Advanced Seismic Processing

A course for the PhD Program in
"Earth Sciences and Fluid Dynamics"

Part I : Seismic Migration
A. Introduction

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Objectives

- Understand why the seismic experiment produces a distorted subsurface view

- Understand how migration corrects the distortion

- Understand the basic principles and mathematical foundations of migration

Subsurface Exploration & Exploitation: a possible scenario

- Initial hypothesis and preliminary geological survey
- Design of seismic programs
- Seismic acquisition
- **Seismic processing >>…**
- Seismic interpretation (+ modelling / inversion)
- Drilling/production

…>> Seismic processing

- Geometry
- Amplitude recovery
- Deconvolution
- Statics
- Noise Attenuation
- Velocities
- Stacking
- **Migration >> …**
- Inversion/AVO

...>> Migration

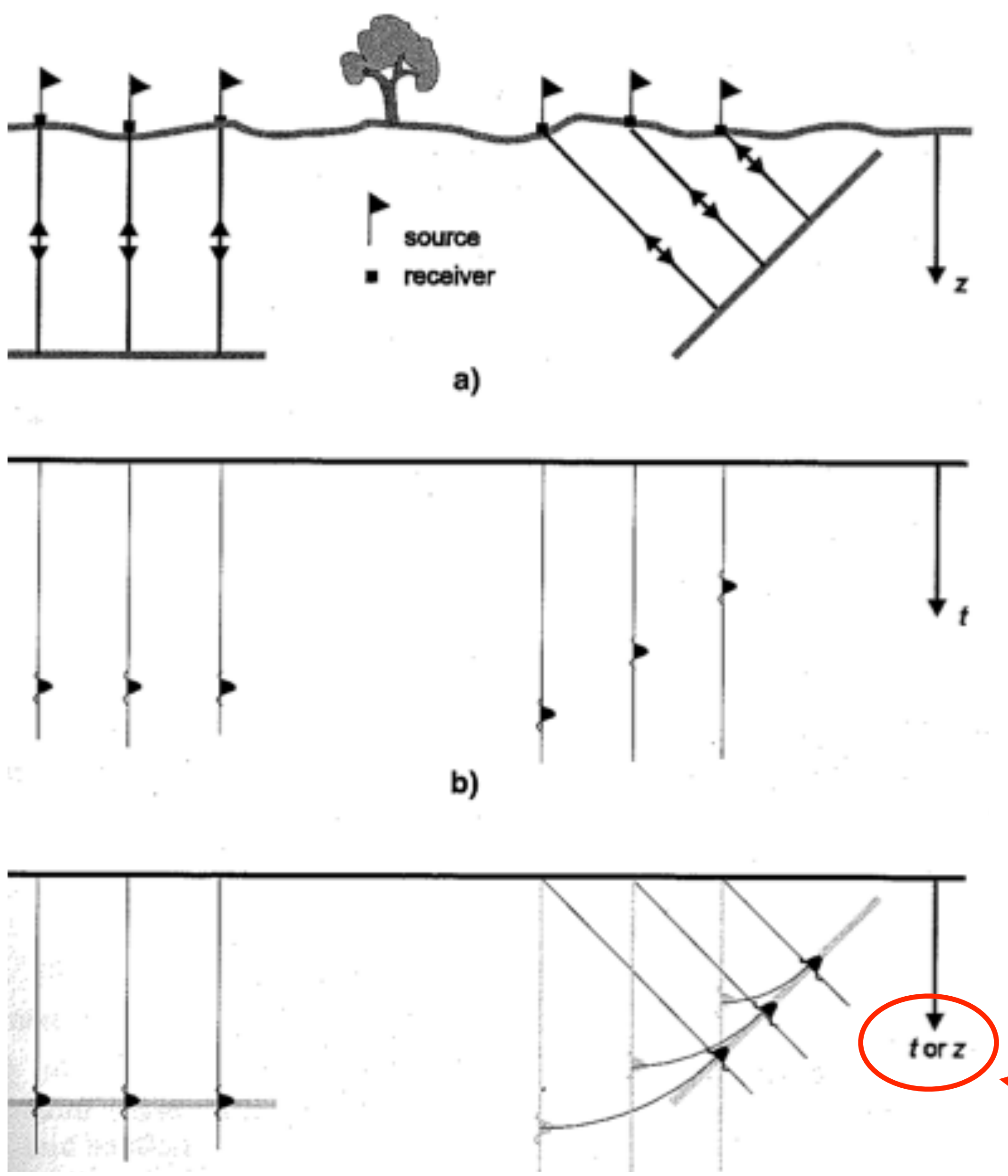
- Time
- Depth
- Post-stack
- Pre-stack
- DMO (Dip MoveOut)
- 2-D
- 3-D
- Constant velocity
- Structured geology
- Datum
- Noise
- Aliasing
- Velocities

- **Migration algorithms >> ...**

...>> Migration algorithms

- Kirchhoff time
- Kirchhoff depth
- F-K
- Downward continuation
- Finite difference
- 15-degree, 45-degree,...
- Phase shift
- PSPI
- $\omega\mathbf{X}$ time
- $\omega\mathbf{X}$ depth

Migration concepts with linear reflectors



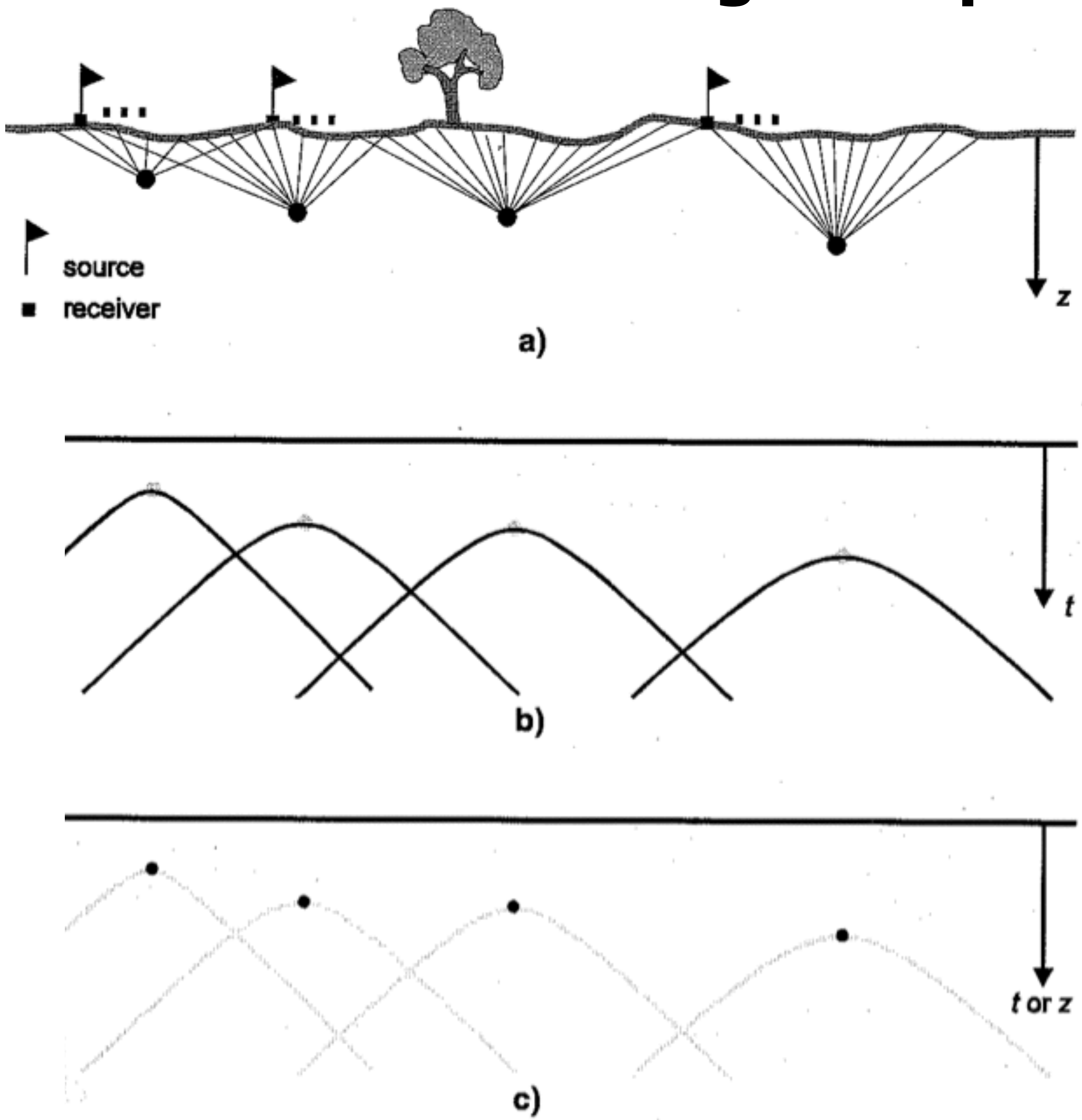
GEOLOGICAL STRUCTURE

SEISMIC SECTION

MIGRATION OF SEISMIC SECTION

*Vertical axis after migration **should** be depth but is common to display the migrated section in time*

Zero-offset recording with point reflectors

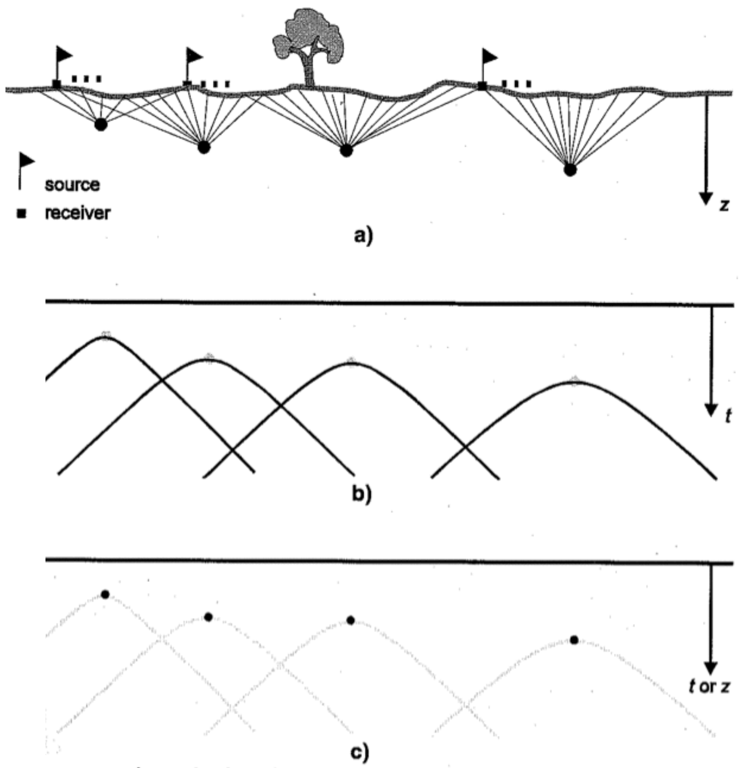


Geological structure with scatter points

seismic section with diffraction hyperbolas

Migration of seismic section

Comments



1. Diffractions at the same depth have the same shape

2. Deeper diffractions have broader shape

3. Migration collapses energy back to the position of the scatterer

SHAPE of DIFFRACTIONS

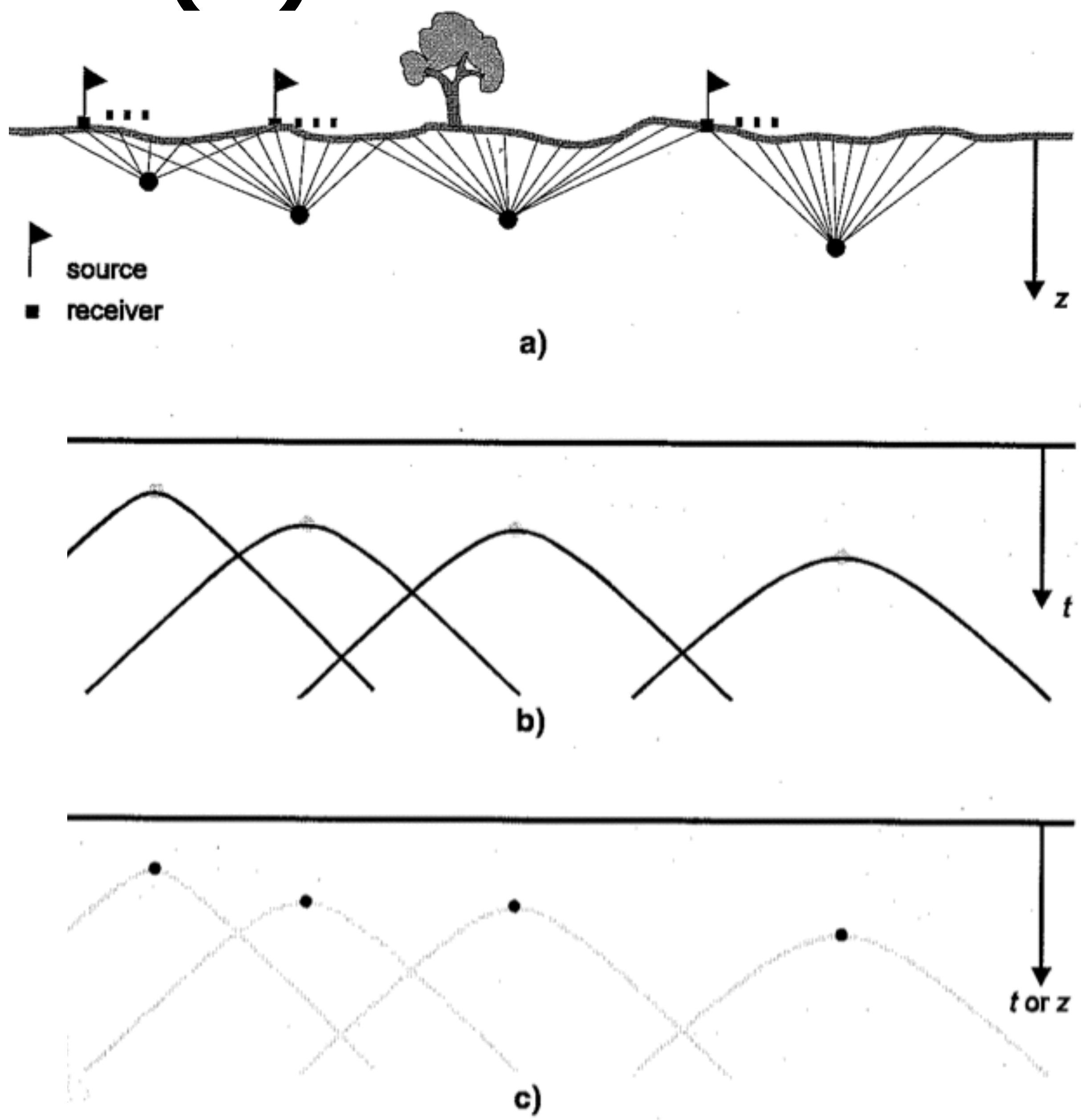
> Constant Velocity medium: hyperbolic

> Smoothly varying velocity medium: approximately hyperbolic

> Rugged velocity medium: to be evaluated by means of ray tracing or wave front analysis

> Extremely rugged velocity medium: may require simplification back to hyperbola for evaluation

Comments (2)

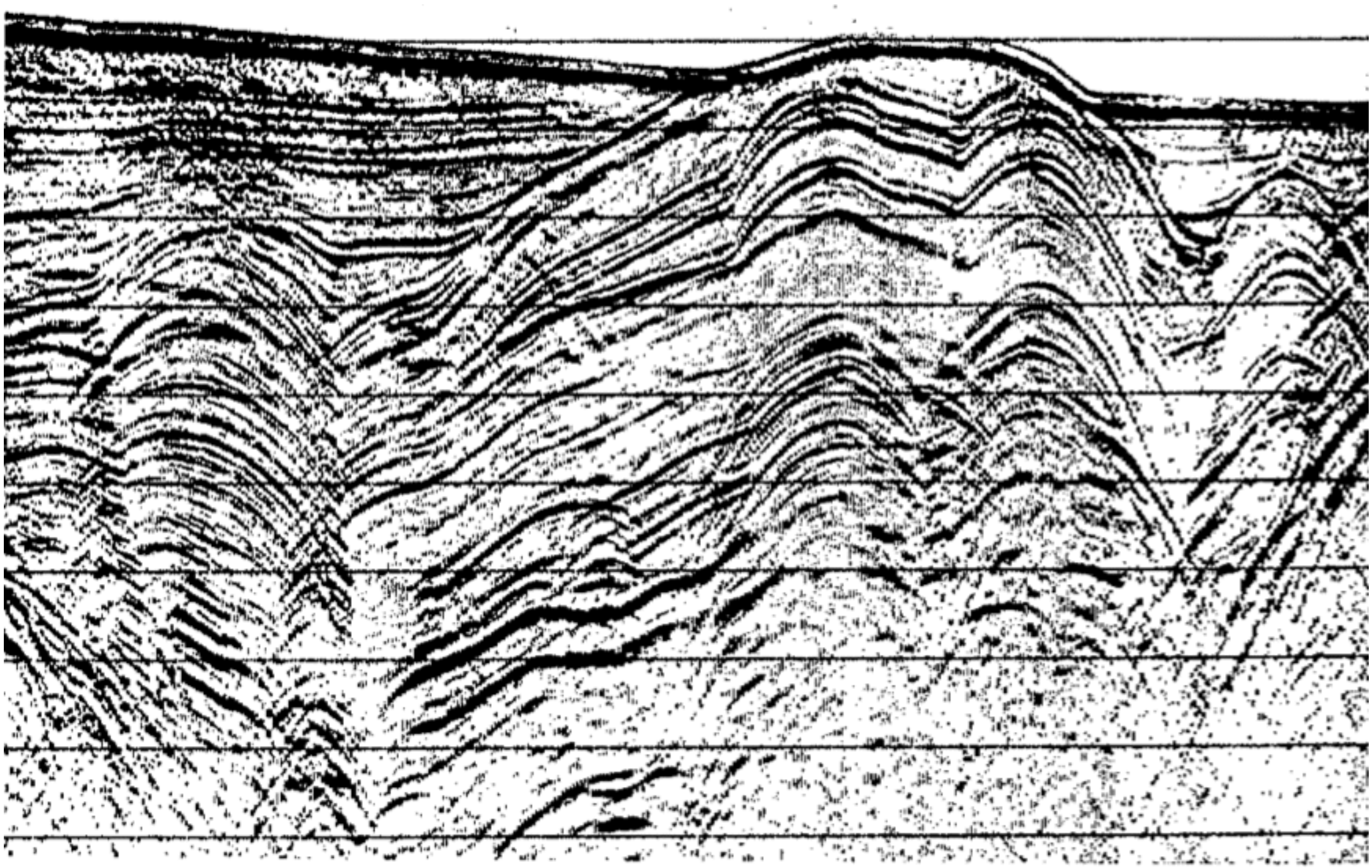


BEWARE

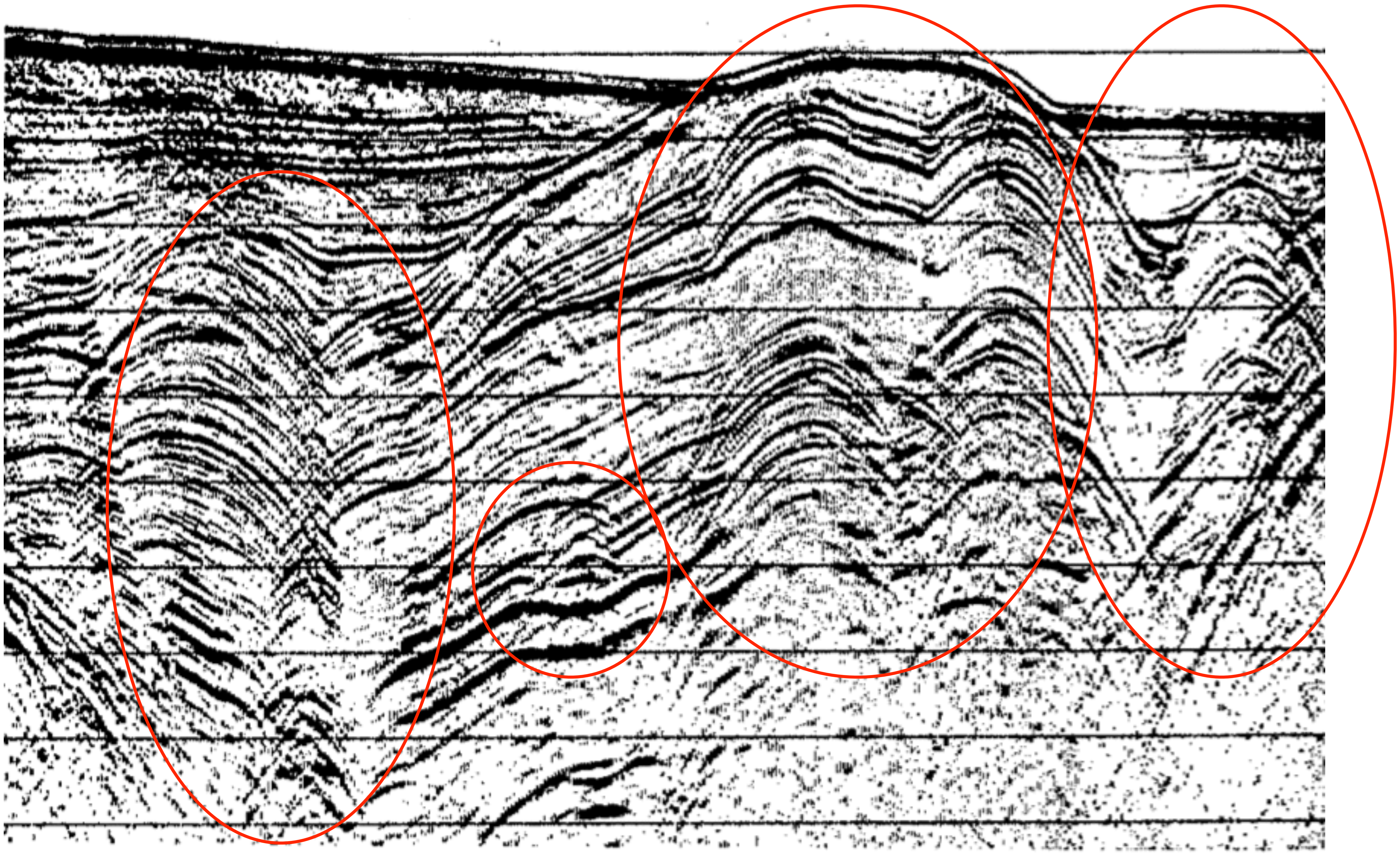
The energy of diffractions becomes **weaker** with increasing **offset**.

This effect is **not** shown in kinematic illustrations

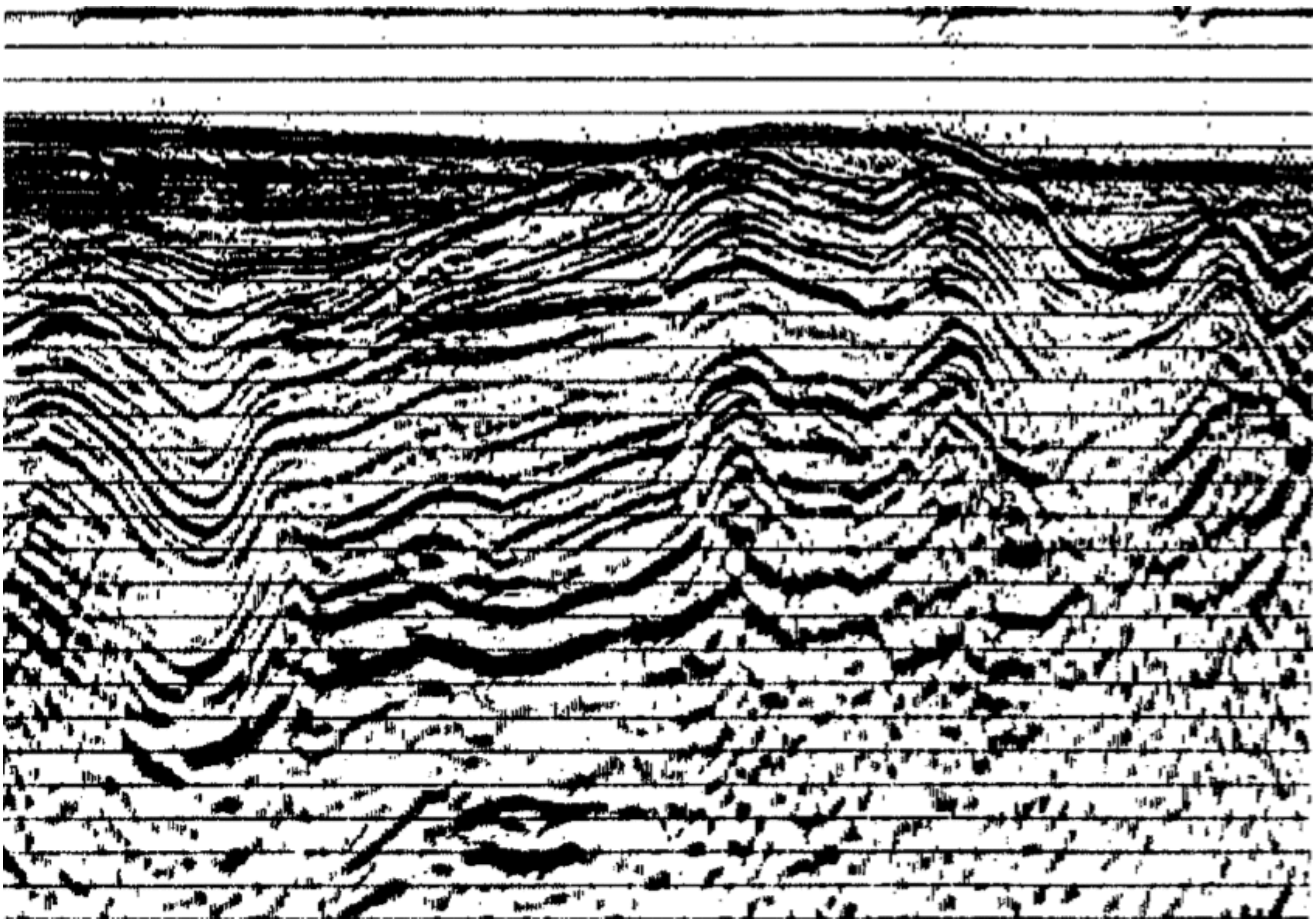
Examples of real data: SEISMIC SECTION



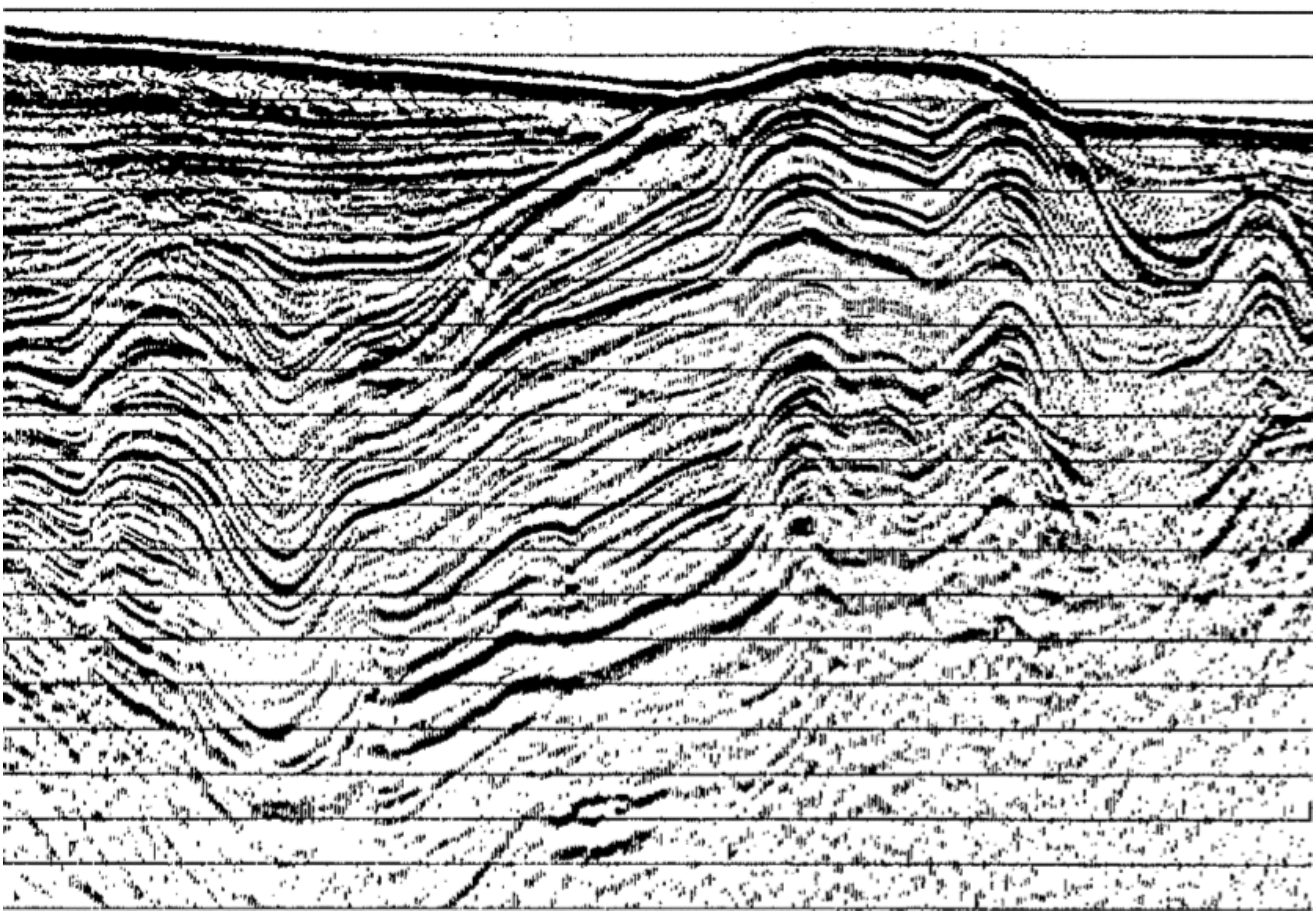
Examples of real data: SEISMIC SECTION



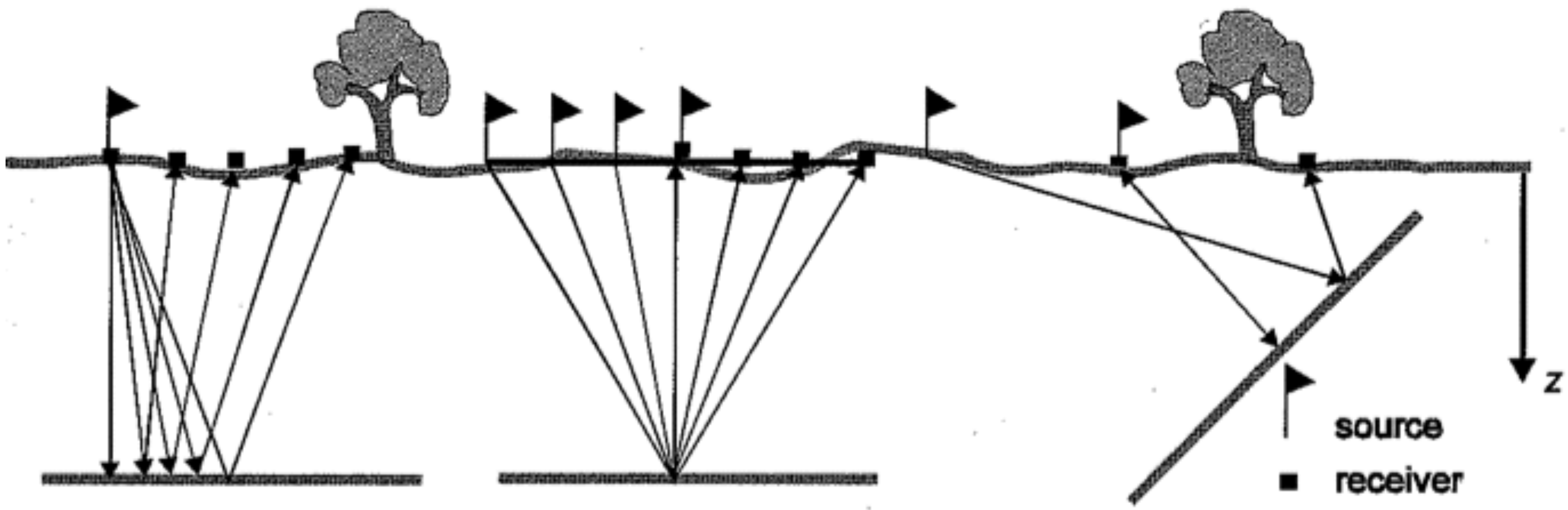
Examples of real data: Time migration



Examples of real data: Depth migration

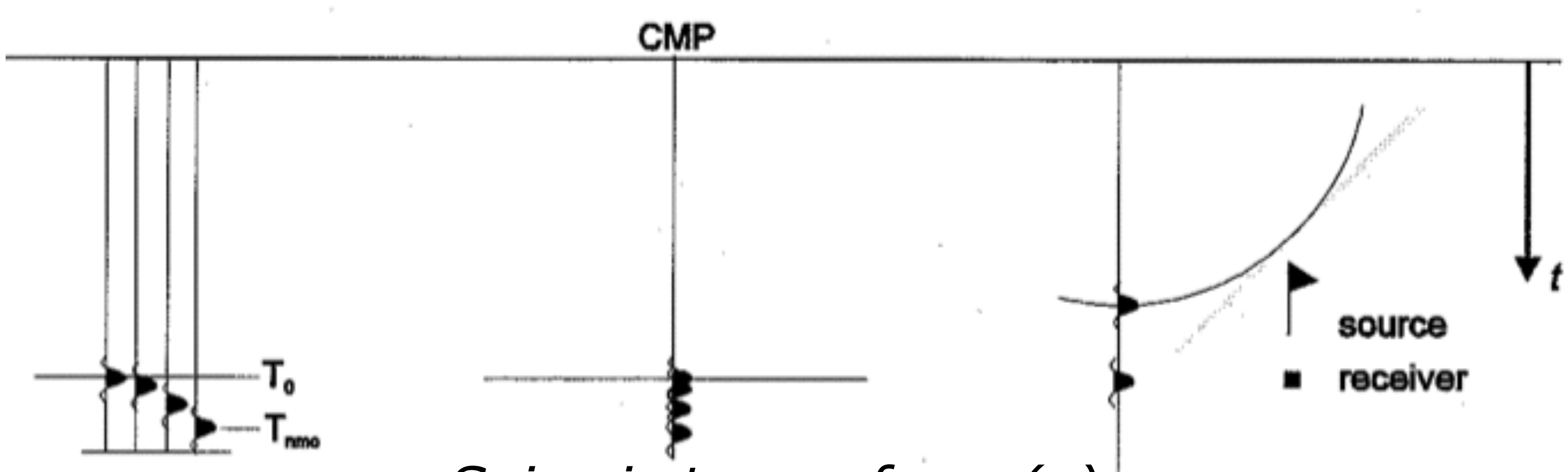


Variable offset



Source gather *CMP gather* *Reflections from dipping PR*

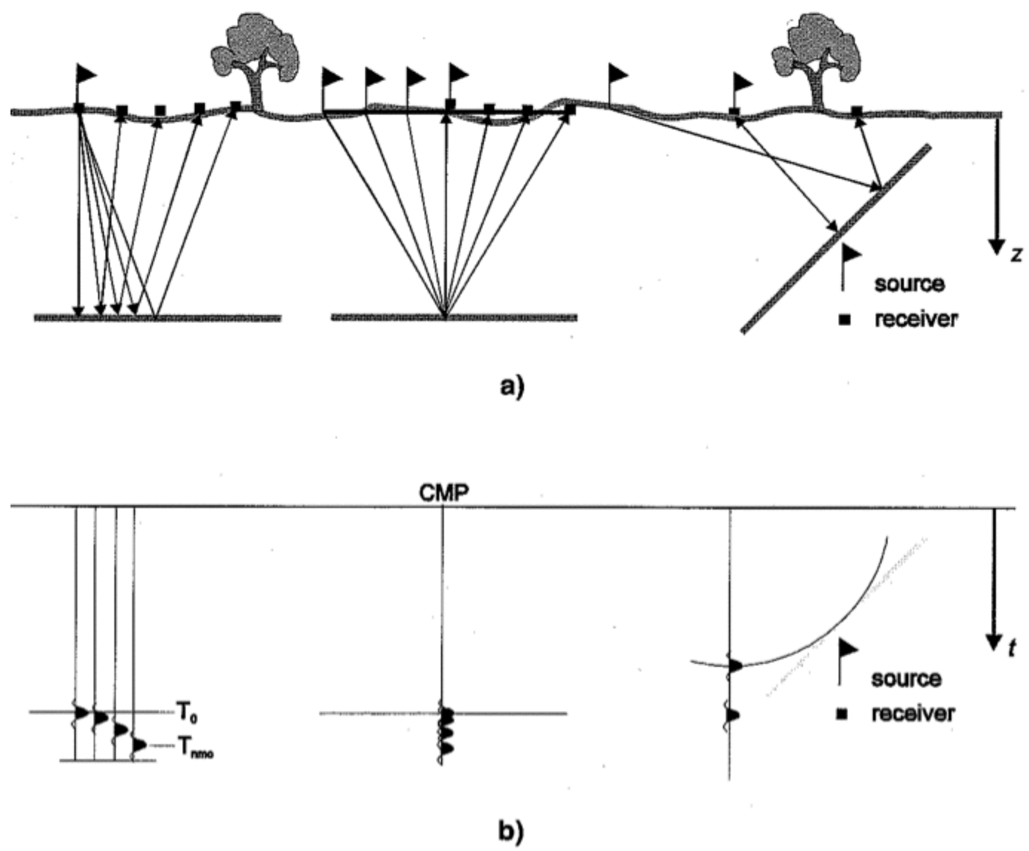
a)



Seismic traces from (a)

b)

Comments



T_0 is the normal reflection time at zero-offset

T_{nmo} is the longer reflection time at non-zero offset

The increment of reflection time with offset is normal moveout (NMO)

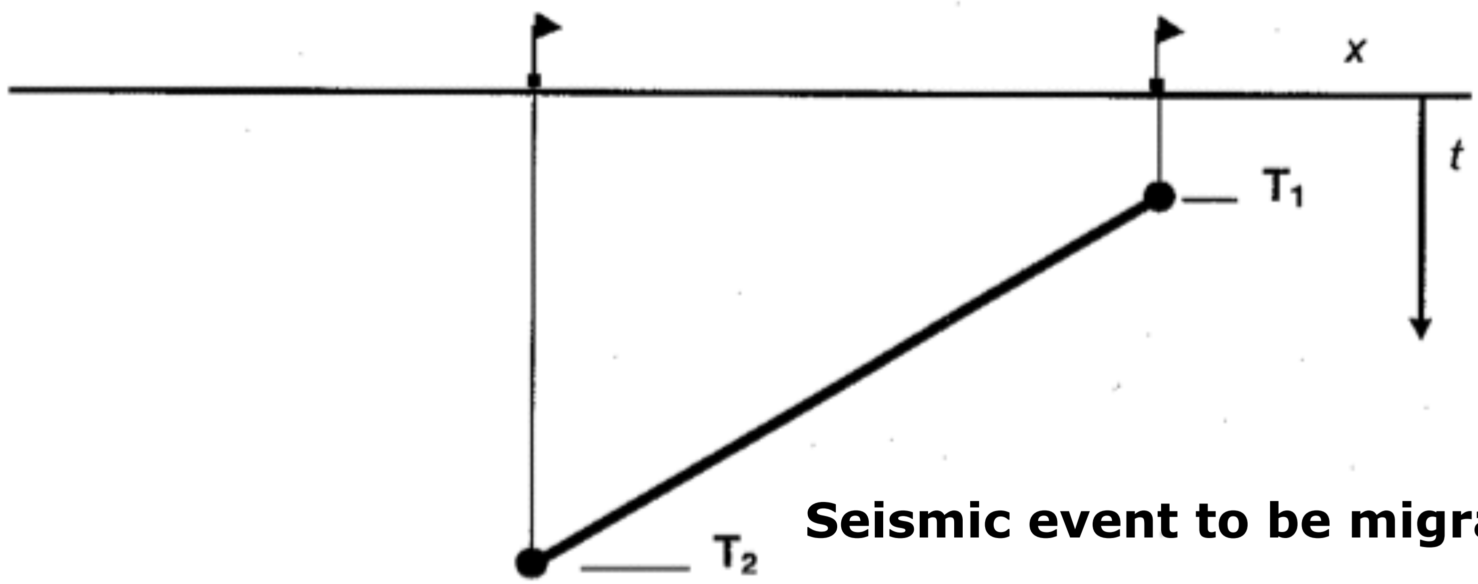
The seismic trace is located midway between source and receiver at the common midpoint (CMP)

Traces with same CMP but different offset require NMO correction for alignment

CMP traces from dipping reflectors contain reflections from different parts of the reflector: they require special NMO for alignment

Dipping reflector point smear requires special pre-stack processing (DMO or pre-stack migration)

Zero-offset migration (≡ post-stack)

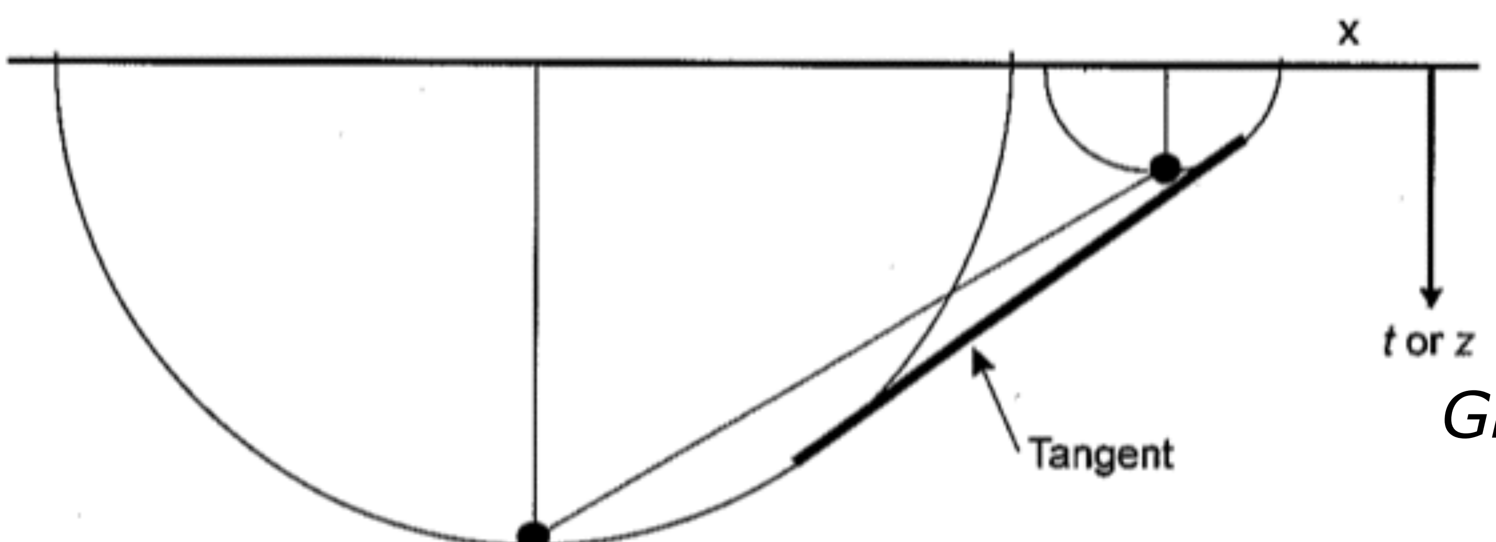


Seismic event to be migrated

For convenience time=distance
i.e v=constant=1
one-way times (OWT) are used
@zero-offset>> OWT=0.5TWT
(Two-Way Time)

a)

Reflection point is plotted below SR surface location
Zero-offset reflection rays are at normal incidence

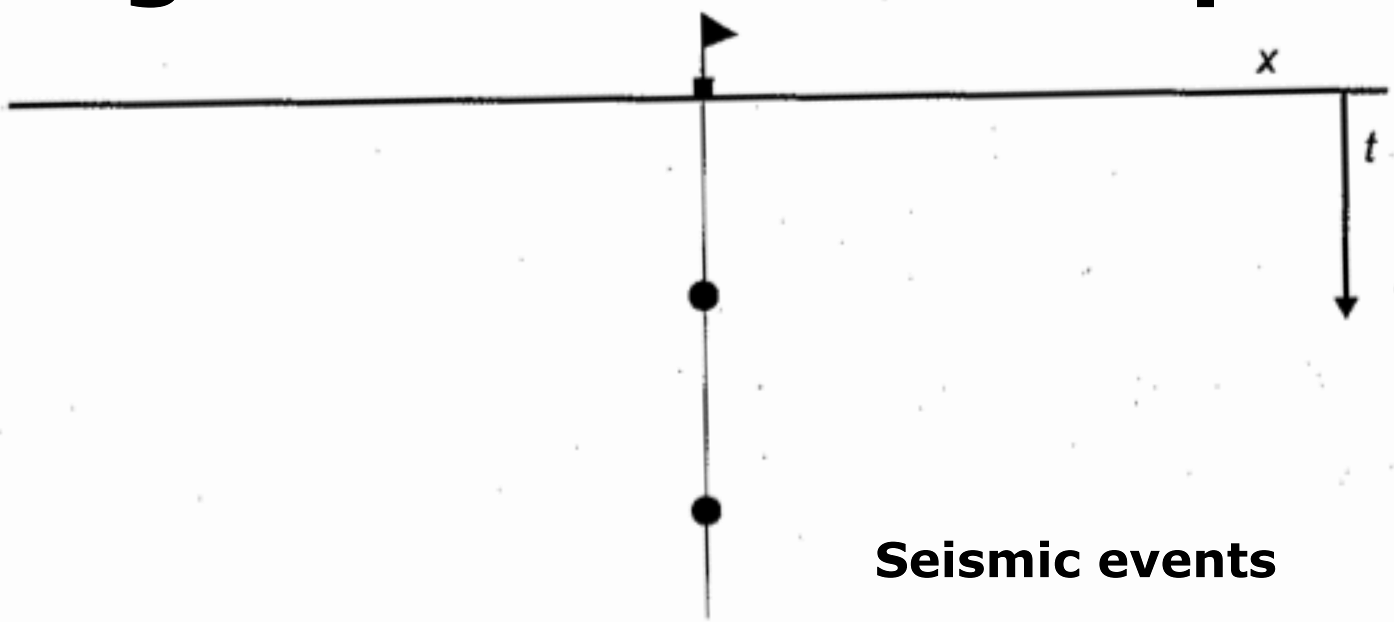


b)

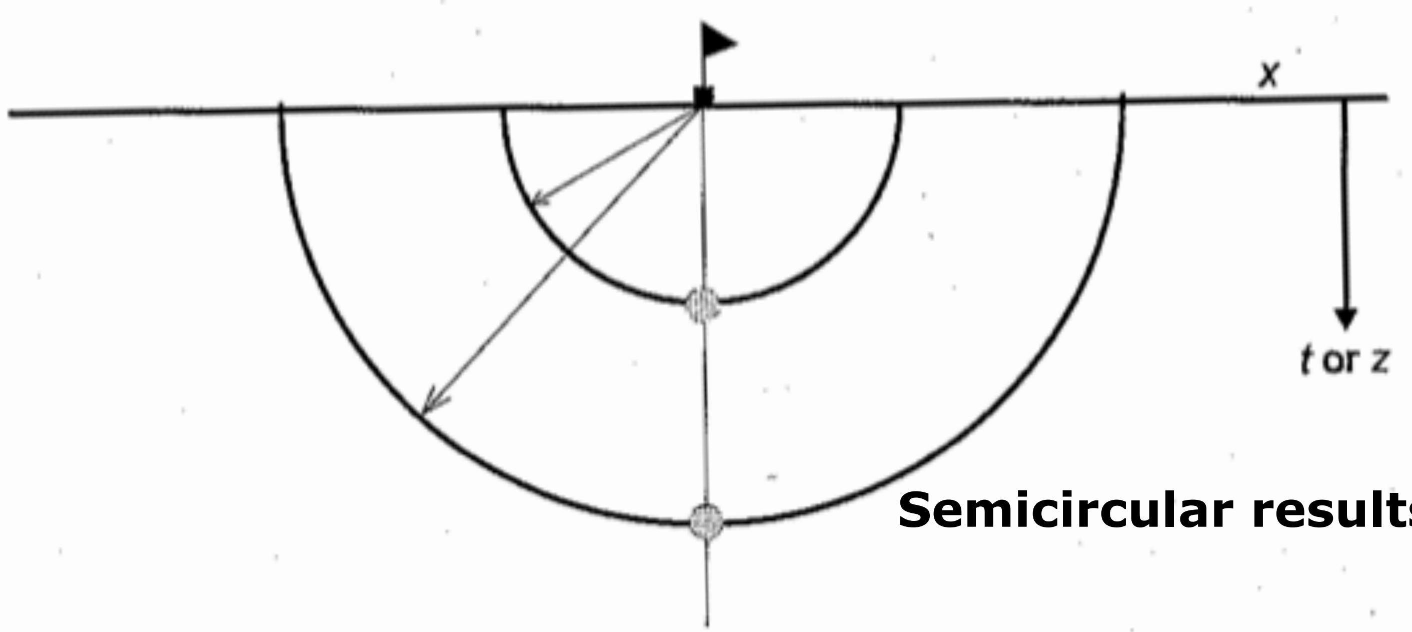
Given a reflection time t, the reflection can be located any position tangent to a semicircle with r=t

Given 2 reflection events from the same dipping reflector, the true location of the dipping interface is the common tangent to the 2 semicircles

Migration of a scatter point



a)



b)

If we have a single seismic trace we do not know where the final (migrated) position of the seismic events will be.
SO WHAT*?*

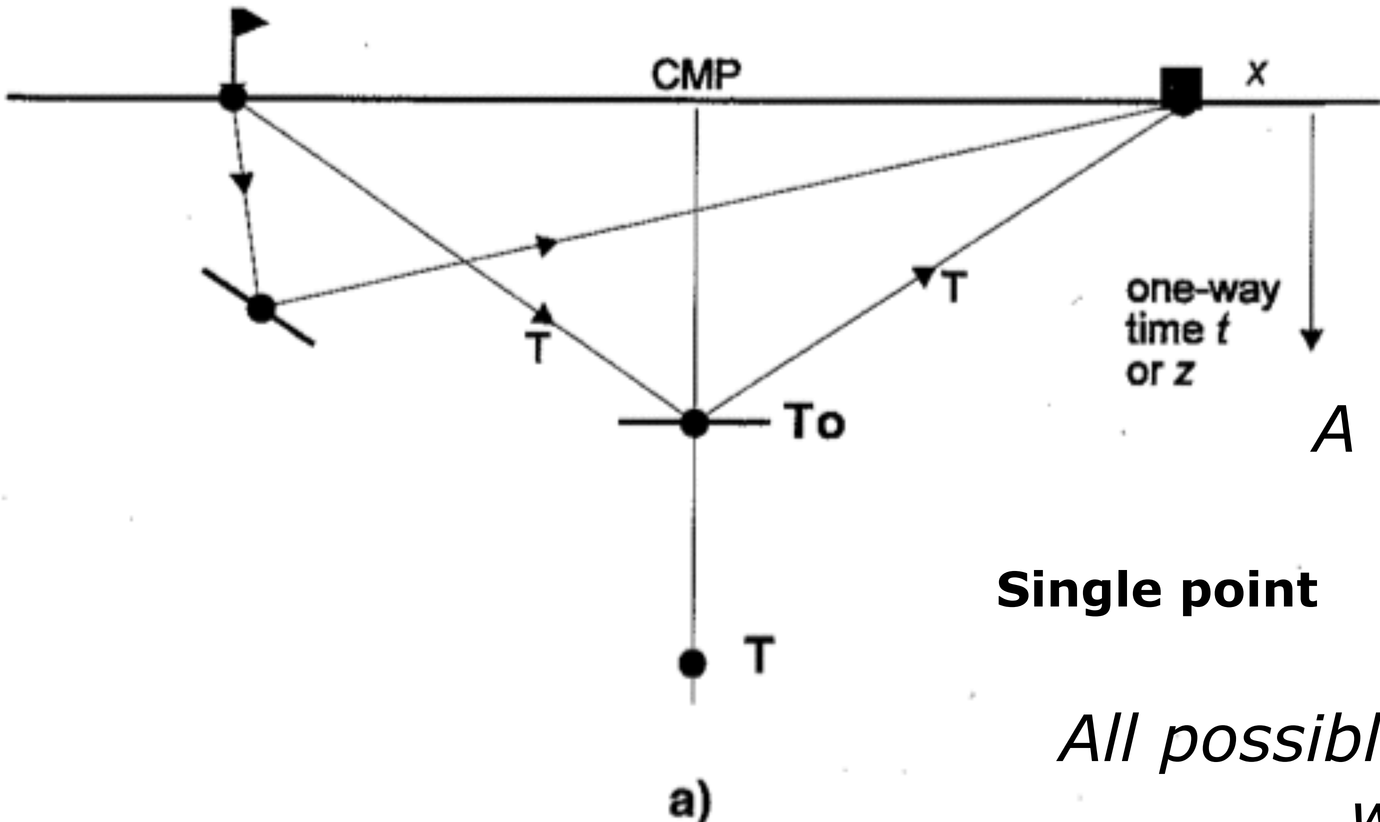
we take the amplitude of the event and distribute it in ***semicircles****.*

constructive interference of semicircles creates the migrated image.

destructive interference will cancel ***smiles****.*

if a seismic section is noisy the results of migration are ***smiles***

Pre-stack migration (PSM) of a single point



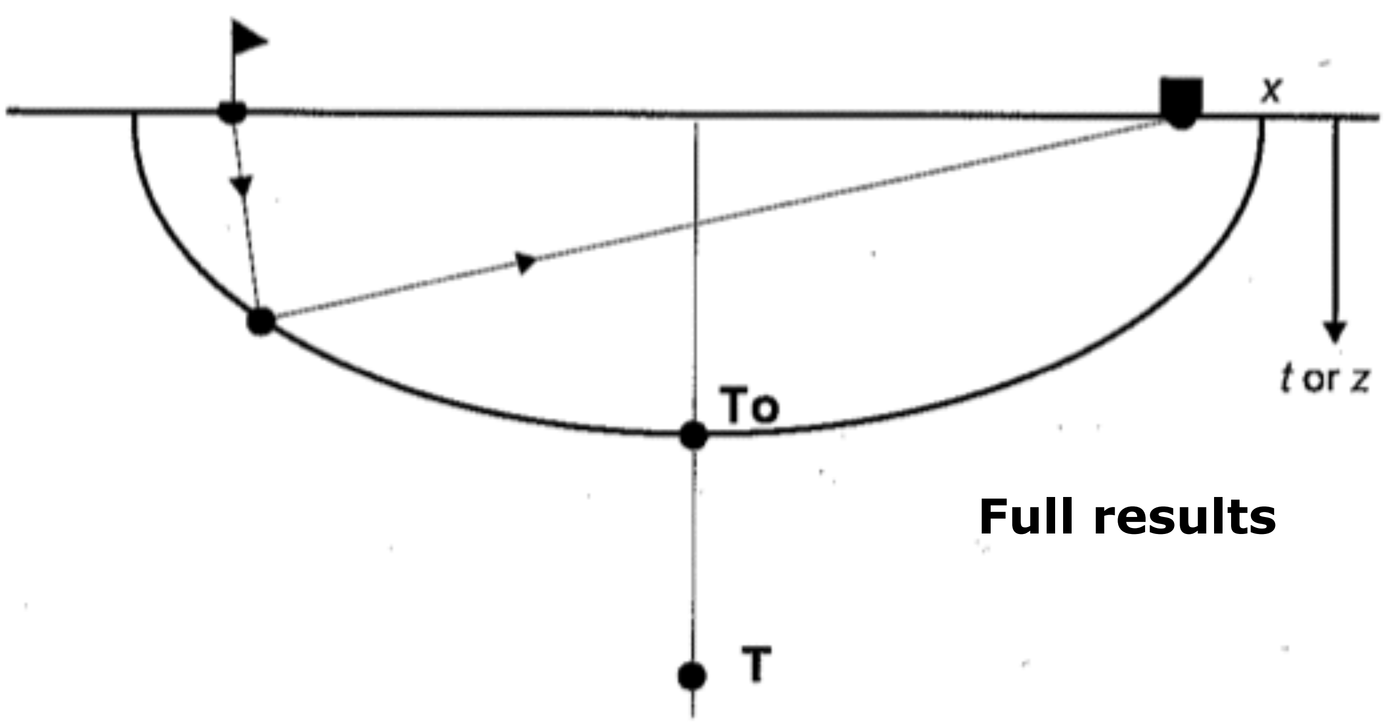
Single point

PSM needs location of SR for each trace to determine reflector location

A seismic event can come from any reflection point that has the same total time for the raypath

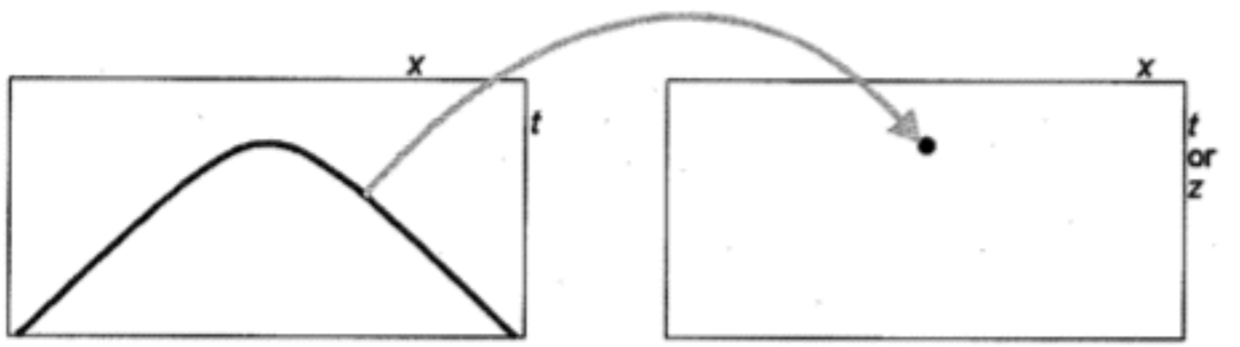
All possible reflection points lie on an ellipse with source and receiver in the foci

Travel times are the same
Reflection angles are equal



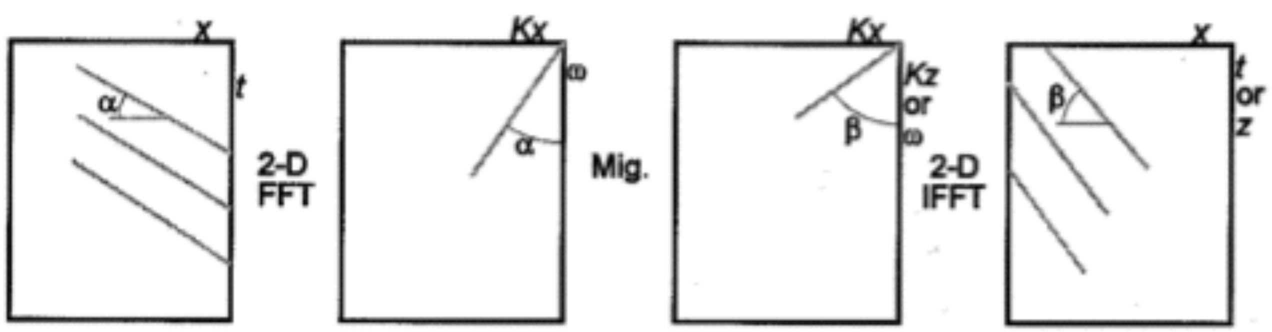
Full results

Examples of 3 major post-stack migration algorithms



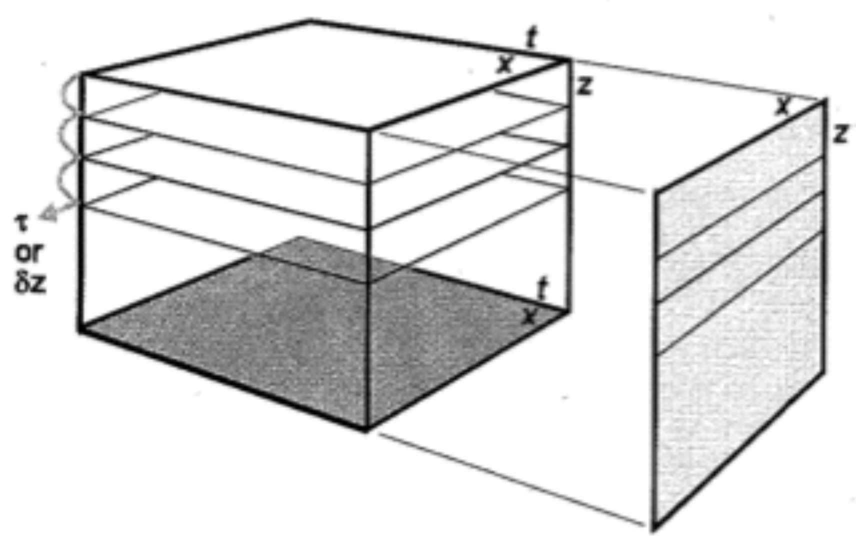
a)

Kirchhoff



b)

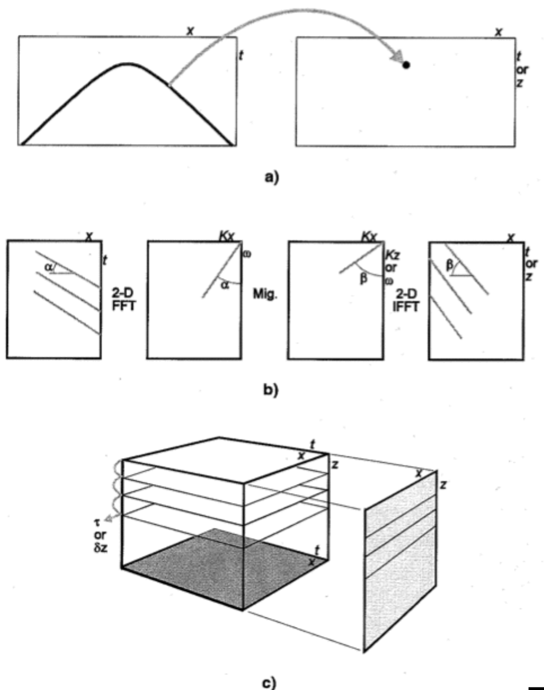
FK



c)

Downward continuation

Examples of 3 major post-stack migration algorithms



Kirchhoff: to produce one output sample, sum the amplitudes along the diffraction (hyperbolic) path on the input section. Additional corrections are required.

FK: convert the input section in the 2-D Fourier domain, migrate by applying a simple multiplicative algorithm, inverse transform to obtain the migrated image

Downward continuation: based on the exploding reflector model, it works on the conceptual data volume (x,z,t), where the plane xz is the geologic (migrated) section and the plane xt is the seismic (unmigrated) section. By using the wave equation, receivers are progressively lowered into the ground until the imaging condition is met at t=0.

Real-world notes

Real-world is more complex

In the models we have introduced so far

> velocity is constant and =1

> topographic surface is flat and horizontal

> noise is zero

> the medium is isotropic

such assumptions help clarify the concepts and test migration algorithms