

May 2, 2019

Editor  
Geophysical Journal International

Dear Editor,

Enclosed you find the revision of our manuscript GJI-19-0166 entitled *Effect of capillarity and relative permeability on Q anisotropy of hydrocarbon source rocks*, to be considered for publication.

Here are the answers to the reviewer's and your comments. In italics the reviewers and editor suggestions, in roman font our answers. The changes are indicated in red in the revised manuscript.

### **Responses to Reviewer 1**

Thanks for your revision.

### **Responses to Reviewer 2**

1. *PAGE 3-line 36: Most recently, physical experiments confirmed the slow wave at a wide range of incident angles. Please add this JGR paper as it explicitly presented results on slow p-wave relevant to this proposed contribution. Article in JGR: Measurement of the speed and attenuation of the Biot slow wave using a large ultrasonic transmitter Authors: Youcef Bouzidi and Douglas R Schmitt Journal of Geophysical Research: Solid Earth Vol. 114, Issue B8, 2009:*

Response 1. Done

2. *PAGE 3-line 49: Including this second slow P-wave as important and not the second shear wave is I think incomplete as some of the fluids referred here are very viscous. Please include here*

*the existence of a second shear wave as given in "Fast compressional wave attenuation and dispersion due to conversion scattering into slow shear waves in randomly heterogeneous porous media" Article in: The Journal of the Acoustical Society of America 129(5):2785-96 May 2011:*

Response 2. Done.

3. *PAGE 5-line 16: Better to refer to these experiments as numerical experiments.:*

Response 3. Done.

4. *PAGE 10-line 37-55: This cannot be a validation as no actual physical experiments were conducted. Please refer to these as numerical simulations. Suggestions: 4. Numerical methodology 4.1 Numerical simulations Or something close to the above:*

Response 4. The section and subsection titles were changed as suggested.

5. *PAGE 14-line 10: Replace by permeabilities, significantly affect:*

Response 5. Done.

6. *PAGE 14-line 14: change to Quasi-static numerical experiments:*

Response 6. Done.

7. *PAGE 15-line 29: change to by physical experiments.:*

Response 7. The last sentence in the CONCLUSIONS containing these words was eliminated as suggested by the editor.

## Responses to the Editor

1. *PAGE 1-line 40:*

Shale reservoir  
changes to  
Shale – reservoir

2. *PAGE 1-line 44:*

The following explanation was added:  
, i.e., much larger than the average layer thickness.

3. *PAGE 1-line 57:*

(UFE) was removed.

4. *PAGE 2-line 14:*

anisotropic behavior of seismic attenuation in  
changes to  
anisotropy in seismic attenuation of

5. *PAGE 2-line 18:*

shale reservoir  
changes to  
shale – reservoir

6. *PAGE 2-line 20:*

The following paragraph was added:  
(with typical thickness of mm)

7. *PAGE 2-lines 59-60:*

Among other authors analyzing the quasi-static and dynamic behavior of porous rocks with partial, miscible or segregated fluid saturation we mention the works of Dutta and Odé (1979), Mochizuki (1982), Berryman, Thigpen and Chin (1988) and Toksöz, Cheng and Timur (1976).

changes to

Among others, Dutta and Odé (1979), Mochizuki (1982), Berryman, Thigpen and Chin (1988) and Toksöz, Cheng and Timur (1976) tackled the analysis of the quasi-static and dynamic behavior of porous rocks with partial, miscible or segregated fluid saturation.

8. *PAGE 3-lines 20-21:*

mesoscopic loss. The mesoscopic-scale length is intended to be larger

changes to

mesoscopic loss envisioning the length scale of the heterogeneities to be larger

9. *PAGE 3-line 28:*

We added a reference to one of Steve Pride's works in this field and added a paragraph

10. *PAGE 3-lines 43-44:*

of the equivalent poro-viscoelastic medium to a finely layered SPBM.  
changes to  
of a poro-viscoelastic medium equivalent to a finely layered SPBM.

11. *PAGE 3-lines 49-50:*

stiffnesses of an equivalent viscoelastic transversely isotropic (VTI)  
medium to a layered SPBM.  
changes to  
stiffnesses of a viscoelastic transversely isotropic (VTI) medium  
equivalent to a layered SPBM.

12. *PAGE 3-line 54:*

patchy-saturated rocks, They found  
changes to  
patchy-saturated rocks and found

13. *PAGE 3-line 52 – 59 and Page 4-lines 6 – 7:*

Qi, Müller, Gurevich, Lopes, Lebedev & Caspari (2014) studied  
the effects of capillarity on attenuation and dispersion in isotropic  
patchy-saturated rocks. They found that the capillary action leads  
to an additional stiffening and thereby to higher phase velocities.  
It also implies a pressure discontinuity at patch interfaces so that  
wave-induced pressure diffusion process is weakened and attenu-  
ation is reduced. As we shall see, we found in the present study  
that attenuation is enhanced by the presence of capillarity.

changes to

Qi, Müller, Gurevich, Lopes, Lebedev & Caspari (2014) studied  
the effects of capillarity on attenuation and dispersion in isotropic  
patchy-saturated rocks and found that the capillary action leads

to an additional stiffening and thereby to higher phase velocities, with weakening diffusion process and attenuation.

14. *PAGE 4-lines 6-7:*

The sentence As we shall see, we found in the present study that attenuation is enhanced by the presence of capillarity was deleted.

15. *PAGE 4-lines 24-43:*

These lines were deleted

16. *PAGE 4-line 57:*

Besides, assuming fully saturation changes to

Besides, we assume full saturation

17. *PAGE 4-line 59:*

We added the following paragraph:

In the shale reservoir model studied in this work, gas is always the non-wetting phase (see Figure 1).

18. *PAGE 5-line 6:*

We added a comma at the end of the equation

19. *PAGE 5-line 53:*

The equations for a 2PBM

changes to

The governing equations for a 2PBM

20. *PAGE 6-line 11:*

In (7)-(8)

changes to

In (7)-(8),

21. *PAGE 6-lines 33-34:*

The sentence

Denoting by  $x_1$  and  $x_3$  the horizontal and vertical coordinates, respectively.

was deleted.

22. *PAGE 6-line 59:*

The words

Note that

were deleted.

23. *PAGE 7-lines 5-6:*

As shown in Santos and Carcione (2015), these stiffnesses can be determined using five time- harmonic experiments.

changes to

Santos and Carcione (2015) have shown that the stiffnesses  $p_{IJ}$  in (11)-(16) can be determined using five time-harmonic experiments.

24. *PAGE 7-line 14:*

The sentence

Denoting by  $x_1$  and  $x_3$  the horizontal and vertical coordinates

was deleted in PAGE 6-lines 33-34, thus this sentence is no more

redundant.

25. *PAGE 7-line 29 to Page 9 line 15:*

We integrated the equations in the text

26. *PAGE 9-line 31:*

The sentence

The proof can be generalized to the case of two-phase fluids analyzed here

changes to

The proof given in (Santos and Carcione 2015) can be generalized to the case of two-phase fluids analyzed here.

27. *PAGE 9-lines 58-60:*

The sentence

The experiments consider 6 periods of 0.0135 cm of illite-smectite and 0.0015 cm of kerogen layers, each layer saturated by a two-phase fluid.

changes to

The experiments consider an square sample of side length 0.09 cm with an alternating sequence of 0.0135 cm of illite-smectite and 0.0015 cm of kerogen layers, each layer saturated by a two-phase fluid.

28. *PAGE 10-line 14:*

We add a reference where energy velocities are defined.

29. *PAGE 10-lines 24-25:*

The sentence

The effective single phase fluid viscosity  $\eta^{(eff)}$ , density  $\rho^{(eff)}$  and bulk modulus  $K^{(eff)}$  are obtained as Reuss averages for the bulk moduli and arithmetic averages for densities and viscosities:

changes to

The effective single phase fluid viscosity  $\eta^{(eff)}$  and density  $\rho^{(eff)}$  are obtained as arithmetic averages of those of the water -gas or oil-gas viscosities, while the effective bulk modulus  $K^{(eff)}$  was determined using a Reuss average of the water -gas or oil-gas bulk moduli:

30. *PAGE 10-lines 37-44:*

The sentence

Figure 2 displays the energy velocities of the qP and qSV waves at 50 Hz for the FE 2PBM and analytical models. Small differences between energy velocities can be observed, due to capillary pressure and relative permeability effects present in the 2PBM. Figures 3 and 4 show that the dissipation factors of the qP and qSV waves are much higher for the 2PBM than for the SPBM.

changes to

Small differences between energy velocities of the qP and qSV waves at 50 Hz for the FE 2PBM and analytical models can be observed, due to capillary pressure and relative permeability effects present in the 2PBM (Figure 2). The dissipation factors of the qP and qSV waves are much higher for the 2PBM than for the SPBM (Figures 3 and 4).

31. *PAGE 11-lines 14-15:*

The sentence

Figure 5 shows that the energy velocities of SH waves are not affected by the relative permeability and capillary pressure.

changes to

The energy velocities of SH waves are not affected by the relative permeability and capillary pressure (Figure 5).

32. *PAGE 11-line 22:*

About your remark: I wonder about the way the ...

We added the sentence

Next we analyze the behavior of the phase velocities and dissipation factors of waves as they travel parallel and normal to the layers as function of frequency. In particular, this study allows to identify the possible existence and location of attenuation peaks.

33. *PAGE 11-line 28:*

The word

Besides

was changed to

Furthermore

34. *PAGE 11-line 34:*

The sentence

there exists always a certain percentage of immobile water or oil (the wetting phases)

was changed to

a certain percentage of immobile water or oil (the wetting phases)

always exists

35. *PAGE 11-line 34:*

The words

In all the remaining experiments,  
were changed to

Thus in the analysis that follows,

36. *PAGE 11-line 48-49:*

The paragraph

Figure 8 shows that the energy velocities of the qP and qSV waves for the 2PBM are not sensitive to changes in gas saturation in the kerogen layers.

were changed to

The energy velocities of the qP and qSV waves for the 2PBM are not sensitive to changes in gas saturation in the kerogen layers (Figure 8).

37. *PAGE 11-line 56-57:*

The paragraph

The opposite situation is observed in Figures 9 and 10, which show the dissipation factors of the qP and qSV waves as a function of the propagation angle at 50 Hz.

was changed to

The dissipation factors of the qP and qSV waves as a function of the propagation angle at 50 Hz are shown in Figures 9 and 10, respectively.

38. *PAGE 12-line 28-34:*

The paragraph

Figures 11-14 show the results. As expected, lower velocity corresponds to higher kerogen content (11- 12). Furthermore, the results exhibit much higher dissipation factors for the 2PBM model than for the SPBM model, and a completely different anisotropic behavior.

was changed to

As expected, lower velocity corresponds to higher kerogen content (Figures 11-12). Furthermore, much higher dissipation factors are observed for the 2PBM model than for the SPBM model, and a completely different anisotropic behavior (Figures 13-14).

39. *PAGE 13-line 42-47:*

The paragraph

Figure 16 shows that energy velocities are very similar for both models. On the other hand, Figure 17 shows that for the SPBM model attenuation of the qP waves is almost isotropic, while the 2PBM exhibits much higher attenuation and strong anisotropy. Besides, qSV attenuation is...

was changed to

Energy velocities of qP and qSV waves are very similar for both models (Figure 16). On the other hand, the attenuation of the qP waves is almost isotropic for the SPBM model, while the 2PBM model exhibits much higher attenuation and strong anisotropy (Figure 17). Furthermore, qSV attenuation is...

40. *PAGE 14-line 10:*

the word

significant

was changed to  
significantly

41. *PAGE 14-lines 29-30: The sentence*

Possibly, these novel results are to be confirmed by experiments  
derived by the present theory.

was eliminated

Sincerely,

Jing Ba et al.  
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Engineering, Hohai University,  
Nanjing, China