Deep learning framework bridges lab and field scale microseismic focal mechanism
Nov 03, 2022
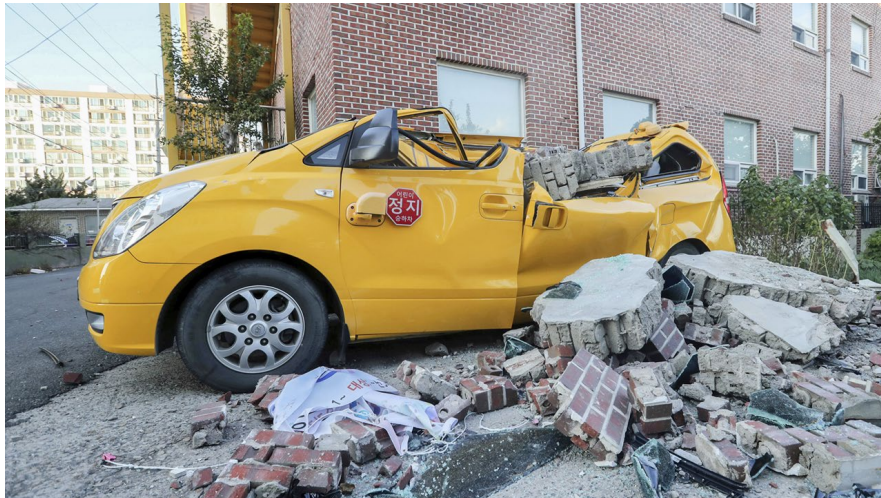
Speaker: Arnold Yuxuan Xie

Civil & Env

2022 - Third Western-ICLR Multihazard Risk and Resilience Workshop

Background

The Pohang earthquake, which struck South Korea 2017, caused $52 million in damage

Pohang is not in seismic region

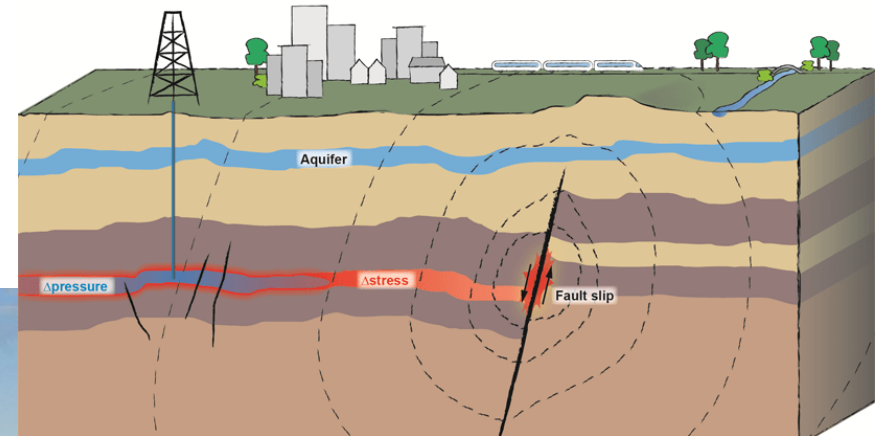M 5.5 anthropogenetic earthquake, Pohang with a **Geothermal field** nearby

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Background

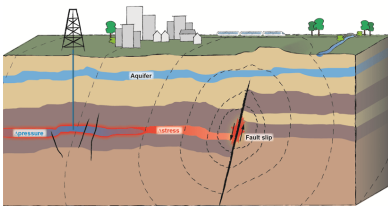Enhanced geothermal system; fluid injection.

Constant micro-earthquake in Basel (Switherland) has caused over $9 million loss.

The city had been destroyed by M6.5 earthquake in 1356.

Background

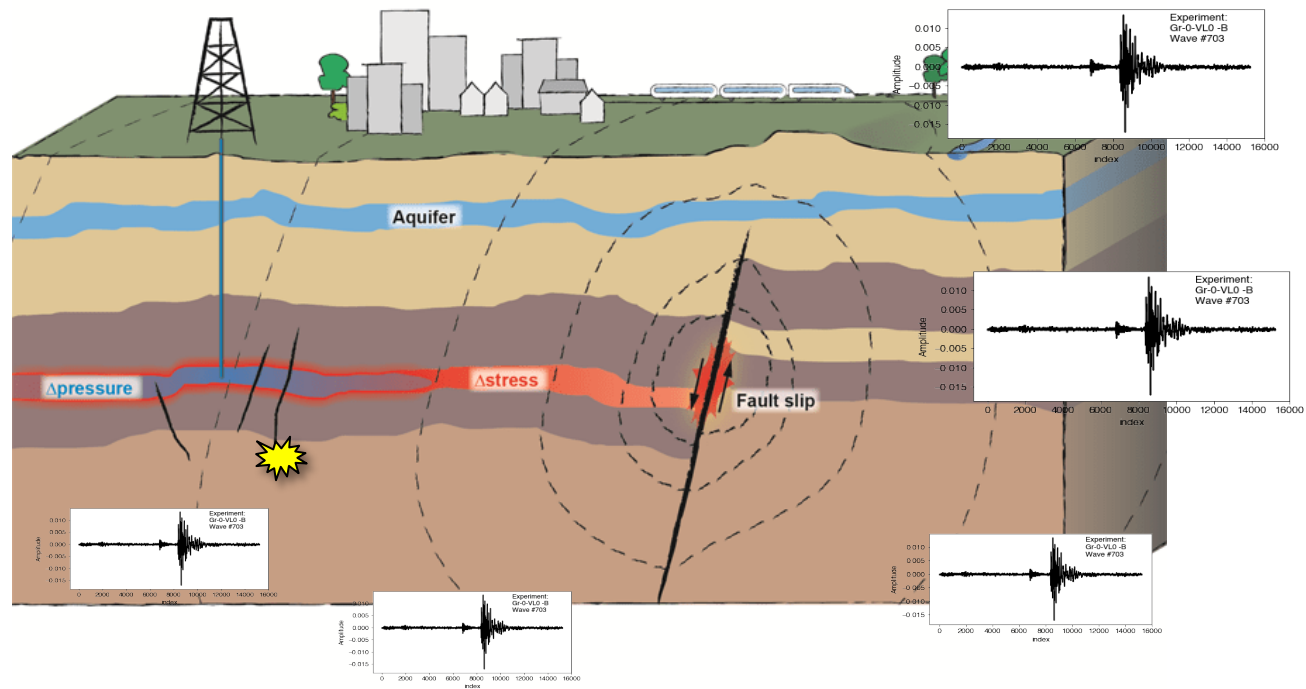Precaution of anthropogenetic seismicity.

Soultz-sous-forêts, France

Utah Forge, USA

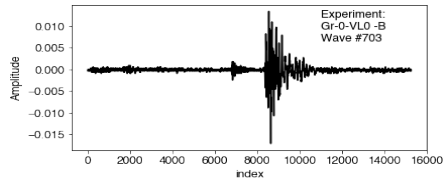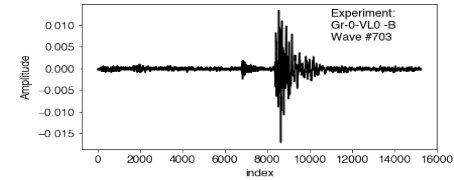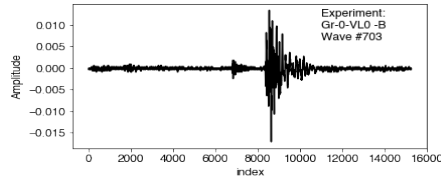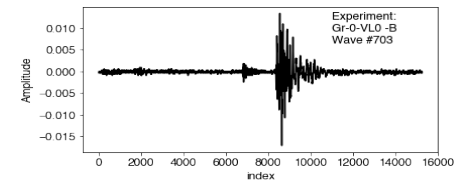**Geyser, California, USA**
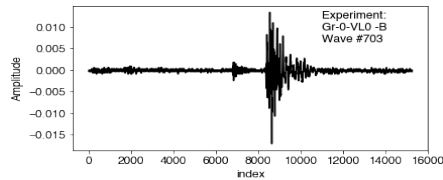(Our field test set)
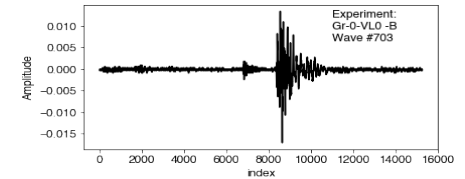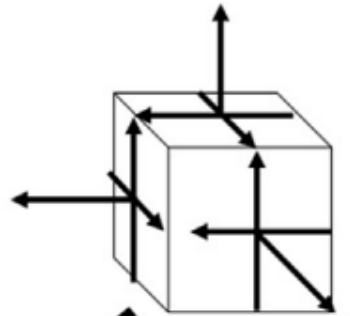
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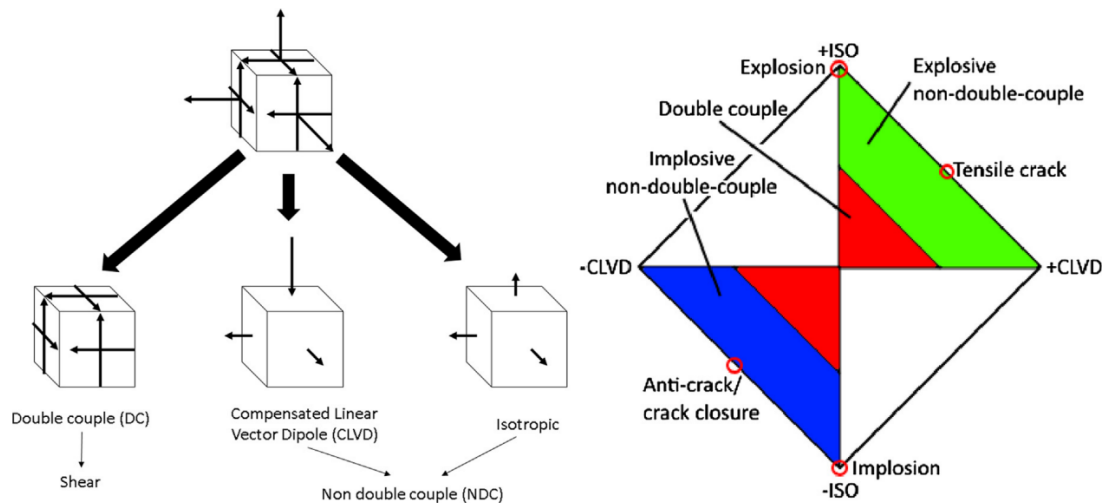
Background

Background

Moment Tensor

Minimum **6** valid stations

$$\begin{bmatrix} M_{11} & M_{12} & M_{13} \\ M_{21} & M_{22} & M_{23} \\ M_{31} & M_{32} & M_{33} \end{bmatrix}$$
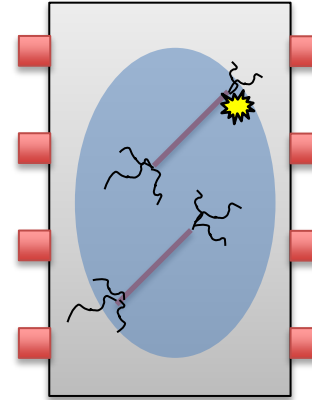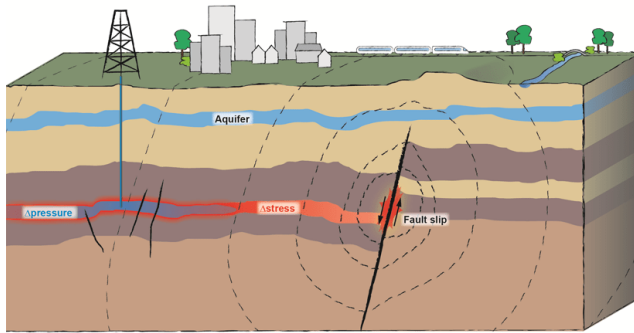
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Background
Moment Tensor

DC: Percentage of shear components
+NDC: Tension (crack expansion)
-NDC: Compression (crack closure)

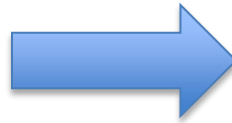Western Engineering   DeepL@Lab&Field

Background

Challenges

- poor coverage for moment tensor inversion (lack of borehole seismometers)
- High magnitude of completeness (High SNR waveforms)

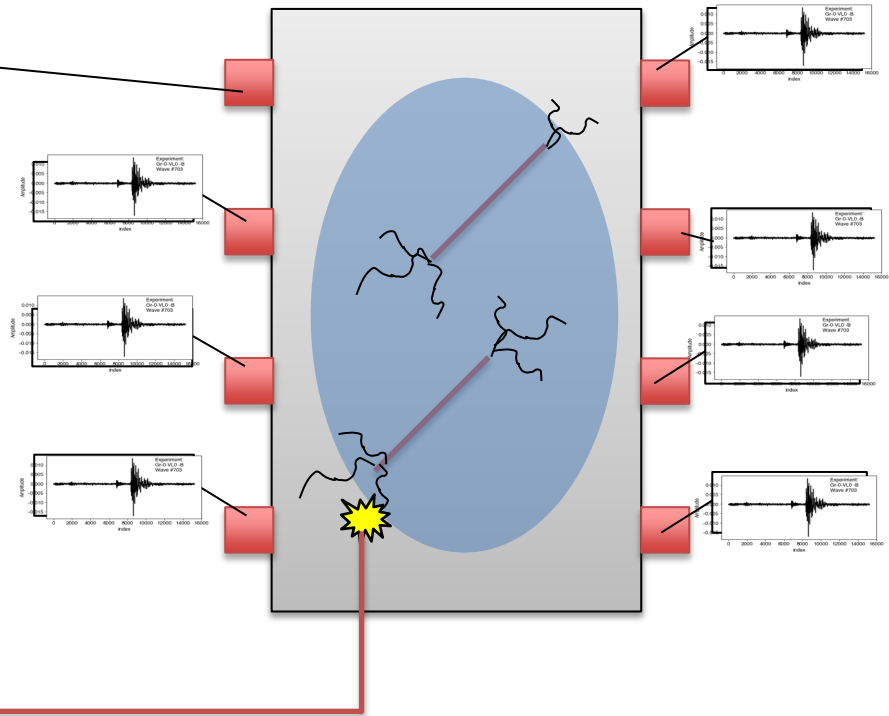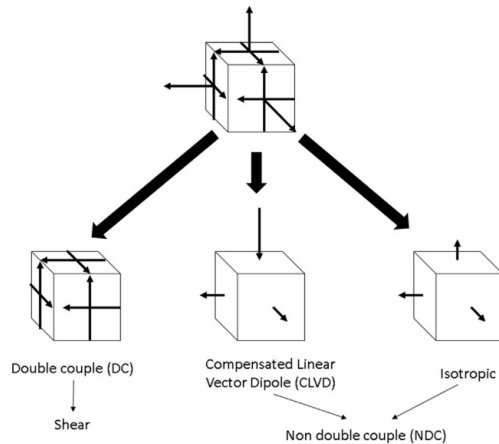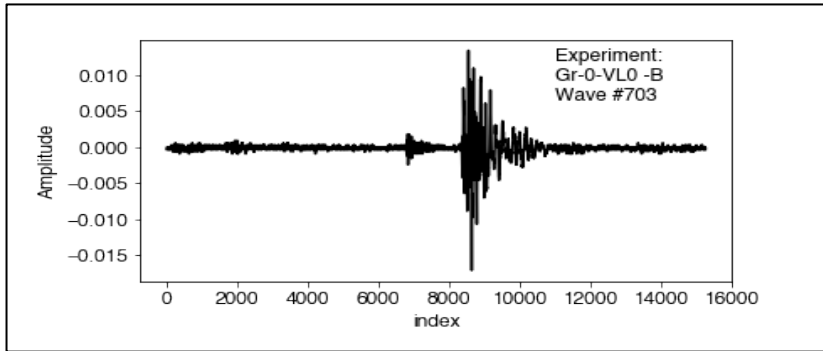https://doi.org/10.1016/j.geothermics.2014.06.005

Solutions

- Single channel detection (just determine +/-)
- Laboratory Acoustic Emission Data (identical mechanism)
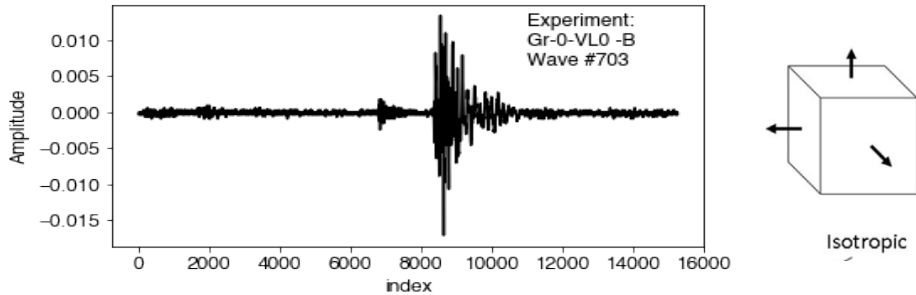
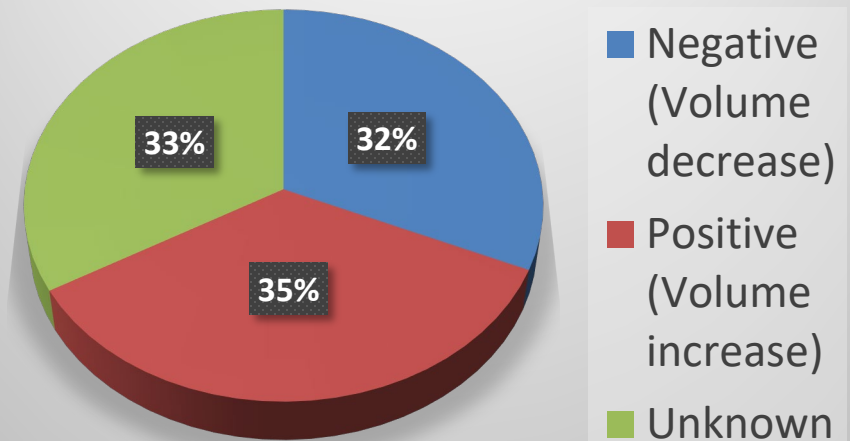https://doi.org/10.1016/j.engfracmech.2019.01.034

Data Description

Data Description
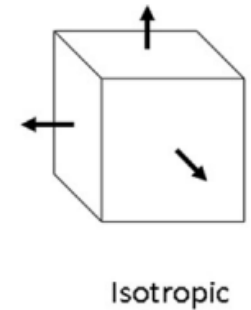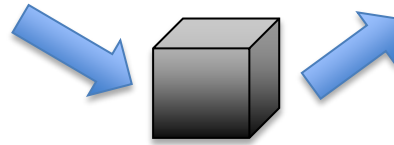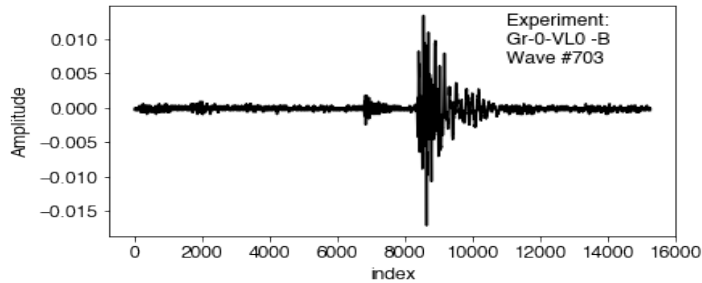

Experiment:
Gr-0-VL0 -B
Wave #703

Isotropic

151,455 waveforms from **52** independent *Hydraulic Fracturing/ Four Point Bending* experiments on *Granite / Shale*

Non-Double Couple focal mechanism Data distribution

- 32% — Negative (Volume decrease)
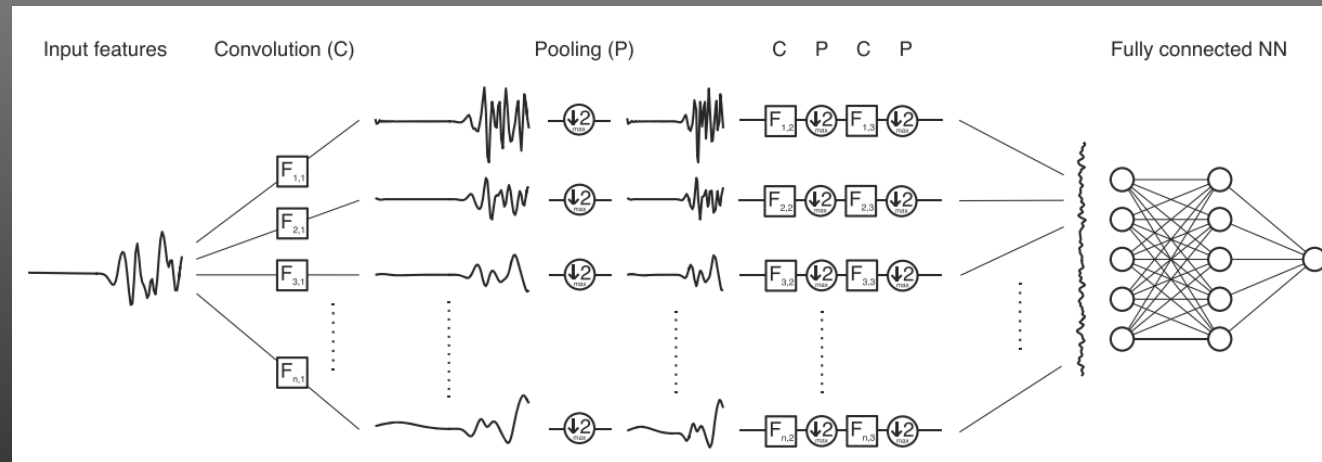- 35% — Positive (Volume increase)
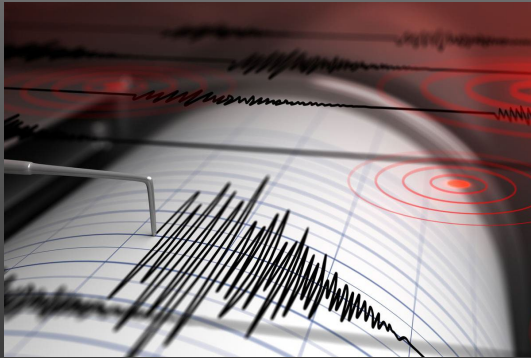- 33% — Unknown

Goal

Extract focal mechanism info (NDC) from single channel.
(Distinguish expanding / closing fractures from one waveforms)

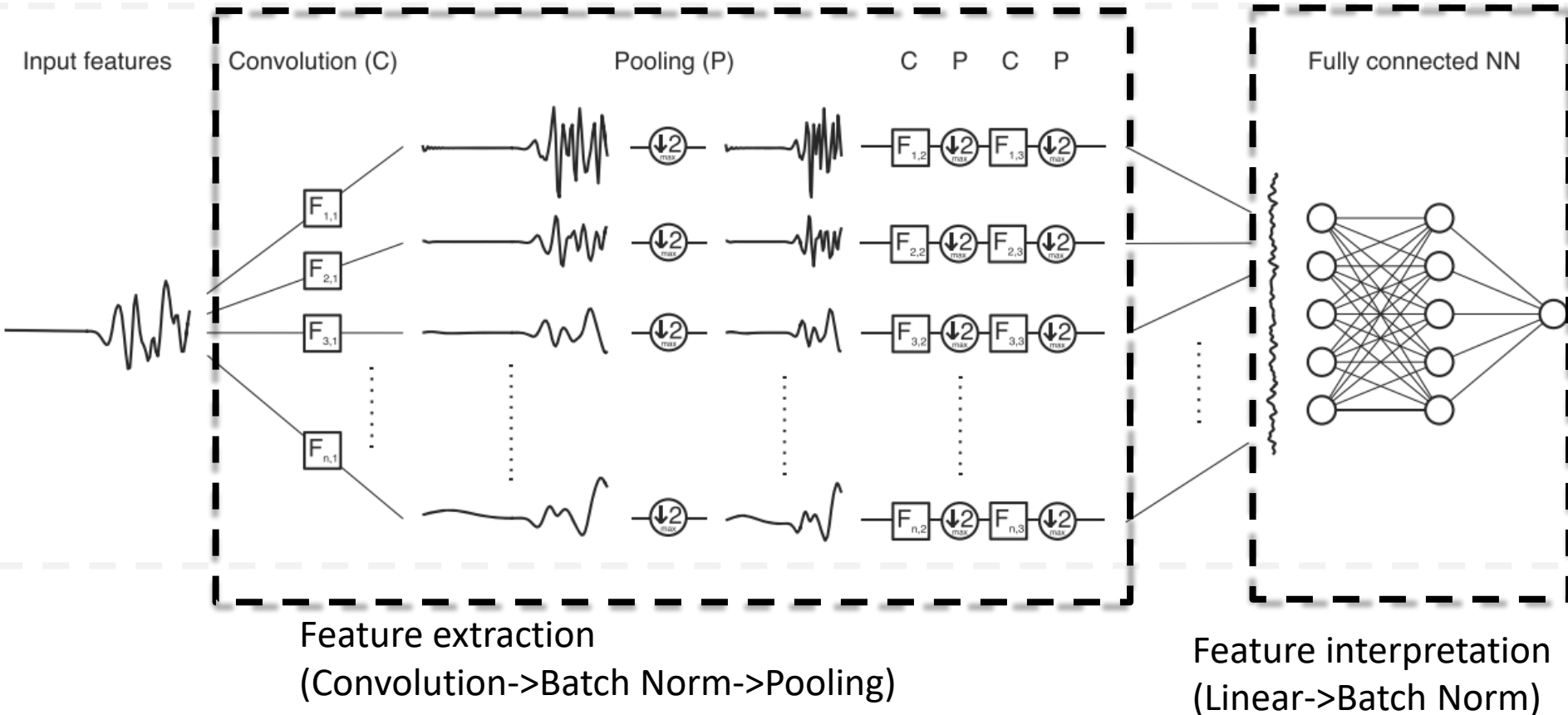# Inside the black box

First motion polarity detection

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Inside the black box

Transfer learning tricks:

How do we *guide* our model to learn?

Feature extraction
(Convolution->Batch Norm->Pooling)

Feature interpretation
(Linear->Batch Norm)

Training Strategy

Input features   Convolution (C)   Pooling (P)   C   P   C   P

Retrain
Freeze all convolution layers

Free all linear and batch norm layers

Learning rate=1e-3
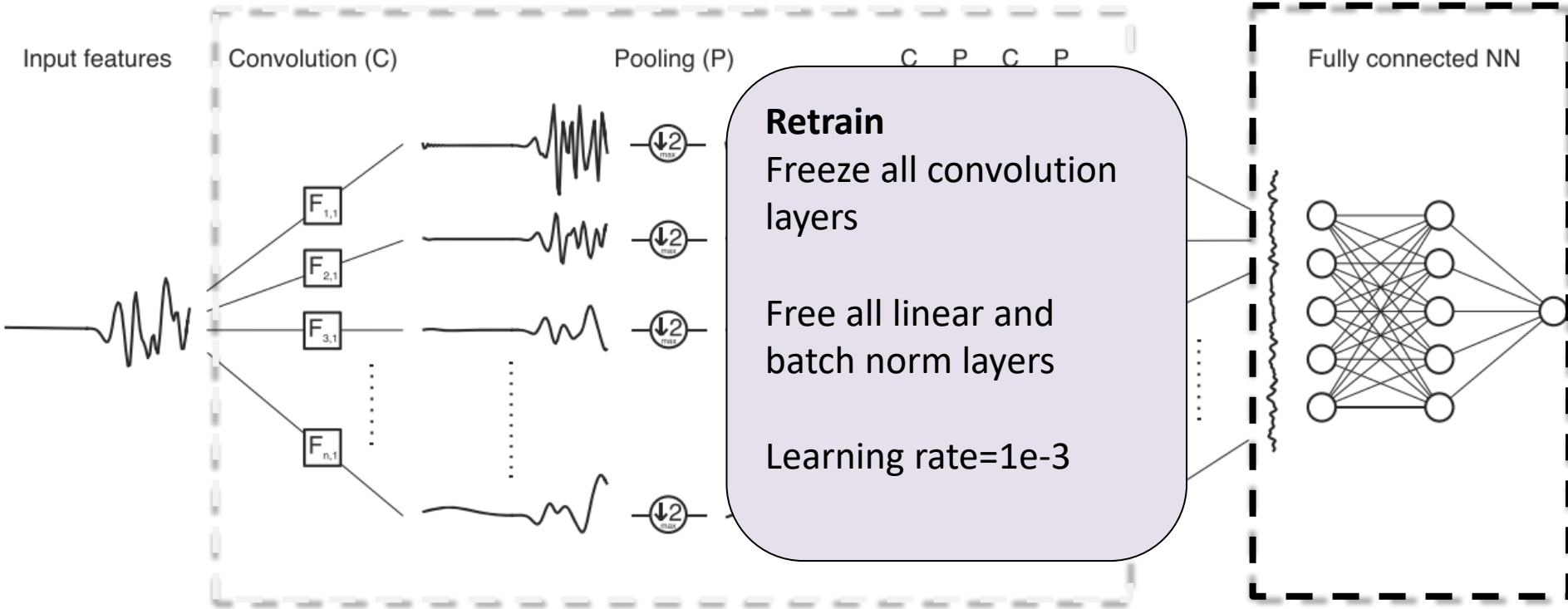
Fully connected NN

Feature extraction
(Convolution->Batch Norm->Pooling)

Fully connected
(Linear->Batch Norm)

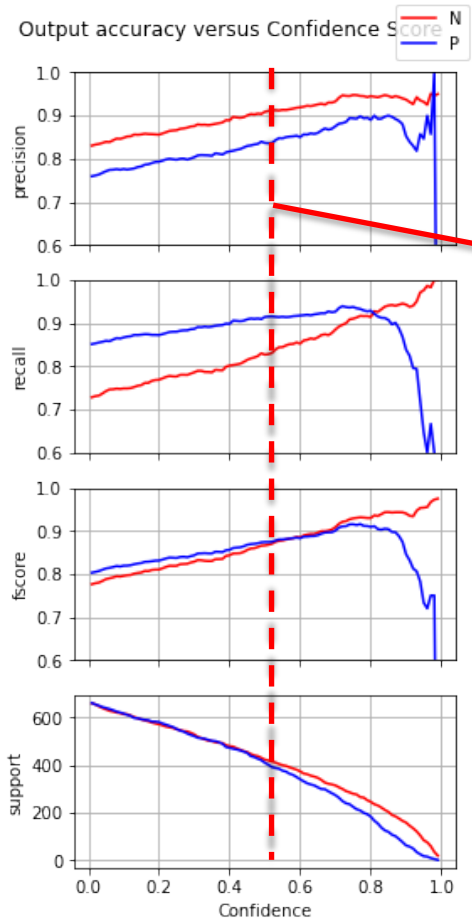# Lab Results

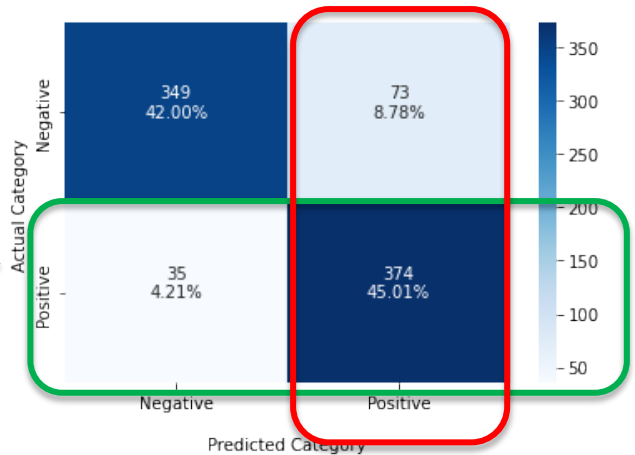Confidence-score =50%

Output accuracy versus Confidence Score

Precision

Recall

Fscore

Support

Confusion Matrix with labels

Precision

Recall

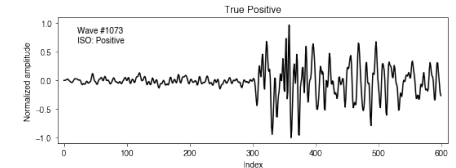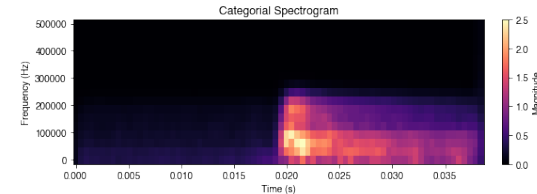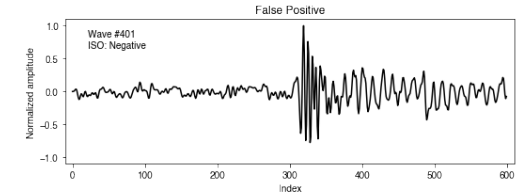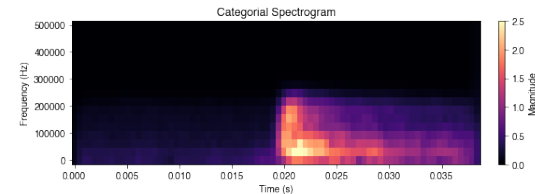$$F\text{-}score = 2 \cdot \frac{precision \cdot recall}{precision + recall}$$

	Lab		Field	
	ISO+	ISO-	ISO+	ISO-
Transfer Learning	**0.8660**	**0.8738**	**0.9231**	**0.8989**
TL+Conv Fine tune	0.8440	0.8587	0.7679	0.8116
Raw Train	0.8357	0.8696	0.6412	0.2295
PolNet	-	-	-	-
Polarity	0.5014	0.4128	0.5354	0.6198

Threshold: Confidence-score=abs(Pred(P)-Pred(N))

Lab Results

True Negative — Wave #139, ISO: Negative

False Positive — Wave #401, ISO: Negative
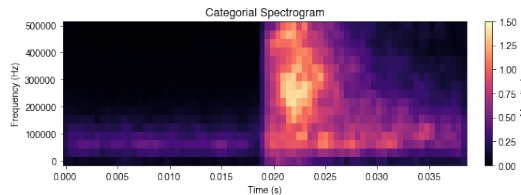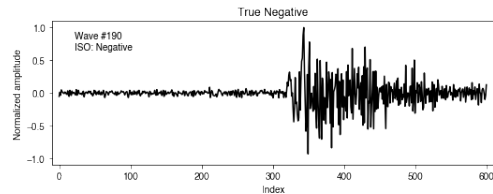
False Negative — Wave #1098, ISO: Positive

True Positive — Wave #1073, ISO: Positive

Confusion Matrix with labels

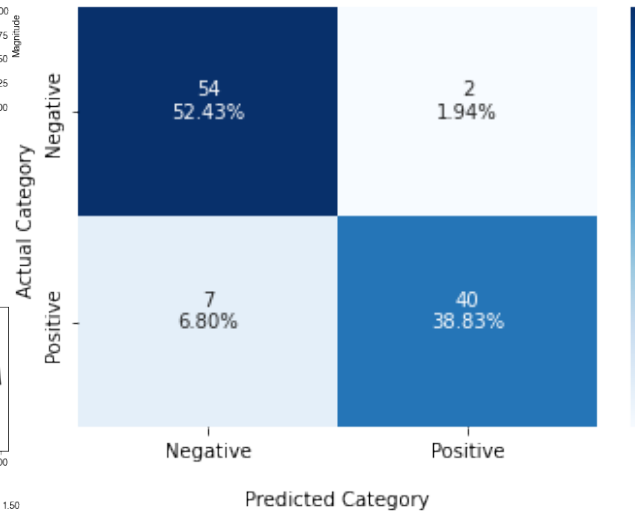|	Predicted Negative	Predicted Positive
Actual Negative	349 / 42.00%	73 / 8.78%
Actual Positive	35 / 4.21%	374 / 45.01%
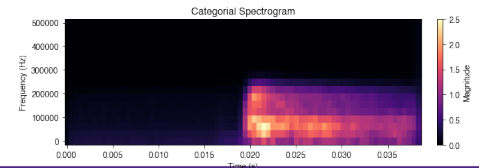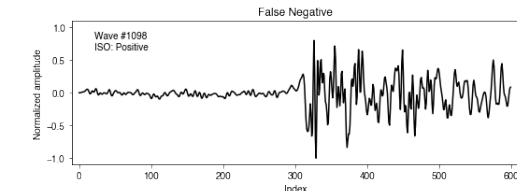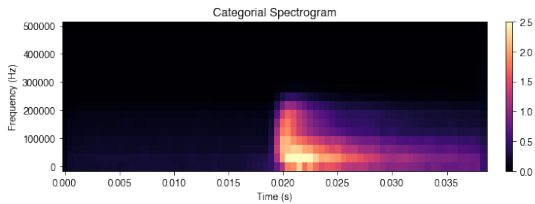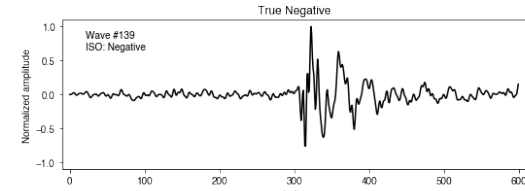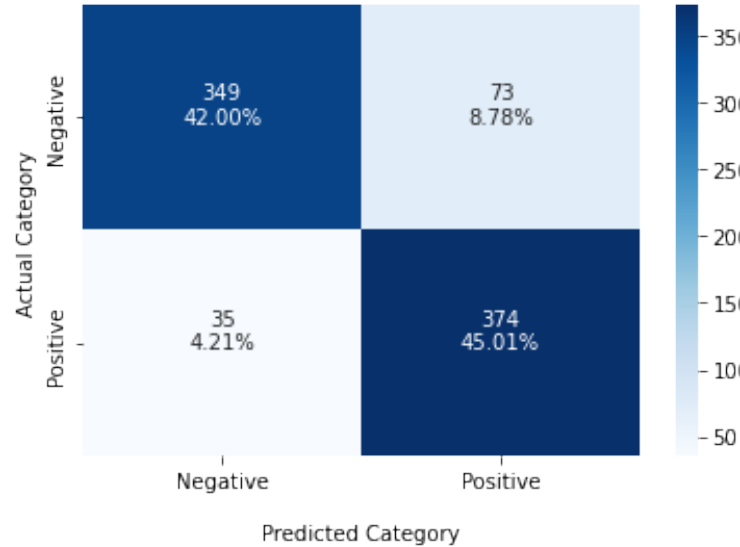
F-score
ISO+: 86.60 %
ISO-: 87.38 %
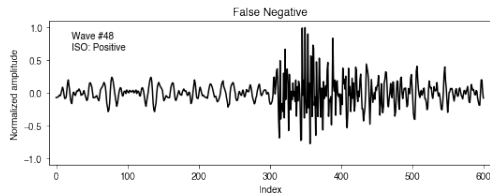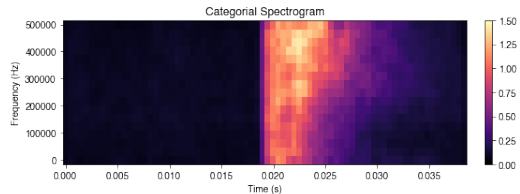
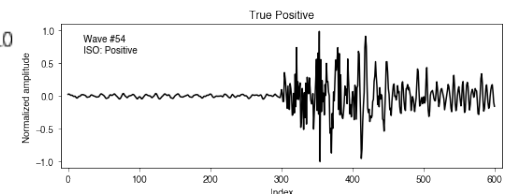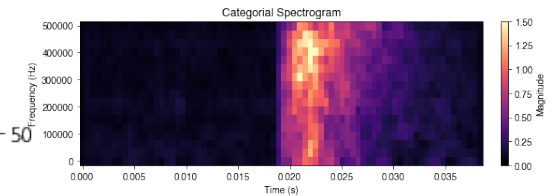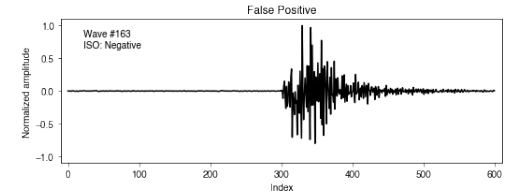# Field Results

F-score
ISO+: 92.31 %
ISO-: 89.89 %
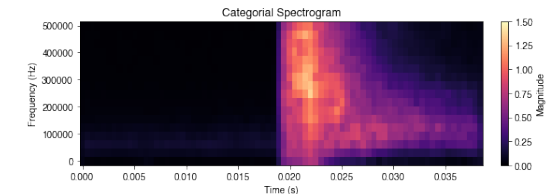
Summary

- Precaution for fluid injection induced earthquake

- Fracture volume change & moment tensor inversion

- Challenges on site.

- Retrain deep learning model with lab scale data (transfer learning)

- Verify performance on more field test sets

Thanks & Questions

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