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3 component laboratory experiments by laser interferometry: anisotropy estimations using polarization of quasi P-waves and S waves

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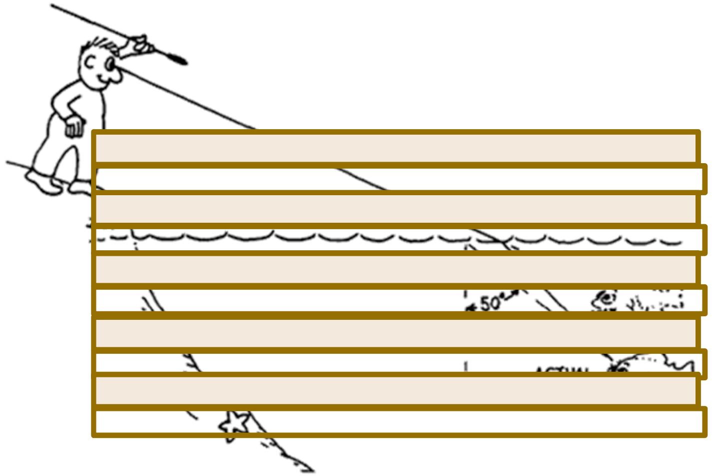
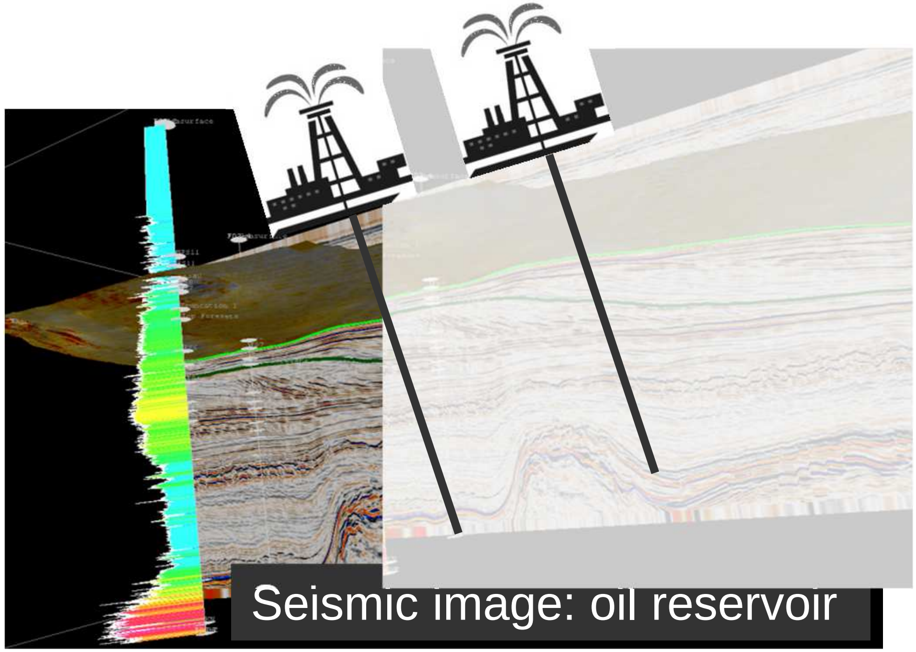
19.10.2011

OUTLINE

- Motivation: *why knowledge of anisotropy is important*
- Anisotropy: *what we do in the lab*
- Anisotropy: *new approach in the field*
- Anisotropy: *bring this approach to the lab*
- Laser Doppler Interferometry
- Validation experiments
- Conclusion

✴ Why knowledge of anisotropy is important?





Seismic image: oil reservoir

How anisotropy is determined at laboratories:

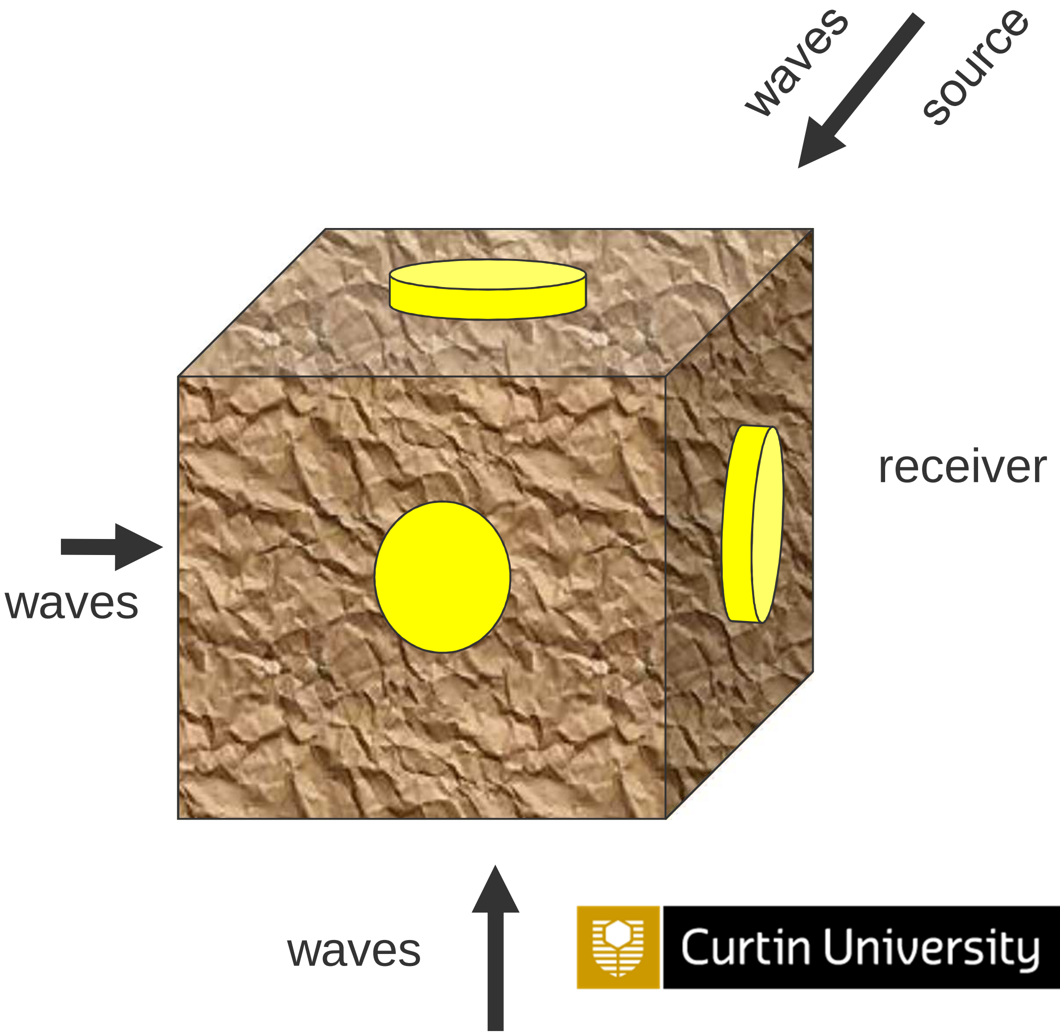
basic principles

1. traveltime
2. travel path
3. velocities

Slowness

Density

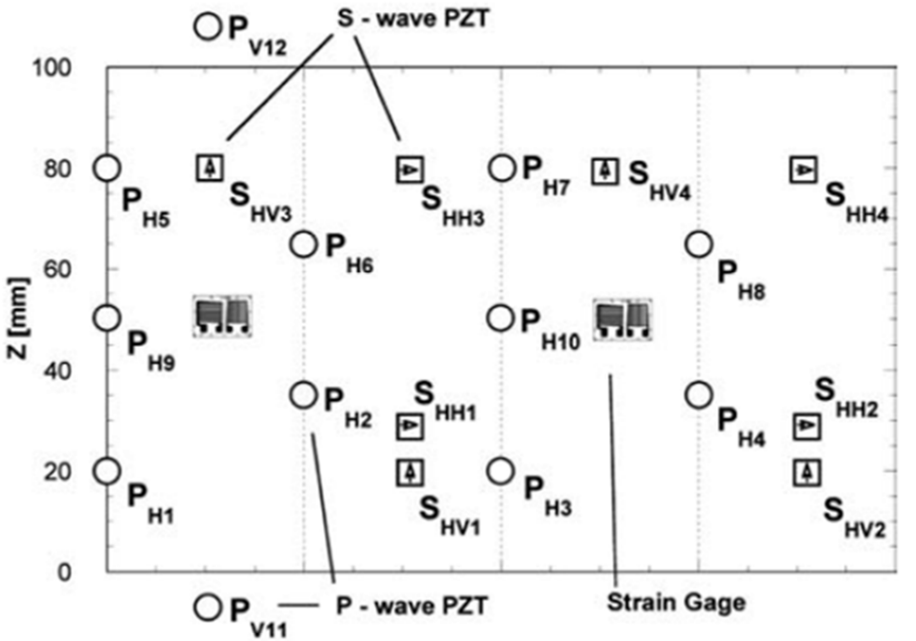
} inversion



How anisotropy is determined at laboratories:

complicate experimental systems

S. Stanchits *et al.* Pure a



Pure appl. geophys. 163 (2006) 974–993
0033–4553/06/060974–20
DOI 10.1007/s00024-006-0059-5

Pure and Applied Geophysics

Ultrasonic Velocities, Acoustic Emission Characteristics and Crack Damage of Basalt and Granite

Sergei Stanchits,[1] Sergio Vinciguerra,[2] and Georg Dresen[1]

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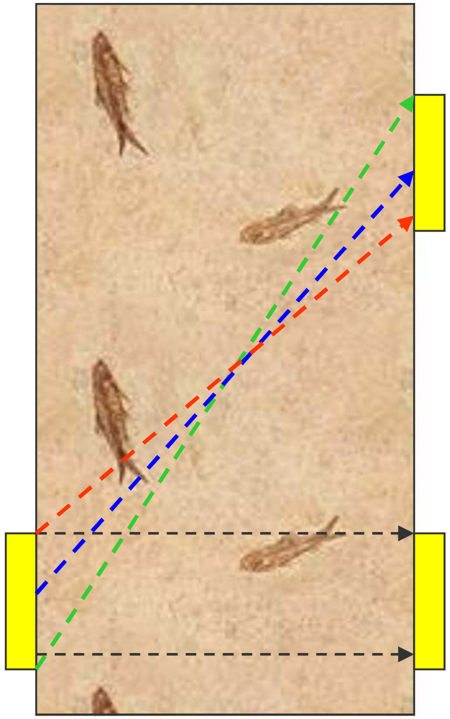
How anisotropy is determined at laboratories:
clear or *unclear* data interpretation

A

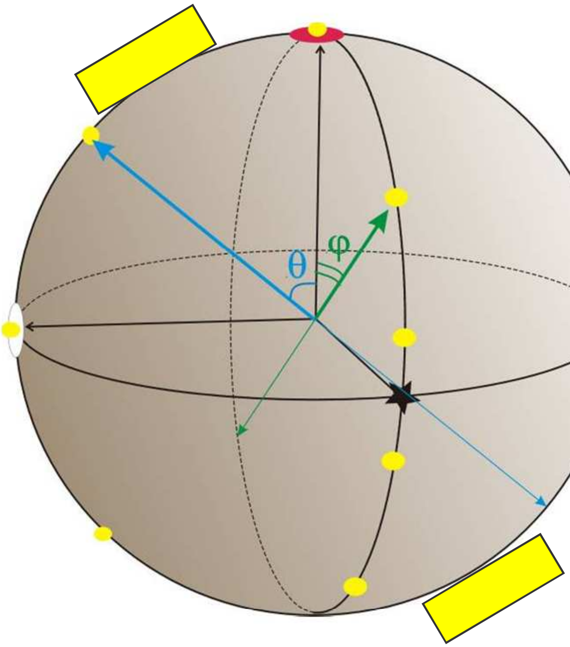
B

C



What is the travelpath A B C ?

How anisotropy is determined at laboratories:
expensive rigs



Institute of Geology, Prague, Czech Republic
Courtesy of Dr. Miroslav Brajanovski

✷ Anisotropy: *new approach in the field*

The inversion approach

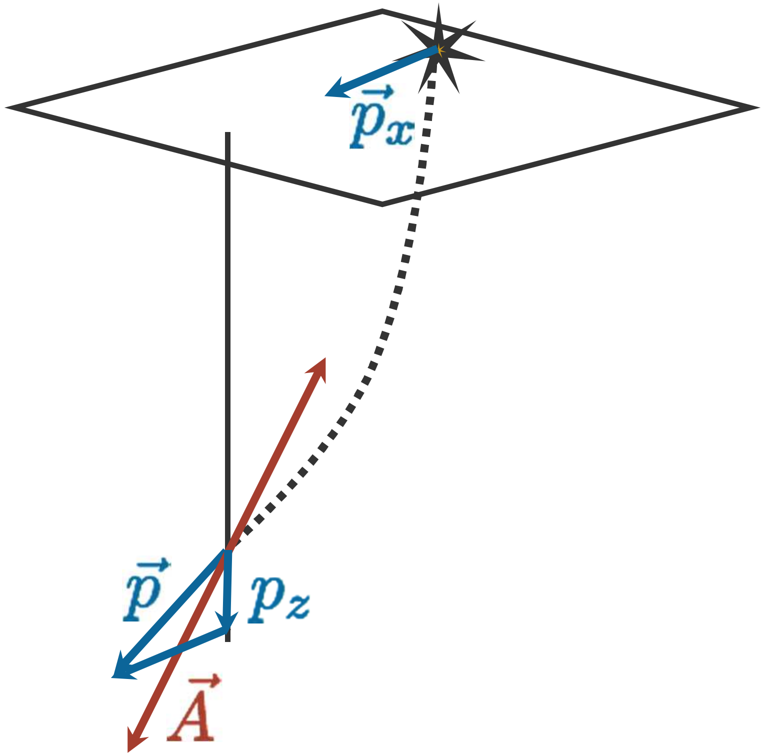
stiffness tensor | slowness | density | polarization

$$c_{ijkl}p_jp_lA_k = \rho A_i$$

- **System of three linear equations in c for each measurement**
- **Solution by**

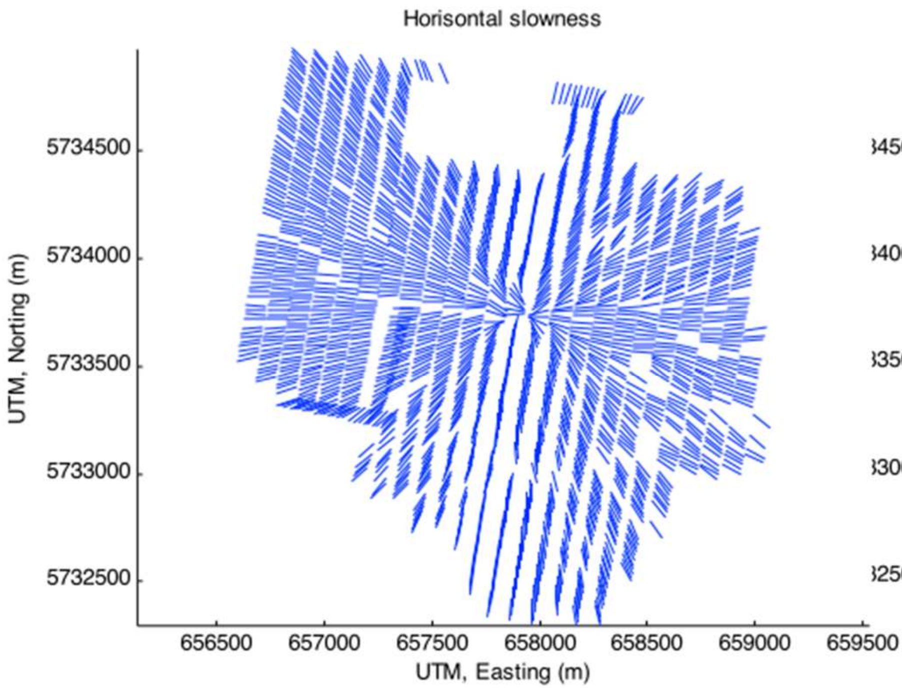
Total Least Squares

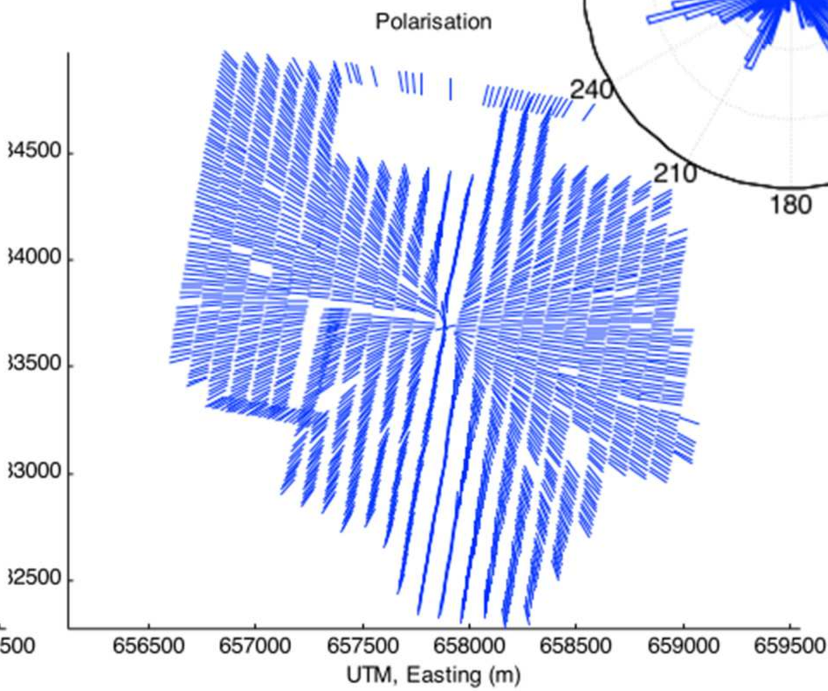
- **Uses P and S waves**
- **Assumes lateral homogeneity**

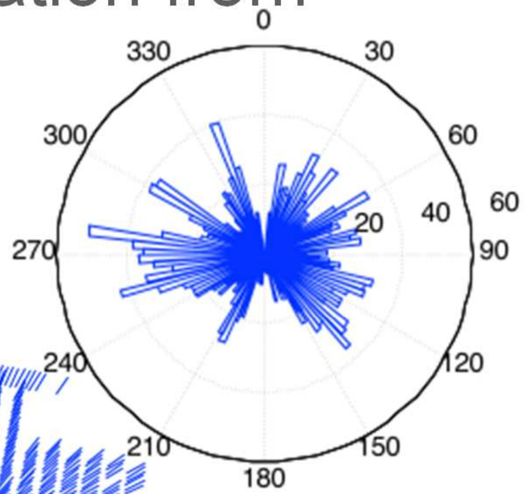


[Dewangan & Grechka, 2003]

P wave: horizontal slowness and polarization from Otway basin (Australia) 3D/3C VSP







3C geophone depth 1590 m

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Data acquired by CO2CRC

Inverted density scaled stiffness tensor

stiffness tensor

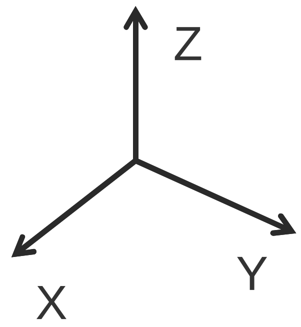
slowness

density

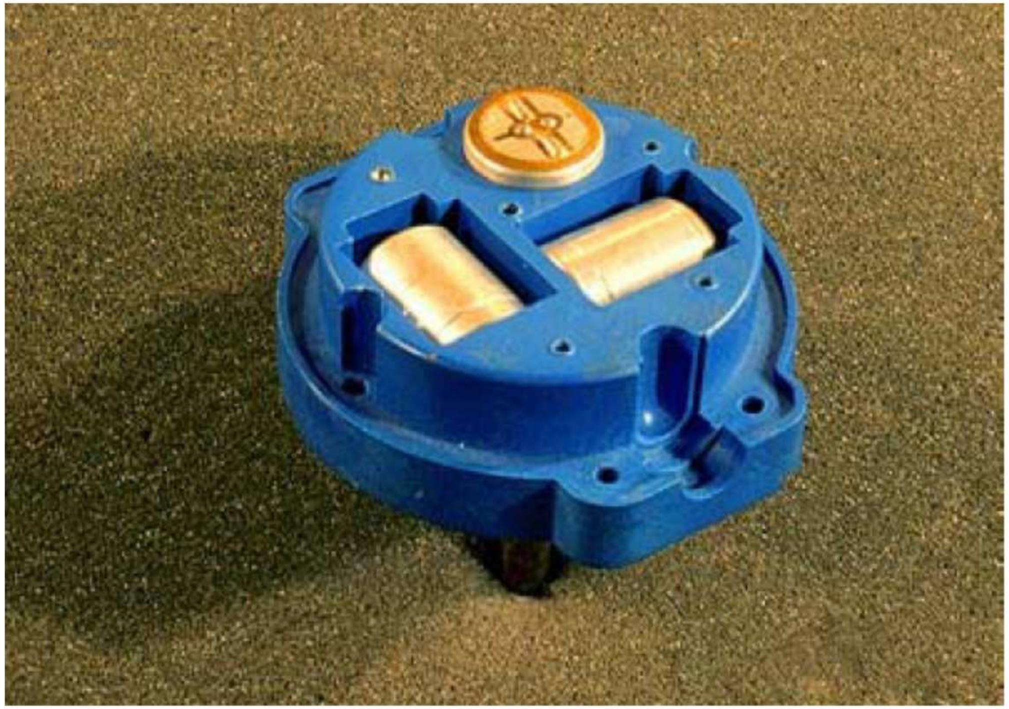
polarization

$$c_{ijkl}p_jp_lA_k = \rho A_i$$

$$\begin{pmatrix} 10.6 & 2.9 & 4.2 & 0.0 & -0.2 & 0.4 \\ 2.9 & 10.6 & 3.6 & -0.3 & -0.1 & 0.2 \\ 4.2 & 3.6 & 9.4 & -0.1 & 0.0 & 0.0 \\ 0.0 & -0.3 & -0.6 & 2.8 & 0.0 & -0.1 \\ -0.2 & -0.1 & 0.0 & 0.0 & 2.9 & -0.3 \\ 0.4 & 0.2 & 0.0 & -0.1 & -0.3 & 3.6 \end{pmatrix} \mathrm{km}^2\mathrm{s}^{-2}$$



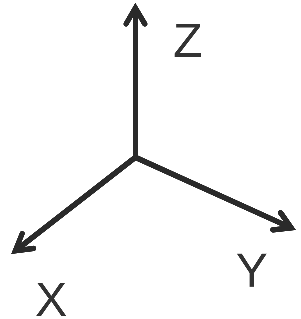
Field:3C geophone

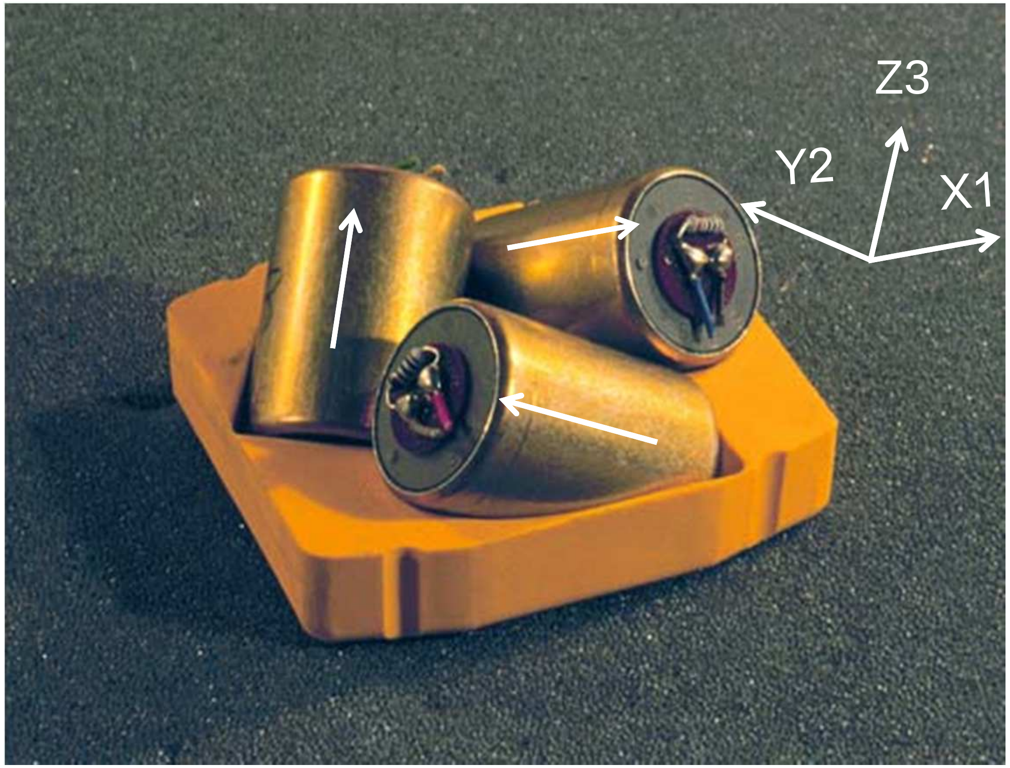


http://www.crewes.org/

E.I. Galperin 1984:

The Polarization Method of Seismic Exploration

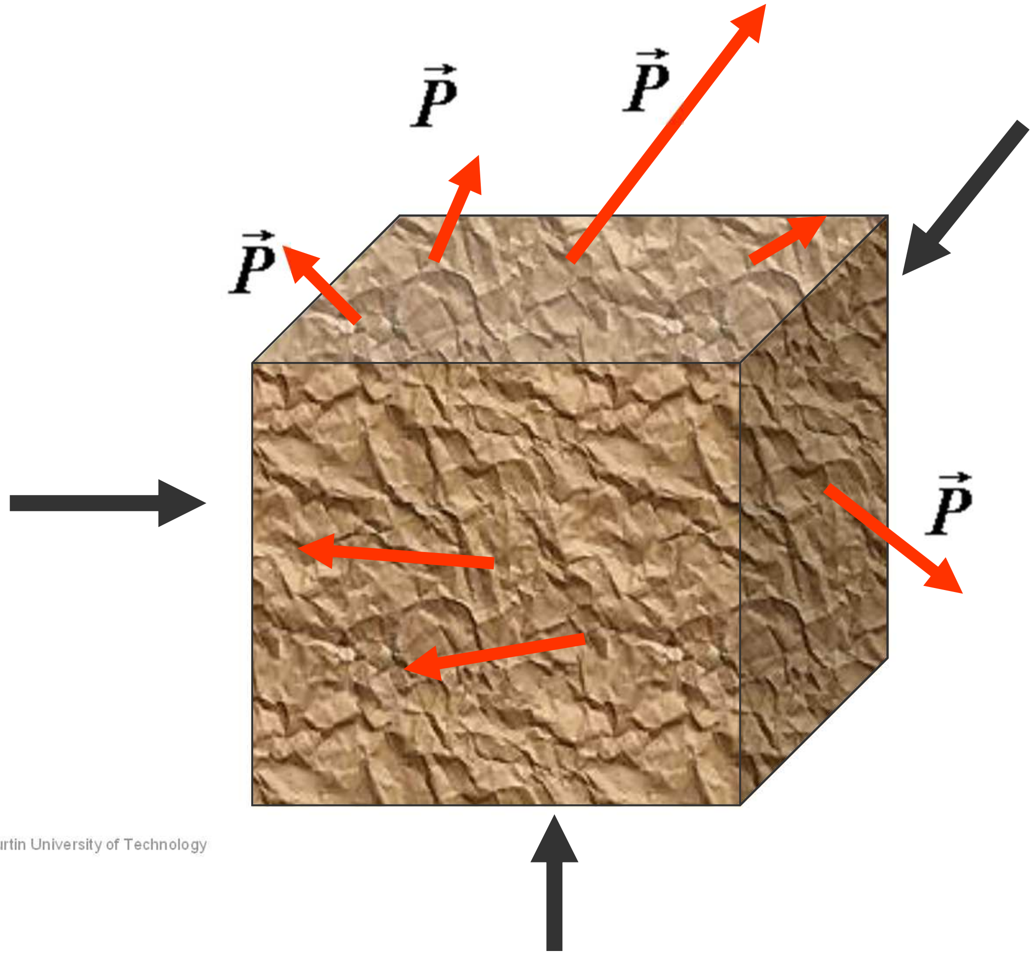




http://www.crewes.org/

<u>It will be nice if,</u>

- Size of receivers will be small
- Complementary measurements of Waves polarizations



Measurements of wave polarisation in laboratories

(54) АКУСТОПОЛЯРИСКОП ДЛЯ ИЗМЕРЕНИЯ УПРУГОСТИ ОБРАЗЦОВ ТВЕРДЫХ МАТЕРИАЛОВ

(57) Акустополярископ для измерения упругости образцов твердых сред относится к средствам неразрушающего контроля ульт- ующей гранью образца. Цель изобретения достигается тем, что акустополярископ, содержащий основание 1, стойку 2, соединенный с ней кронштейн 4 с втулкой 5, подвижной шток 8, дополнительный кронштейн 9 с размещенными на нем поворотной платформой 17 с центральным отверстием

(19) SU (11) 1783412 A1

United States Patent [19] — **Naville**

[11] **Patent Number: 4,789,969**

[45] **Date of Patent: Dec. 6, 1988**

[54] **METHOD OF MEASURING THE ANISOTROPY OF PROPAGATION OR REFLECTION OF A TRANSVERSE WAVE, PARTICULARLY A METHOD OF GEOPHYSICAL PROSPECTING BY MEASUREMENT OF THE ANISOTROPY OF PROPAGATION OR OF REFLECTION OF SHEAR WAVES IN ROCKS**

[75] Inventor: **Charles Naville**, Massy, France

[73] Assignee: **Compagnie Generale de Geophysique**, Massy, France

[21] Appl. No.: **57,279**

[22] Filed: **Jun. 2, 1987**

[30] **Foreign Application Priority Data**

Jun. 3, 1986 [FR] France 86 07964

[51] **Int. Cl.**⁴ **G01V 1/00**

[52] **U.S. Cl.** **367/36**; 367/37; 367/75; 73/152

[58] **Field of Search** 367/36, 37, 43, 46, 367/47, 50, 56, 57, 75, 31; 181/108, 111, 112, 113; 73/152, 574, 584, 645

[56] **References Cited**

U.S. PATENT DOCUMENTS

3,003,577	10/1961	Itria	367/75
3,622,965	11/1971	Wu	367/47
3,946,598	3/1976	Towne et al.	73/574
4,080,836	3/1978	Thompson et al.	73/597
4,138,894	2/1979	Robert et al.	73/645
4,501,150	2/1985	Rouge	73/645
4,648,039	3/1987	Devaney et al.	364/421
4,713,968	12/1987	Yale	73/152

FOREIGN PATENT DOCUMENTS

0169076 7/1985 European Pat. Off. .

OTHER PUBLICATIONS

"Ultrasonic SH Wave Velocity in Textured Aluminum Plates", Ultrasonics, vol. 23, No. 5, Sep. 1985, Allen, Langman, and Sayers.

"Investigation of Shear Waves", by R. N. Jolly, Geophysics, vol. 21, pp. 908–919, 926–938.

"The Anisotropic Distortion of Reflection Seismic Sections", by Mason, Worthington and Smith; 51st Ann. Int. Seq. Mtg. Tech, Pap. #5172 (1981).

"Acoustical Polarameter" by Rouge, 1982 Ultrasonics Symposium Proceedings, vol. 2, pp. 861–863, Oct. 27–29, 1982.

"The detection of Liquids and Viscoelastic Substances Trapped Under Solid Surfaces" by Jones et al., Journal of the Acoustical Society of American, vol. 79, No. 1, Jan. 1986.

Primary Examiner—Charles T. Jordan
Assistant Examiner—John W. Eldred
Attorney, Agent, or Firm—Blakely, Sokoloff, Taylor & Zafman

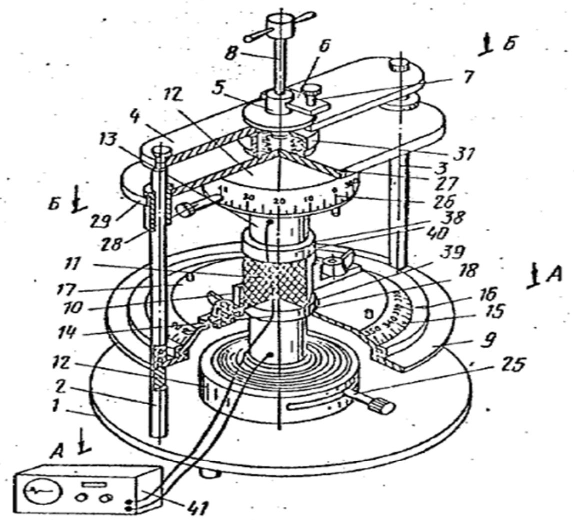
[57] **ABSTRACT**

The invention permits the measurement of the propagation anisotropy of a transverse wave between two given reference points of a non-isotropic medium (M), particularly a shear wave in a stratified or fissured rock.

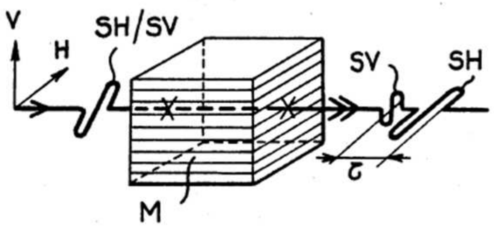
According to the invention: a source (S) and two detectors (G_1, G_2) are arranged along a single ray vector, the detectors being positioned at the location of respective reference points; the source is excited by an excitation signal producing a transverse wave in the medium; the respective resultant measurement signals produced by each of the detectors are received; from the excitation signal and the measurement signals the transfer function of the medium along each of the respective source-detector paths is determined; the differential transfer function of the medium between the two reference points is deduced.

Other configurations can also be provided, particularly two sources and one detector, or the method can be applied to seismic reflection with waves having an oblique incidence or even a zero incidence.

7 Claims, 1 Drawing Sheet



Фиг.1



5. Three-Component Recording Using Speckle Interferometry

The third illustration of the laser system in physical modeling is the use of the speckle interferometer to record all three components (3C) of transient displacement of a point at the surface of a solid physical model (Bayón and Rasolofosaon 1993).

5.1. How to achieve 3C recording ?

Due to the principle of detection of the speckle interferometer (Figs. 5b and 5c), we can only record two components of vibration for a given disposition of sample and interferometer; however, if we turn the sample 90° about an axis parallel to **n** and passing through the point to be ausculted (see Figs. 5b and 5c) we can observe again two components of the displacement, namely the last unknown in-plane component and (again) the normal component of vibration.

Bayon, A., Rasolofosaon, P. N. J., 1996, Three-component recording of ultrasonic transient vibration by optical heterodyne interferometry, *The Journal of the Acoustical Society of America*

(19)日本国特許庁（JP）　(12)公開特許公報（A）　(11)特許出願公開番号

特開平10−319129

(43)公開日　平成10年(1998)12月4日

(51)Int.Cl.6		識別記号	FI			
G01V	1/00		G01V	1/00		C
G01H	1/00		G01H	1/00		E
G01N	29/04	501	G01N	29/04	501	
G06F	17/00		G06F	15/20		D

審査請求　未請求　請求項の数2　OL　（全 6 頁）

(21)出願番号　特願平9−128680

(22)出願日　平成9年(1997)5月16日

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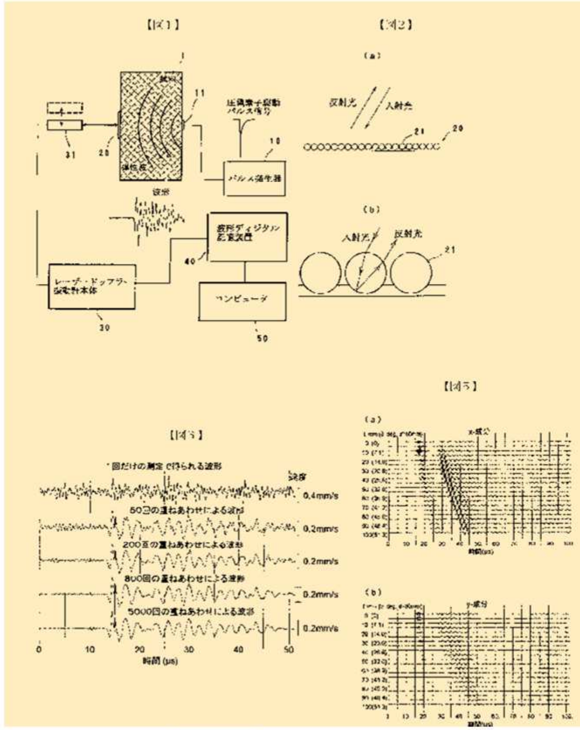
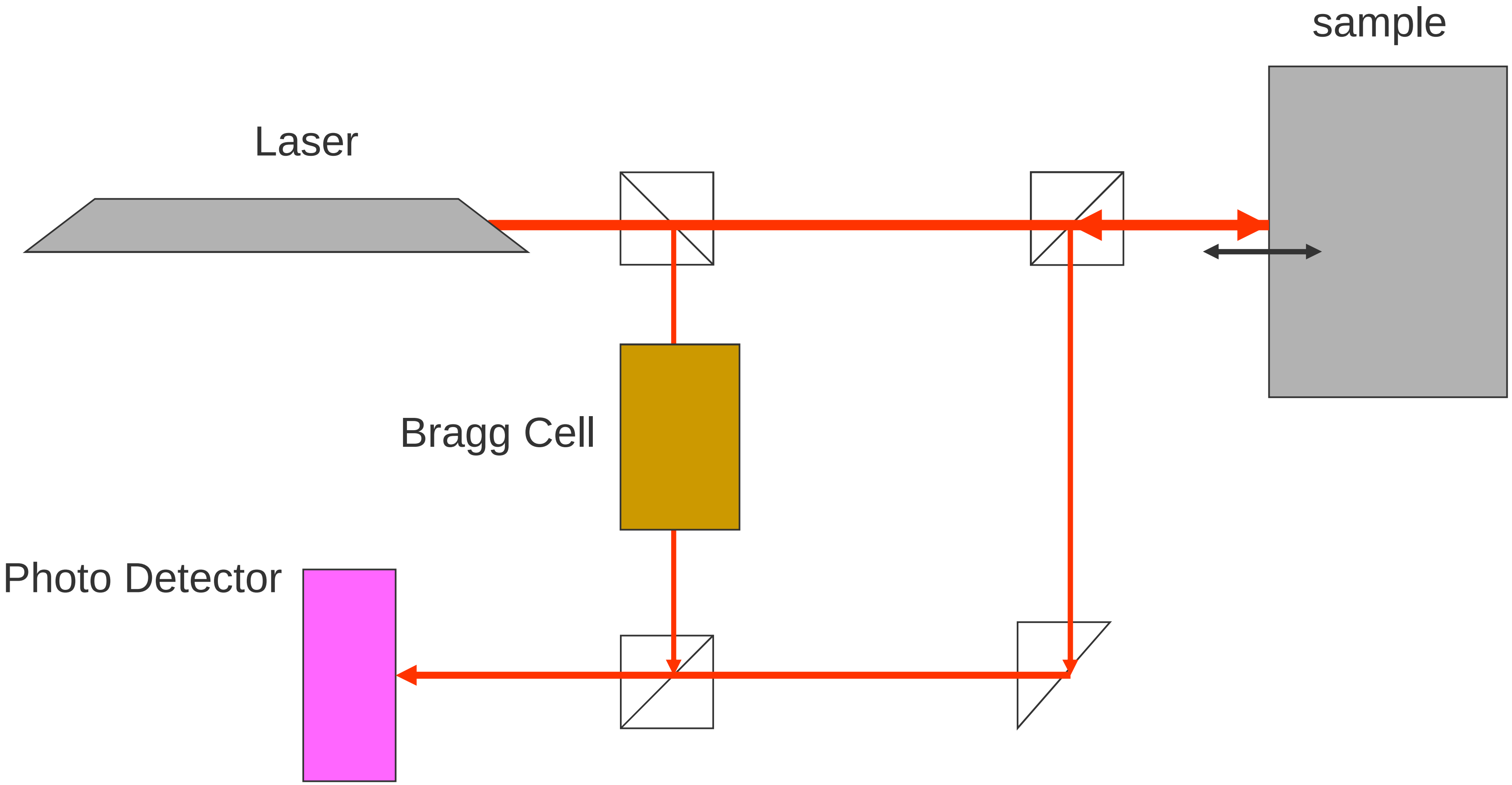
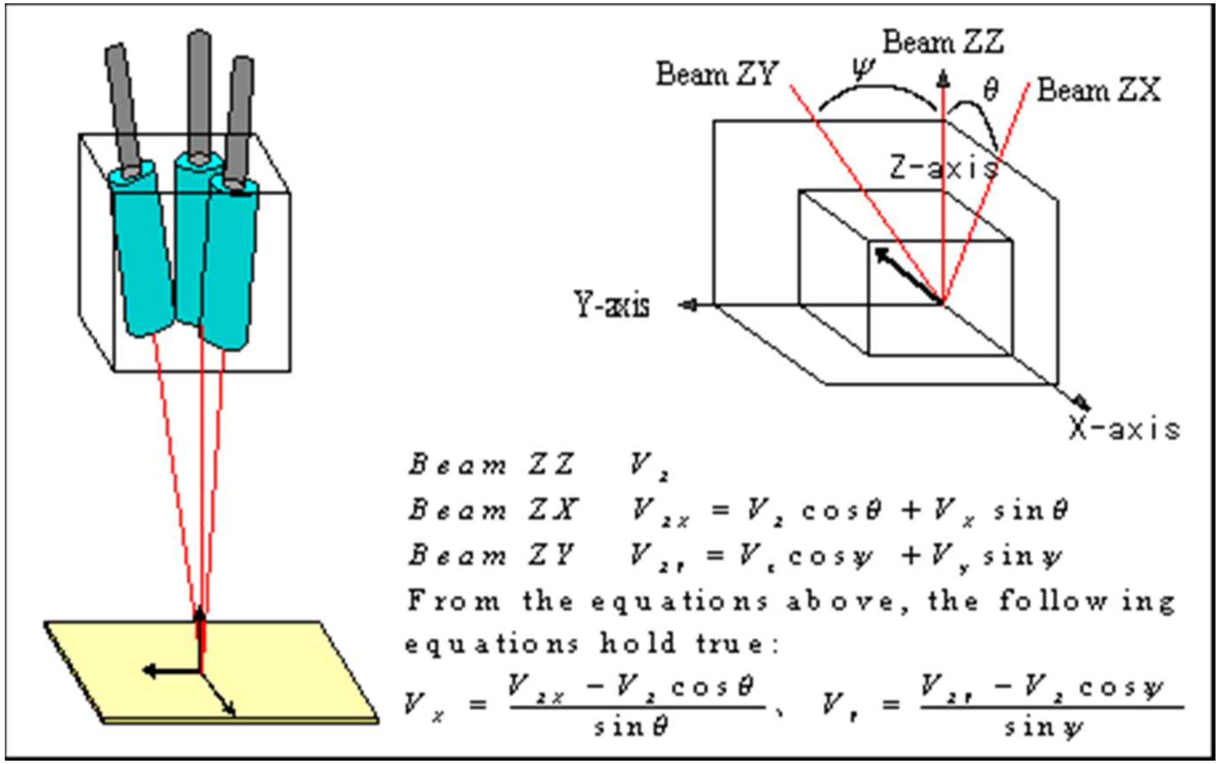
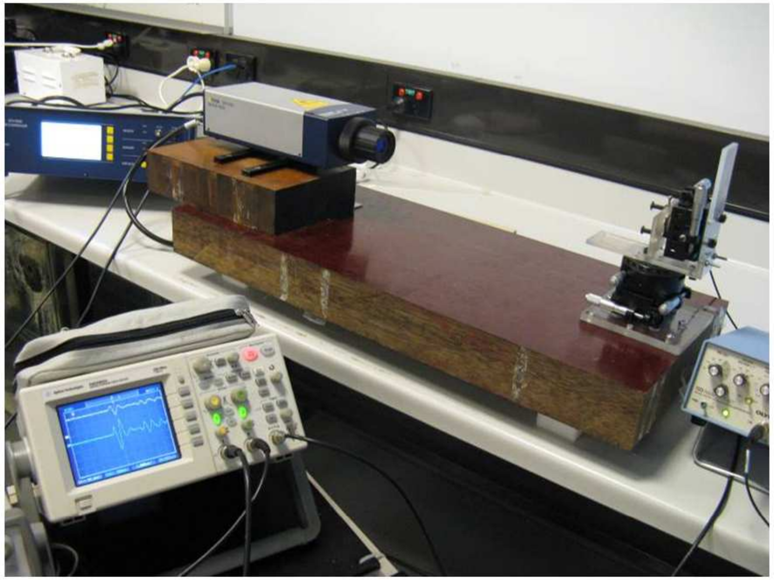


Laser Doppler Interferometer 1C



3 C laser interferometers are available on market, but…





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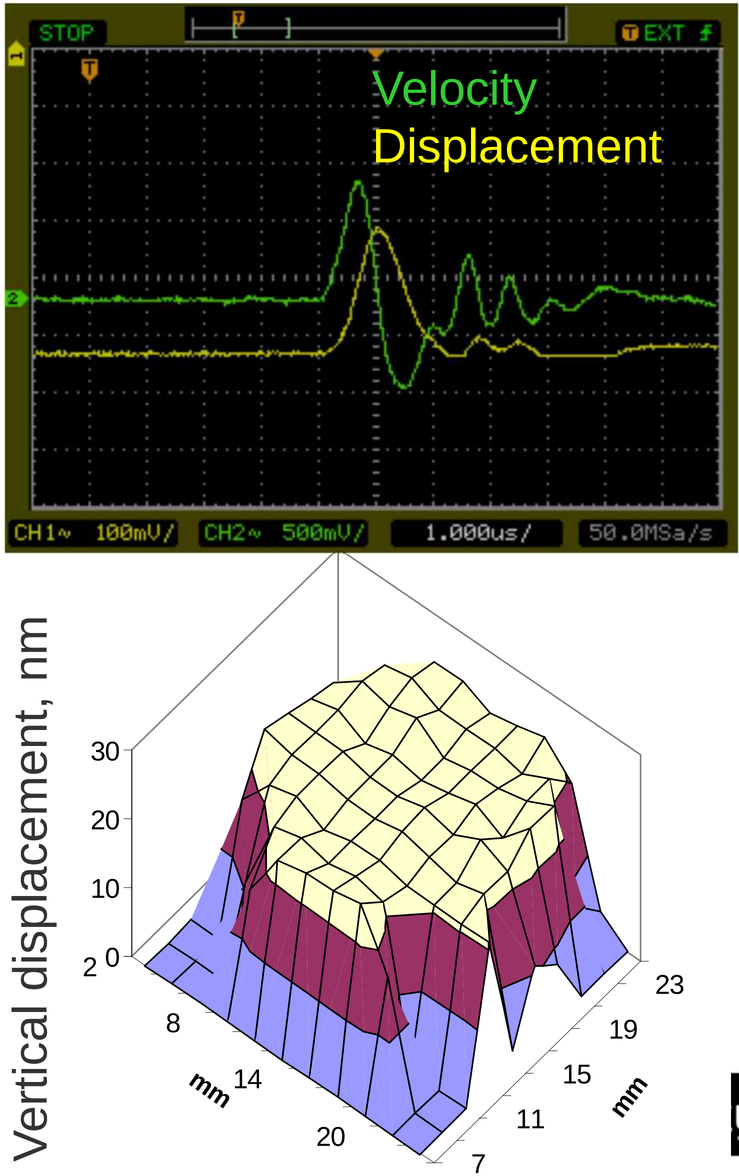
CRI

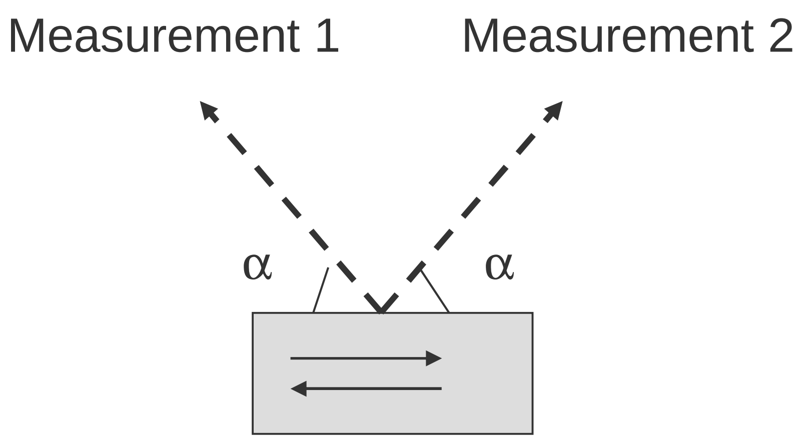


STOP
EXT
Velocity
Displacement
CH1 100mV/
CH2 500mV/
1.000us/
50.0MSa/s
Vertical displacement, nm
30
20
10
2 0
8
14
20
mm
7
11
15
19
23
mm

y

S – wave measurements using interferometer?

It is possible



$$S\ \text{wave} = \tfrac{1}{2}\left(\text{Measurement1} \times \cos(\alpha) - \text{Measurement 2} \times \cos(\alpha)\right)$$

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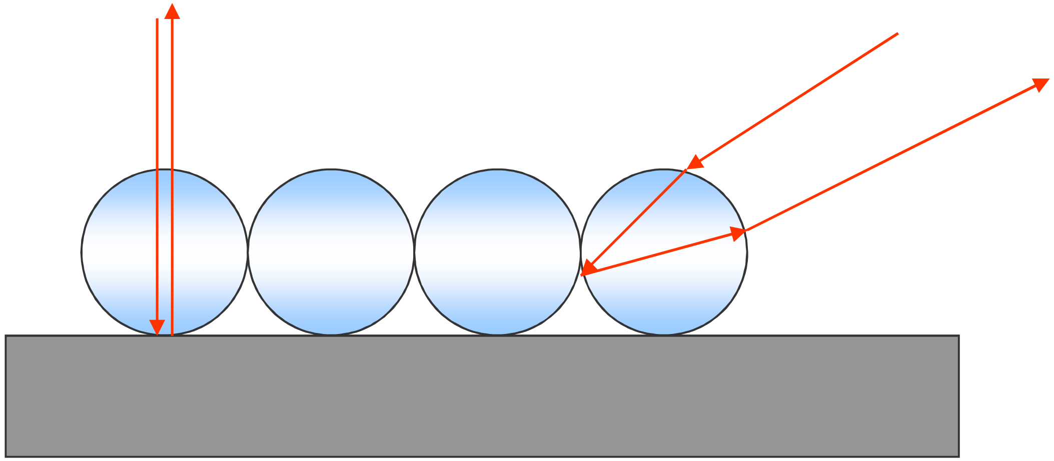
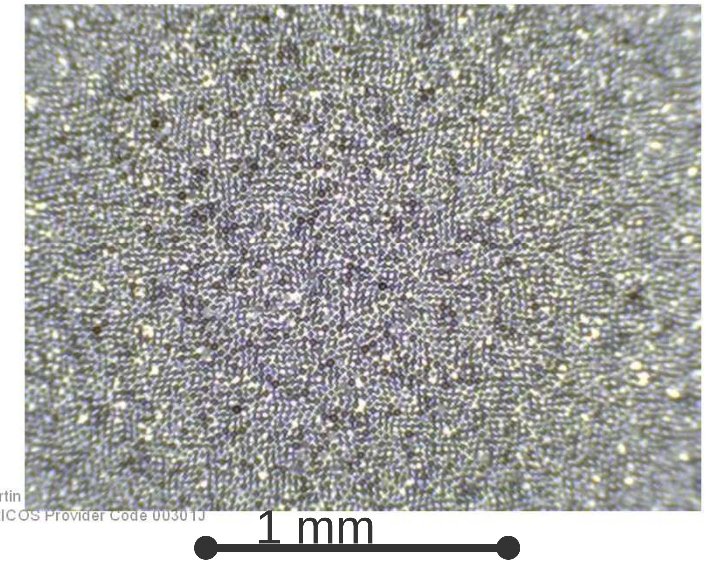
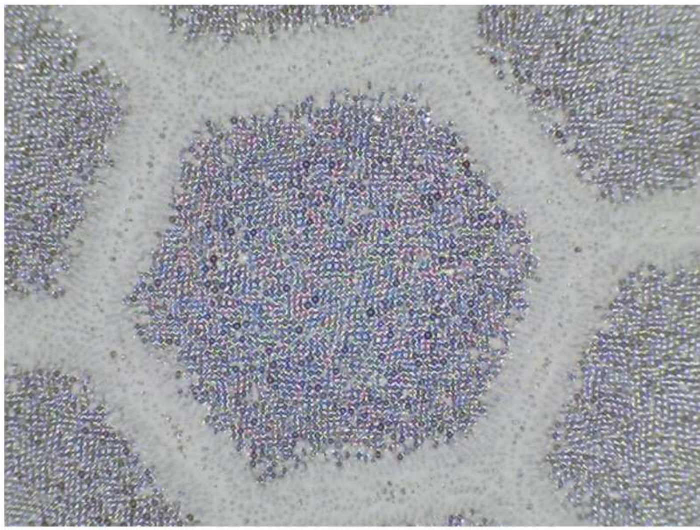
Reflective tape

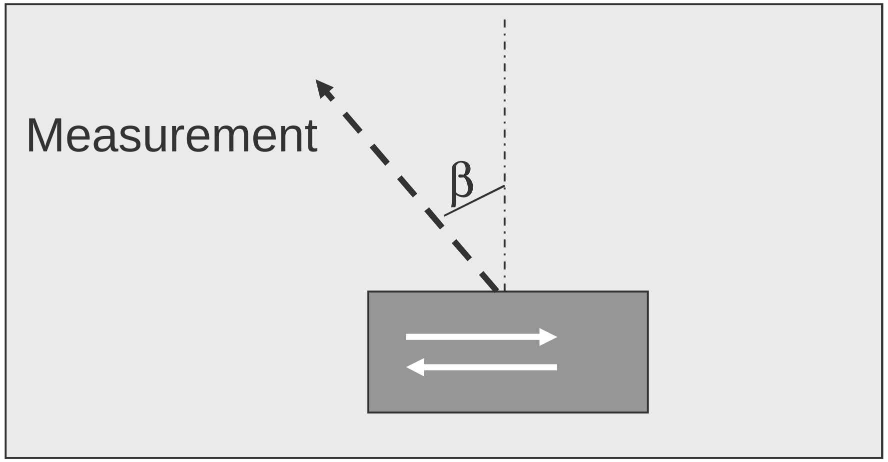


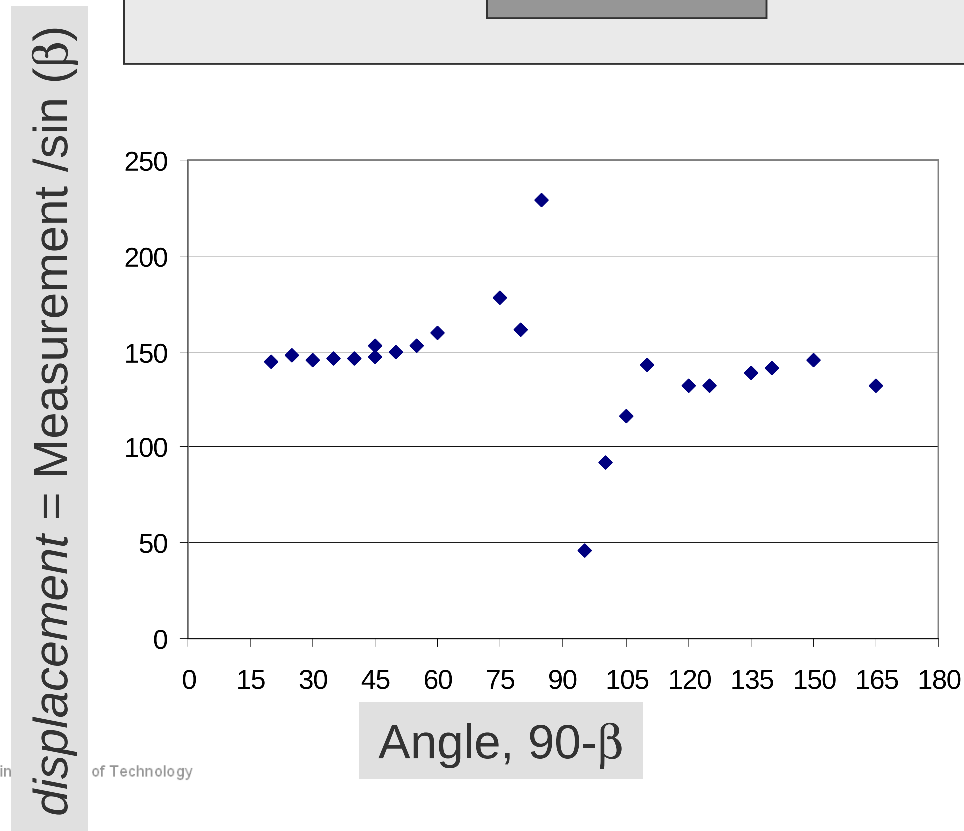
50-μm-diameter glass beads





Optimization of the direction of measurement (laser beam incident angle)





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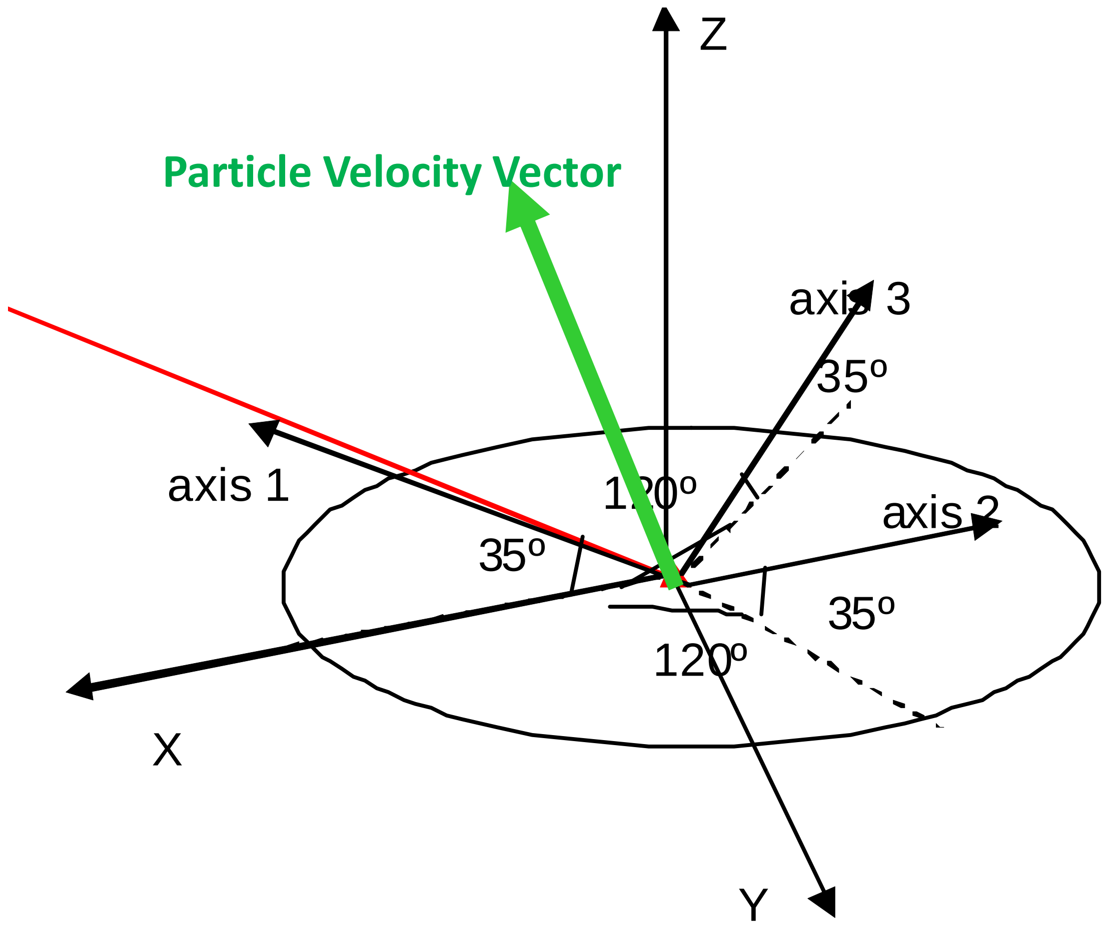
3C at the lab



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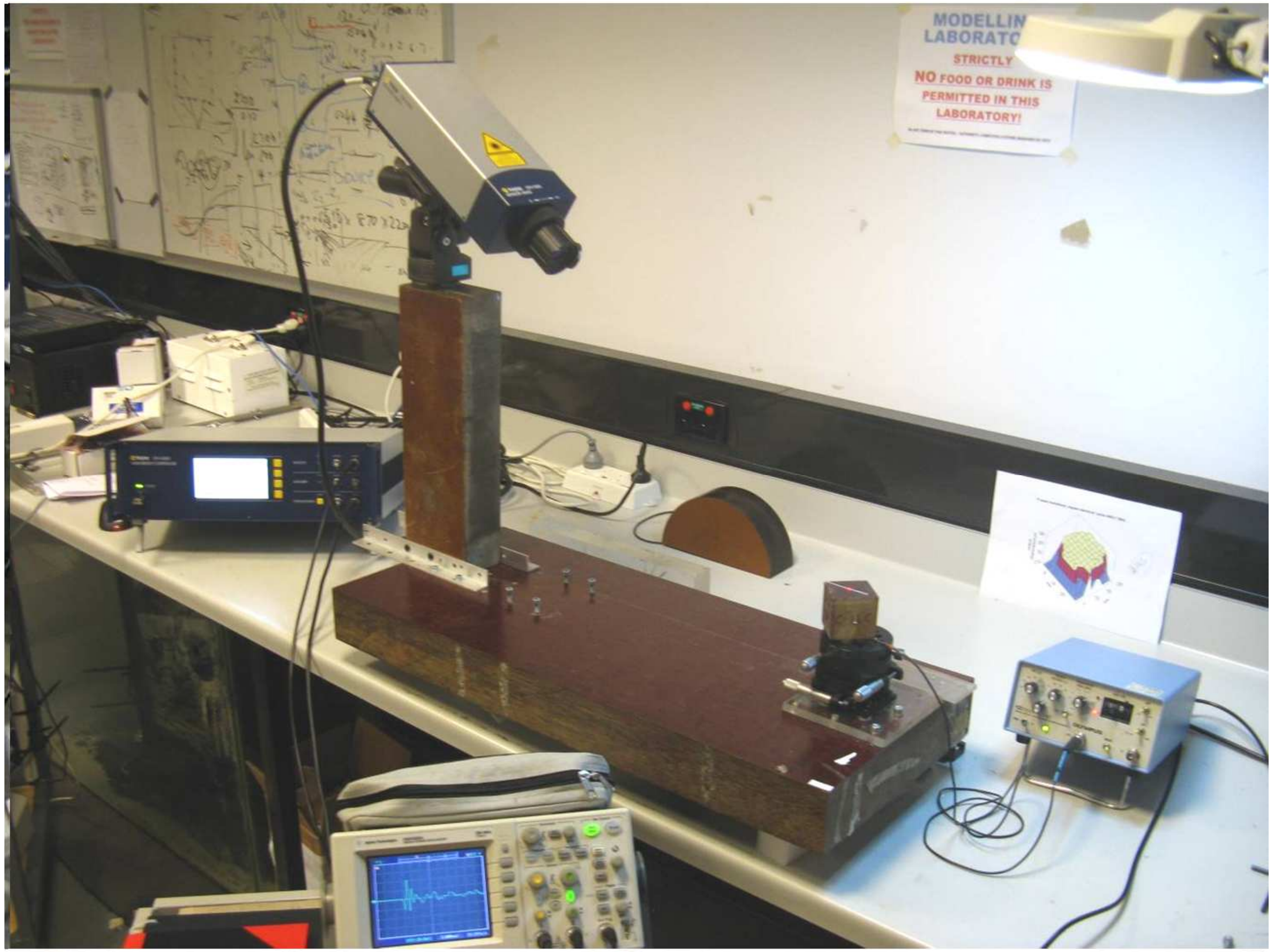
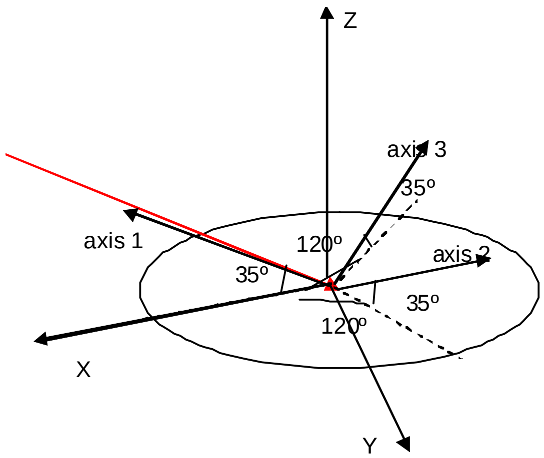
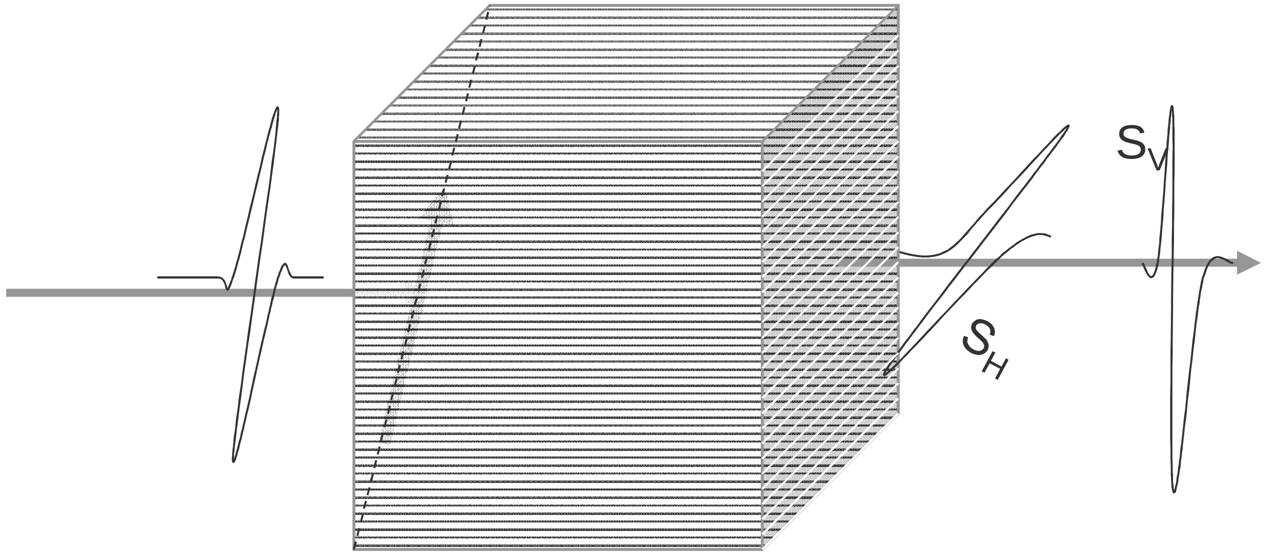


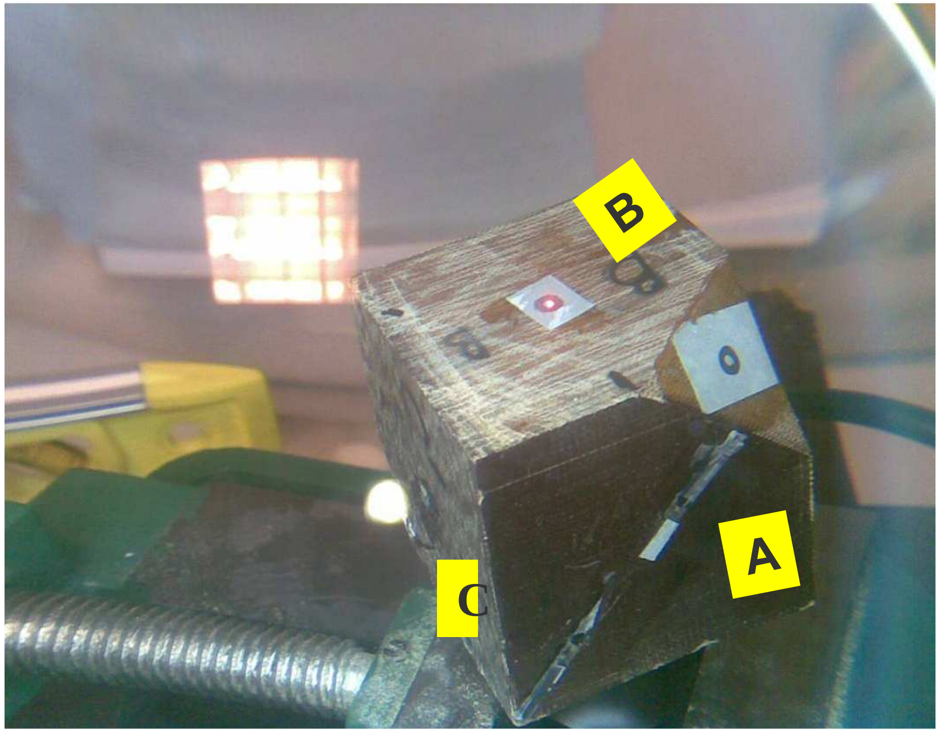


Rock Physics laboratory at *Curtin University*,
Perth, Western Australia

Curtin University

Test experiment 1: S wave splitting

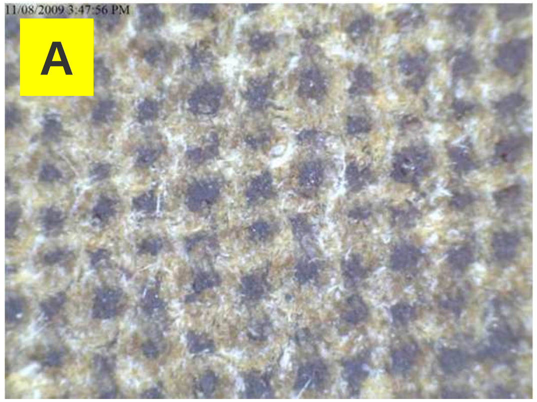


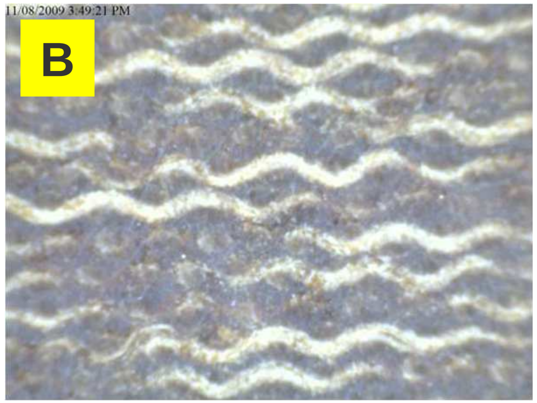


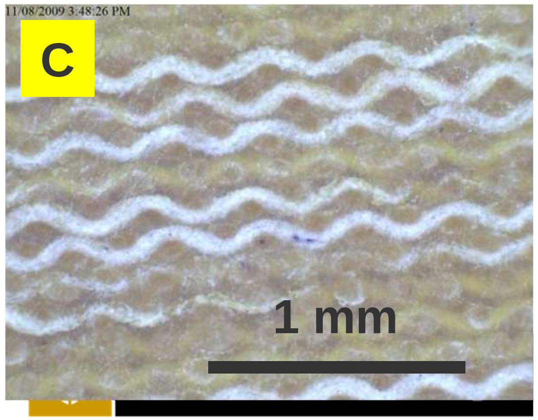
Tested media
"paper reinforced phenolic"

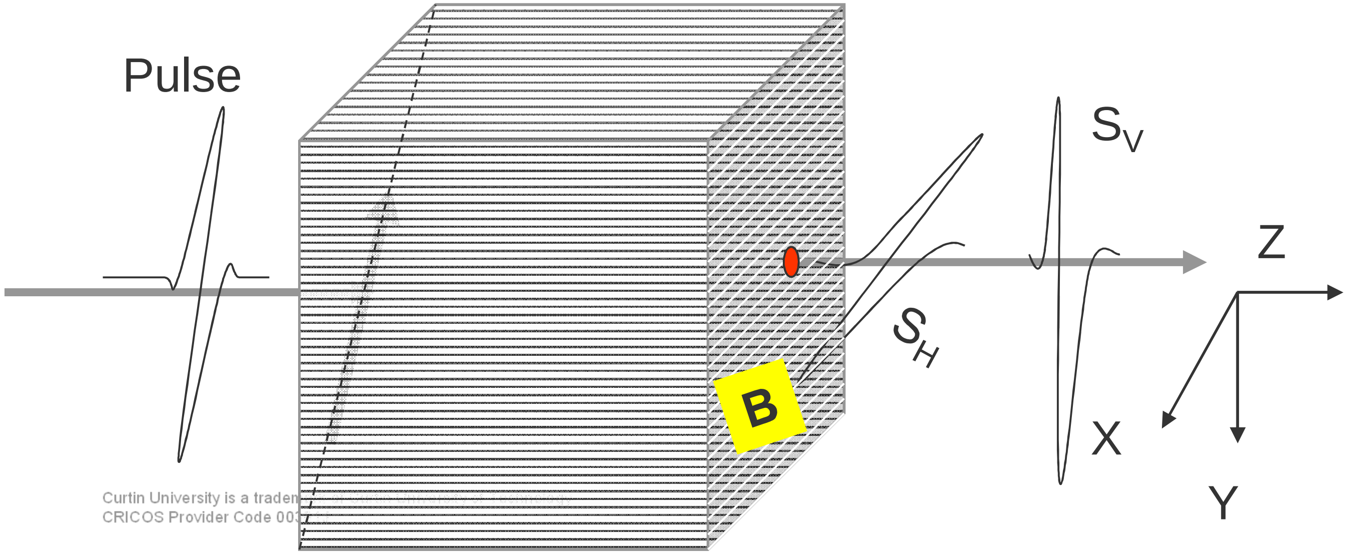
Vp|| **3519m/s**

Vp ⊥ **2875m/s**

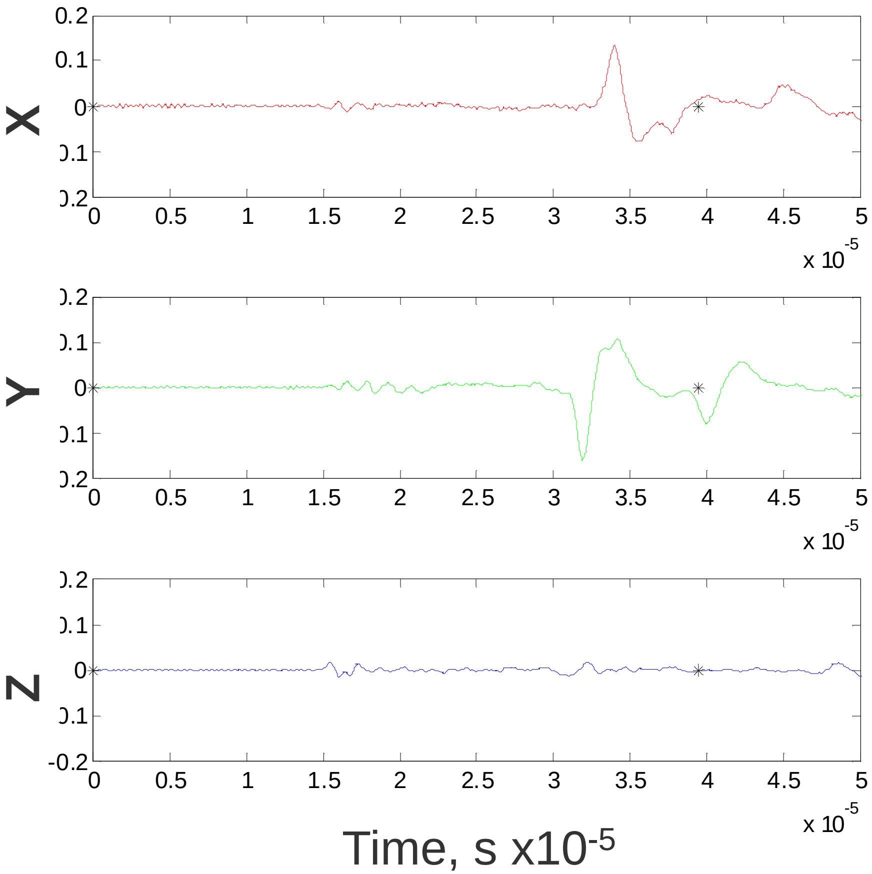


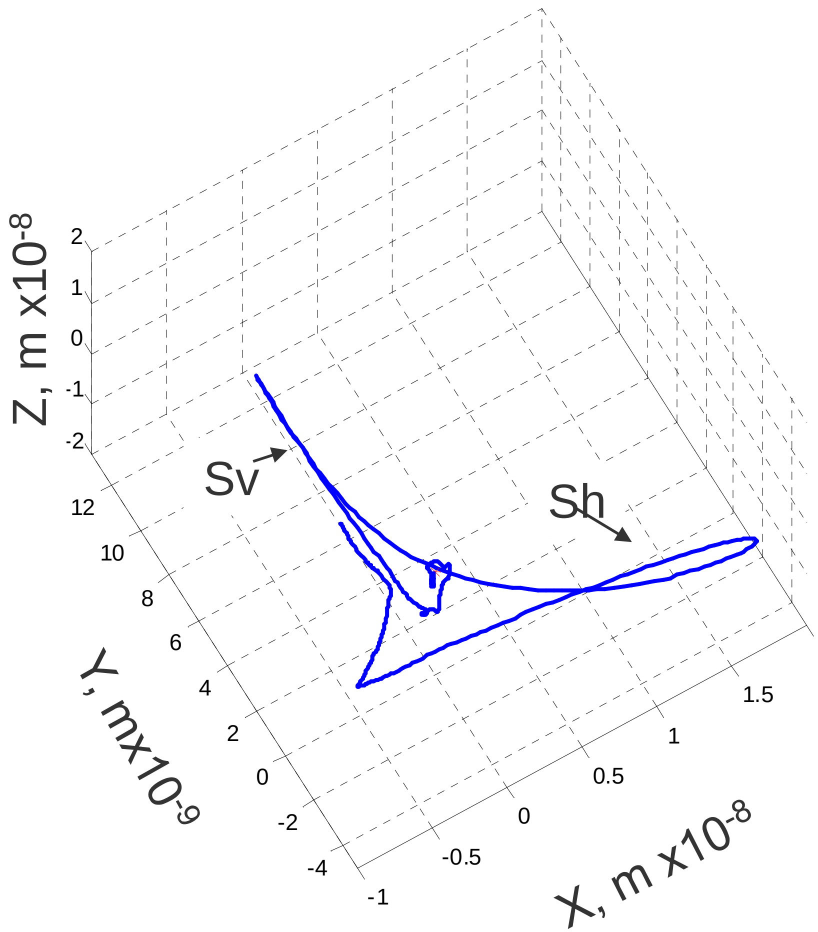


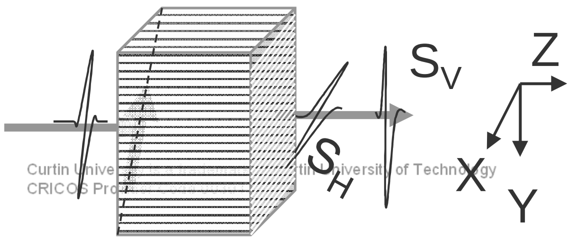




SV and SH measurements at 3C configuration







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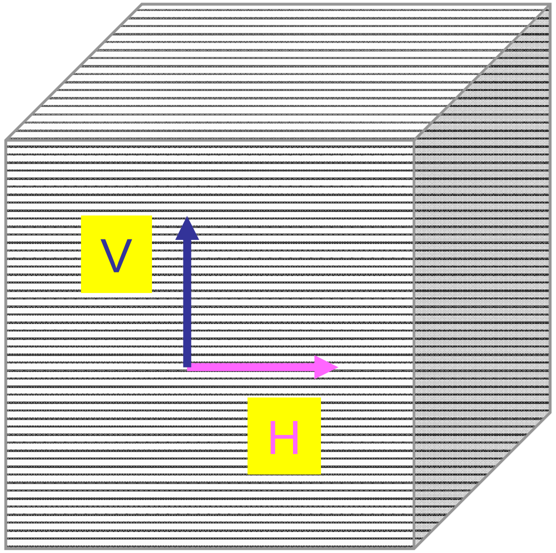
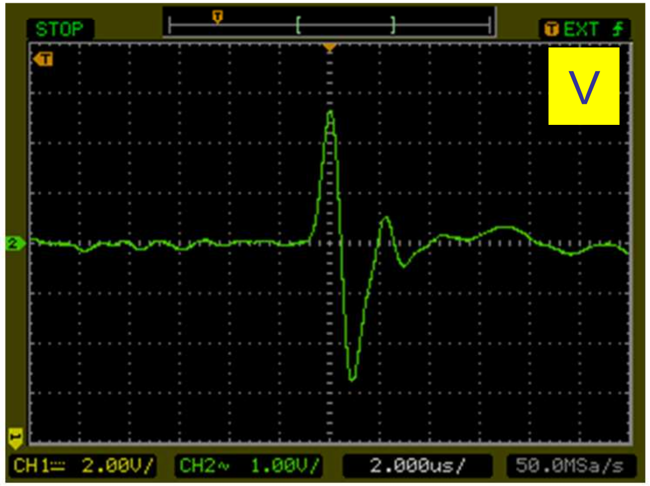
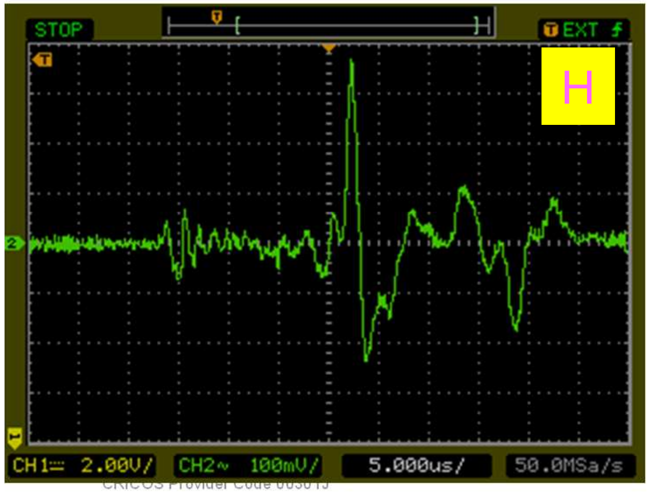
Test experiment 1 (b) Comparison: Interferometer vs Transducer: Same source (S-transducer) and Measurements at the SAME directions

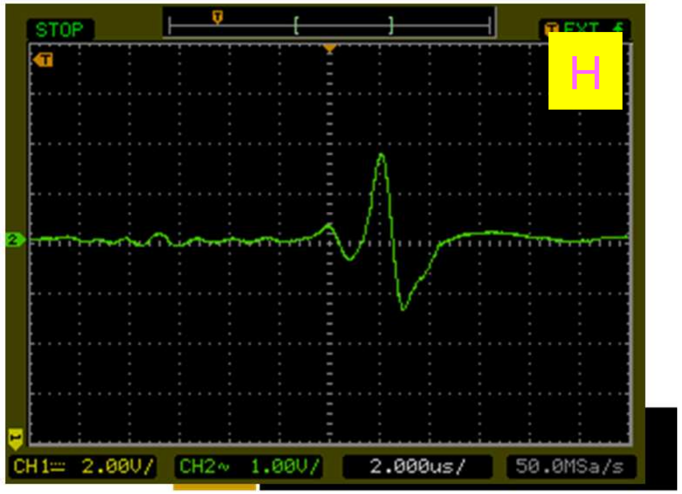
interferometer

S transducer

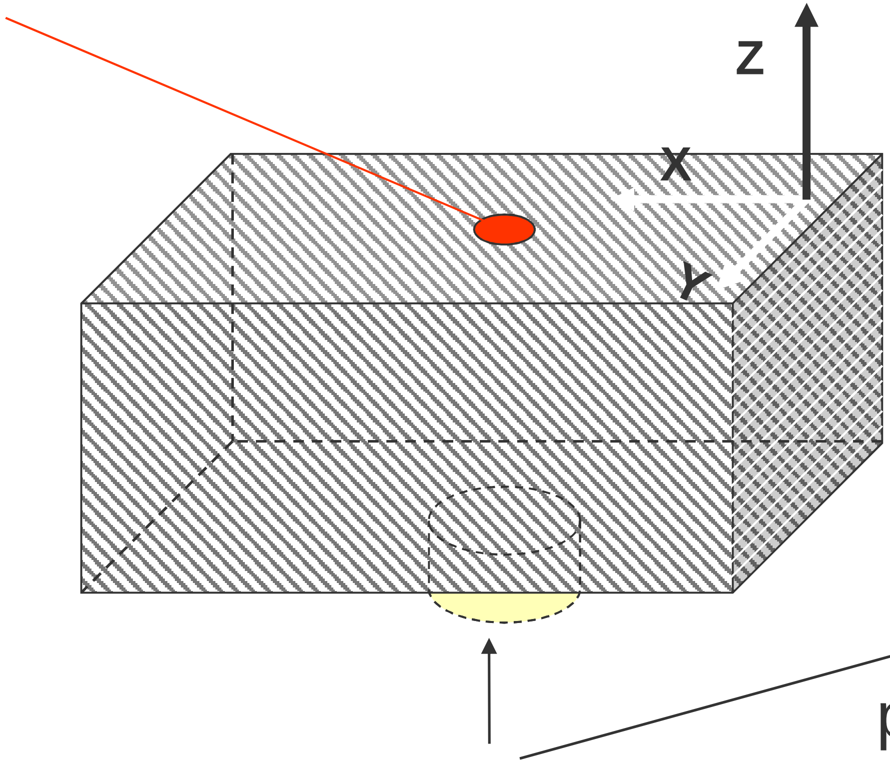


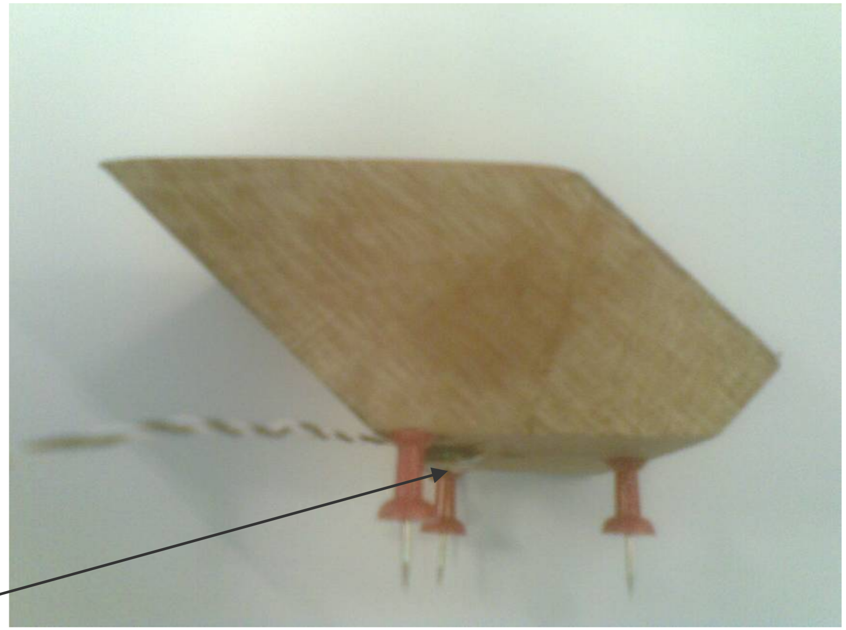






Test experiment 2: *artificial TI media*





paper reinforced phenolic

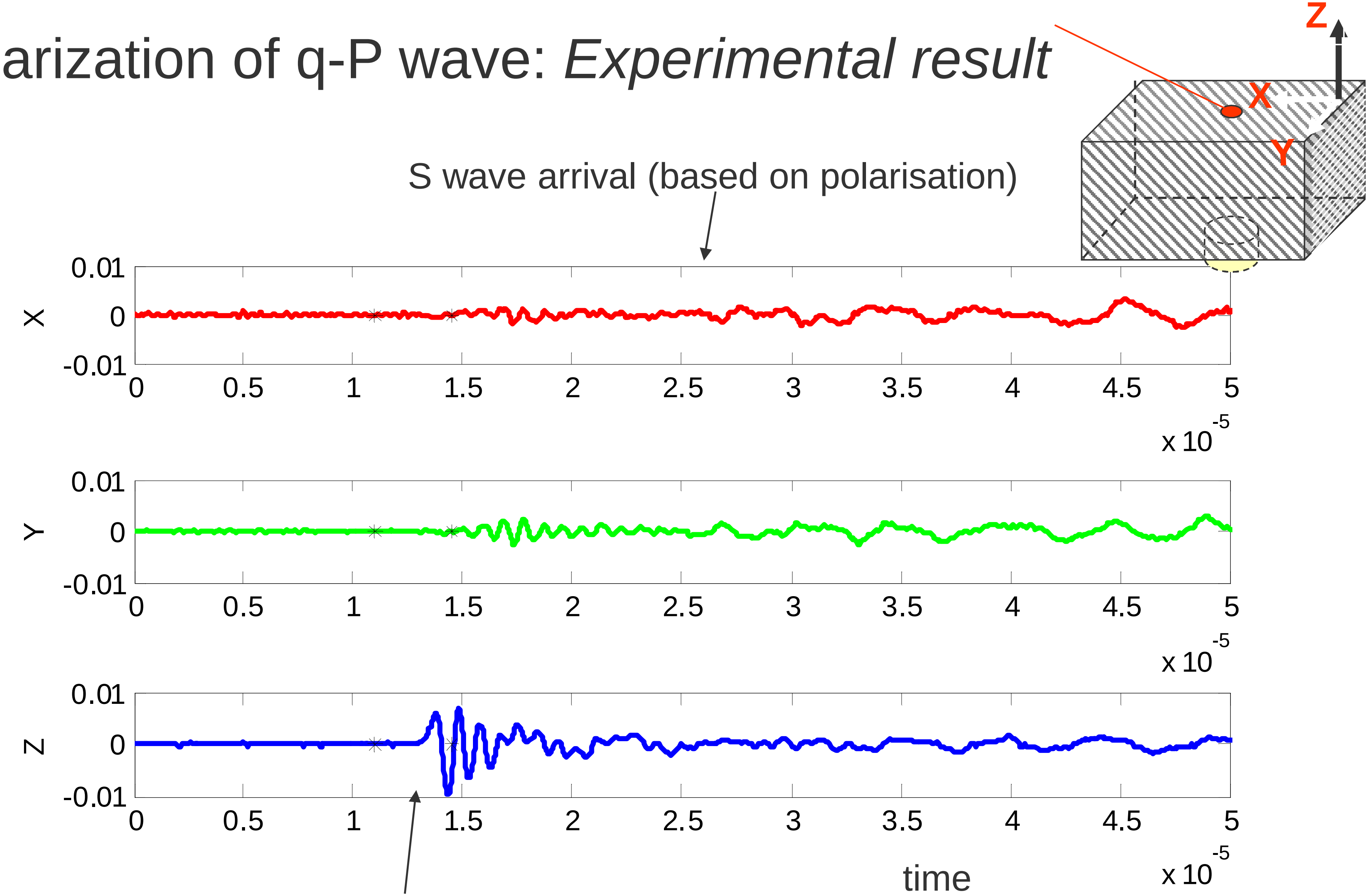
Pulse Source 0.5 MHz

Vp || **3519 m/s**

Vp ⊥ **2875 m/s**

Polarization of q-P wave: *Experimental result*

S wave arrival (based on polarisation)



P wave arrival (based on polarisation)

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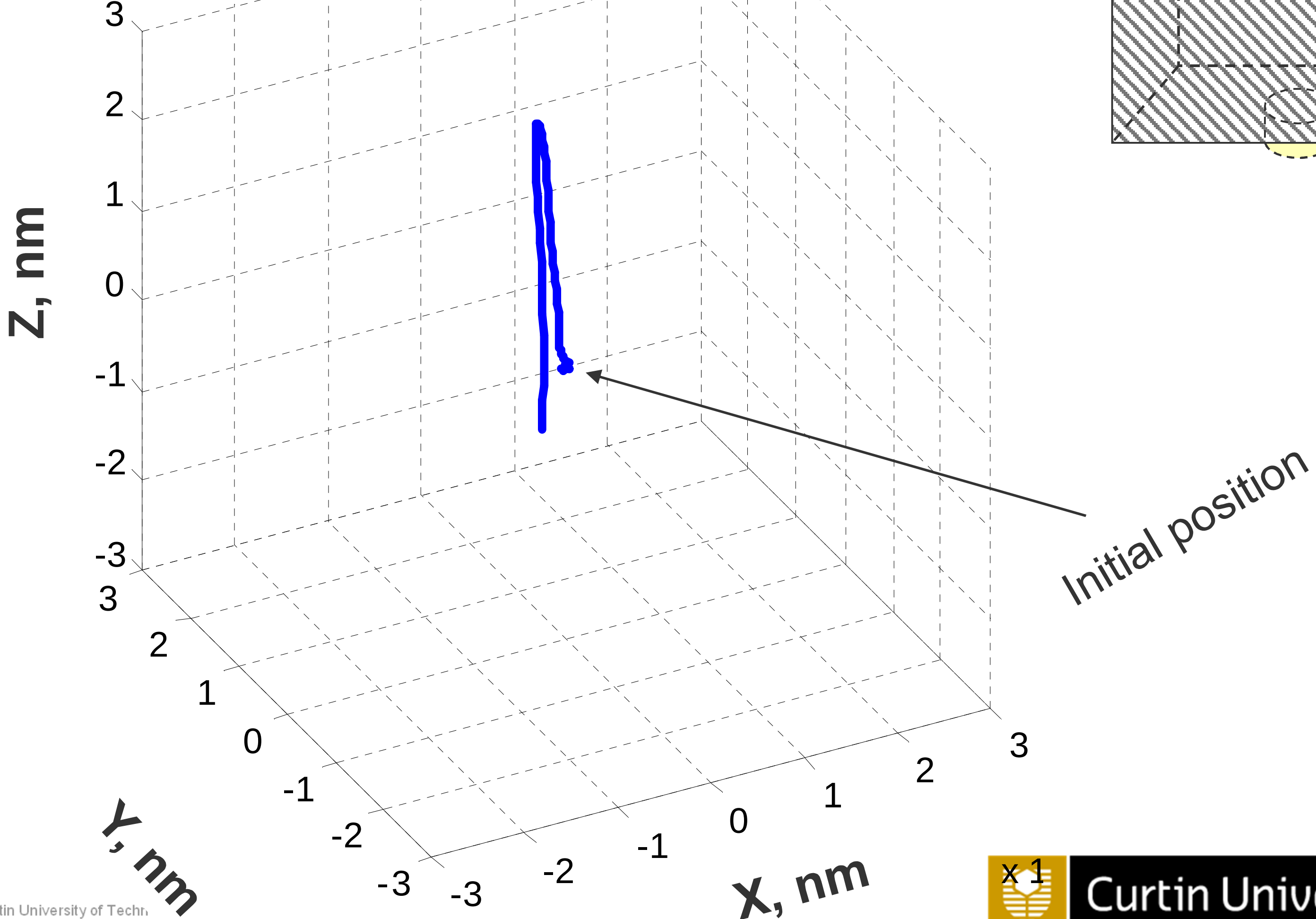
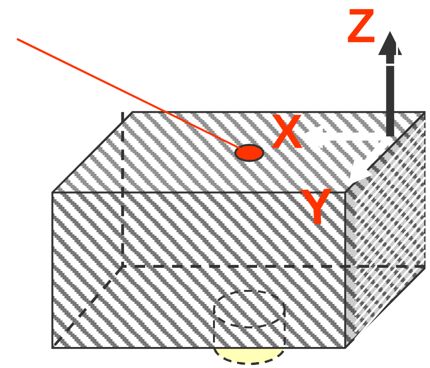
Polarization of q-P wave: *Experimental result*





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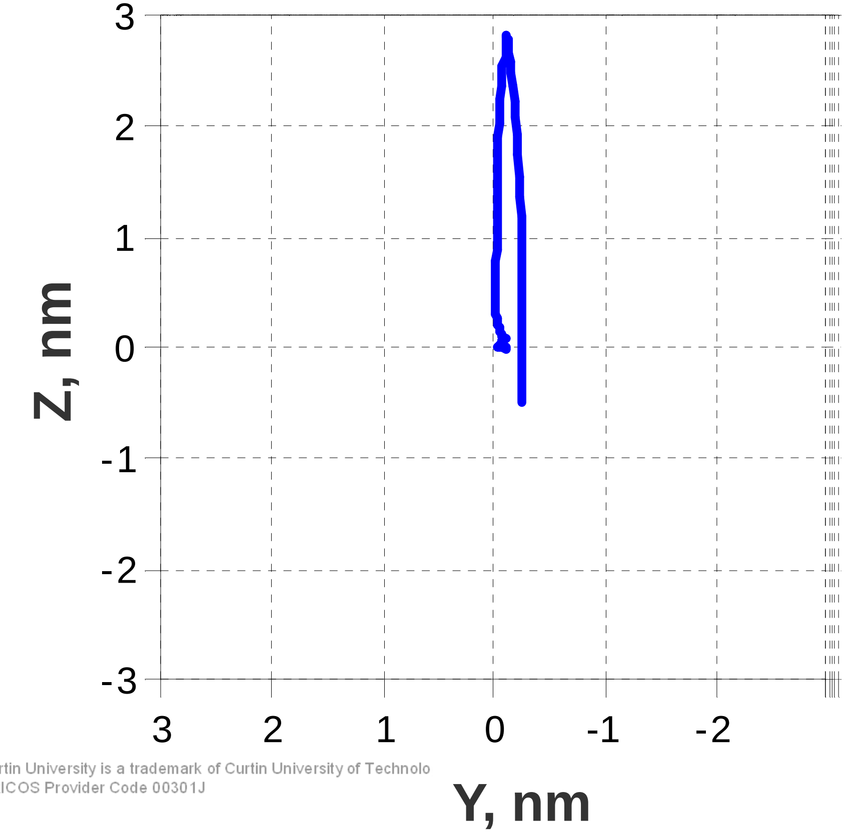
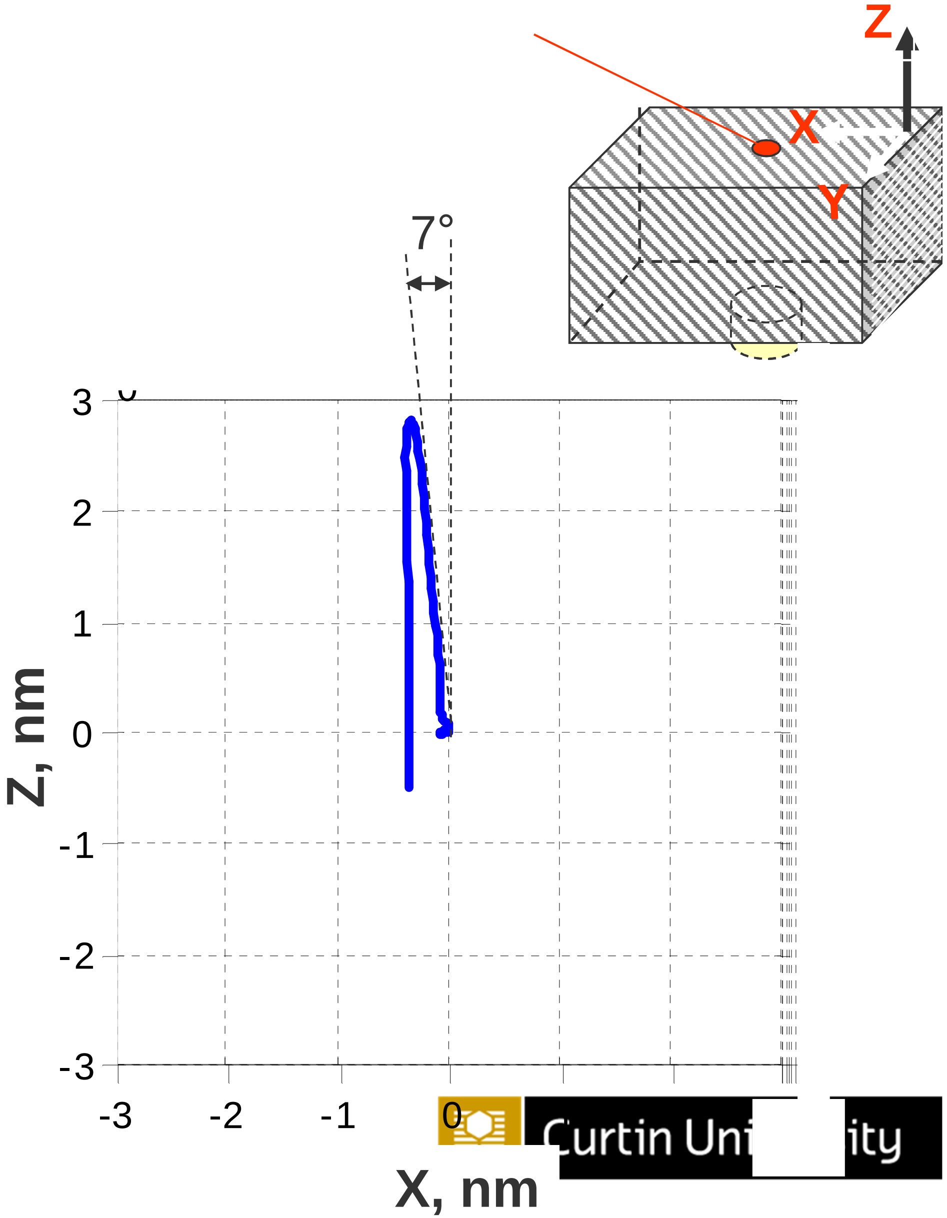
Polarization of q-P wave: *Experimental result*

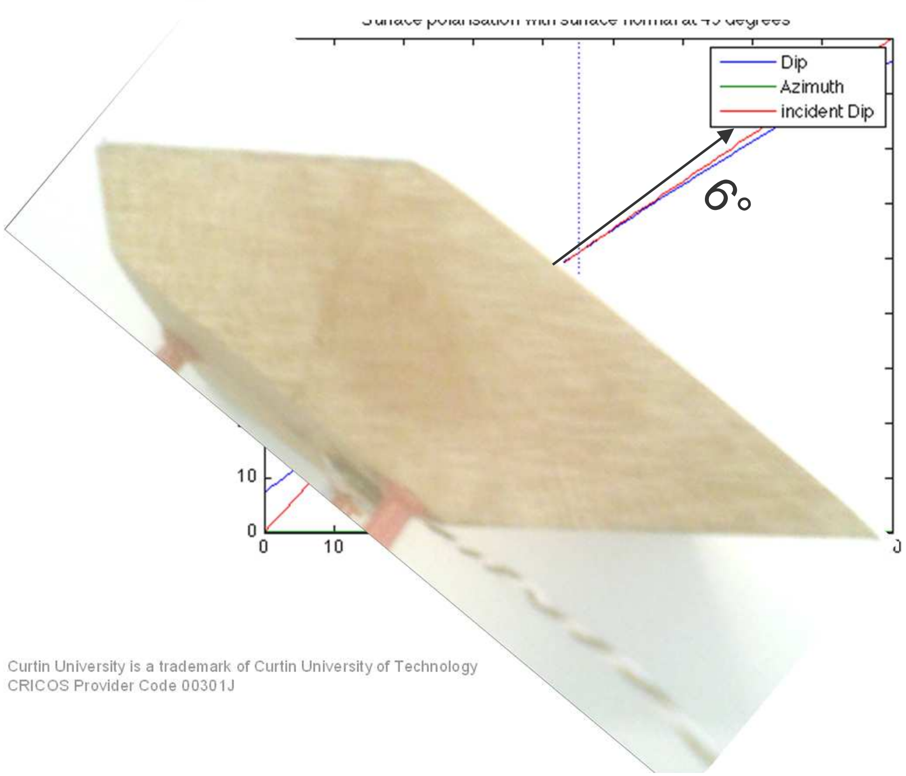


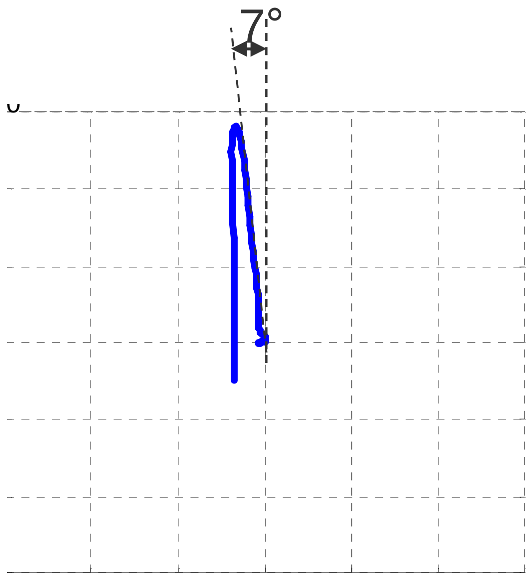


Polarization of q-P wave: *Forward modelling*

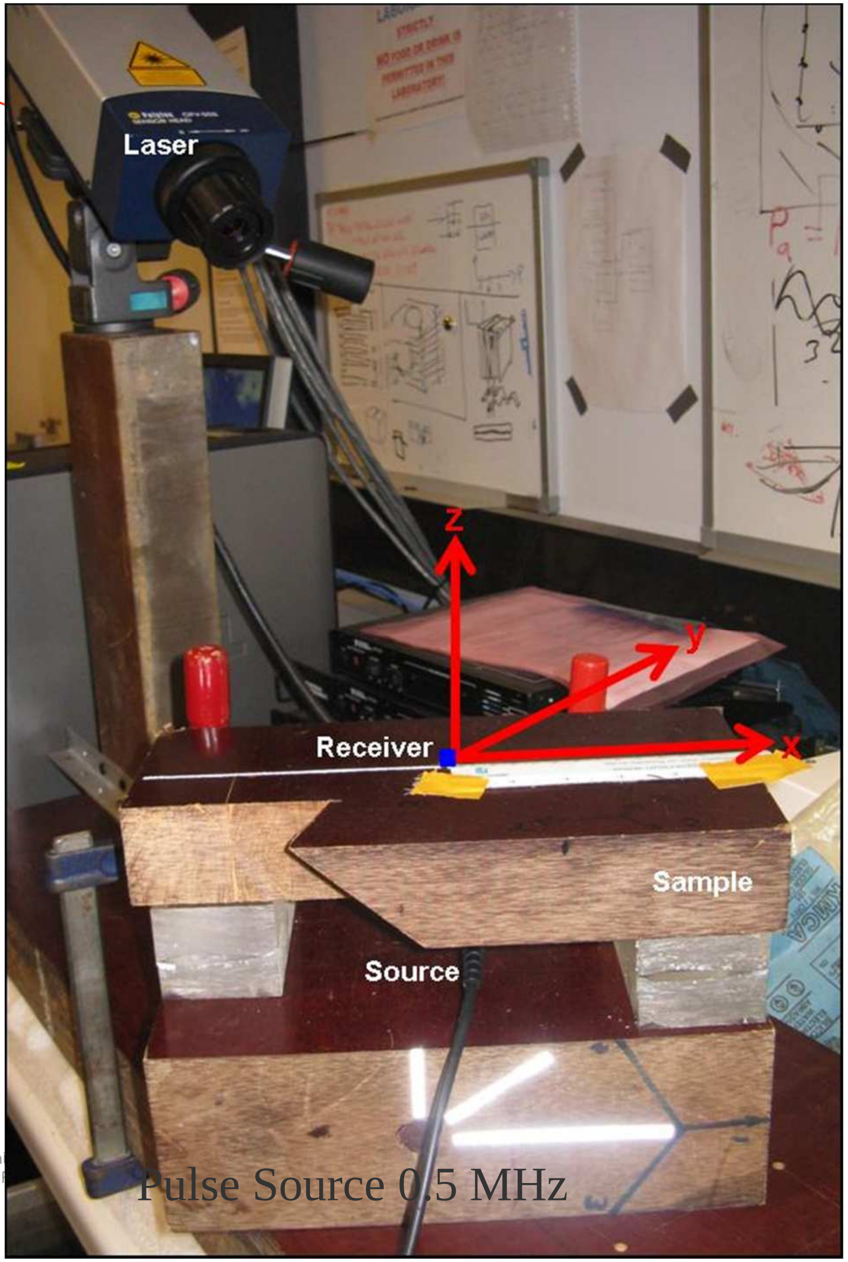
paper reinforced phenolic : Stiffness tensor

$$C = \begin{pmatrix} 17.6 & 9.6 & 7.7 & 0 & 0 & 0 \\ 9.6 & 17.6 & 7.7 & 0 & 0 & 0 \\ 7.7 & 7.7 & 12.0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 3.4 & 0 & 0 \\ 0 & 0 & 0 & 0 & 3.4 & 0 \\ 0 & 0 & 0 & 0 & 0 & 4.0 \end{pmatrix} \text{GPa},$$





Test experiment 3: *walk away artificial TI media*

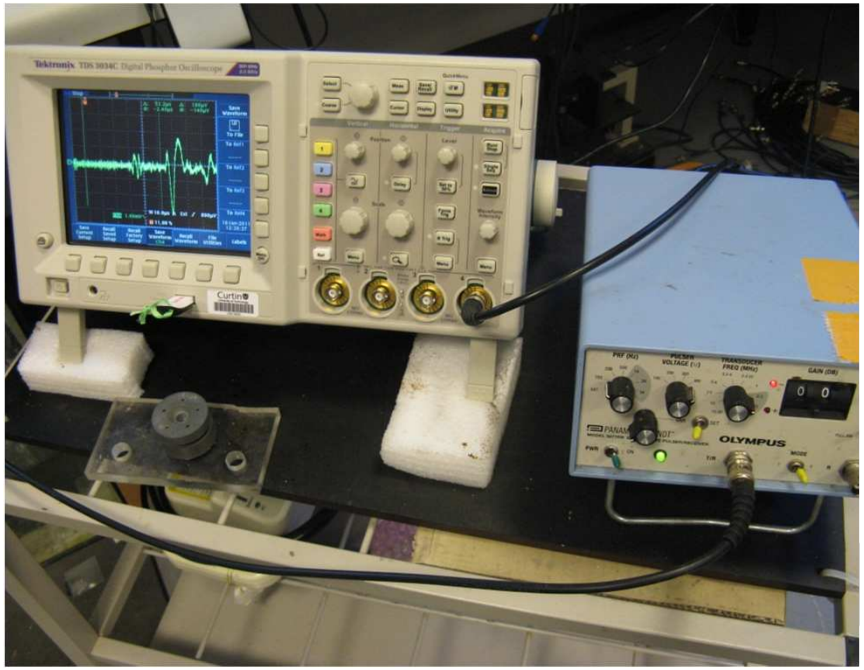


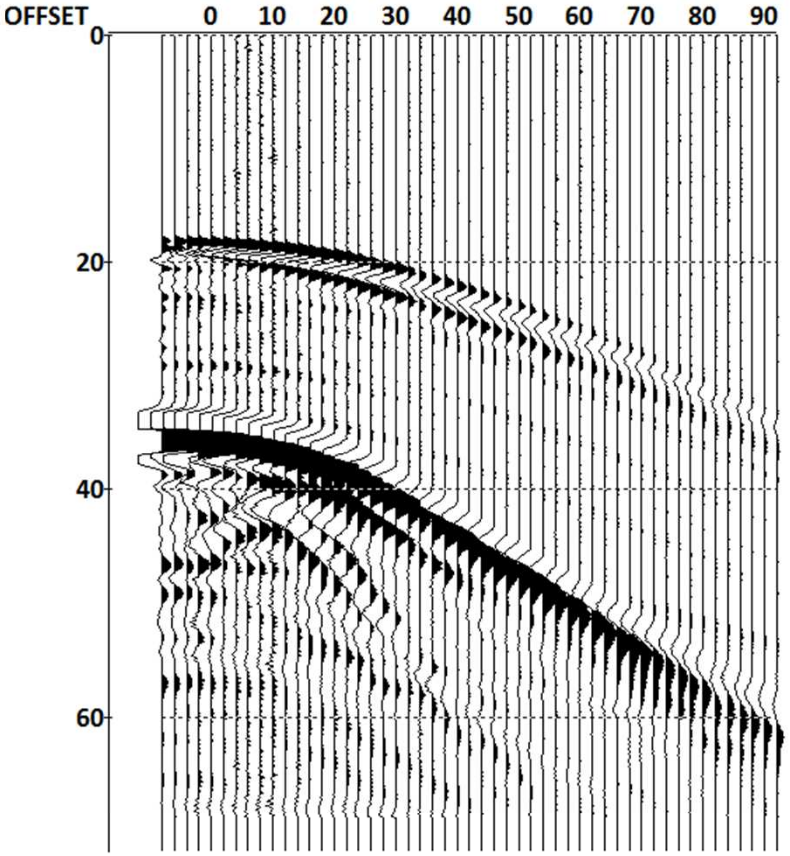
Pulse Source 0.5 MHz

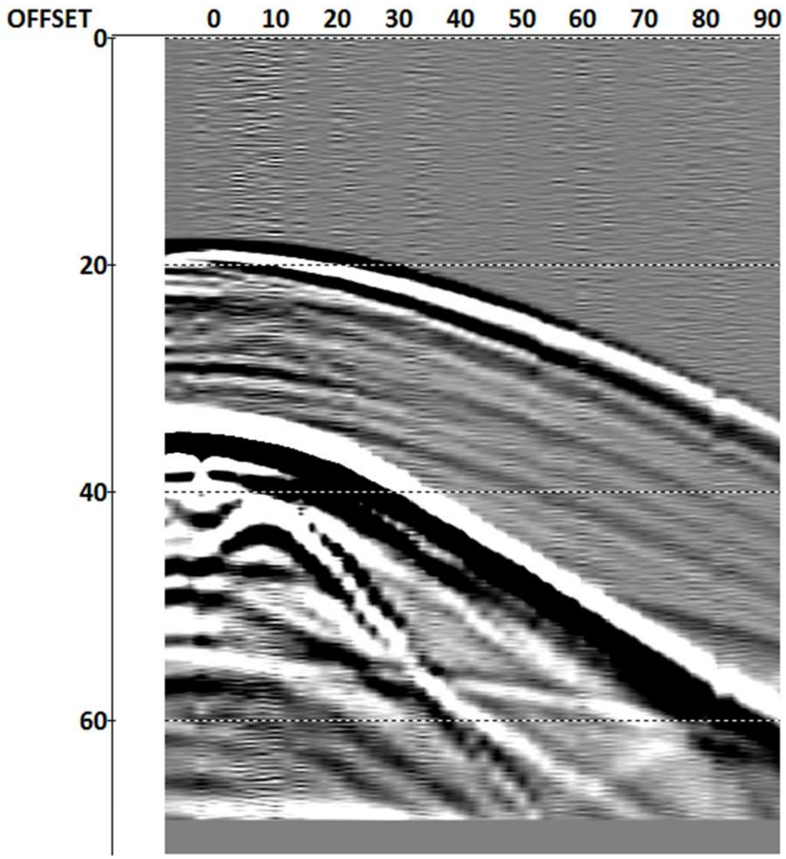
paper reinforced phenolic

Vp || **3519 m/s**

Vp ⊥ **2875 m/s**




OFFSET
0
10
20
30
40
50
60
70
80
90
0
20
40
60


OFFSET
0
10
20
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0
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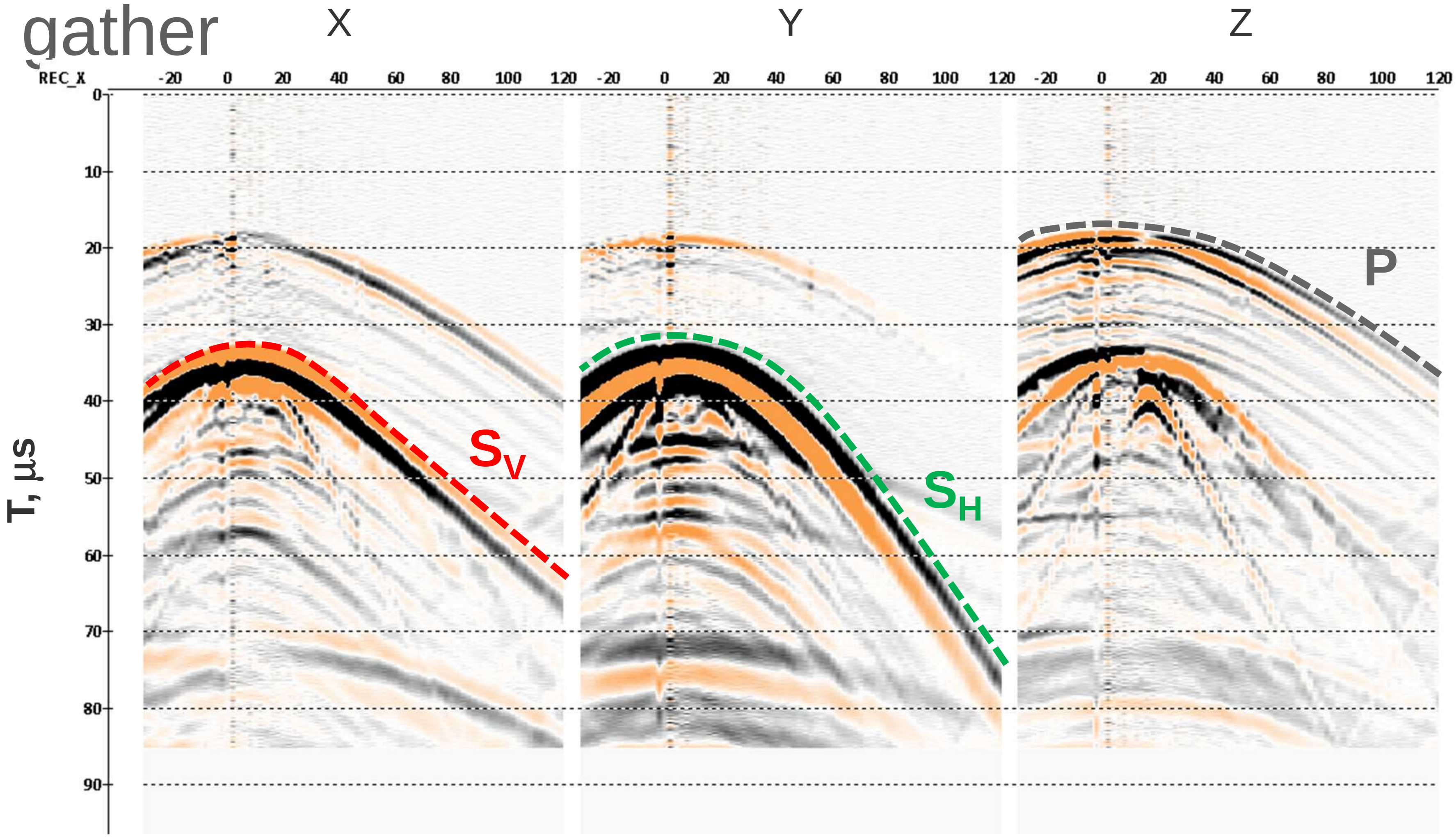
40
60

paper reinforced phenolic: 3C common shot gather

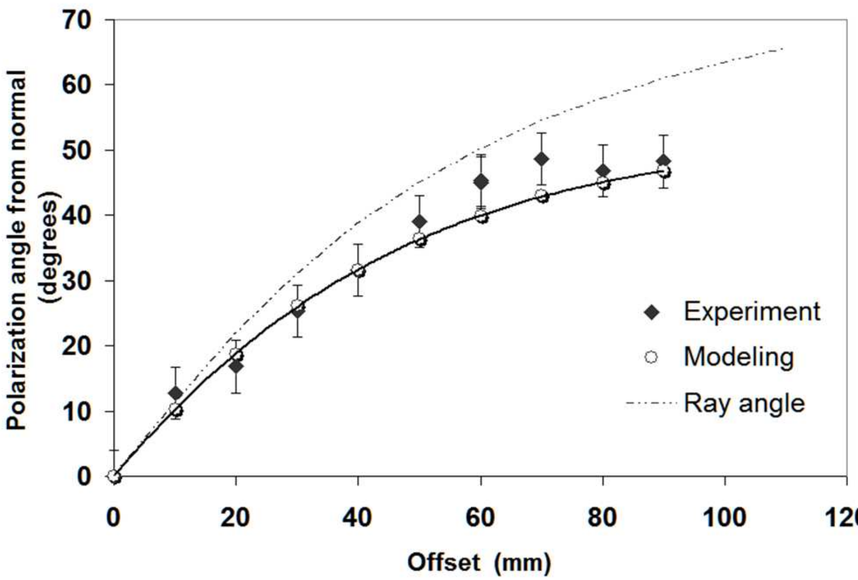


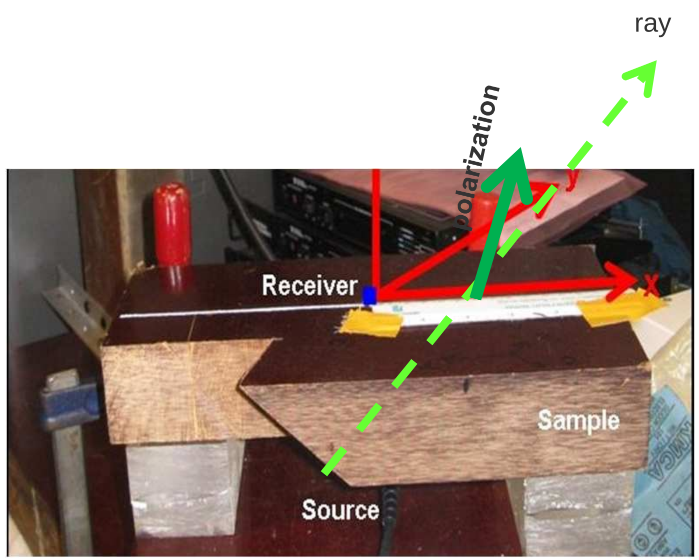
Polarization of q-P wave: *Forward modelling*

paper reinforced phenolic : Stiffness tensor

$$C=\begin{pmatrix} 17.6 & 9.6 & 7.7 & 0 & 0 & 0 \\ 9.6 & 17.6 & 7.7 & 0 & 0 & 0 \\ 7.7 & 7.7 & 12.0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 3.4 & 0 & 0 \\ 0 & 0 & 0 & 0 & 3.4 & 0 \\ 0 & 0 & 0 & 0 & 0 & 4.0 \end{pmatrix}\ \mathrm{GPa},$$

Thomsen parameters are γ=0.08, δ=0.25, ε=0.23, and α=2887m/s, β=1548m/s.





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Anisotropy analysis based on velocities and polarization: *Algorithm*

If we measure the phase (wavefront) velocities:

$$a_{ijkl}\, p_i\, p_k\, A_j = A_l$$

If measured are group (ray) velocities:

$$\Gamma\left(\Gamma^{-1}(A)v\right) = A$$

$$\Gamma(x)_{ik} = a_{ijkl}\, x_j\, x_l$$

A corresponding polarization vector

a density-scaled stiffness tensor.

p phase slowness vect

v group (ray) velocity

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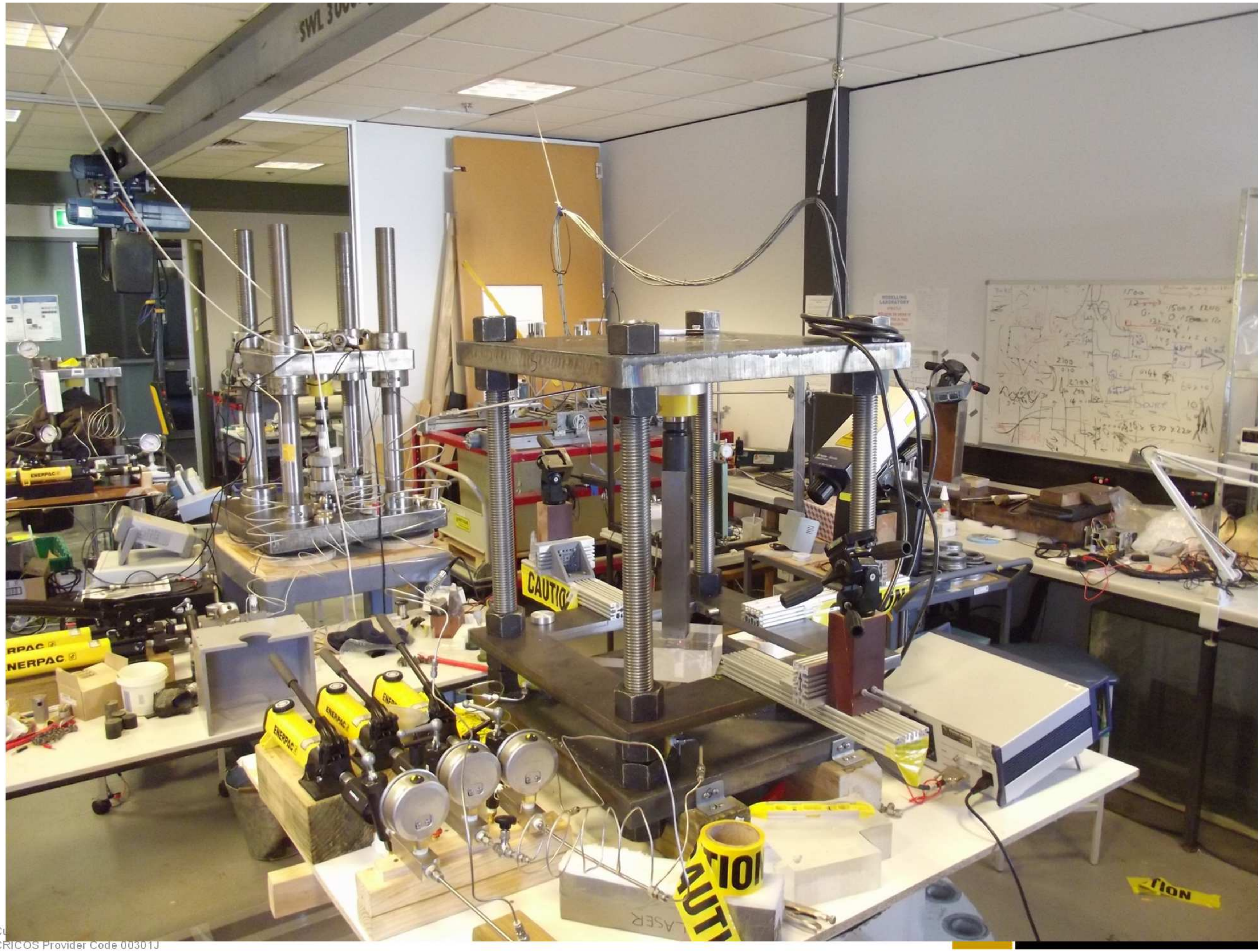
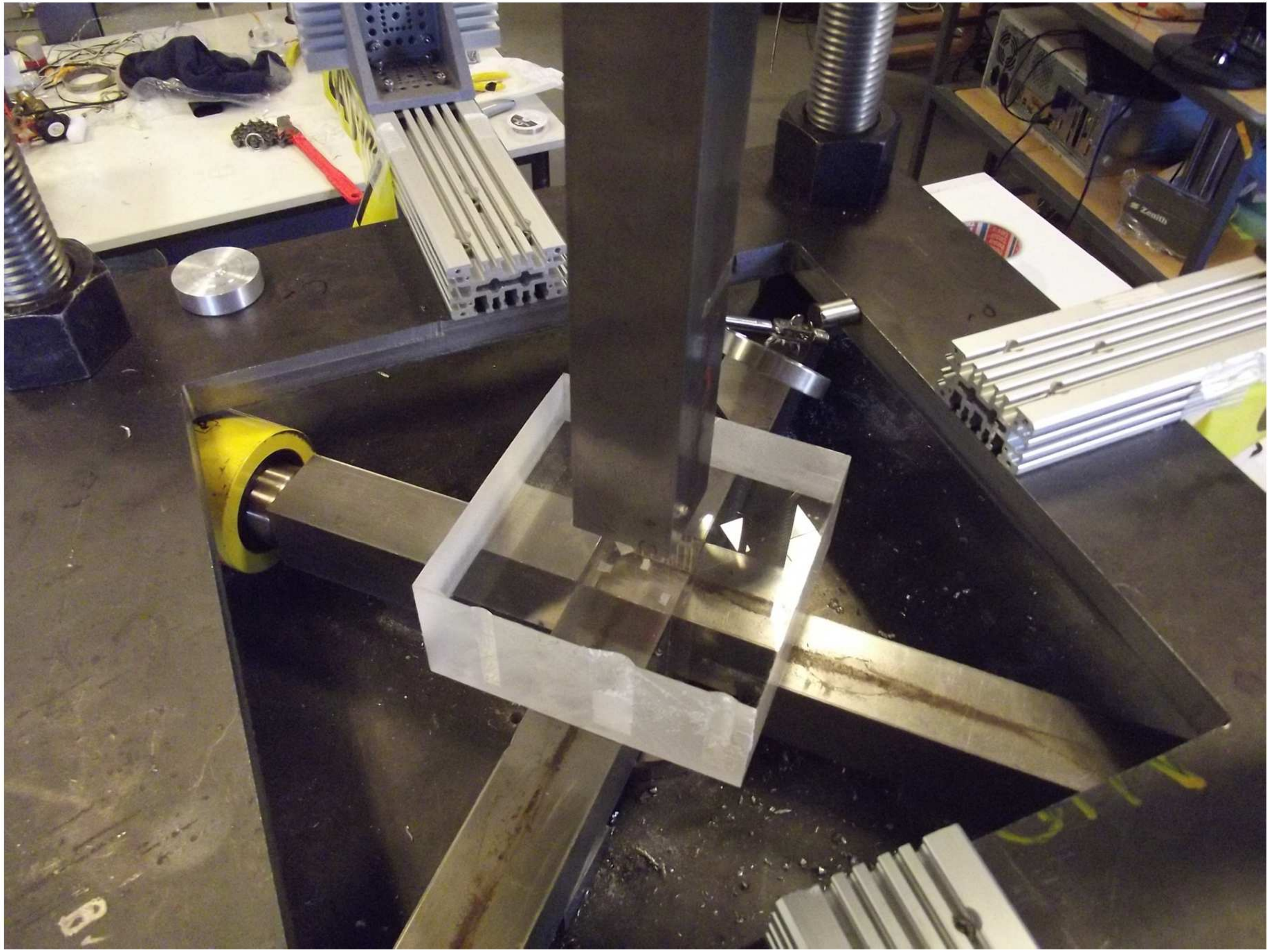
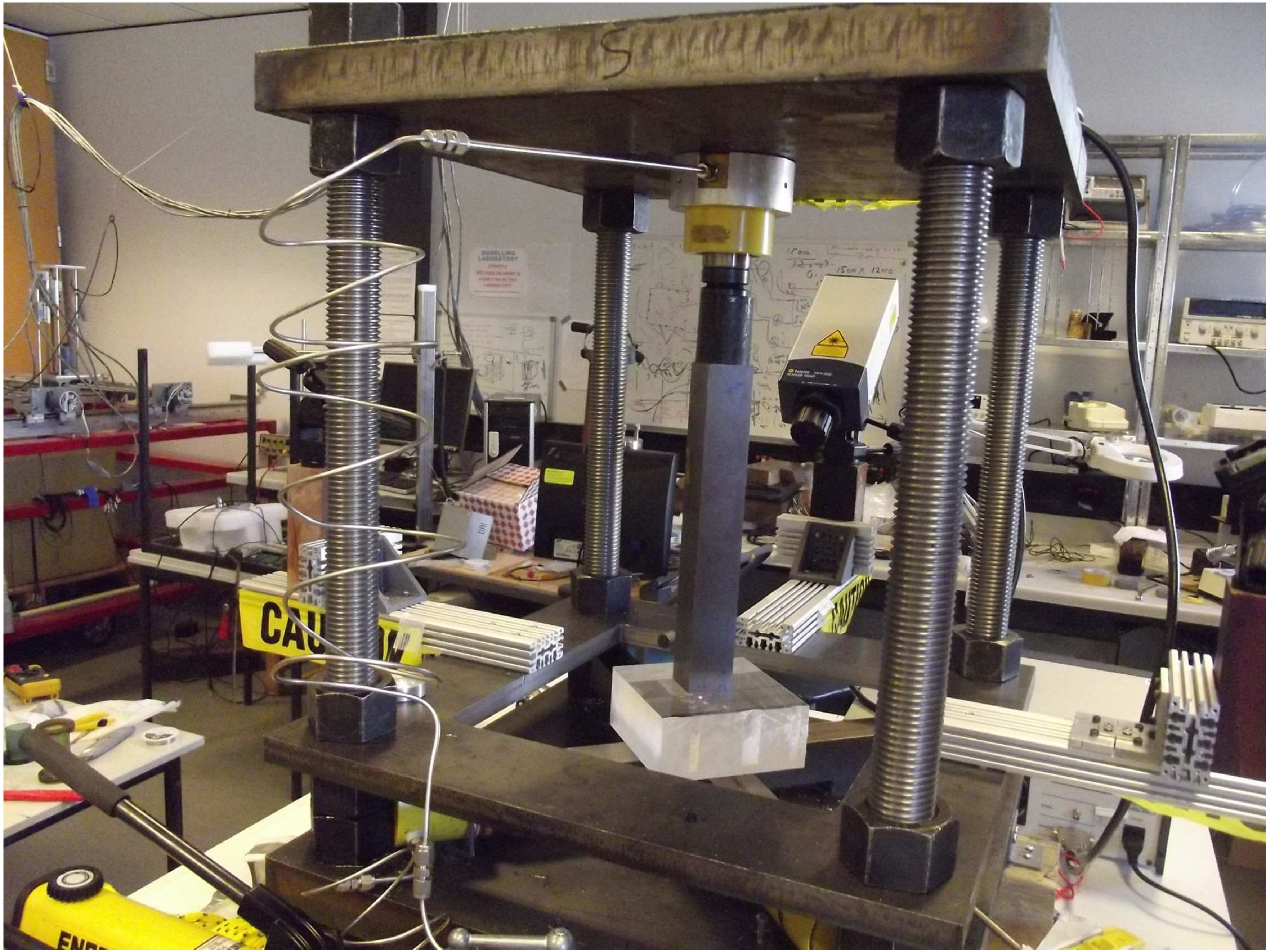
Conclusions (not final!)

- 3 component velocity field method has been transferred to laboratory
- A method for estimation of anisotropy of rock samples based on the laboratories measurements of the velocities and **polarizations** of elastic waves has been proposed
- More theoretical analysis of the wave behavior at interfaces is necessary to fully unlock the potential of the presented method for stiffness tensor estimation.
- Next step in this study: Measurements of anisotropy under triaxial stress


ENERPAC





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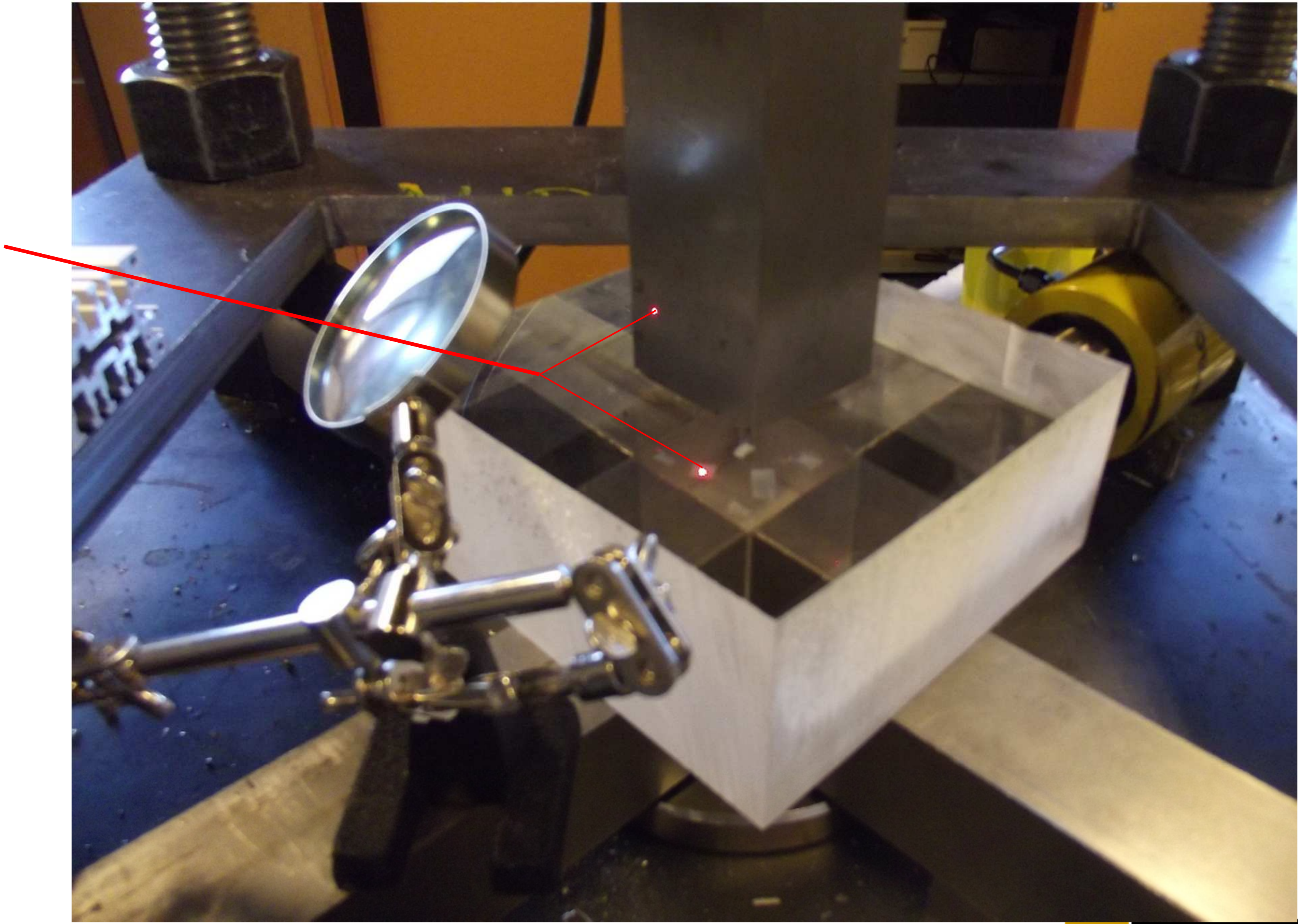

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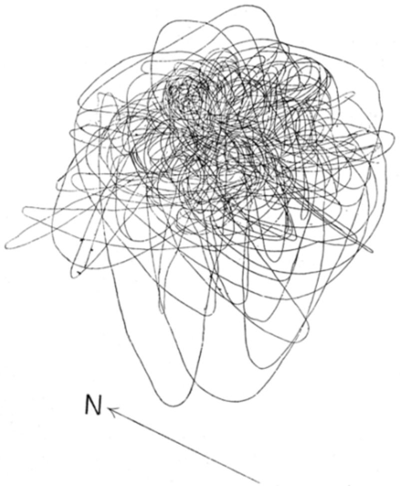
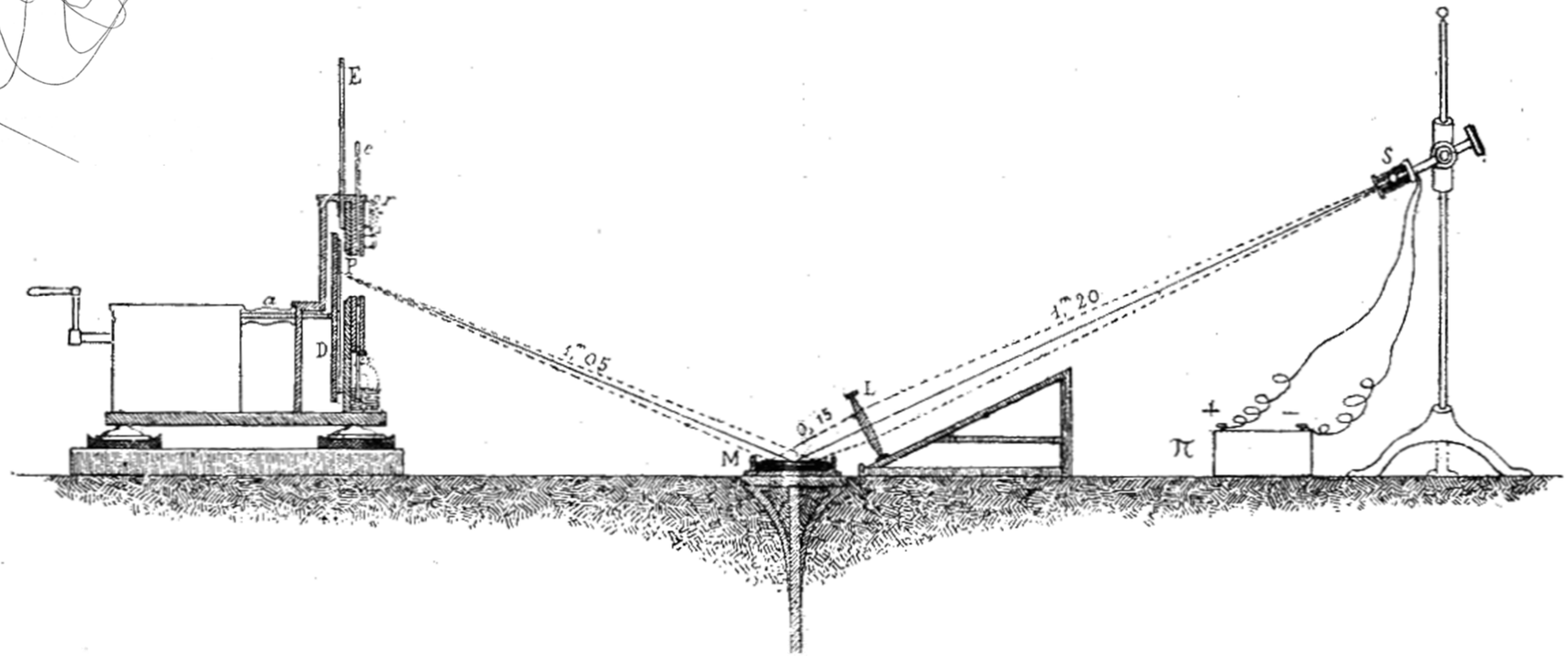
Linking Laboratory, Computational and Field Experience

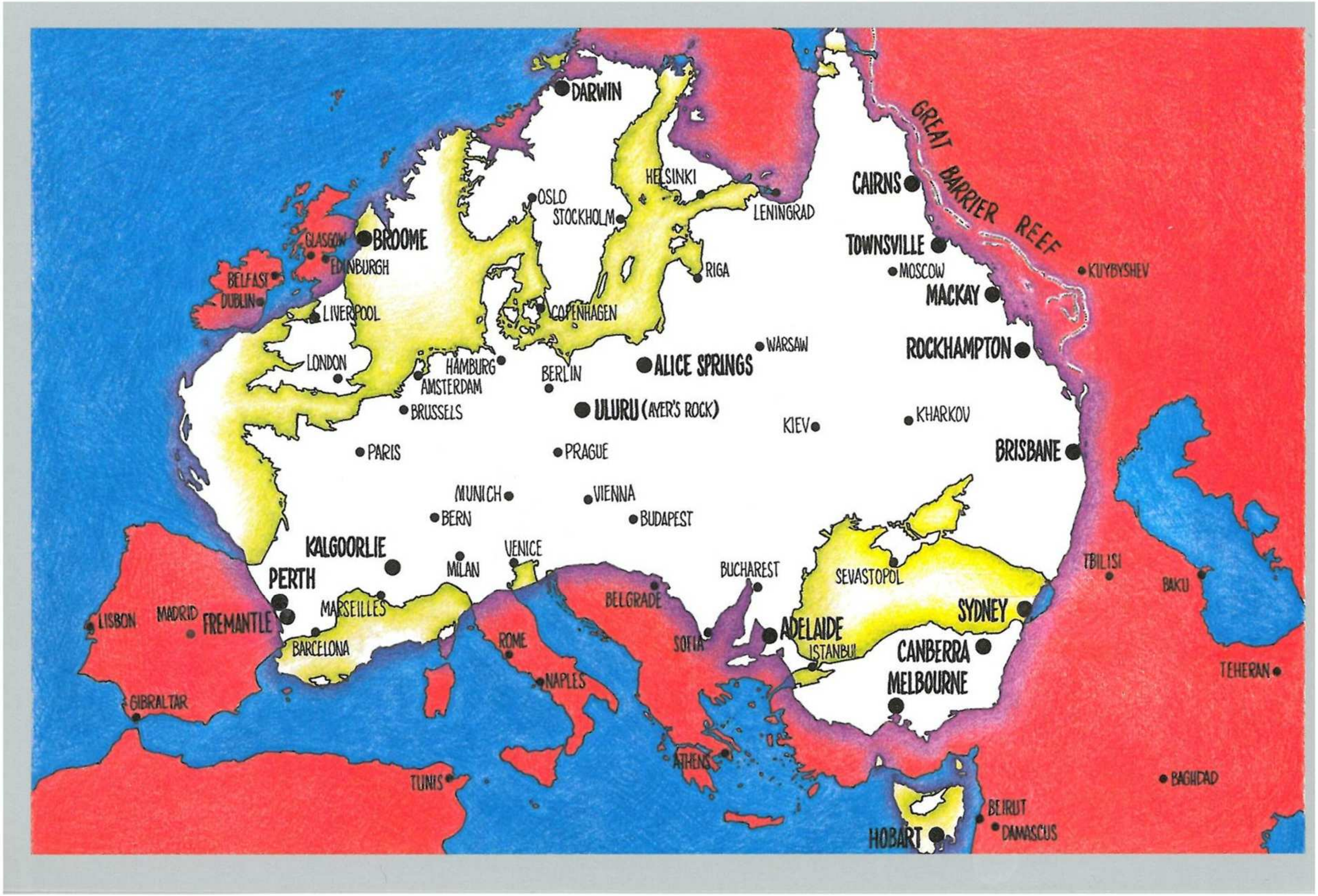




•Figure from the book "*Les Tremblements de terre*" (*Earthquakes*)

by **Ferdinand André Fouqué** 1889

Linking Laboratory, Computational and Field Experience
from countries and continents



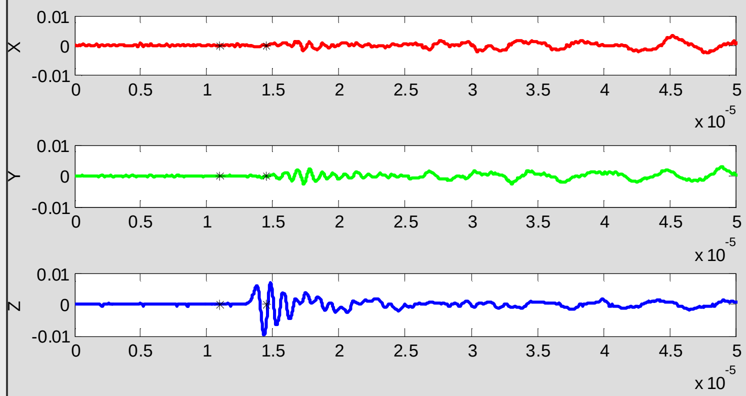
- Thank you!

Elastic anisotropy determination

Apparatus

Apparatus for elastic anisotropy determination at the Rock Physics Laboratory, Department of Exploration Geophysics, Curtin University of Technology 2010.

Measurements



Algorithm

$$a_{ijkl} p_i p_k A_j = A_l$$

$$\Gamma(\Gamma^{-1}(A)v) = A$$

$$\Gamma(x)_{ik} = a_{ijkl} x_j x_l$$

elastic properties
(anisotropy)