Surface consistent statics correction associated with EOM procedure

Xinxiang Li and John C. Bancroft

ABSTRACT

A new method for analyzing surface-consistent statics is presented. The criterion of our method is the power maximization of CSP gathers which is similar to Ronen and Claerbout's stack power maximization method. Our advantages are: (1) applied before NMO; (2) CSP gathers collect contributions from all sources and receivers in the migration aperture, this property solves the coupling problems; and (3) the reference traces constructed from each CSP gather are averaged to get the final reference trace, which will be more stable and may have higher signal to noise ratio. Applications of this method on synthetic data give very good results.

The theory and results given are preliminary work.

INTRODUCTION

Near surface velocity and layer thickness variation cause time anomalies that can be approximated as surface-consistent static time shifts. There are many different methods of automatically estimating statics. (Hileman et al 1968, Taner et al 1974, Wiggins et al 1976, Ronen and Claerbout 1985, Rothman 1985, and Deng et al 1996).The basic mathematical model of the methods is

$$\Delta T_{ij} = S_i + R_j + G_k + M_k h_{ij}^2 \tag{1}$$

where ΔT_{ij} is the total time anomaly (static time shift) on the ij trace, S_i, R_j are contributions from associated i-th source and j-th receiver, G_k is the contribution from k-th CMP location which is called the structure term, M_k are coefficients related to residual NMO effect, h_{ij} is the distance between the i-th source and the j-th receiver. Notice that index k can be determined by indices i and j as $k = i + j - 1$.

All methods mentioned above can be considered as one of the two algorithms: traveltime-picking method and optimization method (See Ronen and Claerbout 1985). The traveltime-picking method is based on getting the time anomalies, i.e. ΔT_{ij} in equation (1), by picking the maxima of crosscorrelations between input traces and their associated model traces (or called reference traces), then solving an overdetermined, underconstrained system of linear equations constructed by equation (1). When signal-to-noise ratio of seismic data is low, the time shift picking is susceptible to failure (Ronen and Claerbout). The optimization method is basically according to the seismic data itself, although the crosscorrelation maxima picking is still a necessary tool. Ronen and Claerbout (1985) use seismic final stack section as model, the way they estimate the time anomalies is to maximize the power of stack section. This method is suggested to be applied on low signal-to-noise data. Rothman's statistical method is also based on optimization standard. The technique he used is called simulated annealing. This method is very slow, as mentioned by the author, thousands of iterations are needed for getting good results.

All these methods require to be used on NMO corrected data. We know that some important procedures in seismic data processing, such as velocity analysis and prestack migration, have to be performed before NMO. In this paper, we present a new approach of static analysis which is applied on pre-NMO data. Our method is also an optimization algorithm, instead of stack section, we use the CSP gathers as the model data. The way we estimate and correct the statics is trying to maximize the "power" of CSP gather, which will, with accurate velocity, maximize the power of final EOM imaging section.

THEORY OF THE METHOD

Contributions of input traces to CSP gathers

The main procedure of EOM is the construction of CSP gathers from input dataset. A CSP gather is a set of traces (actually bins of traces) with different equivalent offset at a common scatter point(CSP) surface position.

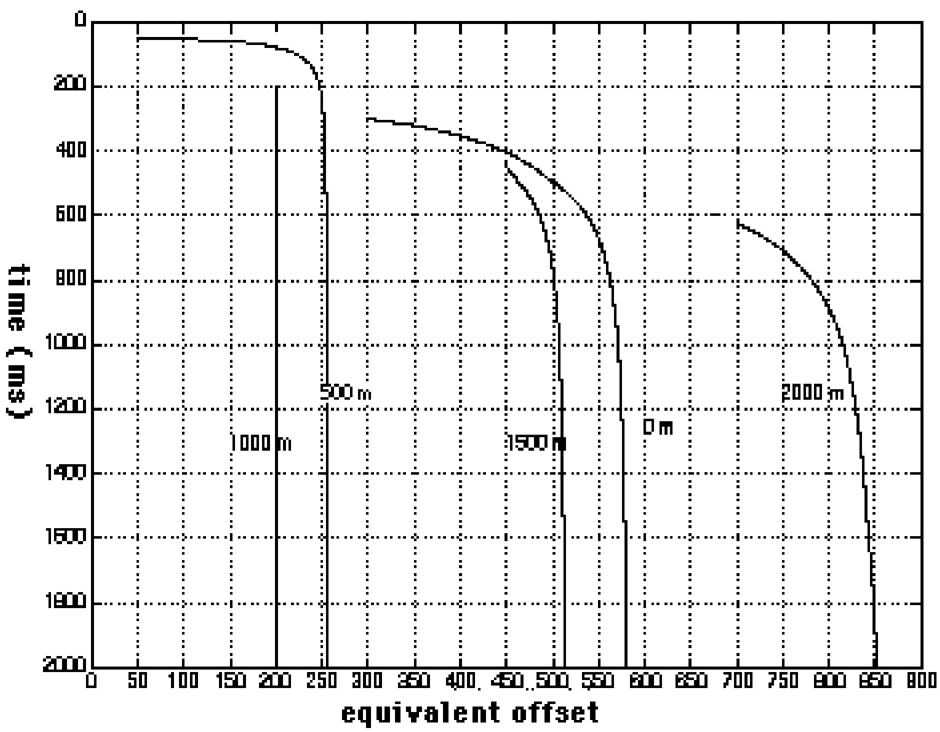


Figure 1. Equivalent offset as function of the sample time on input trace. The parameters used for five input traces are: source location: 1000m, CSP location: 800m, the receiver locations are listed on the figure by each curve.

A given input trace, according to its source and receiver locations, will contribute its energy at different sample times to different equivalent offset traces at each CSP position. The following equation of equivalent offset tells where and how the energy is distributed among the traces in a CSP gather:

$$h_e^2 = x_{off}^2 + h^2 - \frac{4 \cdot x_{off}^2 \cdot h^2}{V^2(T_0)T^2}$$

where x_{off} is the distance between the CMP location of the input trace and the CSP location where the energy will be distributed to; h is the half source-receiver offset of the input trace, $V(T_0)$ is the velocity function at the CSP (not CMP) location at time T_0, while T is the sample time on the input trace. Figure 1 gives examples of the relation between the sample time T and its associated equivalent offset h_e.

As we mentioned above, a trace in a CSP gather is a bin of traces which has equivalent offsets falling in an interval $(h_e - \frac{1}{2}\Delta h_e,\ h_e + \frac{1}{2}\Delta h_e)$. Each of this bin boundaries corresponds to a time location on the input trace, the algorithm for computing these time locations refers to Li and Bancroft (1996), all trace energy between two adjacent time locations will contribute to one common trace in CSP gather.

Comparing to the CMP stacking procedure, all the NMO corrected traces are summed to get one trace in stack section, this summed trace is used as reference trace to all the traces in the CMP gather. In our method, for each input trace, we can construct a reference trace from each CSP gather, thus many reference traces can be obtained from CSP gathers. In the following sections, we will show how we construct reference traces for input traces, how the crosscorrelations are performed, and how the surface-consistent statics are estimated.

Construction of reference traces from CSP gathers

Essentially, for an input trace, constructing its reference trace from a CSP gather is just the inverse operation of distributing its energy to this CSP gather. That is to say, where the energy is distributed to, where we extract the energy out from. Notice that, the energy at a sample time on a CSP trace contains energy from many other input traces. Figure 2 shows how the “forward” and “inverse” processes work.

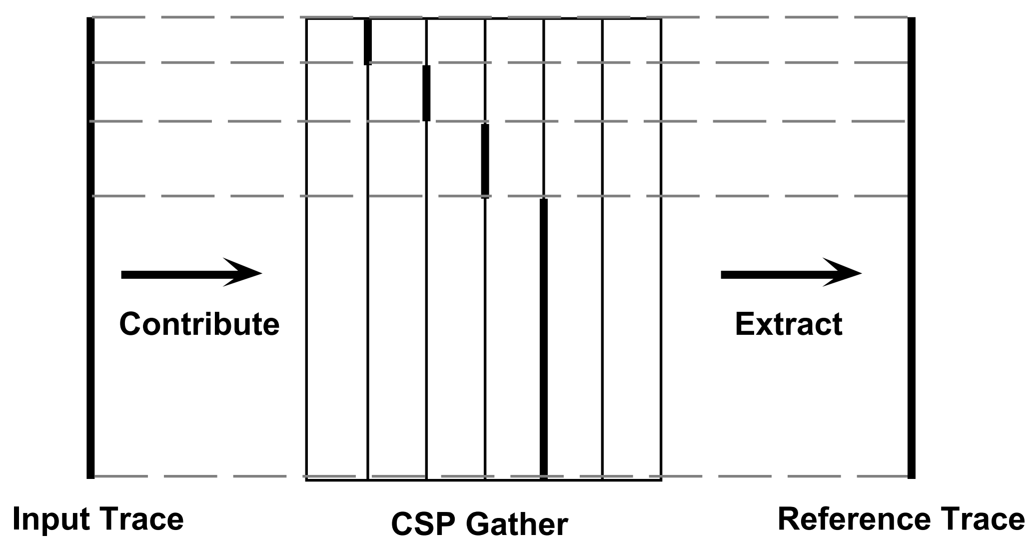


Figure 2. Constructing reference trace for input traces(extraction) is the inverse operation of constructing CSP gathers from input traces(contribution).

We do not know how many traces have contributed their energy to a time location on the CSP trace, but we know it is much more than the CMP fold of input data. It is very important to mention that, the traces which have contributed energy to a CSP trace are associated to all the sources and receivers in the migration aperture. In this point, our reference trace should be better for static estimation than usual stacked trace because it combines the contributions from all the sources and receivers together.

In the way shown in Figure 2, for each input trace, we can get one reference trace from each CSP gather, the final reference trace is the average over all these reference traces. The averaged reference trace will be more stable statistically.

Static estimation: two different approaches

For a trace in a shot gather (discussions about the common receiver gather and CMP gather are the same), we can get its static time shift by picking the maximum of crosscorrelation between it and its reference trace. In our problem, the task is to estimate the overall shot static time shift which is same for all traces in this shot gather. Figure 3 shows two different ways to get the overall static estimation of the shot gather from the traces in this gather and their reference traces.

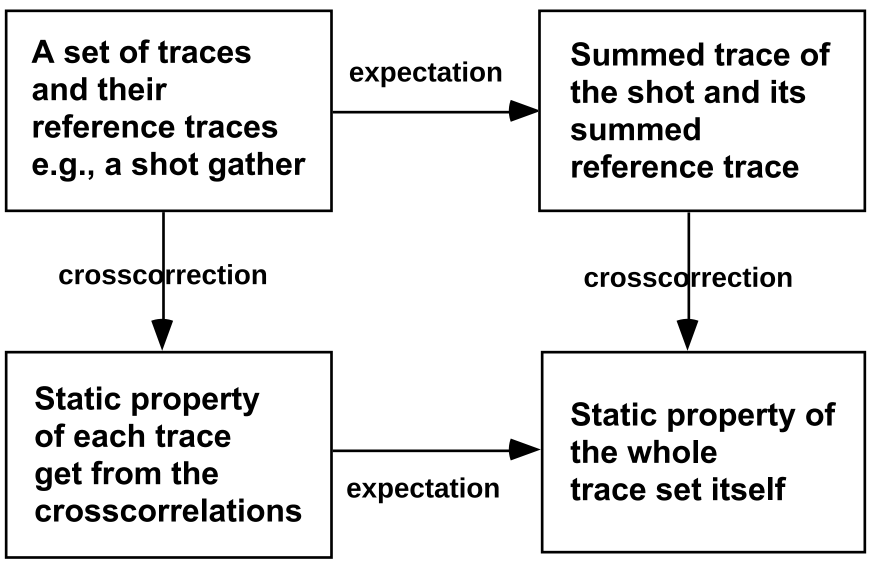


Figure 3. Two different ways to perform the automatic estimation of statics.

Suppose $\{Tr_l, l = 1, 2, \cdots, N\}$ be all the traces of a given shot gather, and their reference traces be $\{MTr_l, l = 1, 2, \cdots, N\}$ respectively, the expectation-then-cross-correlation method can be written as

$$\varphi_1 = \left(\sum_{l=1}^{N} Tr_l\right) \otimes \left(\sum_{l=1}^{N} MTr_l\right)$$

where the symbol $\otimes$ stands for crosscorrelation operation. The crosscorrelation-then-expectation method can be similarly expressed as

$$\varphi_2 = \sum_{l=1}^{N} \left(Tr_l \otimes MTr_l \right)$$

The overall static time shift of the gather can be estimated by picking the maxima of functions φ_1 and φ_2.

The obvious advantage of computing φ_1 is its much less multiplication operations. For high frequency content data, crosscorrelation between averaged traces will be less affected by "ringing" effect (more than one local maxima exist). The problem here is, traces have moveout and the summation of these traces may smear the event locations. Fortunately, the reference traces will also be summed together in exactly the same way, so the crosscorrelation operation does not change mathematically. Applications of this method show that, comparing to the crosscorrelation-then-expectation method, the statics estimated by expectation-then-crosscorrelation method are almost the same for low frequency data, and the results are better for high frequency data.

NUMERICAL EXAMPLES AND DISCUSSIONS

Results on low frequency data

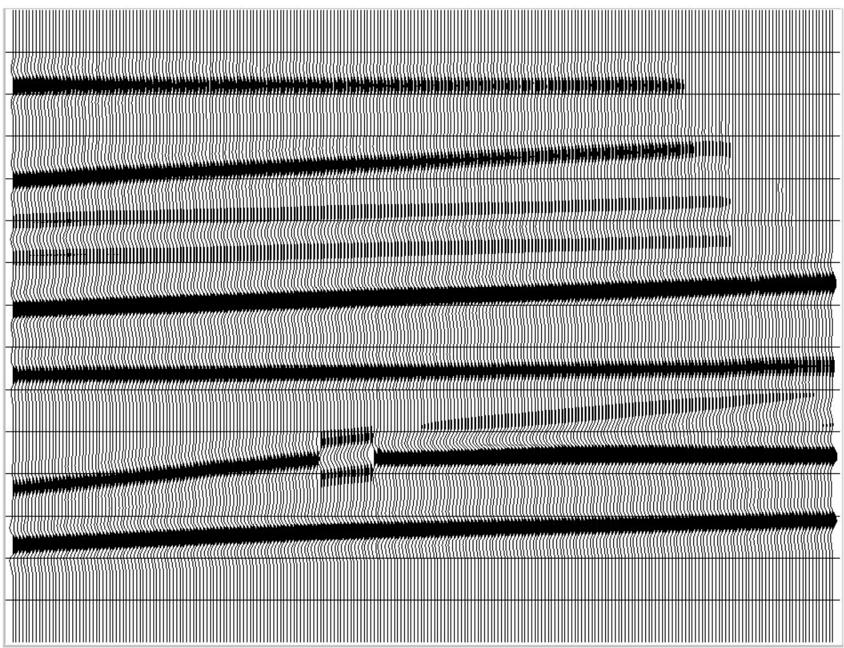


Figure 4. Original no static data stack section. The dominant frequency of the wavelet is 10Hz.

Figure 4 is the low frequency no static data, all the events are straight. Figure 5 shows the stack section of static data. The statics we used are surface consistent shot and receiver random statics, no structure term exist. The maximum time shift for both shots and receivers are from -20ms to 20ms, so on all the traces, the possible maximum time shift difference may be as big as 80ms.

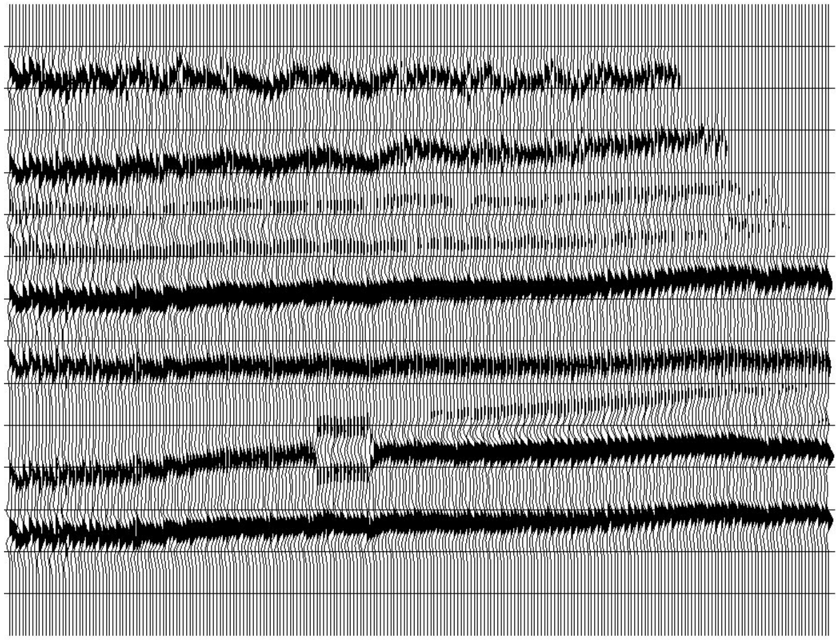


Figure 5. Stack section from static affected synthetic model.

The first experiment on the models in Figure 4 and Figure 5 is about the difference between the expectation-then-crosscorrelation method, which is also called single trace crosscorrelation method or shorted as STC, and the crosscorrelation-then-expectation method, which is called multi-trace crosscorrelation or MTC method.

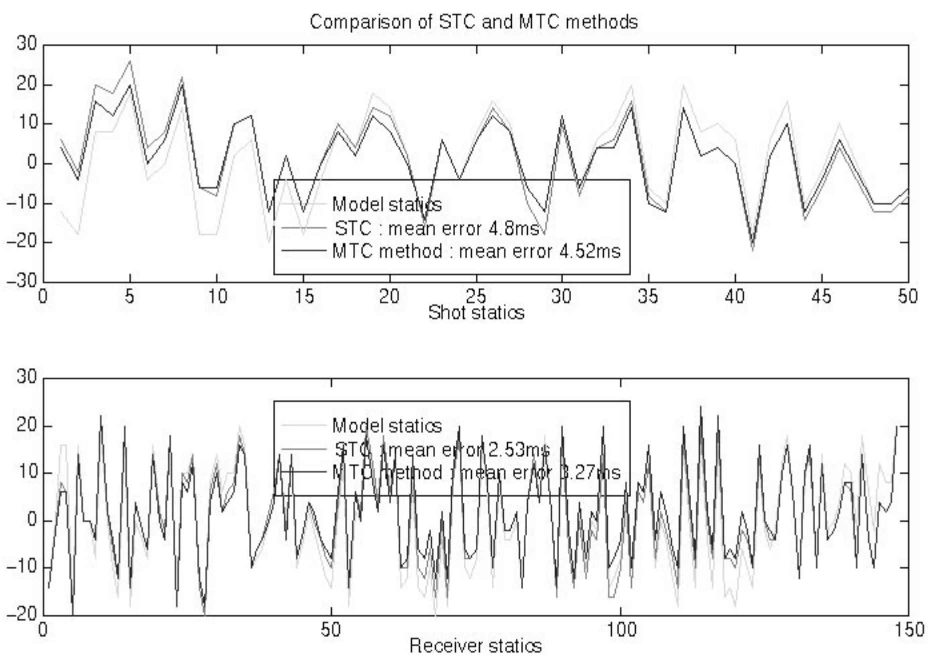


Figure 6. Static model and its estimations by STC and MTC methods.

Before introducing the results, we define an estimation error criterion called mean error, it is the averaged absolute difference between estimate and the accurate. Figure 6 shows the shot and receiver static model we applied on the synthetic data, and the estimations by both STC and MTC methods. The results show that both methods work very well for the data, and there is not obvious difference between the estimation results.

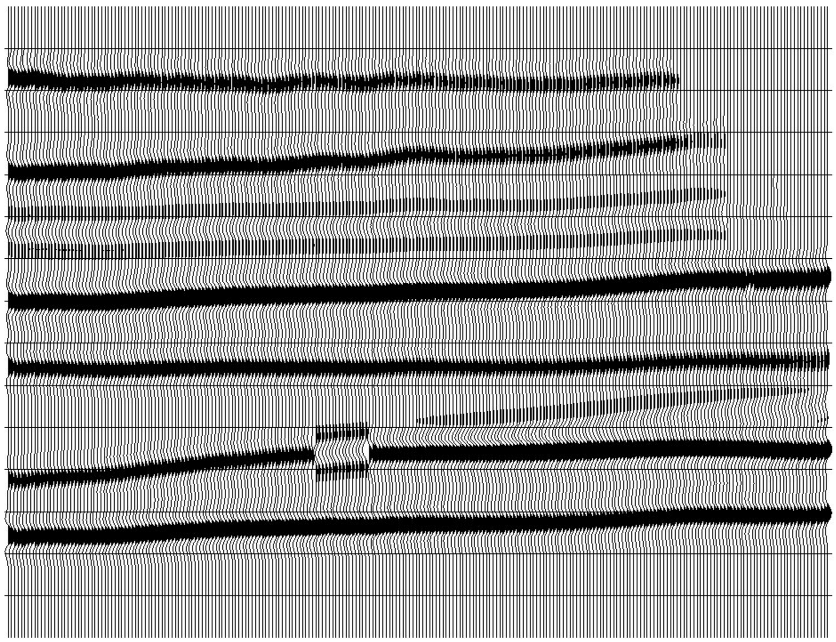


Figure 7. Section got from MTC method static corrected data.

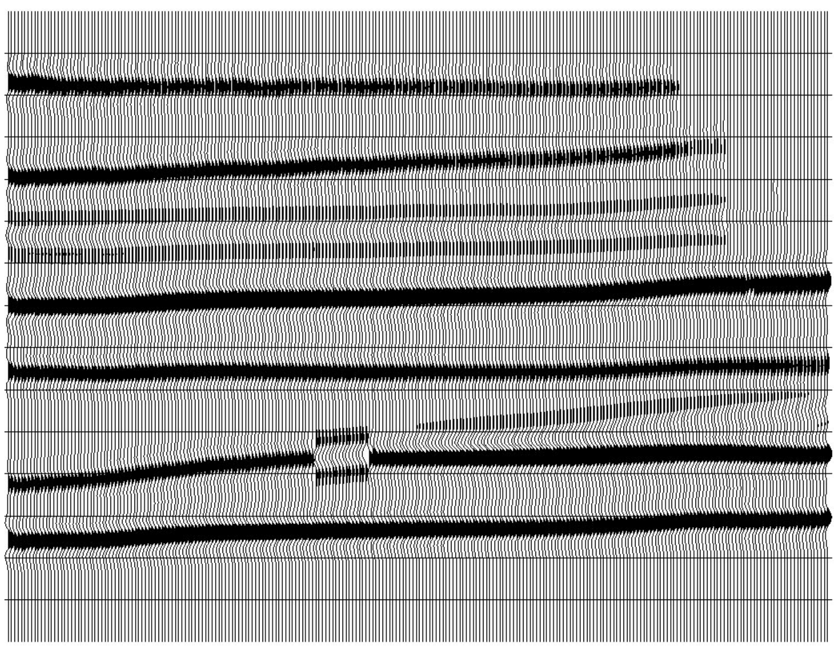


Figure 8. Section got from STC method static corrected data.

After static correction by the estimations from these two methods, two final stack sections were produced, the one by MTC method is shown in Figure 7, the one by

STC method is in Figure 8. Comparing with the model shown in Figure 5, it is obvious that both sections are highly enhanced. But we can not say it is perfect because the events in Figure 7 and 8 are not exactly straight, that means the algorithm we choose by now can not handle the long wavelength statics very well. Comparing Figure 7 and 8, we can say the result by STC method is better(at least on this dataset).

Figure 9 shows the static correction results in a different way, all the five gathers are CMP gathers at same CMP position where, the two gathers in (a) and (e) are the same gather from original no static data, the gather in (b) is from the static model data, the gathers in (c) and (d) are respectively from the static corrected data by MTC and STC methods. We can see the static CMP data is too bad to find reliable velocity, while the data after correction by our methods is ready for velocity analysis and other processing. Again, the STC method gets better result.

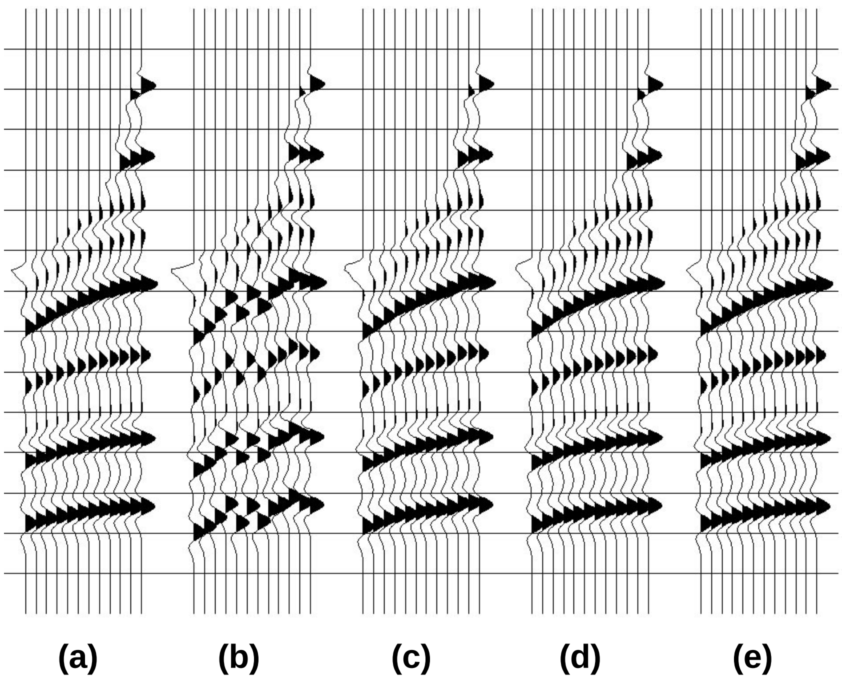


Figure 9. One CMP gather with and without statics, before and after static correction. (a) and (e) are the same gather from original no static data, (b) is the static model data, (c) and (d) are respectively the static corrected data by MTC and STC methods.

Enhancing the CSP gathers

One of the advantages of our method is directly enhancing the quality of the equivalent offset migration by maximizing the “power” of CSP gathers. Figure 10 shows one of the CSP gathers without statics (left) and the CSP gather at the same location with statics (right). As in the case of CMP gathers shown above, the static affected data is distorted. Figure 11 shows two CSP gathers at the same location as in Figure 10, the left is the one from MTC corrected data, the right one is from STC corrected data. Both of them are almost the same, and the static effect is satisfactorily corrected.

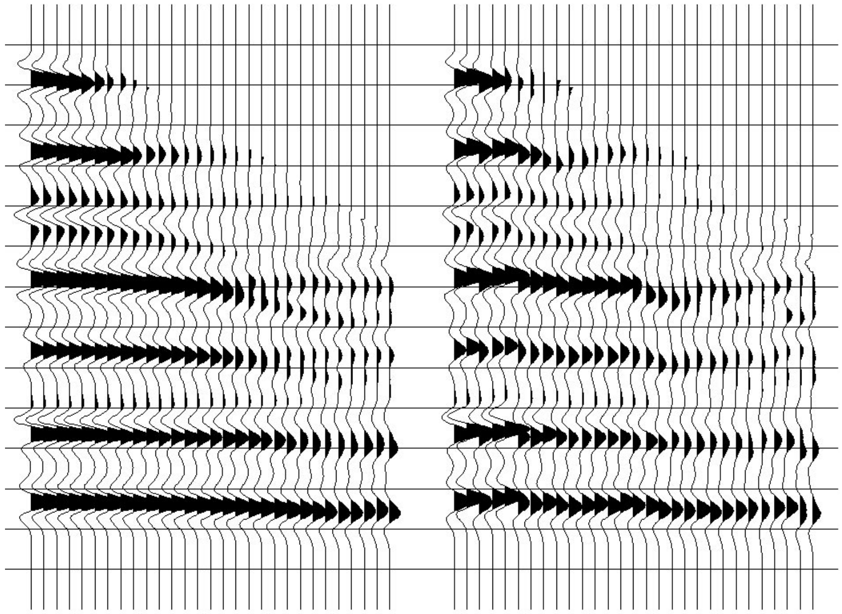


Figure 10. (left) A CSP gather without statics. (right) The same CSP gather with statics.

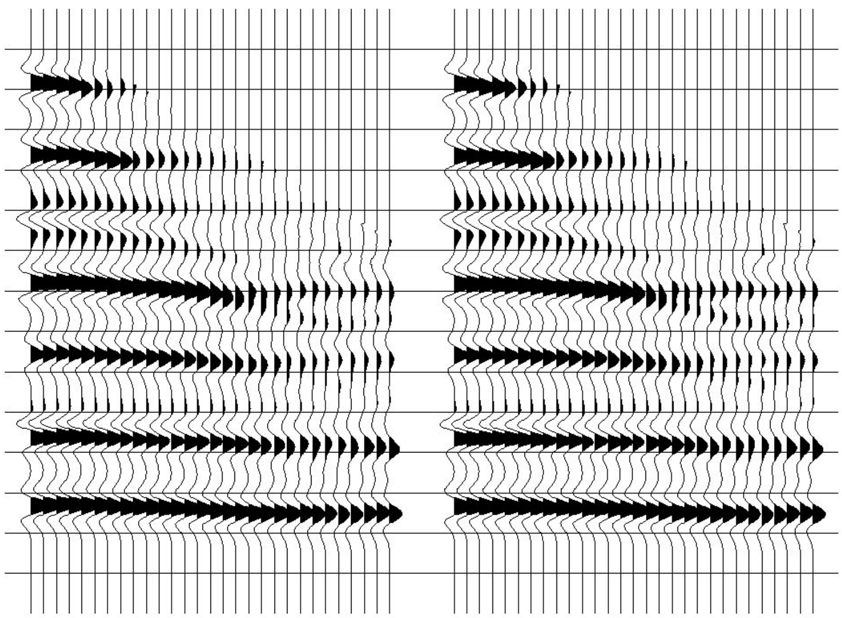


Figure 11. The CSP gathers from MTC method corrected data (left) and STC method (right). We can not tell much difference between these two gathers.

Distribution of estimation error along the seismic line

In our experiments, we found that, the static estimation at the ends of the seismic line is not as good as that in the middle. The effect is more obvious for receiver statics. Detail analysis about the mean error distribution proves that, our method is highly accurate in the middle part of seismic line. Figure 12 shows the receiver statics and the estimations by both MTC and STC methods (upper), and the difference between the model and the estimations (lower).

From both pictures of Figure 12, we can see the accuracy difference of the estimated statics between receivers at ends and those in the middle. Table 1. gives our detail analysis about the mean error distribution along the seismic line. Pay attention to the last column in the table, which is the averaged number of traces in the receiver gathers indicated in the first column.

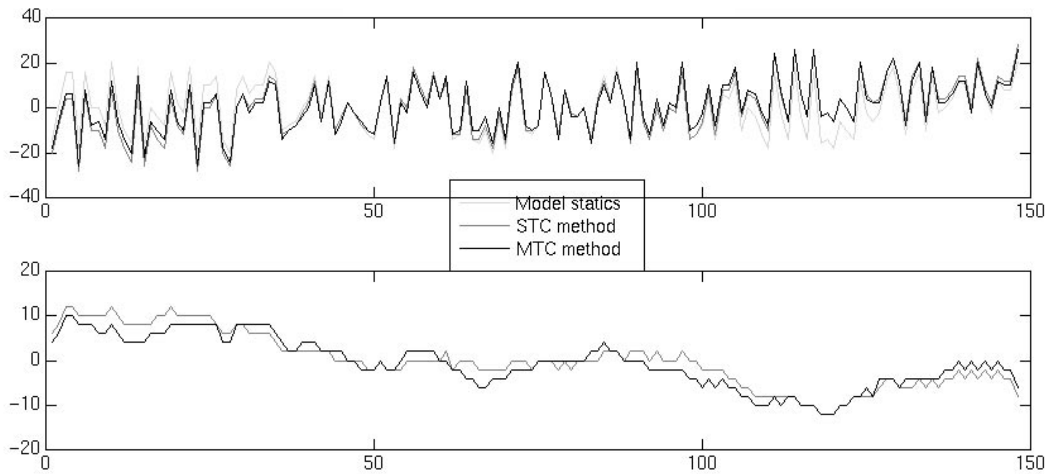


Figure 12. Influence of seismic line end effect on our methods. The upper one is the receiver static model and their estimation by both MTC and STC methods, the lower is the difference between the static model and both MTC estimation and STC estimation.

Table 1. Detail analysis of error distribution of receiver statics estimations

No. of Receivers	**STC Mean Error**	**MTC Mean Error**	**Fold Averaged**
1-148	4.4.5	4.42	16.9
11-138	4.14	4.41	19.1
21-128	3.59	4.35	21.1
31-118	2.45	3.59	23.0
36-113	1.77	2.92	24.2
41-108	1.29	2.44	24.7
46-103	0.93	2.00	24.9
51-98	0.86	1.79	25
1-50	6.52	5.48	13
99-148	5.96	5.88	13

The eighth line in Table 1 contains a range of receivers from the center of the line, has the highest fold and the lowest mean static error (less than one milli-second).

Results of high frequency data

The previous discussion delt with low frequency data. The following experiments and discussions are for a new set of synthetic data with 30Hz dominant frequency. The stack sections of original no static data and static data are shown in Figure 13 and 14.

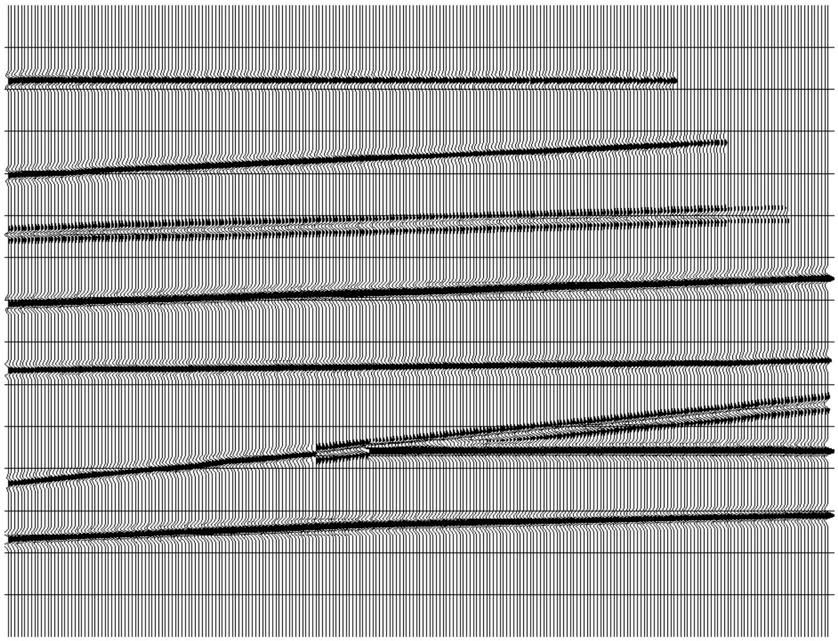


Figure 13. 30 Hz no static data stack section.

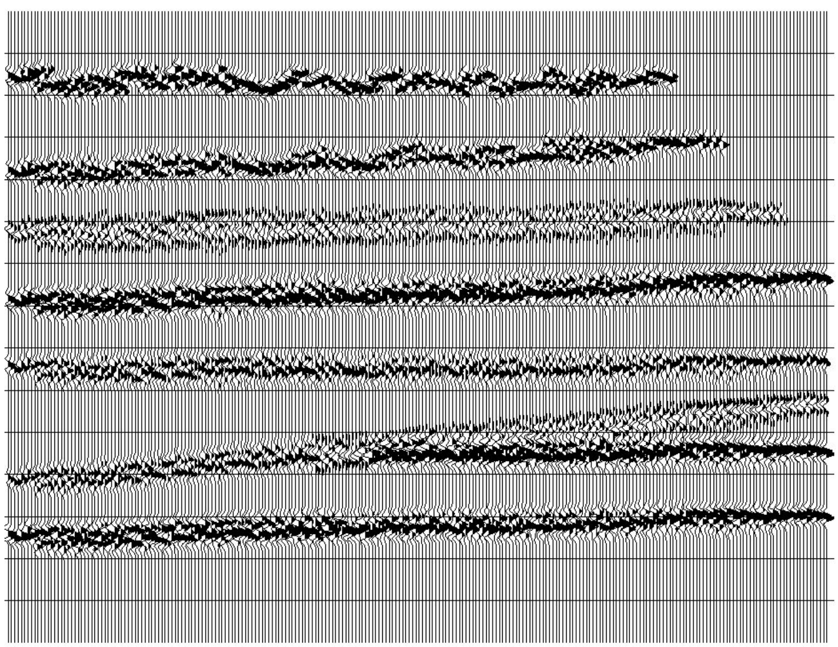


Figure 14. 30Hz static data stack section.

Comparing Figure 14 to 10Hz static data stack section Figure 5, we can say, statics have more influence on high frequency data than on low frequency data. This may make static estimation more difficult, and, picking maximum of crosscorrelation between two higher frequency traces is less reliable. Figure 15 and Figure 16 are the stack sections from MTC and STC corrected data respectively. The two results are not satisfactory, and the MTC result is even worse. One of the reasons cause this problem is obviously the higher frequency contents of data.

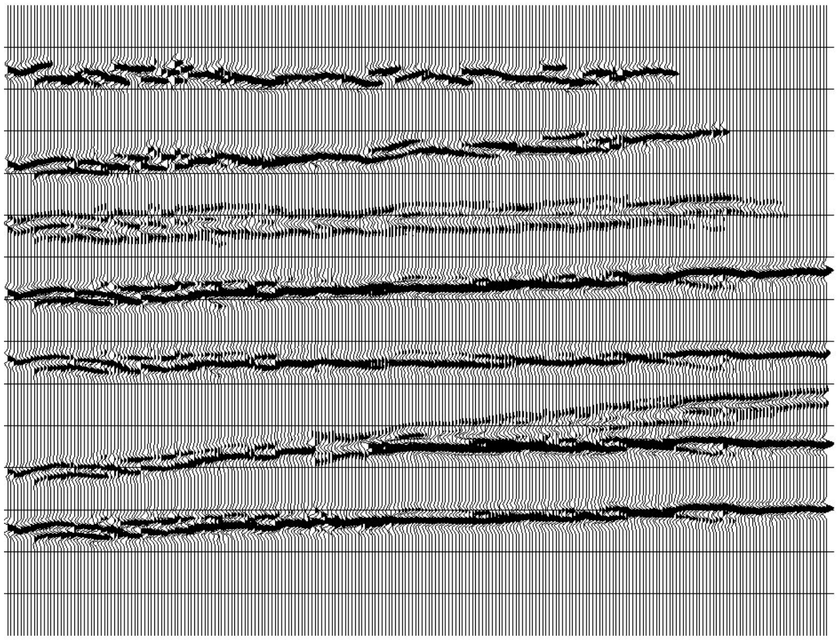


Figure 15. Stack section from directly using MTC method on 30Hz data.

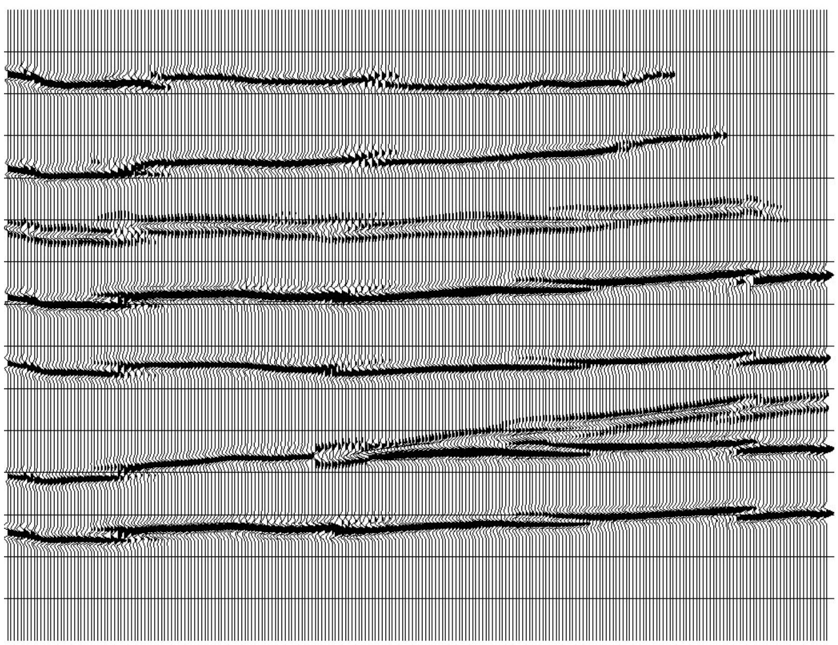


Figure 16. Stack section by directly using STC method on 30 Hz data.

Filtering technique

A direct way to solve this problem is to apply low pass filter on both input data and the CSP gathers. We find a way more efficient than this solution. We just apply filter on traces which take part in crosscorrelation or just filter the crosscorrelation function, this is very efficient when applying the STC method, where only one trace needs to be filtered in a gather. Experiments show that our filtering method result in great improvement on the static estimation. The detail static estimations of shot statics using STC method with and without filtering are shown in Figure 17.

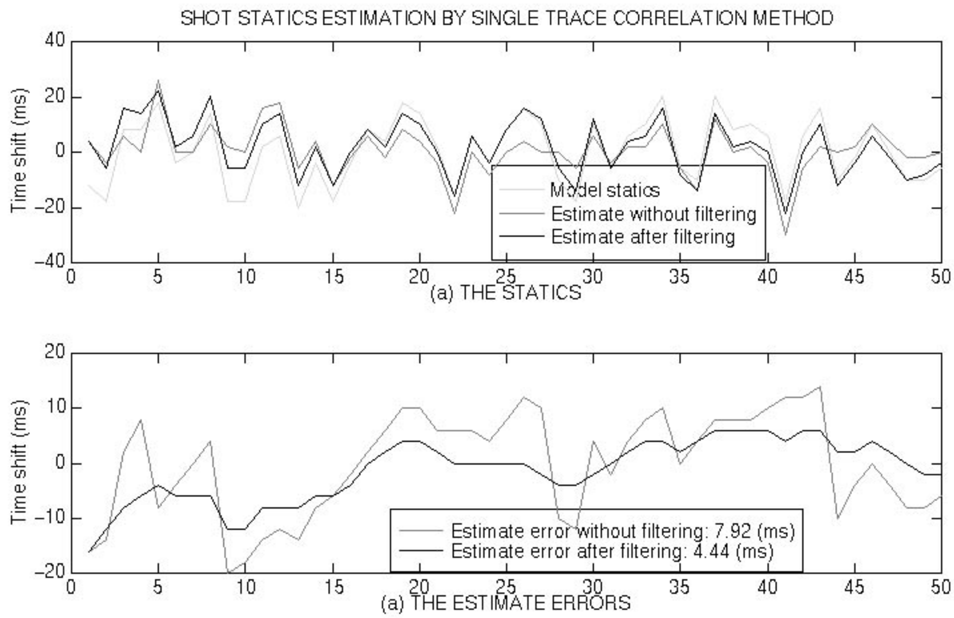


Figure 17. Shot statics estimation with and without filtering by STC method.

The improvement of static correction with our filtering technique on CMP gathers is illustrated in Figure 18, where five CMP gathers are shown, one from the static model data (a), the second from STC without filtering method corrected data (b), the third from MTC with filtering method corrected data (c), the fourth from STC with filtering method corrected data (d) and the last from no static data (e). It is easy to see that from (a) to (e), the quality of data is increasing.

Figure 19 and Figure 20 are the results from MTC and STC methods plus applying 10Hz zero phase Ricker wavelet as a filter. Comparing with the results without filtering, Figure 15 and Figure 16, the quality is much enhanced.

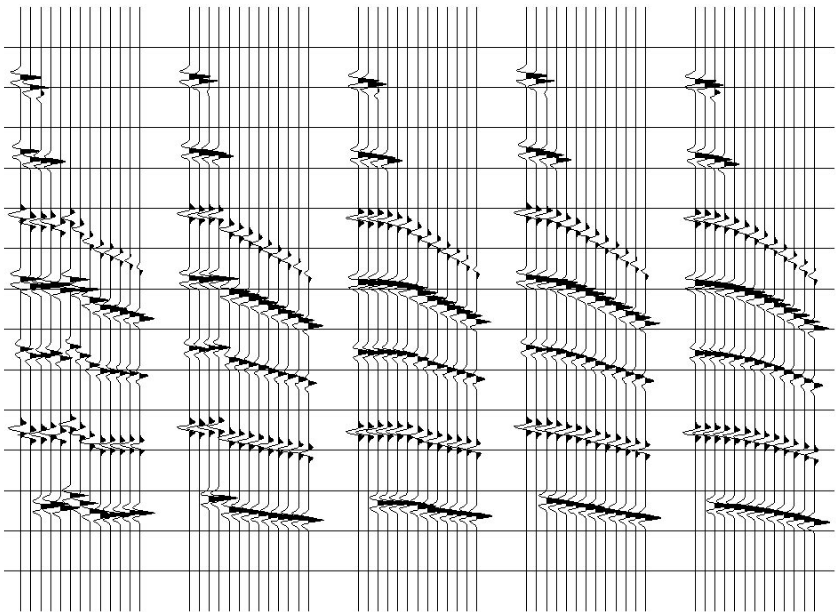
Future work

This work stated here is very preliminary, there is still much work to do, such as:

- More accurate algorithm will be used for both constructing CSP gather and its inverse: extracting reference traces. The future results are going to be better.

- How to handle the long-wavelength contents in statics?

- How to remove the effects of the ends of seismic line?
- The influence of applying static correction in different order of trace grouping, i.e. source then receiver, etc. Preliminary comparison among the results roughly show that the order of static estimations has not much influence on the final results.
- Whether an iterative technique is needed and how does it converge?



(a) (b) (c) (d) (e)

Figure 18. The quality enhancement by applying our filtering technique. Five CMP gathers at same location are shown, (a) is from the static model data, (b) is from no filtering STC method corrected data, (c) is from MTC with filtering method corrected data, (d) is from STC with filtering method corrected data and (e) is from no static model data.

ACKNOWLEDGMENT

The authors would like to thank Darren S. Foltinek and Henry C. Bland for their help about ProMAX programming and other technical problems. We also thank the CREWES sponsors for their financial support.

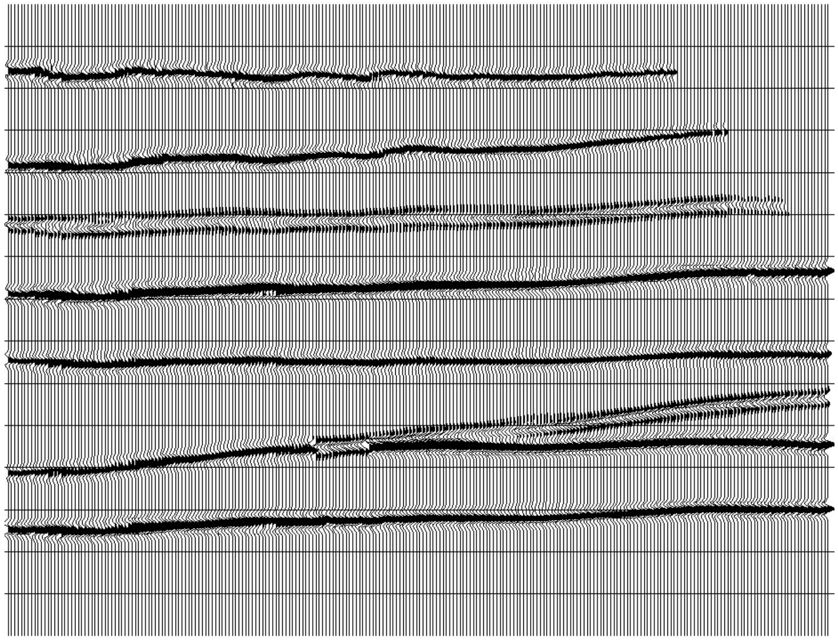


Figure 19. Stack section from MTC plus filtering method static corrected data.

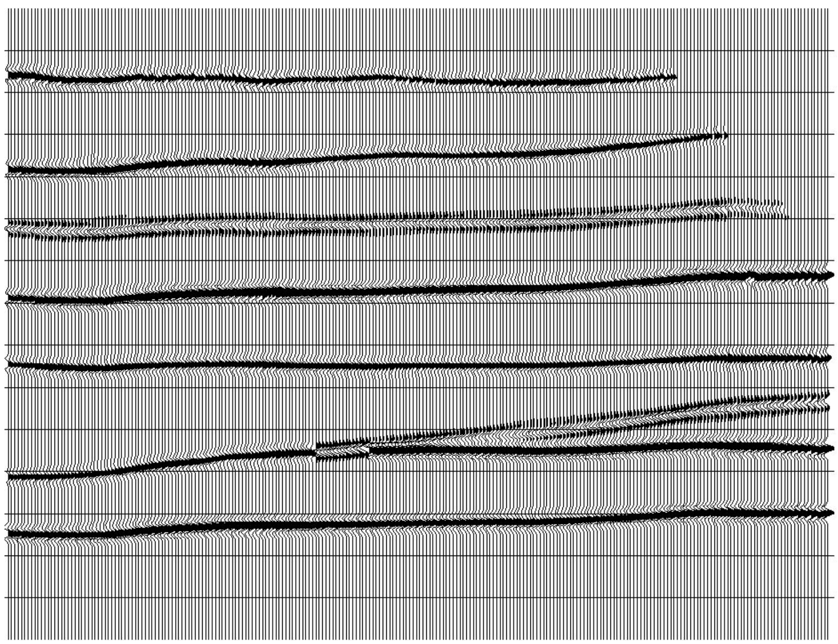


Figure 20. Stack section from STC plus filtering method static corrected data.

REFERENCES

Bancroft, J.C., Geiger, H.D, Wang, S., Foltinek, D.S., 1995: Prestack migration by equivalent offset and CSP gathers: an update : CREWES 1995 Research Report.

Deng, H.L., Wang, B. and Pann, K. 1996: Residual statics estimation by optimizing a complexity-reduced stacking-power function, B035, EAEG 58th Conference and Technical Exhibition, Amsterdam.

Geiger, H.D. and Bancroft, J.C., 1995 : Equivalent offset prestack migration for rugged topography: CREWES 1995 Research Report.

Hileman, J.A., Embree, P. and Pfluger, J.C., 1968: Automated static correction : Geophys. Prosp., **16**, 326-358.

Li, X. and Bancroft, J.C., 1996 : An efficient and accurate algorithm for constructing common scatter point gathers, CREWES 1996 Research Report.

Ronen,S. and Claerbout, J., 1985: Residual statics estimation by stack-power maximization: Geophysics, **50**, 2755-2767.

Rothman, D.H., 1985: Nonlinear inversion, statistical mechanics, and residual statics estimation: Geophysics, **50**, 2784-2796.

Taner, M.T., Koehler, F. and Alhilali, K.A., 1974: Estimation and correction of near-surface time anomalies: Geophysics, **39**, 441-463.

Wiggins, R., Larner, K. and Wisecup, D., 1976: Residual statics analysis as a general linear inverse problem: Geophysics, **41**, 922-938.