GEO 365N/384S Seismic Data Processing
Final Project

Team: Circle

ABSTRACT

In the final project, we processed a deep water 2D seismic line collected near the coast of Japan, over the Nankai Trough subduction zone. We went through the processing steps from raw data to surface-consistent correction, CMP sorting, gain, spherical divergence correction, velocity analysis, NMO, DMO, stack, and migration. The final processing result can be used for geologic interpretations.

ASSIGNED TASKS

1. Conrad summarized the geology and data acquisition of the dataset. He did some interpretations on the published stacked data. He checked the data to see if there are something wrong.

2. Nam processed the data from surface-consistent amplitude balancing, CMP sorting, gain, spherical divergence correction, velocity analysis, NMO, DMO, stack, and migration.

3. The final migrated image is interpreted by Nam and Conrad. We put all the stuffs in the presentation and report.

DATA OVERVIEW

Geology and data acquisition

1. The data were collected near the coast of Japan, over the Nankai trough, where the Philippines plate is subducting beneath Eurasia. The Shikoku Basin section of the northern Philippine Sea plate has been subducting northwestward under southern Japan along the Nankai Trough (Figure 1).

2. 8 two-ship expanding spread profiles (ESPs), 6 split spread profile (SSPs), and 250 km of 96-channel, high-resolution multichannel seismic reflection (MCS) profiles were acquired in the Nankai Trough. Our 2D seismic line is NT62-8 in Figure 2.

3. The deformed sediments in the Nankai Trough consist of a terrigenous trench wedge overlying a Shikoku Basin sequence. Along line NT62-8 the trench sediments are less than 350m thick at the deformation front, and the trench wedge is about 12 km wide. The subduction-related deformation begins seaward of the base of the inner trench slope. The protothrust zone developed seaward of the first thrust is 2.5 km wide and is characterized by thickening and seaward tilting of the trench wedge (Figure 4). The

decollement is localized near the top of the Shikoku Basin lower pelagic unit. There are thrusts after the protothrust zone (Figure 3).

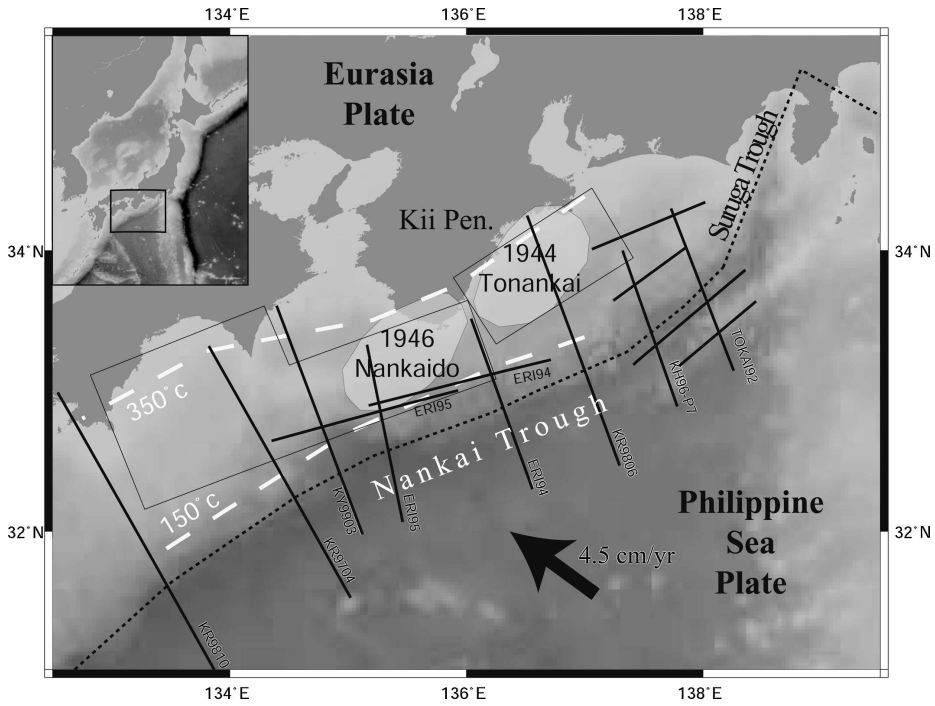


Figure 1: Location of the Nankai Trough (Image from Mochiduki and Obana (2003)). project/ geo

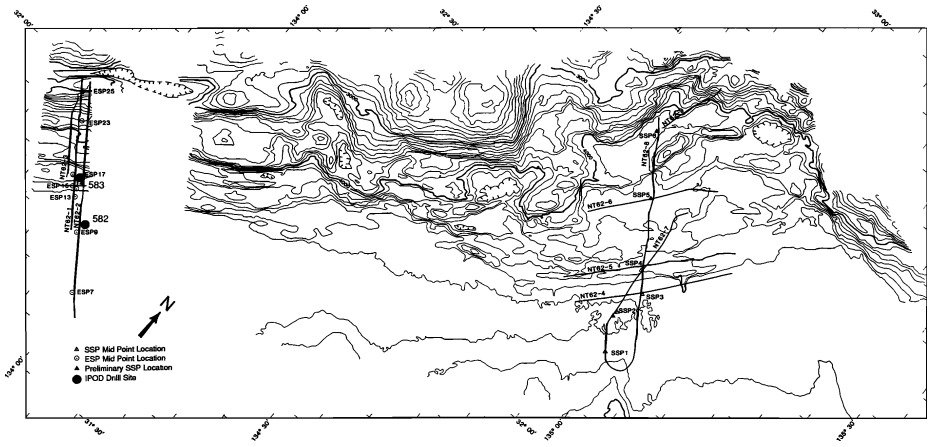


Figure 2: Seismic acquisition (Image from Mochiduki and Obana (2003)). project/ acquisition

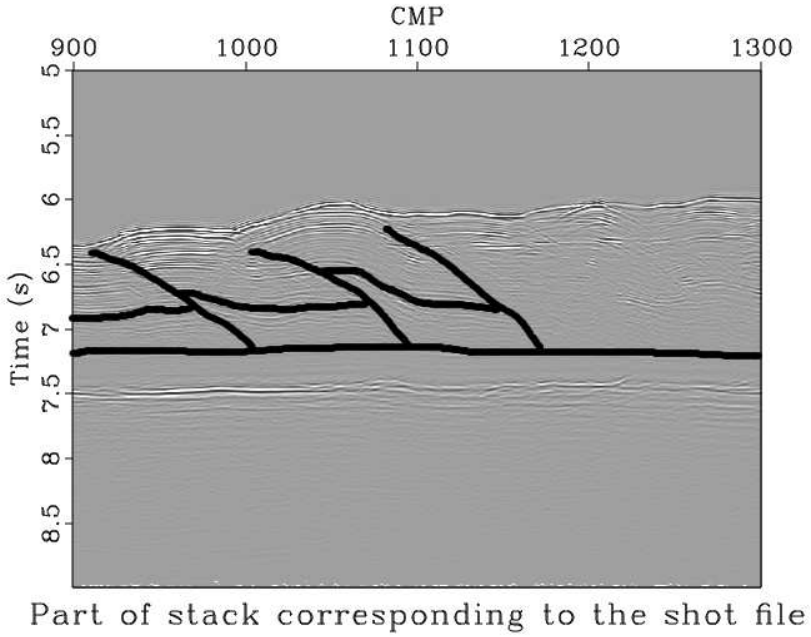


Figure 3: Geologic structure. project/ stack-shot-interpret

First look at data

1. The data were collected by the University of Texas and the University of Tokyo. The original data is in SU, so we converted it to RSF files. The processed dataset was published in Moore et al. (1990). Field data were sorted into 16.66-m bins.

2. There are two data files: shot-ordered gathers (Figure 7a) and published stacked data (Figure 4). The data were collected in very deep water, approximately 6 seconds two-way travel time, which is 4.5 km if the water velocity is 1500 m/s. The shot-gather data has 326 shot gathers with 19057 traces. The total time length of a trace is 11 seconds with a sample interval of 0.002 seconds. The published stacked data has 2250 traces with total time length of 9 seconds and 0.004 seconds sample interval. The shot-gather data has 401 CMPs while the stacked data is the output of 2869 CMPs. Therefore, the shot-gather file is a subset of stacked data.

3. The number of traces per shot gather is Figure 5. The first shot gather, 1687, has one trace, then the number of traces per gather increases to a maximum of 69 at gather 1735 and keeps constant through gather 1965. After gather 1965, the number of traces per gather decreases to 1 at the last gather, 2012. There are missing traces at some shot gathers, for example at gather 1707 (Figure 6). The average frequency spectra of shot gathers is Figure 8a. Our data has low frequencies smaller than 10 Hz that need to be filtered. We later followed the example of the published dataset (Moore et al., 1990) to resample the file from 2 ms to 4 ms sample interval to reduce our prestack processing load by half. The Nyquist frequency of 4 ms sample interval is 125 Hz. Typical seismic data has good high frequency content up to around 50-70 Hz, above this are usually noise. Therefore, we filtered high frequencies above 125 Hz to prevent aliasing and remove noise.

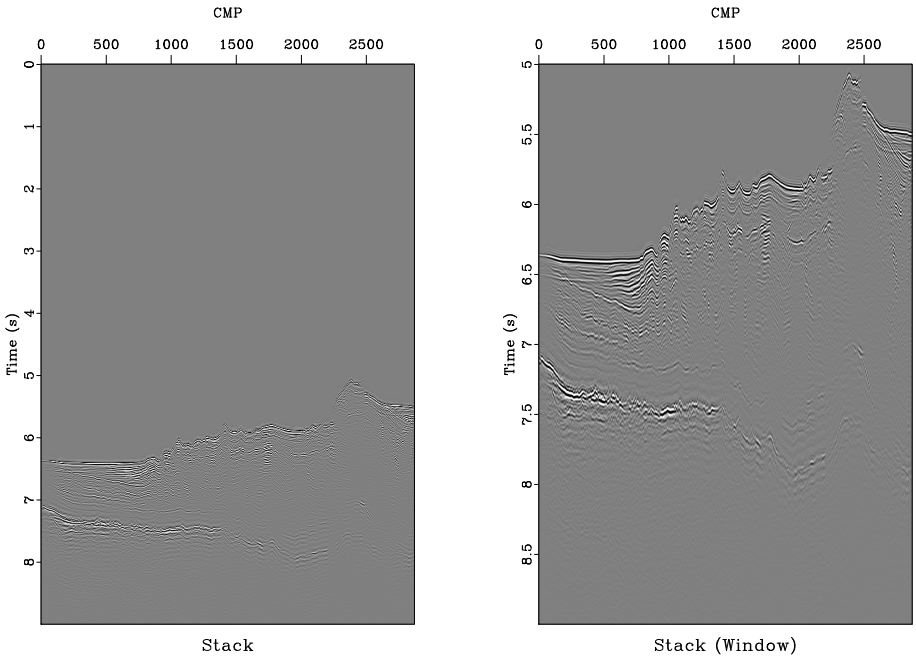


Figure 4: Published stacked data. project/ stackd

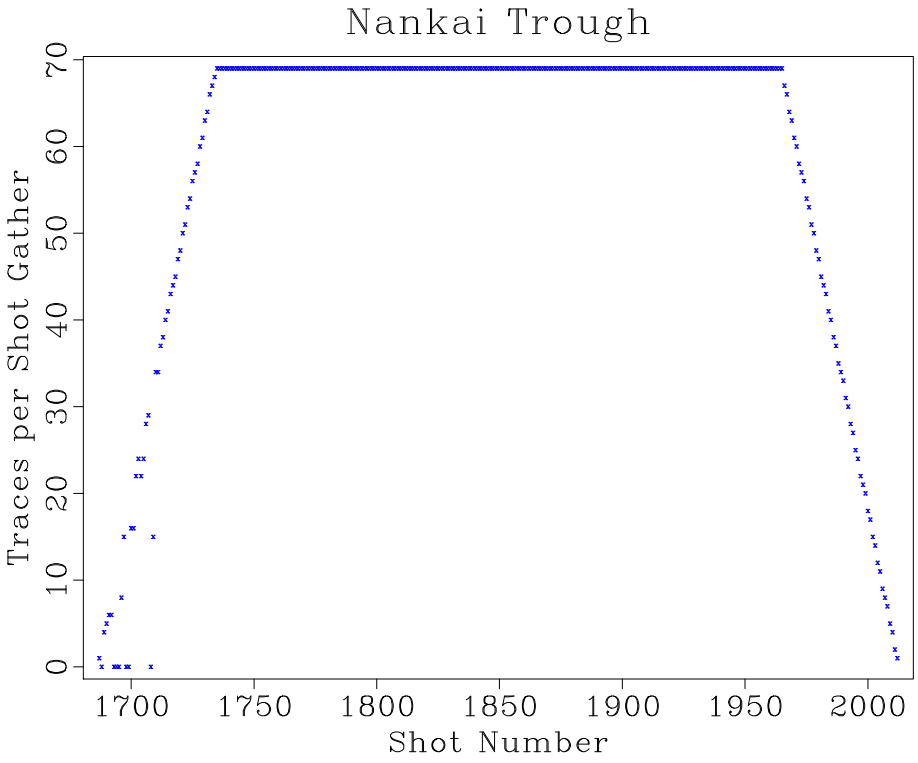


Figure 5: Number of traces per shot-gather. project/ smask

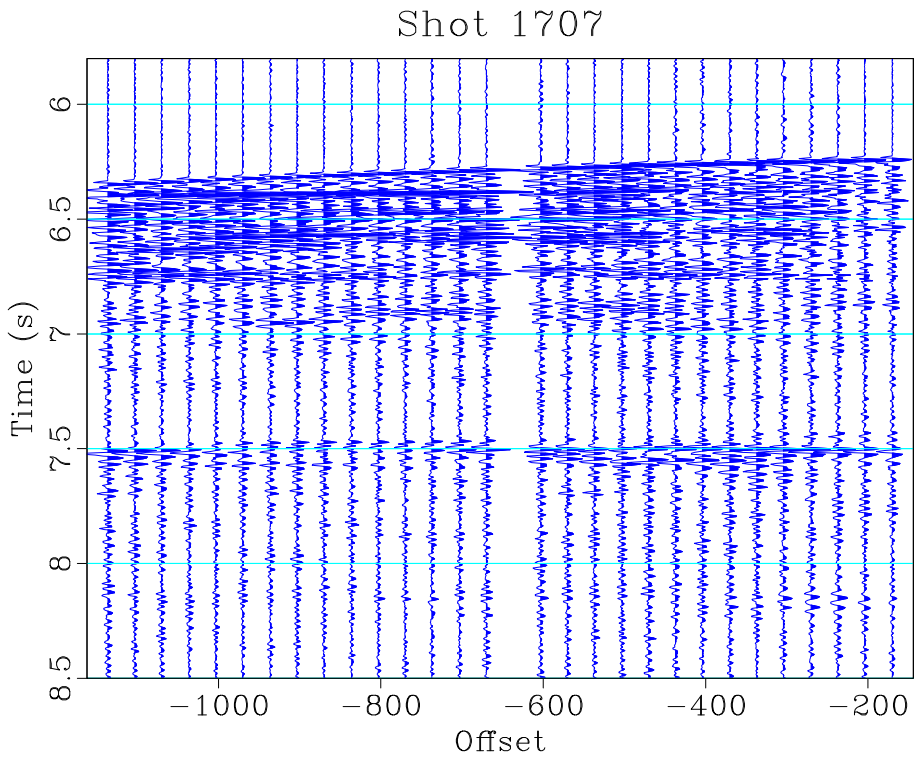


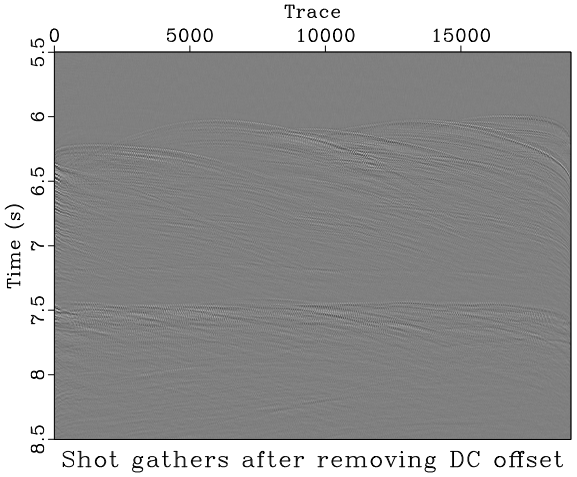
Figure 6: Shot-gather 1707. project/ shot

SURFACE-CONSISTENT AMPLITUDE BALANCING

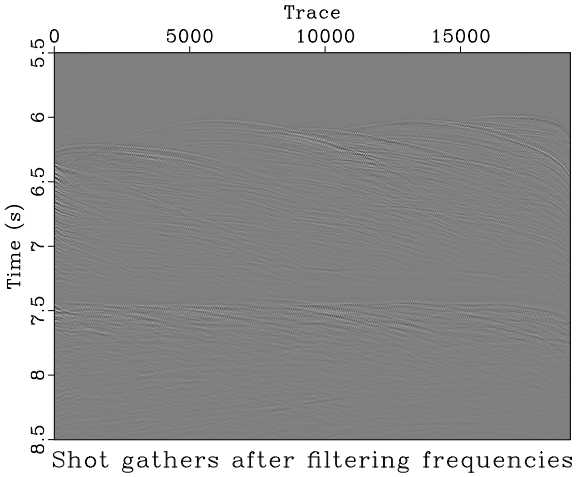
1. The first step is to do surface-consistent amplitude balancing. Typical seismic instruments introduce significant direct current (DC) offset that is effectively added to the desired signal from the sensor. We removed DC offset from the shot gathers data to facilitate processing and analysis of data (Figure 7b). We then filtered the low frequencies and high frequencies in the data (Figure 7c).

2. We created a mask to remove zero traces and calculated trace amplitudes of the shot gathers displayed in shot-offset coordinates (Figure 10a). The stripes in the amplitude might be caused by near-surface conditions in deploying sources and receivers. The horizontal stripes come from the offset term (Figure 9a). The vertical stripes come from the shot term (Figure 9b). The diagonal stripes come from the CMP and receiver terms (Figure 9c and Figure 9d). The surface-consistent model (Taner and Koehler, 1981) tries to explain the trace amplitude using a product of source, receiver, offset, and midpoint factors. After running iterative inversion using the least-squares method and the conjugate-gradient algorithm (Hestenes and Stiefel, 1952; Fletcher and Reeves, 1964), the stripes are predicted (Figure 10b). The shot gathers after the surface-consistent amplitude correction are the right figure in Figure 11.

(a)

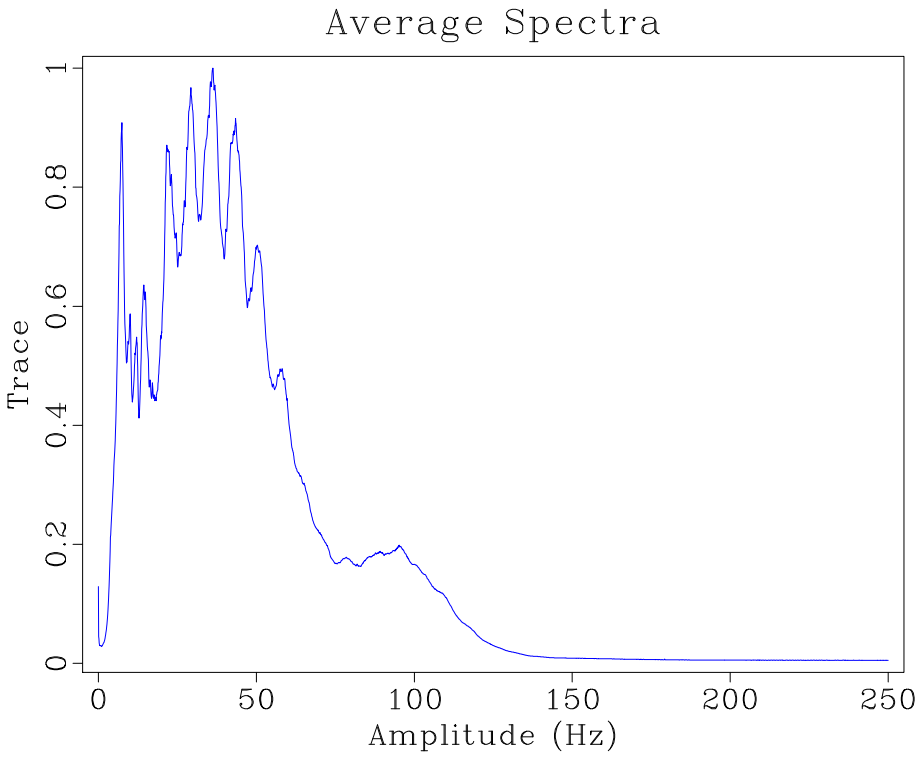


(b)

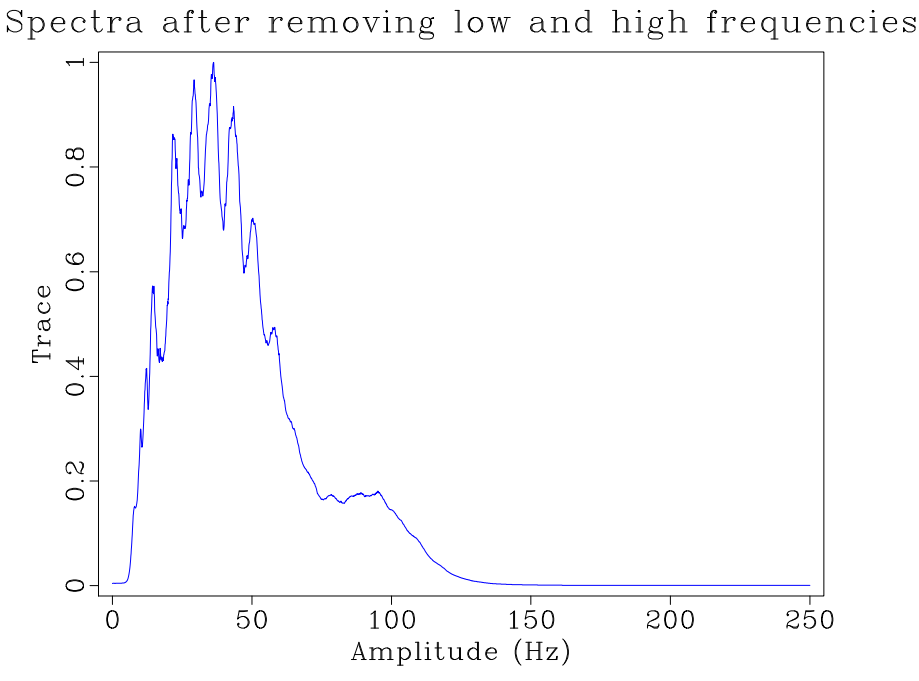


(c)

Figure 7: (a) Raw shot gathers (b) Shot gathers after DC removal. (c) Shot gathers after filtering low and high frequencies. project/ shots,shotsdc,shotsf



(a)



(b)

Figure 8: (a) Raw data frequency spectra. (b) Frequency spectra after filtering low and high frequencies. project/ spectra,spectraf

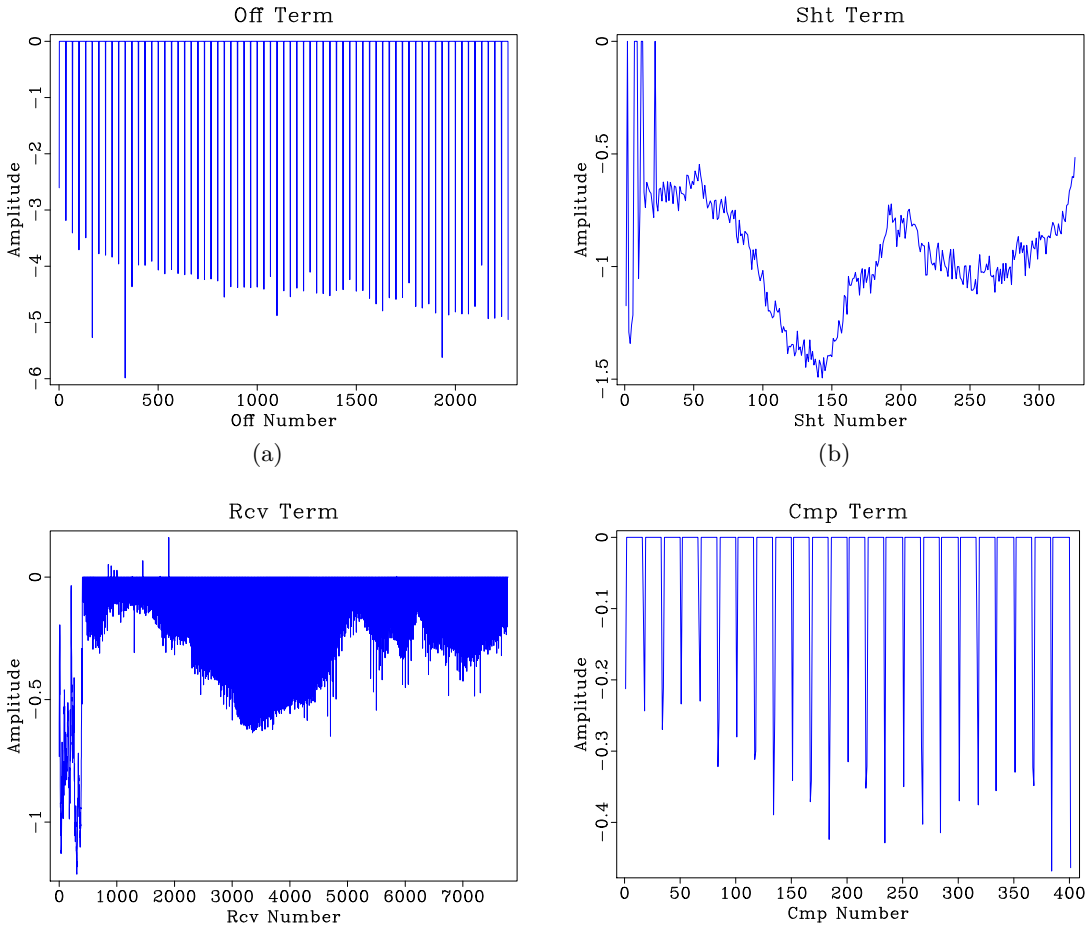


Figure 9: Estimated surface-consistent factors. project/ off,sht,rcv,cmp

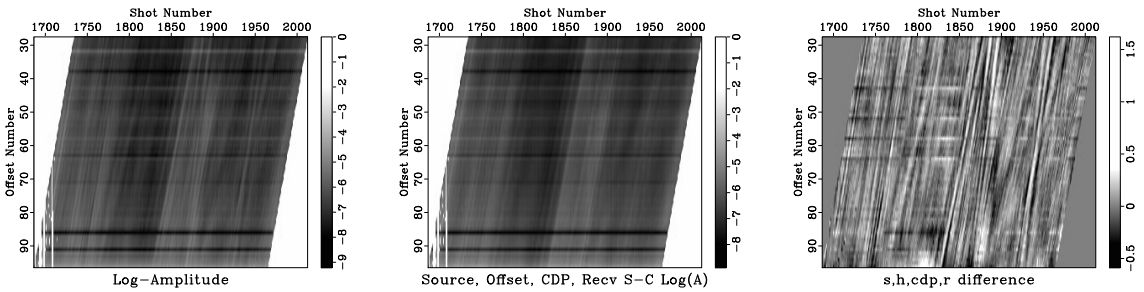


Figure 10: Trace amplitudes from the data. (a) Initial. (b) Estimated surface-consistent. (c) Difference. project/ varms,recvvscarms,recvadiff

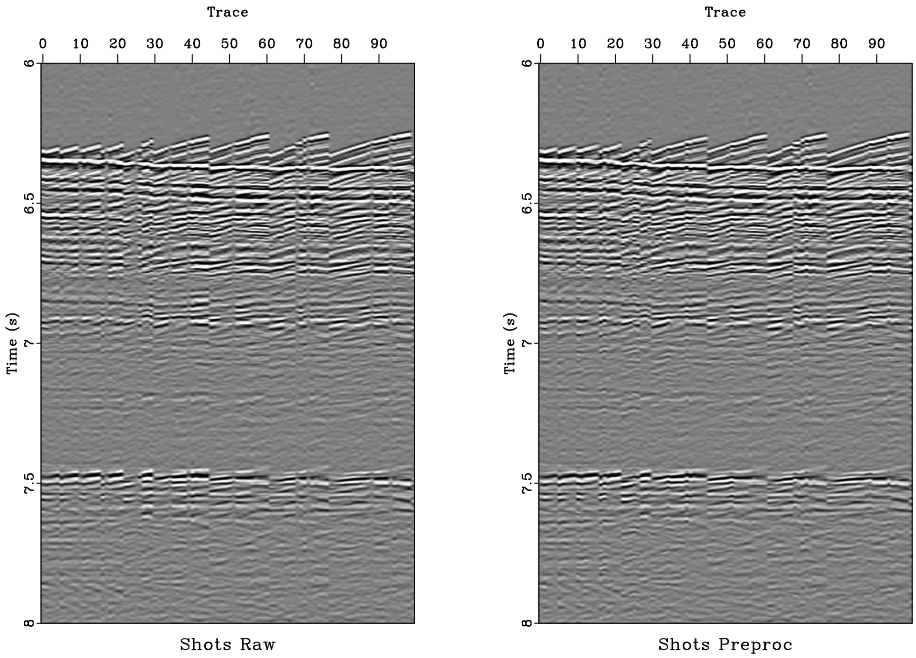


Figure 11: (a) Raw shot gathers (b) Shot gathers after surface-consistent amplitude correction. project/ shotsfc

CMP SORTING

1. The shot gathers are resampled to 4 ms sample interval and applied spherical divergence correction (Figure 12). We then sorted the data to CMP (Figure 13). The fold values of data is Figure 14. We have 401 CMPs but the first CMPs are not full fold. The first full-fold CMP gather is CMP 933 with 48 traces.

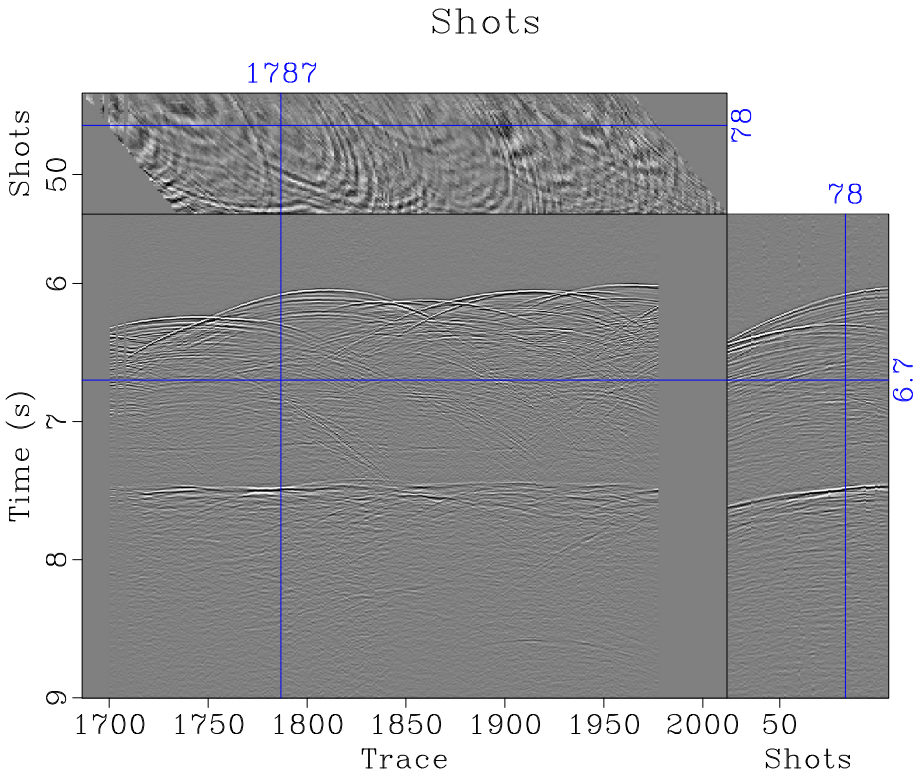


Figure 12: Shot gathers after resampling. project/ shots2

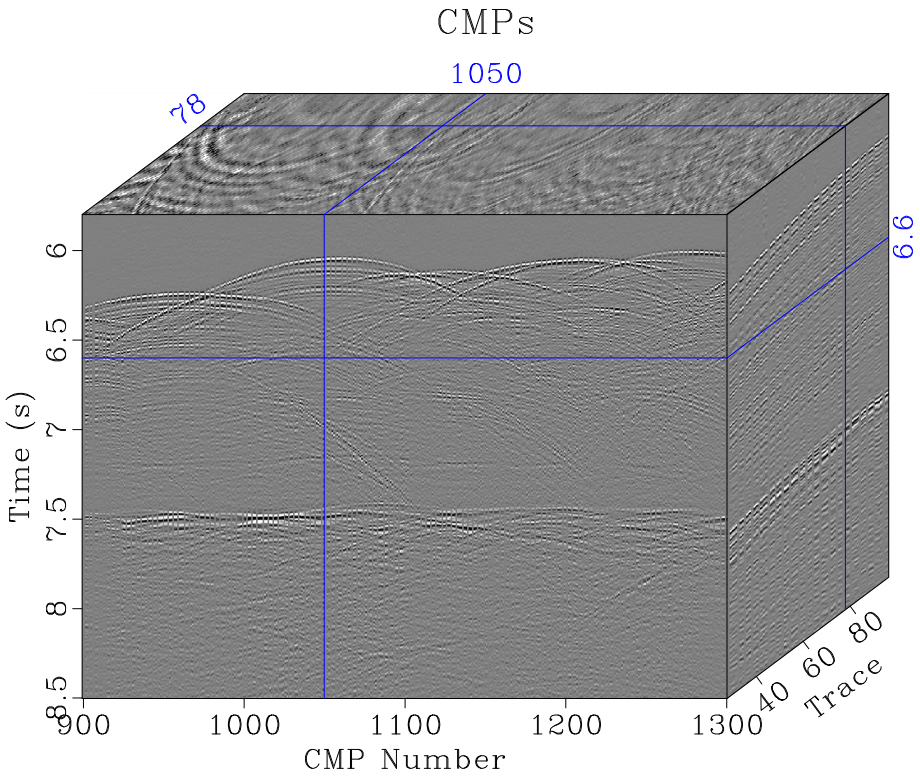


Figure 13: CMP gathers. project/ cmps

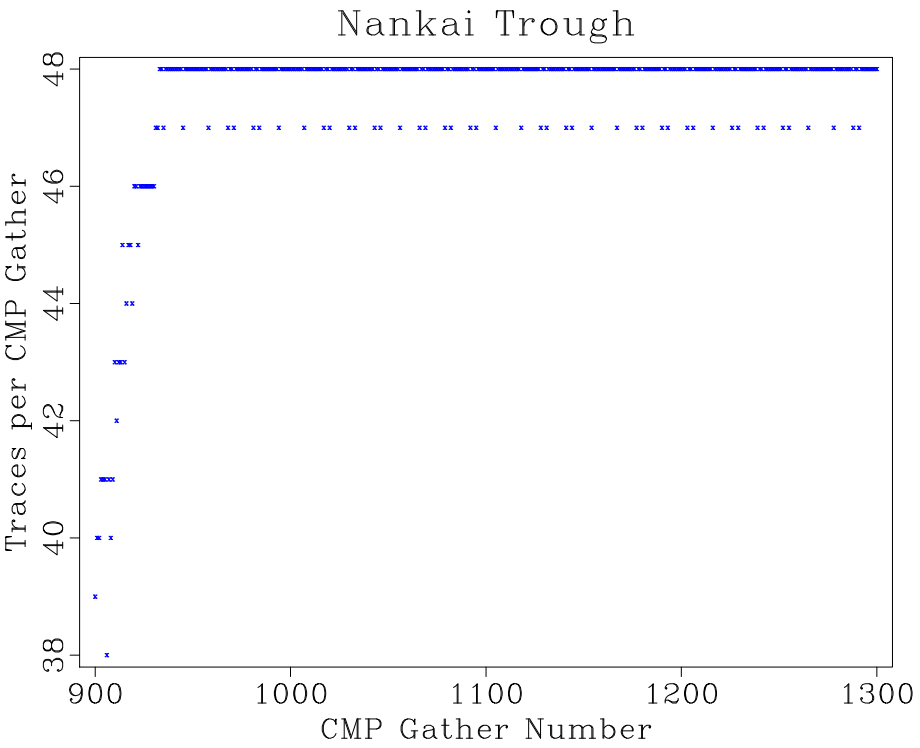


Figure 14: Fold values of data. project/ cmask

VELOCITY ANALYSIS, NMO, DMO, AND STACK

1. We examined CMP gather 1280 (Figure 15). We did velocity analysis using semblance scan and automatically picked the velocity (Figure 16). We then applied NMO using picked velocity to flatten the events (Figure 17).

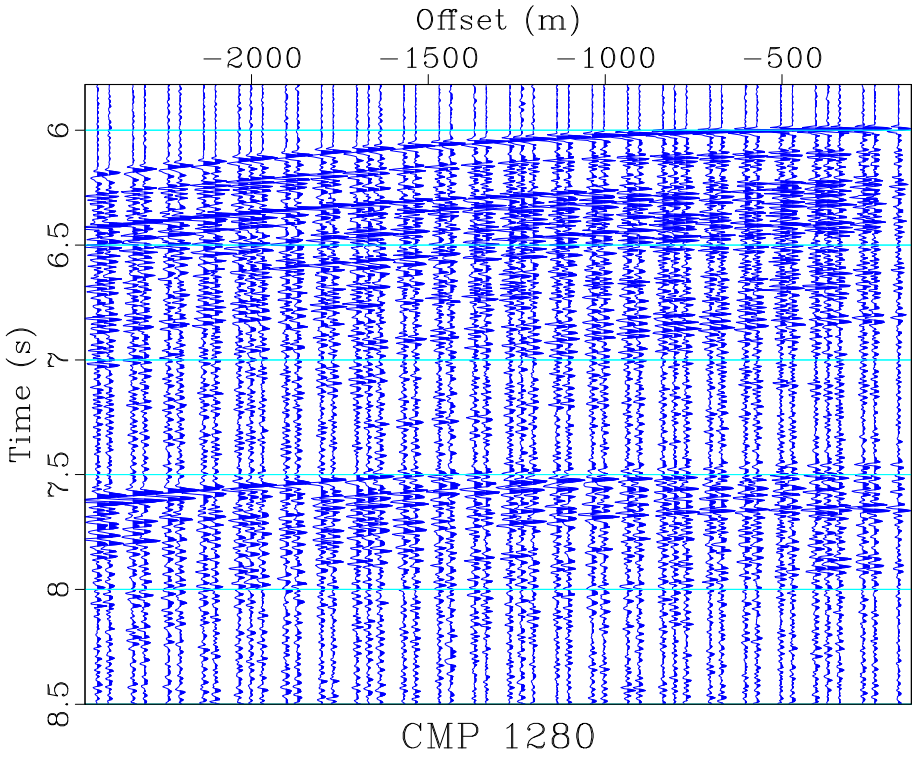


Figure 15: CMP 1280. project/ cmp1

2. We applied the same procedure with all CMP gathers. NMO velocity (Figure 18) was picked using semblance scan. The events were flatten (Figure 19). We then stacked all the CMP gathers (Figure 20a). Our stack result does not resemble the published stacked data, which is actually a stacked and migrated file.

3. We also tried DMO to correct for dips. We created a constant-velocity stack with 60 velocities starting from 1400 m/s and spacing interval of 20 m/s (Figure 21). We applied Fowler's method (Fowler, 1988) to transform the stack volume into the frequency-wavenumber domain and applied the velocity mapping (Figure 22). The result after applying Fowler's method is Figure 23. We then picked the DMO-corrected velocity automatically from the envelope (Figure 24). After the velocity was picked, we generated a DMO stack by slicing through the velocity cube (Figure 25). We examined CMP 1280 where there is a dipping event to evaluate the velocity picking and to observe the change brought by DMO (Figure 26). The velocity is corrected in the shallow layers to account for the dips. The picked velocity is smoother and increases with depth. We extracted a small window of DMO stack and normal stack for comparison (Figure 27). The events in DMO stack are clearer than in normal stack.

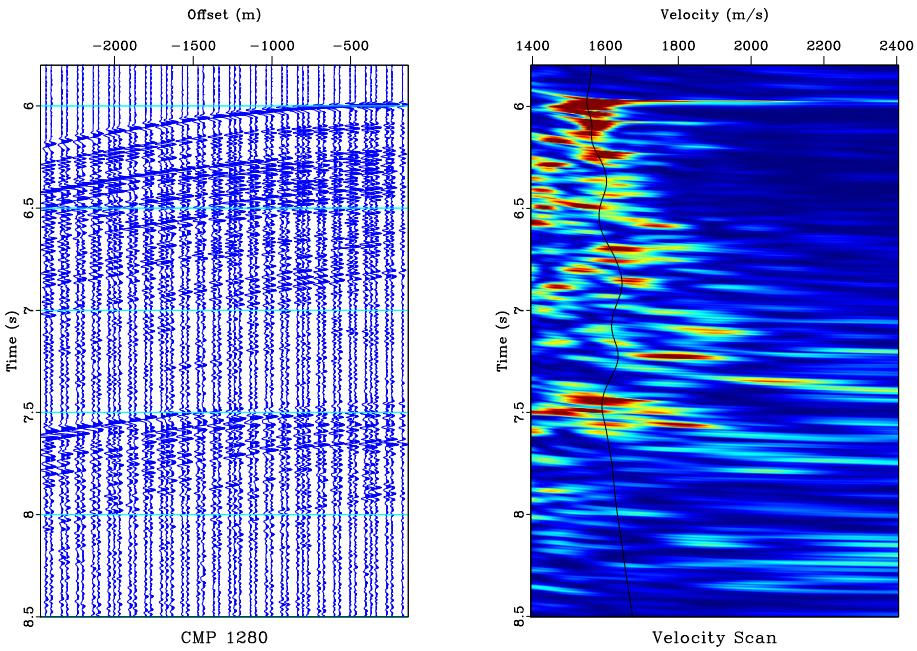


Figure 16: Velocity analysis for CMP 1280. project/ vscan

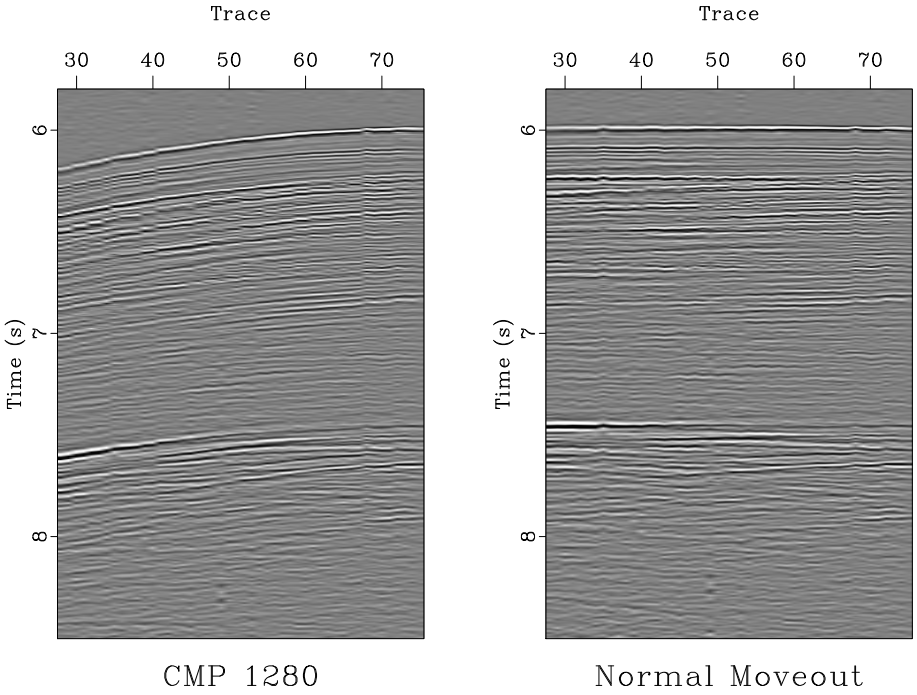


Figure 17: CMP 1280 after NMO. project/ nmo1

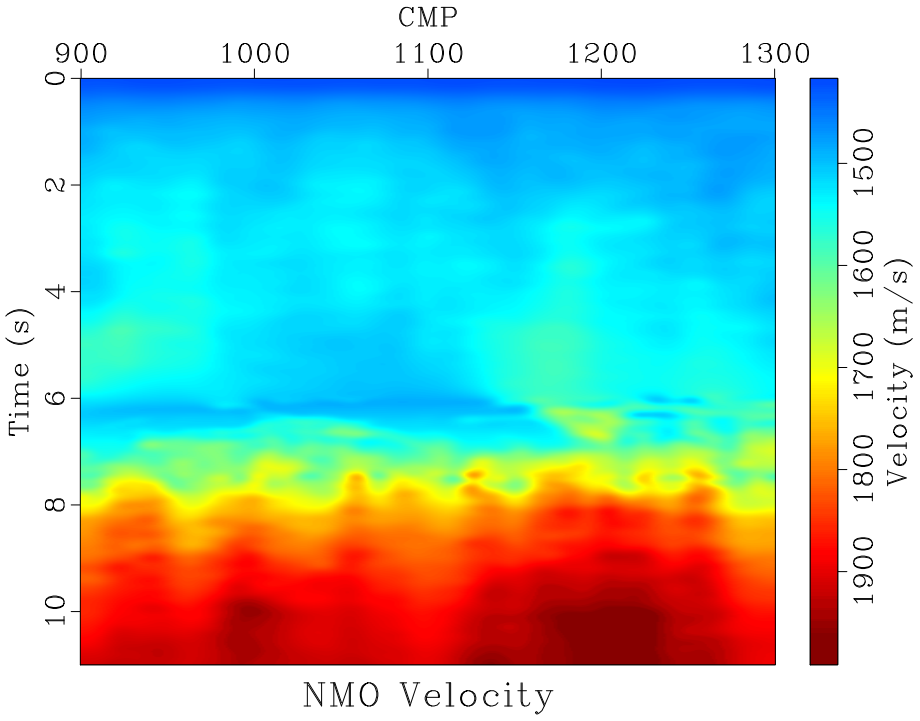


Figure 18: NMO velocity. project/ picks

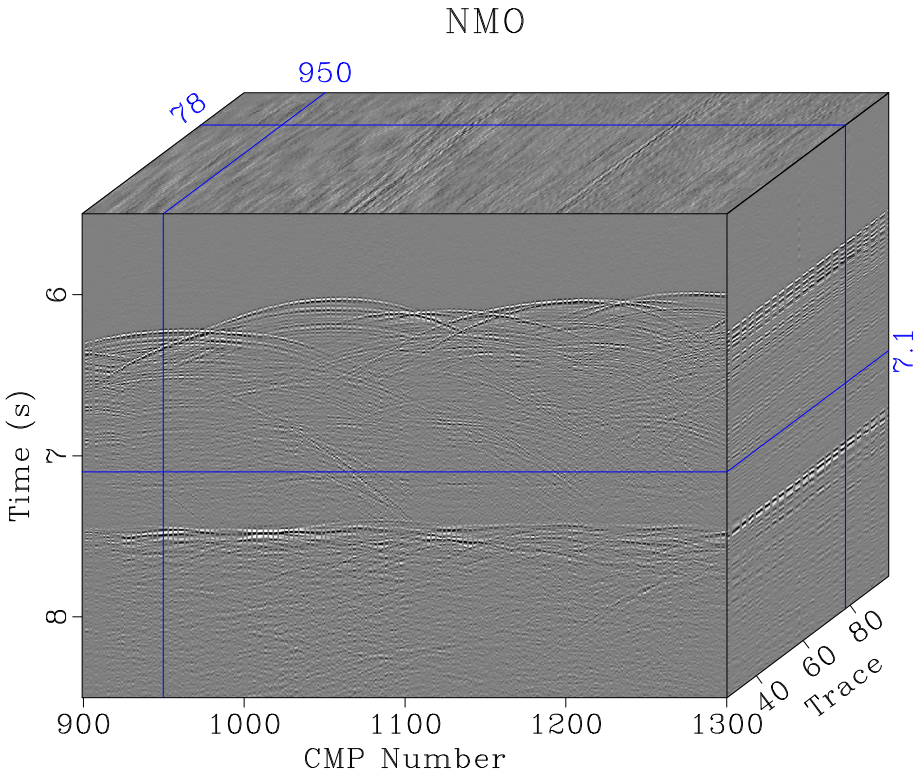
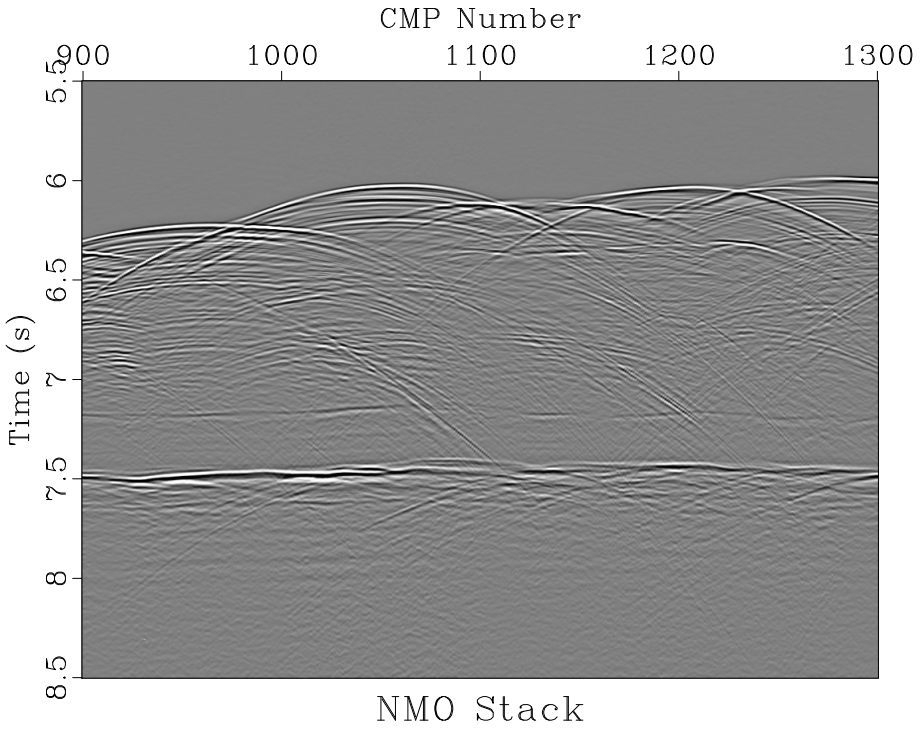
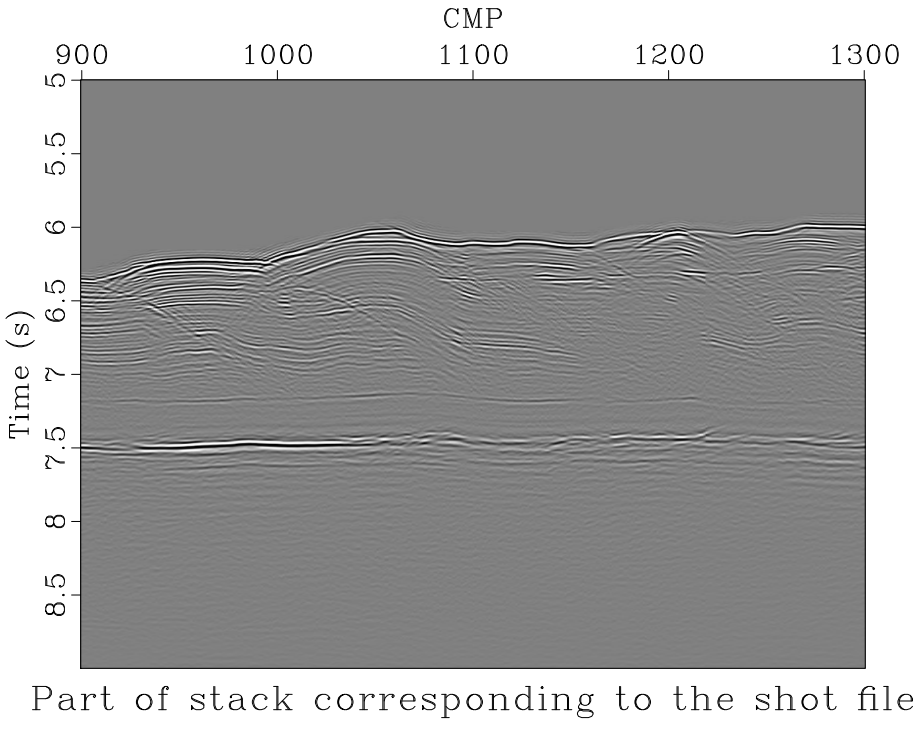


Figure 19: CMP gathers after NMO. project/ nmos



(a)



(b)

Figure 20: (a) Stacked data. (b) Published stacked data. project/ stack,stack-shot

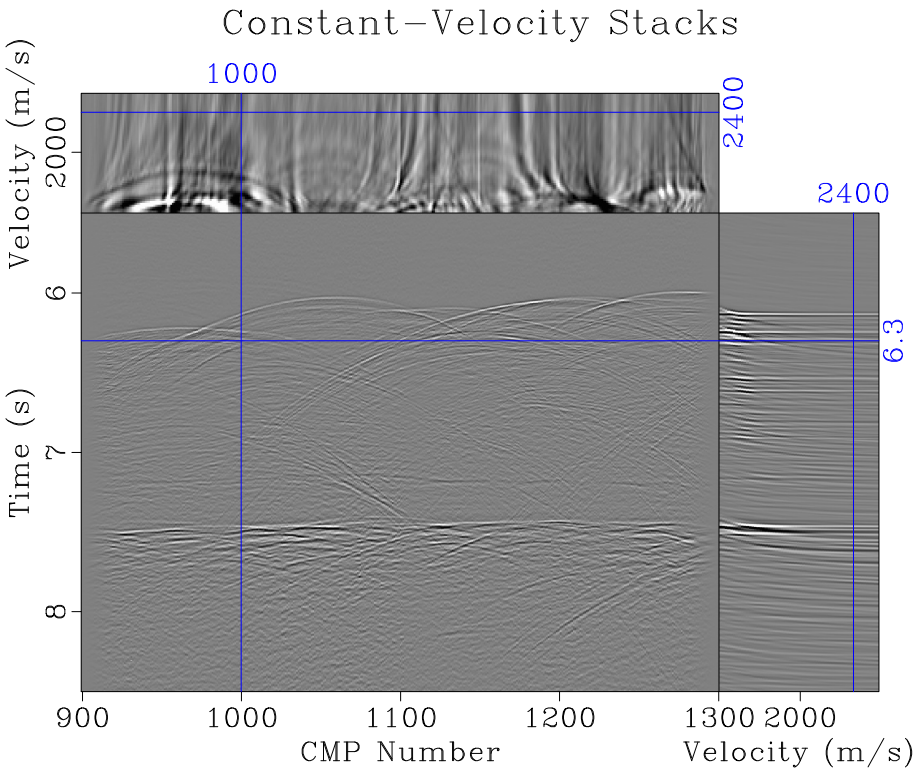


Figure 21: NMO stack with an ensemble of constant velocities. project/ stacks

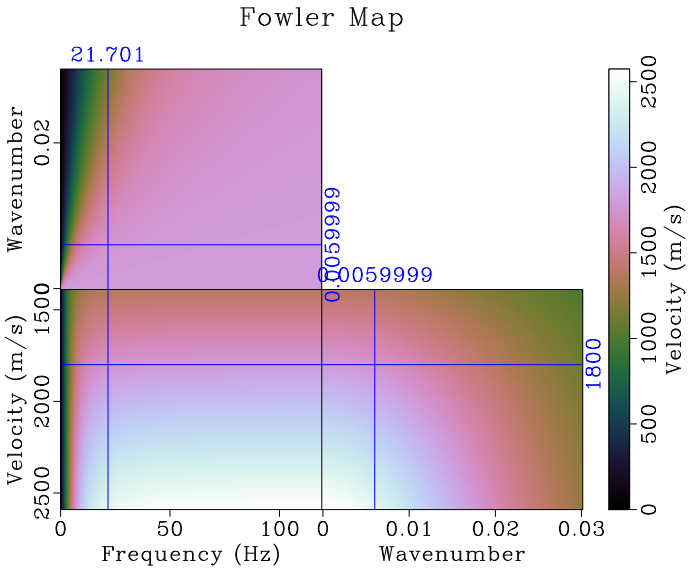


Figure 22: Fourier-domain velocity map used in Fowler's DMO method. project/ map

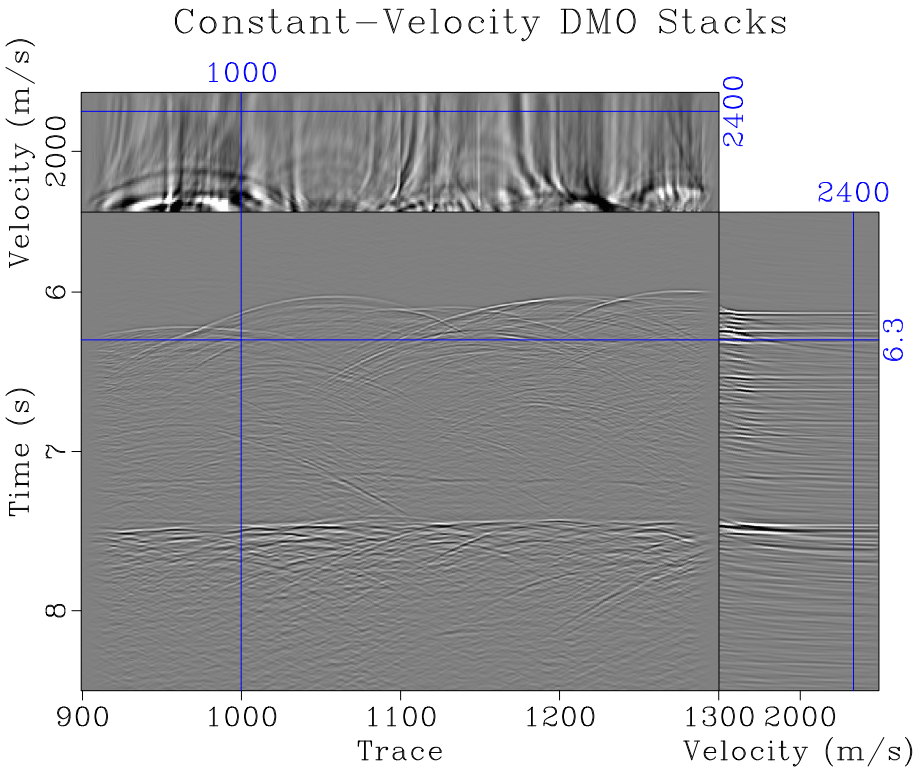


Figure 23: Nankai dataset after DMO stacking with an ensemble of constant velocities. project/ dmo

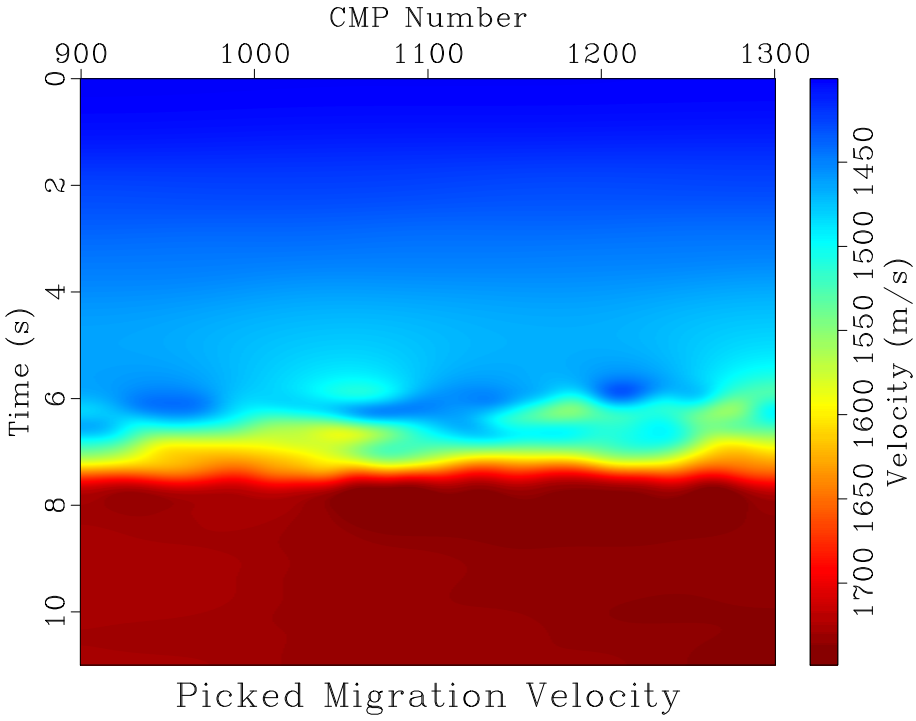


Figure 24: Migration velocity picked automatically from DMO stacks. project/ vpick

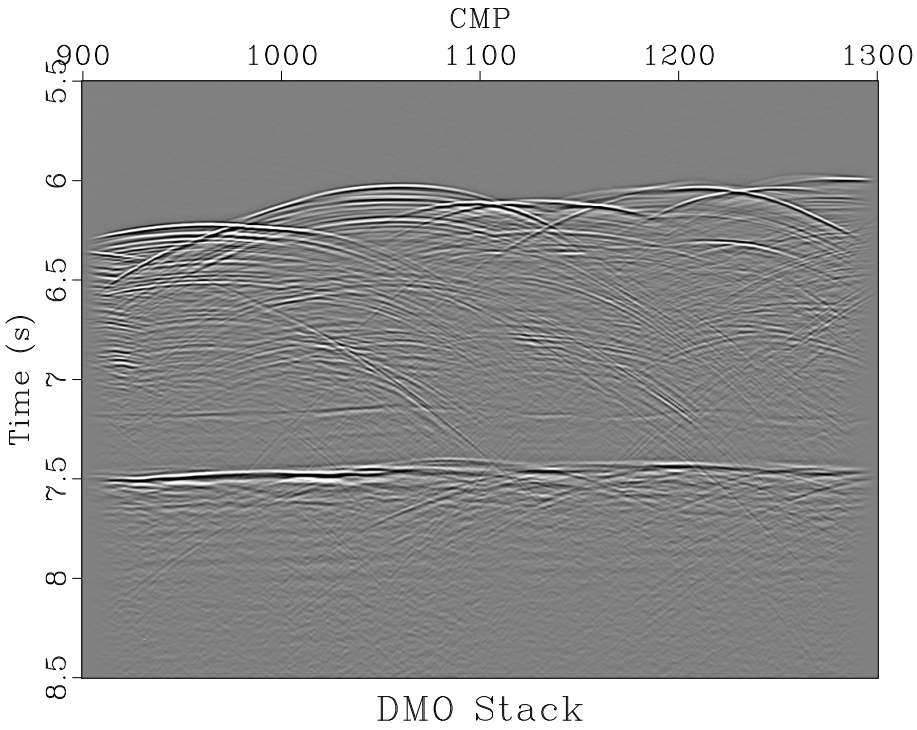


Figure 25: DMO stack generated by slicing the constant-velocity stacks. project/ slice

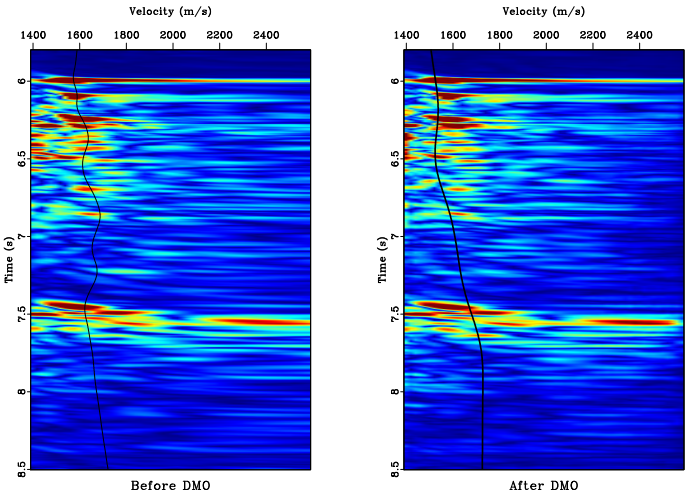


Figure 26: Comparison of velocity analysis (a) before and (b) after DMO at a selected CMP location. project/ envelope

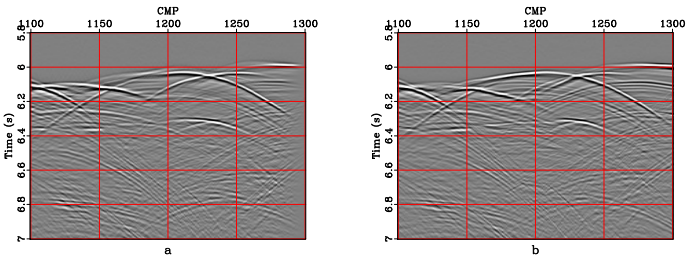


Figure 27: (a) Windowed DMO stack (b) Windowed normal stack. project/ zoomd

MIGRATION

Stolt migration

1. We used Stolt migration based on the Fourier transform (Stolt, 1985). We first mapped from ω to ω_0 in frequency-wavenumber domain (Figure 28). The 2-D cosine transform of the data before and after Stolt mapping is Figure 29. The data after Stolt migration with constant velocity 1500 m/s is Figure 30. The diffractions are not imaged properly because of wrong velocity (Middle figure in Figure 52a, Figure 53a, Figure 54a, Figure 55a).

2. We tried a more realistic velocity distribution starting with 1500 m/s (water velocity) at the surface and increasing quadratically with vertical time (Figure 31). We first migrated the data with a number of constant velocities in the range from 1500 to 2452 m/s with the spacing interval of 8 m/s (Figure 32). We then sliced through this ensemble of migrations to create an image (Figure 33) (Mikulich and Hale, 1992). The diffractions are imaged better but still need to be improved by improving the migration velocity (Right figure in Figure 52a, Figure 53a, Figure 54a, Figure 55a). Comparing with the published stacked and migrated data (Right figure in Figure 52c, Figure 53c, Figure 54c, Figure 55c), the diffractions are more collapsed and the events are clearer.

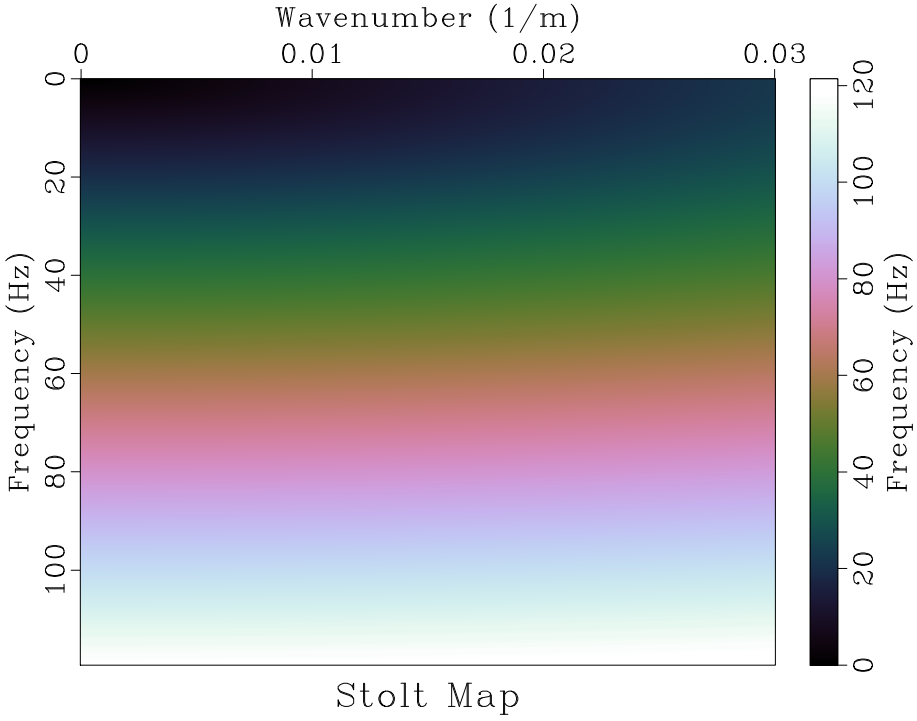


Figure 28: Stolt map. project/ map2

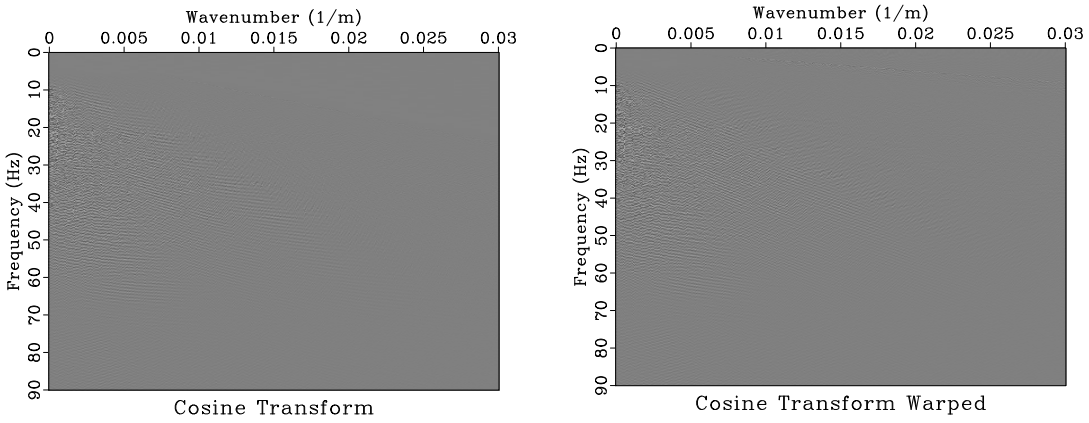


Figure 29: Nankai stack in the Cosine transform domain before (a) and after (b) Stolt migration with velocity 1500 m/s. project/ cosft,cosft2

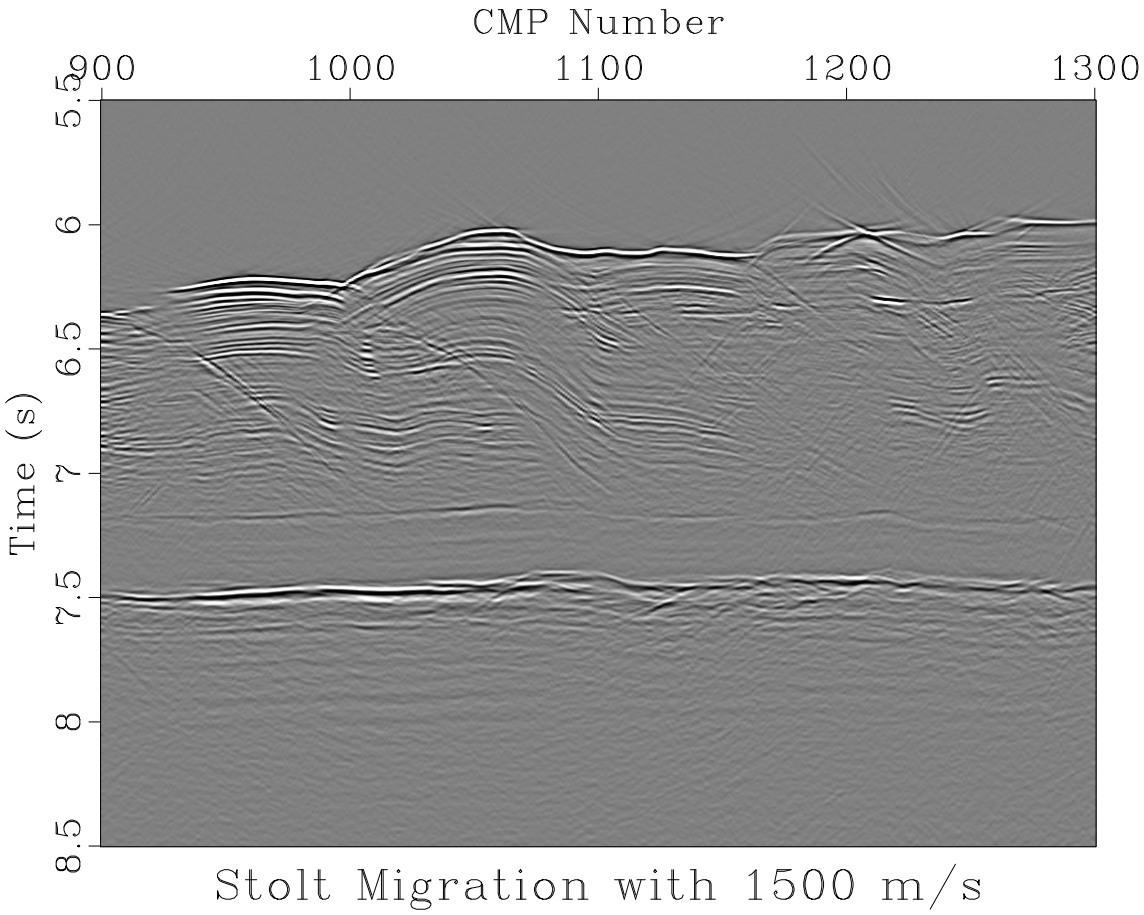


Figure 30: Nankai stack Stolt migrated with velocity of 1500 m/s. project/ mig2

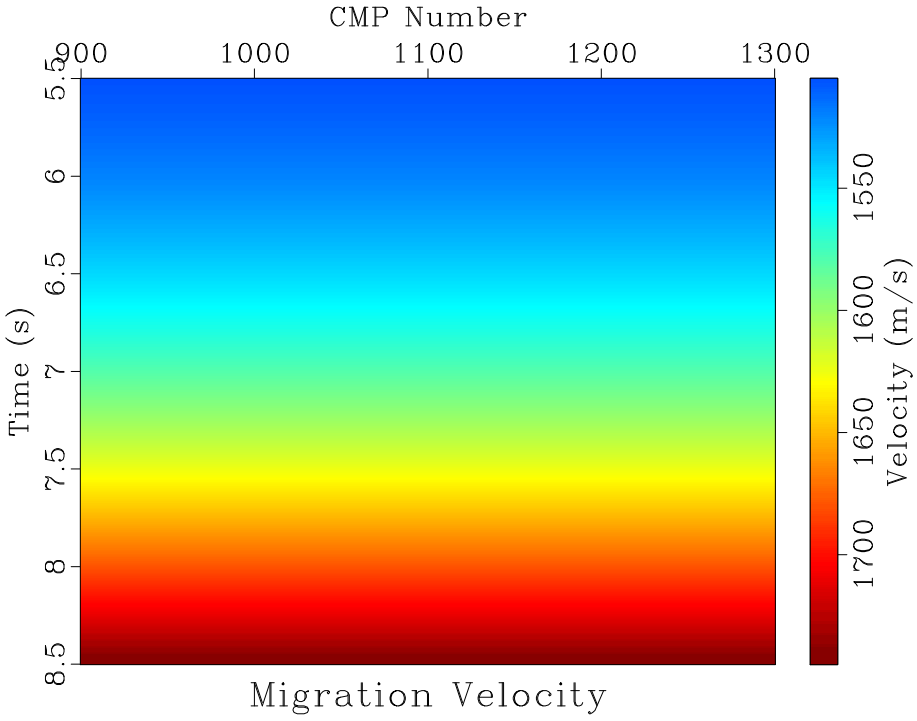


Figure 31: Velocity distribution. project/ vmig

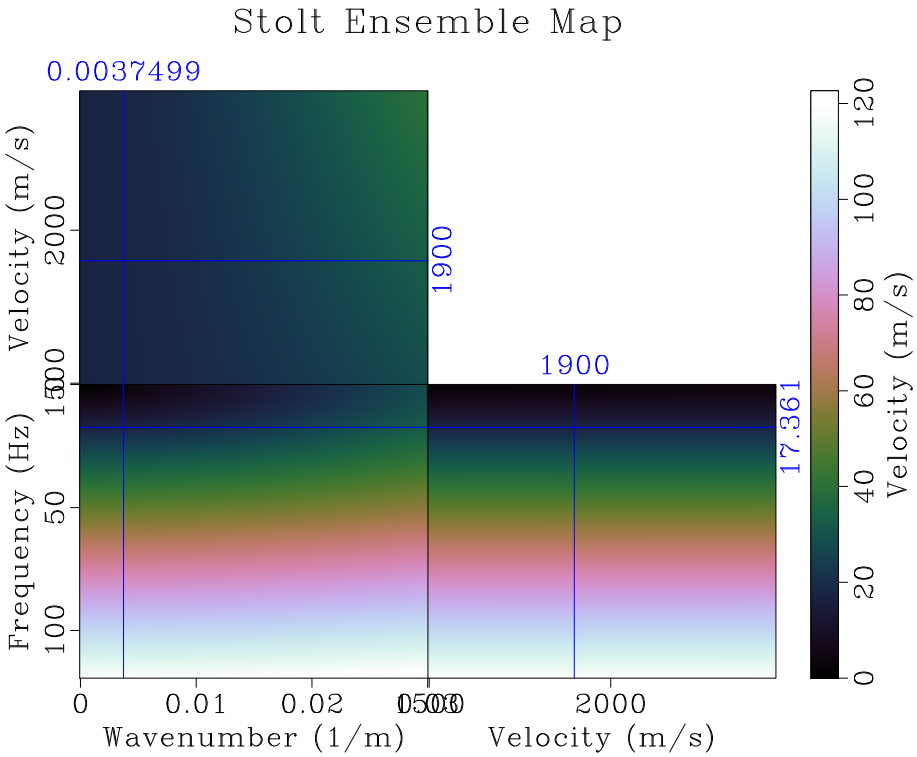


Figure 32: Stolt ensemble map. project/ map1

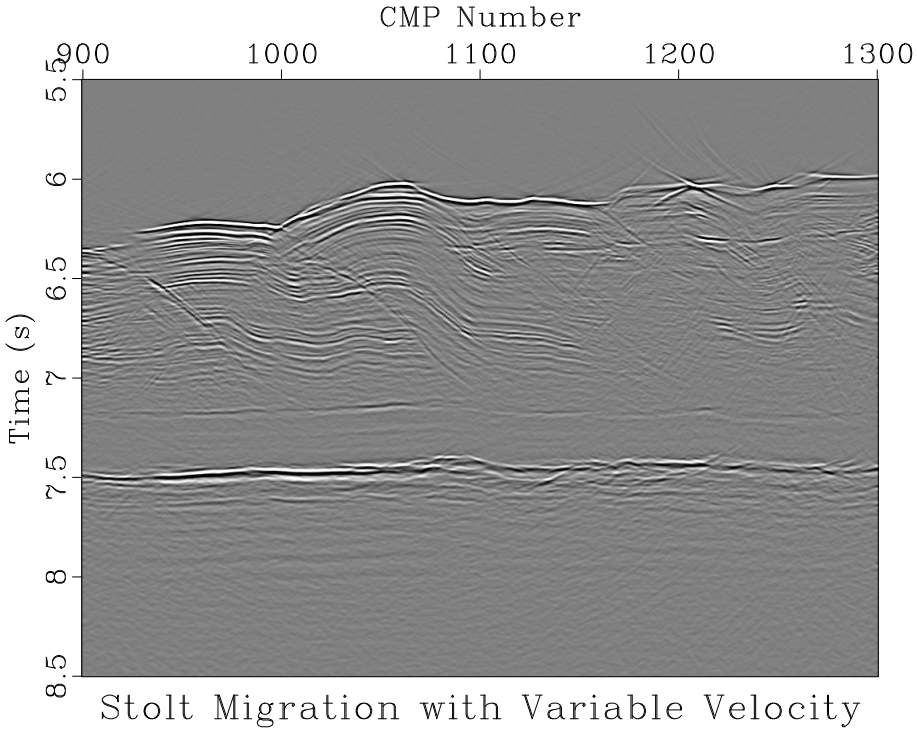


Figure 33: Nankai stack Stolt migrated with velocity increasing with time. project/ migd

Gazdag migration

1. To corretly image the diffractions, we used the picked velocities in DMO for phase-shift migration also known as Gazdag migration (Gazdag, 1978). We used Dix conversion to calculate the interval velocities in time (Figure 34). Stolt migration with constant velocity 1550 m/s images the water bottom clearly (Figure 35) so the water velocity is about 1550 m/s. We set the velocity above 5.5 seconds to 1550 m/s and kept the dix velocities below 5.5 seconds (Figure 36). We then applied phase-shift migration in time coordinate to get the image (Figure 37). The diffractions are clearly imaged (Right figure in Figure 52b, Figure 53b, Figure 54b, Figure 55b). Comparing with the published stacked and migrated data (Right figure in Figure 52c, Figure 53c, Figure 54c, Figure 55c), the diffractions at ocean bottom are collapsed and the events are clearer.

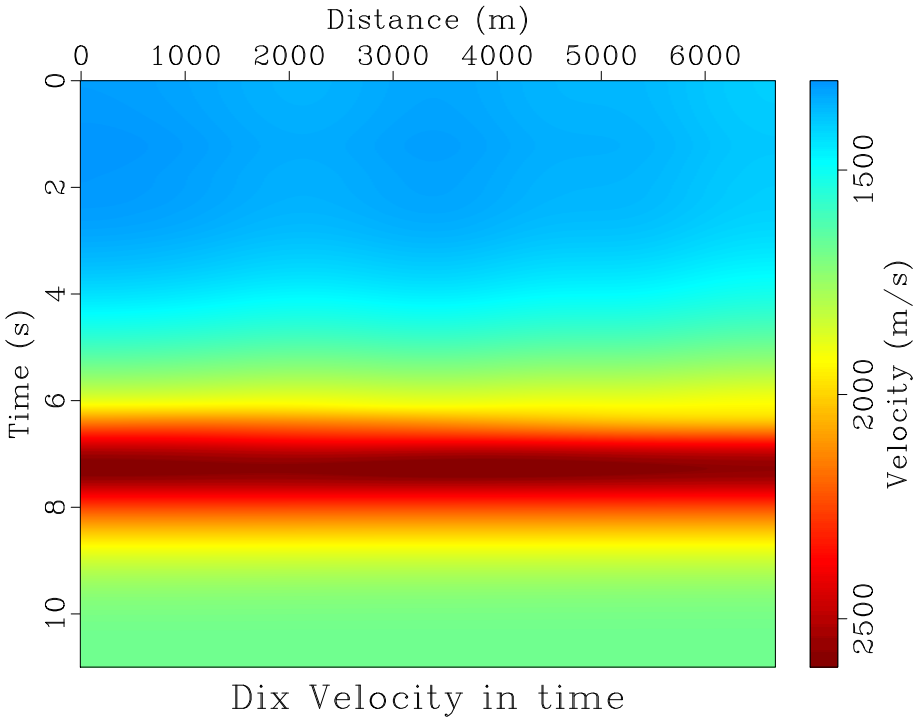


Figure 34: Dix velocity in time. project/ vdix2

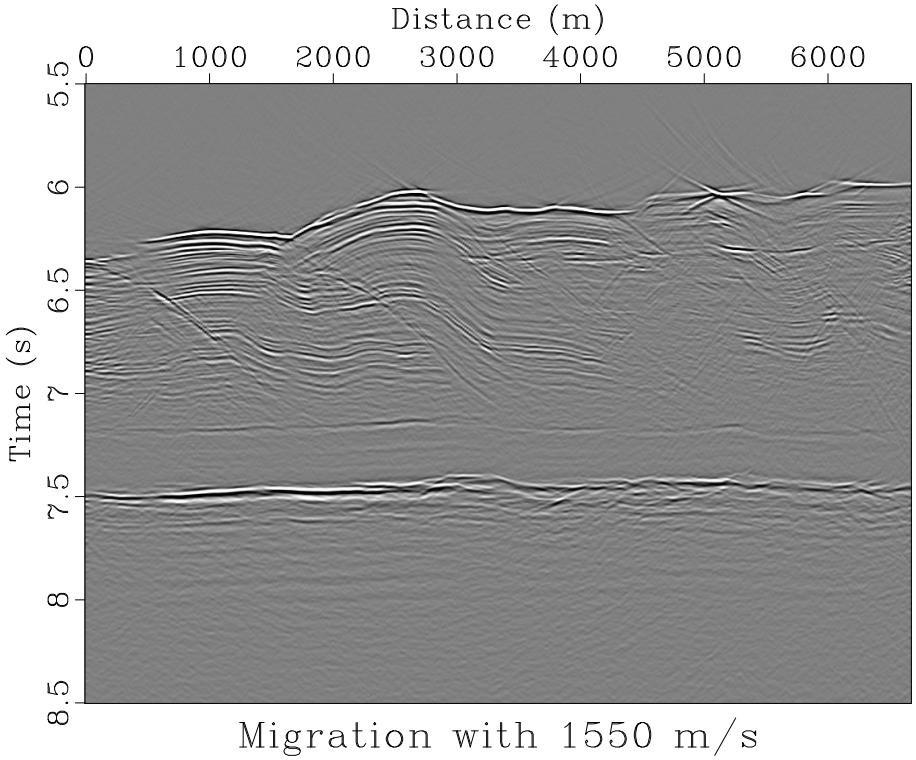


Figure 35: Stolt migration with constant velocity 1550 m/s. project/ mig1

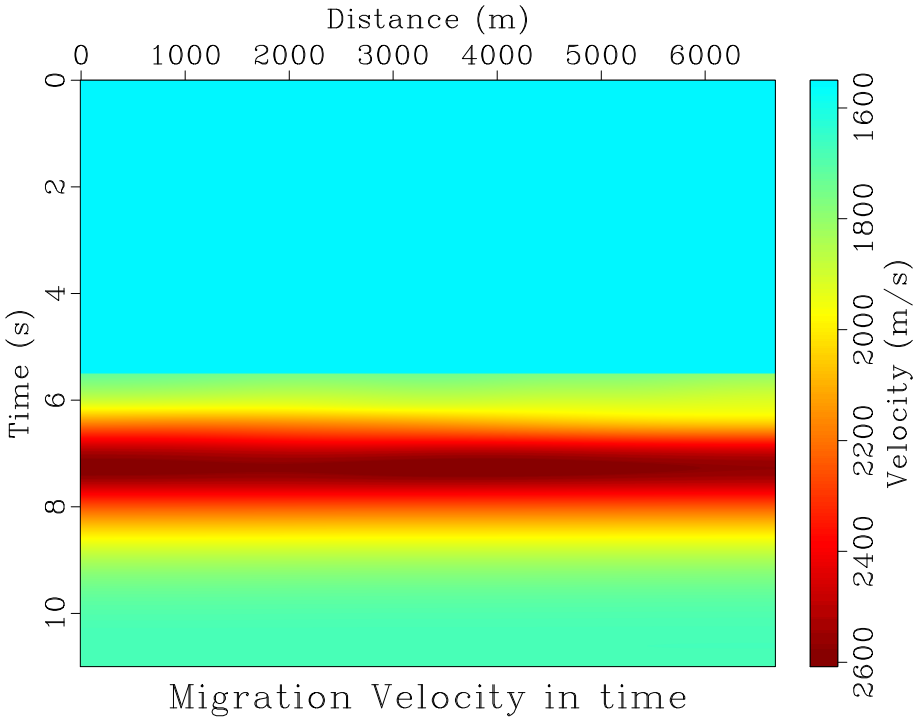


Figure 36: Migration velocity in time. project/ vmigr

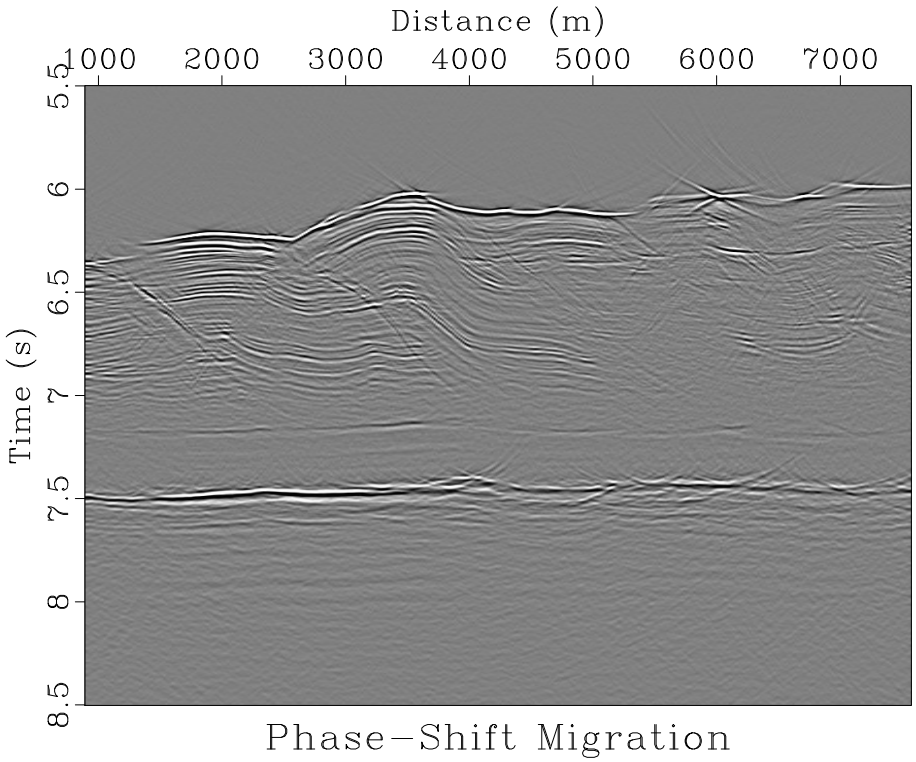


Figure 37: Gazdag migration. project/ image

Velocity continuation

1. In order to have correct migration velocity, we used the velocity continuation method proposed by (Fomel, 2003) to do the time migration velocity analysis. We first used Stolt migration with constant velocity 1400 m/s (Figure 38). We then used velocity continuation with 101 velocities starting with 1400 m and spacing interval of 10 m/s (Figure 39). We then sliced through this velocity continuation volume using stacking velocity to create a migration image (Figure 40). Migrating with stacking velocities is still not sufficient to correctly image the diffractions (Left figure in Figure 52b, Figure 53b, Figure 54b, Figure 55b).

2. In order to have more focused velocity to image the diffractions correctly, we used plane-wave destruction (Fomel, 2002) to estimate the dip of reflections and diffractions (Figure 41). We then separated reflections from diffractions (Figure 42). The diffractions are in Figure 43. We then used velocity continuation to analyze time migration diffraction velocity (Figure 44). The focusing velocity was picked (Figure 45). The diffractions are focused (Figure 46). Nankai stack migration with focusing velocity is Figure 47. Focusing velocities improve the quality of migrated image (Middle figure in Figure 52b, Figure 53b, Figure 54b, Figure 55b). Comparing with the published stacked and migrated data (Right figure in Figure 52c, Figure 53c, Figure 54c, Figure 55c), the diffractions at ocean bottom are collapsed and the events are clearer.

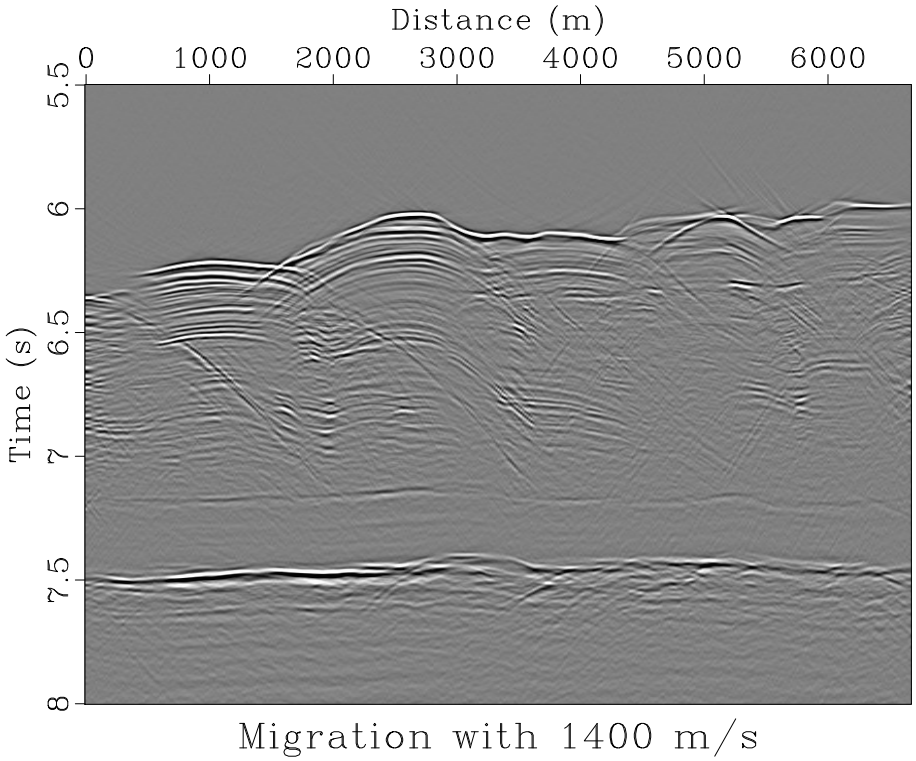


Figure 38: Stolt migration with velocity 1400 m/s. project/ first

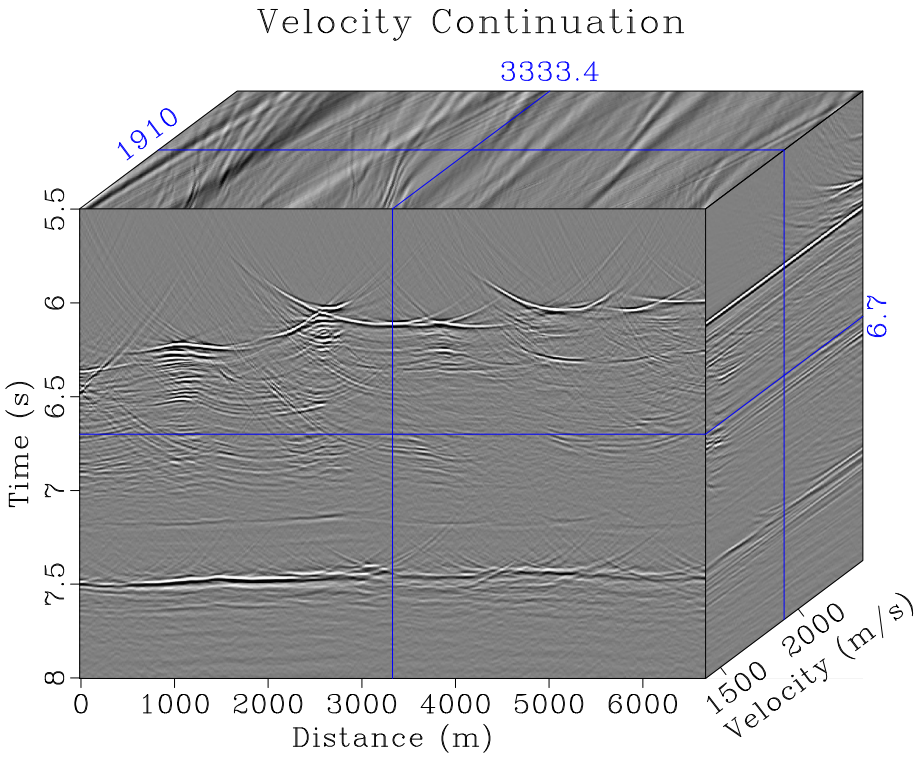


Figure 39: Velocity continuation. project/ velcon

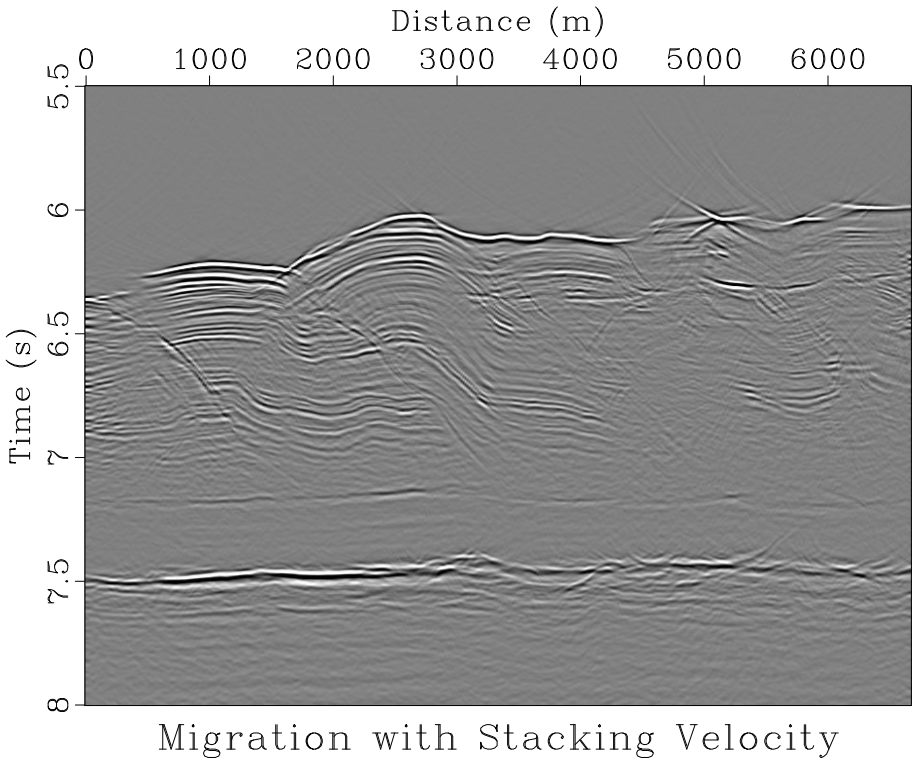


Figure 40: Migration with the stacking velocity. project/ mstack

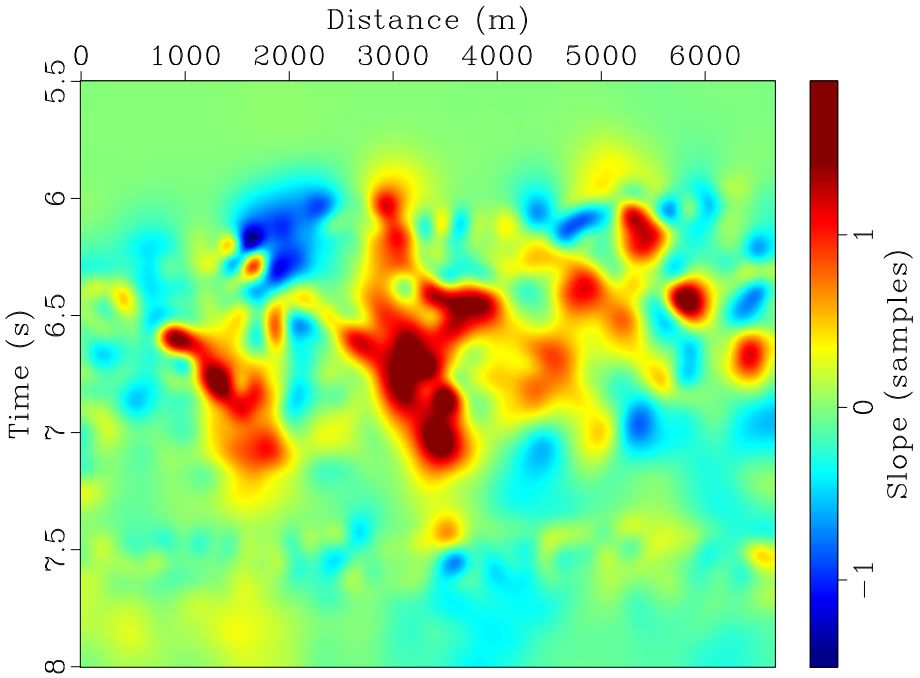


Figure 41: Estimated dips. project/ dip

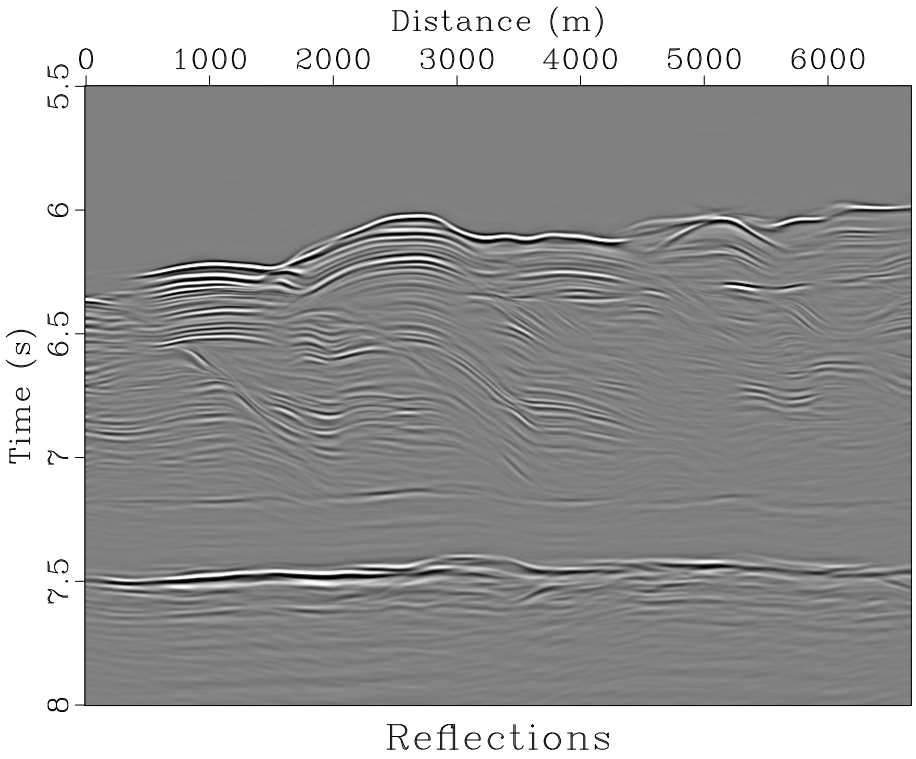


Figure 42: Reflections. project/ refl

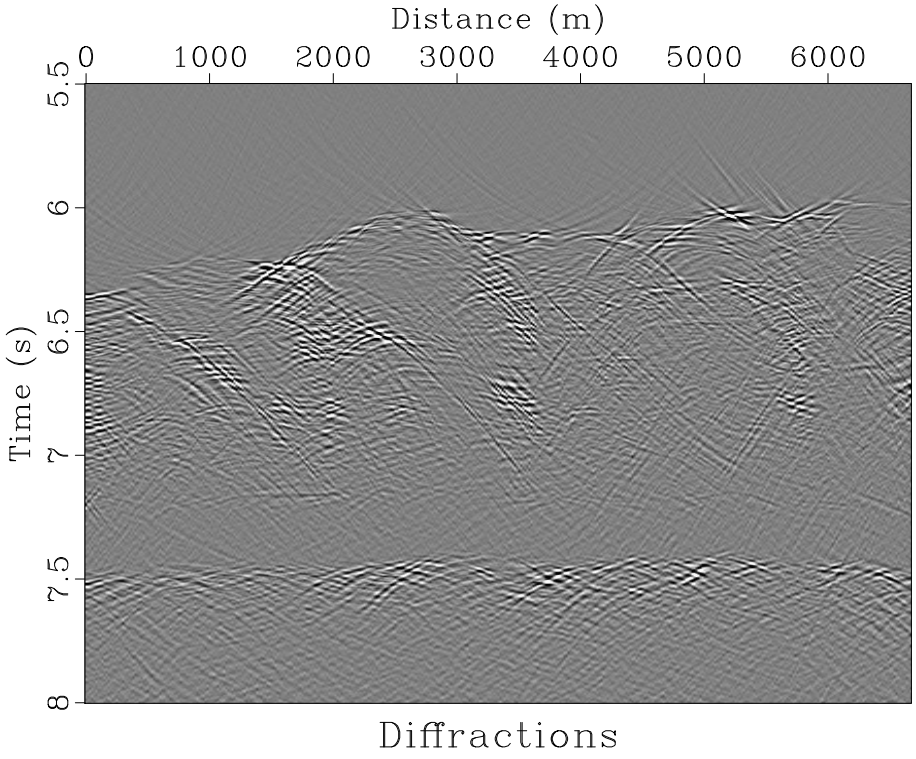


Figure 43: Diffractions. project/ diff

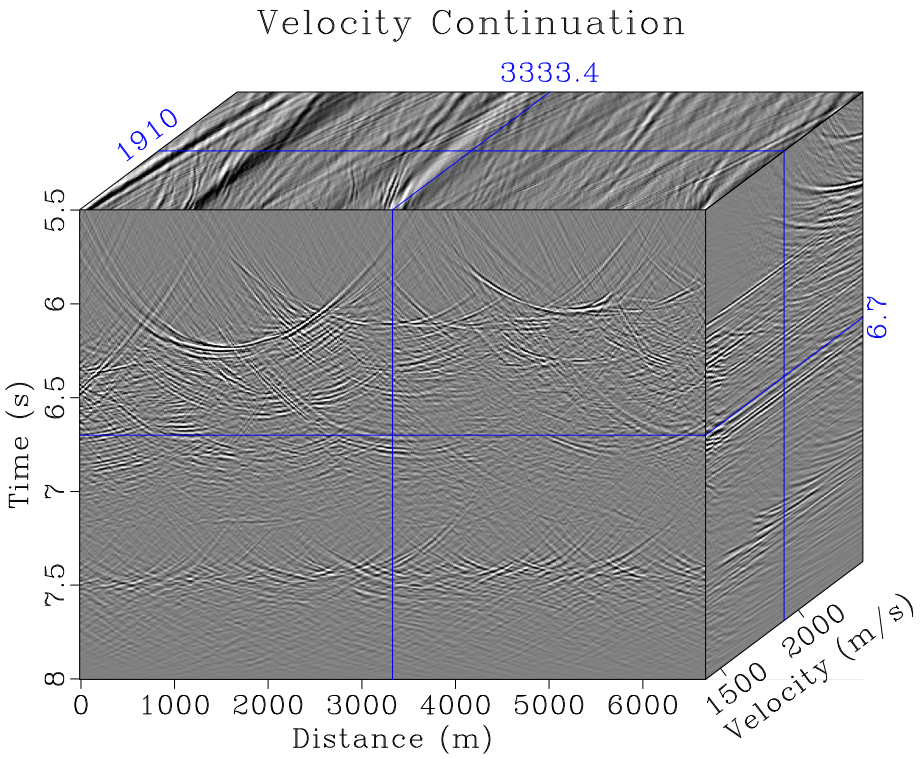


Figure 44: Velocity continuation with diffractions. project/ velcond

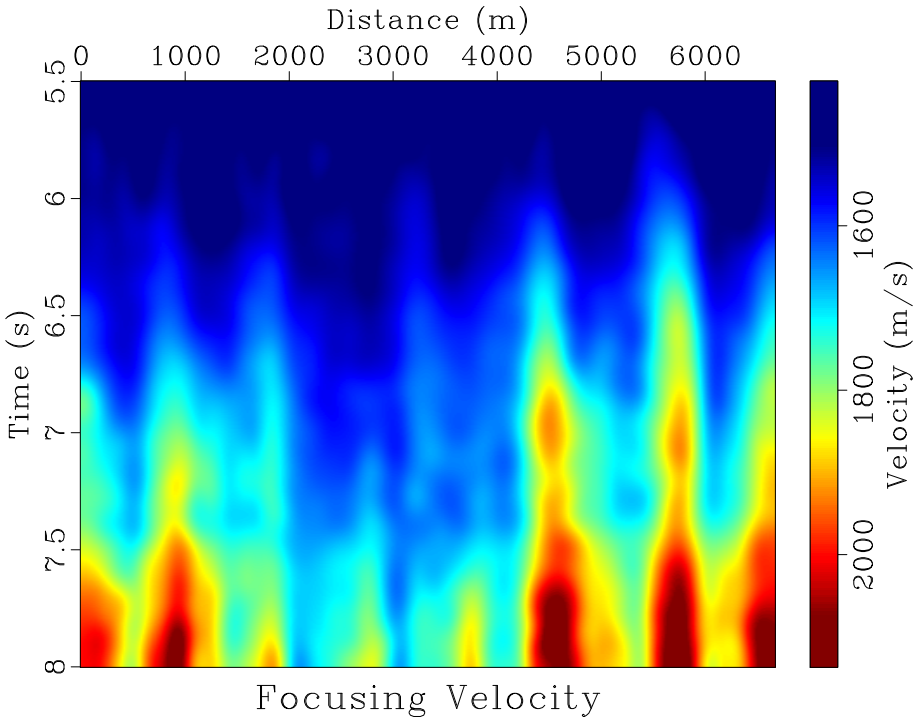


Figure 45: Focusing velocity. project/ fpik

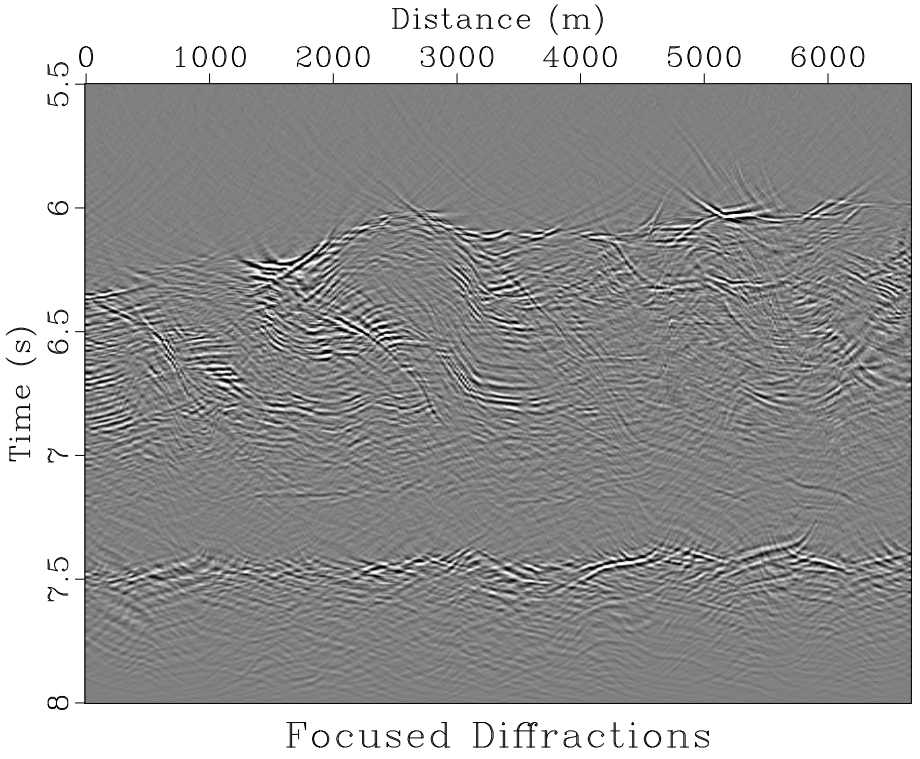


Figure 46: Focused diffractions. project/ mdif

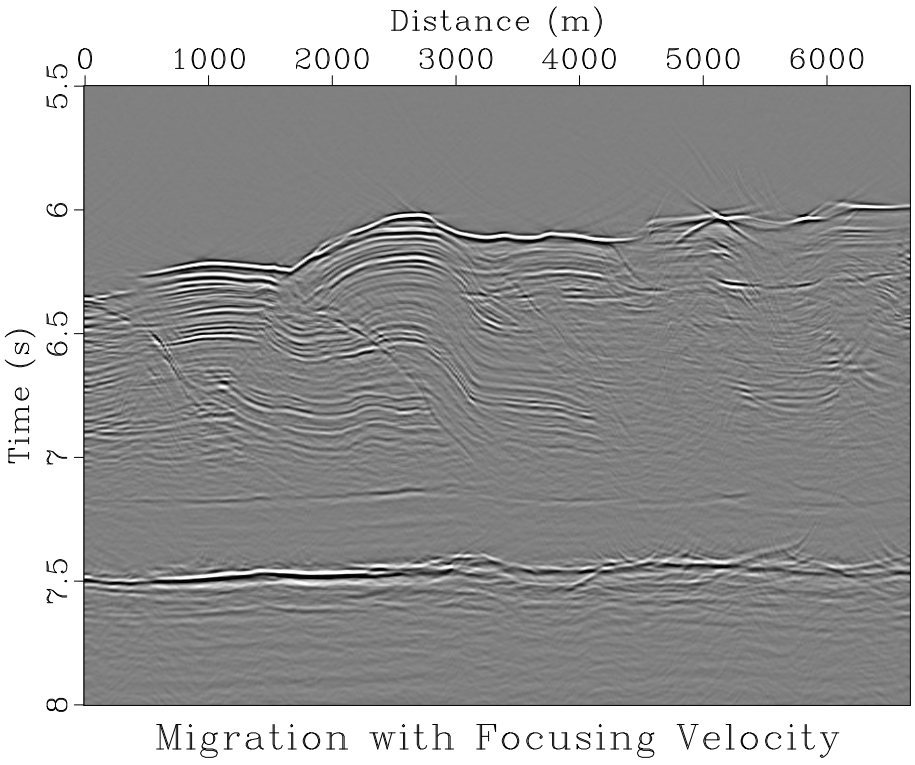


Figure 47: Migration with focusing velocity. project/ mfpik

Reverse-time migration

1. In order to account for laterally variations in velocity, we used reverse-time migration by the lowrank approximation (Fomel et al., 2013). We converted the time-migration velocity to depth for depth-migration initial velocity model (Figure 48). We used reverse-time migration to migrate the data (Figure 49). Because there are not much laterally variations in velocity so there are few improvements in RTM image (Left figure in Figure 52c, Figure 53c, Figure 54c, Figure 55c). Comparing with the published stacked and migrated data (Right figure in Figure 52c, Figure 53c, Figure 54c, Figure 55c), the diffractions at ocean bottom are collapsed and the events are clearer and more continuous.

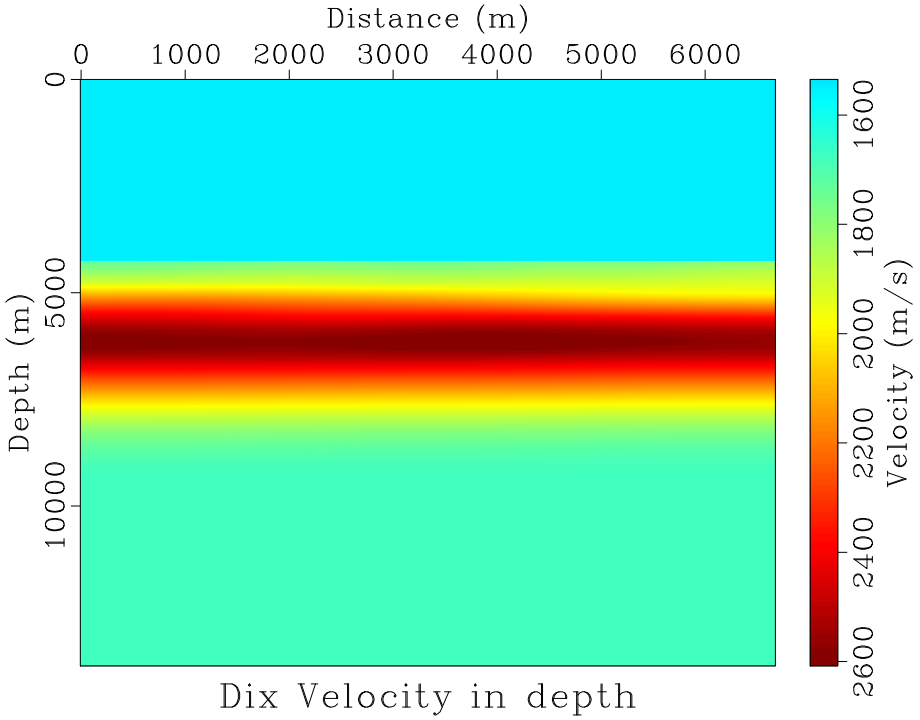


Figure 48: Dix velocity in depth. project/ vdixz

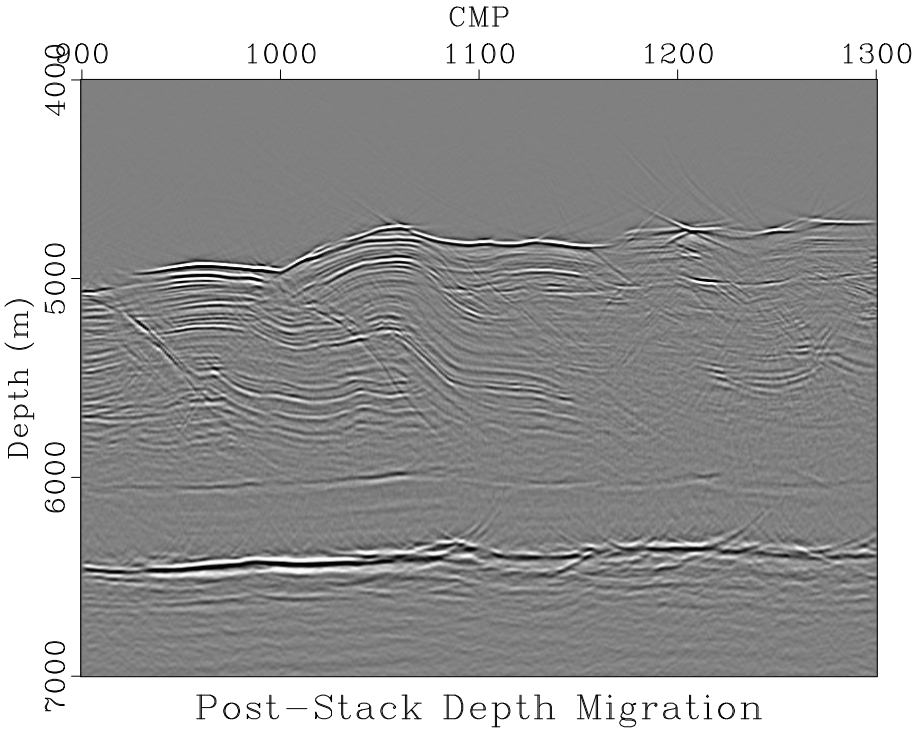


Figure 49: Reverse-time migration. project/ rtm

Split-step migration

1. In order to account for laterally variations in velocity, we used split-step migration (Stoffa et al., 1990). We calculated slowness from the depth-migration velocity (Figure 50). We then used the split-step migration to migrate the data (Figure 51). Because there are not much laterally variations in velocity so there are few improvements in Split-step image (Second left figure in Figure 52c, Figure 53c, Figure 54c, Figure 55c). Comparing with the published stacked and migrated data (Right figure in Figure 52c, Figure 53c, Figure 54c, Figure 55c), the diffractions at ocean bottom are collapsed and the events are clearer and more continuous.

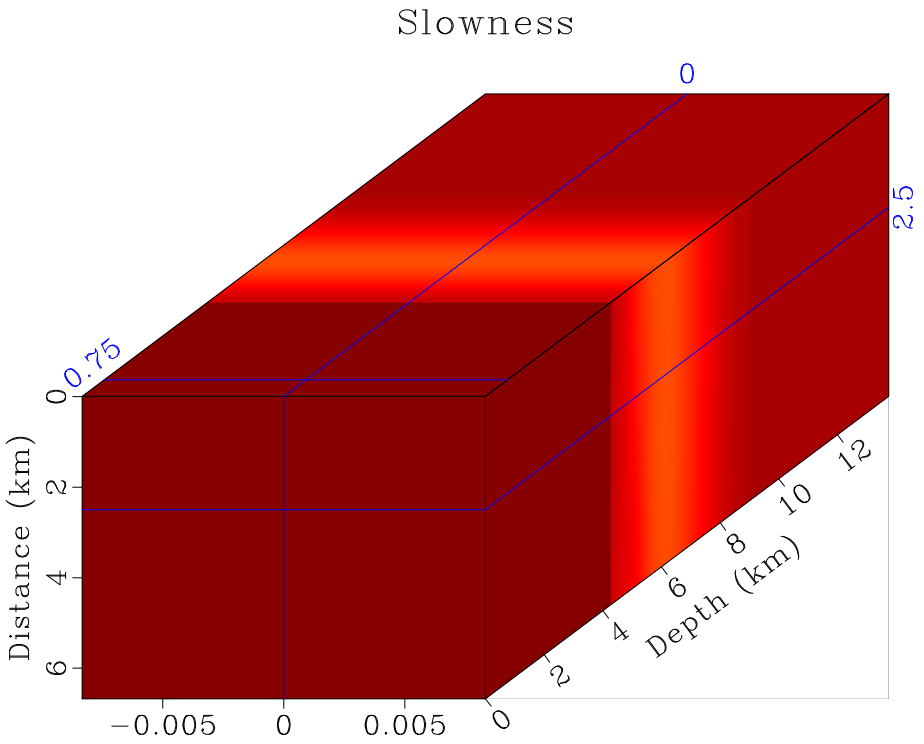


Figure 50: Slowness. project/ slo

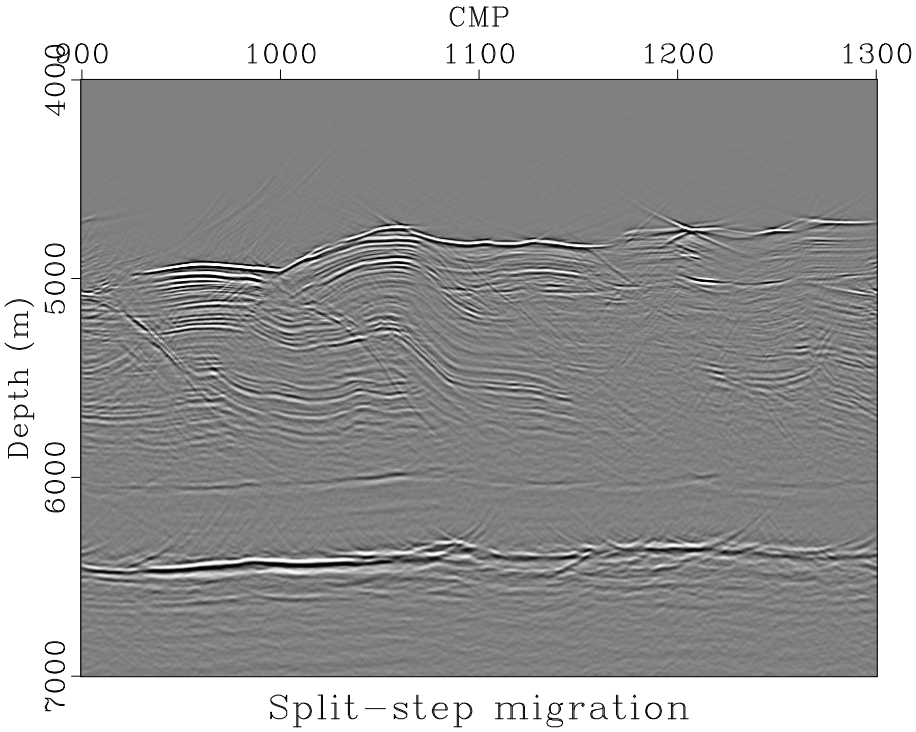


Figure 51: Split-step migration. project/ mig

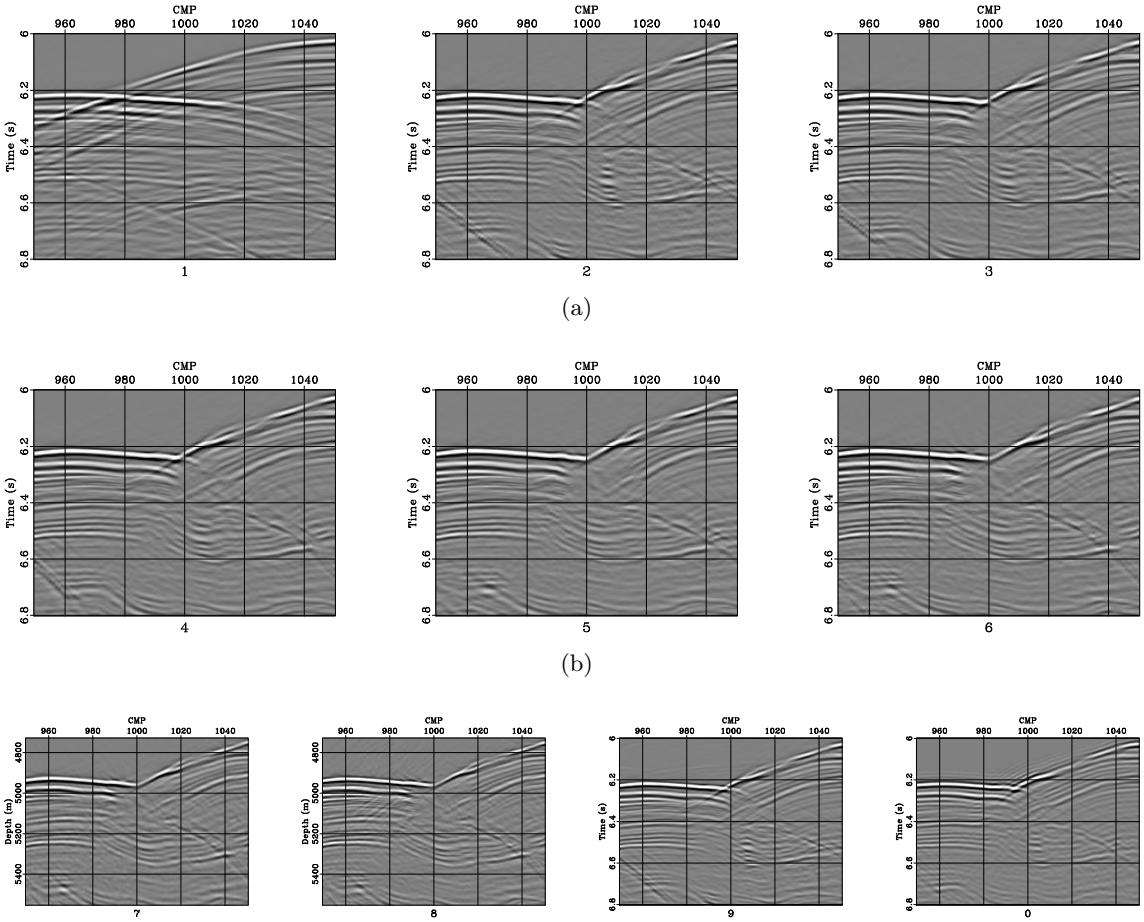


Figure 52: Migration comparison (a1) DMO stack (a2) Stolt migration with constant velocity 1500 m/s (a3) Stolt migration with variable velocity (b4) Migration with stacking velocity (b5) Migration with focusing velocity (b6) Gazdag migration (c7) Reverse-time migration (c8) Split-step migration (c9) Post-stack Kirchhoff time migration (c0) Published stacked and migrated data. project/ zoom1,zoom2,zoom3

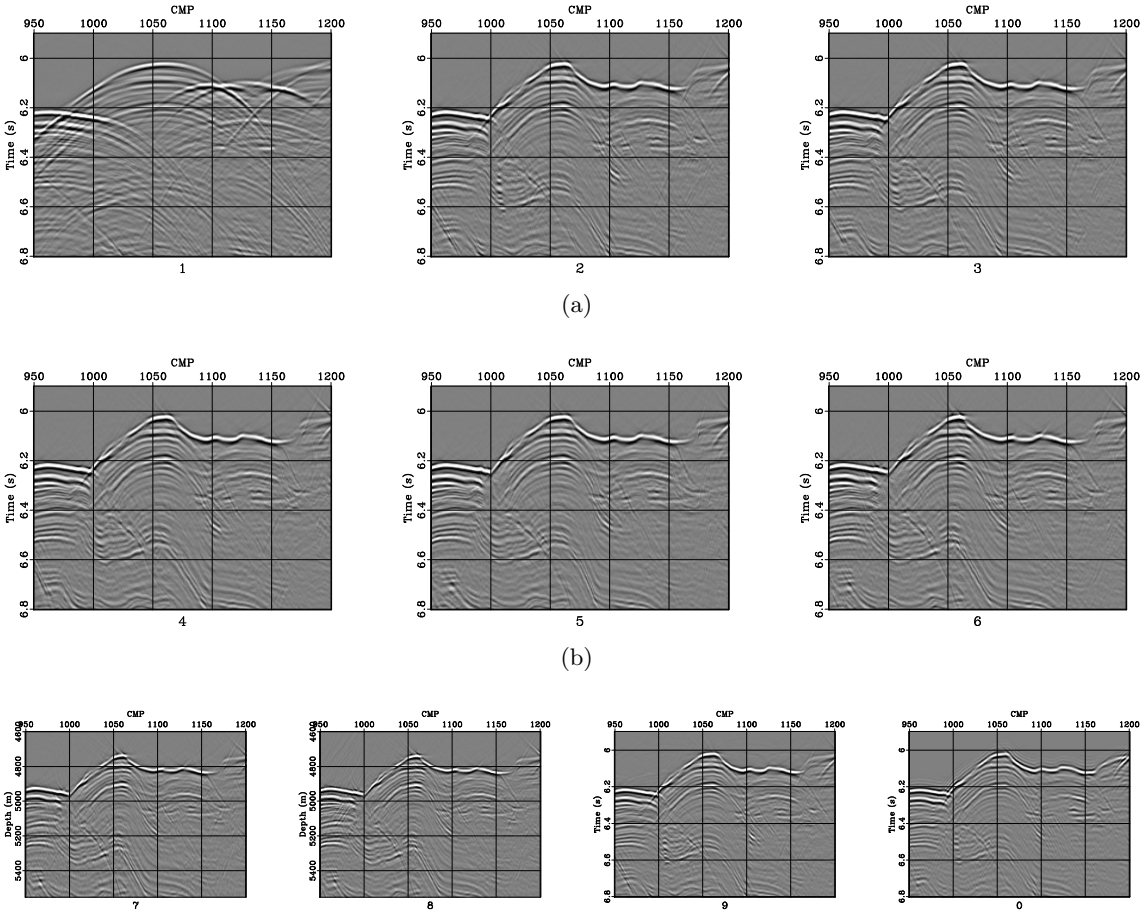


Figure 53: Migration comparison (a1) DMO stack (a2) Stolt migration with constant velocity 1500 m/s (a3) Stolt migration with variable velocity (b4) Migration with stacking velocity (b5) Migration with focusing velocity (b6) Gazdag migration (c7) Reverse-time migration (c8) Split-step migration (c9) Post-stack Kirchhoff time migration (c0) Published stacked and migrated data. project/ zoom4,zoom5,zoom6

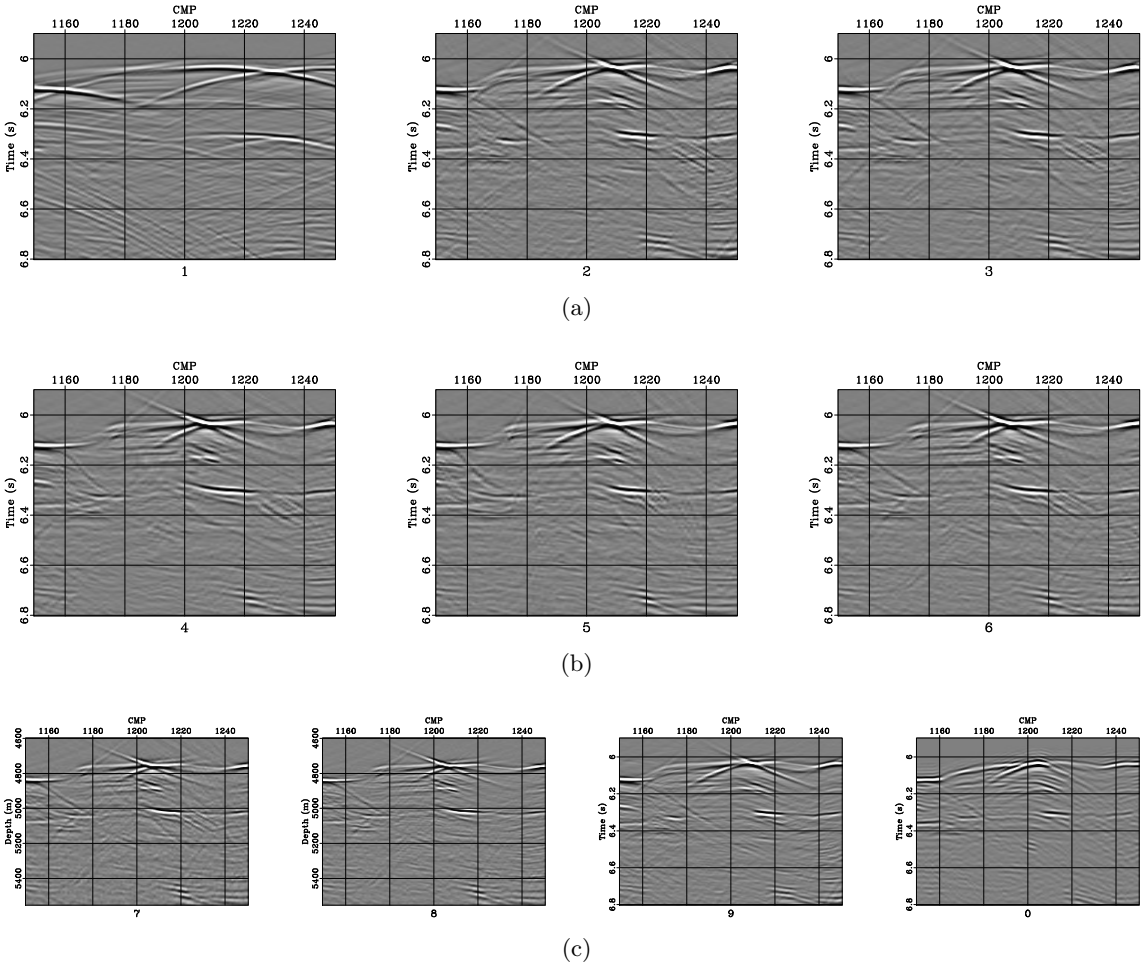


Figure 54: Migration comparison (a1) DMO stack (a2) Stolt migration with constant velocity 1500 m/s (a3) Stolt migration with variable velocity (b4) Migration with stacking velocity (b5) Migration with focusing velocity (b6) Gazdag migration (c7) Reverse-time migration (c8) Split-step migration (c9) Post-stack Kirchhoff time migration (c0) Published stacked and migrated data. project/ zoom7,zoom8,zoom9

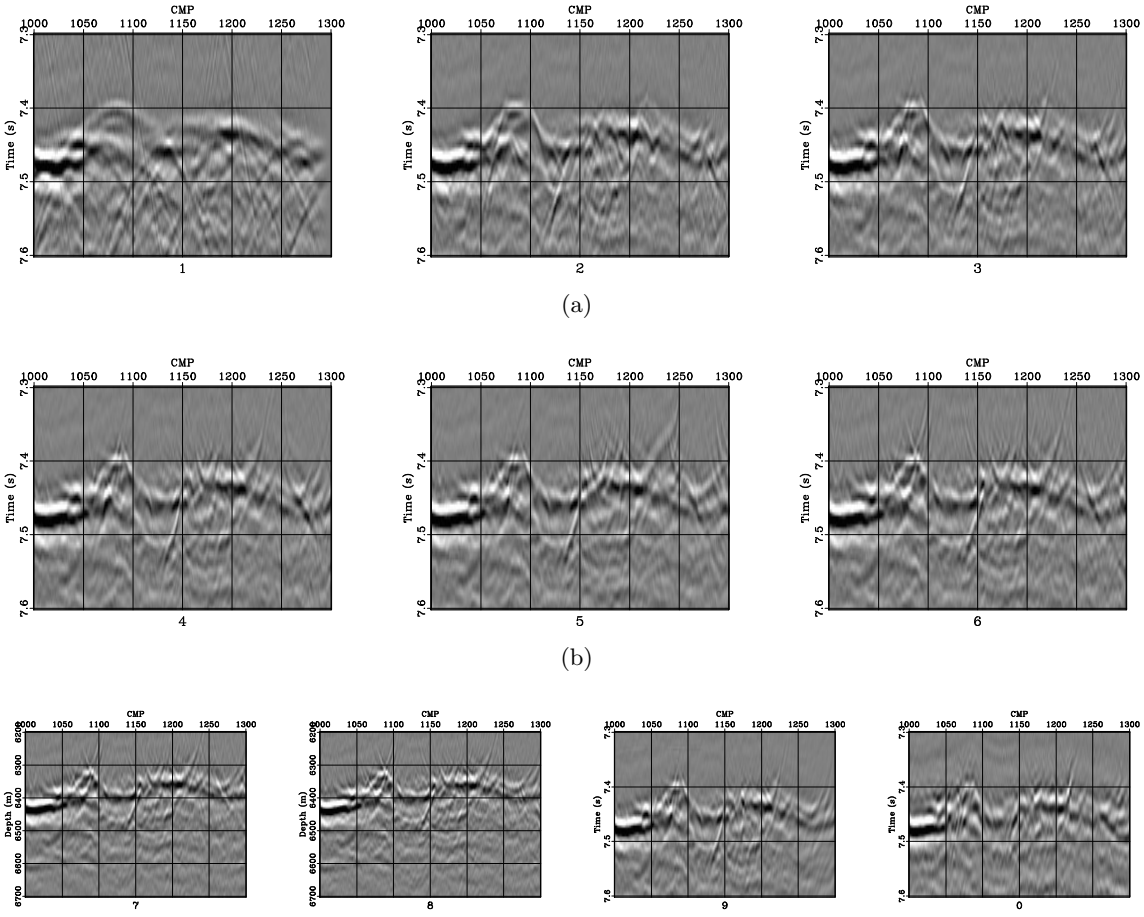


Figure 55: Migration comparison (a1) DMO stack (a2) Stolt migration with constant velocity 1500 m/s (a3) Stolt migration with variable velocity (b4) Migration with stacking velocity (b5) Migration with focusing velocity (b6) Gazdag migration (c7) Reverse-time migration (c8) Split-step migration (c9) Post-stack Kirchhoff time migration (c0) Published stacked and migrated data. project/ zoom10,zoom11,zoom12

INTERPRETATIONS

1. Our processing result has improvements on imaging the diffractions. Based on the final processing output, we can have some geologic interpretations (Figure 56).

2. Oceanic crust of the Pacific Plate lies under sediments at the left side of Figure 4, and is subducted at the trench, which is filled with recent sediments (CDPs 200-600, approximately). On the right of these flat-lying sediments, there is an accretionary prism with distorted sediment layer thickens to the right, which results in interesting topography.

3. The reflector, which is about 300 ms later, mimic the ocean-bottom topography and cuts across the folded sediments, is called the bottom-simulating reflector (Forel et al., 2005). It reflects a change in fluid phases.

4. The Shikoku Basin sequence in our 2D seismic line has two units. A lower 400-m-thick transparent unit lies directly on oceanic basement and is overlain by a 500-m-thick layered unit. The boundary of the protothrust zone is marked by the first major thrust fault which uplifts trench sediments in a ramp anticline. Thrust ramps are developed farther landward, forming a series of parallel linear structural terraces.

5. The decollement is within the Shikoku Basin sedimentary section. The decollement is the Pacific Plate oceanic crust at about 7.2 seconds. It appears to be flatten. The thrusts are imaged as a fault plane reflection and has overlying fault-bend folds.

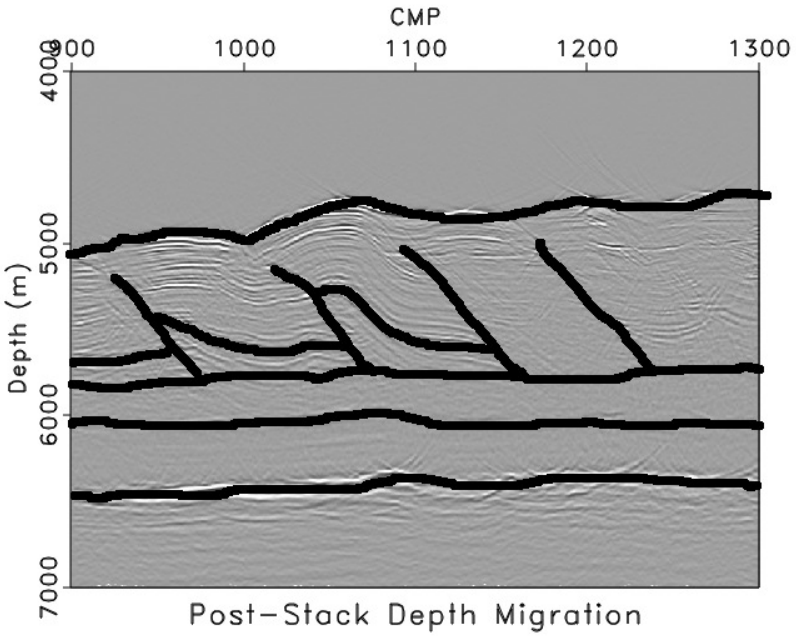


Figure 56: Interpretations. project/ inter

project/SConstruct

```
from rsf.proj import *


def section(title,label1='Time',unit1='s',min1=5.8,max1=8.0,extra=""):
    return '''
    window min1=%g max1=%g |
    grey title="%s"
    label1="%s" unit1="%s" label2=Distance unit2=m %s
    ''' % (min1,max1,title,label1,unit1,extra)

# Download data

Fetch('Nshots.su','nankai')

# Convert from SU to RSF

Flow('shots tshots','Nshots.su',
         '''
         suread suxdr=y tfile=${TARGETS[1]}
         ''')

Result('spectra','shots',
        '''
        spectra all=y | scale axis=1 |
        graph title="Average Spectra" label1=Amplitude
        ''')
Result('shots',
        '''
        window min1=5.5 max1=8.5 |
        grey title="Raw shot gathers"
        ''')

Fetch('Nstack.su','nankai')

Flow('stackd tstackd','Nstack.su',
      '''
      suread suxdr=y tfile=${TARGETS[1]}
      ''')
Flow('stack-win','stackd','window min1=5')
Flow('stack-shot','stack-win',
      '''
      window min2=900 max2=1300 | put label2=CMP
      ''')
Plot('stackd','window j1=2 j2=2 | grey title=Stack label2=CMP')
Plot('stack-win',
      '''
```

```
47        window  j2=2 | grey title="Stack (Window)" label2=CMP
48        ''')
49  Plot('stack-shot','stack-win',
50        '''
51        window min2=900 max2=1300 |
52        grey title="Part of stack corresponding to the shot file"
53        label2=CMP
54        ''')
55  Result('stack-shot','stack-win',
56          '''
57          window min2=900 max2=1300 |
58          grey title="Part of stack corresponding to the shot file"
59          label2=CMP
60          ''')
61  Result('stackd','stackd stack-win','SideBySideAniso')
62
63  ####### DC Removal
64
65  Flow('mean','shots',
66        '''
67        stack axis=1 | spray axis=1 n=5500 o=0.0 d=0.002
68        ''')
69
70  Flow('shotsdc','shots mean','add scale=1,-1 ${SOURCES[1]}')
71  Result('shotsdc',
72          '''
73          window min1=5.5 max1=8.5 |
74          grey title="Shot gathers after removing DC offset"
75          ''')
76
77  ####### Bandpass Filtering
78
79  Flow('shotsf','shotsdc','bandpass flo=10 fhi=125')
80  Result('shotsf',
81          '''
82          window min1=5.5 max1=8.5 |
83          grey title="Shot gathers after filtering frequencies"
84          ''')
85  Result('spectraf','shotsf',
86          '''
87          spectra all=y |  scale axis=1 |
88          graph title="Spectra after removing low and high frequencies"
89          label1=Amplitude
90          ''')
91
92  ####### Mask zero traces
93
94  Flow('mask0','shotsf','mul $SOURCE | stack axis=1 | mask min=1e-20')
```

```
95  Flow('shots0','shotsf mask0','headerwindow mask=${SOURCES[1]}')
96
97  # update a database
98  Flow('tshots0','tshots mask0','headerwindow mask=${SOURCES[1]}')
99
100 ####### Surface consistent
101
102 # Average trace amplitude
103 Flow('arms','shots0',
104      'mul $SOURCE | stack axis=1 | math output="log(input)"')
105 Result('arms','grey title=Log-Amplitude mean=y pclip=90')
106
107 # shot/offset indeces: fldr and tracf
108
109 Flow('indexshot','tshots0','window n1=1 f1=2')
110
111 Flow('offsets4index','tshots0',
112      '''
113      headermath output=offset | dd type=float | window
114      ''')
115
116 Flow('offsetindex','offsets4index',
117      '''
118      math output="abs(input) - 170" | dd type=int
119      ''')
120
121 # receiver/midpoint
122
123 Flow('midpoint','tshots0','window n1=1 f1=5')
124
125 Flow('cmps4index','tshots0',
126      '''
127      headermath output=cdp | dd type=float |
128      math output="input*16.667" | window
129      ''')
130
131 Flow('recv','cmps4index offsets4index',
132      '''
133      add scale=1,0.5 ${SOURCES[1]} |
134      math output="input - 13799" | dd type=int
135      ''')
136
137 Flow('index','indexshot offsetindex',
138      '''
139      cat axis=2 ${SOURCES[1]}
140      ''')
141
142 Flow('extindex','index midpoint',
```

```
143         '''
144         cat axis=2 ${SOURCES[1]}
145         ''')
146 
147 Flow('extindrecv','extindex recv',
148         '''
149         cat axis=2 ${SOURCES[1]}
150         ''')
151 
152 def plot(title):
153     return '''
154     spray axis=1 n=1 |
155     intbin head=${SOURCES[1]} yk=fldr xk=tracf | window |
156     grey title="%s" label2="Shot Number" unit2=
157     label1="Offset Number" unit1= scalebar=y
158     ''' % (title)
159 
160 def plotb(title,bias=-5):
161     return '''
162     spray axis=1 n=1 |
163     intbin head=${SOURCES[1]} yk=fldr xk=tracf | window |
164     grey title="%s" label2="Shot Number" unit2=
165     label1="Offset Number" unit1= scalebar=y clip=3 bias=%g
166     ''' % (title,bias)
167 
168 # Display in shot/offset coordinates
169 Flow('varms','arms tshots0',
170         '''
171         spray axis=1 n=1 |
172         intbin head=${SOURCES[1]} yk=fldr xk=tracf | window
173         ''')
174 Result('varms','arms tshots0',plotb('Log-Amplitude'))
175 
176 prog = Program('surface-consistent.c')
177 sc = str(prog[0])
178 
179 # recv index
180 
181 # get model dimensions
182 Flow('recvmodel',['arms','extindrecv',sc],
183         './${SOURCES[2]} index=${SOURCES[1]} verb=y')
184 
185 # find a term
186 Flow('recvsc',['arms','extindrecv',sc,'recvmodel'],
187         '''
188         conjgrad ./${SOURCES[2]} index=${SOURCES[1]}
189         mod=${SOURCES[3]} niter=150
190         ''')
```

```
191
192 # project to a data space
193 Flow('recvscarms',['recvsc','extindrecv',sc],
194      './${SOURCES[2]} index=${SOURCES[1]} adj=n')
195
196 Result('recvvscarms','recvscarms tshots0',
197        plotb('Source, Offset, CDP, Recv S-C Log(A)'))
198
199 # compute difference
200 Flow('recvadiff','arms recvscarms','add scale=1,-1 ${SOURCES[1]}')
201
202 Result('recvadiff','recvadiff tshots0',plot('s,h,cdp,r difference'))
203
204 size=dict(sht=326,off=2266,rcv=7784,cmp=401)
205 f1 = 0
206 for case in ('sht','off','rcv','cmp'):
207     n1=size[case]
208
209     Result(case,'recvsc',
210            '''
211            window n1=%d f1=%d | put o1=1 d1=1 |
212            graph title="%s Term"
213            label1="%s Number" unit1= label2=Amplitude unit2=
214            ''' % (n1,f1,case.capitalize(),case.capitalize()))
215     f1 += n1
216
217 ### apply to traces to all times
218
219 Flow('ampl','recvscarms',
220      'math output="exp(-input/2)" | spray axis=1 n=5500 d=0.002 o=0')
221
222 Flow('shots-preproc','shots0 ampl','mul ${SOURCES[1]}')
223
224 Plot('shots-preproc','shots-preproc',
225      '''
226      window n2=100 |
227      grey min1=6.0 max1=8.0 title="Shots Preproc"
228      ''')
229
230 Plot('shots-raw','shots0',
231      '''
232      window n2=100 |
233      grey min1=6.0 max1=8.0 title="Shots Raw"
234      ''')
235
236 Result('shotsfc','shots-raw shots-preproc','SideBySideAniso')
237
238 # Resample to 4 ms
```

```
239
240 Flow('subsamples','shots-preproc',
241       '''
242       bandpass fhi=125 | window j1=2
243       ''')
244
245 Result('spectrasub','subsamples',
246        'spectra all=y | graph title="Subsampled Spectra"')
247
248 Result('spectra-check','shots-preproc',
249        'spectra all=y | graph max1=160 title="Spectra Check"')
250
251 # Extract shots
252 Flow('shots2','subsamples tshots0',
253          '''
254          intbin xk=tracf yk=fldr head=${SOURCES[1]}
255          ''')
256 Result('shots2',
257         '''
258         window min1=5.5 max1=9 | byte gainpanel=all |
259         transp plane=23 memsize=5000 |
260         grey3 frame1=300 frame2=100 frame3=50
261         point1=0.8 point2=0.8 clip=8.66
262         title="Shots" label3="Shots"
263         ''')
264
265
266 # Create a mask to remove misfired shots
267
268 Flow('smask','shots2','mul $SOURCE | stack axis=1 | mask min=1e-20')
269
270 Result('smask',
271         '''
272         dd type=float |
273         stack axis=1 norm=n |
274         graph symbol=x title="Nankai Trough"
275         label2="Traces per Shot Gather"
276         label1="Shot Number" unit1=
277         ''')
278
279 Flow('offsets','tshots0',
280       '''
281       window n1=1 f1=11 squeeze=n | dd type=float |
282       intbin head=$SOURCE xk=tracf yk=fldr
283       ''')
284
285
286 # Select one shot (fldr)
```

```
287
288 shot=1707
289
290 Flow('mask','smask','window n2=1 min2=%g' % shot)
291
292 Flow('shot','shots2 mask',
293       '''
294       window n3=1 min3=%g squeeze=n |
295       headerwindow mask=${SOURCES[1]}
296       ''' % shot)
297
298 Flow('offset','offsets mask',
299       '''
300       window n3=1 min3=%g squeeze=n |
301       headerwindow mask=${SOURCES[1]}
302       ''' % shot)
303
304 Result('shot','shot offset',
305         '''
306         window min1=5.8 max1=8.5 |
307         wiggle xpos=${SOURCES[1]} yreverse=y transp=y poly=y
308         title="Shot 1707" label2=Offset
309         ''')
310
311 Plot('shot',
312       '''
313       window min1=5.8 max1=8.5 |
314       grey title="Selected Shot" clip=2
315       ''')
316
317
318 # Extract CMPs and apply t^2 gain
319
320 Flow('cmps maskcmp','subsamples tshots0',
321       '''
322        intbin head=${SOURCES[1]} mask=${TARGETS[1]}
323        xk=tracf yk=cdp           |
324        pow pow1=2
325        ''')
326
327 Result('cmps',
328          '''
329          window min1=5.8 max1=8.5 |
330          byte gainpanel=all | transp plane=23 memsize=5000 |
331          grey3 frame1=200 frame2=150 frame3=50
332          title="CMPs" label2="CMP Number"
333          flat=n point1=0.8 point2=0.8
334          ''')
```

```
335
336 Flow('cmask','cmps','mul $SOURCE | stack axis=1 | mask min=1e-20')
337
338 Result('cmask',
339         '''
340         dd type=float |
341         stack axis=1 norm=n |
342         graph symbol=x title="Nankai Trough"
343         label2="Traces per CMP Gather"
344         label1="CMP Gather Number" unit1=
345         ''')
346
347 Flow('offs','tshots0',
348       '''
349       window n1=1 f1=11 squeeze=n | dd type=float |
350       intbin xk=tracf yk=cdp head=$SOURCE
351       ''')
352
353 # Examine one CMP gather
354
355 Flow('mask1','cmask','window n2=1 min2=1280')
356
357 Flow('cmp1','cmps mask1',
358       '''
359       window n3=1 min3=1280 | headerwindow mask=${SOURCES[1]}
360       ''')
361
362 Flow('off','offs mask1',
363       '''
364       window n3=1 min3=1280 squeeze=n | headerwindow mask=${SOURCES[1]}
365       ''')
366
367 Result('cmp1','cmp1 off',
368       '''
369       window min1=5.8 max1=8.5 |
370       wiggle xpos=${SOURCES[1]} title="CMP 1280"
371       yreverse=y transp=y poly=y label2=Offset unit2=m
372       wherexlabel=t wheretitle=b
373       ''')
374
375 Plot('cmp1','cmp1 off',
376       '''
377       window min1=5.8 max1=8.5 |
378       wiggle xpos=${SOURCES[1]} title="CMP 1280"
379       yreverse=y transp=y poly=y label2=Offset unit2=m
380       wherexlabel=t wheretitle=b
381       ''')
382
```

```
# Velocity analysis and NMO

Flow('vscan','cmp1 off mask1',
     '''
     vscan half=n offset=${SOURCES[1]}
     v0=1400 nv=101 dv=10 semblance=y
     ''')

Plot('vscan',
     '''
     window min1=5.8 max1=8.5 |
     grey color=j allpos=y title="Velocity Scan" unit2=m/s
     ''')

Flow('pick','vscan',
     '''
     mutter inner=y half=n t0=5 x0=1400 v0=75 |
     pick v0=1500 rect1=25
     ''')

Plot('pick',
     '''
     window min1=5.8 max1=8.5 |
     graph transp=y yreverse=y plotcol=7 plotfat=3
     pad=n min2=1400 max2=2400 wanttitle=n wantaxis=n
     ''')

Plot('vscanp','vscan pick','Overlay')

Flow('nmo','cmp1 off mask1 pick',
     '''
     nmo half=n offset=${SOURCES[1]}
     velocity=${SOURCES[3]}
     ''')

Result('nmo','window min1=5.8 max1=8.5 | grey title="Normal Moveout"')

Plot('cmpg','cmp1',
     '''
     window min1=5.8 max1=8.5 |
     grey title="CMP 1280" labelsz=12 titlesz=18
     ''')

Plot('nmog','nmo',
     '''
     window min1=5.8 max1=8.5 |
     grey title="Normal Moveout" labelsz=12 titlesz=18
     ''')
```

```
431
432 Result('nmo1','cmpg nmog','SideBySideAniso')
433
434 Result('vscan','cmp1 vscanp','SideBySideAniso')
435
436 # Apply to all CMPs
437
438 Flow('cmask2','cmask','transp plane=23 | transp plane=21')
439
440 Flow('vscans','cmps offs cmask2',
441       '''
442       vscan half=n offset=${SOURCES[1]} mask=${SOURCES[2]}
443       v0=1400 nv=101 dv=10 semblance=y nb=5
444       ''',split=[3,'omp'])
445
446 Flow('picks','vscans',
447       '''
448       mutter inner=y half=n t0=5 x0=1400 v0=75 |
449       pick v0=1500 rect1=25 rect2=10
450       ''')
451
452 Result('picks',
453         '''
454         window | grey color=j mean=y scalebar=y title="NMO Velocity"
455         label2=CMP barreverse=y barlabel=Velocity barunit=m/s
456         ''')
457
458 Flow('nmos','cmps offs cmask picks',
459       '''
460      nmo half=n offset=${SOURCES[1]} mask=${SOURCES[2]}
461       velocity=${SOURCES[3]}
462       ''')
463
464 Result('nmos',
465          '''
466          window min1=5.5 max1=8.5 |
467               byte gainpanel=all | transp plane=23 memsize=5000 |
468          grey3 frame1=400 frame2=50 frame3=50
469               title="NMO" label2="CMP Number"
470          flat=n point1=0.8 point2=0.8
471               ''')
472
473 Flow('stack','nmos','stack')
474
475 Result('stack',
476         '''
477         window min1=5.5 max1=8.5 |
478         grey title="NMO Stack" label2="CMP Number"
```

```
479         ''')
480
481 Plot('stack',
482       '''
483       window min1=5.5 max1=8.5 |
484       grey title="NMO Stack" label2="CMP Number"
485       ''')
486
487 # Try DMO
488
489 nv=60
490
491 Flow('stacks','cmps offs maskcmp',
492       '''
493       stacks half=n v0=1400 nv=%g dv=20
494       offset=${SOURCES[1]} mask=${SOURCES[2]}
495       '''%nv, split=[3,'omp'])
496
497 Flow('stackst','stacks','costaper nw3=20')
498
499 Result('stacks','stackst',
500         '''
501         window min1=5.5 max1=8.5 |byte gainpanel=all |
502         transp plane=23 memsize=5000 |
503         grey3 frame1=200 frame2=100 frame3=50 point1=0.8 point2=0.8
504         title="Constant-Velocity Stacks" label3=Velocity unit3=m/s
505         label2="CMP Number"
506         ''')
507
508 # Apply double Fourier transform (cosine transform)
509
510 Flow('cosft3','stackst',
511       '''
512       put d3=16.667 o3=0 label2=Distance unit2=m |
513       cosft sign1=1 sign3=1
514       ''')
515
516 # Transpose f-v-k to v-f-k
517
518 Flow('transp','cosft3','transp')
519
520 # Fowler DMO: mapping velocities
521
522 Flow('map','transp',
523       '''
524       math output="x1/sqrt(1+0.25*x3*x3*x1*x1/(x2*x2))" |
525       cut n2=1
526       ''')
```

```
Result('map',
       '''
       window j3=4 |
       byte gainpanel=all allpos=y bar=bar.rsf |
       grey3 title="Fowler Map" label1=Velocity
       unit1=m/s label3=Wavenumber barlabel=Velocity barunit=m/s
       frame1=20 frame2=500 frame3=20 color=x scalebar=y
       ''')

Flow('fowler','transp map','iwarp warp=${SOURCES[1]} | transp')

# Inverse Fourier transform

Flow('dmo','fowler','cosft sign1=-1 sign3=-1')

Result('dmo',
       '''
       put d3=1 o3=900 unit2='' label2=Trace | window min1=5.5 max1=8.5 |
       byte gainpanel=all | transp plane=23 memsize=5000 |
       grey3 frame1=200 frame2=100 frame3=50 point1=0.8 point2=0.8
       title="Constant-Velocity DMO Stacks"
       label3=Velocity unit3=m/s
       ''')

# Compute envelope for picking

Flow('envelope','dmo','envelope | scale axis=2')

# Mute and Pick velocity

Flow('vpick','envelope',
     '''
       mutter v0=130 x0=1300 t0=4.0 half=n inner=n |
       mutter x0=1400 v0=20 t0=5.0 half=n inner=y |
       mutter v0=2500 x0=1400 t0=5.8 half=n inner=n |
       mutter v0=500 x0=1400 t0=7.0 half=n inner=y  |
       pick rect1=80 rect2=20 vel0=1400
       ''')

Result('vpick',
       '''
       put d2=1 o2=900 unit2= label2="CMP Number" |
       grey mean=y color=j scalebar=y
       barreverse=y barunit=m/s barlabel=Velocity
       title="Picked Migration Velocity" label2="CMP Number" unit2=
       ''')

# Take a slice
```

```
575
576 Flow('slice','dmo vpick',
577       '''
578       slice pick=${SOURCES[1]} |
579       put d2=1 o2=900 unit2= label2="CMP Number"
580       ''')
581
582 Result('slice',
583         '''
584         window min1=5.5 max1=8.5 |
585         grey title="DMO Stack"
586         ''')
587
588 Plot('slice',
589       '''
590       window min1=5.5 max1=8.5 |
591       grey title="DMO Stack" label2="CMP Number"
592       ''')
593
594 # Check one CMP location
595
596 p = 380
597
598 min1=5.8
599 max1=8.5
600
601 Flow('before','stackst',
602       '''
603       window n3=1 f3=%d min1=%g max1=%g | envelope
604       ''' % (p,min1,max1))
605 Flow('after','envelope',
606       '''window n3=1 f3=%d min1=%g max1=%g
607       ''' % (p,min1,max1))
608
609 for case in ('before','after'):
610     Plot(case,
611           '''
612           grey color=j allpos=y title="%s DMO"
613           label2=Velocity unit2=m/s
614           ''' % case.capitalize())
615
616 Flow('vpick1','vpick',
617       '''
618       window n2=1 f2=%d min1=%g max1=%g
619       '''%(p,min1,max1))
620
621 Plot('vpick1',
622       '''
```

```
623         graph yreverse=y transp=y plotcol=7 plotfat=7
624         pad=n min2=%g max2=%g wantaxis=n wanttitle=n
625         ''' % (1400,2600))
626
627 Plot('before2','before pick','Overlay')
628 Plot('after2','after vpick1','Overlay')
629 Result('envelope','before2 after2','SideBySideAniso')
630
631 ##################################################
632 # Zoom an interesting area
633 ##################################################
634 min1,max1=5.8,7
635 min2,max2=1100,1300
636
637 Flow('box.asc',None,
638       '''
639       echo %s n1=2 n2=5 data_format=ascii_float in=$TARGET
640       ''' % ' '.join(map(str,(min1,min2,max1,min2,
641                               max1,max2,min1,max2,min1,min2))))
642 Plot('box','box.asc',
643       '''
644       dd form=native type=complex | window |
645       graph transp=y yreverse=y min1=0 max1=4 min2=0 max2=26.7625
646       wanttitle=n plotfat=5 plotcol=6 wantaxis=n
647       ''')
648
649 for i in range(2):
650     case=('slice','stack')[i]
651     zoomd = case + '-zoomd'
652     Flow(zoomd,case,
653           '''
654           window min1=%g max1=%g min2=%g max2=%g
655           ''' % (min1,max1,min2,max2))
656     Plot(zoomd,'grey title=%s grid=y gridcol=5 label2=CMP' % ('ab'[i]))
657 Result('zoomd','slice-zoomd stack-zoomd',
658 'SideBySideIso')
659
660 # Stolt Migration
661
662 # 2D cosine transform
663
664 Flow('cosft','slice',
665       '''
666       put d2=16.667 label2=Distance unit2=m |
667       cosft sign1=1 sign2=1 |
668       put label2=Wavenumber
669       ''')
670 Result('cosft',
```

```
671         '''
672         window max1=90 |
673         grey title="Cosine Transform" pclip=95 label1=Frequency
674         ''')
675
676 # Stolt migration with constant velocity
677
678 Flow('map2','cosft',
679       '''
680       math output="sqrt(x1*x1+%g*x2*x2)"
681       '''%(562500))
682
683 Result('map2',
684         '''
685         grey color=x allpos=y scalebar=y
686         title="Stolt Map" barlabel=Frequency barunit=Hz label1=Frequency
687         ''')
688
689 Flow('cosft2','cosft map2','iwarp warp=${SOURCES[1]} inv=n')
690
691 Result('cosft2',
692         '''
693         window max1=90 |
694         grey title="Cosine Transform Warped" pclip=95 label1=Frequency
695         ''')
696
697 Flow('mig2','cosft2',
698       '''
699       cosft sign1=-1 sign2=-1 |
700
701       put d2=1 unit2=''
702       ''')
703
704 Result('mig2',
705         '''
706         window min1=5.5 max1=8.5 |
707         grey title="Stolt Migration with 1500 m/s"
708         label2="CMP Number"
709         ''')
710
711 # Ensemble of Stolt migrations with different velocities
712
713 Flow('spray','cosft',
714       'spray axis=3 n=120 o=1500 d=8 label=Velocity unit=m/s')
715
716 Flow('map1','spray','math output="sqrt(x1*x1+0.25*x3*x3*x2*x2)" ')
717
718 Result('map1',
```

```
719         ''')
720         byte gainpanel=all allpos=y bar=bar1.rsf |
721         grey3 title="Stolt Ensemble Map" scalebar=y barlabel=Velocity barunit=m/s
722         frame1=400 frame2=50 frame3=50 color=x label1=Frequency
723         ''')
724
725 Flow('migd','spray map1',
726       '''
727       iwarp warp=${SOURCES[1]} inv=n |
728       cosft sign1=-1 sign2=-1
729       ''')
730
731 Flow('migt','migd','transp plane=23 memsize=5000')
732
733 Plot('migd',
734       '''
735       window min1=5.5 max1=8.5 |
736       grey title="Ensemble of Stolt Migrations"
737       ''',view=1)
738
739 # Migration velocity increasing with time
740
741 Flow('vmig1','slice',
742       '''
743       pad beg1=1250 | math output="1500" |
744       window n1=1250 | put o1=0
745       ''')
746
747 Flow('vmig2','slice',
748       '''
749       window min1=5 | put o1=0 |
750       math output="1500+20*x1*x1" | put o1=5
751       ''')
752
753 Flow('vmig','vmig1 vmig2','cat ${SOURCES[1:2]} axis=1')
754
755 Result('vmig',
756         '''
757         window min1=5.5 max1=8.5 |
758         grey color=j mean=y barreverse=y title="Migration Velocity"
759         scalebar=y barlabel=Velocity barunit=m/s label2="CMP Number"
760         unit2=
761         ''')
762 # Slice through the ensemble of migrations
763
764 Flow('slice1','migt vmig',
765       '''
766       slice pick=${SOURCES[1]} | put d2=1 o2=900
```

```
767         ''')
768
769 Result('migd','slice1',
770           '''
771           window min1=5.5 max1=8.5 |
772           grey label2="CMP Number"
773           unit2= title="Stolt Migration with Variable Velocity"
774           ''')
775
776 # Dix conversion to interval velocity
777 Flow('semb','vscans picks','slice pick=${SOURCES[1]}')
778 Flow('vdix','picks semb',
779         '''
780         dix weight=${SOURCES[1]} rect1=50 rect2=10
781         ''')
782
783 # Velocity continuation
784 Flow('first','slice',
785         '''
786         put o2=0 d2=16.667 label2=Distance unit2=m o3=0 |
787         cosft sign2=1 |
788         stolt vel=1400
789         ''')
790
791 Flow('mig0','first',
792         '''
793         window min1=5.5 max1=8.0 |
794         cosft sign2=-1
795         ''')
796
797 Result('first','mig0',
798           '''
799           grey title="Migration with 1400 m/s"
800           ''')
801
802 Flow('velcon','first',
803         '''
804         vczo nv=101 dv=10 v0=1400 verb=y |
805         window min1=5.5 max1=8.0 |
806         transp plane=23 memsize=1000 |
807         cosft sign2=-1
808         ''')
809 Result('velcon',
810           '''
811           byte gainpanel=a |
812           grey3 frame1=300 frame2=200 frame3=50
813           point1=0.8 point2=0.8 flat=n unit3=m/s
814           title="Velocity Continuation"
```

```
        ''')
Plot('movie','velcon','grey title="velocity continuation"',view=1)

# Migration with the stacking velocity
Flow('mpick','picks','window min1=5.5 max1=8.0')
Flow('mstack','velcon mpick',
     '''
     transp plane=23 memsize=1000 |
     slice pick=${SOURCES[1]}
     ''')
Result('mstack',
       'grey title="Migration with Stacking Velocity"')

# Separating diffractions

Flow('dip','mig0','dip rect1=20 rect2=10 order=2')
Result('dip',
       '''
       grey color=j scalebar=y wanttitle=n
       barlabel=Slope barunit=samples
       ''')

Flow('refl','mig0 dip',
     '''
     pwspray dip=${SOURCES[1]} ns=5 order=2 reduce=stack
     ''')
Result('refl',
       '''
       window min1=5.5 max1=8 | grey title="Reflections"
       ''')

Flow('diff','mig0 refl','add scale=1,-1 ${SOURCES[1]}')
Result('diff','window min1=5.5 max1=8 | grey title="Diffractions"')

Flow('stoltd','diff',
     '''
     cosft sign2=1 |
     pad beg1=1250
     ''')

Flow('velcond','stoltd',
     '''
     vczo nv=101 dv=10 v0=1400 verb=y pad2=3000 |
     window min1=5.5 max1=8 |
     transp plane=23 memsize=1000 |
     cosft sign2=-1
     ''')
Plot('velcond','grey title="Velocity Continuation"',view=1)
```

```
Result('velcond',
       '''
       byte gainpanel=a |
       grey3 frame1=300 frame2=200 frame3=50
       point1=0.8 point2=0.8 flat=n unit3=m/s
       title="Velocity Continuation"
       ''')

Flow('focus','velcond',
     '''
     transp plane=23 |
     pad beg1=1250
     focus rect1=40 rect3=20 |
     window min1=5.5 |
     math output="1/abs(input)" |
     clip clip=8 |
     scale axis=2
     ''')

Flow('fpik','focus','pick v0=1400 rect1=25 rect2=10')

Result('fpik',
       '''
       window | grey color=j allpos=y bias=1500
       scalebar=y title="Focusing Velocity"
       barreverse=y barlabel=Velocity barunit=m/s
       ''')

Flow('mdif','velcond fpik',
     '''
     transp plane=23 memsize=1000 |
     slice pick=${SOURCES[1]}
     ''')
Result('mdif',
       'grey title="Focused Diffractions"')

Flow('mfpik','velcon fpik',
     '''
     transp plane=23 memsize=1000 |
     slice pick=${SOURCES[1]}
     ''')
Result('mfpik',
       'grey title="Migration with Focusing Velocity"')

# RTM
# Dix conversion to interval velocity
Flow('first1','slice',
     '''
```

```
911         put o2=0 d2=16.667 label2=Distance unit2=m o3=0 |
912         cosft sign2=1 |
913         stolt vel=1550
914         ''')
915
916 Flow('mig1','first1',
917         '''
918
919         cosft sign2=-1
920         ''')
921
922 Result('mig1',
923           '''
924           window min1=5.5 max1=8.5 |
925           grey title="Migration with 1550 m/s"
926           ''')
927 Flow('weight','envelope vpick','slice pick=${SOURCES[1]}')
928 Flow('vdix2','vpick weight',
929         'dix rect1=20 rect2=50 weight=${SOURCES[1]}')
930 Result('vdix2',
931           '''
932
933           grey color=j mean=y barreverse=y
934           title="Dix Velocity in time"
935           scalebar=y barlabel=Velocity
936           barunit=m/s label2="Distance" unit2=m
937           ''')
938 Flow('vmigr1','slice',
939         '''
940         pad beg1=1375 | math output="1550" |
941         window n1=1375 | put o1=0 d2=16.667 o2=0
942         ''')
943 Flow('vmigr2','vdix2','window min1=5.5')
944 Flow('vmigr','vmigr1 vmigr2','cat ${SOURCES[1:2]} axis=1')
945
946 Result('vmigr',
947           '''
948
949           grey color=j mean=y barreverse=y
950           title="Migration Velocity in time"
951           scalebar=y barlabel=Velocity
952           barunit=m/s label2="Distance" unit2=m
953           ''')
954
955 # Gazdag migration
956 Flow('gazdag','cosft vmigr',
957         'cosft sign1=-1 | gazdag velocity=${SOURCES[1]} verb=y')
958
```

```
959 Flow('image','gazdag','cosft sign2=-1')
960
961 Result('image',
962         '''
963         window max1=8.5 min1=5.5 | grey
964         title="Phase-Shift Migration"
965         ''')
966
967 # Kirchhoff time migration
968 Flow('kmig','slice vpick',
969       '''
970       put d2=16.667 o2=0 | kirchnew velocity=${SOURCES[1]}
971       ''')
972 Result('kmig',
973         '''
974         window max1=8.5 min1=5.5 | grey
975         title="Kirchhoff Post-stack Migration"
976         ''')
977
978 Flow('vdixz','vmigr',
979       '''
980       time2depth velocity=$SOURCE intime=y nz=2750 z0=0 dz=5 |
981       put label1=Depth unit1=m
982       ''')
983 Result('vdixz',
984         '''
985
986         grey color=j mean=y barreverse=y
987         title="Dix Velocity in depth"
988         scalebar=y barlabel=Velocity
989         barunit=m/s label2="Distance" unit2=m
990         ''')
991 Flow('fft','vdixz','transp | fft1 | fft3 axis=2 pad=1')
992 Flow('right left','vdixz fft',
993       '''
994       transp | scale dscale=0.5 |
995       isolr2 seed=2016 dt=0.002 npk=50
996       fft=${SOURCES[1]} left=${TARGETS[1]}
997       ''')
998
999 Flow('rtm snaps','slice left right',
1000      '''
1001      put o2=0 d2=16.667 | spline n1=5500 o1=0 d1=0.002 |
1002      reverse which=1 |
1003      transp | fftexp0 mig=y snap=10 snaps=${TARGETS[1]}
1004      left=${SOURCES[1]} right=${SOURCES[2]}
1005      nz=2750 dz=5
1006      ''')
```

```
1007
1008 Result('rtm',
1009         '''
1010         put d2=1 o2=900 unit1=m label1=Depth
1011         unit2= label2=CMP | window min1=4000 max1=7000 |
1012         grey title="Post-Stack Depth Migration"
1013         ''')
1014 Plot('snaps','grey title=Snapshots gainpanel=all unit2=m',view=1)
1015
1016 # Split-step
1017 Flow('slo','vdixz',
1018       '''
1019       put d4=1 o4=1 d2=0.016667 d1=0.005 d3=0.016667 |
1020       transp | transp plane=23 |
1021       math output="1/(input/1000)"
1022       ''')
1023 Result('slo',
1024         '''
1025         put label1=Distance unit1=km label2=
1026         unit2= unit3=km | byte |
1027         sfgrey3 color=j frame1=150 frame2=150 frame3=150
1028         flat=n title="Slowness"
1029         ''')
1030 Flow('fft2','slice',
1031       '''
1032       put d2=0.016667 o2=0 d3=0.016667 | fft1 |
1033       transp plane=12 | transp plane=23
1034       ''')
1035 Flow('mig','fft2 slo',
1036       '''
1037       zomig3 ompnth=1 mode=m --readwrite=y verb=y
1038       nrmax=10 slo=${SOURCES[1]}
1039       ''',split=[3,'omp',[0]],reduce='add')
1040
1041 Result('mig',
1042         '''
1043         put d1=1 o1=900 d3=5 d2=16.667 unit3=m
1044         label3=Depth unit1= label1=CMP |
1045         transp plane=23 | transp plane=12 |
1046         window min1=4000 max1=7000 | grey
1047         title="Split-step migration"
1048         ''')
1049
1050 ##################################################
1051 # Zoom an interesting area
1052 ##################################################
1053 min1,max1=6.0,6.8
1054 min2,max2=950,1050
```

```
1055
1056 for i in range (3):
1057     case=('slice','mig2','slice1')[i]
1058     zoom = case + '-zoom'
1059     Flow(zoom,case,
1060          '''
1061          window min1=%g max1=%g min2=%g max2=%g
1062          ''' % (min1,max1,min2,max2))
1063     Plot(zoom,'grey title=%s grid=y gridcol=9 label2=CMP unit2='%('123'[i]))
1064 for i in range (5):
1065     case=('mstack','mfpik','image','stack-shot','kmig')[i]
1066     zoom2 = case + '-zoom'
1067     Flow(zoom2,case,
1068          '''
1069          put d2=1 o2=900 | window min1=%g max1=%g min2=%g max2=%g
1070          ''' % (min1,max1,min2,max2))
1071     Plot(zoom2,
1072          '''
1073          grey title=%s grid=y gridcol=9
1074          label2=CMP unit2=
1075          ''' % ('45609'[i]))
1076 Plot('mig-zoom','mig',
1077       '''
1078       put d1=1 o1=900 d3=5 d2=16.667
1079       unit3=m label3=Depth unit1= label1=CMP |
1080       transp plane=23 | transp plane=12 |
1081       window min1=4730 max1=5550 min2=950 max2=1050 |
1082       grey title="%s" grid=y gridcol=9
1083       ''' % ('8'))
1084 Plot('rtm-zoom','rtm',
1085       '''
1086       put d2=1 o2=900 unit1=m label1=Depth unit2= label2=CMP |
1087       window min1=4730 max1=5550 min2=950 max2=1050 |
1088       grey title="%s" grid=y gridcol=9
1089       ''' % ('7'))
1090 Result('zoom1','slice-zoom mig2-zoom slice1-zoom','SideBySideIso')
1091 Result('zoom2','mstack-zoom mfpik-zoom image-zoom','SideBySideIso')
1092 Result('zoom3','rtm-zoom mig-zoom kmig-zoom stack-shot-zoom',
1093        'SideBySideIso')
1094
1095 ##################################################
1096 # Zoom an interesting area
1097 ##################################################
1098 min1,max1=5.9,6.8
1099 min2,max2=950,1200
1100
1101 for i in range (3):
1102     case=('slice','mig2','slice1')[i]
```

```
    zoom = case + '-zoom2'
    Flow(zoom,case,
         '''
         window min1=%g max1=%g min2=%g max2=%g
         ''' % (min1,max1,min2,max2))
    Plot(zoom,'grey title=%s grid=y gridcol=9 label2=CMP unit2='%('123'[i]))
for i in range(5):
    case=('mstack','mfpik','image','stack-shot','kmig')[i]
    zoom2 = case + '-zoom2'
    Flow(zoom2,case,
         '''
         put d2=1 o2=900 | window min1=%g max1=%g min2=%g max2=%g
         ''' % (min1,max1,min2,max2))
    Plot(zoom2,
         '''
         grey title=%s grid=y gridcol=9
         label2=CMP unit2=
         ''' % ('45609'[i]))
Plot('mig-zoom2','mig',
     '''
     put d1=1 o1=900 d3=5 d2=16.667 unit3=m
     label3=Depth unit1= label1=CMP |
     transp plane=23 | transp plane=12 |
     window min1=4600 max1=5550 min2=950 max2=1200 |
     grey title="%s" grid=y gridcol=9
     ''' % ('8'))
Plot('rtm-zoom2','rtm',
     '''
     put d2=1 o2=900 unit1=m label1=Depth unit2= label2=CMP |
     window min1=4600 max1=5550 min2=950 max2=1200 |
     grey title="%s" grid=y gridcol=9
     ''' % ('7'))
Result('zoom4','slice-zoom2 mig2-zoom2 slice1-zoom2','SideBySideIso')
Result('zoom5','mstack-zoom2 mfpik-zoom2 image-zoom2','SideBySideIso')
Result('zoom6','rtm-zoom2 mig-zoom2 kmig-zoom2 stack-shot-zoom2',
       'SideBySideIso')

##############################################
# Zoom an interesting area
##############################################
min1,max1=5.9,6.8
min2,max2=1150,1250

for i in range(3):
    case=('slice','mig2','slice1')[i]
    zoom = case + '-zoom3'
    Flow(zoom,case,
         '''
```

```
1151            window min1=%g max1=%g min2=%g max2=%g
1152            ''' % (min1,max1,min2,max2))
1153      Plot(zoom,
1154            '''
1155            grey title=%s grid=y gridcol=9 label2=CMP unit2=
1156            ''' % ('123'[i]))
1157  for i in range (5):
1158      case=('mstack','mfpik','image','stack-shot','kmig')[i]
1159      zoom2 = case + '-zoom3'
1160      Flow(zoom2,case,
1161            '''
1162            put d2=1 o2=900 | window min1=%g max1=%g min2=%g max2=%g
1163            ''' % (min1,max1,min2,max2))
1164      Plot(zoom2,
1165            '''
1166            grey title=%s grid=y gridcol=9 label2=CMP unit2=
1167            ''' % ('45609'[i]))
1168  Plot('mig-zoom3','mig',
1169        '''
1170        put d1=1 o1=900 d3=5 d2=16.667 unit3=m
1171        label3=Depth unit1= label1=CMP |
1172        transp plane=23 | transp plane=12 |
1173        window min1=4600 max1=5550 min2=1150 max2=1250 |
1174        grey title="%s" grid=y gridcol=9
1175        ''' % ('8'))
1176  Plot('rtm-zoom3','rtm',
1177        '''
1178        put d2=1 o2=900 unit1=m label1=Depth unit2=
1179        label2=CMP | window min1=4600 max1=5550
1180        min2=1150 max2=1250 | grey title="%s" grid=y gridcol=9
1181        ''' % ('7'))
1182  Result('zoom7','slice-zoom3 mig2-zoom3 slice1-zoom3','SideBySideIso')
1183  Result('zoom8','mstack-zoom3 mfpik-zoom3 image-zoom3','SideBySideIso')
1184  Result('zoom9','rtm-zoom3 mig-zoom3 kmig-zoom3 stack-shot-zoom3',
1185         'SideBySideIso')
1186
1187  ##################################################
1188  # Zoom an interesting area
1189  ##################################################
1190  min1,max1=7.3,7.6
1191  min2,max2=1000,1300
1192
1193  for i in range (3):
1194      case=('slice','mig2','slice1')[i]
1195      zoom = case + '-zoom4'
1196      Flow(zoom,case,
1197            '''
1198            window min1=%g max1=%g min2=%g max2=%g
```

```
            ''' % (min1,max1,min2,max2))
    Plot(zoom,
            '''
            grey title=%s grid=y gridcol=9 label2=CMP unit2=
            ''' % ('123'[i]))
for i in range(5):
    case=('mstack','mfpik','image','stack-shot','kmig')[i]
    zoom2 = case + '-zoom4'
    Flow(zoom2,case,
            '''
            put d2=1 o2=900 | window min1=%g max1=%g min2=%g max2=%g
            ''' % (min1,max1,min2,max2))
    Plot(zoom2,
            '''
            grey title=%s grid=y gridcol=9 label2=CMP unit2=
            ''' % ('45609'[i]))
Plot('mig-zoom4','mig',
      '''
      put d1=1 o1=900 d3=5 d2=16.667 unit3=m
      label3=Depth unit1= label1=CMP |
      transp plane=23 | transp plane=12 |
      window min1=6200 max1=6700 min2=1000 max2=1300 |
      grey title="%s" grid=y gridcol=9
      ''' % ('8'))
Plot('rtm-zoom4','rtm',
      '''
      put d2=1 o2=900 unit1=m label1=Depth unit2=
      label2=CMP | window min1=6200 max1=6700
      min2=1000 max2=1300 | grey title="%s" grid=y gridcol=9
      ''' % ('7'))
Result('zoom10','slice-zoom4 mig2-zoom4 slice1-zoom4','SideBySideIso')
Result('zoom11','mstack-zoom4 mfpik-zoom4 image-zoom4','SideBySideIso')
Result('zoom12','rtm-zoom4 mig-zoom4 kmig-zoom4 stack-shot-zoom4',
       'SideBySideIso')

End()
```

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