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RECORD

RECORD 1988/49

STATIC CORRECTIONS for LAND SEISMIC PROCESSING

by

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CONTENTS

ABSTRACT

The Bureau of Mineral Resources has been processing seismic reflection data using the Digicon DISCO system over the last four years. One of the more critical steps in the processing sequence is the calculation of accurate static corrections. This report reviews the standard uphole-depth method of calculating shot and receiver static corrections and illustrates sources of errors together with a means of reducing these errors when using this technique. The use of first break data to improve the calculation of statics is illustrated in the case of the reciprocal technique. A novel but not new technique of merging time variations apparent in the first breaks with uphole-depth statics is illustrated and shows convincing results. This latter technique has the ability to correct for errors introduced by the uphole-depth method and can bridge gaps resulting from the absence of continuous uphole-depth information.

INTRODUCTION

In recent years the Bureau of Mineral Resources has been processing seismic reflection data using the Digicon DISCO System. One of the more critical steps in the the processing of land seismic data is the calculation of receiver and shot statics corrections. The standard method of calculating these is to use uphole times and shot depths. Unfortunately insufficient emphasis has been given to ensuring that the uphole and depth information is correct or that they are applicable to the general formulae. The basic assumption used when calculating statics from uphole information is that the shot is below the weathering. Inclusion of shallow shots or shots with depths incorrectly recorded will lead to errors in the static corrections which can affect the entire section. The use of autostatics routines to correct such situations is not always successful, particularly when the signal to noise ratio is poor.

The importance of obtaining accurate static corrections has become obvious from a comparison of sections produced using routine DISCO statics and those using edited uphole -depth statics which incorporate information from the first breaks.

This report reviews the uphole-depth method of calculating statics, gives examples of obvious errors and a method of correcting for errors. The use of first break data to reduce errors and to determine residual statics is illustrated. In particular the reciprocal method of calculating weathering times and a novel technique of using "floating weathering times" are illustrated with examples.

Technical details of the formats and checks used when analysing first breaks are given in appendix 1.

UPHOLE-DEPTH STATICS

Shot and receiver static corrections (hereafter referred to as simply "statics") are usually calculated from uphole times, depth of shot and elevations. The method, illustrated in Fig.1, is based on the assumption that the charge is below the weathering.

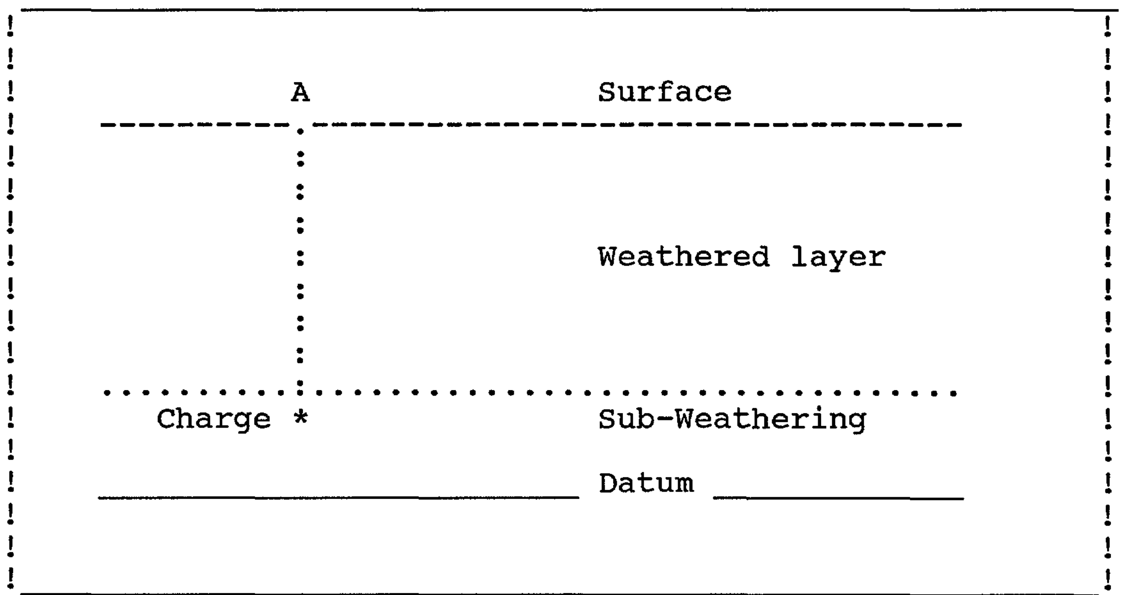

Fig. 1. Uphole-depth method of calculating statics.

Referring to Fig. 1 the shot and receiver statics at shot station "A" are given by:

SSTAT=-{(Elev-Ds-Datum)/Ve}
RSTAT=-{(Elev-Ds-Datum)/Ve + Tuh}

where SSTAT = shot static (ms)
RSTAT = receiver static (ms)
Elev = elevation of shot station (metres)
Ds = depth of shot (metres)
Datum = elevation of datum (metres)
Ve = subweathering velocity (metres/ms)
Tuh = uphole time (ms)

The negative sign immediately on the right of both of these equations is necessary in order to comply with industry convention. The standard convention dictates that if time is to be subtracted from a seismic trace then the static correction is set negative.

This method defines the shot and receiver statics at each shot station. Receiver statics for intermediate stations are interpolated from adjacent shot stations while accommodating elevation changes. Hence errors inherent in the shot static will produce errors in receiver statics for adjacent stations. For normal CDP recording (6 fold, 48 channel) a single shot static error will affect as many as 100 output traces from the stack.

One of the more successful methods of detecting sources of error in depth, uphole times and calculated receiver static is to display the information in the format illustrated in Tables 1 and 2. The relative changes between each of the parameters are readily observed when information is displayed in this format.

There are two possible sources of errors associated with calculating statics from the uphole and depth information. These are:

(a) The shot is not below the weathering. The effect is illustrated in Table 1 for several data sets.

Table 1. Examples of static errors caused by shallow shot holes.

SHOT STATION	DEPTH Metres	UPHOLE msecs	ELEV Metres	RSTAT msecs	SSTAT msecs	VELOCITY m/sec
Millmerran 1986						
1203	40	30	314	-13	17	1333
1208	40	30	313	-13	17	1333
1212	38	29	311	-12	17	1310
1218	**10**	**14**	**312**	**-8**	**6**	**714**
1219	40	28	313	-11	17	1428
1223	40	34	316	-18	16	1176
1229	36	31	316	-16	15	1161
Megine 1984						
4044	40	41	354	-47	-6	975
4048	**28**	**20**	**350**	**-29**	**-9**	**1400**
4052	35	29	343	-32	-3	1206
4056	40	40	337	-39	1	1000
4060	**27**	**21**	**332**	**-23**	**-2**	**1285**
4064	40	42	327	-37	5	952
4068	40	33	329	-29	4	1212
Megine 1984						
4086	40	41	336	-40	1	975
4088	40	45	335	-44	1	888
4090	**20**	**30**	**326**	**-32**	**-2**	**666**
4092	40	40	315	-30	10	1000
4094	40	38	311	-26	12	1052
Megine 1984						
4176	40	41	295	-22	19	975
4178	40	42	297	-24	18	952
4180	**31**	**22**	**302**	**-10**	**12**	**1409**
4182	40	46	301	-30	16	869
4184	40	43	304	-28	15	930
Dunkeld 1986						
1330	40	33	307	-36	-3	1212
1336	40	40	300	-40	0	1000
1342	**17**	**17**	**296**	**-26**	**-9**	**1000**
1347	40	40	297	-39	1	1000
1355	40	35	298	-35	0	1142

Shots at stations 1218, 4048, 4060, 4090, 4180 and 1342 in Table 1 are all fired at shallow depths compared to the normal. In all cases the receiver static calculation show unacceptable changes compared with adjacent stations. A plot of receiver static verus station location will show strong correlation between receiver static and the location of a shot hole. It must be remembered that the value of a receiver static should be completely independent of the location of a shot hole.

(b) The depth of the shot as stated in drill logs is in error. Table 2 illustrates examples of this type of error.

Table 2. Example of static error caused by incorrectly recorded shot depth.

SSN	DEPTH Metres	UPHOLE msecs	ELEV Metres	RSTAT msecs	SSTAT msecs	VELOCITY m/sec
Millmerran 1986						
1338	40	35	339	-28	7	1142
1343	40	38	340	-31	7	1052
1349	**36**	**26**	**342**	**-21**	**5**	**1384**
1353	40	38	342	-32	6	1052
1356	40	38	343	-32	6	1052
1358	40	40	343	-34	6	1000
Megine 1984						
4494	40	40	365	-51	-11	1000
4496	40	38	363	-48	-10	1052
4500	**31**	**24**	**357**	**-35**	**-11**	**1291**
4502	40	45	350	-49	-4	888
4506	40	38	340	-38	0	1052
Megine 1984						
4642	40	31	299	-14	17	1290
4644	23	19	297	-9	10	1210
4648	**34**	**16**	**295**	**0**	**16**	**2125**
4652	40	29	293	-9	20	1379
4656	40	28	291	-7	21	1428
Dunkeld 1986						
1288	40	36	318	-45	-9	1111
1294	32	36	318	-49	-13	888
1301	**32**	**24**	**332**	**-44**	**-20**	**1333**
1306	40	36	327	-49	-13	1111
1312	40	36	324	-48	-12	1111

Shot stations at 1349, 4500, 4648 and 1301 all have depths recorded incorrectly while the shot at 4644 is another example of a shot fired at a shallow depth. Receiver statics calculated for these stations all show abrupt changes compared with adjacent stations. It could be argued that such changes are genuine and in some cases this is correct. Doubtful cases can be resolved by plotting first breaks of the suspected shot along with those from adjacent shots. Fig. 2 shows a first break plot from shots surrounding station 1349.

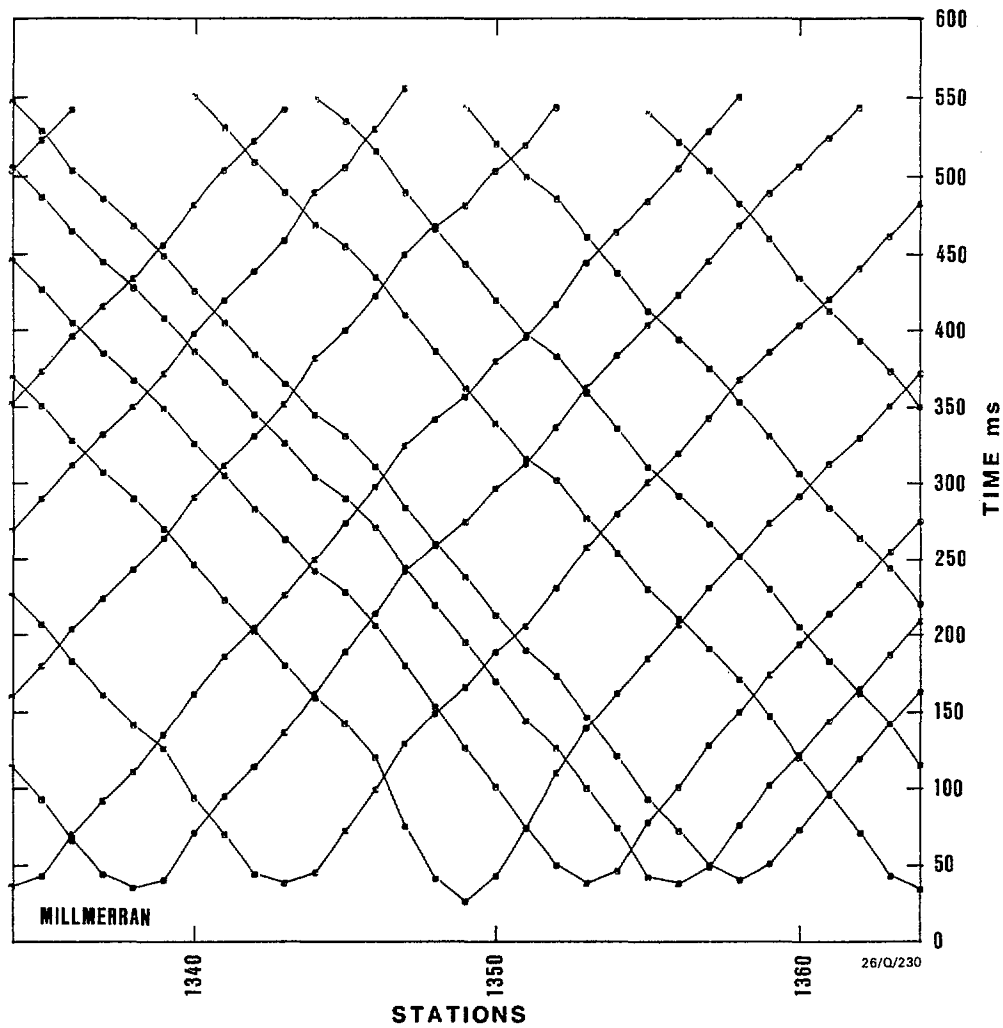

Fig. 2. First break plot. The shot at station 1349 was fired in the weathering.

It is obvious that the shot at station 1349 was fired in the weathered layer and hence the depth of the charge is probably 26 m instead of 36 m as shown in the log.

Shallow shots are easily distinguished by examining depths as well as the calculated receiver statics. Detecting incorrectly recorded depths however is more difficult. As a general rule errors in depths are characterized by an increase in uphole velocity, a decrease in uphole time and a sharp change in receiver static. Uphole velocities exceeding 2000 m/s or below 700 m/s must always be regarded with suspicion.

One method of correcting for shot static errors associated with both of the above is as follows. In the absence of any additional information we assume that the receiver static is comparable to that of adjacent stations. The following formula is then used to estimate the shot static at the station in question.(Table 3.)

SSTAT(1349) = SSTAT(1343)-(Tuh(1343)-Tuh(1349))

That is, the shot static at station 1349 is equal to the shot static at 1343 less the difference in the corresponding uphole times. The receiver static is then calculated from the edited shot static. For this example the edited statics would be:

SSTAT=-5
RSTAT=-31

Care must be exercised when using this technique because of the influence of elevation on the receiver static. The examples shown here depicting these errors are very common. Of the 2500 shots along Line 14 of the 1984 survey in SE Queensland (Wake-Dyster and Johnstone 1985) there are as many as 300 which fit into the categories illustrated in Tables 1 and 2. For line 19 at Dunkeld there are eight shots fired at shallow depths and one where the depth is incorrectly recorded out of a total of 60 shots. Some of the errors in the calculated shot static associated with these shots exceed 15 ms.

RESIDUAL STATIC CALCULATION

Small errors in both shot and receiver statics will exist even after careful editing. Processing centres use autostatics routines to detect such variations and whilst these techniques are largely successful they are subject to cycle skipping and can be complete failures where the signal to noise ratio is not adequate. It must be remembered that crosscorrelation techniques cannot distinguish between signal and noise if the eye cannot see the signal. There is a large amount of published data pertaining to the estimation of accurate static corrections. (Wiggins et al 1976, Booker et al 1976). These earlier publications describe methods which use crosscorrelation techniques to detect differences in received signal from data pertaining to the same subsurface point. In recent years more attention has been given to the utilization of the vast amount of information contained in the first breaks. Since most of the static variations which affect seismic reflection data are associated with the near surface it follows that these variations must also be present in the first break data. The advantage of using first breaks is that the onset of the first arrival is well defined and not contaminated by noise. Hence first breaks can be used where conventional autostatics routines cannot work because of poor signal to noise ratio. The problem involved here is the extraction of information from the first breaks and incorporation into the receiver statics.

Reciprocal Method.

The author experimented with several techniques to extract relevant information from the first breaks. The most obvious method is to calculate weathering times based on the reciprocal technique, (Hawkins, 1961). This technique is commonly used in shallow engineering surveys where the depth to bedrock or depth of weathering is required during the design stage of construction projects. The reciprocal method is illustrated in Fig. 3.

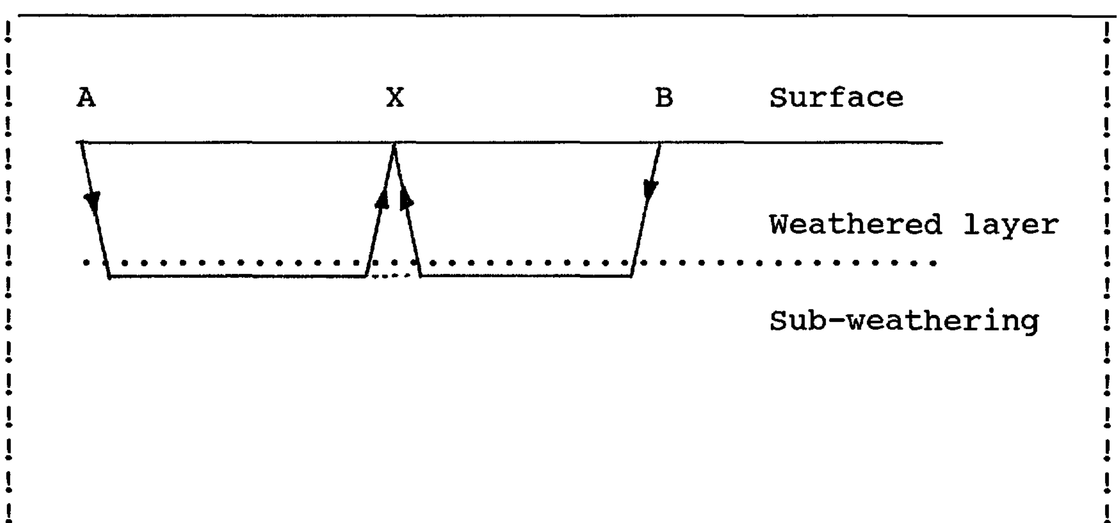

Fig. 3. Reciprocal method of calculating weathering times.

The theory is based on reverse shooting into a spread of detectors. Arrivals which have a common refractor velocity are combined to give weathering times according to the formula below.

$$Tw=(Tax+Tbx-Tab)/2$$

where Tw = weathering time at X.
Tax = travel time from A to X.
Tbx = travel time from B to X.
Tab = reciprocal travel time between A and B.

Before the method can be applied to first breaks from any two shots the following conditions must exist.

(1) The arrival times Tab, Tbx and Tab must all pertain to the same refractor.
(2) Uphole times must be known for the shots at A and B.
(3) The arrival times picked must be the first breaks.
(4) The reciprocal time Tab must be known.

Given that these conditions apply it is possible to calculate Tw from all possible combinations of shots acquired from CDP recording. For 6 fold data as many as 20 different values of Tw can be calculated for each receiver station. All values of Tw calculated for the same receiver station can be used to provide an average or median value which can be converted to a receiver static. Table 3 shows the calculated weathering weathering times from a segment of the Millmerran 1986 line, (Johnstone et al 1987).

Table 3. Calculated weathering times,Millmerran 1986.

**Millmerran,Qld,Weathering times.
**Window 4-24.

Station	Weathering Times(ms)	Median(ms)
1087	49 36 36 39 43 44 45	43
1088	50 41 41 44 44 45 47	44
1089	53 43 44 47 46 46 48	46
1090	55 45 47 50 47 47 51	47
1091	56 49 53 52	53
1092	57 49 53 44 45 48 52	49
1093	58 50 53 48 49 53 54	53
1094	59 51 55 50 51 55 54	54
1095	58 54 52 57	57
1096	59 56 53 59	59
1097	58 54 52 58	58
1098	56 52 51 58 48 52 50 53	52
1099	54 50 49 57 48 53 52 54	53
1100	55 51 51 52	52
1101	58 54 55 57	57
1102	59 55 56 58 52 53 55	55
1103	54 50 52 54 48 50 51	51
1104	49 46 48 51 45 47 49	48
1105	44 43 46 49 41 44 47	44
1106	43 47 42 45	45
1107	35 40 38 39 45 39 43	39
1108	34 41 39 38 45 37 43	39
1109	32 40 39 35 43 35 42	39
1110	42 41 44 43	43
1111	40 40 41 40	40
1112	41 42 41 41	41
1113	41 42 34 35 36 37 40 39	39
1114	36 40 31 34 35 35 35 35	35
1115	40 35 36 37	37

The average or median of the weathering time is converted to a receiver static using the following folmulae:

$$Cf \text{ (conversion factor)} = \frac{Vo \times Ve}{\sqrt{(Ve)^2 - (Vo)^2}}$$

$$Dw = Tw \times Cf$$

$$RSTAT = -(Dw/Vo + (Elev - Dw - Datum)/Ve)$$

where RSTAT = receiver static (ms)
Elev = elevation of station (metres)
Dw = depth of weathering (metres)
Datum = elevation of datum (metres)
Vo = weathering velocity (metres/ms)
Ve = subweathering velocity (metres/ms)
Tw = weathering time (ms)

Floating Weathering Times.

The reciprocal technique imposes restrictions on the the amount of first break data which can be included in the calculation of receiver statics. These restrictions discriminate against the following cases.

(1) Useable data exist but there are no recorded reciprocal times.
(2) The useable window of data is short because of several refractors.
(3) Shots may be fired "off end" and no uphole times available.
(4) Cases of good quality arrivals which are not first arrivals but are consistent with P waves travelling along a continuous refractor. An example of this is where a later trough or peak can be clearly picked.

If instead of calculating absolute weathering times we calculate what the author describes as "floating weathering times" then almost all first break data can be included in the computations. Referring to Fig. 3 the following formulae defines the term "floating weathering time".

$$Twf = (Tax + Tbx)/2$$
$$Tw = Twf - K$$

where Twf = floating weathering time.
Tw = absolute weathering time.
K = DC component.

When the first breaks from two shots are combined according to the above formulae the result is a group of times spanning several stations. These times are essentially "floating" since the value derived for a station varies with each pair of shots. The length of the span from two shots is referred to in this report as the "group length". The problem associated with using "floating weathering times" is to determine a method of removing the DC component from each group. This DC component will depend on the following:

(1) Distance between shots.
(2) Subweathering velocity.
(3) Uphole times at each shot.
(4) The cycle of the trace which is picked.

In order to remove the DC level from Twf one technique is to use the receiver statics calculated from uphole times as control data. Accurate receiver statics at selected stations on the seismic line can serve as control information in much the same way as uphole shots are used when processing Vibroseis data. With control from uphole statics, Twf can be converted direct to receiver static corrections by a merger of Twf and uphole-depth receiver statics. The final receiver statics will then contain the time variations apparent in the first breaks as well as the control provided from uphole-depth data.

Once again the groups of arrivals Tax, Tbx (Fig. 3) must be from the same refractor. However in the event that there are several refractors present it is possible to isolate data pertaining to each refractor and perform separate calculations on each data set. This procedure vastly increases the amount of first break data which can be used in the calculations. The technique illustrated in Fig. 4 involves the following steps:

(a) calculation of Twf from all combinations of shots and using all refractors, Fig. 4(a). The sign of Twf has been changed in order to give the time variations the same sign as the receiver statics.

(b) calculation of receiver statics (RSTAT) at selected shot stations, Fig. 4(b).

(c) removal of the DC component from Twf, Fig. 4(c).

(d) selection of a median value from 4(c) to give a receiver static at each station, Fig. 4(d) (continuous line).

The DC component associated with the combination of any two shots is removed using the following formula.

$$Ti=Twf-RSTAT$$

In Fig. 4, the differences between the receiver statics and Twf (Ti) are calculated for the combination of two shots and the median value of this group of Ti is assumed to be the DC component associated with the two shots. This process is applied to all combinations of shots and the result is shown in Fig 4(c). Finally the median value of (Twf-Ti) calculated for each station is selected as the receiver static.

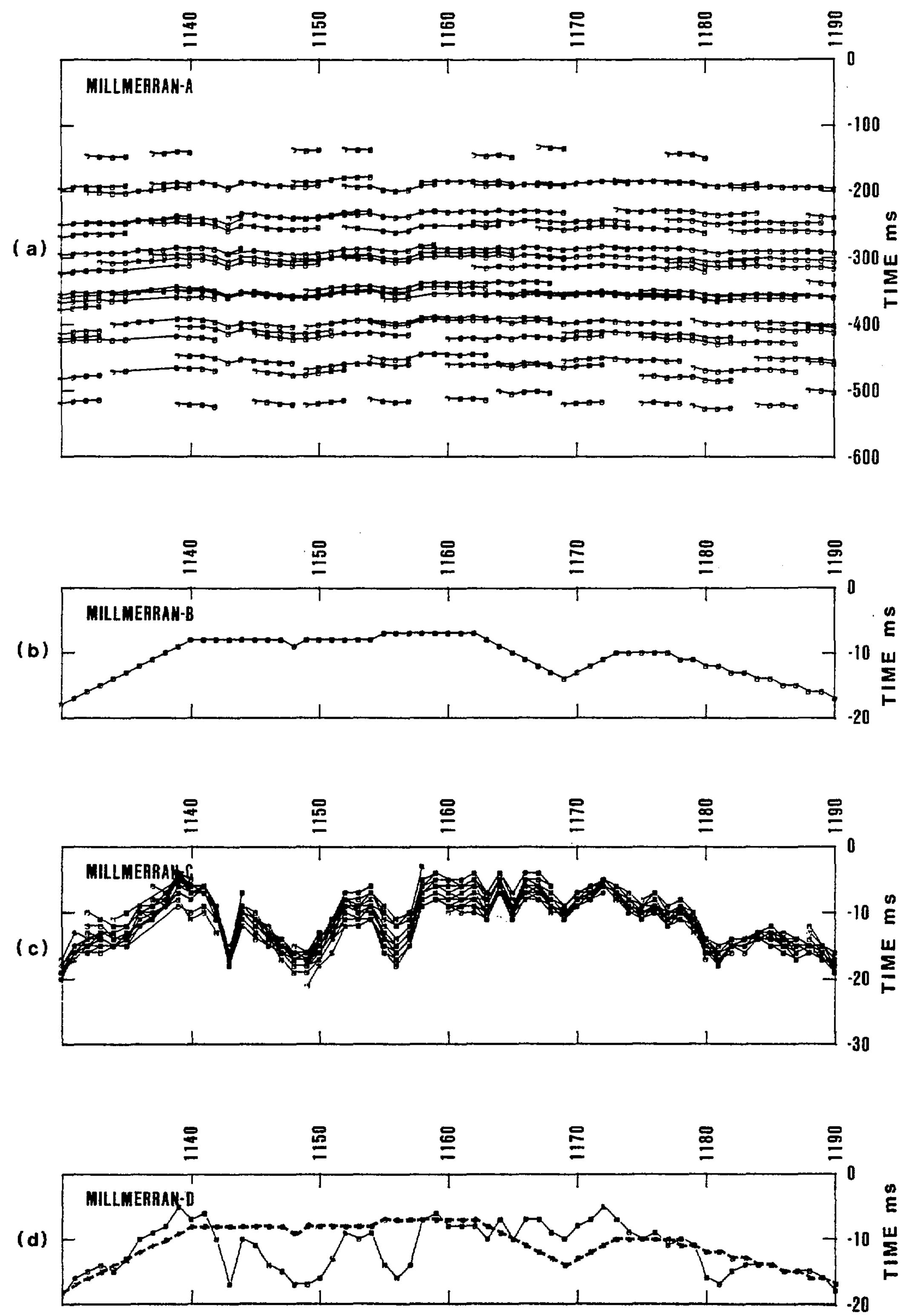

Fig. 4. Receiver statics from first breaks,Millmerran 1986.
(a) Floating weathering times,Twf
(b) UH receiver statics,RSTAT
(c) Twf-RSTAT
(d) FB receiver static,continuous line.
UH receiver static,dashed line.

The final result, shown in Fig. 4(d), is compared with the original receiver statics calculated from uphole times (dashed line). Further examples from different data sets are illustrated in Figures 5 and 6. The abrupt change in (Twf-Ti) at station 4622 (Fig. 5) is associated with faulting near the Kincora gas field. The large increase in (Twf-Ti) at station 1350 (Fig. 6) occurs between two shots and is not apparent on the original receiver statics calculated from uphole times.

The process essentially merges the short wavelength time-shifts evident in the first breaks with the long wavelength variations provided by the uphole-depth information. Control from the uphole data has effectively forced the final result to conform with long wavelength trends without compromising the high frequency changes evident in the first break data.

The process lends itself to iteration in that the new set of receiver statics can be used as new control data for removing the DC component from Twf. Fig. 7 shows the effect of one,three and six iterations on reducing scatter associated with converting Twf to RSTAT.

The technique has the capacity to correct for the types of errors illustrated in Tables 2 and 3 and can bridge large gaps in receiver statics when consecutive uphole-depth data are absent or unreliable. Fig. 8 gives an example where uphole control is present every 0.3 km and two examples where gaps of 1.0 km and 3.0 km exist in this control. In this example from Kumbarilla (Wake-Dyster and Johnstone, 1985) there is negligible difference in the final result between control every 0.3 km and leaving a gap of 3.0 km. The reason for this is that there are no large changes in the receiver statics over the gap. In addition there are no long wavelength variations present. The example shown in Fig. 9, however, illustrates what happens to large changes when control is lacking. The example is from Megine, 1984 seismic survey, and once again shows a comparison of receiver statics obtained using complete control and gaps in control. Time differences of 7 ms appear between corrections obtained with complete control and those calculated when a control gap of 3.0 km exist. The effect is illustrated more clearly in Fig. 10 where results of different calculations are plotted on an expanded scale.

Limitations

There are several limitations to the technique. Firstly accurate results could not be expected where sudden large changes in elevation occur. This is because the first break data essentially monitors time variations in the weathered layer whereas receiver statics are time variations between datum and the surface. A second limitation exists when a combination of short group lengths occurs with large errors in the control data. The errors in the control data can force (Twf-Ti) to conform with the receiver statics rather than of vice versa. Finally long gaps in the control data or gaps at critical points along the line will leave long

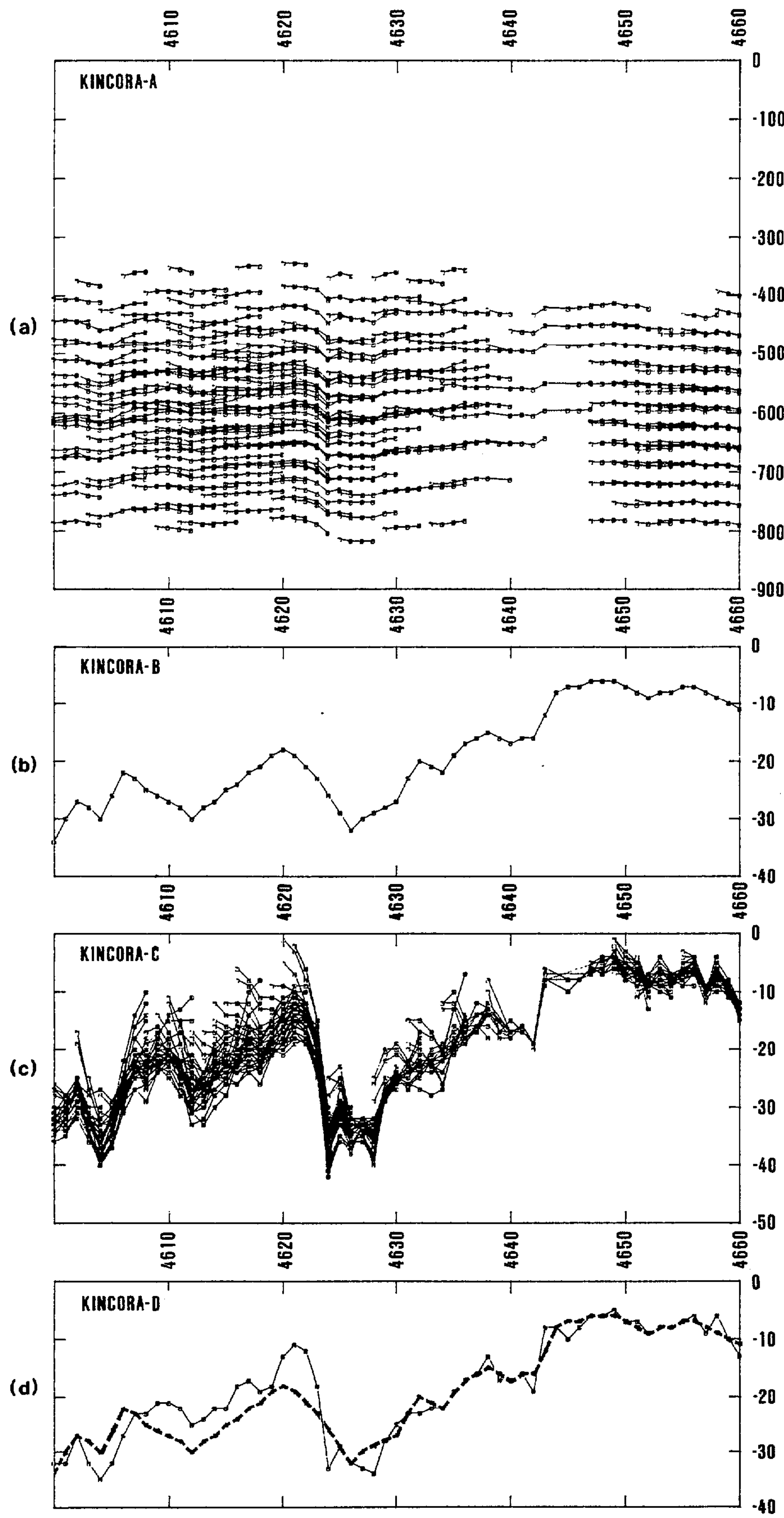

Fig. 5. Receiver statics from first breaks, Kincora 1984.
(a) Floating weathering times, Twf
(b) UH receiver statics, RSTAT
(c) Twf-RSTAT
(d) FB receiver static, continuous line.
UH receiver static, dashed line.

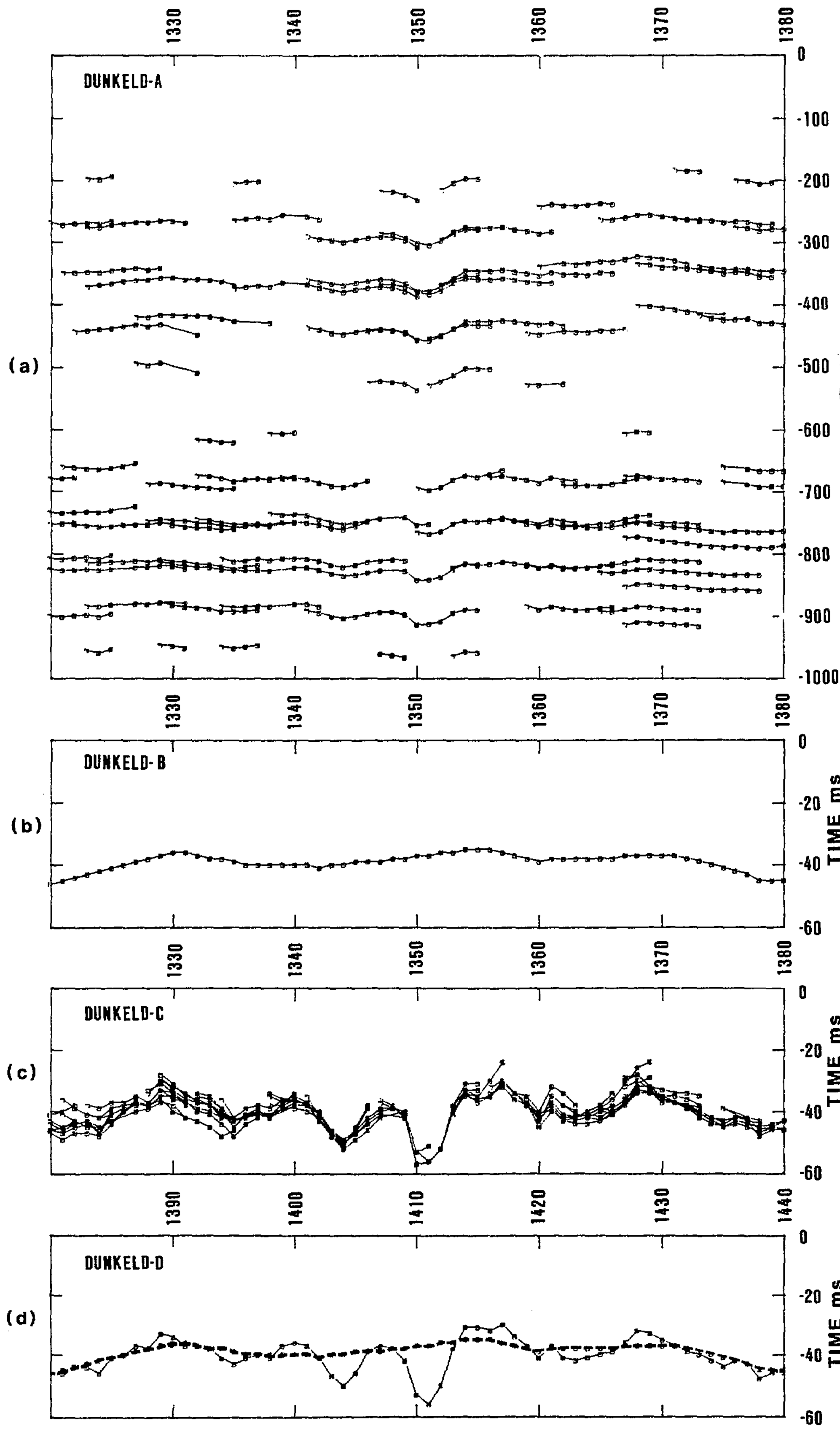

Fig. 6. Receiver statics from first breaks, Dunkeld 1986.
(a) Floating weathering times, Twf
(b) UH receiver statics, RSTAT
(c) Twf-RSTAT
(d) FB receiver static, continuous line.
UH receiver static, dashed line.

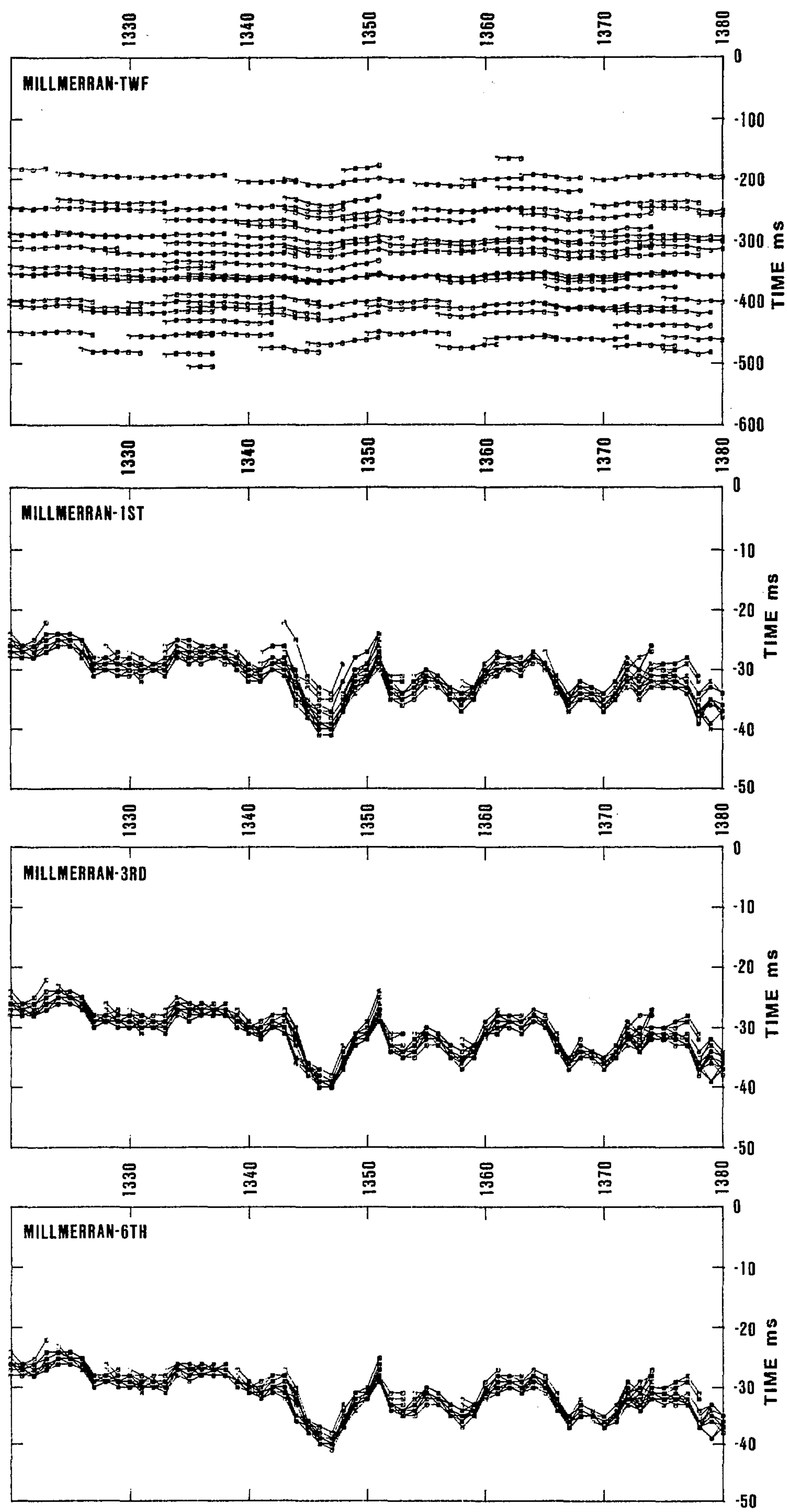

Fig. 7. Illustration of 1st,3rd and 6th iteration.

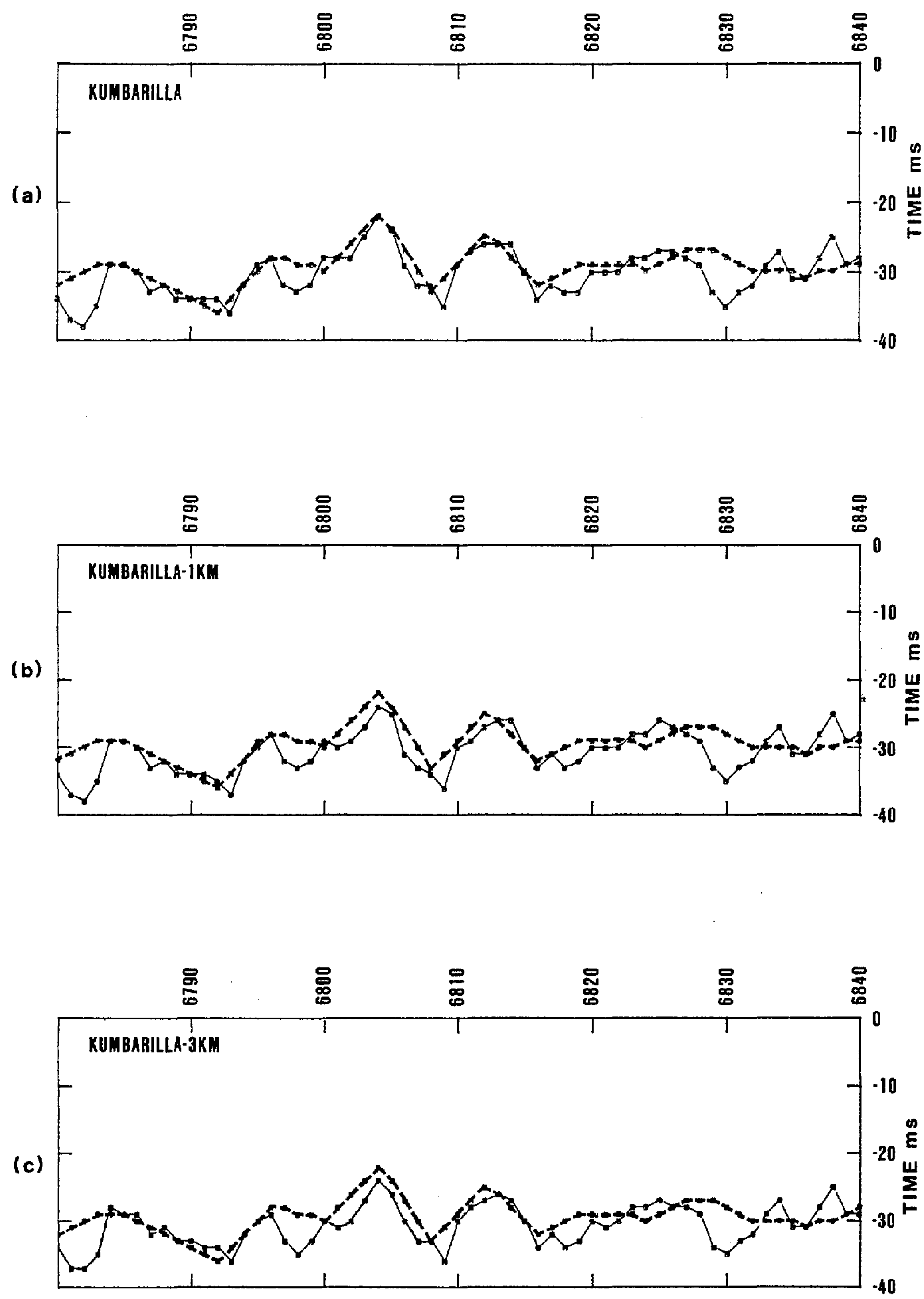

Fig. 8. Effect of gaps in control data, Kumbarilla 1984.
Continuous line - FB receiver statics.
Dashed line - UH receiver statics.

(a) No gap in control.
(b) 1km gap in control.
(c) 3km gap in control.

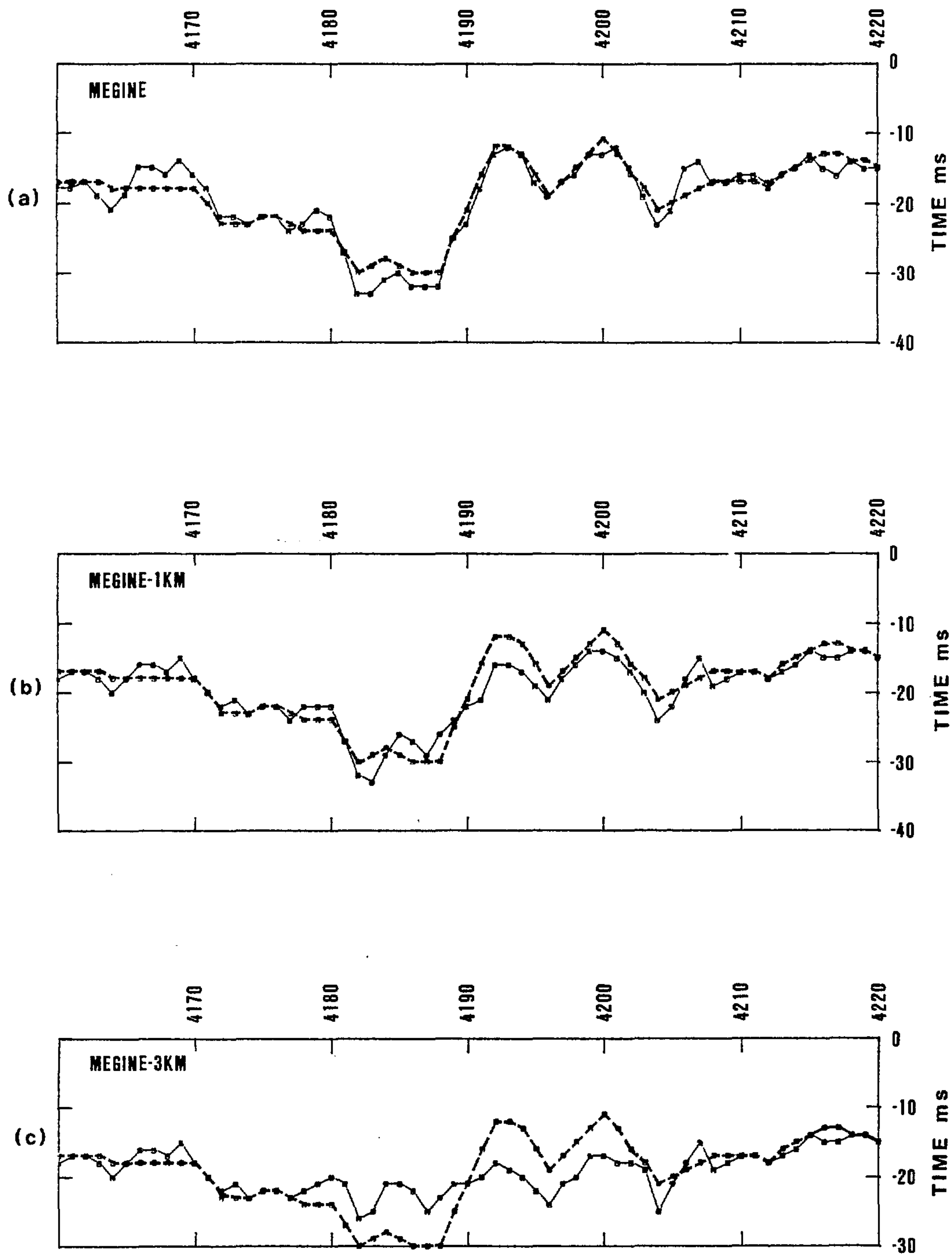

Fig. 9. Effect of gaps in control data,Megine 1984.
Continuous line - FB receiver statics.
Dashed line - UH receiver statics.
(a) No gap in control.
(b) 1km gap in control.
(c) 3km gap in control.

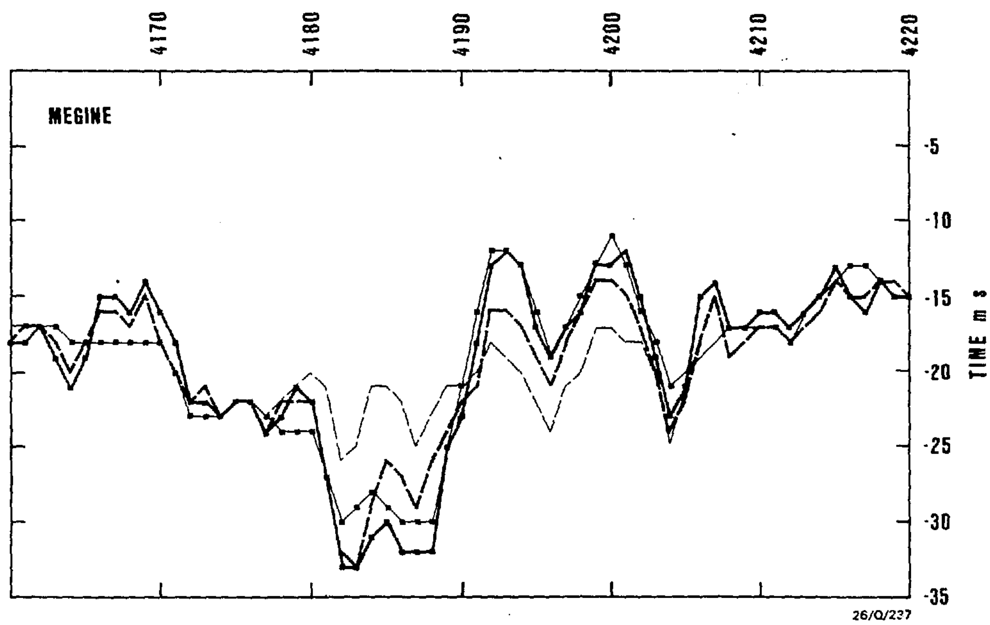

Fig. 10. Comparison of receiver statics with different control,Megine 1984.
——— UH receiver static
——— FB receiver static,no gaps.
----- FB receiver static,gap between 4184 and 4198
----- FB receiver static,gap between 4174 and 4208

wavelength static changes undefined or give errors when static changes are large.

CONCLUSIONS

Careful editing of uphole-depth data prior to calculating receiver and shot static corrections is considered essential in order to minimize errors affecting the processing chain. Autostatics routines are not capable of correcting these errors at a later stage if the signal to noise ratio is poor. The use of "floating weathering times" together with uphole-depth data leads to more accurate receiver static corrections and hence better quality control in the processing sequence.

The technique of using "floating weathering times" was applied in the 1950's and early 1960's as a means of improving hand calculated static corrections. The essential difference between the past and the present is the availability of multi-fold data and high speed computers.

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APPENDIX 1

The most difficult part in calculating weathering times or "floating weathering times" is organizing the "input to" and "outputs from" the program. There are a multitude of checks applied to any two shots before they are accepted for inclusion in the computations. These checks depend on how the first breaks are organized for each shot and on the order in which the shots are input to the program. In order to minimise the complexity of the checking procedure, the input data is ordered such that shot station numbers are numerically increasing and receiver stations associated with each arrival time are increasing.

The format used for the first breaks is illustrated below. The key word "shot" is followed by the shot station, first receiver station and receiver increment, (e.g. shot station 1113, first receiver 1089 and receivers are increasing by 1). This is followed by arrival times in milliseconds. A zero is inserted when an arrival time is not defined.

```
SHOT      1113     1089       1
       580      561      541      524      501      481      463      440
       416      394      375      353      334      313      283      256
       236      209      183      158      135      109       79       40
        24       40       80      108      132      160      184      207
       236      254      277      297      320      339      359      379
       400      420      439      459      478
SHOT      1118     1094       1
       585      565      543      521      500      480      455      438
       418      388      362      343      317      294      272      251
       227      202      182      153      129      108       80       40
        28       43       82      117      138      163      185      209
       229      248      268      289      310      328      350      369
       391      414        0        0        0      494      516      539
       561
```

The list of checks is given below. Those relating to uphole times and reciprocal times are used only with the reciprocal method.

Definitions:

```
SSN1  first shot station
RSN1  first receiver associated with SSN1
LRN1  last receiver associated with SSN1

SSN2  second shot station
RSN2  first receiver associated with SSN2
LRN2  last receiver associated with SSN2

UH1  uphole time associated with SSN1
UH2  uphole time associated with SSN2
RT1  reciprocal time associated with SSN1
RT2  reciprocal time associated with SSN2
FSTN first station number
LSTN last station number
LOW  minimum shot to receiver gap.
HIGH maximum shot to receiver gap.
```

GENERAL

CONDITION	ACTION if not met.
SSN2 > SSN1	Get new second shot
SSN2 > RSN2	Get new second shot
SSN2 > RSN1	Get new first shot
LRN1 > SSN1	Get new second shot
LRN1 > RSN2	Get new second shot
LRN2 > SSN1	Get new second shot

RECIPROCAL TIMES

IF SSN1 > RSN1	then	F1=SSN1	otherwise	F1=RSN1
IF LRN2 > SSN2	then	L2=SSN2	otherwise	L2=LRN2
IF RSN2 > F1	then	FSTN=RSN2	otherwise	FSTN=F1
IF L2 > LRN1	then	LSTN=LRN1	otherwise	LSTN=L2

For valid RT1

```
F1.LE.SSN2 .AND. SSN2.LE.LRN1
(SSN1+LOW).LE.SSN2 .AND. SSN2.LE.(SSN1+HIGH)
```

For valid RT2

```
RSN2.LE.SSN1 .AND. SSN1.LE.L2
(SSN2-LOW).LE.SSN1 .AND. SSN1.LE.(SSN2-HIGH)
```

UPHOLE TIMES

For valid UH1

```
SSN1.GE.RSN1 .AND. SSN1.LE.LRN1
```

For valid UH2

```
SSN2.GE.RSN2 .AND. SSN2.LE.LRN2
```