[0009] In view of the drawbacks of methods known in the art, there is a great need for reliable and accurate estimation and modeling of elastic attributes of subterranean formations. The present disclosure seeks to provides for improved methods and systems that produce reliable estimates of elastic parameters of subterranean formations.

BRIEF SUMMARY OF THE INVENTION

[00010] The present disclosure provides an improved method for estimating elastic parameters that considers the anisotropic elastic properties of the subterranean formation. The present disclosure seeks to overcomes the problems associated with methods known in the art. For example, the present disclosure provides for a model of angle-limited seismic traces using the anisotropic Zoeppritz equation to generate equivalent reflectivity volumes which are then convolved with appropriate user defined wavelets, generating 3D volumes of the fracture parameters. As such, rather than producing fractional elastic parameter estimates, the embodiments of the present disclosure produce elastic parameter estimates. Also, the embodiments of the present disclosure incorporate wavelets and can handle anisotropic over anisotropic layers. Further, the present disclosure may allows each calculated layer to be HTI anisotropic with an arbitrary rotation for the symmetry axis. Unlike known methods, by calculating the reflectivity using the anisotropic Zoeppritz equation or some linearization of this, the embodiments of the present disclosure do not rely on some near offset approximation to enhance stability. Lastly, embodiments of the present invention may removes the 90 degree symmetry axis ambiguity. In addition, the present disclosure provides for alternative parameterizations using rock physics models to reduce and constrain the solution space.

[00011] Furthermore, the present disclosure provides for a new and innovative way of estimating elastic parameters by incorporating anisotropic elastic properties. As mentioned above, the embodiments of present invention incorporates various forward models, e.g., the Zoeppritz equation. Also, the various aspects of the present disclosure can use various ways of defining the necessary parameters, parameterization, such as the Thomsen parameters. Alternative parameterizations include incorporating fractured rock physics such as the penny-shaped crack model disclosed in Hudson or linear slip deformation (LSD) theory disclosed by Schoenberg, M. and Sayers, C.M., 1995, "Seismic anisotropy of fractured rock" Geophysics, 60, 1, pp. 204-211 (hereinafter "Schoenberg and Sayers").

These theories describe how fractures lead to anisotropy. For example, the disclosures of Bakulin, et. al., 2000, "Estimation of fracture parameters from reflection seismic data—Part II: Fractured models with orthorhombic symmetry," Geophysics, 65, 6, pp. 1803–1817, describe one way fractures can lead to orthorhombic media. Also, Sayers, C.M. and Kachanov M., 1995, "Microcrack-induced elastic wave anisotropy of brittle rocks" J. Geophysical Research, 100, pp. 4149-4156, shows how two fractures can lead to anisotropic media.

[00012] According to one aspect, the present disclosure provides a method for performing azimuthal simultaneous elastic inversion of seismic data of a subterranean formation comprising the step of determining a HTI stiffness matrix from seismic data, using parameterization means, for at least one azimuth and at least one angle of incidence from said seismic data, wherein the HTI stiffness matrix varies spatially with respect to one or more layers. The method further includes the steps of applying a Bond transformation to the HTI stiffness matrix to rotate anthe isotropy symmetry plane such that it is referenced with respect to true North; and calculating a reflectivity series for the at least one azimuth and angle of incidence using one or more reflection coefficientsthe ~~Zoeppritz equation~~, wherein anisotropy media is incorporated.

[00013] According to certain embodiments of the present disclosure, the reflectivity is calculated in the forward modeling step using the Zoeppritz equation. In some embodiments, the reflection coefficients are calculated using a linearization of the anisotropy Zoeppritz equation. In other embodiments, the forward modeling begins with determining the spatially varying HTI stiffness matrix from seismic data using parameterization means. In one embodiment, the parameterization is performed with the linear slip deformation theory. In another embodiment, the parameterization is performed with the Hudson's penny-shaped crack theory. In yet another embodiment, the parameterization is performed with Thomsen parameters. The forward modeling proceeds with the Bond transformation, which then applied to the HTI stiffness matrix to rotate the isotropy symmetry plane so it is referenced with respect to true North. The rotated HTI stiffness matrix serve as inputs to calculate the reflectivity using the Zoeppritz equation. Alternatively, the reflectivity is calculated using the approximate linearized Zoeppritz equation, wherein the stiffness matrix is expressed in terms of Weak Anisotropy Parameters.

[00014] In some embodiments, the reflectivity is calculated for each azimuth, angle of incidence, and interface. Synthetic seismic traces for one or more azimuths and angle of incidences