*Stanford Exploration Project, Report 100, April 20, 1999, pages 361–**??***

## Short Note

# A short tour through the Stanford Exploration Project contributions to anisotropy

*Tariq Alkhalifah*[1]

***keywords:*** *Anisotropy*

Browsing through the countless Stanford exploration Project (SEP) reports, I was amazed to find a large number of quality papers that tackle the sensitive issue of anisotropy. The amazement stems from the fact that a hidden principle, which states "anisotropy is not an important", existed in SEP. This principle evolved from statements like "If you believe in anisotropy!" and "avoid the two A's (anisotropy and AVO)" uttered by SEP's leader and chief executive, Jon Claerbout, through the years. Despite such statements Jon has maintained an environment in SEP that allows its students to work on any subject they desire. The fact that some students choose anisotropy is a testament to the importance of this subject, and a testament to Francies Muir (past SEP professor and a devote anisotropist) positive influence on the group.

SEP exploits into this subject ranged for modeling seismic waves in anisotropic media to imaging data from such media. Jacobs (1979) was the first to write an anisotropic paper, titled "Velocity anisotropy", in an SEP report. This paper, among other things, suggested stretching the z-axis to accommodate the ambiguity of resolving depth from surface seismic data in anisotropic media. This was one of the earliest papers to acknowledge the depth problem faced in practice due to anisotropy– the difference between the vertical and imaging velocities. Jacobs (1982) later included anisotropy in his thesis in a chapter titled "Pseudo-*P* and Pseudo-*S* Waves in a Hexagonally Anisotropic Earth", where he discussed the downward continuation of the Pseudo-*S* wave despite that shear waves was another *taboo* at SEP.

Consistent with the low popularity of anisotropy in the early 80's, the next paper to treat anisotropy at SEP appeared years later (Dellinger and Muir, 1985) and was titled "Axisymmetric Anisotropy I : Kinematics". This paper seemingly had opened a flood gate on this subject because the very next report included four papers (Muir and Dellinger, 1985; Dellinger, 1985a; Woodward and Muir, 1985; Dellinger, 1985b) tackling issues ranging from modeling to moveout. The following year, Muir (1987) looked at Dix and Backus averaging for obtaining equivalent parameters and Etgen (1987) applied finite difference to the anisotropic elastic wave equation. One report later, Muir and Dellinger (1988) examined the relation between layering and anisotropy; they sought to obtain an equivalent homogeneous anisotropic media that approximated the layered model. In the same report, Nichols (1988)

[1]**email:** tariq@sep.stanford.edu

generated synthetic seismograms for anisotropic models and Guiziou (1988) did some 3-D raytracing in anisotropic media.

Dellinger (1988) built a filter capable of separating the *P* and *S*-wave components of the elastic anisotropic wavefield. Inversion of anisotropic parameters was discussed first in SEP by Dellinger (1989), where he examined the feasibility of inverting for the elastic coefficients in a Vertical-seismic-profile (VSP) type of setting. Nichols (1989) showed the equivalence between the Hudson model of the elastic properties of fractured rocks and the Schoenberg model. Karrenbach (1989) uses a paraxial approximation to separate the effect of anisotropy versus $v(z)$ variation of velocity. Popovici and Muir (1989) use an algorithm based on a Markov random field to model anisotropic porous rocks. Muir and Nichols (1989) use the compliance rather than the stiffness tensor to show that rocks can be fractured in any order.

A year later, Dellinger and van Trier (1990) devised one of the earliest implementations of finite difference scheme to the eikonal equation in anisotropic media. Though they had some stability problems at the time, that was treated later (Dellinger, 1991), they managed to produce interesting traveltime curves in inhomogeneous media. Ji (1990) compares the nonhyperbolic moveout equation of Muir with that of Byun in inverting for an anellipticity parameter. Dellinger et al. (1990) show the success of the Schoenberg-Muir technique of equivalent media on synthetic data. More study on equivalent media followed (Nichols and Karrenbach, 1990; Karrenbach, 1990; Muir, 1993). Cunha (1990) inverted for an elliptical anisotropic parameters using data from a cross well configuration.

In 1991, the double elliptic approximation of Muir (1990) was used in moveout and imaging applications (Dellinger and Muir, 1991; Karrenbach, 1991a); an approximation built to utilize the simplicity of the elliptical anisotropic model to represent a transversely isotropic model. Also, Michelena and Muir (1991) looked at anisotropic tomography. Many other papers that range from azimuthal anisotropy to fine layering to imaging exists in the newer SEP reports (Karrenbach et al., 1992; Berryman, 1996; Alkhalifah and Rampton, 1997a; Alkhalifah and Fomel, 1997; Karrenbach, 1991b; Michelena, 1992; Alkhalifah, 1997a; Alkhalifah et al., 1997; Karrenbach and Muir, 1994; Alkhalifah, 1997c,b; Fomel and Grechka, 1996; Alkhalifah and Rampton, 1997b; Alkhalifah, 1998).

The above is just a highlight of the many papers at SEP that promote and discuss the important subject of anisotropy. The above is in no way inclusive of all the SEP papers published on this subject. The only way to benefit from and appreciate the level of anisotropy contribution in SEP is to directly read and study the papers involved.

## REFERENCES

Alkhalifah, T., and Fomel, S., 1997, Residual migration in VTI media using anisotropy continuation: SEP–**94**, 327–337.

Alkhalifah, T., and Rampton, D., 1997a, Seismic anisotropy in Trinidad: Processing and interpretation: SEP–**94**, 299–325.

Alkhalifah, T., and Rampton, D., 1997b, Seismic anisotropy in trinidad: More parameter estimation: SEP–**95**, 205–218.

Alkhalifah, T., Fomel, S., and Biondi, B., 1997, Time-domain anisotropic processing in arbitrarily inhomogeneous media: SEP–**95**, 77–99.

Alkhalifah, T., 1997a, An acoustic wave equation for anisotropic media: SEP–**95**, 283–307.

Alkhalifah, T., 1997b, An anisotropic Marmousi model: SEP–**95**, 265–282.

Alkhalifah, T., 1997c, Prestack time migration for anisotropic media: SEP–**94**, 263–298.

Alkhalifah, T., 1998, The fast marching method in spherical coordinates: SEG/EAGE salt-dome model: SEP–**97**, 251–264.

Berryman, J. G., 1996, Range of the P-wave anisotropy parameter for finely layered VTI media: SEP–**93**, 177–190.

Cunha, C., 1990, Traveltime inversion of a cross well dataset for elliptically anisotropic media: SEP–**67**, 31–40.

Dellinger, J., and Muir, F., 1985, Axisymmetric anisotropy I : Kinematics: SEP–**42**, 1–24.

Dellinger, J., and Muir, F., 1991, The double elliptic approximation in the group and phase domains: SEP–**70**, 361–366.

Dellinger, J., and van Trier, J., 1990, Anisotropic finite difference traveltimes: SEP–**65**, 59–66.

Dellinger, J., Muir, F., and Etgen, J., 1990, Putting Schoenberg Muir to the test: SEP–**65**, 157–166.

Dellinger, J., 1985a, Some anisotropic modeling examples: SEP–**44**, 63–66.

Dellinger, J., 1985b, Two domains of anisotropy: SEP–**44**, 59–62.

Dellinger, J., 1988, Wavefield separation in anisotropic media: SEP–**59**, 55–72.

Dellinger, J., 1989, Anisotropic travel time inversion with error bars : Theory: SEP–**60**, 253–260.

Dellinger, J., 1991, Finite-difference traveltimes: SEP–**69**, 114–136.

Etgen, J., 1987, Finite difference elastic anisotropic wave propagation: SEP–**56**, 23–58.

Fomel, S., and Grechka, V., 1996, On nonhyperbolic reflection moveout in anisotropic media: SEP–**92**, 135–158.

Guiziou, J. L., 1988, Three dimensional ray tracing in anisotropic media: SEP–**57**, 207–226.

Jacobs, B., 1979, Velocity anisotropy: SEP–**16**, 227–231.

Jacobs, B., 1982, Pseudo-*p* and pseudo-*s* waves in a hexagonally anisotropic earth: SEP–**34**, 89.

Ji, J., 1990, Anisotropic velocity analysis: SEP–**65**, 261–270.

Karrenbach, M., and Muir, F., 1994, The quest for anisotropic moveout: SEP–**82**, 91–96.

Karrenbach, M., Nichols, D., and Muir, F., 1992, Modeling reflections from the Austin chalk – A practical application of azimuthal anisotropy: SEP–**75**, 251–272.

Karrenbach, M., 1989, Velocity and Q in transverse isotropic media: SEP–**60**, 271–284.

Karrenbach, M., 1990, A general theory for equivalent media: SEP–**67**, 5–10.

Karrenbach, M., 1991a, Anisotropic scalar imaging using the double elliptic approximation: SEP–**70**, 123–130.

Karrenbach, M., 1991b, Prestack reverse time migration in anisotropic media: SEP–**70**, 113–122.

Michelena, R., and Muir, F., 1991, Anisotropic tomography: SEP–**70**, 201–226.

Michelena, R. J., 1992, Kinematic ray tracing in anisotropic layered media: Practical details: SEP–**73**, 345–360.

Muir, F., and Dellinger, J., 1985, A practical anisotropic system: SEP–**44**, 55–58.

Muir, F., and Dellinger, J., 1988, A calculus for layered elastic media: SEP–**57**, 179–190.

Muir, F., and Nichols, D., 1989, Elastic properties of fractured rocks: SEP–**61**, 235–242.

Muir, F., 1987, Layered models, equivalence, and Abelian groups: SEP–**56**, 59–70.

Muir, F., 1990, A modified aniostropic system: SEP–**67**, 41–42.

Muir, F., 1993, A result in equivalent medium theory: SEP–**77**, 319–324.

Nichols, D., and Karrenbach, M., 1990, What is equivalent in an equivalent medium ?: SEP–**67**, 1–4.

Nichols, D., 1988, Building anisotropic models: SEP–**57**, 191–206.

Nichols, D., 1989, A comparison of two models for the elastic properties of fractured rock: SEP–**60**, 261–270.

Popovici, M., and Muir, F., 1989, Modeling anisotropic porous rocks: SEP–**60**, 295–302.

Woodward, M., and Muir, F., 1985, Anisotropic NMO removal: SEP–**44**, 67–74.