

H. Gjoystdal, J. E. Reinhardsen and B. Ursin.
Traveltime and wavefront curvature calculations in three-dimensional inhomogeneous layered media with curved interfaces

The seismic rays and wavefront curvatures are determined by solving a system of nonlinear ordinary differential equations. For media with constant velocity and for media with constant velocity gradient, simplified solutions exist. In a general inhomogeneous medium these equations must be solved by numerical approximations. The integration of the ray-tracing and wavefront curvature equations is then performed by a modified divided difference form of the Adams PECE (Predict-Evaluate-Correct-Evaluate) formulas and local extrapolation. The interfaces between the layers are represented by bicubic splines. The changes in ray direction and wavefront curvature at the interfaces are computed using standard formulas. For three-dimensional media, two quadratic traveltimes approximations have been proposed. Both are based on a Taylor series expansion with reference to a ray from a reference source point to a reference receiver point. The first approximation corresponds to expanding the square root of the result. The second approximation corresponds to expanding the traveltimes in a Taylor series. The two traveltimes approximations may be expressed in source-receiver coordinates or in midpoint-half-offset coordinates. Simplified expressions are obtained when the reference source and receiver coincide, giving zero-offset approximations, for which the reference ray is a normal-incidence ray. A new method is proposed for computing the second derivatives of the normal-incidence traveltimes with respect to the source-receiver midpoint coordinates. By considering a beam of normal-incidence rays it is shown that the second-derivative matrix may be found by computing the wavefront curvature along a reference normal-incidence ray starting at the reflection point with the wavefront curvature equal to the curvature of the reflecting interface. From this second-derivative matrix the normal moveout velocity can be computed for any seismic line through the reference source-receiver midpoint. It is also shown how a reverse wavefront curvature calculation may be used, in a time-to-depth migration scheme, to compute the curvature of the reflecting interface from the estimated second derivatives of the normal-incidence traveltimes. Numerical results for different three-dimensional models indicate that the first traveltimes approximation, based on an expansion of the square of the traveltimes, is the most accurate for shallow reflectors and for simple models. For deeper reflectors the two approximations give comparable results, and for models with complicated velocity variations the second approximation may be slightly better than the first one, depending on the particular model chosen. A simplified traveltimes approximation may be used in a three-dimensional seismic velocity analysis. Instead of estimating the stacking velocity one must estimate three elements in a 2×2 symmetric matrix. The accuracy and range of validity of the simplified traveltimes approximation are investigated for different three-dimensional models.

M. Tygel and P. Hubral. *Transient representation of the Sommerfeld-Weyl integral with application to the point source response from a planar acoustic interface*

Point source responses from a planar acoustic and/or elastic layer boundary (as well as from a stack of planar parallel

layers) are generally obtained by using as a starting point the Sommerfeld-Weyl integral, which can be viewed as decomposing a time-harmonic spherical source into time-harmonic homogeneous and inhomogeneous plane waves. This paper gives a powerful extension of this integral by providing a direct decomposition of an arbitrary transient spherical source into homogeneous and inhomogeneous transient plane waves. To demonstrate with an example the usefulness of this new point source integral representation, a transient solution is formulated for the reflected/transmitted response from a planar acoustic reflector. The result is obtained in the form of a relatively simple integral and essentially corresponds to the solution obtained by Bortfeld (1962). It, however, is arrived at in a physically more transparent way by strictly superimposing the reflected/transmitted transient waves leaving the interface in response to the incident transient homogeneous and inhomogeneous plane waves coming from the centre of the point source.

C. Z. Tarlowski, A. P. Raiche and M. Nabighian.
The use of summary representation for electromagnetic modeling

The method of summary representation developed by G. N. Polozhii is a quasi-analytical method for solving self-adjoint, finite-difference boundary value problems expressed on regular meshes. In principle, the method should allow considerable savings in computing time as well as improved accuracy when compared to commonly used finite-difference schemes. We have used summary representation as the basis for a new hybrid scheme to solve the two-dimensional Helmholtz equation for electromagnetic modeling. The theory behind this hybrid scheme is presented. Preliminary results for the two-dimensional problem show that substantial computing time and storage savings can be made.

P. E. Wannamaker, G. W. Hohmann and S. H. Ward. *Magnetotelluric responses of three-dimensional bodies in layered earths*

The electromagnetic fields scattered by a three-dimensional (3-D) inhomogeneity in the earth are affected strongly by boundary charges. Boundary charges cause normalized electric field magnitudes, and thus tensor magnetotelluric (MT) apparent resistivities, to remain anomalous as frequency approaches zero. However, these E -field distortions below certain frequencies are essentially in-phase with the incident electric field. Moreover, normalized secondary magnetic field amplitudes over a body ultimately decline in proportion to the plane-wave impedance of the layered host. It follows that tipper element magnitudes and all MT function phases become minimally affected at low frequencies by an inhomogeneity. Resistivity structure in nature is a collection of inhomogeneities of various scales, and the small structures in this collection can have MT responses as strong locally as those of the large structures. Hence, any telluric distortion in overlying small-scale extraneous structure can be superimposed to arbitrarily low frequencies upon the apparent resistivities of buried targets. On the other hand, the MT responses of small and large bodies have frequency dependencies that are separated approximately as the square of the geometric scale factor distinguishing the different bodies.

Therefore, tipper element magnitudes as well as the phase of all MT functions due to small-scale extraneous structure will be limited to high frequencies, so that one may 'see through' such structure with these functions to target responses occurring at lower frequencies. About a 3-D conductive body near the surface, interpretation using 1-D or 2-D TE modeling routines of the apparent resistivity and impedance phase identified as transverse electric (TE) can imply false low resistivities at depth. This is because these routines do not account for the effects of boundary charges. Furthermore, 3-D bodies in typical layered hosts, with layer resistivities that increase with depth in the upper several kilometres, are even less amenable to 2-D TE interpretation than are similar 3-D bodies in uniform half-spaces. However, centrally located profiles across geometrically regular, elongate 3-D prisms may be modeled accurately with a 2-D transverse magnetic (TM) algorithm, which implicitly includes boundary charges in its formulation. In defining apparent resistivity and impedance phase for TM modeling of such bodies, we recommend a fixed coordinate system derived using tipper-strike, calculated at the frequency for which tipper magnitude due to the inhomogeneity of interest is large relative to that due to any nearby extraneous structure.

H. Soininen. *The behaviour of the apparent resistivity phase spectrum in the case of a polarizable prism in an unpolarizable half-space*

In the application of the broadband induced polarization method, it is necessary to know how a petrophysical resistivity spectrum is transformed into an apparent spectrum measured in the field. Investigated in the present work was the forming of an apparent spectrum in the case of a polarizable three-dimensional prism embedded in an unpolarizable half-space for gradient and dipole-dipole arrays. The computations were done numerically using the integral equation technique. The frequency dependence of the resistivity of the prism was depicted by means of the Cole–Cole dispersion model. With this simple model geometry, the phase spectra of apparent resistivity resemble quite closely in functional form the original

petrophysical phase spectrum of the Cole–Cole dispersion model. The apparent spectra have shifted on the log-log scale downward, owing to geometric attenuation, and toward lower frequencies. The apparent Cole–Cole parameters have been inverted from the apparent spectra. The apparent chargeability is generally noticeably smaller, owing to the geometric attenuation, than the chargeability of the original petrophysical spectrum. The apparent frequency dependence, on the other hand, is very close to the value of the original frequency dependence. The shift of the apparent phase spectrum toward lower frequencies partly compensates for the decrease in the apparent time constant caused by attenuation of the spectrum. The apparent time constant is thus close to the true time constant of the petrophysical spectrum. It is therefore possible in principle to obtain by direct inversion from an apparent spectrum measured in the field a reasonable estimate of the frequency dependence and time constant of the true spectrum of a polarizable body.

Fang-wei Yang and S. H. Ward. *Inversion of borehole normal resistivity logs*

This paper reports on an investigation of the inversion of borehole normal resistivity data via ridge regression. Interpretation is afforded of individual thin beds and of complicated layered structures. A theoretical solution is given for a layered model containing an arbitrary number of layers in the forward problem. Two forward model results for resistive and conductive thin beds indicate that for high-resistivity contrasts, the departure between true and apparent resistivity may be more important than the effects caused by the variations in borehole diameter and mud resistivity. Four normal resistivity logs were chosen to test the inversion scheme. Two of the logs were theoretical logs with and without random noise added, and the remaining two were field examples. Theoretical model results and field examples indicate that the inverse method can be used to obtain the resistivity for each layer when the boundary position is known, but it also can be used to obtain the thickness and resistivity for each layer simultaneously.