



Can we hear the shape of the earth?

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Picture from internet:
https://www.vice.com/en_uk/article/mv5knx/we-need-to-remove-the-taboo-of-talking-about-miscarriage-337

Introduction to exploration seismology without agonizing pain

Who are we?

What can we do in energy industry?

How do we do?

What shall we do in the future?

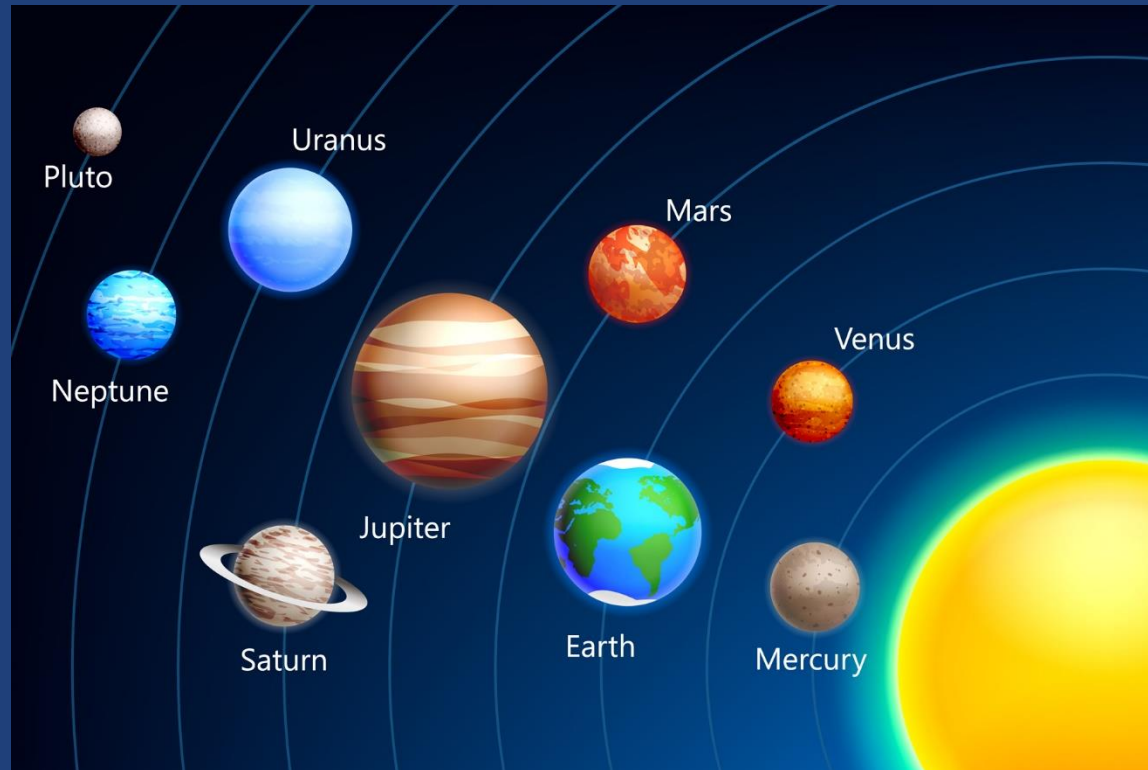
Geophysics



Picture from internet:
<https://www.gettyimages.ch/detail/nachrichtenfoto/the-majestic-spiral-galaxy-ngc-4414-as-photographed-by-nachrichtenfoto/904137#/the-majestic-spiral-galaxy-ngc-4414-as-photographed-by-the-hubble-picture-id904137>

Geophysics

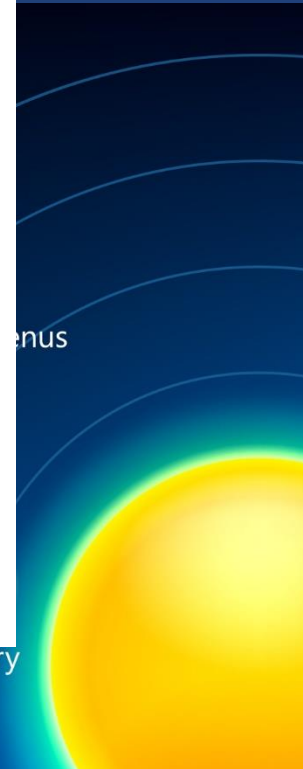
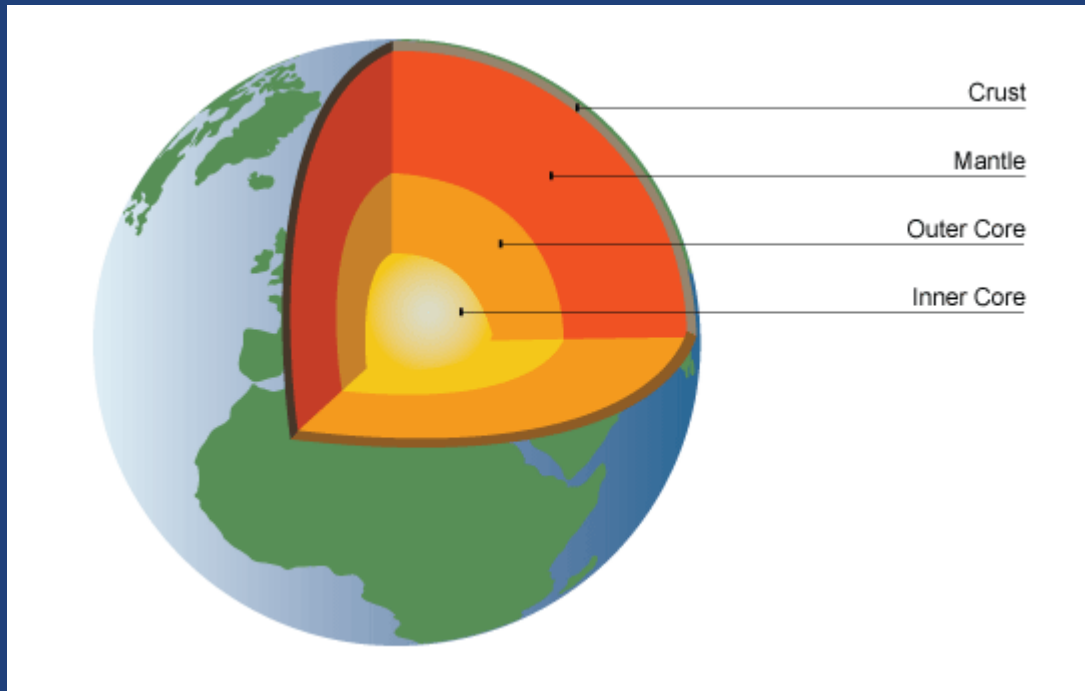
Physical properties and processes



Picture from internet:
<https://universavvy.com/planets-in-order-from-sun>

Geophysics

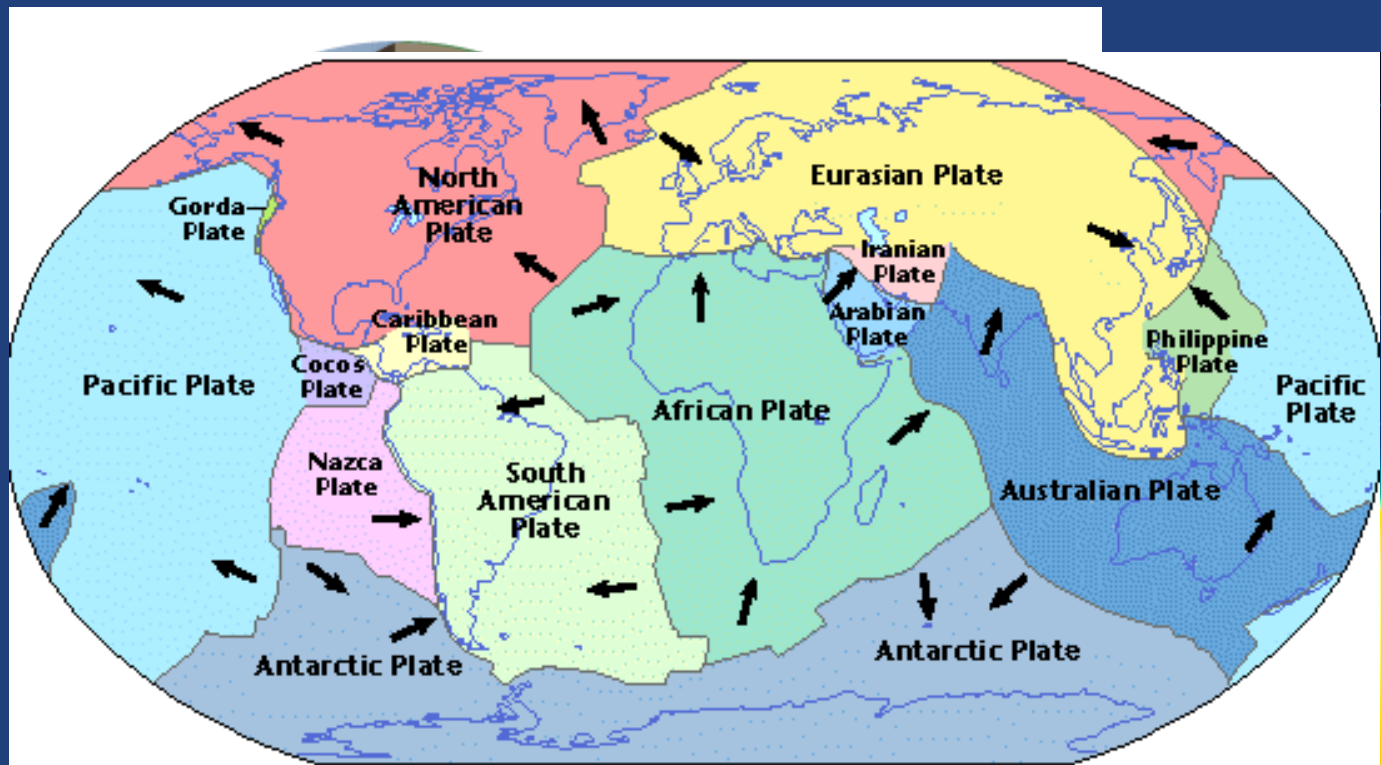
Physical **properties** and processes



Picture from internet:
<https://garsidej.wordpress.com/gcse-aqa-new/the-challenge-of-natural-hazards/tectonic-hazards/>

Geophysics

Physical properties and processes



Picture from internet:
<https://nerdgeek.ks.co/tectonic-map-us/possible-water-levels-in-usa-during-and-after-massive-tectonic>

Geophysics

... via the use of **quantitative** methods.
measurement & computation

Geophysics

... quantitative methods includes

electrical
magnetic
electromagnetic
gravity
seismic

Geophysics ... via the use of **seismology**



Seismologist
listens to the shape
of the earth.

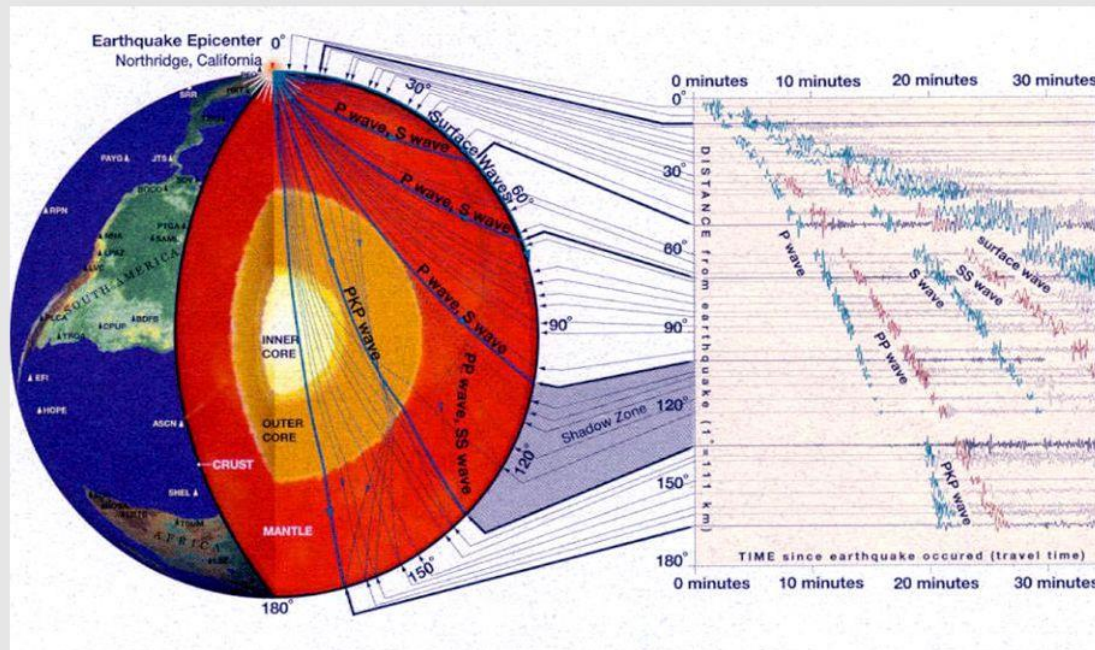
Picture from internet:
<http://findinghappinesmovie.com/happiness-quotes/>

Geophysics

... via the use of **seismology**

IRIS Earth's Interior Structure Poster –
Seismic waves through the Earth

IRIS



Picture from internet:
https://serc.carleton.edu/quant_skills/activities/interior_seismic.html

Seismologists

What can we do in **energy industry**?

How do we do?

What shall we do in the future?

Flowchart of Oil industry

Exploration

Production

Refinement

Marketing

Mission:
Find **location** of oil and gas reservoir and estimate its **size**.

Target area:
0 to 10 km below surface or ocean floor.

Seismologists

Find oil and gas reservoirs

How can we do?

What shall we do in the future?

Workflow of exploration seismology

Measurement

Data acquisition

Data preconditioning

Computation

Seismic migration

Application

Interpretation

Seismic source 'loud speaker'

Seismic truck

**Advantage: mobility,
controlled source
and safe**

**Disadvantage:
Weak and too big**

Picture from internet:
<https://infolupki.pgi.gov.pl/en/technologies/exploration-methods-seismic-analysis>



Seismic source 'loud speaker'



Dynamite (TNT):

Advantage: strong

Disadvantage: destructive

Picture from internet:
<https://www.akgunpatlayici.com/en/products/mke-products/explosive-products/seismic-dynamite>

Seismic source 'loud speaker'



Air gun:

Advantage: mobility

**Disadvantage:
potential hazard to
marine animals**

Picture from internet:
<https://www.cgg.com/en/What-We-Do/Offshore/Products-and-Solutions/Source-Solutions>

Acquisition 'Listen to the earth'



Acquisition 'Listen to the earth'



Picture from internet:
<http://www.mitchamindustries.com/products-for-lease/land-seismic/sensors/sercel-sg-5/>

http://www.geomega.hu/mergeo/?page_id=32&lang=en

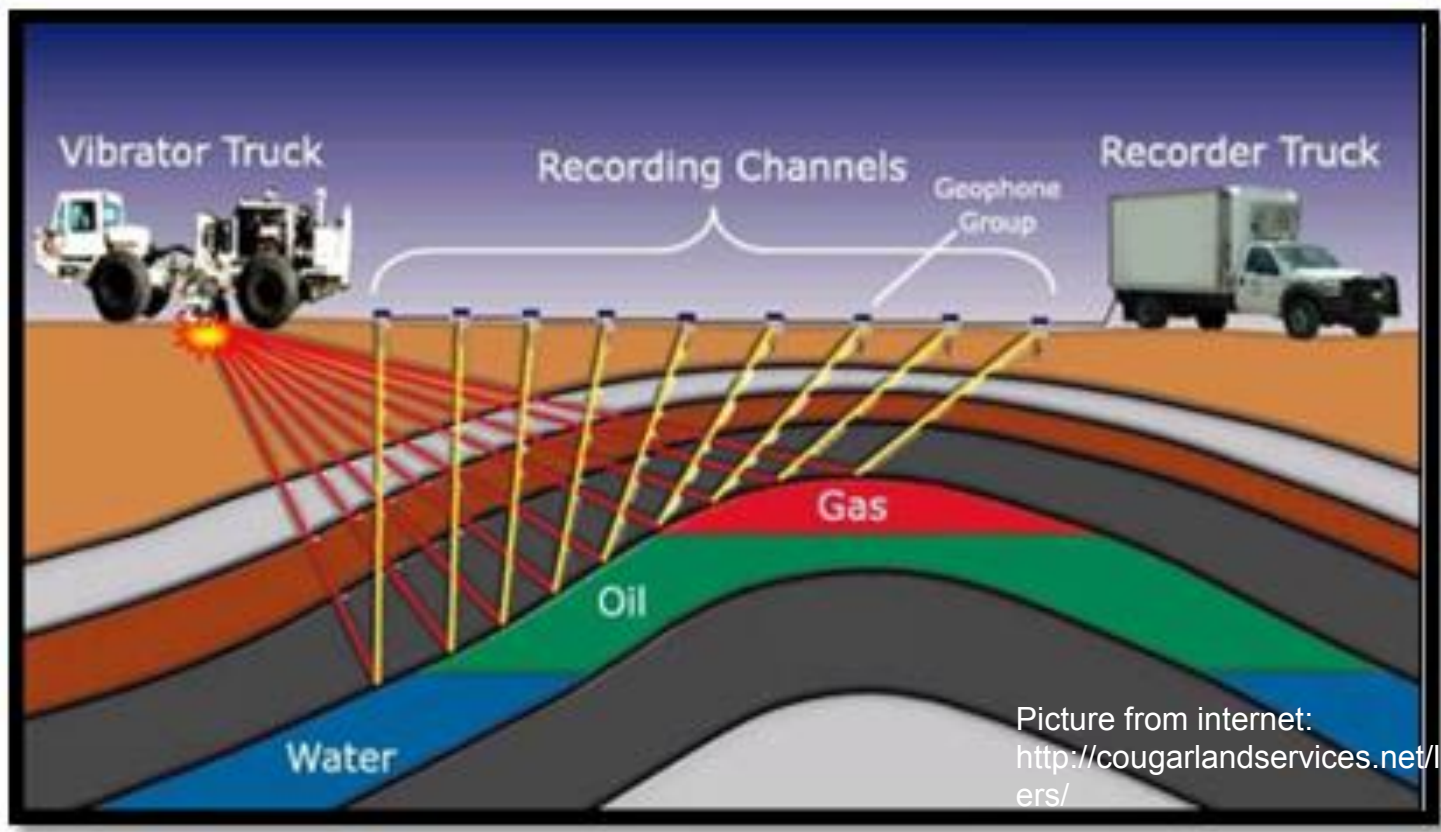


Acquisition 'Listen to the earth'

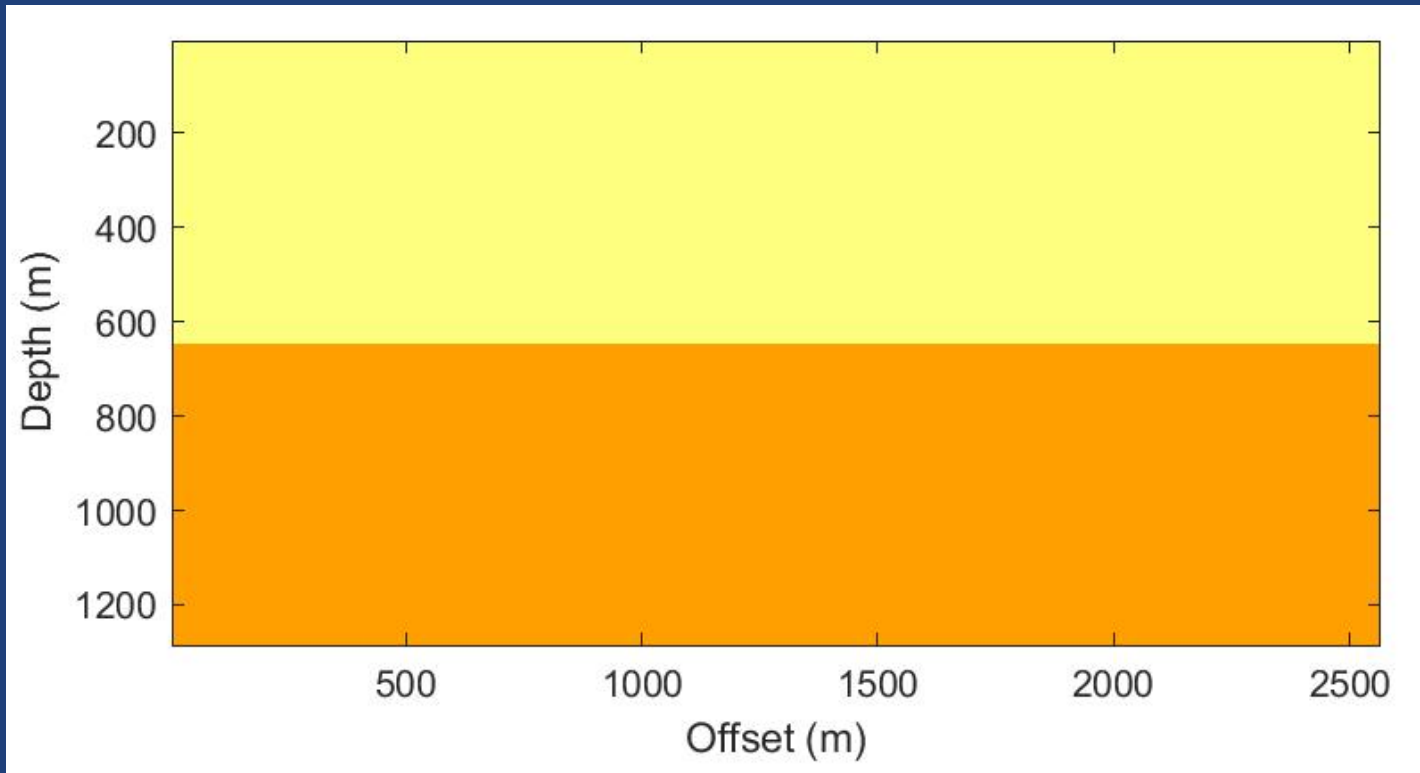


Picture from internet:
<https://www.pddnet.com/news/2016/01/photos-day-largest-man-made-moving-object-earth>

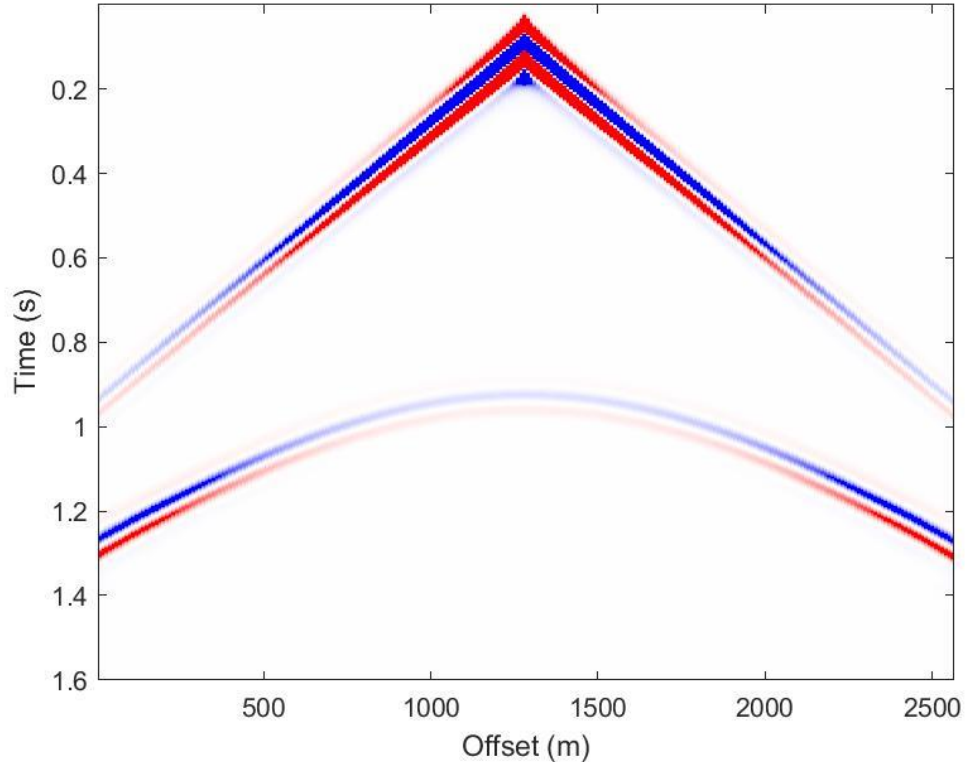
Acquisition 'Listen to the earth'



Acquisition (Listen to the earth)



Acquisition (Listen to the earth)



Workflow of exploration seismology

Measurement

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Data preconditioning

Computation

Seismic migration

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Preconditioning (HiFi music)

Data degradation due to

(1) Electric noise

(2) Civilians noise

...

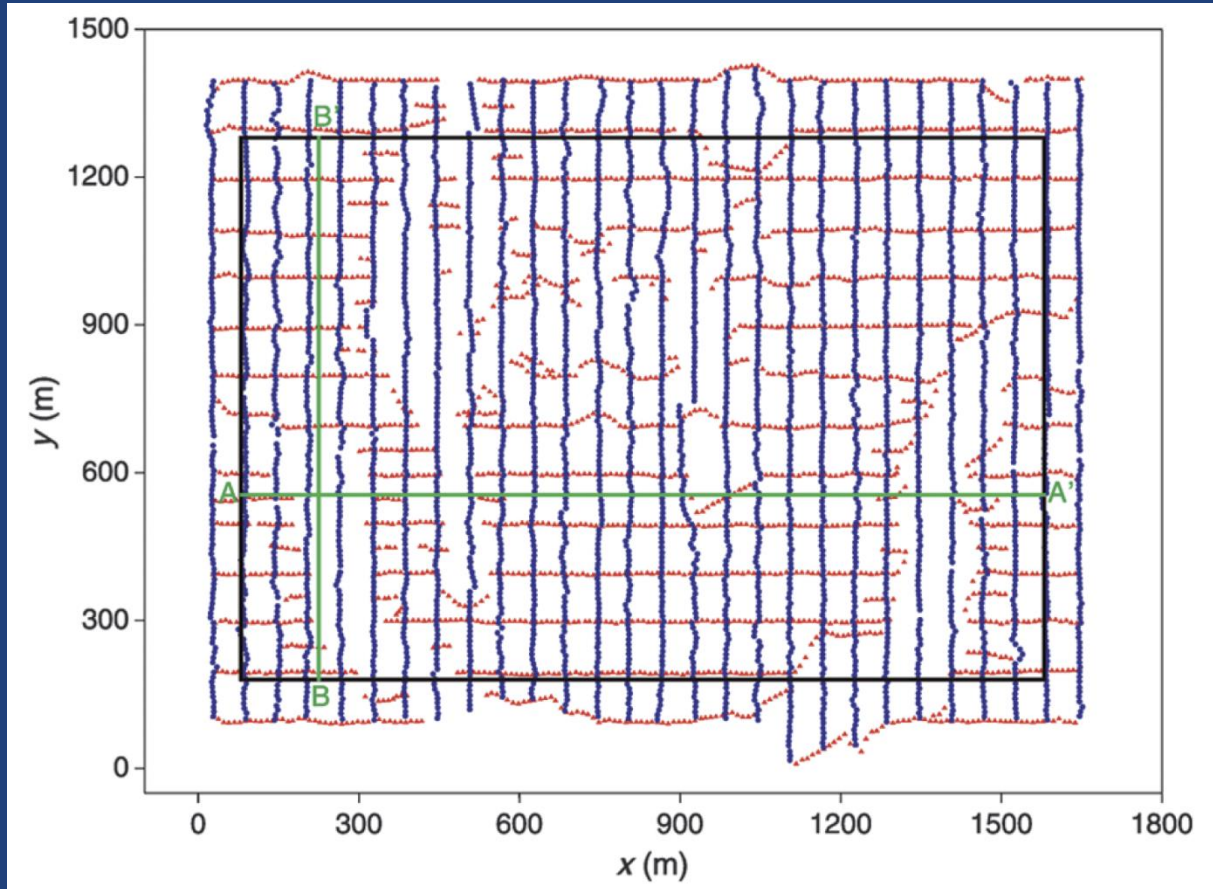
(n) Acquisition geometry

Preconditioning Acquisition geometry



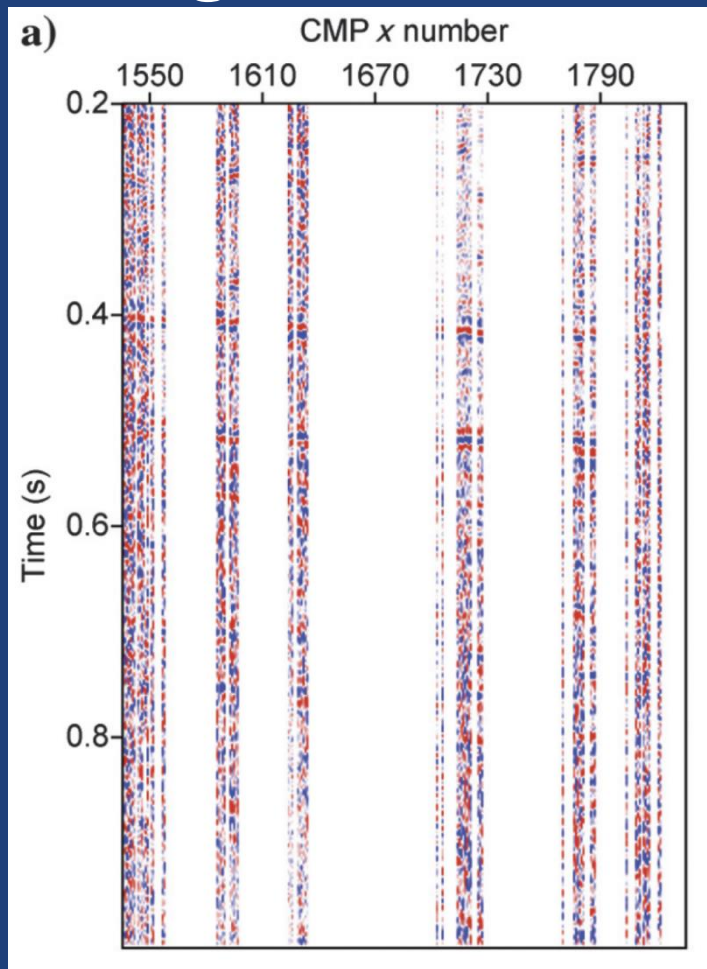
Picture from internet:
<http://www.geoseis.tn/en/equipments/cableless-seismic->

Preconditioning Acquisition geometry



Gao et al.,
Geophysics-2015



Preconditioning Degraded data



Gao et al.,
Geophysics-2015

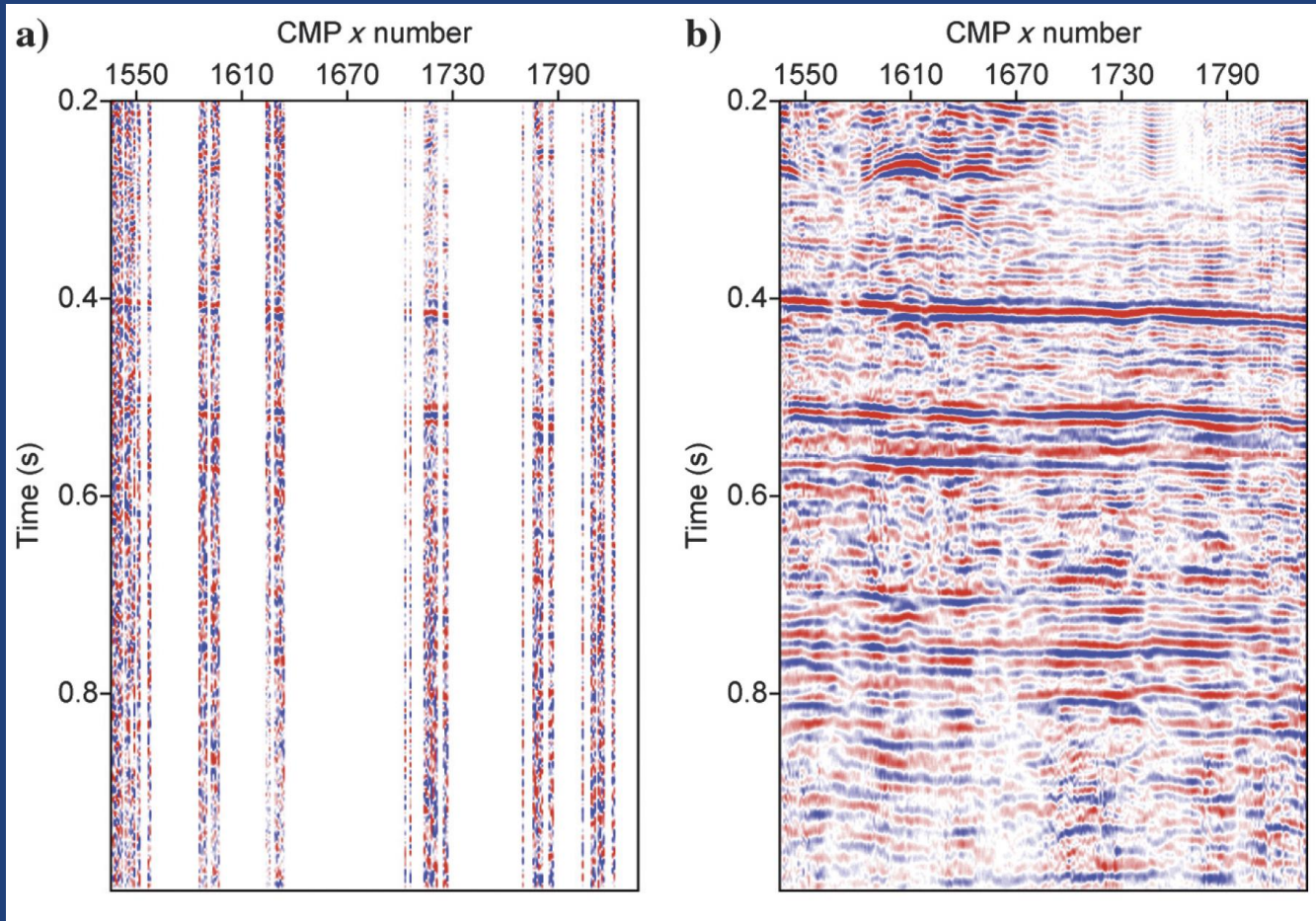
Preconditioning Netflix

Gao et al.,
Geophysics-2015

		Movie 					
		Taxi Driver	Sense and Sensibility	Battleship Potemkin	Raging Bull	Titanic	Alexander Nevsky
User 	John	5	1	5	4	1	3
	Mary	1	4	?	1	4	?
	Pepe	4	2	2	3	4	?
	Adrian	3	1	?	3	3	?
	Tony	?	?	?	?	4	?
	Kevin	3	3	?	3	2	?
	Jianjung	2	1	?	2	4	?
	Natasha	?	?	3	?	5	3

Preconditioning 5D data reconstruction

Gao et al.,
Geophysics-2015



Workflow of exploration seismology

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Seismic migration

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Interpretation

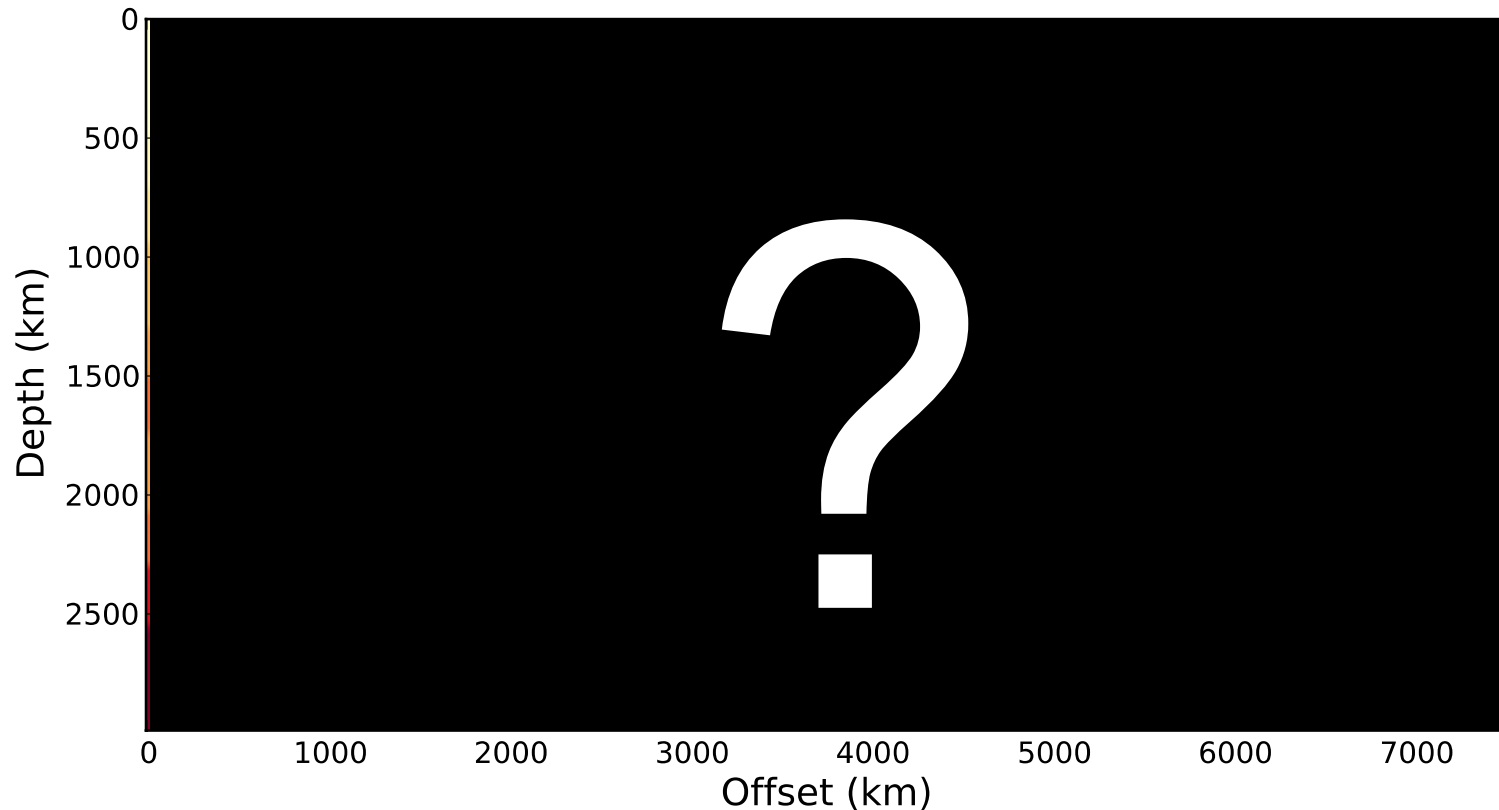
Seismic migration

Migration: translate data into the image of the earth

$$\delta m = \mathcal{L}^T \delta d$$

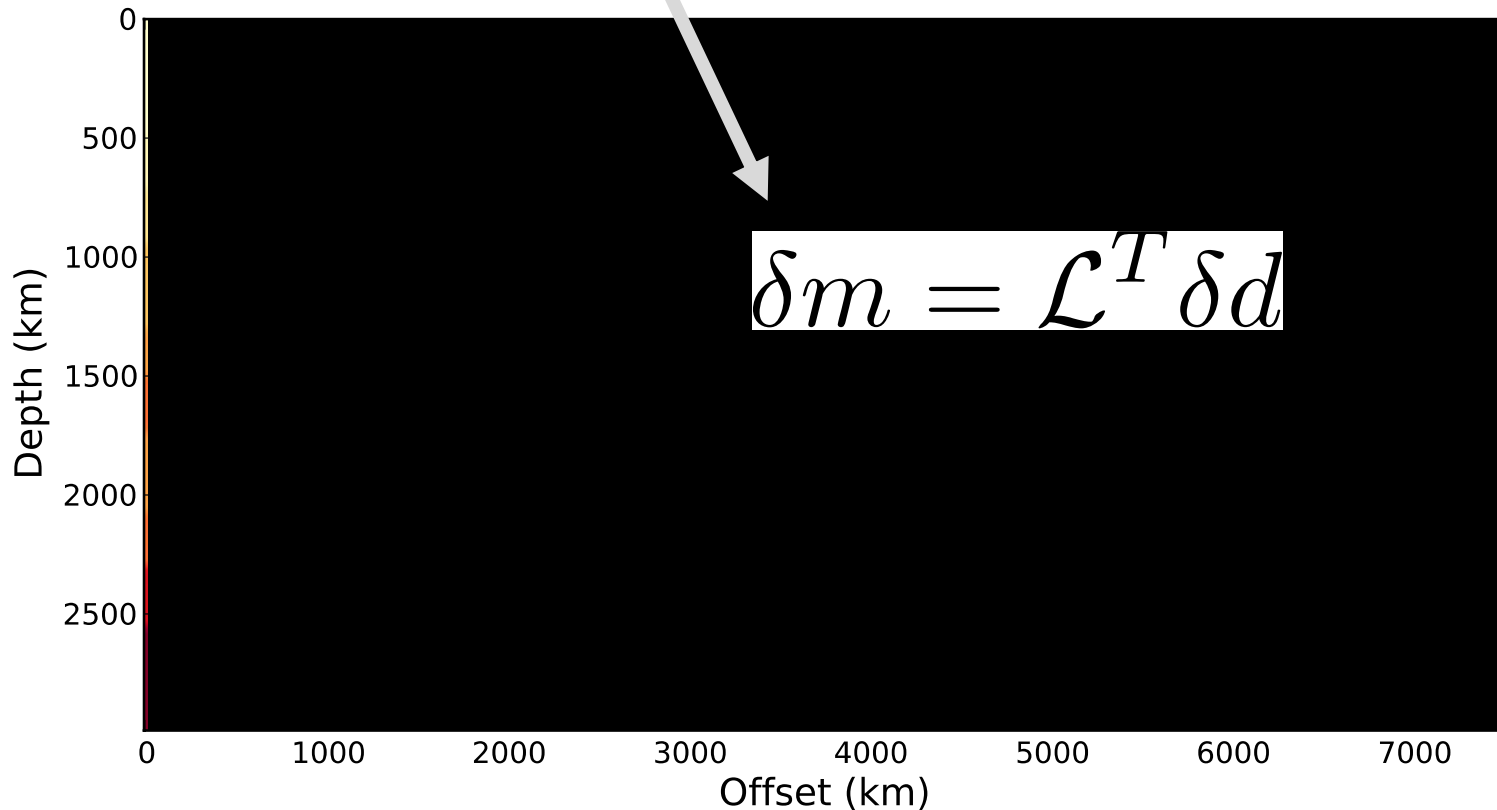
Seismic migration

Migration: Find the **images** from data



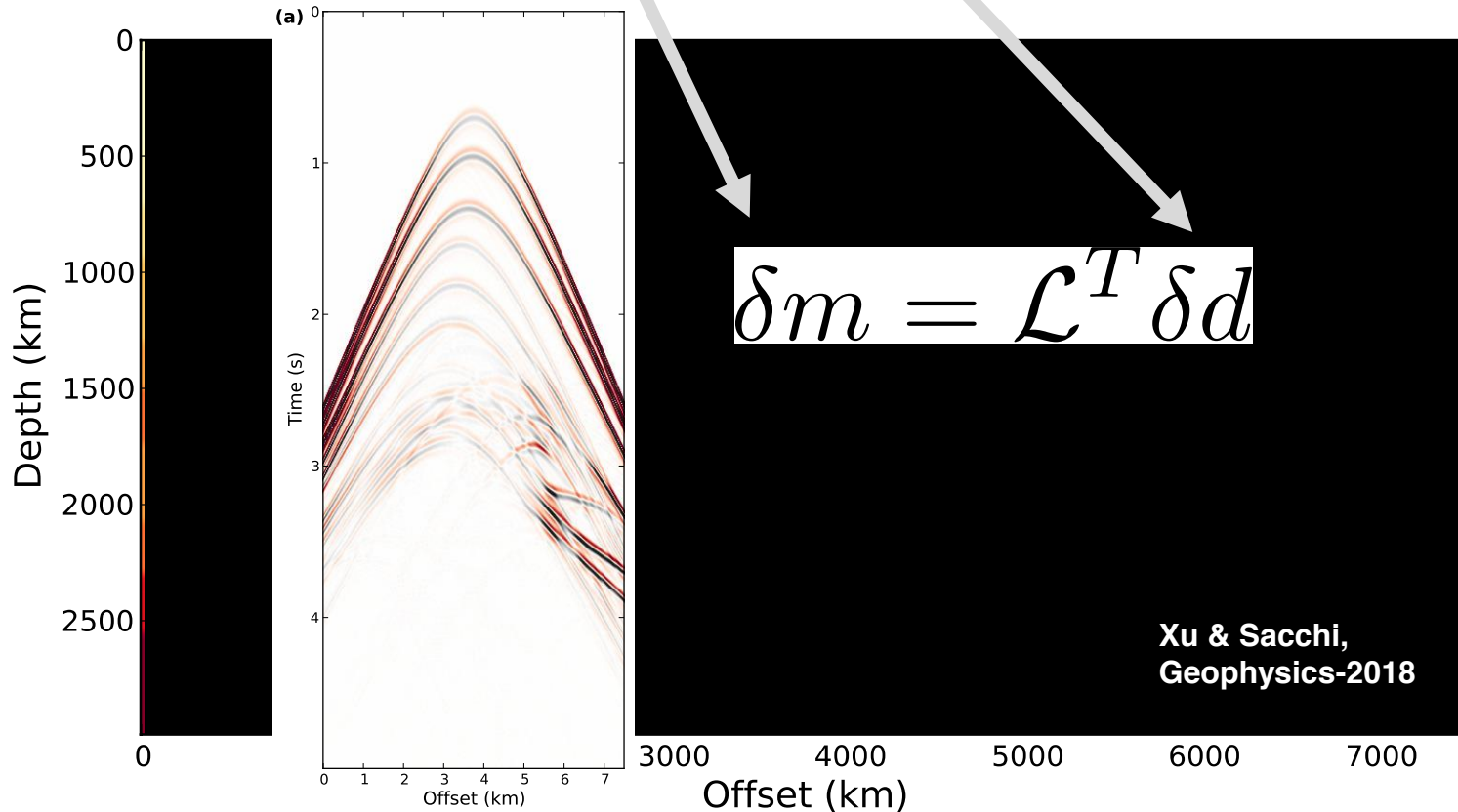
Seismic migration

Migration: Find the **images** from data



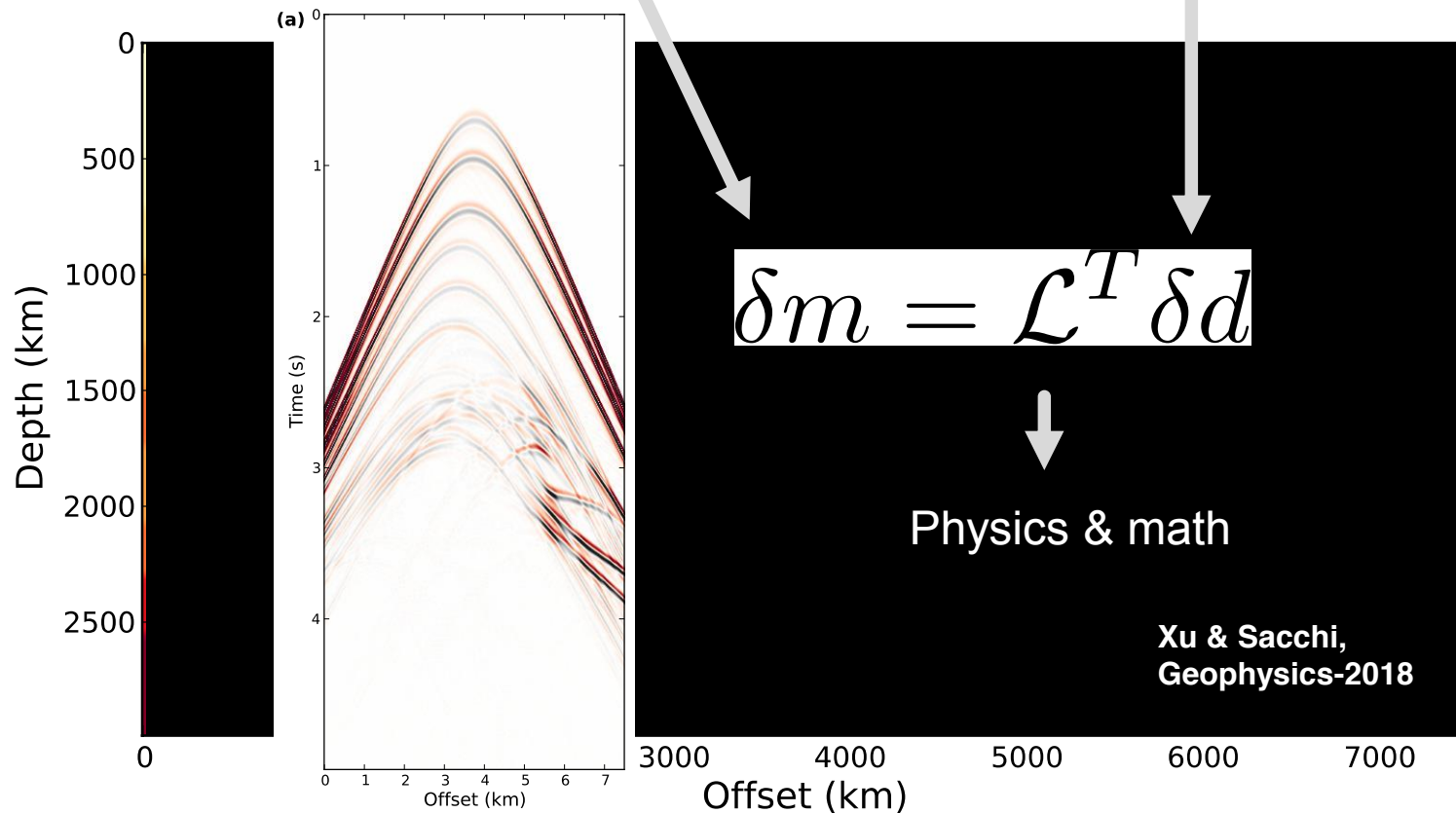
Seismic migration

Migration: Find the **images** from **data**



Seismic migration

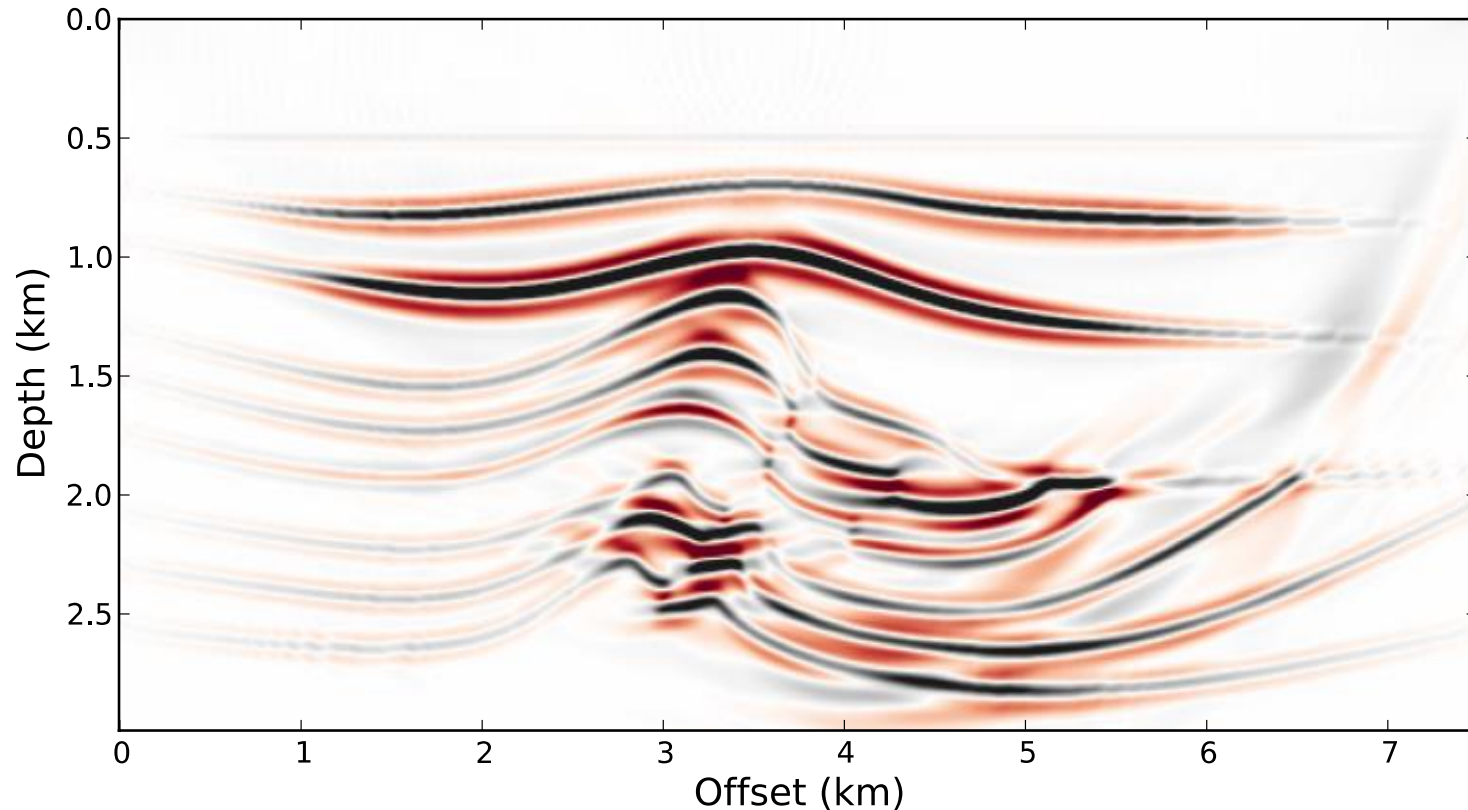
Migration: Find the **images** from **scattered data**



Seismic migration

Migration: Find the images from data

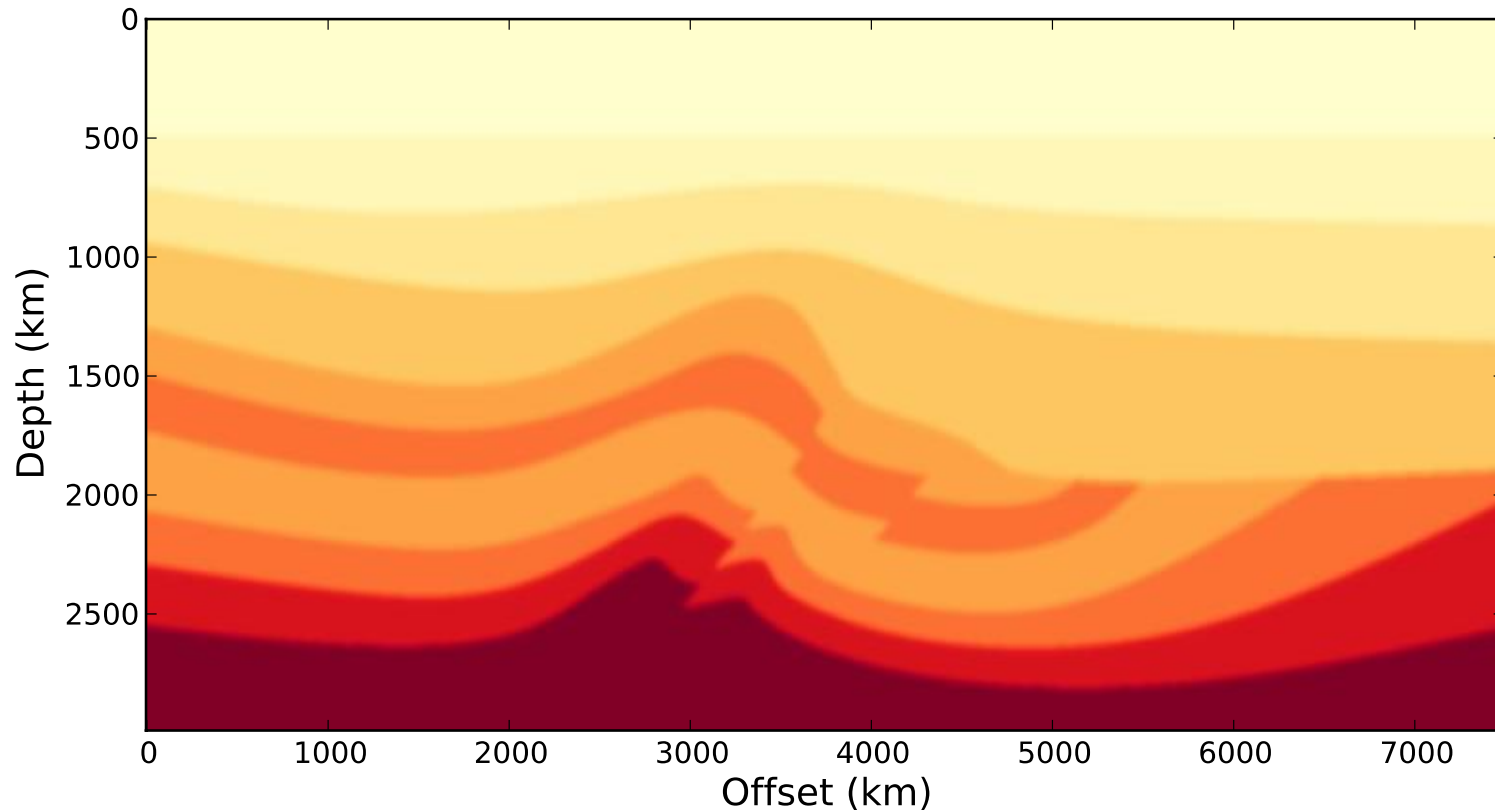
Xu & Sacchi,
Geophysics-2018



Seismic migration

Migration: Find the images from data

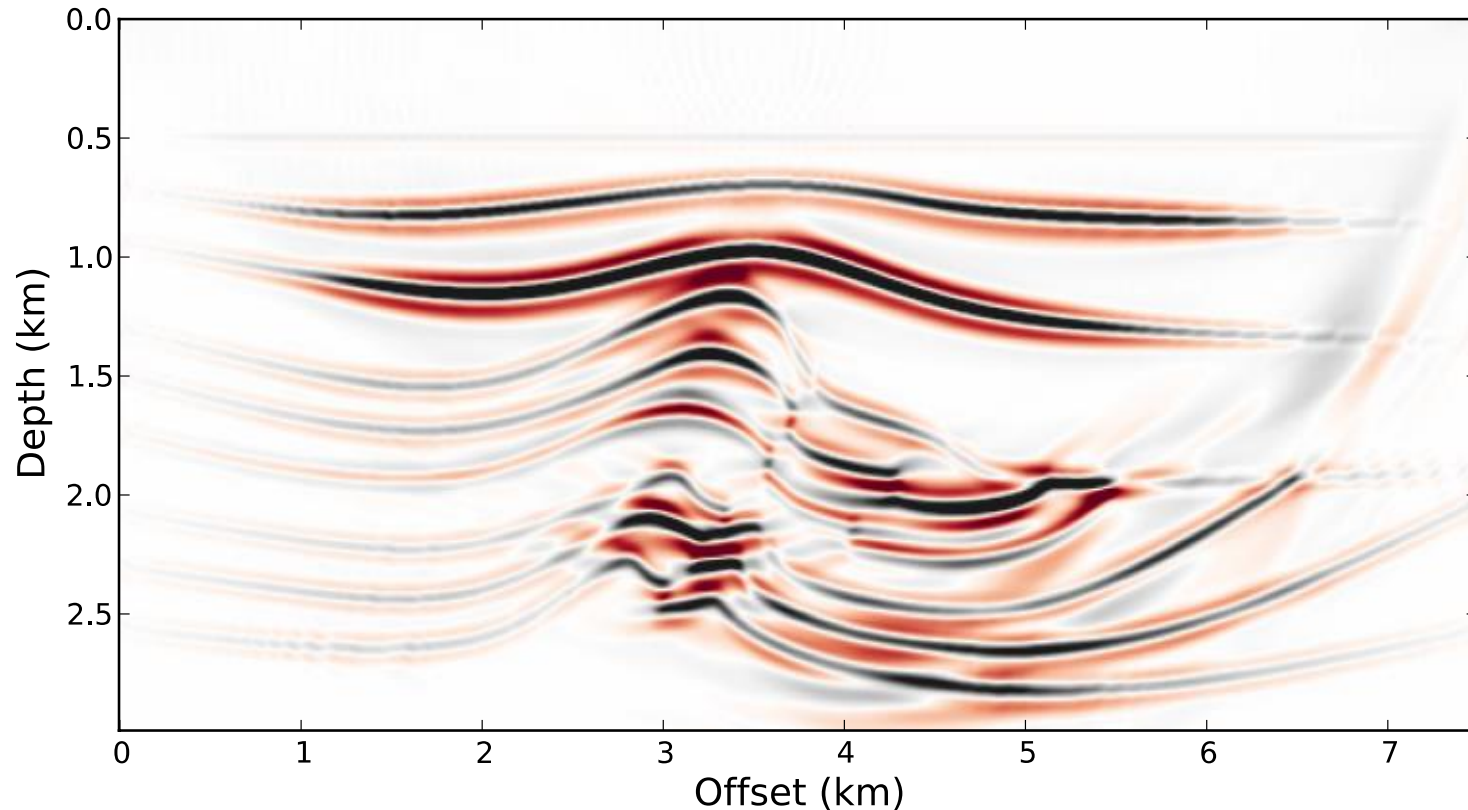
Xu & Sacchi,
Geophysics-2018



Seismic migration

Migration: Find the images from data

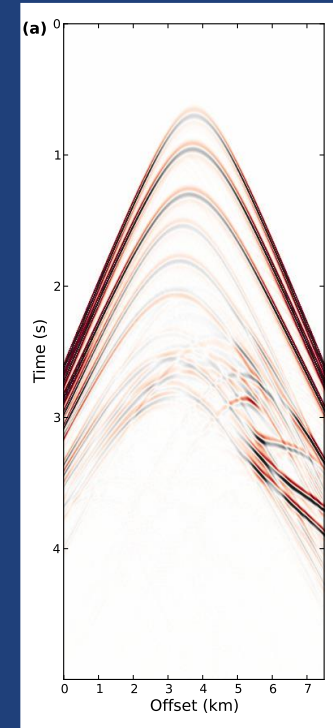
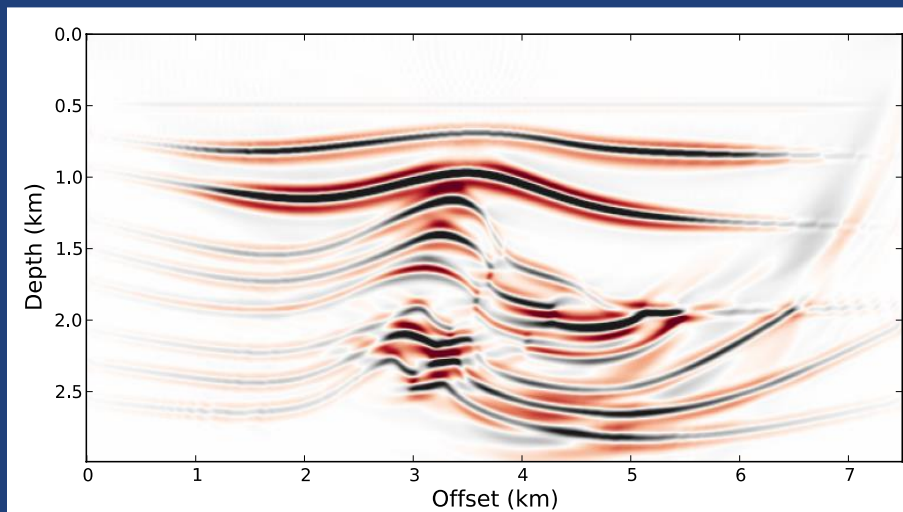
Xu & Sacchi,
Geophysics-2018



Seismic migration

Migration: Find the images from scattered data

$$\delta m = \mathcal{L}^T \delta d$$



Image



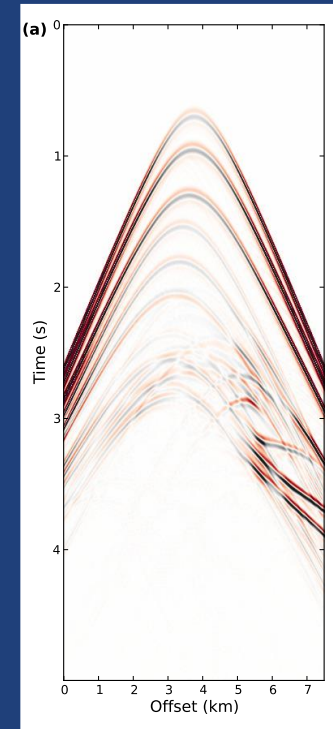
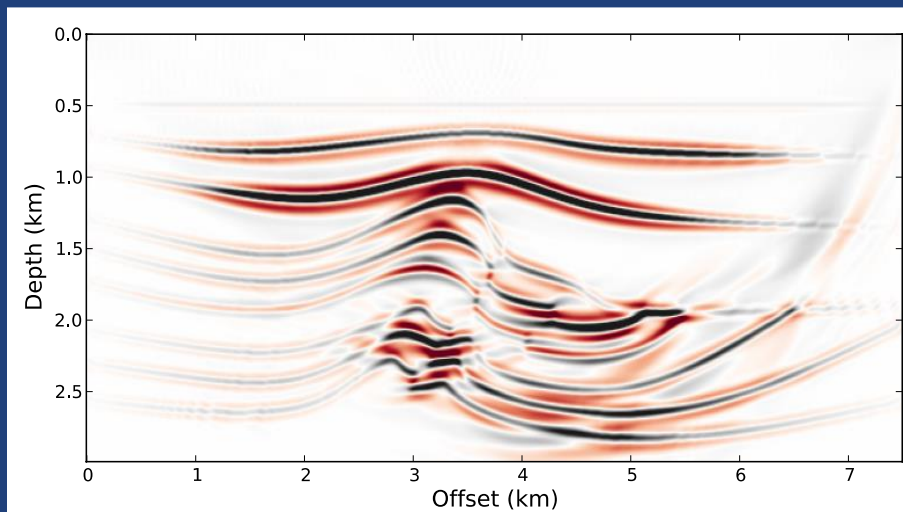
Data

Xu & Sacchi,
Geophysics-2018

Seismic migration

Migration: Find the images from scattered data

$$\delta m = \mathcal{L}^T \delta d$$



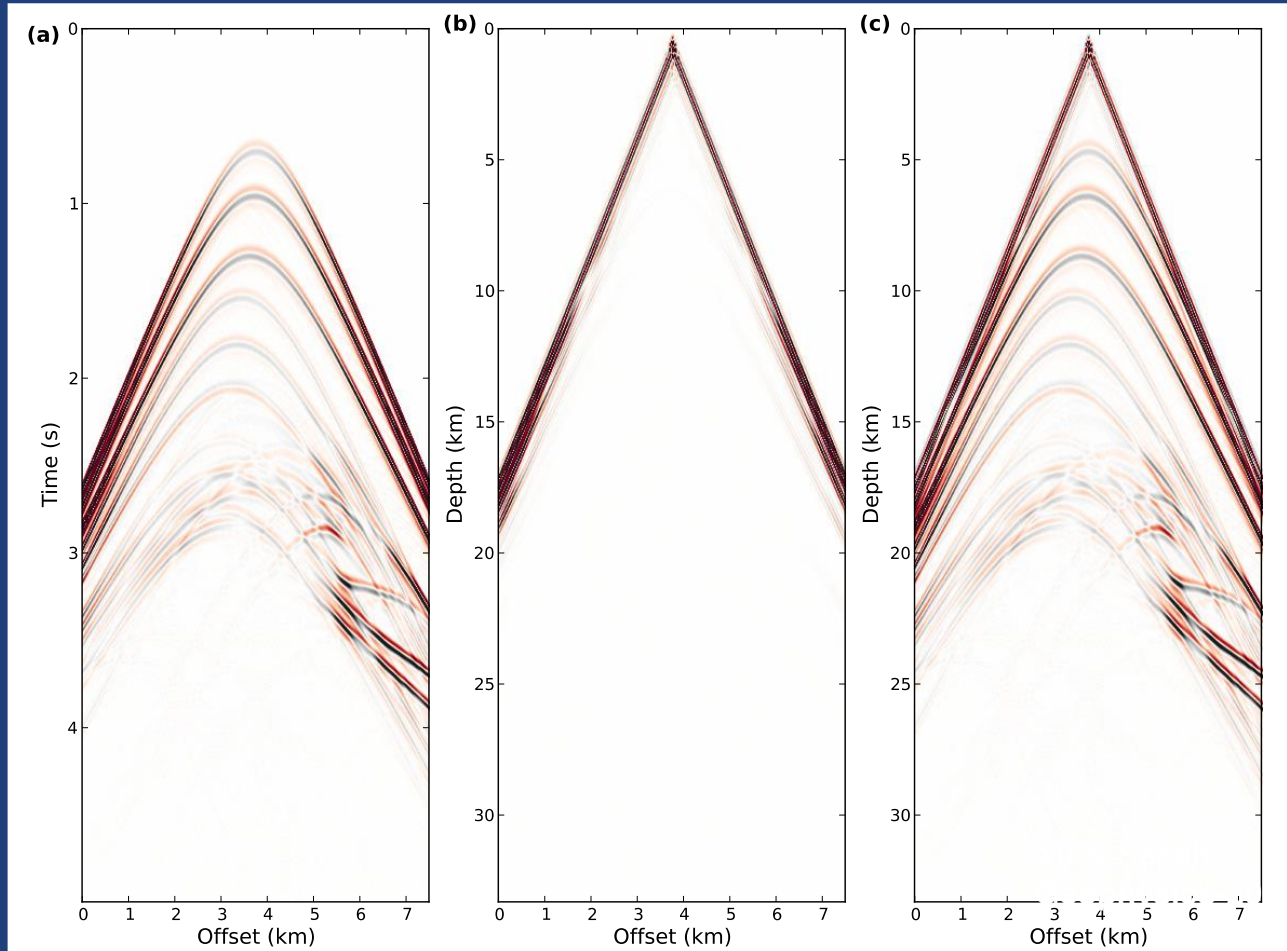
Image



Data

Xu & Sacchi,
Geophysics-2018

Seismic migration



Xu & Sacchi,
Geophysics-2018

Data

Prediction

Residual

Seismic migration

Migration: Find the images from scattered data

$$\delta m = \mathcal{L}^T \delta d$$

Least squares migration: Find the images that fits the data residual *

$$\delta d \approx \mathcal{L} \delta m$$

* Xu & Sacchi, EAGE-2016
Xu & Sacchi, SEG-2016
Xu & Sacchi, SAIG-2016
Xu & Sacchi, GEO-2017

[Acoustic LSRTM]
[Elastic LSRTM]
[Elastic RTM two-way LSM via Born approximation]
[Preconditioned acoustic least-squares two-way wave-equation migration with exact adjoint operator]

Least-squares migration (LSM)

Least-squares migration: solve for the image by minimizing

$$J = \underbrace{\|\mathcal{L}\delta m - \delta d\|_2^2}_{\text{Quadratic measure of data fidelity}} + \mu \underbrace{\|\mathcal{H}\delta m\|_2^2}_{\text{Quadratic Regularization term that minimize bad features}}$$

Quadratic measure
of data fidelity

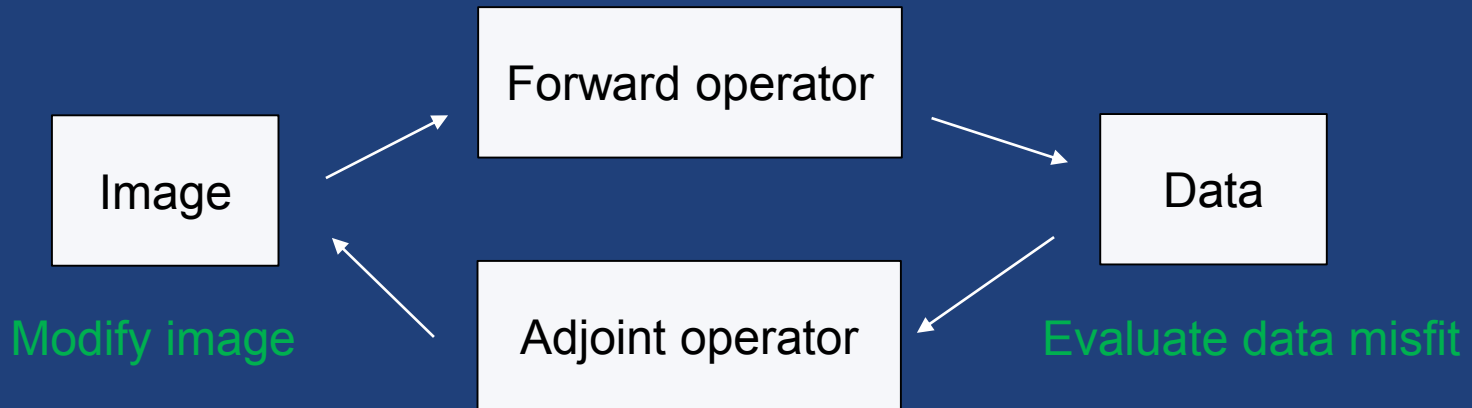
Quadratic Regularization
term that minimize bad
features

Least-squares migration (LSM)

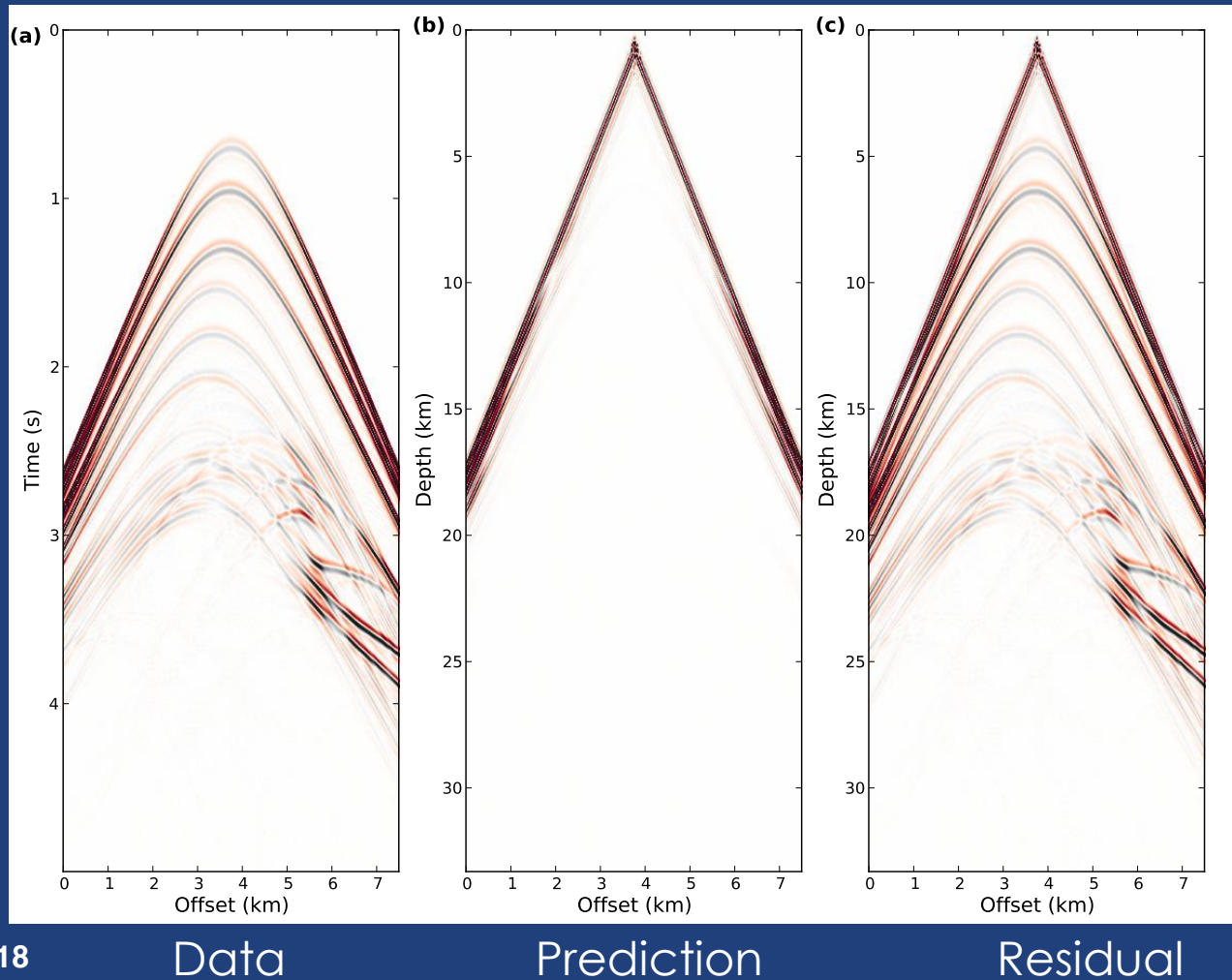
Minimization of J via Conjugate Gradients (**iterative solver**):

$$J = \|\mathcal{L}\delta m - \delta d\|_2^2 + \mu \|\mathcal{H}\delta m\|_2^2$$

Two fundamental operators needed by Conjugate Gradients (CG):



Seismic migration



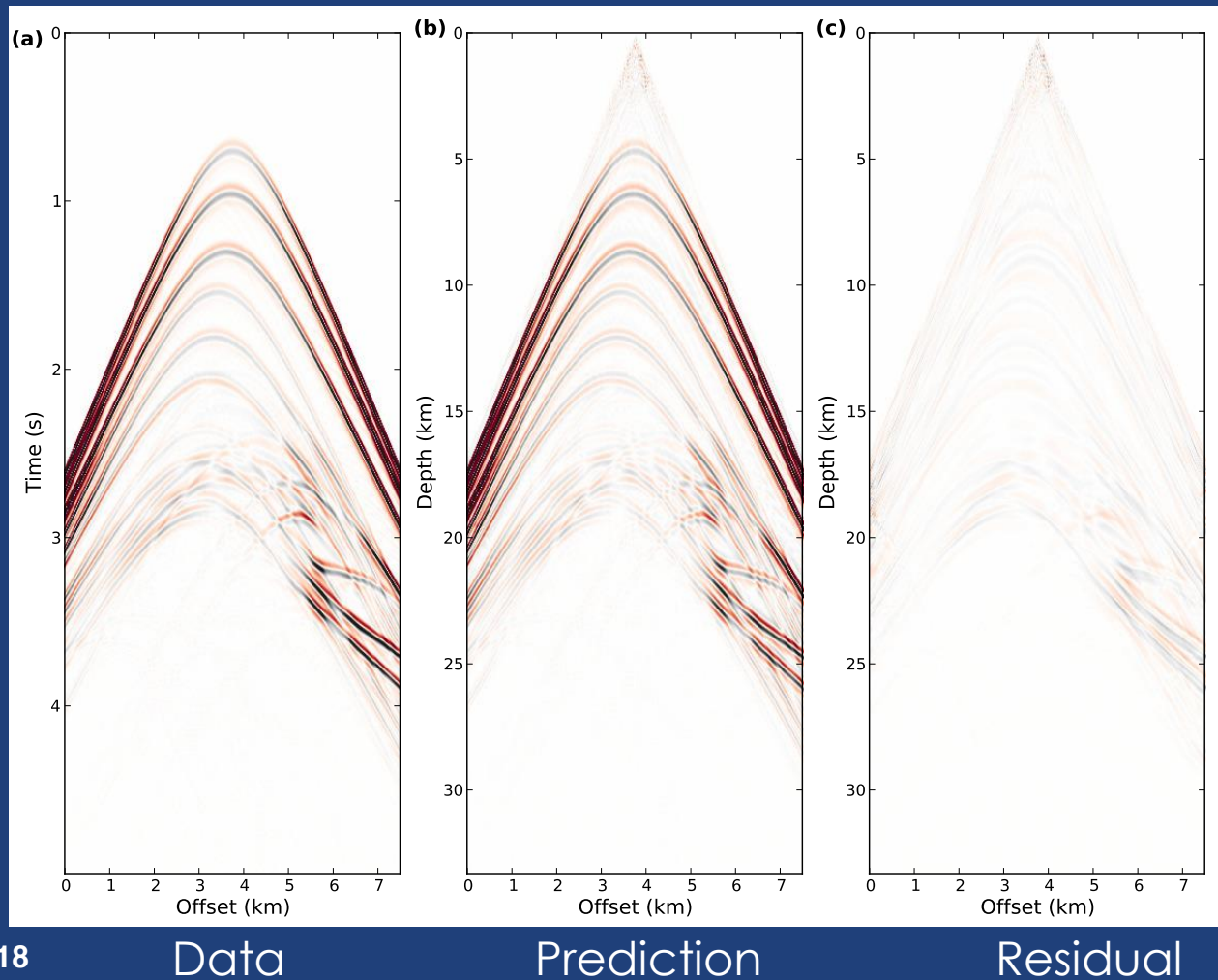
Xu & Sacchi,
Geophysics-2018

Data

Prediction

Residual

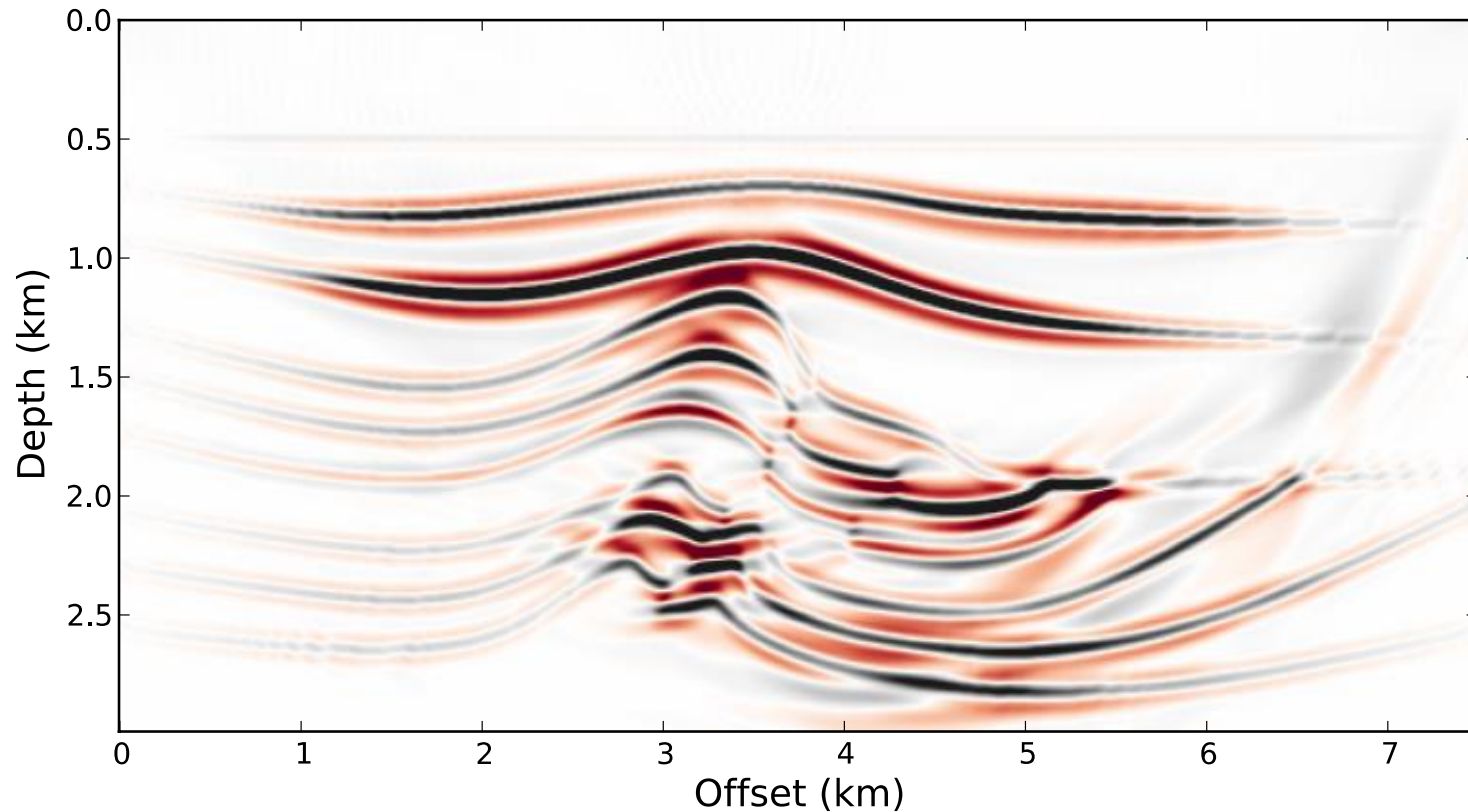
Least-squares migration (LSM)



Xu & Sacchi,
Geophysics-2018

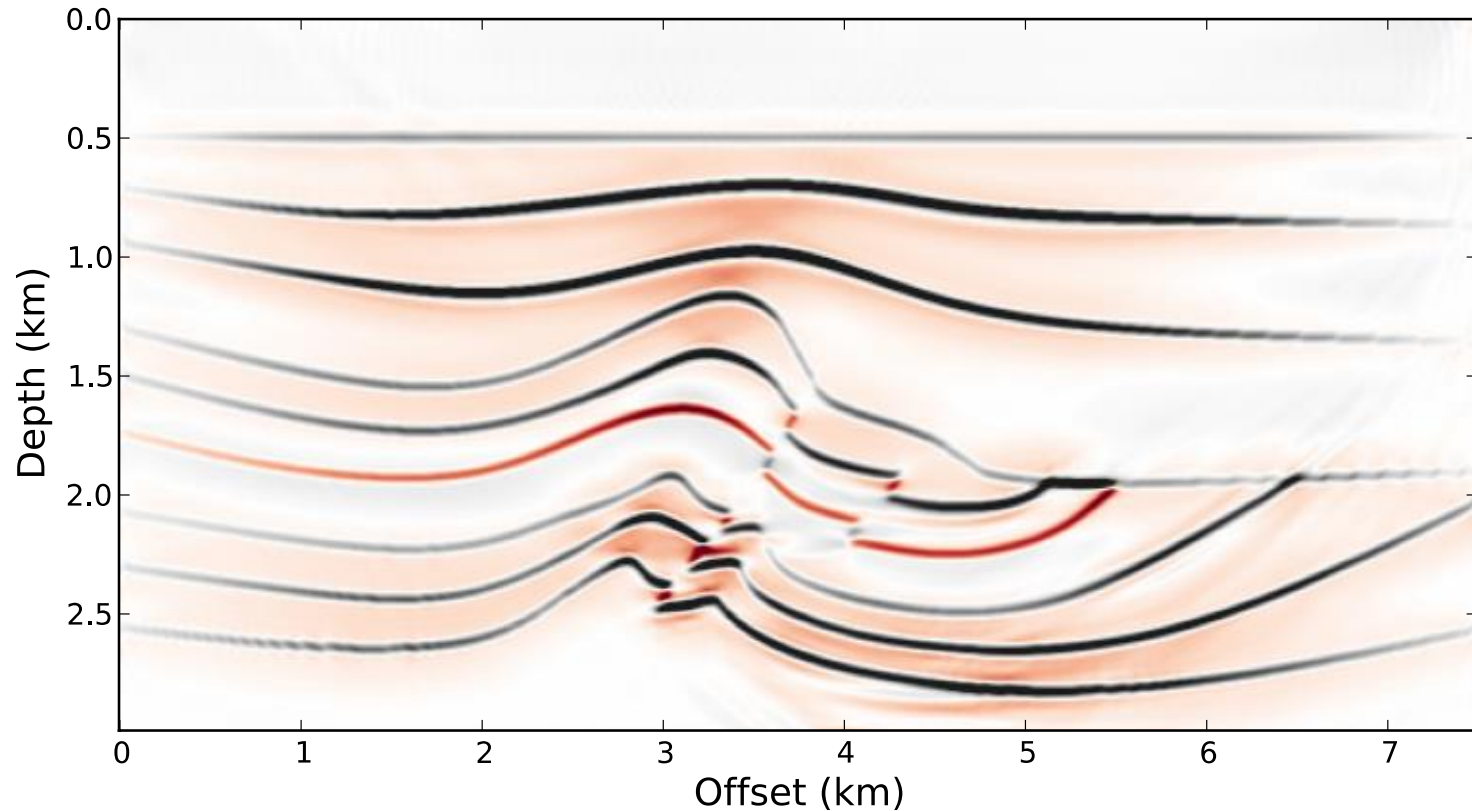
Seismic migration

Xu & Sacchi,
Geophysics-2018



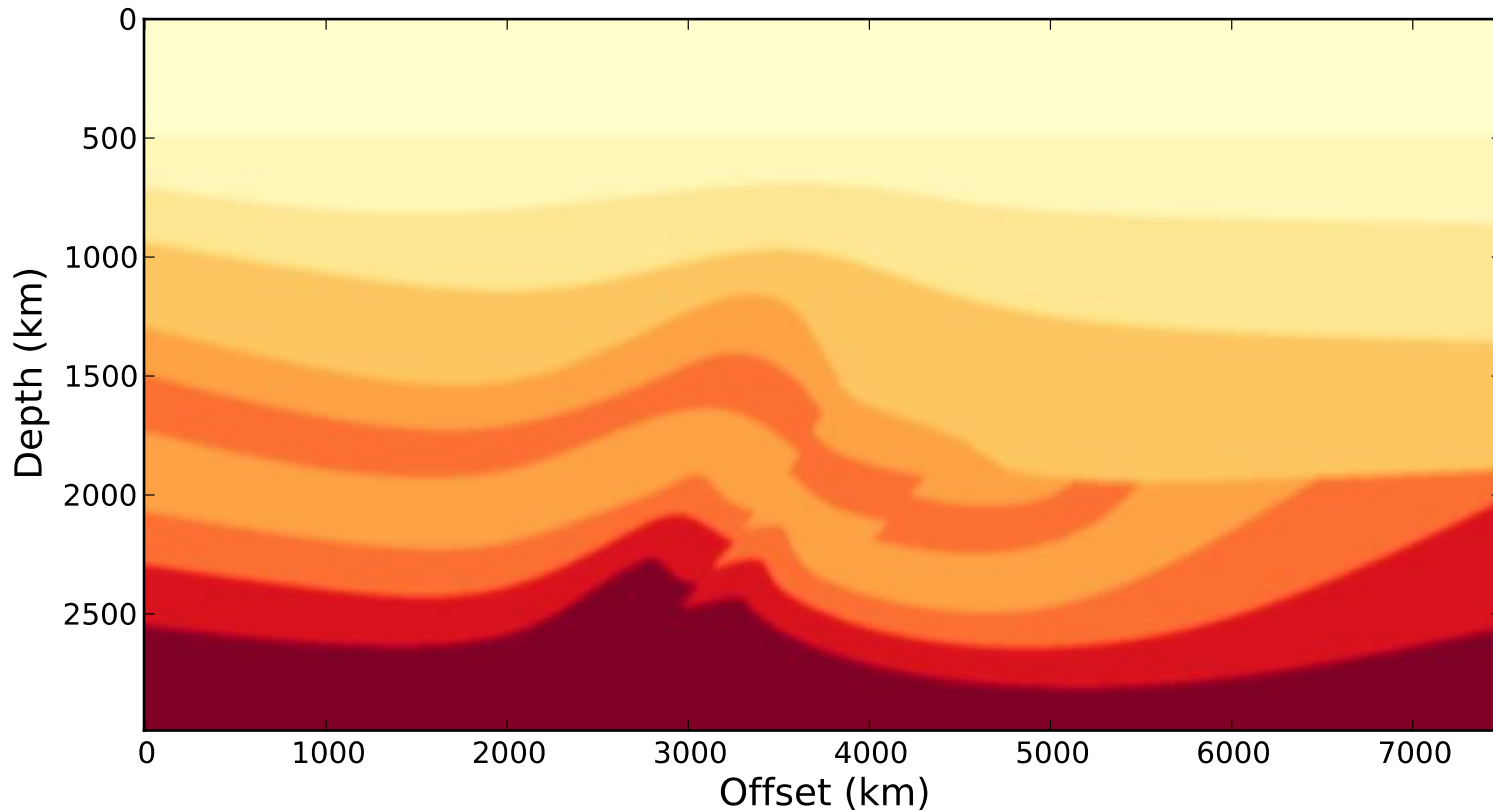
Least-squares migration (LSM)

Xu & Sacchi,
Geophysics-2018



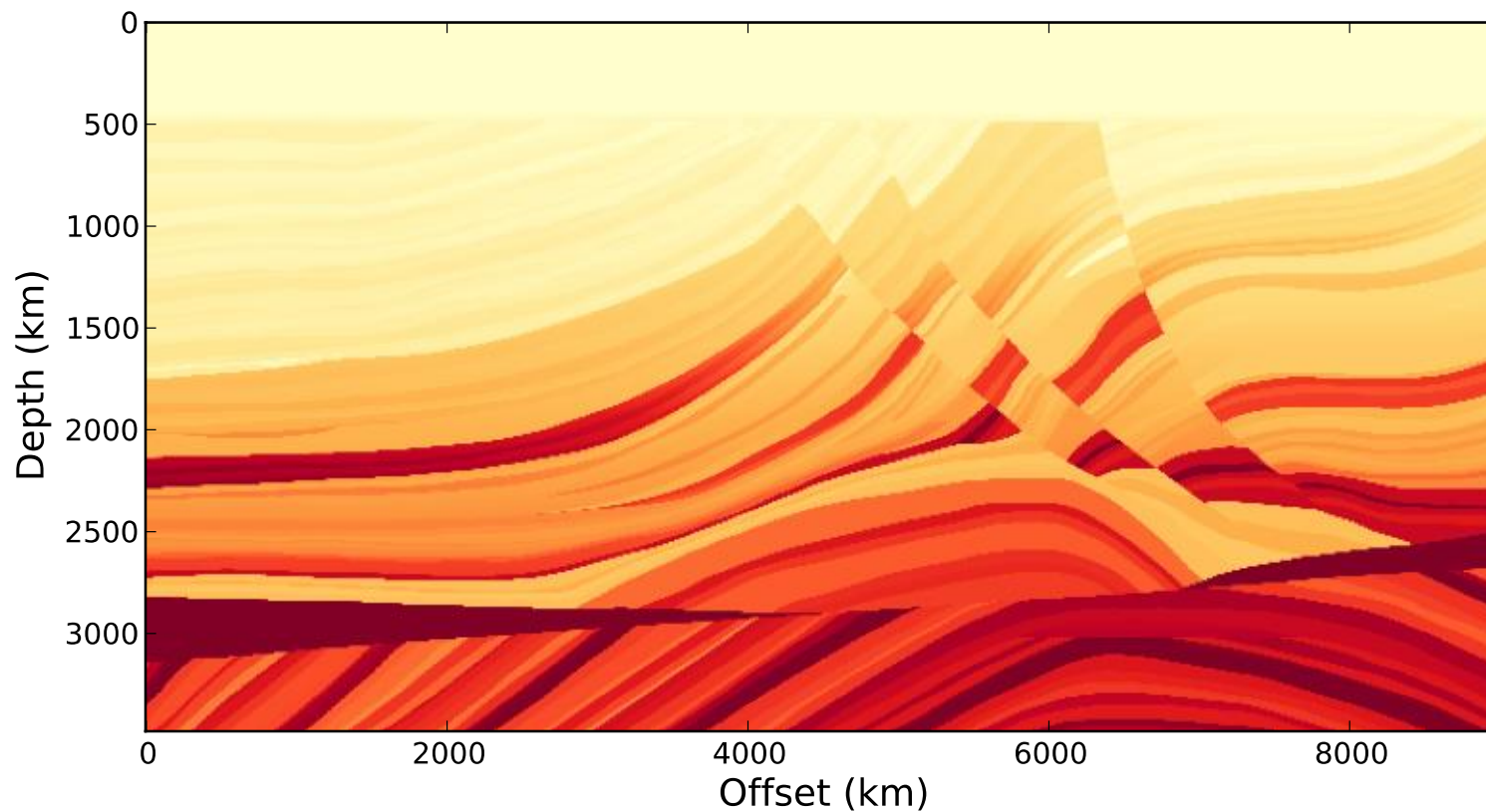
True model

Xu & Sacchi,
Geophysics-2018



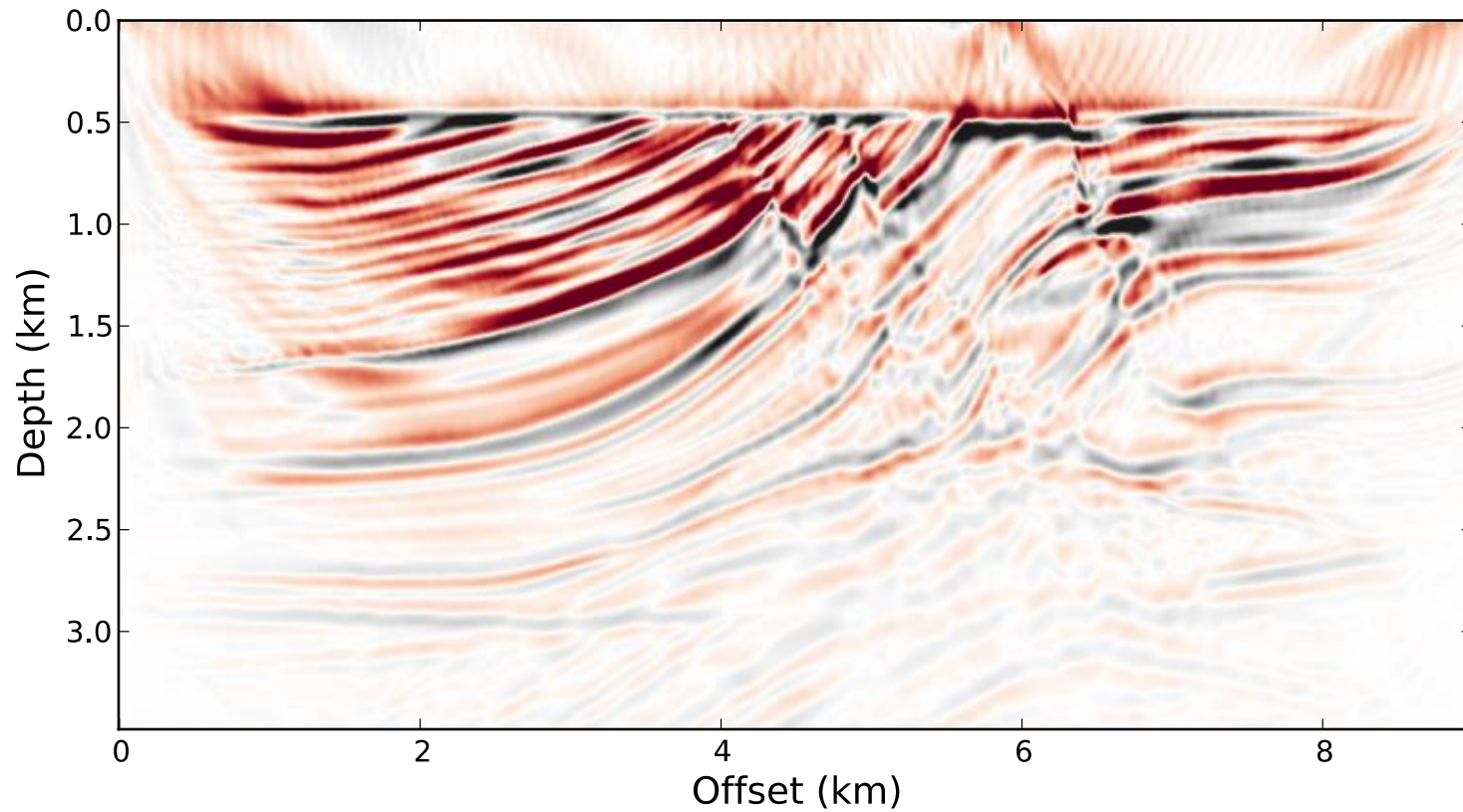
True model

Xu & Sacchi,
Geophysics-2018



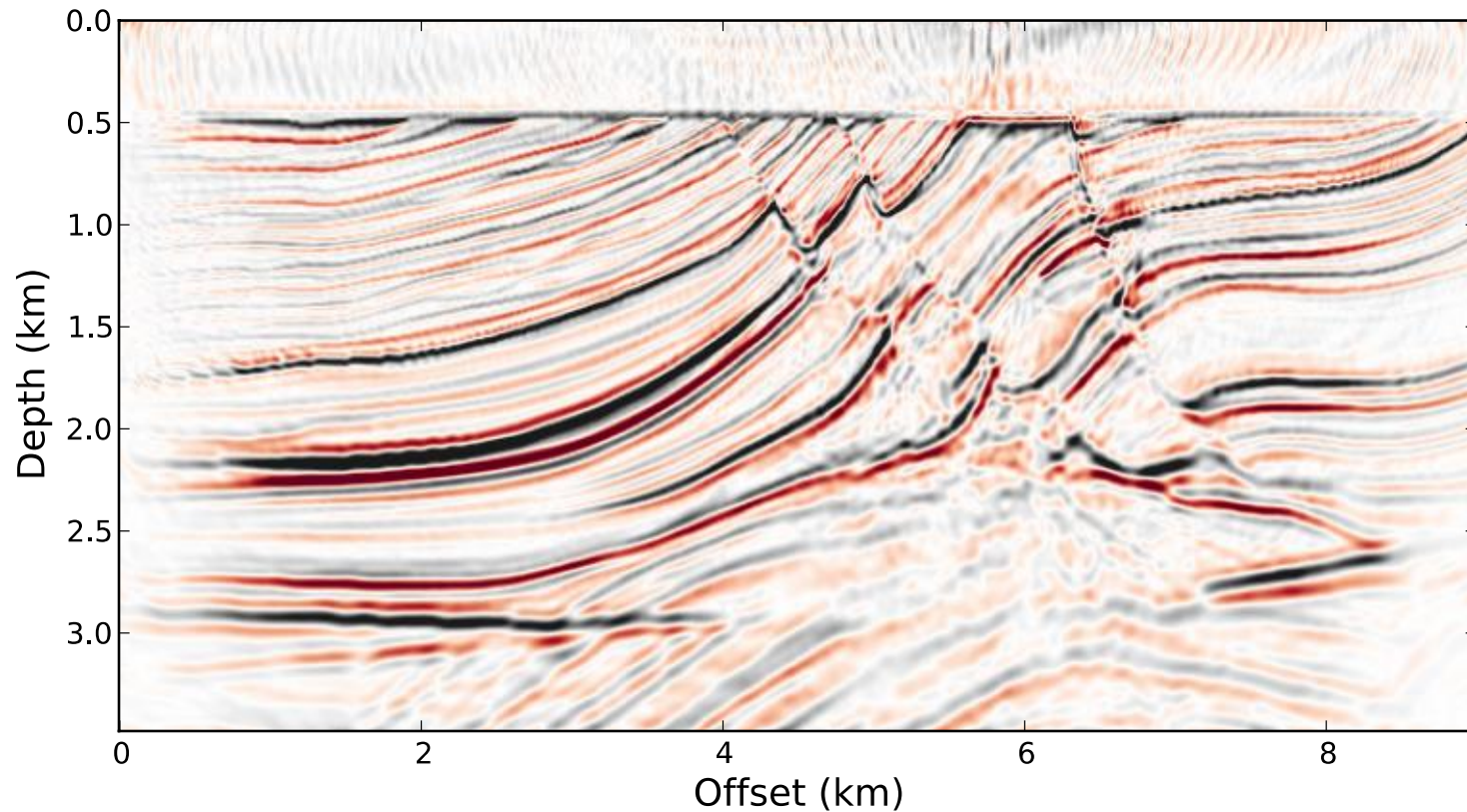
Seismic migration

Xu & Sacchi,
Geophysics-2018



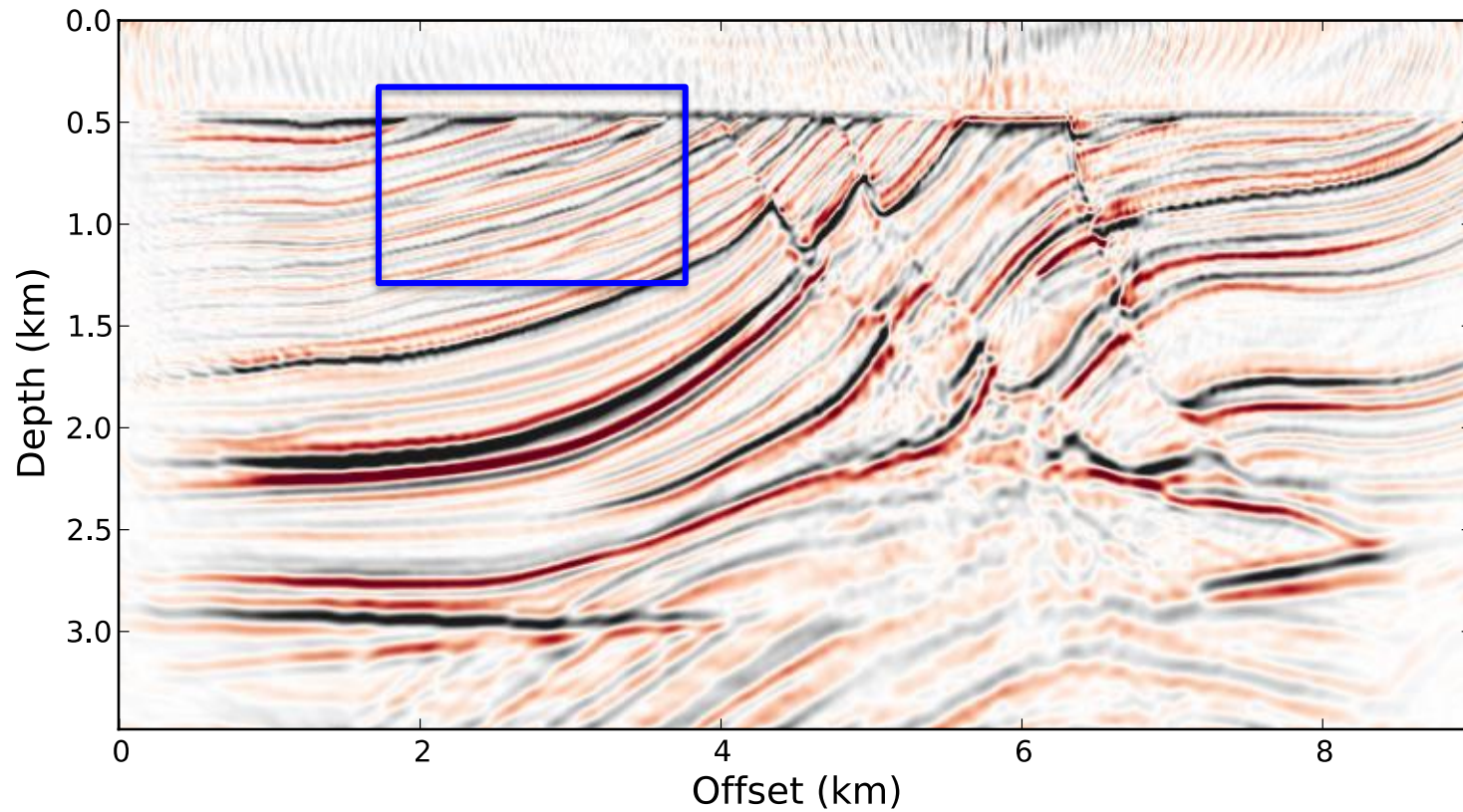
Least-squares migration (LSM)

Xu & Sacchi,
Geophysics-2018



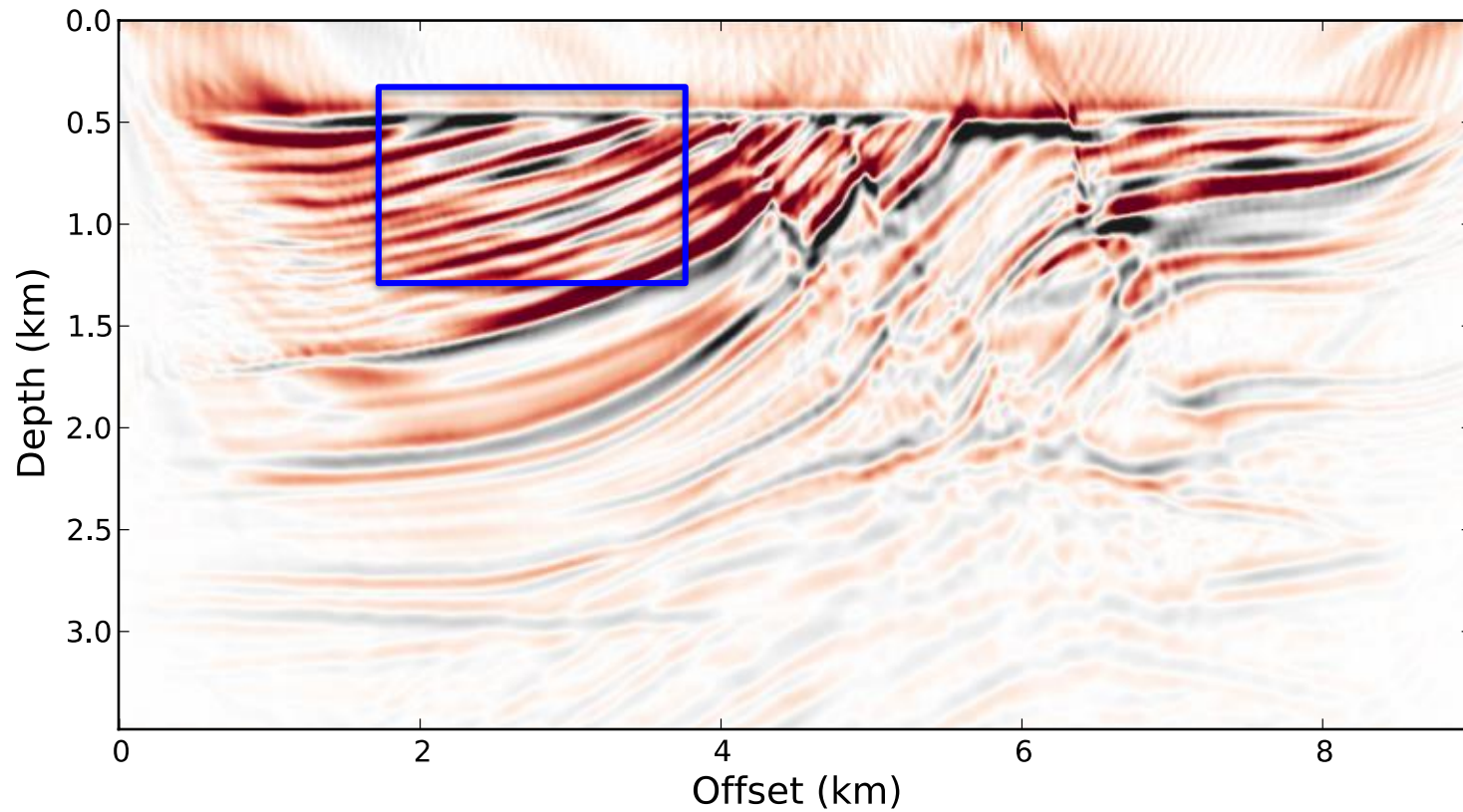
Seismic migration (LSM)

Xu & Sacchi,
Geophysics-2018



Seismic migration

Xu & Sacchi,
Geophysics-2018



Seismologists

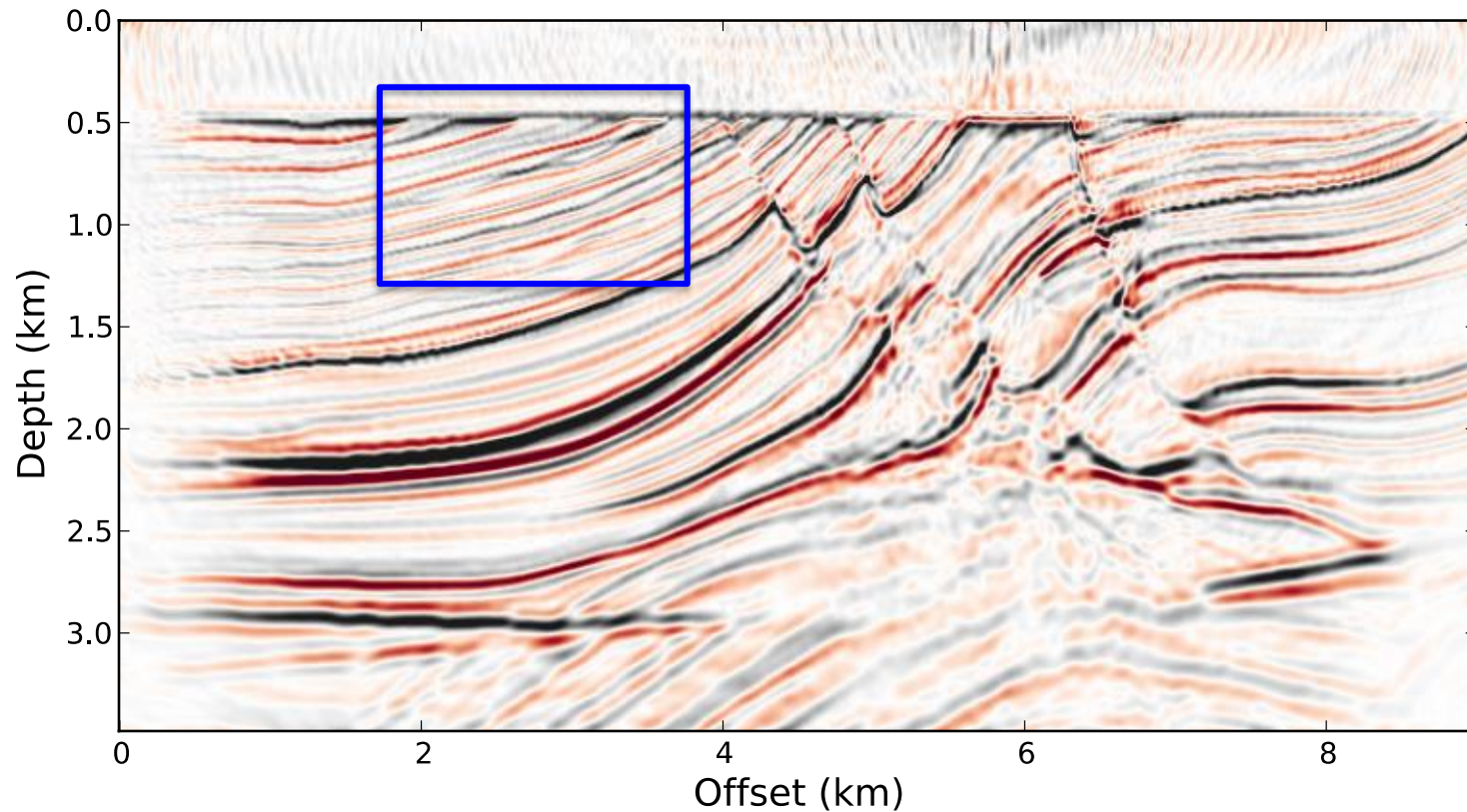
Find oil and gas reservoirs

via listening to the earth

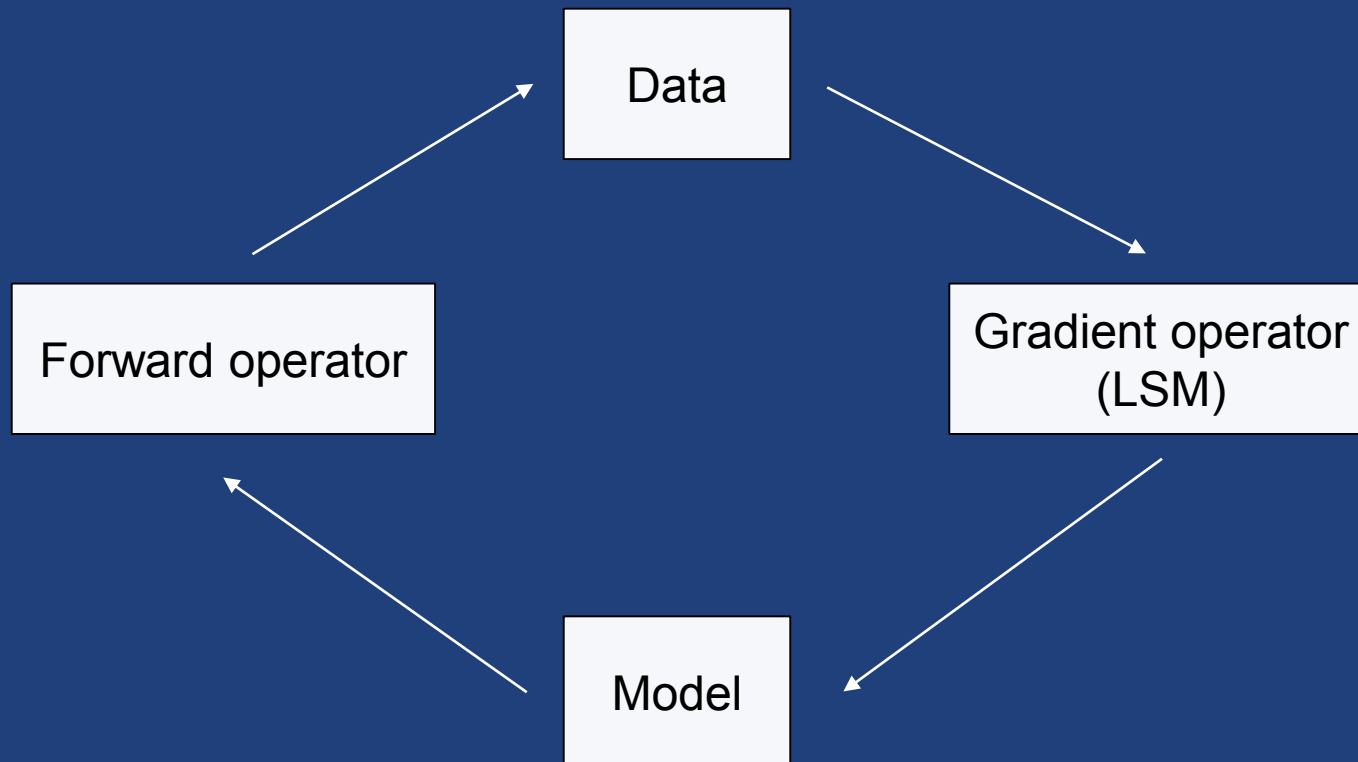
What shall we do in the **future**?

Least-squares migration (LSM)

Xu & Sacchi,
Geophysics-2018



Full Waveform Inversion



More
(higher resolution, rock identification)

Cheaper
(More cost-efficient computation)

Safer
(Continuous monitoring)

Seismologists

find oil and gas reservoirs

via listening to the earth.

Make exploration cheaper and safer

Contact information and credits

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Acknowledge: Nele Boersing

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Reference of Papers

Gao, J., A. Stanton, and M. Sacchi, 2015, Parallel matrix factorization algorithm and its application to 5D seismic reconstruction and denoising: Geophysics, 80, no. 6, V173–V187, doi: 10.1190/geo2014-0594.1.

**Linan Xu and Mauricio D. Sacchi (2018). "Preconditioned acoustic least-squares two-way wave-equation migration with exact adjoint operator." GEOPHYSICS, 83(1), S1-S13.
<https://library.seg.org/doi/abs/10.1190/geo2017-0167.1>**