Datapages/Search and Discovery Article #90211 CSPG© 2015 CSPG/CSEG/CWLS Convention 2006, What's New? Where is Our Industry Heading? Calgary, AB, Canada, May 15-18, 2006

TTI Anisotropic Depth Migration: Which Tilt Estimate Should We Use?

Francois Audebert[1] and Volker Dirks[1]

[1]CGG Americas, Calgary, Alberta, Canada (faudebert@cgg.com)

Abstract

We perform a series of numerical modelling and migration experiment with different homogeneous TTI anisotropic media, characterized by tilt axis, polar velocity and anisotropy parameters. In the case of structurally conformable media, where the tilt of the medium coincides with the dip of the structure, great simplifications arise in the decoupling of the anisotropy parameters. In particular, positioning and short spread focusing become decoupled from long-spread behaviour. We show that in this case, the tilt of the medium can be observed with sufficient accuracy on an image obtained by isotropic or VTI elliptic migration with an educated estimate of the Thomsen parameter delta.

Introduction

Anisotropic velocity model building tools and migration techniques have been in use for many years and have gained industry acceptance for at least simple VTI anisotropic media. Slightly more complex anisotropic media are now gradually being used; they are commonly referred to as TTI. TTI stands for Tilted Transverse Isotropy and it characterizes a medium exhibiting polar anisotropy around an arbitrary tilt axis (polar axis). The polar anisotropy, with respect to the tilt axis, is entirely determined as a function of the polar velocity (velocity along the pole axis) and the well known Thomsen parameters ε and δ (Thomsen, 1986). As it proves next to impossible to determine, from surface seismic alone, the exact and spatially varying orientation of the polar axis of such TTI media, a simplifying assumption is usually made that the polar axis of the TTI medium coincides with the dip field of the reflecting subsurface structure. We will henceforth in our study referred to this special TTI medium as a Structurally Conformable TTI, or STI, medium. In such an STI medium, seismic propagation can be fully described with the same parameters as for polar anisotropy with the addition of a reflector dip field. A potential problem with STI media is that the reflector dip field has to be extracted from a seismic image, which must be produced using a non-STI/TTI velocity model. Our paper therefore seeks to answer the question: what is the best velocity model that can be used to compute the structural dip field for an ensuing TTI (STI) anisotropic depth migration? To answer this question we use a simple numerical modeling and migration experiment for a single reflecting planar facet and study the migration 'errors' for different isotropic and anisotropic velocity model.

The Intrinsic Properties of a TTI Medium

In a TTI medium, the polar anisotropy, with respect to the tilt axis, is entirely determined in function of the polar velocity (velocity along the pole axis) and the Thomsen parameters ε and δ. The phase velocity as a function of the relative phase angle with respect to the pole axis can be expressed under the weak anisotropy expression or under the more complex exact anisotropy form. For sake of simplicity, we consider here only the weak anisotropy formulation. The medium itself is thus characterized by four independent parameters: β, the tilt angle of the polar axis, Vp0, the polar velocity, and the Thomsen parameters ε and δ.

The Simple Dipping Facet Case

To study the effect of different migration models on the positioning of TTI reflector we build analytically a simple dipping facet (a local planar reflector) model. The facet dip is characterized by the phase angle α with respect to the polar axis of the TTI medium (see Figure 1). This relative phase angle α determines the phase velocity (as a function of α, Vp0, ε and δ), the group angle and the group velocity. The group angle defines the direction of the normal ray, which reaches the surface at some emergence point, intersecting the surface through some apparent phase angle Φ (direction of the slowness vector). The only difference between a VTI medium and a general TTI medium is that in the TTI medium the tilt angle β is equal to zero. We found in the following analytical experiments that it is α, not β or Φ that creates all the kinematic complications in TTI media.

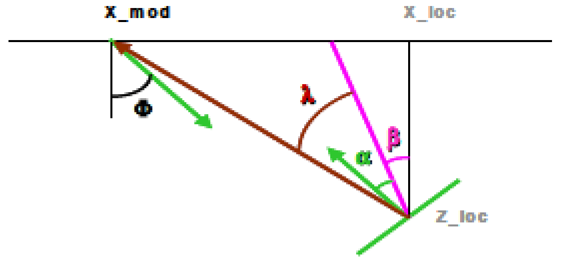

Figure 1. Angles involved in the normal ray tracing from a dipping facet.
β : tilt axis of polar anisotropy
α: reflector dip (phase angle) w.r.t to the tilt axis
Φ: incidence angle at the surface
λ: groupe angle w.r.t. the tilt axis.

The Analytical Modeling Experiments

For the modeling experiments, we consider a single reflecting facet, arbitrarily located at a depth of 200m and at an abscissa of 2000m, in a homogeneous TTI anisotropic medium with fixed polar velocity equal to 2000m per second. Throughout the modeling experiments, we vary the dip of the reflecting facet, as well as the tilt of the TTI medium and the value of the Thomsen parameters ε and δ. In all cases, the TTI medium is homogeneous and characterized by β (tilt angle), Vp0 (polar velocity), ε and δ. Each analytical modeling experiment produces the following observations at the surface: the emergence point of the normal ray, the two-way traveltime along the normal ray, the apparent slowness (traveltime gradient) at the emergence point, and the apparent NMO velocity, Vnmo (related to the derivative of the traveltime gradient) at the emergence point. The modeling experiment, see Figure 1, is a forward problem: the dip of the reflector defines the phase direction of the normal ray, which then defines the group angle (hence the ray trajectory) and the group velocity along the normal ray (hence the two-way traveltime). The Vnmo can be computed from the derivatives of the phase velocity.

The Numerical Migration Experiments

For the migration experiment, we set a priori the tilt of the TTI medium and the pair of ε and δ Thomsen parameters, Figure 2. We emulate here the real situation, where we have to first perform a velocity analysis, accounting for the apparent Vnmo, and second, perform a migration (relocalization of the reflecting facet in space) in a given velocity medium. To emulate this real situation, we perform a double inversion of the Vnmo and P, Figure 2. The result of the inversion is a polar velocity and a phase direction for the normal ray, Figure 3.

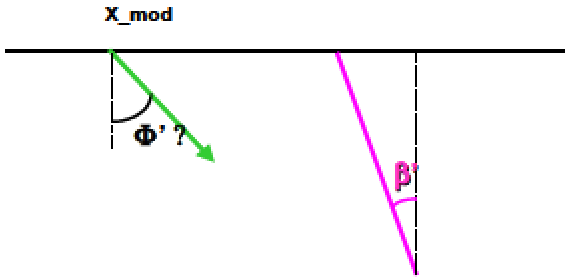

Figure 2. migration experiment:
parameters set a priori:
β_mig = β', δ_mig, ε_mig,
observations at the emergence point
T0 = zero-offset traveltime
P = horizontal traveltime gradient.
Vnmo = traveltime curvature at the surface.

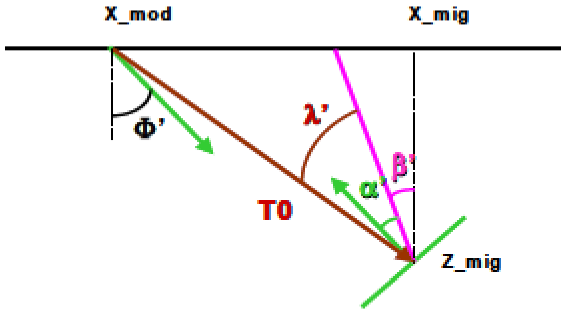

Figure 3. migration experiment:
parameters found by inversion:
- Vp_mig, the inverted polar velocity,
- α_mig, the phase angle, associated to Φ'.

The Study

Given the infinite number of combination between modeling experiments and migration experiments, we concentrate on the cases when, at the modeling stage, the dip of the reflector is equal to the tilt of the medium, i.e. an STI medium. Then we try to qualify and quantify the error we commit by migrating the observed event in an isotropic medium, in a VTI medium and in a TTI medium with erroneous tilt or Thomsen anisotropy parameters. We try to answer the question: what error do we commit either by ignoring the tilt of the medium (i.e. wrongly assuming it is isotropic or VTI), or by having a bad estimate of its tilt? Additionally, we try to determine a best way to estimate the tilt of the medium. The qualifying and quantifying criteria we use are a measurement of the error in dip, a measurement of the magnitude of the spatial error and a measurement of the direction of the spatial error.

The General Results

We find that the paramount parameter is the difference α between the tilt of the medium and the dip of the reflector. If the dip of the reflector, in the true medium, is equal to the tilt of the medium (the STI case), then the dip direction, the phase and the group directions of the normal ray are all equal to the direction of the tilt, and the short spread behavior is similar to the case of the elliptic VTI medium. In particular, the short spread focusing and positioning are independent from the true η□of the modeling medium ($\eta = \ \varepsilon$ δ). Reciprocally, as soon as α becomes significant, all parameters become coupled, and in particular η intervenes in the short spread focusing and positioning. This is typically what happens for a dipping reflector in a VTI medium. We also find that for any tested combinations of the modeling parameters (tilt, ε, δ) and of the migration parameters (tilt, ε, δ), there exists a solution in terms of Vp0 and the migrated dip of the reflector in the migration medium. Our study hence confirms the intrinsic 'non-uniqueness' of the determination of the anisotropy parameters for general TTI media!

The Results for an STI Medium

For all the results we present now, the true model was STI with δ = 20%. We find that the error committed by an isotropic migration (while the true model is STI), is independent from the true η of the medium. The magnitude of the error (in dip and in space) is proportional to the magnitude of the true δ. We further find (Figure 4a) that the error in dip committed by isotropic migration of a dipping reflector (while the true medium is STI) is small (maximum of 5°, at 45° of true dip, for a δ = 20%). The error in dip (though not the error in space, Figure 4b) becomes smaller with VTI elliptic migration, through improved estimates of δ. In other words, a tilt model estimated from an isotropic migration, or better, from a VTI elliptic migration with an educated estimate of δ, is a sufficient approximation of the true tilt model. This solves the chicken and egg conundrum of the estimation of a tilt model for an STI medium.

We also find (Figures 4c and 4d) that by using the tilt model extracted from the isotropically migrated image, the error in dip decreases further as a function of the residual error in δ. In other word, the estimation of the tilt model, first by isotropic migration, then by TTI migration with the previous tilt model, is a converging problem (in as much as the determination of δ improves). We finally find (Figure 4d and 4f) that if the tilt model of the migration is accurate or close enough to the true tilt (condition ensured by the aforementioned sequence), the positioning error (and the short spread focusing) is independent from the true η, and is proportional to the residual error in δ.

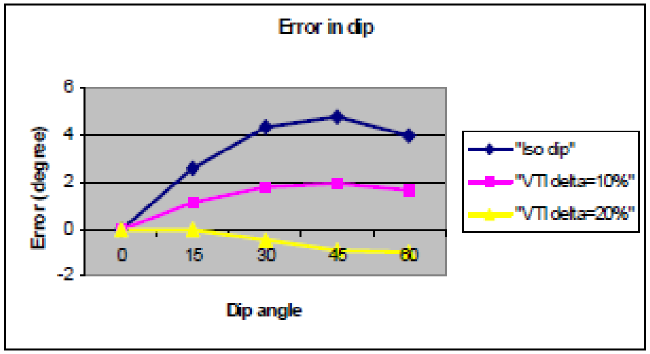

Figure 4a: error in dip, VTI elliptic migration, δ={0, 10, 20%}, (top to bottom curves).

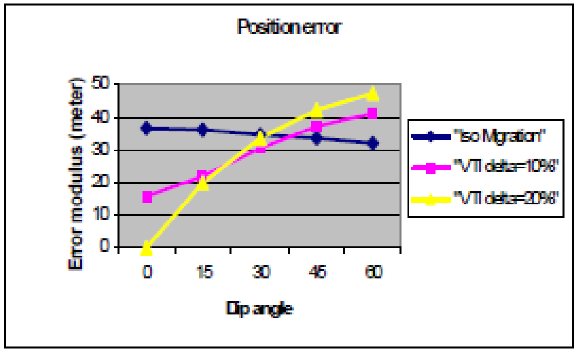

Figure 4b. error modulus, VTI elliptic migration, δ={0, 10, 20%).

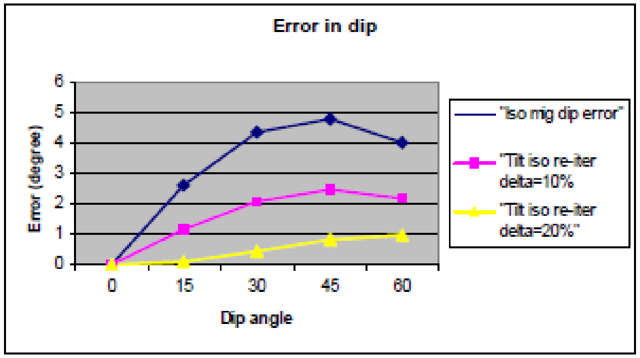

Figure 4c. error in dip, TTI elliptic migration, tilt from isotropic migration, δ={0, 10, 20%}, (top to bottom curves).

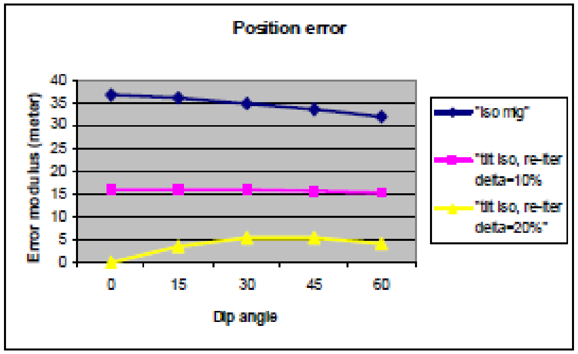

Figure 4d. error modulus, TTI elliptic migration, tilt from isotropic migration, δ={0, 10, 20%}, (top to bottom curves).

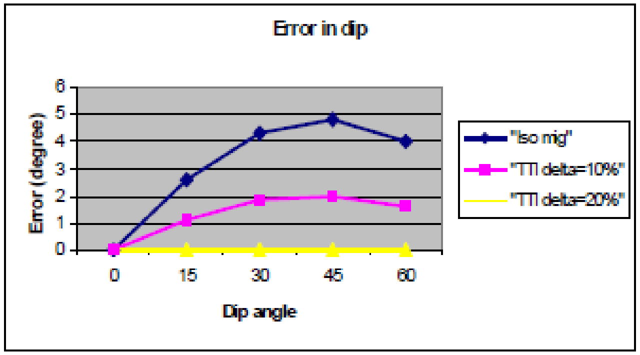

Figure 4e. error in dip, TTI elliptic migration with correct tilt, δ={0, 10, 20%}, (top to bottom curves). Error=0 for δ=20%.

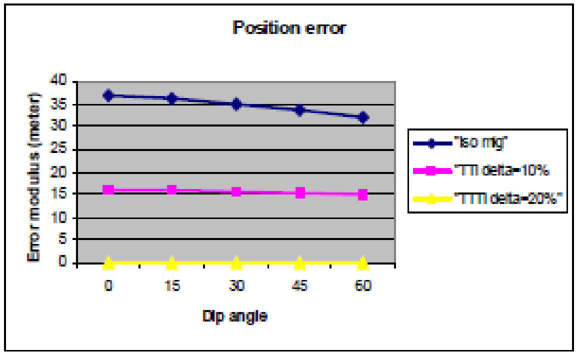

Figure 4f. error modulus, TTI elliptic migration with correct tilt, δ={0, 10, 20%}, (top to bottom curves). Error=0 for δ=20%.

Conclusion

For structurally conforming TTI (STI) media the dip model can be determined by means of isotropic or VTI elliptic migration. In such media, the seismic tie to the well is found by simple adjustment of only δ. The positioning of the reflector as a function of (Vp0, δ) is approximately a translation along the direction of the normal to the reflector.

Reference Cited

Thomsen, L., 1986, Weak Elastic Anisotropy: Geophysics, v. 51, p. 1954-1966.