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# HOW EFFECTIVE IS THE STACK-ARRAY?

## Yığma Düzeni Ne Kadar Etkili?

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### ABSTRACT

Stack-array concept which has been introduced to the geophysical world by Anstey in 1986, led to long theoretical discussions among geophysicists. In contrary, very few real life examples were presented or published. This paper aims to fill the gap which exists on the practical side, by testing the efficiency of stack-array criterion on real land data.

A full fold test line has been shot in a good seismic quality area in South Turkey, with a 120 channel recording system. Every effort has been spent to acquire a very regular set of data with no misfires or dead traces. Stress has been put on applying the exact geometry of the geophone array and good coupling of the individual phones. Processing has been carried out to produce two different sections-one, using all the available data and the other, omitting every alternate shot to halve the fold. Same procedure was repeated after suppressing the signal partly by FK filtering, and so, reducing the S/N ratio of the shot records.

In this paper, the simple theory behind the spatial filter behaviour of the stacking geometry is discussed and the results of the field test is presented.

### ÖZET

Jeofizik dünyasına 1986 yılında Anstey tarafından kazandırılan Yığma-Düzeni kavramı, jeofizikçiler arasında uzun teorik tartışmalara yol açmıştır. Buna karşılık, gerçek dünyadan çok az sayıda örnek sunulmuş ya da yayınlanmıştır. Bu bildiri, yığma-düzeni kriterinin etkinliğini gerçek saha verileri üzerinde test ederek, pratik tarafta bulunan boşluğu doldurmayı amaçlamaktadır.

Türkiye'nin güneyinde, iyi sismik kaliteye sahip bir sahada, 120 kanallı kayıt sistemi ile, tam katlamalı bir test hattı atılmıştır. Hiçbir patlamayan kuyu ya da ölü iz içermeyen, çok düzenli bir veri seti toplamak üzere her türlü çaba sarfedilmiştir. Jeofon düzeninin tam geometrisinin uygulanması ve herbir jeofonun iyi kuplajı özellikle vurgulanmıştır. Biri, bütün eldeki veriyi kullanarak, diğeri ise, katlamayı yarıya indirmek üzere her iki atıştan birini ihmal ederek iki ayrı kesit elde edilmiştir. Aynı işlem, kayıtlardaki sinyal/gürültü oranını azaltmak üzere sinyali kısmen F-K filtresi ile bastırdıktan sonra tekrarlanmıştır.

Bu makalede, yığma geometrisinin uzaysal filtre davranışı arkasında yatan basit teori tartışılmış, ve saha testinin sonuçları sunulmuştur.


## INTRODUCTION

The term "stack-array" was first mentioned by Anstey (1986), and the simple theory behind this concept became subject to long and still ongoing discussions among our colleagues. But in contrary, very few real life examples were presented or published. Morse and Hildebrandt (1989) presented brute stack sections of real data, for testing the effectiveness of stack-array on low velocity ground-roll. My purpose in this paper is to give you an idea on how this compound spatial filter suppresses different types of coherent noise in different S/N ratio conditions, and what happens if the criterion is not satisfied. I will try to discuss those points by presenting the results of a field test.

## FIELD TEST

A five kilometers long test line was shot in Adana area, South Turkey, with a 120 channel recording system and with symmetrical split recording geometry (Fig. 1). Group and shot intervals were 25 m, shots were placed halfway between the geophone stations and 2 kg of dynamite in a single 6 m deep hole made up the source. Four rows of six geophones with 4.16 m in-line spacing and 4.16 m stagger between rows were employed at each station so that a continuous, equally intervalled and equally weighted geophone lay out was achieved along the line. Every effort was spent to acquire a very regular set of data, with no misfires or dead traces. Stress was put on applying the exact geometry of geophone array and good coupling of the individual phones. In other words, all the requirements of the stack-array criterion were fulfilled in the field to the extent allowed by practical limits.

The acquired data was then processed to yield two different output sets-one, which made use of all the shot gathers recorded, and the other which used only half of them, by omitting every alternate shot and thus doubling the shot interval and halving the fold.

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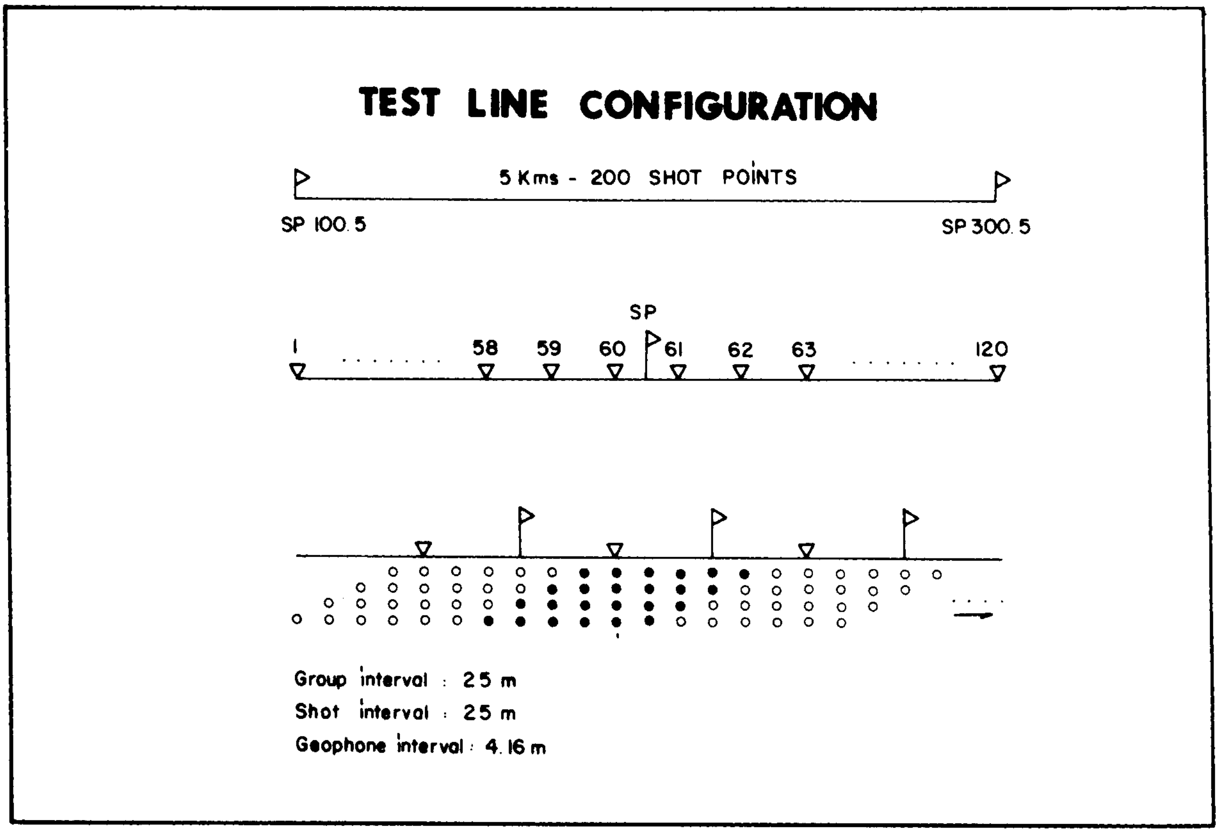


Fig. 1. Geometrical configuration of the field test.
Şekil 1. Saha test düzeni.

Before going into comparisons of the results, I would like to review the basic principles of stack-array briefly and try to explain what was expected from these comparisons.

## STACK-ARRAY APPROACH

The upper part of Fig. 2 shows reflections from a common midpoint, formed by a symmetrical split recording geometry with shot interval equal to group interval and shots halfway between geophone stations. Solid lines show the forward reflected traces and dashed lines show the backward reflected ones. When these traces are put together side by side as a CMP gather, an equally intervalled and equally weighted linear array of traces is formed. Also note that the offset intervals become equal to the group interval.

We can easily compute its wavelength or wavenumber response to see how it acts on different wavelength coherent events, when the traces are stacked. Figure 3 shows the stacking response of a 120 channels 60 fold spread geometry with 25 m group and shot intervals, just as in the field test.

Remember that each trace in a CMP gather is the output of a geophone array. So, the wavenumber response of the geophone array must be superimposed on this stacking response. Figure 4 displays the response of the geophone array that we laid out along our test line. It had an effective length of 25 meters.

The total k domain stacking response is given in Fig. 5. Since the process of stacking will be applied after NMO correction, all the apparent signal wavelengths will hopefully be compressed to the vertical axis and they will pass without any attenuation. But all the other coherent noise waves will be

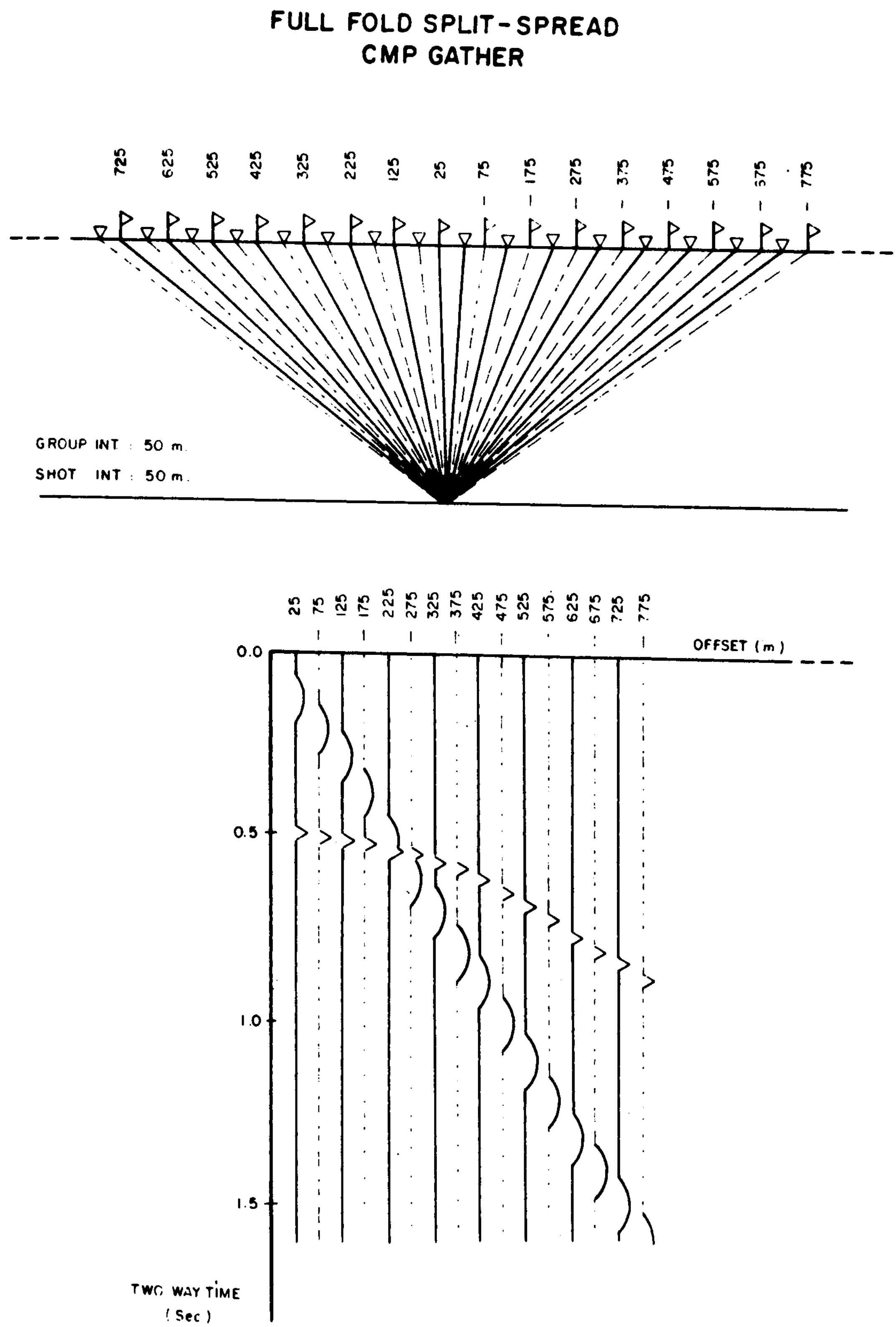


Fig. 2. Field and processing geometries of a full-fold CMP gather obtained by a symmetrical-split geophone spread.
Şekil 2. İki taraflı simetrik jeofon yayılımı ile elde edilen bir Ortak Orta Nokta topluluğunun saha ve veri-işlem geometrileri.

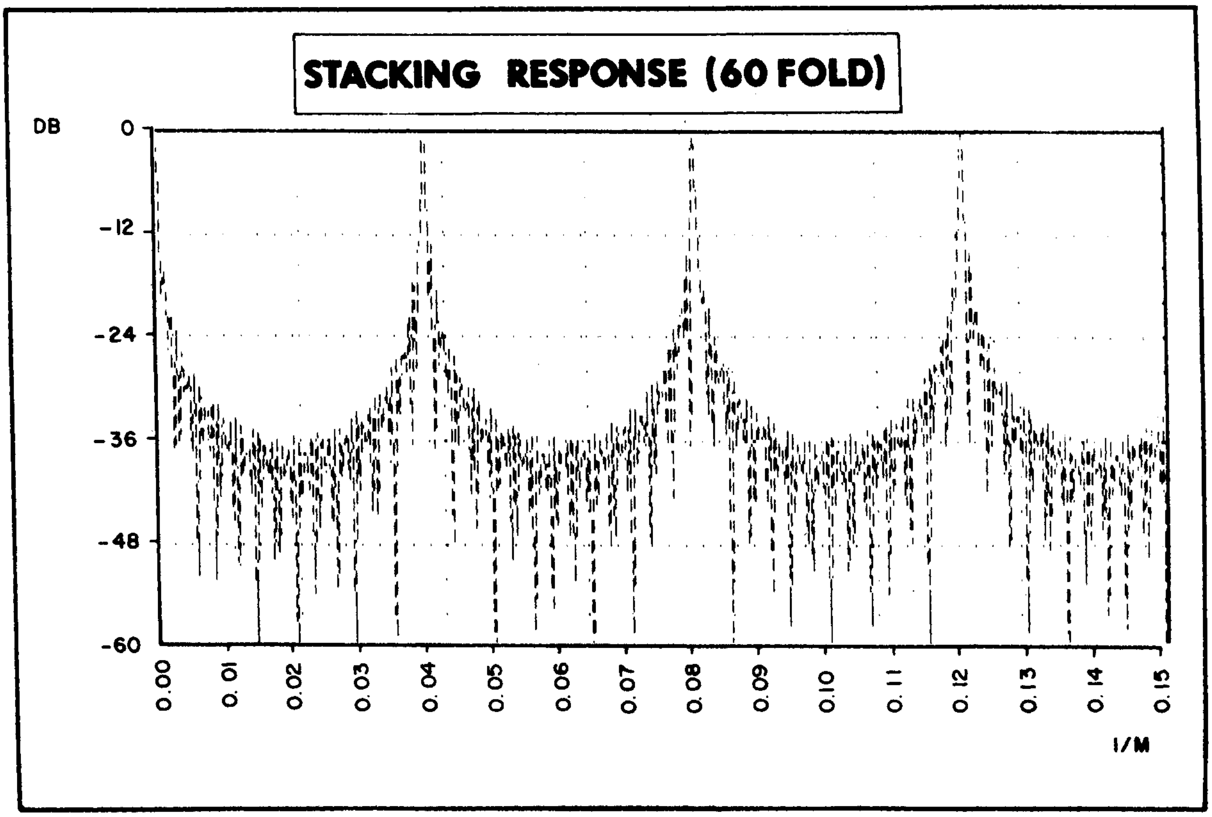


Fig. 3. K-domain stacking response of a 120 channel, 60 fold spread geometry with 25 m group and shot intervals.
Şekil 3. 25 m grup ve atış aralığına sahip 120 kanallı ve 60 katlamalı bir yayılım geometrisinin k (dalga sayısı) ortamı yığma tepkisi.

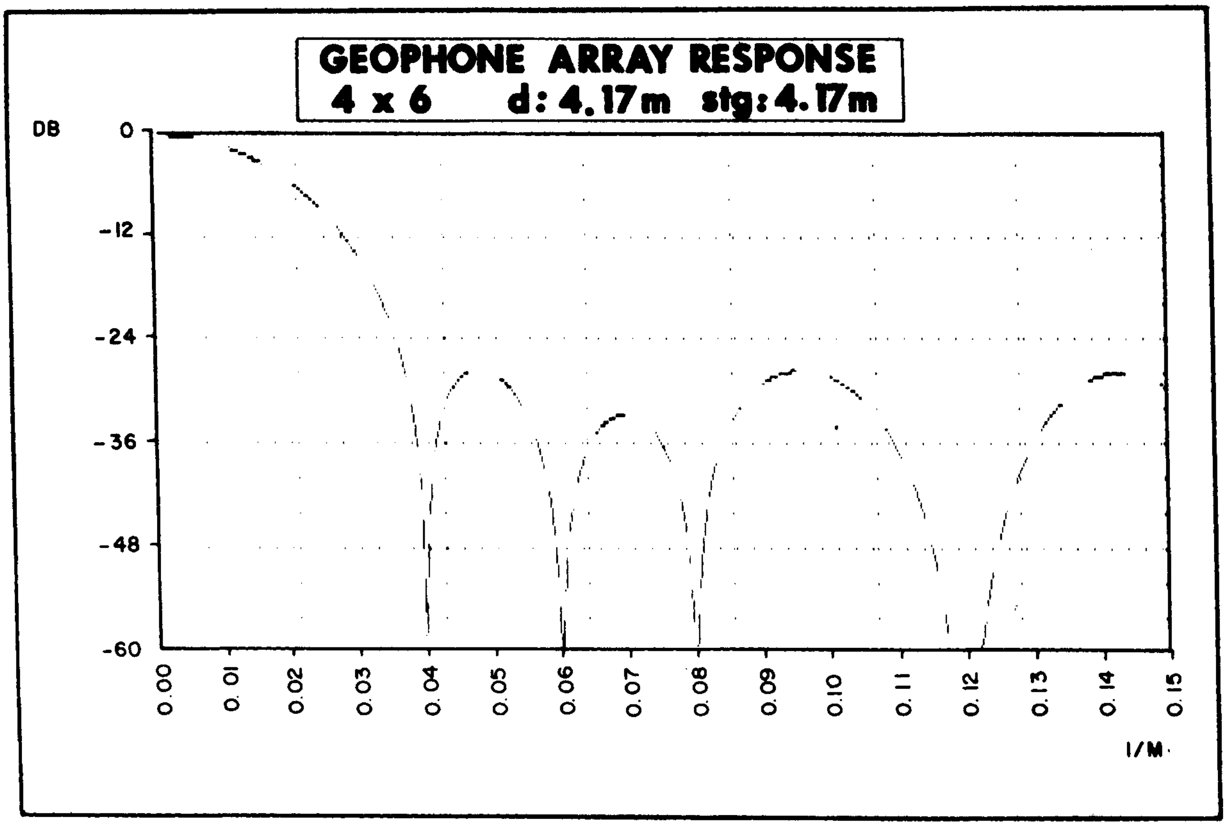


Fig. 4. K-domain response of the geophone array employed in the test line.
Şekil 4. Test hattında kullanılan jeofon düzeninin k ortamı tepkisi.

suppressed relatively.

This is the basic principle behind the stack-array approach (Anstey, 1986). If the method works properly, that means, any coherent noise will be suppressed by at least 30 dB, and with a fair S/N ratio in the records, we are not going to see any noise in the 60 fold stack section.

For a symmetrical split recording geometry, with shots in between geophone stations, if the shot interval is increased to be twice the group interval, then the CMP fold becomes reduced by two and the stacking array is no more equally intervalled as shown in the lower part of Fig. 6. In this case; we may expect more alias peaks in the wavenumber response of such an array.

Figure 7 shows how the 30 fold stacking array behaves to coherent events in the wavenumber domain, with recording geometry of the test line. Superimposing the geophone array response on to the stacking array response, we come up with the total k domain stacking response for our 30 fold output set, which is given in Fig. 8. As seen in the figure, this spatial filter will suppress some of the coherent noise events less than the others. So, we may expect some narrow band noise to leak into our 30 fold sections.

So far, it was the optimistic approach-we neglected the effects of NMO correction. While flattening the hyperbolic reflection events, NMO imposes two important effects on linear noise waves: velocity shift and wavelet stretch (Ongkiehong and Askin, 1988). These two factors depend on the velocity and frequency of the noise and the correction velocity. Additionally, the linearity of noise is disturbed if the correction velocity is time-variant. Therefore k domain NMO effects on the stack-array are not easily predictable. Nevertheless, we know that in the case of low velocity noise, these effects are negligable, but, the opposite is true for higher velocity coherent events.

Now, we have at least an idea about what is expected from the real data examples.

## TEST RESULTS

Figure 9 shows two characteristic shot records from the test line. Reflections in the noise cone are hardly visible. The velocity of ground-roll changes from 500 m/s to 750 m/s.

60 and 30 fold brute stack sections of the test line are given in Figures 10 and 11 respectively. No decon before stack is applied. The only notable difference is in the very shallow parts. This is most probably due to the fact that, the

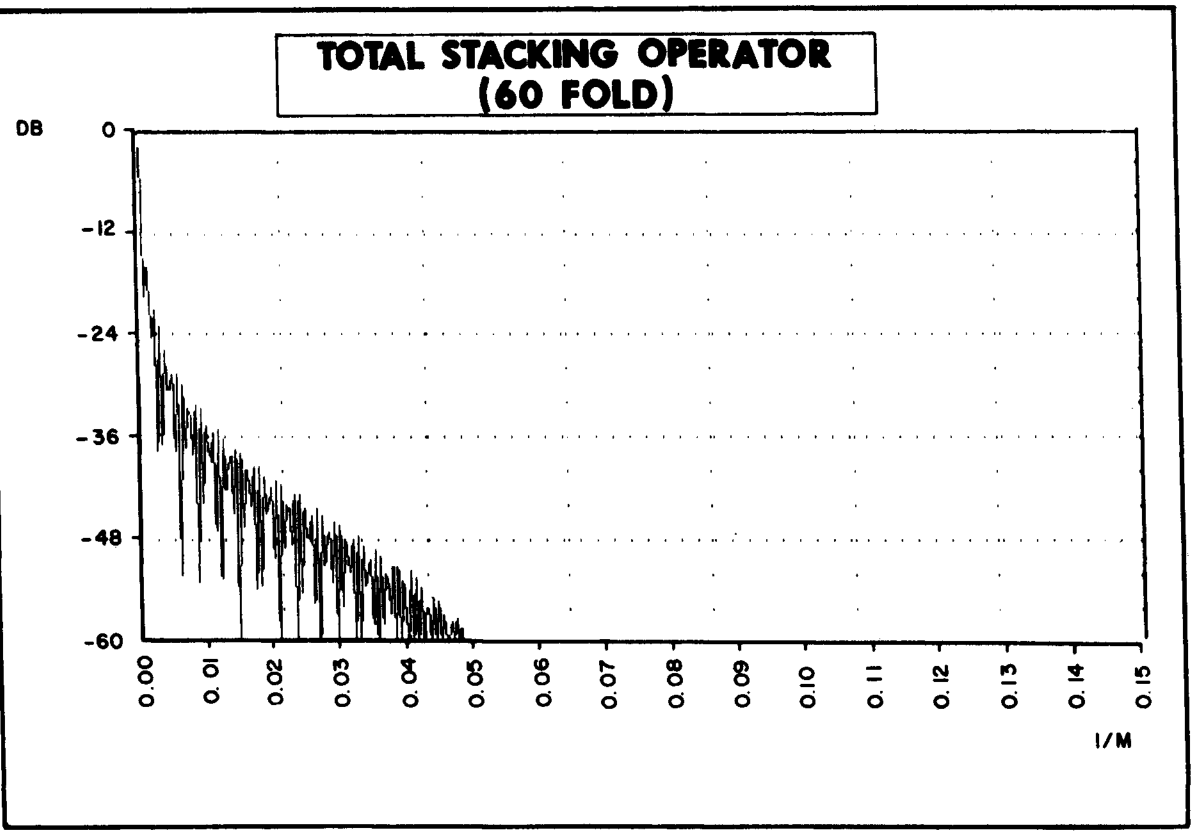


Fig. 5. Total stacking operator response obtained by adding the response curves of Figures 3 and 4.
Şekil 5. Şekil 3 ve 4'teki tepki eğrilerinin toplanmasıyla elde edilen toplam yığma işlemcisi tepkisi.

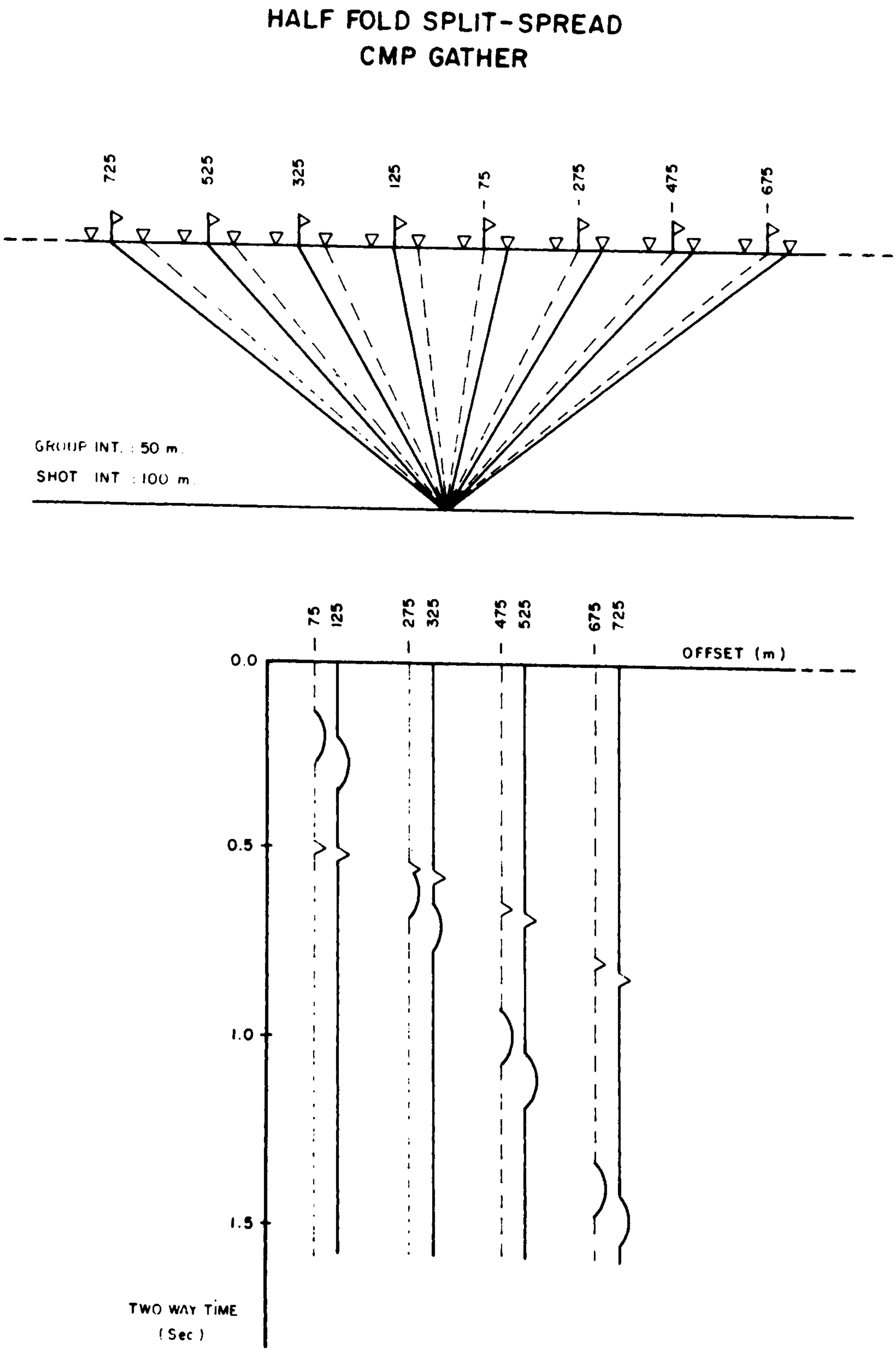


Fig. 6. Field and processing geometries of a half-fold CMP gather obtained by a symmetrical-split geophone spread.
Şekil 6. İki taraflı simetrik jeofon yayılımı ile elde edilen bir Ortak Orta Nokta topluluğunun saha ve veri-işlem geometrileri.

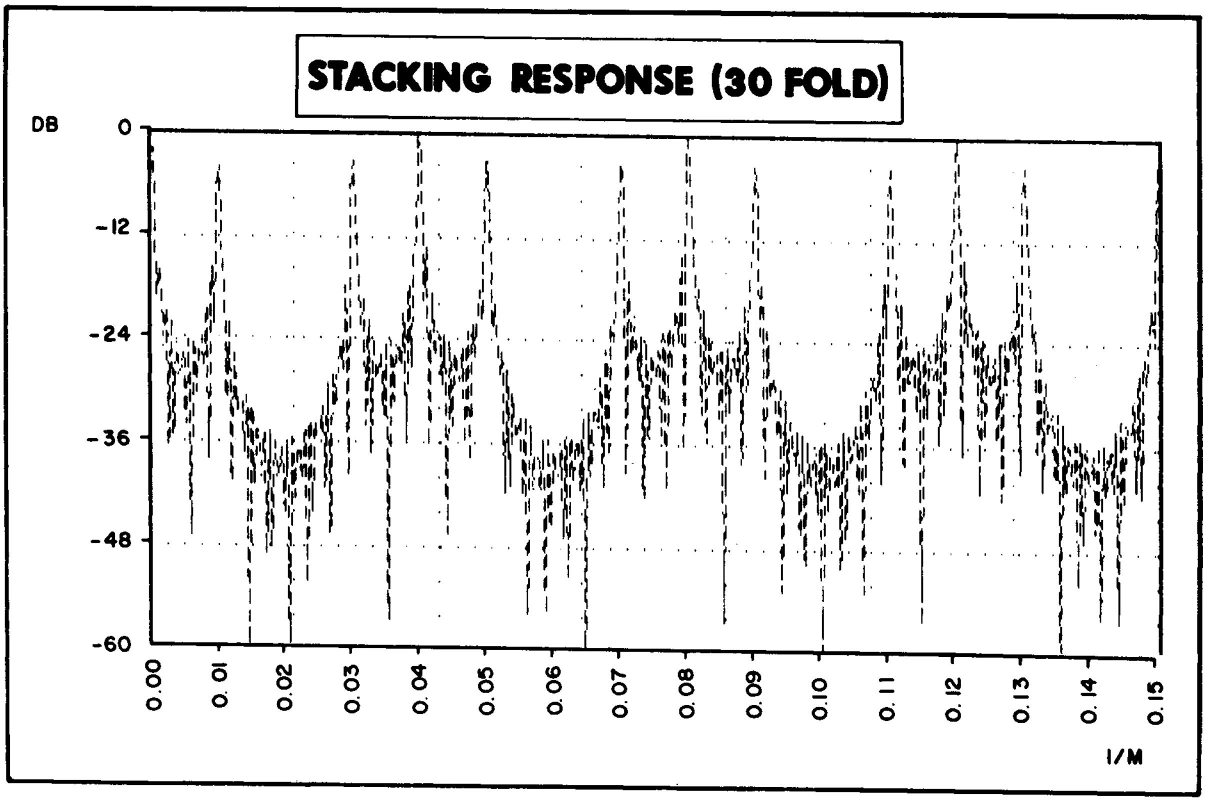


Fig. 7. K-domain stacking response of a 120 channel, 30 fold spread geometry with 25 m group and 50 m shot intervals.
Şekil 7. 25 m grup ve 50 m atış aralığına sahip 120 kanallı ve 30 katlamalı bir yayılım geometrisinin k ortamı yığma tepkisi.

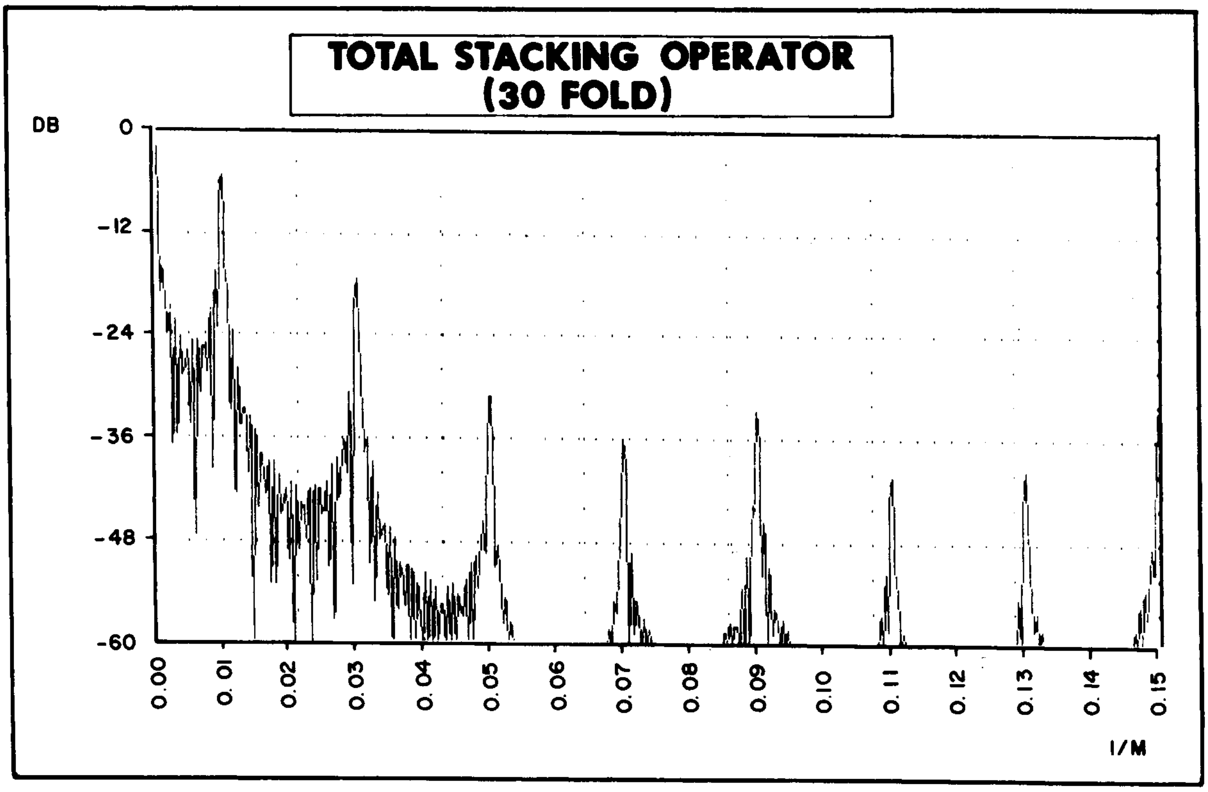


Fig. 8. Total stacking operator response obtained by adding the response curves of Figures 4 and 7.
Şekil 8. Şekil 4 ve 7'deki tepki eğrilerinin toplanmasıyla elde edilen toplam yığma işlemcisi tepkisi.

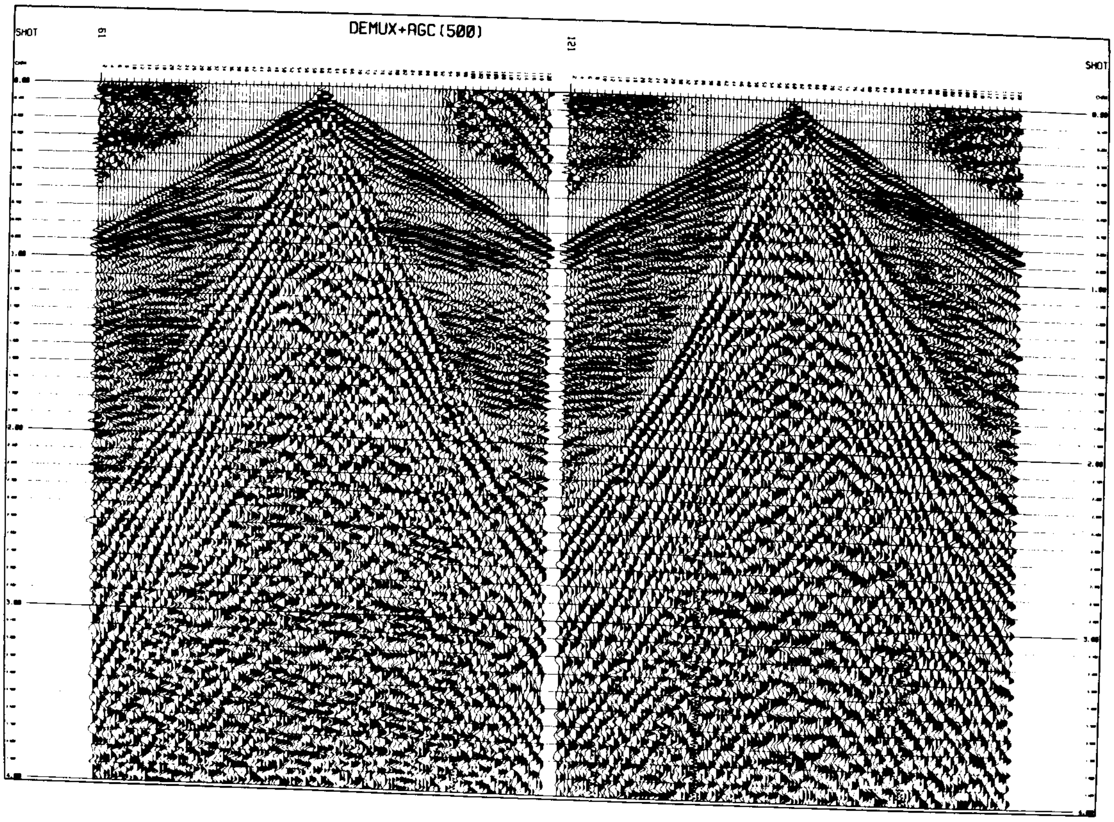


Fig. 9. Two characteristic shot records from the test line.
Şekil 9. Test hattına ait iki karakteristik atış kaydı.

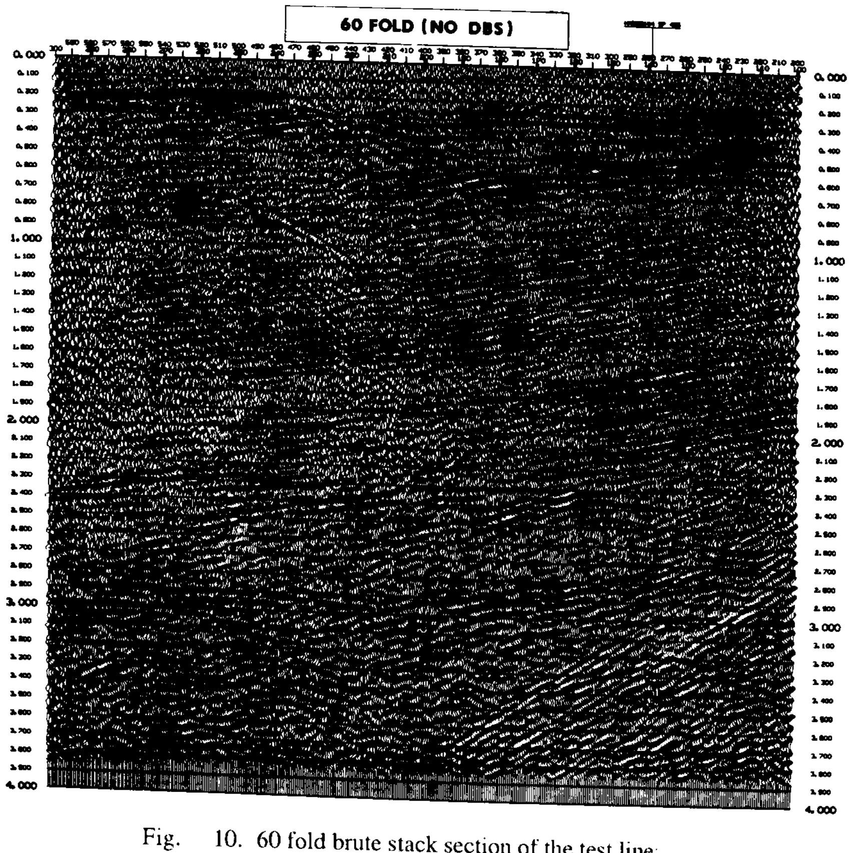


Fig. 10. 60 fold brute stack section of the test line.
Şekil 10. Test hattına ait 60 katlamalı ham yığma kesiti.

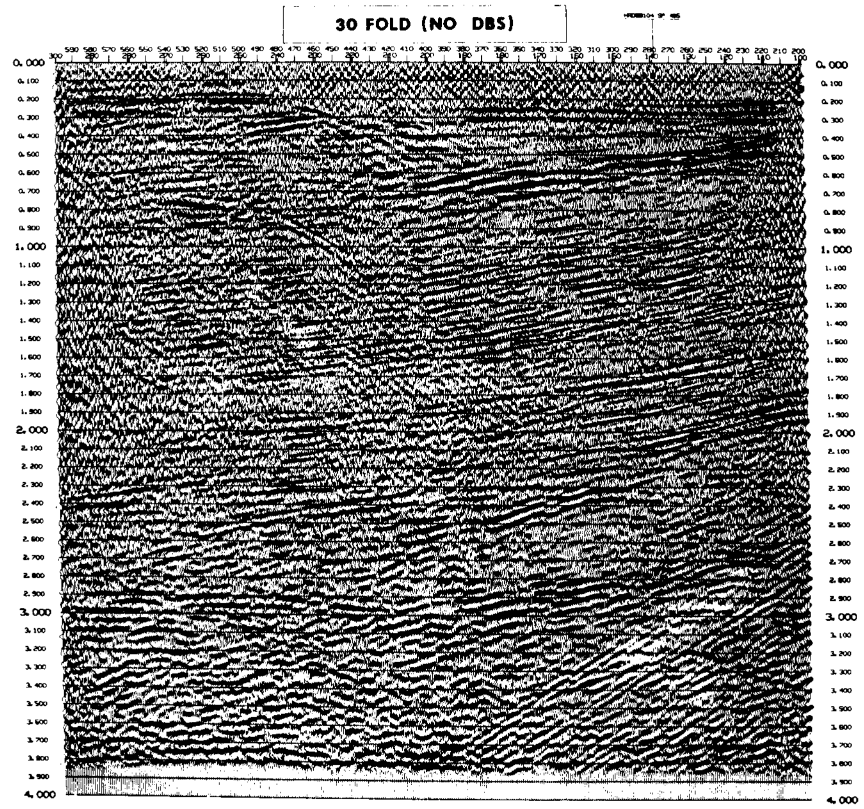


Fig. 11. 30 fold stack section of the test line.
Şekil 11. Test hattına ait 30 katlamalı ham yığma kesiti.

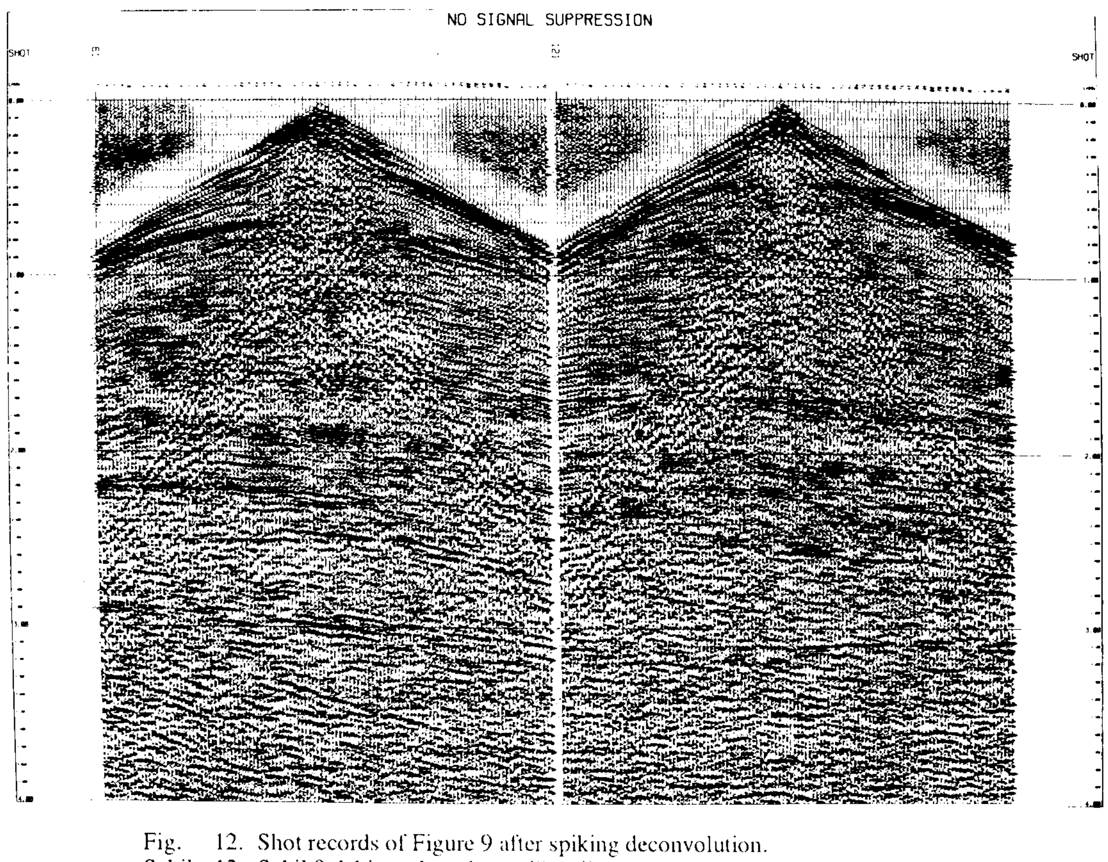


Fig. 12. Shot records of Figure 9 after spiking deconvolution.
Şekil 12. Şekil 9 daki atış kayıtlarına iğnecik dekonvolüsyonu uygulandıktan sonra.

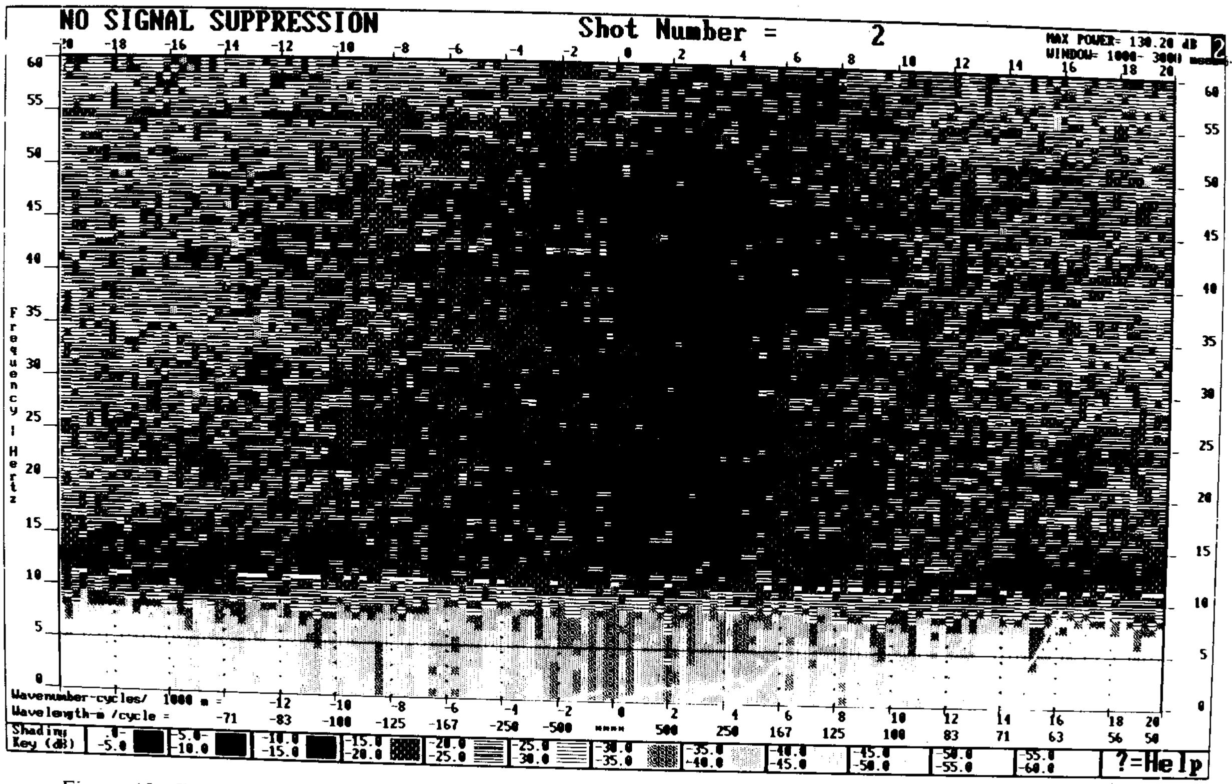


Fig. 13. F-K plot produced from 1 to 3 seconds of the record on the left of Figure 12.
Şekil 13. Şekil 12 de solda bulunan atış kaydının 1 ve 3 sn. ler arasındaki bölümünden elde edilen F-K spektrumu.

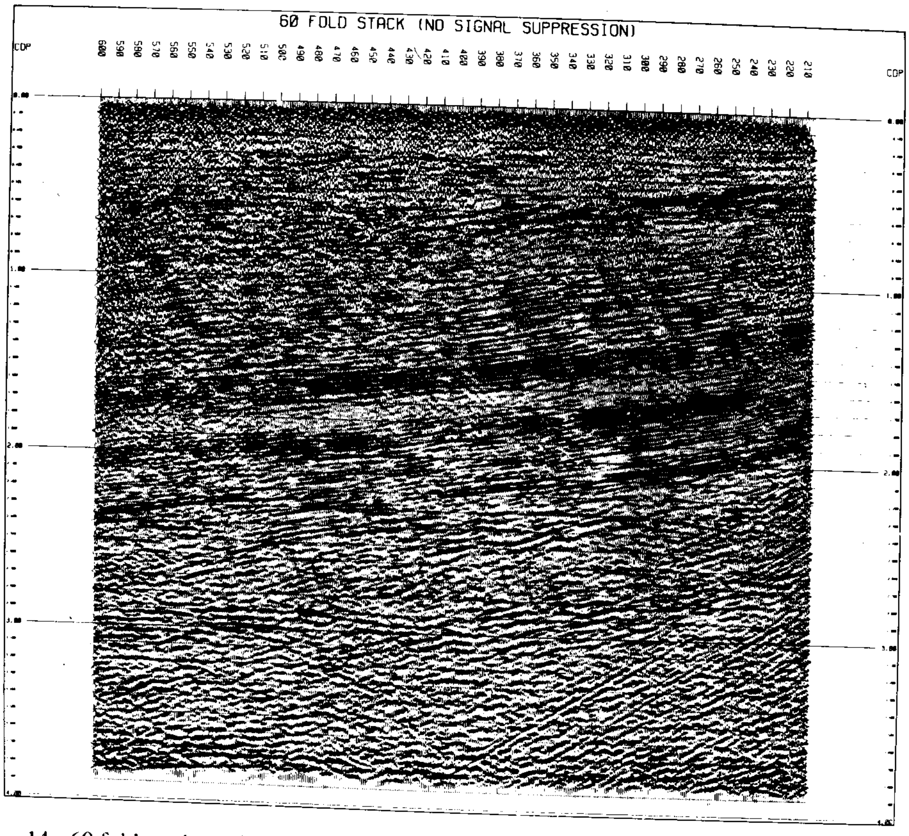


Fig. 14. 60 fold stack section of the test line with decon before stack applied.
Şekil 14. Test hattının, yığma öncesi dekonvolüsyon uygulanarak elde edilmiş 60 katlamalı kesiti.

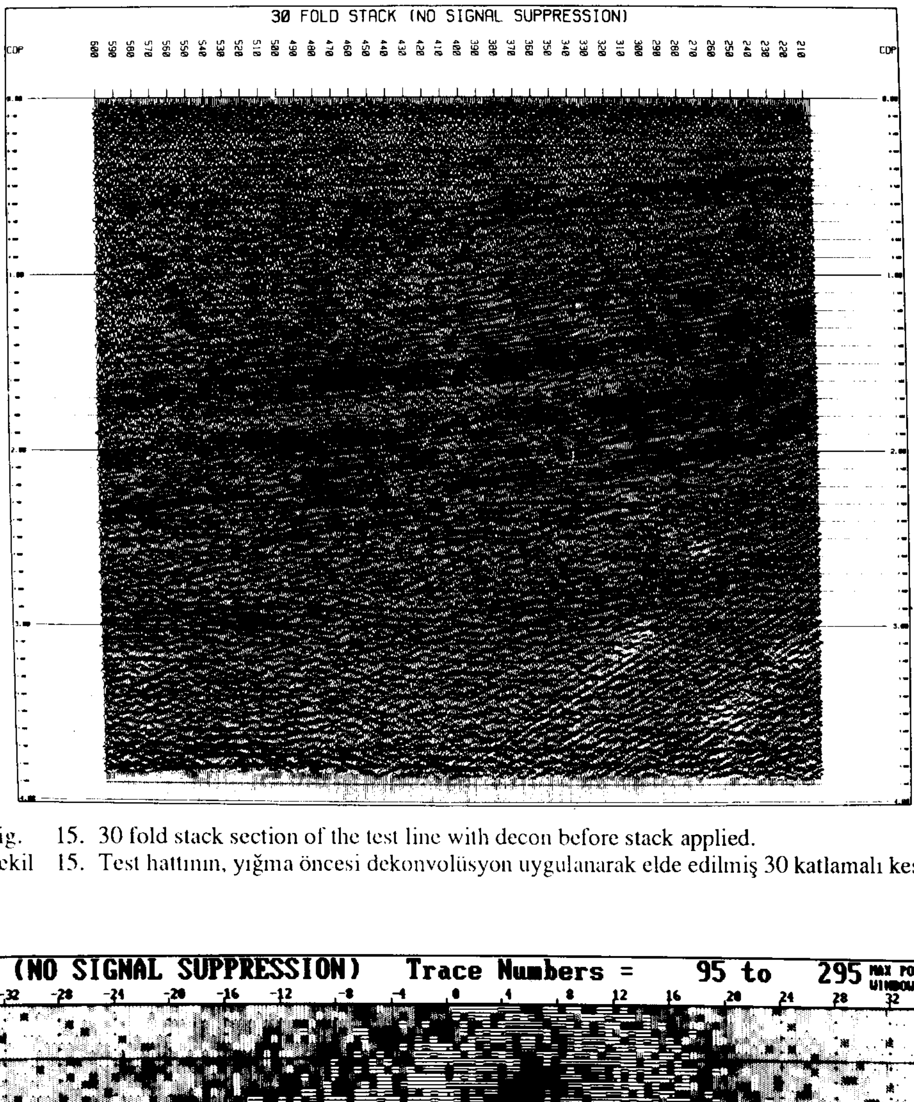


Fig. 15. 30 fold stack section of the test line with decon before stack applied.
Şekil 15. Test hattının, yığma öncesi dekonvolüsyon uygulanarak elde edilmiş 30 katlamalı kesiti.

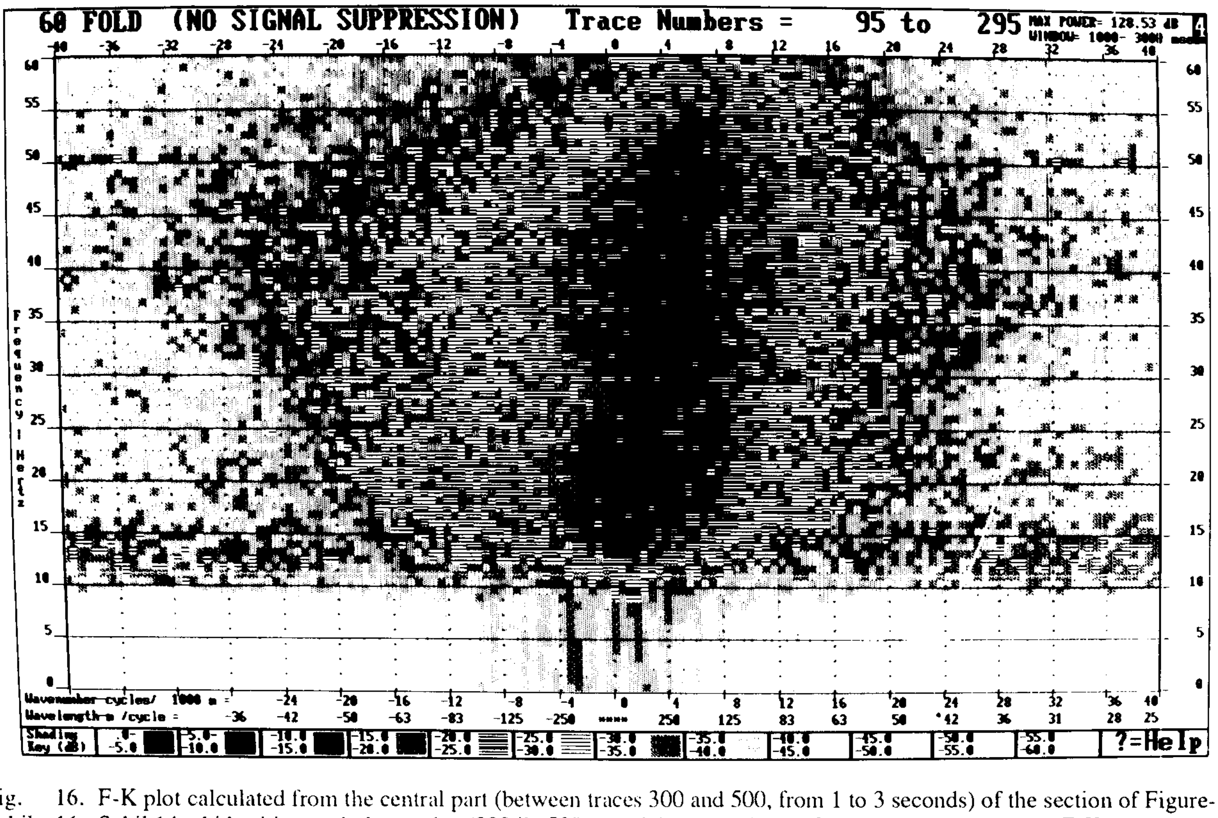


Fig. 16. F-K plot calculated from the central part (between traces 300 and 500, from 1 to 3 seconds) of the section of Figure-14.
Şekil 16. Şekil 14 teki kesitin orta bölümünden (300 ile 500 üncü izler arası, 1s den 3s ye kadar) hesaplanmış F-K spektrumu.

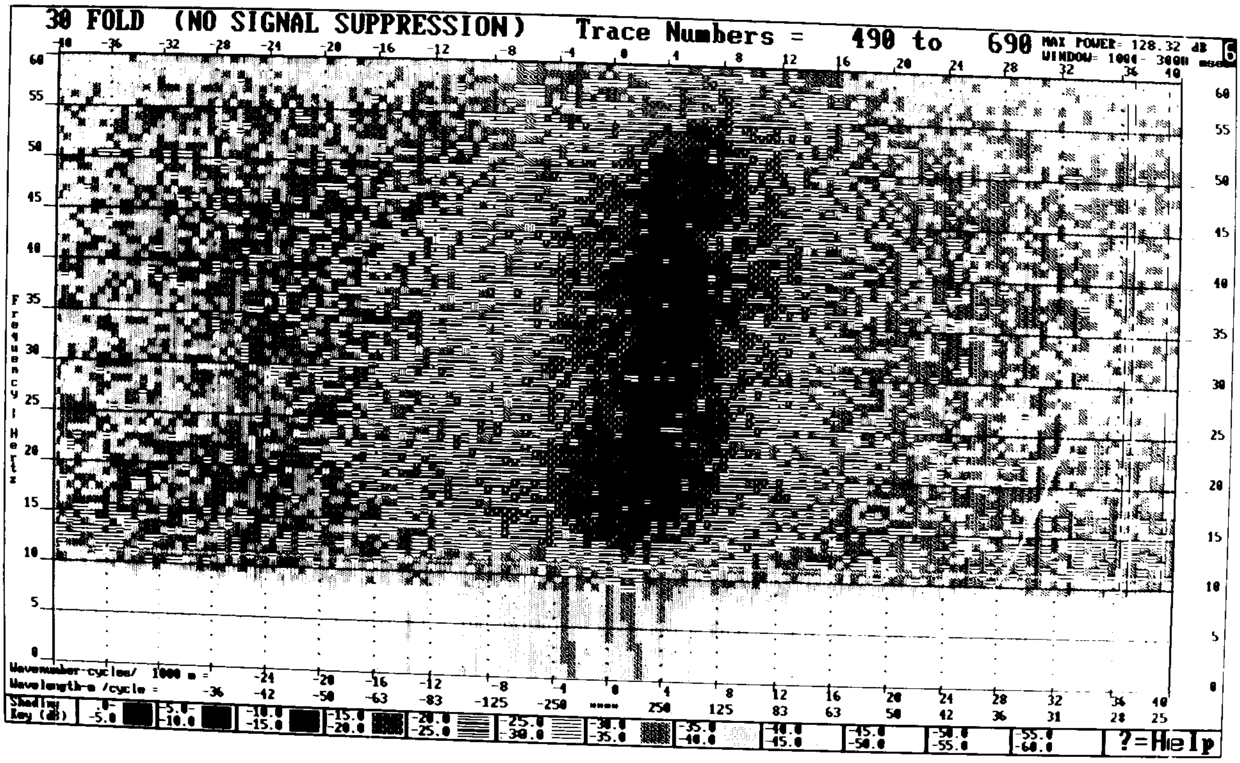


Fig. 17. F-K plot calculated from the middle part (between traces 300 and 500, from 1 to 3 seconds) of the section of Figure-15.
Şekil 17. Şekil 15 teki kesitin orta bölümünden (300 ile 500 üncü izler arası, 1s den 3s ye kadar) hesaplanmış F-K spektrumu.

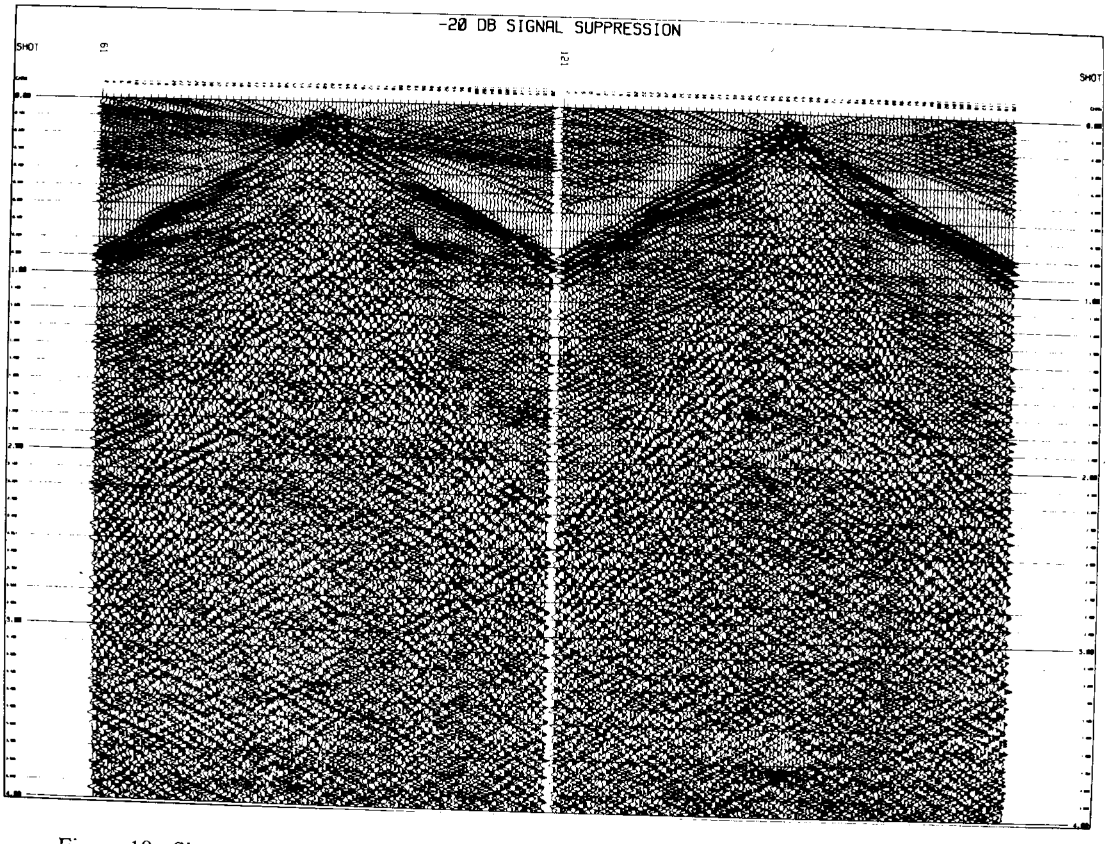


Fig. 18. Shot records of Figure-12 after -20 dB signal suppression.
Şekil 18. Şekil 12 deki atış kayıtlarının -20 dB sinyal bastırılmasından sonraki görünümleri.

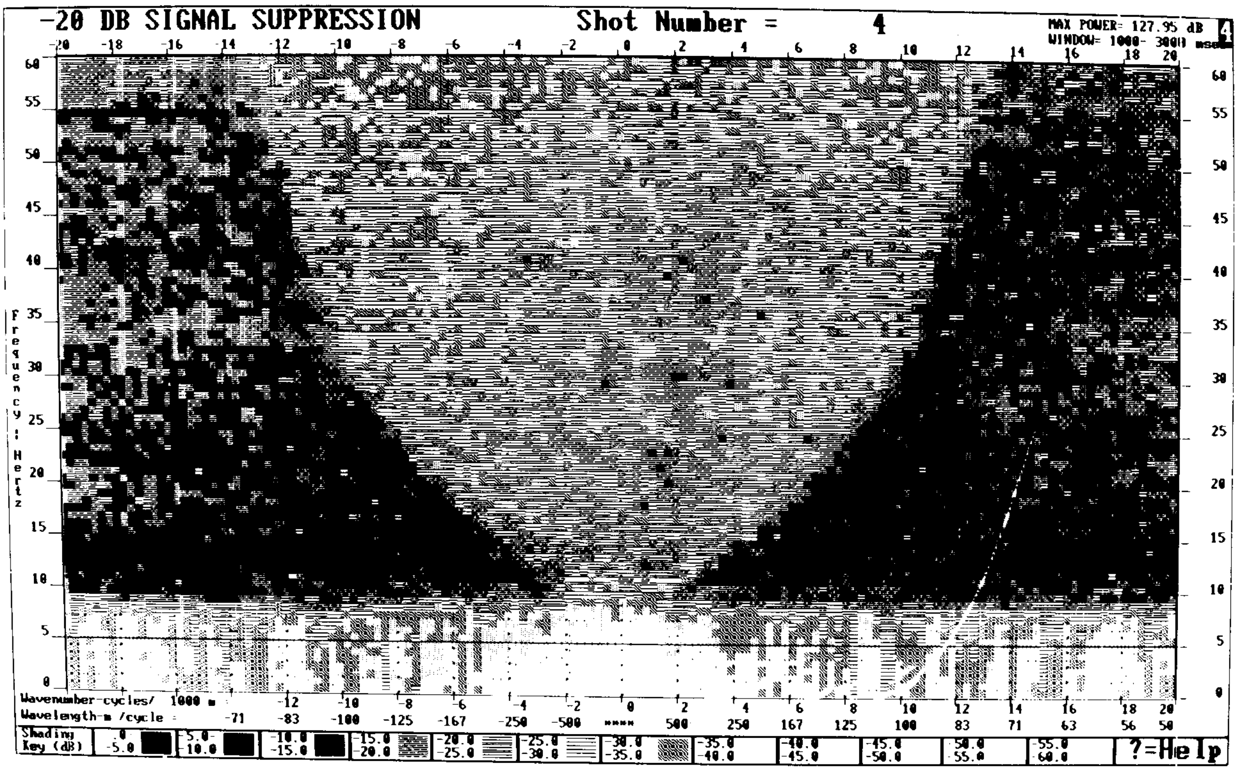


Fig. 19. F-K spectrum produced from the record on the left of Figure-18.
Şekil 19. Şekil-18 in sol bölümündeki atış kaydının F-K spektrumu.

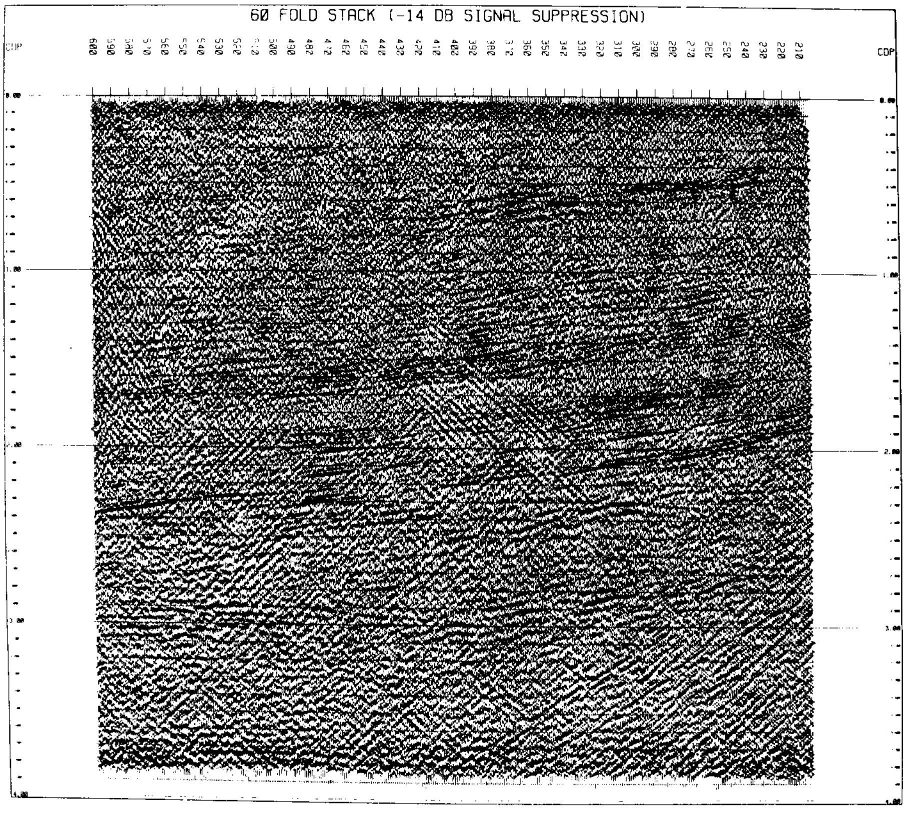


Fig. 20. 60 fold stack section produced from–14 dB signal suppressed shot records.
Şekil 20. –14 dB sinyal bastırılmış atış kayıtlarından elde edilen 60 katlamalı yığma kesiti.

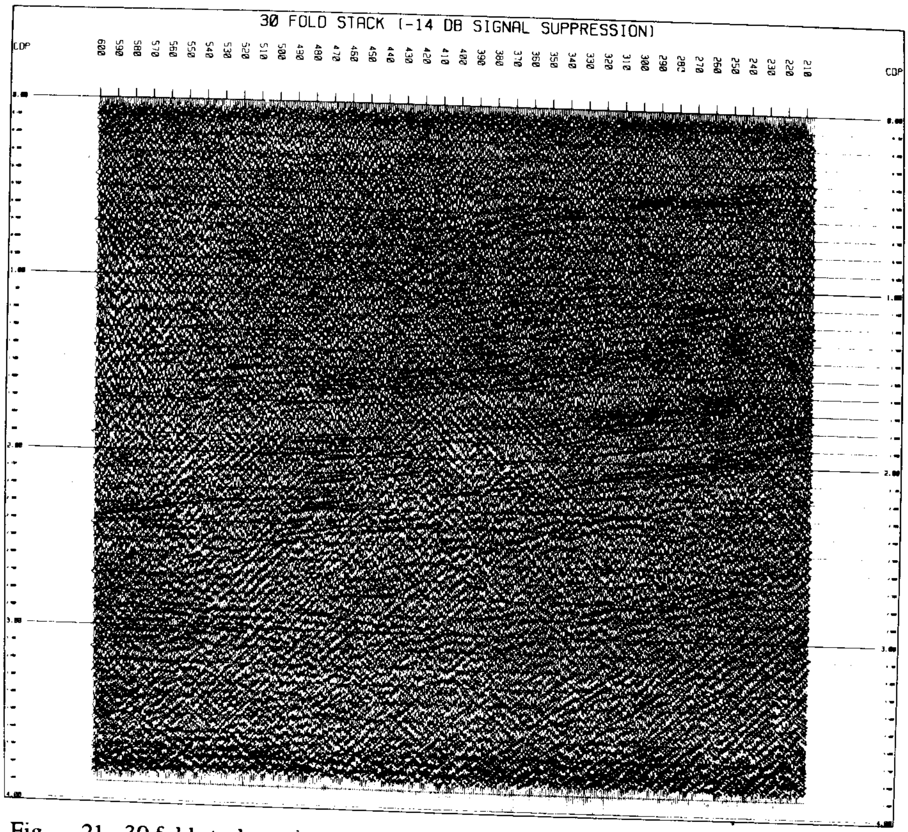


Fig. 21. 30 fold stack section produced from–14 dB signal suppressed shot records.
Şekil 21. –14 dB sinyal bastırılmış atış kayıtlarından elde edilen 30 katlamalı yığma kesiti.

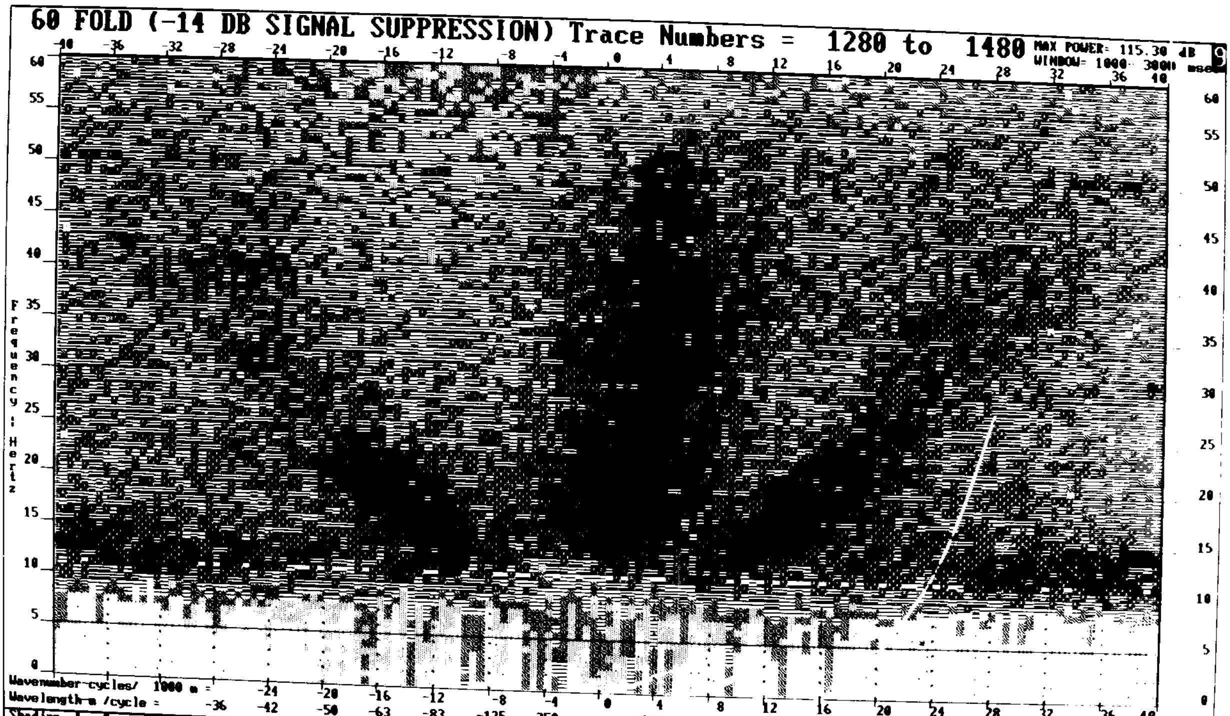


Fig. 22. F-K plot calculated from the section of Figure-20.
Şekil 22. Şekil-20 deki kesitten hesaplanan F-K spektrumu.

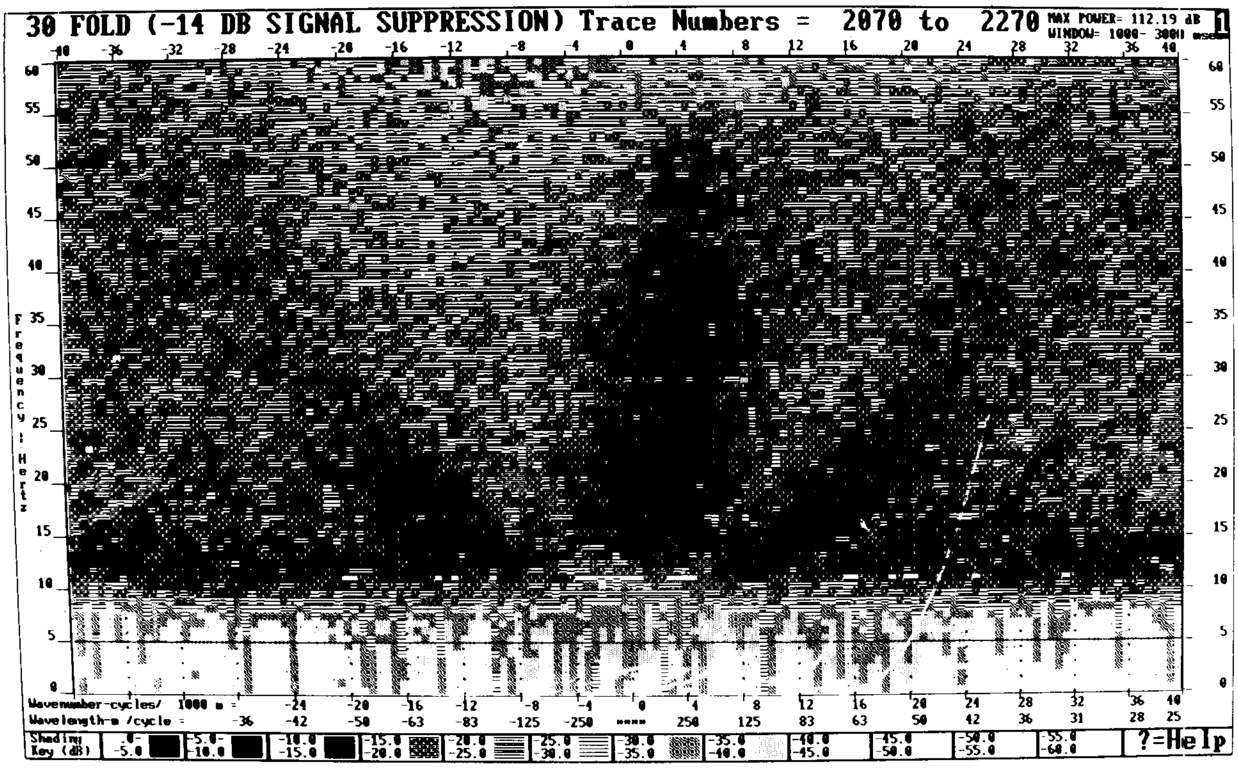


Fig. 23. F-K plot calculated from the section of Figure-21.
Şekil 23. Şekil-21deki kesitten hesaplanan F-K spektrumu.

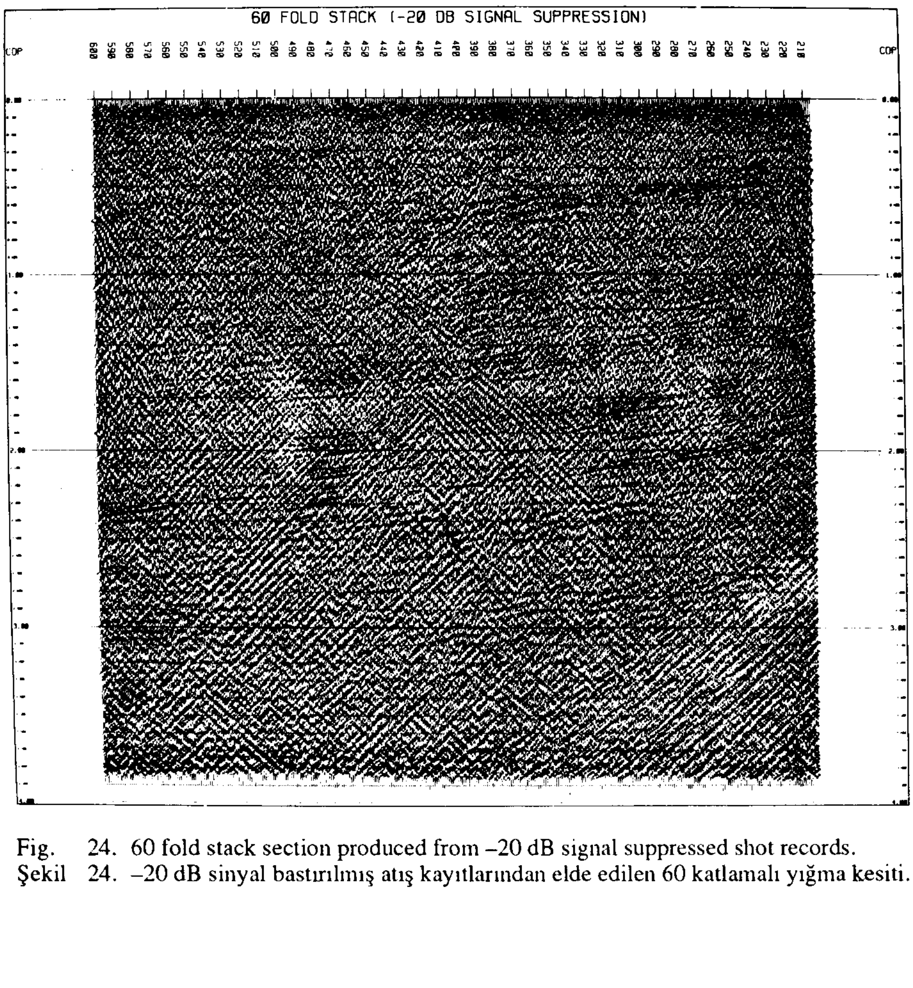


Fig. 24. 60 fold stack section produced from –20 dB signal suppressed shot records.
Şekil 24. –20 dB sinyal bastırılmış atış kayıtlarından elde edilen 60 katlamalı yığma kesiti.

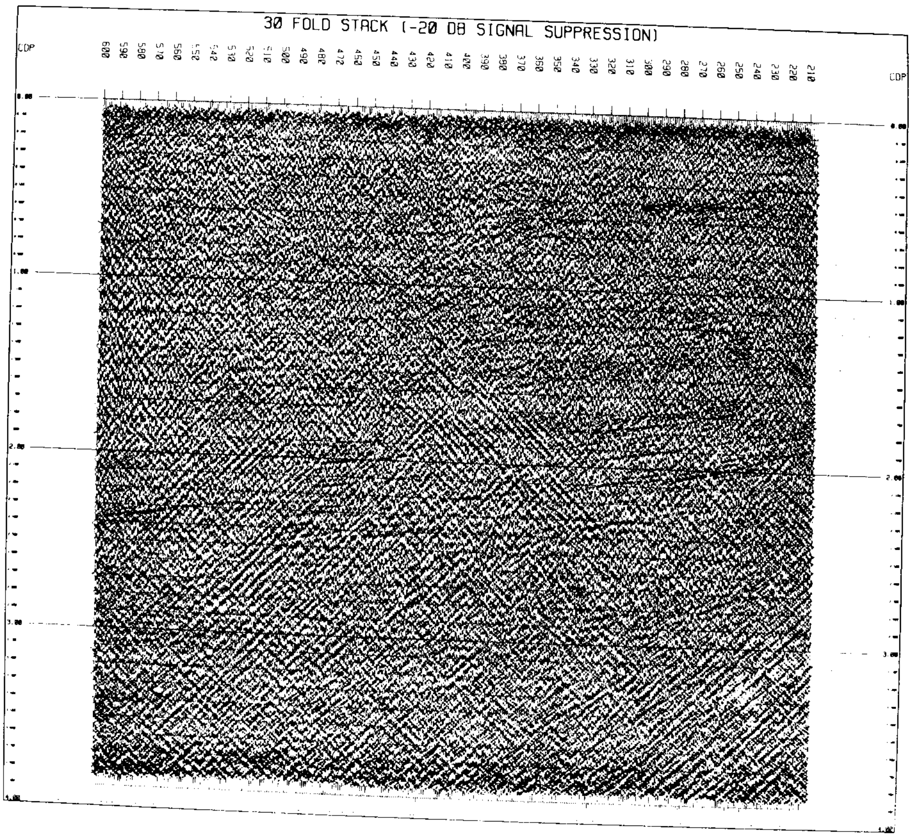


Fig. 25. 30 fold stack section produced from –20 dB signal suppressed shot records.
Şekil 25. –20 dB sinyal bastırılmış atış kayıtlarından elde edilen 30 katlamalı yığma kesiti.

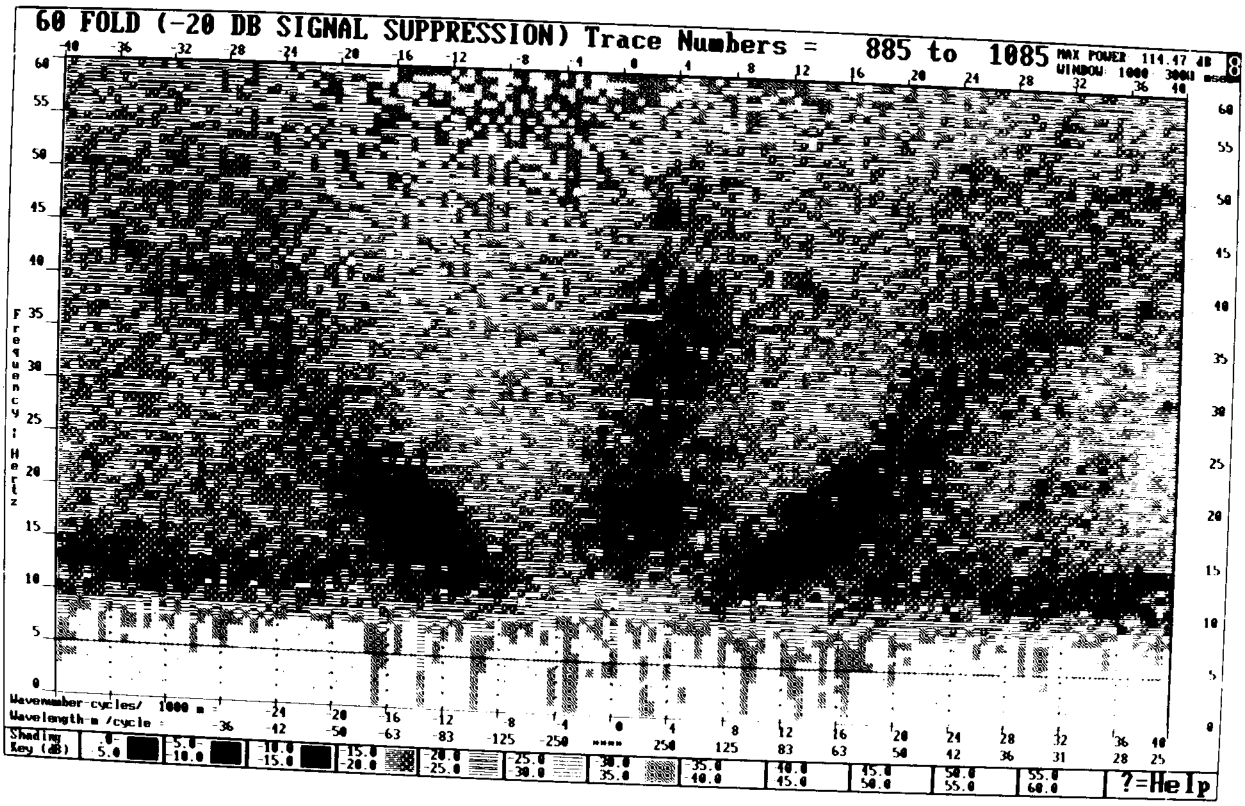


Fig. 26. F-K plot calculated from the section of Figure-24.
Şekil 26. Şekil-24 teki kesitten hesaplanan F-K spektrumu.

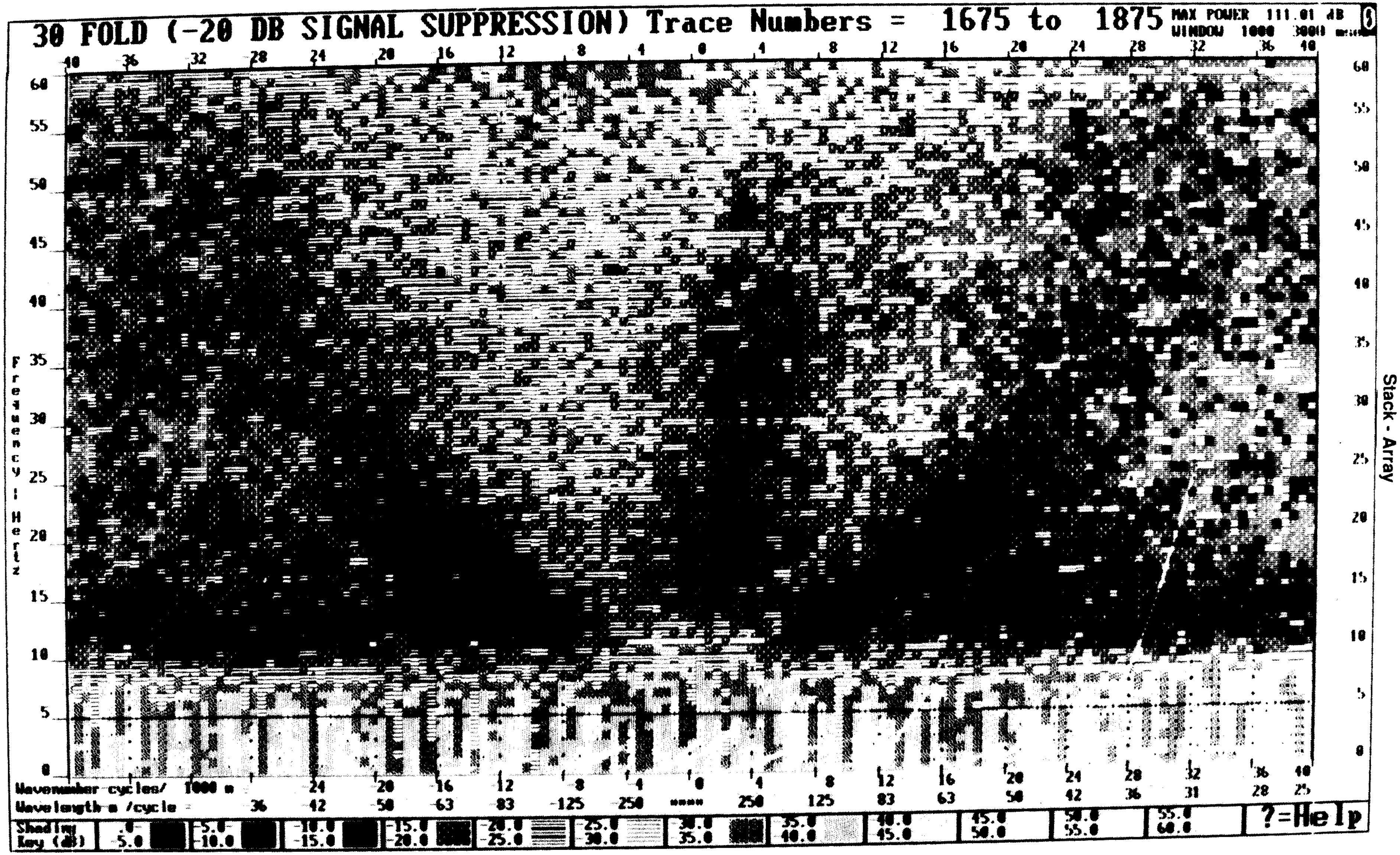


Fig. 27. F-K plot calculated from the section of Figure-25.
Şekil 27. Şekil-25 teki kesitten hesaplanan F-K spektrumu.

unmuted tails of the near-trace head waves remained in the pass band of the pre-stack frequency filter, and thus they leaked into the 30 fold section where the stack-array criterion is not satisfied. Also note that they appear as very narrow band wave trains as is expected. Ground-roll seems to be suppressed quite efficiently by the frequency filter, except near the edges of both sections.

In Fig. 12, the shot records of Fig. 9 after deconvolution are shown. Decon has effectively suppressed ground-roll and now reflections can be seen easily. FK plot displayed in Fig. 13 is produced from 1 to 3 seconds of one of the records and it shows no clear evidence of coherent noise, except some ground-roll energy in the low frequency region.

The sections in Figures 14 and 15 are the outputs of basic processing sequence with decon before stack. The minor differences are again in the very shallow parts,especially between 200 and 400 milliseconds. But this time, the noise disturbing those shallow reflections is not as effective as the one in the previous sections.

FK spectrums of Figures 16 and 17 are calculated from the central parts of the sections, between traces 300 and 500 and from 1 to 3 seconds. There seems to be no evident noise energy in the first 25 dB portion of the dB scale which is almost the visual dynamic range. Comparing them, we can conclude that, if the S/N ratio of the shot records that are input to the stacking process is high, then satisfying the stack-array criterion, we cannot achieve considerable visual improvements on the sections. But nevertheless, we get a correctly and evenly sampled wavefield for further processing.

In the second stage of processing, we applied FK filtering to all the shot gathers before stack. We had two main purposes. First,to suppress signal down to a certain level and so reduce the S/N ratio, and second, to introduce higher velocity coherent noise generated by the steep cut-off of the filter. This would enable us to test the efficiency of the stack array in poor data quality conditions and on high velocity linear noise.

In Fig. 18, you can see how the shot records look like after–20 dB signal suppression. All the reflection events are now masked by the linear noise trains generated as the impulse response of the filter, with velocities ranging between 2000 m/s and 4000 m/s. Figure 19 shows the FK spectrum of the first record. Bright region in the middle is the reject band. Its bending edge is the reason for the ranging velocity noise.

Stack sections produced from–14 dB signal suppressed shot records are displayed in Figures 20 and 21. Same basic processing routines are applied, including DBS and two passes of residual statics. The masked reflections have now been recovered to enter into the dynamic range of the human eye again. The continuity of the reflectors are slightly better and detection of faults is easier in the 60 fold section. But it is obvious that both ground-roll and filter noise, with their apparent velocities halved, have leaked into both sections.

For comparison, FK plots again produced from the same middle parts of the sections are given in Figure 22 and 23. First thing to notice is that there is more noise on the plot of Fig. 23. Another point is that the stacking velocity functions have been chosen quite accurately, because the signal spectrum has not changed with the reduction of the fold. Also we can say that, signal in general, is the highest amplitude event in both sections. Overall noise attenuation in 60 fold section, seems to be 0 to 5 dB more than the 30 fold section. This difference is about 5 dB for the low velocity, short wavelength ground-roll, and negligable for the higher velocity, longer wavelength filter noise. Some high frequency uncorrelated noise energy has also been suppressed better on the full fold section, but this is most probably due to the number of traces stacked, not to the stack-array itself. So we can say that, mainly ground-roll and random noise are responsible for the difference between the two sections.

After an additional 6 dB signal suppression on the shot gathers, the sections in Figures 24 and 25 are produced. Although the overall picture does not seem to be much different, several horizons and faults that can be defined in the 60 fold section, are hard to trace in the 30 fold section. This is a good example of how a small difference in the S/N ratio effects visual perception.

FK plots of Figures 26 and 27 display more or less the same features as before. Signal to noise ratio is obviously less than one in both sections, but there is more noise energy in the plot of Fig. 27. Again, ground-roll and high frequency uncorrelated events are attenuated better in the 60 fold section, but the artificial filter noise looks the same.

## CONCLUSIONS

The question was, "How effective is the stack-array ?". With so many factors effecting the quality of a seismic section, such as acquisition and processing parameters, field conditions, character of noise etc., it is meaningless to give a quantitative answer. But it is possible to derive some qualitative conclusions from the test presented.

First of all, stack-array is more effective on low velocity noise. Theory has been approved by the results of the test, where ground-roll is attenuated more than the high velocity filter noise. The responsibility of this phenomenon goes partly to NMO correction which distorts the evenness of the spatial filter more for high velocities, and partly to the side lobes of the wavenumber response of the stack-array itself.

Secondly, on the sections presented, signal to groundroll differences were not as remarkable as the results of Morse and Hildebrandt (1989). This is mainly due to the prestack algorithms that suppress ground-roll before the stack-array is formed. Therefore we can conclude that stack-array is more effective in low S/N ratio conditions where a few decibels may be critical for interpretation.

And finally, as a general theoretical remark, it can be stated that stack-array is the only way of getting the full advantage of the CMP method. Deflecting from this criterion, will lead us to discriminate against some of the noise wavelengths, ie to suppress some noise less than the others. It is needless to say that an unevenly sampled wavefield, whether signal or noise, will be an unwanted input for many of the processing routines. So, even though a few decibels increase in the S/N ratio may not be critical in some cases, it is always wise to be on the safe side.

## ACKNOWLEDGEMENTS

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