Key

BPG150

Midterm Test, 2012 October 16

Time allowed: 100 minutes

Write your answers in the test paper. It is okay to write on both sides of the paper. Be sure to write the number of the question you are working on.

If you need more paper, just ask.

Write your name on the exam paper.

Try to write your answers in English.

Det går også an med norsk.

This test will count for 50% of the semester component, i.e. 25% of the total course grade.

25% 1. Density and P-wave velocity of fluid-saturated porous rocks

A clastic (shaly sand) unit has porosity $\phi = 24\%$. The solid matrix material has a density of 2600 kg/m^3 and a P-wave velocity of V_m = 5000 m/s. The water (or brine) in the pores has a density of 1030 kg/m^3 and a P-wave velocity of V_w = 1500 m/s

(a) Determine the bulk density (or overall density) of this two-phase rock.

(b) Estimate its P-wave velocity using two (2) different approximate equations.

(c) Suppose that one quarter of the brine were displaced by natural gas, with a density of 2 kg/m^3 and a P-wave velocity of 400 m/s. Find the bulk density of this three-phase rock.

(d) For this three-phase rock, determine the P-wave velocity using two (2) different approximate equations.

$\phi = 24\%$ $\quad \rho_m = 2600\ kg/m^3 \quad V_m = 5000\ m/s$

$\rho_w = 1030$ — $\quad V_w = 1500$ —

(4) (3)

(a) $\rho = 0.24 \times 1030 + 0.76 \times 2600$ / $\rho = 2223\ kg/m^3$ (2223.2) (or 2220 —)

(b)(i) Time-ave:

$\frac{1}{V} = \frac{0.24}{1500} + \frac{0.76}{5000}$ || $V = 3205\ m/s$ (or $V = 3200\ m/s$) (4)

(b)(ii) Gardner $\rho = 310 V^{0.25} \Rightarrow V = \left(\frac{\rho}{310}\right)^4$

$V = \left(\frac{2223.2}{310}\right)^4 = 2645.3\ m/s$ (2650 m/s) (4)

(c) $\rho = 0.06 \times 2 + 0.18 \times 1030 + 0.76 \times 2600 = 2161.52$ (4)

$= 2162\ kg/m^3$

or 2160 —

(d)(i) $\frac{1}{V} = \frac{0.06}{400} + \frac{0.18}{1500} + \frac{0.76}{5000}$ // $V = 2370\ m/s$ (5)

(ii) $V = \left(\frac{2161.52}{310}\right)^4$ $\quad V = 2364$ (3.7) m/s (or 2360) (4)

25% 2. Resolution

(a) In a particular survey area, pinnacle reefs are found at a depth of ~4 km, corresponding to a P-wave two-way zero-offset time of $t_0 \cong 2.5$ s. The seismic acquisition equipment sends out a wavelet with a dominant frequency of ~40 Hz. What is the horizontal extent of reefs that one can hope to resolve here?

(b) In the same area, sandstone beds with P-wave velocities of about 3000 m/s can be productive, even if only 25 m thick. Can such thicknesses be reolved here using the same equipment? Give details.

(a)

$z = 4000$ m; $t_0 = 2.5$ s

$f_d \simeq 40$ Hz

$t_0 = \frac{2z}{\bar{V}}$ or $\bar{V} = \frac{2z}{t_0}$ (2)

$\bar{V} = \frac{2 \times 4000}{2.5} = 3200$ m/s; (2) $\lambda = \frac{\bar{V}}{f_d} = \frac{3200}{40} = 80$ m (4)

Fresnel-zone width: $w = \sqrt{2z\lambda}$ (2)

or $w = \sqrt{2 \times 4000 \times 80} = \sqrt{640{,}000} = 800$ m (2)

One can resolve reefs of width of about 800 m or more. (3)

(b)

Same equipment so: $f_d \simeq 40$ Hz (2)

25 m $V = 3000$ m/s

$\lambda = \frac{3000}{40} = 75$ m (2)

To resolve we need a thickness of at least $\lambda/8$ or $\lambda/4$, i.e. at least about 9 or 19 m

i.e. about 10 – 20 m. (2)

We have 25 m so: YES, should be resolvable. (4)

25% 3. Snell's law and apparent velocity

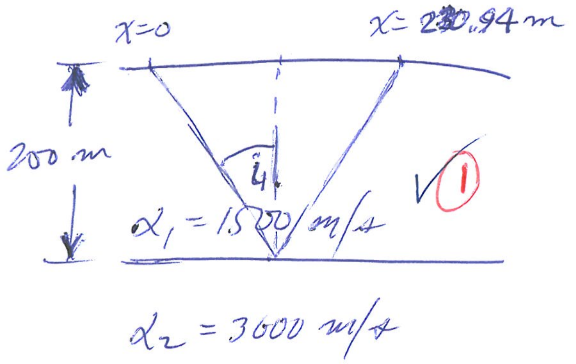
Sketch the following set-up. Layer 1 (the seawater) has $\alpha_1 = 1500$ m/s and layer 2 (the carbonate seabed) has $\alpha_2 = 3000$ m/s. The sea here is 200 m deep and the carbonate is very thick. An airgun is detonated at zero depth and a P-wave generated. Consider the reflected P-wave energy that returns to the surface and registers on a hydrophone at an offset accurately determined as 230.94 m. This energy was reflected from a reflection point on the seafloor halfway (horizontally) between airgun and hydrophone, i.e. 115.47 m (horizontally) from each. Focus your attention on this reflection point on the seafloor.

(a) What is the angle of incidence in layer 1 of the original downgoing P-wave that hits the reflection point on the seafloor?

(b) In your sketch (maybe a separate sketch) show what happens at this reflection point on the seafloor in terms of new waves that are generated; i.e. sketch raypaths for these waves and draw them with realistic directions of travel.

(c) Continuing with this same set-up, consider a hydrophone at 250 m offset. State in order of arival time what the first three P-wave arrivals will be at this hydrophone.

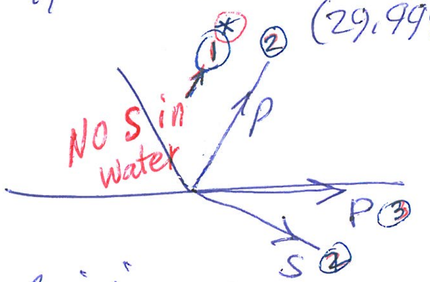
(d) Determine the apparent velocity for each of these three arrivals.



(a) ④ $\tan i_1 = \frac{115.47}{200} = 0.577351$ ✓

$i_1 = 30.00°$ ✓ (29.99999°)

(b) ⑧

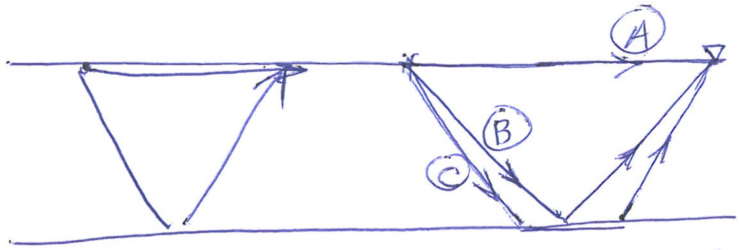


Check i_2: $\frac{\sin i_1}{\alpha_1} = \frac{\sin i_2}{\alpha_2}$ (Snell's law)

So ~~$\alpha_2 = \alpha_1$~~ $\sin i_2 = \frac{\alpha_2 \sin i_1}{\alpha_1} = 2 \sin 30° = 1$

or $i_2 = 90°$, so the P ray is horizontal.

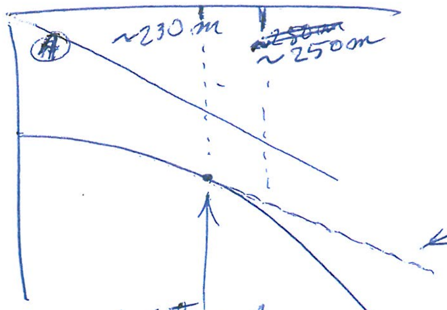
(c) ⑦

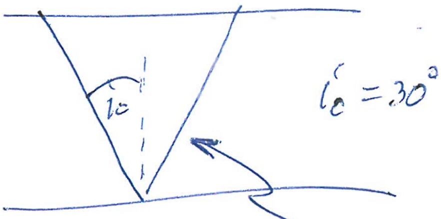


3 P-wave arrivals are Ⓐ the direct P-wave Ⓑ the reflected P-wave; Ⓒ the refracted P-wave

Ⓐ has to arrive before Ⓑ. They travel at speed α_1 the whole way and Ⓐ takes the shortest path.

At the critical angle, Ⓑ and Ⓒ are identical.





From the traveltime curve it's clear that Ⓒ arrives before Ⓑ at a distance greater than the critical distance.

So: from first to last:

1st Ⓐ direct ✓✓½ ($t = 167$ ms) 2½

2nd Ⓒ refraction ✓✓✓½ ($t = 314.3$ ms) 2½

3rd Ⓑ reflection ($t = 314.5$ ms) 2

[(4th Ⓜ multiple ($t = 2 \times t(125) = 559$ ms))] 1

(d) For Ⓐ, direct, $\alpha_a = \alpha_1 = 1500$ m/s ✓

⑤ Ⓒ, refraction $\alpha_a = \alpha_2 = 3000$ m/s ✓

Ⓑ, reflection $\alpha_a = \dfrac{\alpha_1}{\sin i_0}$

where $\tan i_0 = \dfrac{125}{200}$ or $i_0 = 32.0054°$ ✓✓ (-1 for 30°)

and $\sin i_0 = 0.529999$

So for Ⓑ $\alpha_a = \dfrac{1500}{0.529999} = 2830$ m/s ✓ (2830.19)

25% 4. Density and P-wave velocity

Figure 3.6 (below) from Keary et al. (2002) shows some modelled (calculated) data for two non-reservoir rocks: a sandstone and a limestone. Answer the questions following Figure 3.6.

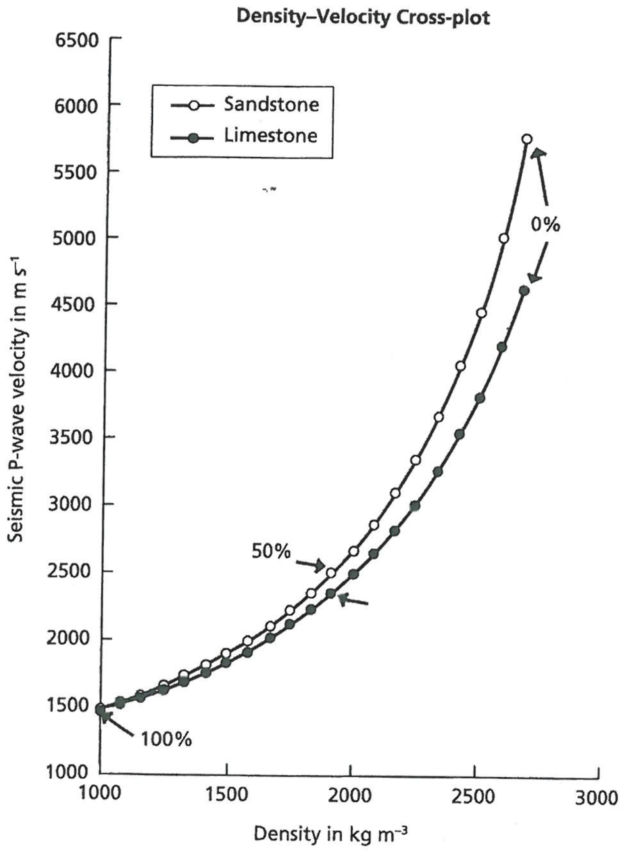


Fig. 3.6 The relationship of seismic velocity and density to porosity, calculated for mono-mineralic granular solids: open circles – sandstone, calculated for a quartz matrix; solid circles – limestone, calculated for a calcite matrix.

(a) Each rock type consists of two components. What are they for each rock?

(b) For all of the components involved in the two rock types, estimate as well as you can from the graph their densities and P-wave velocities.

(c) A third property of each rock type is indicated in the figure. What is it?

(d) Is there any place in the figure where each of these three properties has the same value for the two rock types? Give details.

(e) What equation was probably used to calculate the values plotted in this figure?

(f) You are told that Gardner's relation is almost exactly valid (within 0.1%) for the sandstone. What then is the situation for the limestone? Could Gardner's relation be (i) almost exactly valid for it too; (ii) clearly not exactly valid; or (iii) is it impossible to say from this figure? Explain your answer briefly.

4. (a) SS: quartz and water

or a quartz matrix and ✓ ½

water-filled pores ✓ ½

LS: calcite matrix ✓ ½ & water-filled pores ½

[matrix & pore fluid: 3½] (2, 1½) pores: ½

(5)

(b) quartz: $\alpha \approx 5750$ or 5800 m/s ✓

$\rho \approx 2700$ kg/m^3 ✓

calcite: $\alpha \approx 4650$ or 4700 m/s ✓

$\rho \approx 2700$ kg/m^3 ✓

water: $\alpha \approx 1500$ m/s ✓

$\rho \approx 1000$ kg/m^3 ✓

(6)

(c) porosity ✓✓

(3)

(d) At the left end of both curves ✓

$\phi = 100\%$ so no matrix, just water

(not realistic rock!) ✓

Here $\alpha \approx 1500$ m/s and $\rho \approx 1000$ kg/m^3 ✓✓

(4)

(e) Time-average eq'n or Wyllie eq'n ✓✓✓

(3)

(f) Gardner valid for SS within 0.1%.

Therefore, at $\phi = 0$

$$\rho_{SS} \approx 2700 = 310 \times 5770^{0.25}$$

At $\phi = 0$, ρ_{LS} also ≈ 2700 but $\alpha_{LS} \approx 4675$ m/s

This can't be a good fit to Gardner.

(4)

Some geophysical formulae:

$$t^2 = t_0^2 + \frac{x^2}{V^2}$$

$$t \approx t_0 + \frac{x^2}{2V^2 t_0}$$

$$V = \lambda f$$

$$V_a = \frac{V}{\sin i}$$

$$\alpha \equiv V_P = \left[\frac{K + \frac{4}{3}\mu}{\rho}\right]^{1/2}$$

$$\beta \equiv V_S = \left[\frac{\mu}{\rho}\right]^{1/2}$$

$$\overline{V} = \frac{\sum_{i=1}^{n} V_i t_i}{\sum_{i=1}^{n} t_i}$$

$$V_{\mathrm{rms},n} = \left[\sum_{i=1}^{n} V_i^2 t_i \Big/ \sum_{i=1}^{n} t_i\right]^{1/2}$$

$$w = \sqrt{2z\lambda}$$

$$\frac{1}{V} = \frac{\phi}{V_f} + \frac{1-\phi}{V_m}$$

$$\rho = 310\alpha^{0.25}$$