2)}M_{n-1, t_2 - \Delta}\}$

is examined for a non-zero element. After the third element has been found, all consecutive elements are located by the procedure previously described.

If a non-zero element is not found while attempting to define the second or third element of a reflector segment, then the first element $^{(2)}M_{n, t_0}$ is excluded from any further operations and the initiation procedure starting with a previously untested element attempts to generate a new reflector segment. This is repeated until all elements in the $^{(2)}M_{st}$ matrix have either been tested to initiate segments or included within previously defined segments.

The set of all reflection segments identified in the foregoing manner from the original matrix M_{st} constitute an estimate of the cross-section matrix C_{st} . They are stored on magnetic tape, and then appropriately scaled and displayed by a digital incremental plotter in the form of line segments. Each line segment corresponds to a reflector segment. The

reflector itself consists of one or more of these segments.

In general, the number of picked reflection segments generally exceeds the number which would be conventionally carried for further analysis such as migration or mapping. It is thus desirable to assign a grade to each reflection segment. The grade preferably is a function of its average amplitude and may be made dependent upon its spatial span or length. The graded segment is compared with an appropriate threshold signal. If the segment grade exceeds this threshold signal, then the segment is carried forward in the production of a section. Conversely, the segment is rejected and not used if its grade is less than the threshold signal.

A length threshold may initially be incorporated in the picking logic. That is, at least three consecutive elements must satisfy the picking logic in order to define a reflection segment. After all reflector segments have been picked, each one is given a grade

$$G_i = \sum_{k=1}^n A_{ik}$$

where n is the number of elements in segment i and A_{ik} is the amplitude magnitude of element k . Physically G_i is the product of the mean amplitude of segment i times its length, i.e., the number of elements in segment i . By incorporating length in the grade as well as the mean amplitude, weak (low mean amplitude) but relatively long reflector segments are more likely to pass the threshold test. On the other hand, short segments with relatively low to average mean amplitude, generally characteristic of picked random noise, are more likely to be rejected.

A threshold signal for a particular record section is determined directly from the picked elements. Its magnitude is time-varying to take into account gain difference as a function of record time.

In order to define the time-varying thresholds, each of the S traces is first divided into R disjoint sets of consecutive elements. The arbitrary integer R usually is less than 5 in magnitude. Each set is restricted to contain $(P-Q)/R$ elements from the matrix of relative maxima $^{(2)}M_{st}$. The average terminal time position T_r of each disjoint set is computed as

$$\frac{1}{S} \sum_{s=1}^S t_{sr} \quad r=1, 2, \dots, R$$

where t_{sr} is the terminal time of disjoint set r contained in trace s . The set of T_r 's computed in this manner serve to quantitatively subdivide a record section into $(R-1)$ distinct time zones.

Average picked extrema amplitudes

$$A_{sr} = \frac{1}{N_r} \sum_{t=T_{r-1}}^{T_r} \hat{C}_{s,t}$$

are then determined for $s=1, 2, \dots, S$ and $r=1, 2, \dots, R$. The number N_r is the

number of elements contained in $\hat{C}_{s,t}$ between times T_{r-1} and T_r . Finally, these averages are subjected to a space average to determine

$$A_r = \frac{1}{S} \sum_{s=1}^S A_{sr}, \quad r=1, 2, \dots, R.$$

The threshold A_r applies to all segments picked in the time zone T_{r-1} to T_r . In practice, it has been found useful to weight A_r by a variable positive rational number X in order to generate several segment graded displays. A graded display is defined by the set

of reflection segments whose individual grades G_i exceed the product $X \cdot A_r$. When X is small, very little segment discrimination is attained. However, a large X value will permit only those segments which correspond to strong or laterally persistent reflectors to be displayed or retained for further analysis.

In FIGURE 6, portions of four traces have been illustrated wherein an event has been identified on traces I-1, I-2, and I-3. The event is comprised of peaks 50, 51, and 52, respectively. With such an event having been identified, it is desired to determine whether or not the event can be extended, within proper limits, to trace I. As illustrated, a peak 53 is present on trace I. However, it may happen that, in the particular time interval, there would be no peak and that the trace would have the character represented by the dotted portion 54. If the peak actually exists within the limits set, then the event will be extended to trace I and will then be checked to determine whether or not it extends to trace I+1 (not shown).

A time gate is generated centered at the predicted time, i.e., the record time at which the line 55 intersects the time axis for trace I. The gate has time span dependent upon the average period of the seismic waves represented on trace I, and is preferably about one third of the mean separation of peaks in the trace I. More particularly, the periods T_1, T_2, T_3 , and T_4 represent the intervals between successive peaks on trace I with the peak 53 being at the center of the four intervals. Signals are generated representative of the time intervals T_1 to T_4 and the gate 56, in the form of a gate signal, is then generated to have a length which is related to the average period $\bar{T}_m$, in accordance with the relationship illustrated in FIGURE 7.

In FIGURE 7, this relationship is assumed to be linear and is based upon general knowledge of the characteristics of data from the area in which the investigation is conducted. As shown a value of ± 6 milliseconds has been chosen for the aperture K when the average value between successive peaks of the trace

has the value $\bar{T}_0 = 33.1/3$ milliseconds. Thus, as shown in FIGURE 7, the line 60 represents a preferred relationship between the average period between peaks preceding and following the given record time of interest and the length of the gate 56. If, within the gate 56, a peak is identified on trace I, the event represented by the line 55 of peaks is extended onto the next succeeding trace I+1. Preferably at least three traces will be employed for establishing the presence of an event and for determining the point at which the gate 56 should be centered on the fourth or succeeding trace.

The operation preferably will be carried out in accordance with the foregoing criteria

on a data processor wherein, as indicated in FIGURE 8, traces I-1, I-2, and I-3 are employed in a first step 70 wherein the peak time for an event is determined, that is, the record time at which the peak 50 occurs on trace I-1, FIGURE 6. Having determined, on the basis of a least-squares-fit of the peaks 50, 51, and 52, the time at which a peak would be expected on trace I, a gate 56 of length 2K is applied to trace I in the step 71. The step 72 is carried out to determine whether or not a peak on trace I lies within the gate 2K centered at time T. The resultant times from steps 70 and 72 are compared in step 73. If the comparison is valid, i.e., if the peak on the trace I lies within the time gate 56, FIGURE 6, based upon the record time from trace I-1, then the event is extended in step 74 to trace I. If the peak does not occur within the limits of the gate 56, then the event is terminated in step 74 and the search moves on, for example, to successive peaks along traces I+1, I+2, and I+3.

The foregoing operations are carried out in the processor 65 of FIGURE 1. Processor 65 preferably will be a digital computer programmed in accordance with the foregoing specifications to carry out the successive operations for identifying events and the extent thereof throughout the length of the several seismograms in the manner shown in FIGURE 11.

An additional operation may be carried out. This operation is indicated diagrammatically in FIGURE 1 wherein the amplitudes of events are sensed as generated by a bank of units 80 for each of six traces. More or less than six traces may be employed. The outputs of the sensing units are applied to a multiplier 81. A threshold signal, above described, is produced by unit 65a. When the output of the multiplier 81 exceeds the threshold signal as determined by comparator 83, then a control function on channel 84 is applied to the recorder 30a and causes the event producing the high output product to be recorded by the recorder 30a with selective emphasis relative to other events. It is this type of emphasis that is clearly depicted in FIGURE 5 wherein events which have extended length or have relatively short lengths with high amplitude are recorded with line widths much greater than the events whose amplitude-length product does not exceed a given threshold. As above described, this threshold signal is a time-varying threshold and is based upon the general level of the signal amplitudes for given record times.

As illustrated in FIGURE 9, the combination of an extended number of traces having a lineup such as represented by the set 90 would represent a large length-amplitude product. In the set 90, ten traces of relatively low amplitude are as significant as a set 91 of

six traces which have peaks of intermediate amplitude and thus would provide a length amplitude product of value corresponding with that of set 90. In set 92, only three traces are aligned but they have considerably larger amplitude and thus the length product would correspond with that of sets 90 and 91. In contrast, the lineup of three peaks in set 93 of low amplitude would provide length amplitude product which would not exceed a threshold signal comparable to that against which the sets 90-92 are graded. Sets 90-92 would be employed to form line segments of higher emphasis on a record section by control of the recorder by a length-amplitude product comparison signal. Set 93 might be used to form a low emphasis line segment.

While the foregoing has been based upon the proposition that an event would be extended based upon at least three traces to a fourth, it has been found that where the data is exceptionally good and where it is preprocessed as by wide-band velocity filtering as described in Geophysics, Vol. 28, No. 6, December 1963, pages 948-974, then acceptable operations can be carried out by identifying an event on two traces and extending that to the next adjacent trace. This operation is illustrated in FIGURE 10 wherein a trace 100 has a peak 11 and trace 102 has a peak 103 and these data are applied to trace 14. Where two traces are employed, the prediction time for trace 104 would be the time on a straight line connecting peaks 101 and 103. Gate 105 is then centered on the line 100. However, the operation set forth in FIGURES 6-9 represents the more general case.

In FIGURE 11, the flow diagram illustrates extension of an event from one trace to an adjacent trace upon satisfying the conditions and constraints noted therein with the legends particularly related to computer operations. Two input channels 110 and 111 represent flow channels for data on trace I-1 and trace I, respectively.

The traces are first processed and effectively filtered to select extrema. For the purposes of this description, the extrema selected will be peaks. In step 120, trace I-1 is scanned and a number k is produced representative of the position of a given peak in a train of peaks comprising trace I-1. That is, in an initial scanning step, a counter is set to the number k. In step 122, the record time of peak k is examined to see if it has been previously "flagged", indicating the existence of an event that previously has been used in the section production operation. In practice, such record time is flagged by applying a negative sign thereto. All other peaks are positive since, on a seismic record, only positive record times exist. Thus, if peak k has not previously been flagged as an ele-

ment of an event, then an indication in step 123 is provided whereupon, in step 124, a determination is made as to the estimated time at which a peak should appear on the next consecutive trace I. This predicted time is then employed in step 125 to determine the time zero in which the predicted time falls.

Information from trace I is also employed in step 125 as follows. Trace I is employed in step 130 wherein all of the peaks in trace I are read-in to provide a signal representative of such total number of peaks. The signal representing the total number of peaks is then divided, in step 131, into M equal units of peaks. Each such unit or time zone preferably contains equal numbers of peaks.

In step 132, the mean or average period between the peaks in each time zone is determined to produce an average separation

20 interval $\bar{T}_1$.

In step 133, a search aperture is determined in accordance with the relations set forth in FIGURE 7 and expressed as

$$\Delta = \frac{\bar{Q}\bar{T}_1}{33.33},$$

25 where as above indicated Q is a constant and, from experience, has been found to be from the order of 6 milliseconds per trace.

The results from step 131 are employed in step 125 to determine in which time zone the estimated time falls.

30 Having determined the time zone in step 125, then step 135 involves generating the limits of the search aperture for trace I

35 which will be $t_1 \pm \Delta$. Thus, in step 133, the limits of the search apertures are set.

In step 135, the location of the search aperture is set. In step 136, trace I is scanned to identify the peaks in trace I and to determine whether or not the peaks lie within the search aperture.

In step 137, a test is made to determine whether none, one, or more peaks lie within the search aperture. In step 138, a first test is made to determine whether the number of peaks exceeds zero, that is, to determine if at least one peak lies within the search aperture. If there is no peak within the search aperture as indicated in step 139, then in step

50 140, again a check is made as to whether or not an element of an event had been defined as earlier checked at operation 122. If the answer is yes, as indicated in step 141, then in step 142, a check is made as to whether or not the event thus defined had a length in excess of two elements. If the answer is yes in step 143, then in step 144 the event is terminated at trace I-1 and retained. In the

latter case, a counter, employed in step 121, is incremented as indicated by step 145. 60

In step 146, the number in the counter is then tested to determine if it exceeds the total number of peaks in trace I-1. If it does not exceed the number of peaks, as indicated in step 147, then in step 148, the sequence returns to step 120 and the process is then repeated for the next peak counted in trace I-1. If the number in the counter for step 145 exceeds the number of peaks and the answer is yes in step 149, then the trace counter is incremented by one as indicated in step 150 to shift the operation to the next trace since all peaks in trace I-1 have been examined. The counter, in step 121, is reset back to one, the result being indicated in step 151. 75

In step 140, if no event was defined at the time of pulse k on trace I-1, then, as in step 152, pulse k in trace I-1 is excluded from further analysis by step 153. 80

Further, if the number of elements in the identified event does not exceed two points as indicated in step 154, a negative indication is employed by step 155 to terminate the event and the event is not retained. Further, as a result of step 155, and as indicated in step 156, the peak $t_{i-2}(k)$ is also excluded from further analysis and the counter employed in step 145 is incremented. 85

The foregoing discussion has been based upon operation 122 as having involved an event not previously identified. However, as indicated in step 160, if the element on trace I-1 had previously been identified, then in step 161 inquiry is made as to whether or not the event is of length in excess of two points as indicated by step 162, or less than two points as indicated by step 163. In the former case, step 164 provides 90

a predicted time t_1^A , based upon the flagged time of peaks in three adjacent traces. In

step 165, a predicted time t_1^A is provided based upon elements of the flagged event in two adjacent traces t_{i-1} and t_{i-2} . 95

In the foregoing description, it was assumed that there were no peaks in the search aperture so that the operation proceeded from step 138 to step 139. However, if a peak on trace I is identified within the search aperture as indicated in step 170, then a check is made in step 171 to determine if there is only one peak within such aperture or if there is more than one peak. If there is only one peak, then through steps 172 and 173 the previously flagged event is extended to trace I, intersecting at $t_1(j)$. Also when the event is extended in step 173, step 174 involves flagging the time of peak k on trace I with a negative sign. In addition, the times of peaks k on trace I-1 and on trace I-2 are also flagged with a negative sign if the 110 115 120

event equals three elements. If the event does not equal or exceed the three elements, then none of the record times for this particular peak are flagged.

5 It should be understood that in pursuing this operation, the event is not flagged but the individual elements of the event are flagged by applying a negative sign to the record time for such element.

10 Where more than one peak appears in the search aperture, then through steps 180 and 181 a plurality of comparisons are carried out to determine the differences between the predicted time and the times of peaks in the search aperture. Only one peak is used where more than one peak is present in the aperture. The peak which is used is that peak which occurs at a time which differs from the predicted time less than the time occurrences of any other peak in the aperture. The event thus identified is then employed in step 173 for extension of the event as above described.

25 The method embodied in the operations set forth above, particularly in connection with FIGURE 11, involves reproduction of the seismic traces as electrical signals and generating an electrical time gate that is proportional to the separation between peaks in one electrical signal in the time region of an event identified on adjacent traces. The time gate is centered at a predicted time, the prediction being based upon the times at which the event occurs on the adjacent trace. 30 An output signal is then generated on coincidence between a peak in the one signal and the time gate.

When carried out in digital form, pulses representative in time of the occurrence of peaks of a selected polarity from each trace are employed. A control signal is generated when one of the pulses on a first of the traces lies within the above time gate. In response thereto, time spaced indicia representative of reflecting horizons are then utilized only in response to such control signal. The method assures that the elements of reflection are present on each trace across which an event extends before recording an event as a continuous segment on a record section.

WHAT WE CLAIM IS:—

1. A method of producing a display of subsurface earth structure from a set of seismograms in which adjacent seismic traces represent seismic waves detected at adjacent locations spaced along a traverse, which method comprises: generating respective electrical pulses from said seismograms at the times of peaks of a selected polarity in the traces, generating an electrical control signal when one of said pulses from a first of said traces on a seismogram lies within a time gate which is dependent in which upon mean peak separation in said first trace and

centred at the predicted time for one of said pulses from said first trace, and producing a display of time-spaced indicia representative of reflecting horizons on said seismogram only in response to said control signal.

2. A method as set forth in claim 1, wherein said gate is centred on said first trace at a point which would lie on a line connecting corresponding peaks on at least two adjacent traces.

3. A method as set forth in either of claims 1 or 2, wherein said time-spaced indicia are enhanced in response to the amplitudes of such pulses exceeding a predetermined threshold signal.

4. A method as set forth in any of claims 1 to 3, wherein said first trace is reproduced as an electrical signal to generate said electrical pulses.

5. A method as set forth in claim 4, further including generating the time gate as an electrical time gate having a length which is proportional to the mean peak separation as denoted by the mean pulse separation in said electrical signal representing said first trace, said gate being in the time region of a seismic event comprising corresponding peaks from a plurality of consecutive adjacent traces, and centring said time gate at a predicted time based upon the times of said corresponding peaks in said consecutive traces, said control signal being generated as an output signal upon coincidence between a pulse of the electrical signal representing said first trace and said time gate.

6. A method as set forth in claim 5, wherein the length of said electrical time gate is about one-third of said mean pulse separation in said electrical signal representing said first trace.

7. A method as set forth in either of claims 5 or 6, wherein said consecutive traces are at least three in number.

8. A method as set forth in claim 7, wherein said electrical time gate is centred on said electrical signal representing said first trace at a point which would lie on a least-squares fit line connecting corresponding peaks on said consecutive traces.

9. A system for producing a display of subsurface earth structure from a set of seismograms in which adjacent seismic traces represent seismic waves detected at adjacent locations spaced along a traverse, which comprises: means for generating from said seismograms respective electrical pulses at the times of the peaks of a selected polarity in the traces, means for generating an electrical control signal when one of said pulses from a first of said traces on a seismogram lies within a time gate which is dependent in width upon the mean separation period between peaks in said first trace and centred at the predicted time for one of said pulses from said first trace, an X—Y section plotter



event equals three elements. If the event does not equal or exceed the three elements, then none of the record times for this particular peak are flagged.

5 It should be understood that in pursuing this operation, the event is not flagged but the individual elements of the event are flagged by applying a negative sign to the record time for such element.

10 Where more than one peak appears in the search aperture, then through steps 180 and 181 a plurality of comparisons are carried out to determine the differences between the predicted time and the times of peaks in the search aperture. Only one peak is used where
15 more than one peak is present in the aperture. The peak which is used is that peak which occurs at a time which differs from the predicted time less than the time occurrences of any other peak in the aperture. The event thus identified is then employed in step
20 173 for extension of the event as above described.

The method embodied in the operations set forth above, particularly in connection with
25 FIGURE 11, involves reproduction of the seismic traces as electrical signals and generating an electrical time gate that is proportional to the separation between peaks in
30 one electrical signal in the time region of an event identified on adjacent traces. The time gate is centered at a predicted time, the prediction being based upon the times at which the event occurs on the adjacent trace.
35 An output signal is then generated on coincidence between a peak in the one signal and the time gate.

When carried out in digital form, pulses representative in time of the occurrence of
40 peaks of a selected polarity from each trace are employed. A control signal is generated when one of the pulses on a first of the traces lies within the above time gate. In response thereto, time spaced indicia representative of
45 reflecting horizons are then utilized only in response to such control signal. The method assures that the elements of reflection are present on each trace across which an event extends before recording an event as a continuous segment on a record section.
50

WHAT WE CLAIM IS:—

1. A method of producing a display of subsurface earth structure from a set of seismograms in which adjacent seismic traces represent seismic waves detected at adjacent
55 locations spaced along a traverse, which method comprises: generating respective pulses electrical pulses from said seismograms at the times of peaks of a selected polarity
60 in the traces, generating an electrical control signal when one of said pulses from a first of said traces on a seismogram lies within a time gate which is dependent in which upon mean peak separation in said first trace and

centred at the predicted time for one of said
65 pulses from said first trace, and producing a display of time-spaced indicia representative of reflecting horizons on said seismogram only in response to said control signal.

2. A method as set forth in claim 1, wherein
70 said gate is centred on said first trace at a point which would lie on a line connecting corresponding peaks on at least two adjacent traces.

3. A method as set forth in either of claims
75 1 or 2, wherein said time-spaced indicia are enhanced in response to the amplitudes of such pulses exceeding a predetermined threshold signal.

4. A method as set forth in any of claims
80 1 to 3, wherein said first trace is reproduced as an electrical signal to generate said electrical pulses.

5. A method as set forth in claim 4,
85 further including generating the time gate as an electrical time gate having a length which is proportional to the mean peak separation as denoted by the mean pulse separation in said electrical signal representing said first
90 trace, said gate being in the time region of a seismic event comprising corresponding peaks from a plurality of consecutive adjacent traces, and centring said time gate at a predicted time based upon the times of said
95 corresponding peaks in said consecutive traces, said control signal being generated as an output signal upon coincidence between a pulse of the electrical signal representing said first trace and said time gate.

6. A method as set forth in claim 5, where-
100 in the length of said electrical time gate is about one-third of said mean pulse separation in said electrical signal representing said first trace.

7. A method as set forth in either of claims
105 5 or 6, wherein said consecutive traces are at least three in number.

8. A method as set forth in claim 7, where-
110 in said electrical time gate is centred on said electrical signal representing said first trace at a point which would lie on a least-squares fit line connecting corresponding peaks on said consecutive traces.

9. A system for producing a display of
115 subsurface earth structure from a set of seismograms in which adjacent seismic traces represent seismic waves detected at adjacent locations spaced along a traverse, which comprises: means for generating from said seismograms respective electrical pulses at the
120 times of the peaks of a selected polarity in the traces, means for generating an electrical control signal when one of said pulses from a first of said traces on a seismogram lies within a time gate which is dependent in
125 width upon the mean separation period between peaks in said first trace and centred at the predicted time for one of said pulses from said first trace, an X—Y section plotter

adapted to write time-spaced indicia representative of reflecting horizons on said seismograms, and means for actuating said plotter only in response to said control signal.

- 5 10. A system as set forth in claim 9, wherein said pulse-generating means is effective for generating from each of said seismograms electrical signals representative of the time occurrence of each peak of a selected polarity in each trace, and said time gate
10 being centred on said first trace at a point which would lie on a least-squares fit line connecting corresponding peaks on three consecutive traces adjacent to said first trace.

- 15 11. A method of producing a display of subsurface earth structure, substantially as

herein described with reference to the accompanying drawings.

12. A system for producing a display of subsurface earth structure, substantially as
20 herein described with reference to the accompanying drawings.

13. A display of subsurface earth structure produced by a method according to any of claim 1 to 8 and 11 or by a system according to any of claims 9, 10 and 12.
25

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