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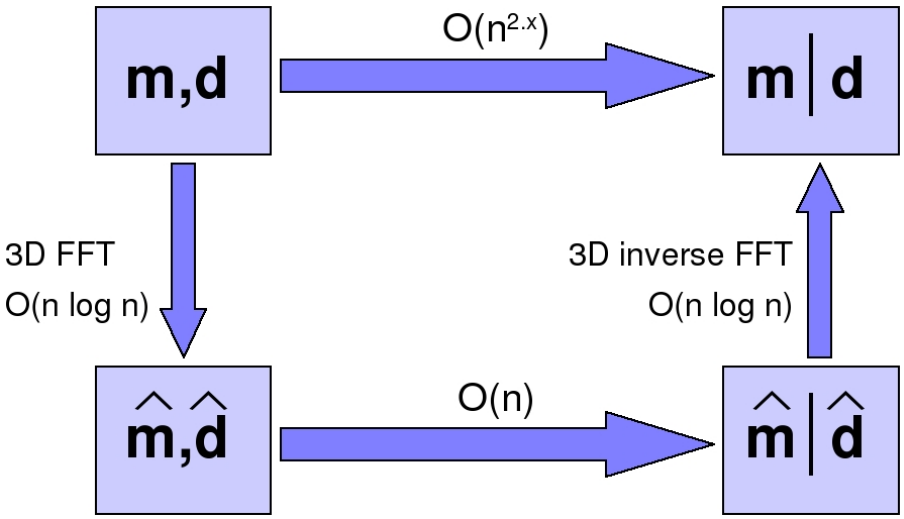
Note

CRAVA User Manual version 2.0



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Abstract

CRAVA is a simple inversion tool, particularly suited for quick generation of first pass inversions and facies probabilities for use in geological modeling. This manual describes the theory behind, the main implementation structure, and the actual use of this program.

Keywords	CRAVA, seismic, inversion, geostatistical, Bayesian, AVO, FFT
Target group	NR, Statoil, Norsar, Roxar
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1 Model

1.1 Introduction

Seismic inversion has traditionally been treated as a deterministic problem. However, there are several uncertain aspects: There is noise in the seismic amplitude data, and the frequency resolution is limited. This means that neither high nor low frequencies can be resolved from the seismic amplitude data alone. Using a geostatistical approach to the problem of seismic inversion, the uncertainty may be treated in a consistent and robust way.

The CRAVA program uses the Bayesian linearised AVO inversion method of Buland et al. (2003) to take the uncertainty in seismic amplitude data into account. Since we only use amplitude data, we will from here on use the term seismic data for these. The seismic data are described using multi-normal distributions, and modelled as the seismic response of the earth model plus an error term. The earth model and error term are modelled as multi-normal distributions in which spatial coupling is imposed by correlation functions. Using a Bayesian setting, prior models for the earth and error terms are set up based on prior knowledge obtained from well logs, and the process of seismic inversion is reduced to that of finding a posterior distribution for the earth given the seismic data. The linearised relationship between the model parameters and the AVO data, makes it possible to obtain the posterior distribution analytically.

The posterior distribution for earth model parameters V_p (pressure-wave velocity), V_s (shear-wave velocity), and ρ (density), gives a laterally consistent seismic inversion. The lateral correlation can follow the stratigraphy of the inversion interval by following the top and/or base of the inversion volume, but can also be specified independently using a correlation surface. As a consequence of the spatial coupling, the solution in each location depends on the solutions in all other locations. From the posterior distribution the best estimate of the model parameters and a corresponding uncertainty can be extracted. Moreover, since the distribution is Gaussian, kriging can be used to match the well data, and the posterior covariance can be computed. This spreads full frequency information in an area around the wells. Full frequency realizations can be generated by sampling from the posterior distribution. A set of such realizations represents the uncertainty of the inversion.

1.2 AVO

Amplitude versus offset (AVO) inversion can be used to extract information about the elastic subsurface parameters from the angle dependency in the reflectivity, see e.g., Buland et al. (1996); Hampson and Russell (1990); Lörtzer and Berkhout (1993); Pan et al. (1994). In practice, and especially for 3-D surveys, linearised AVO inversion is attractive since it can be performed with use of moderate computer resources. Prior to a linearised AVO inversion, the seismic data must be processed to remove nonlinear relations between the model parameters and the seismic response. Important steps in the processing are the removal of the move-out, multiples, and the effects of geometrical spreading and absorption. The seismic data should be pre-stack migrated, such that dip related effects are removed. After pre-stack migration, it is reasonable to assume that each single bin-gather can be regarded as the response of a local 1-D earth model. The benefits of pre-stack migration before AVO analysis are discussed in Brown (1992); Buland and Landrø (2001); Mosher et al. (1996). It is further assumed that wave mode conversions, interbed multiples and anisotropy

effects can be neglected after processing. Ideally, the pre-stack gathers are also transformed from offsets to reflection angles. Offset gathers are often close to angle gathers, so we can use these, but if the inversion area is thick, this will give more noise in the CRAVA model.

1.3 Seismic model

The seismic response of an isotropic, elastic medium is completely described by the three material parameters $\{V_p(\mathbf{x},t), V_s(\mathbf{x},t), \rho(\mathbf{x},t)\}$, where the vector $\mathbf{x}$ gives the lateral position (x,y), and t is the vertical seismic travel time.

The weak contrast approximation by Aki and Richards (1980), relates the seismic reflection coefficients $c(\mathbf{x},t,\theta)$ to the elastic medium, and is a linearization of the Zoeppritz equations. A continuous version of this approximation is given by Stolt and Weglein (1985):

$$\begin{aligned} c(\mathbf{x},t,\theta) = & \, a_{Vp}(\theta)\frac{\partial}{\partial t}\ln V_p(\mathbf{x},t) \\ & + a_{Vs}(\mathbf{x},t,\theta)\frac{\partial}{\partial t}\ln V_s(\mathbf{x},t) \\ & + a_{\rho}(\mathbf{x},t,\theta)\frac{\partial}{\partial t}\ln \rho(\mathbf{x},t), \end{aligned} \tag{1.1}$$

where θ is the PP reflection angle, and

$$\begin{aligned} a_{Vp}(\theta) &= \frac{1}{2}\left(1+\tan^2\theta\right), \\ a_{Vs}(\mathbf{x},t,\theta) &= -4\frac{V_s^2(\mathbf{x},t)}{V_p^2(\mathbf{x},t)}\sin^2\theta, \\ a_{\rho}(\mathbf{x},t,\theta) &= \frac{1}{2}\left(1-4\frac{V_s^2(\mathbf{x},t)}{V_p^2(\mathbf{x},t)}\sin^2\theta\right) \end{aligned} \tag{1.2}$$

for PP reflections, and

$$\begin{aligned} a_{Vp}(\theta) &= 0 \\ a_{Vs}(\mathbf{x},t,\theta) &= 2\frac{\sin\theta}{\cos\phi}\left(\frac{V_s^2(\mathbf{x},t)}{V_p^2(\mathbf{x},t)}\sin^2\theta - \frac{V_s(\mathbf{x},t)}{V_p(\mathbf{x},t)}\cos\theta\cos\phi\right), \\ a_{\rho}(\mathbf{x},t,\theta) &= \frac{\sin\theta}{\cos\phi}\left(-\frac{1}{2}+\frac{V_s^2(\mathbf{x},t)}{V_p^2(\mathbf{x},t)}\sin^2\theta + \frac{V_s(\mathbf{x},t)}{V_p(\mathbf{x},t)}\cos\theta\cos\phi\right), \end{aligned} \tag{1.3}$$

for PS reflections. Here, ϕ is the PS reflection angle, given by $\sin\phi = (V_s/V_p)\sin\theta$. These equations are linearised by replacing the ratio $V_s(\mathbf{x},t)/V_p(\mathbf{x},t)$ with a constant value $\bar{V}_p/\bar{V}_s$ when computing the coefficients.

The seismic data are represented by the convolutional model

$$d_{obs}(\mathbf{x},t,\theta) = \int w(\tau,\theta)\, c(\mathbf{x},t-\tau,\theta)\, d\tau + e(\mathbf{x},t,\theta), \tag{1.4}$$

where w is the wavelet, and e is an angle and location dependent error term. The integral is the synthetic seismic. The wavelet can be angle dependent, and can vary laterally according to scale and shift maps. The wavelet is assumed to be stationary within a limited target window.

The signal-to-noise ratio is defined as the ratio of the energy of the data to the energy of the noise as given in Equation 1.4, that is,

$$S/N = \left(\|w * c\|^2 + \|e\|^2\right)/\|e\|^2, \tag{1.5}$$

where the operator * denotes the convolution. Since the error is independent of the synthetic seismic, the energy form the synthetic seismic and the noise can simply be added. Note that there also exists another definition of the S/N ratio where the noise energy is not included in the enumerator.

1.3.1 Convolution with 3D wavelet

The seismic data can also be represented as a convolution in three dimensions

$$d_{obs}(\mathbf{x}, t, \theta) = \int w(\mathbf{x}, \tau, \theta)\, c(\mathbf{x} - \chi, t - \tau, \theta)\, d\chi d\tau + e(\mathbf{x}, t, \theta), \tag{1.6}$$

where w now denotes a 3D wavelet. The 3D wavelet is derived from the point-spread function (PSF) which acts as a filter on the reflectivity cube to mimic the imaging process of pre-stack depth migration. For a thorough description on how the PSF is calculated with ray-tracing by identifying the illumination vectors, see Lecomte (2008). For a more physical interpretation of the PSF, the parametrisation in the wavenumber (Fourier) domain is done in terms of spherical coordinates. The relationship between these coordinates and the spatial frequencies $\mathbf{k} = (k_x, k_y, k_z)$ for a point P is given by

$$k_x = r\cos(\phi)\sin(\psi),\ \ k_y = r\sin(\phi)\sin(\psi),\ \ k_z = r\cos(\psi), \tag{1.7}$$

where r is the radial distance from origo to P, ϕ is the azimuth angle between the line from origo to P projected into the (k_x, k_y)-plane and the k_x-axis and ψ is the dip angle defined as the inclination angle between the line from origo to P and the upward pointing k_z-axis. ϕ varies between $0°$ and $360°$ while ψ varies between $0°$ and $90°$ implying that only upwards scattering reflections are considered, and not turning waves.

Defining the temporal frequency $\omega = V_0 r(2\cos\theta)^{-1}$ where V_0 is the average velocity for the region of interest and $\cos\theta$ represents a stretch factor due to reflection angle, the model for the point-spread function, f, is given by

$$\tilde{f}(r, \phi, \psi; \theta) = \tilde{\alpha}_1(\phi, \psi; \theta)\tilde{\alpha}_2(\omega, \phi, \psi; \theta)\tilde{w}_0(\omega; \theta), \tag{1.8}$$

where the tilde denotes Fourier transform, $\tilde{w}_0(\omega; \theta)$ is the 1D pulse and functions $\tilde{\alpha}_1(\phi, \psi; \theta)$ and $\tilde{\alpha}_2(\omega, \phi, \psi; \theta) = \exp(-\pi|\omega|\tilde{H}(\phi, \psi; \theta))$ are frequency independent and frequency dependent processing factors respectively.

Since the point-spread function is defined in the depth domain, and the 3D wavelet in expression (1.6) is in time domain, a relation between time and depth is needed. In the region of interest, a target centre is defined at depth Z_0. A reference time surface $T_0(x, y)$ corresponds to this depth. For a given time τ the corresponding depth is ζ. Let $T_\tau(x, y)$ be the time to a point, and $Z_\zeta(x, y)$ the depth to the same point, the time-depth relation is:

$$T_\tau(x, y) = T_0(x, y) + \frac{2}{V_0}(Z_\zeta(x, y) - Z_0) \tag{1.9}$$

1.4 Statistical model

The elastic parameters $V_p(\mathbf{x}, t)$, $V_s(\mathbf{x}, t)$, and $\rho(\mathbf{x}, t)$ are assumed to be log-normal random fields. This means that the distribution $\mathbf{m}(\mathbf{x}, t) = [\ln V_p(\mathbf{x}, t), \ln V_s(\mathbf{x}, t), \ln \rho(\mathbf{x}, t)]^T$ is multi-normal or multi-Gaussian, that is,

$$\mathbf{m}(\mathbf{x}, t) \sim \mathcal{N}\left(\boldsymbol{\mu}_m(\mathbf{x}, t), \boldsymbol{\Sigma}_m(\mathbf{x}_1, t_1; \mathbf{x}_2, t_2)\right), \tag{1.10}$$

where $\boldsymbol{\mu}_m(\mathbf{x}, t)$ are the expectations of $\mathbf{m}(\mathbf{x}, t)$ and $\boldsymbol{\Sigma}_m(\mathbf{x}_1, t_1; \mathbf{x}_2, t_2)$ gives the covariance structure. We assume that the covariance function is stationary and homogeneous (i.e., translationally invariant), and can be factorised as

$$\boldsymbol{\Sigma}_m(\mathbf{x}_1, t_1; \mathbf{x}_2, t_2) = \boldsymbol{\Sigma}_{0,m}\, \nu_m(\xi)\nu_m(\tau), \tag{1.11}$$

where $\nu_m(\xi)$ and $\nu_m(\tau)$ are correlation functions depending on the lateral and temporal distances $\xi = \|\mathbf{x}_2 - \mathbf{x}_1\|$ and $\tau = |t_2 - t_1|$, respectively, and $\boldsymbol{\Sigma}_{0,m}$ is a 3×3 matrix of the variances and

covariances of $\ln V_p$, $\ln V_s$ and $\ln \rho$. Any covariance structure giving a positive definite $\mathbf{\Sigma}_m$ may be used.

If we let $\mathbf{m}$ and $\mathbf{d}_{obs}$ be discrete representations of $\mathbf{m}(\mathbf{x}, t)$ and $d_{obs}(\mathbf{x}, t, \theta)$ in a time interval, Equation (1.4) may be written in matrix notation as

$$\begin{aligned} \mathbf{d}_{obs} &= \mathbf{WADm} + \mathbf{e} && (1.12) \\ &= \mathbf{Gm} + \mathbf{e} && (1.13) \end{aligned}$$

where $\mathbf{W}$ is the matrix representation of the wavelets, $\mathbf{A}$ is a matrix encompassing discrete representations of the coefficients a_{Vp}, a_{Vs}, and a_ρ, $\mathbf{D}$ is a differential matrix and $\mathbf{G} = \mathbf{WAD}$. The error matrix $\mathbf{e}$ is a time discretization of the error vector $\mathbf{e}(\mathbf{x}, t) = [e(\mathbf{x}, t, \theta_1), \ldots, e(\mathbf{x}, t, \theta_{n_\theta})]^T$ and is assumed to be zero-mean coloured Gaussian noise, that is,

$$\mathbf{e}(\mathbf{x}, t) \sim \mathcal{N}_{n_\theta} \left(\mathbf{0}, \mathbf{\Sigma}_e(\mathbf{x}_1, t_1; \mathbf{x}_2, t_2) \right). \tag{1.14}$$

The covariance of the error vector is

$$\mathbf{\Sigma}_e(\mathbf{x}_1, t_1; \mathbf{x}_2, t_2) = \mathbf{\Sigma}_{0,e}\, \nu_e(\xi)\nu_e(\tau), \tag{1.15}$$

where $\mathbf{\Sigma}_{0,e}$ is an $n_\theta \times n_\theta$ covariance matrix containing the noise variances for the different reflection angles on the diagonal, and the covariances between the angles off the diagonal. Furthermore, $\nu_e(\xi)$ and $\nu_e(\tau)$ are lateral and temporal correlation functions, similar to those given for $\mathbf{m}(\mathbf{x}, t)$ in Equation (1.11).

Since the relationship between the reflection coefficients and the elastic parameters given in Equation (1.1) is linear, and the elastic parameters are assumed Gaussian distributed, the reflection coefficients become Gaussian. Moreover, since the convolution is a linear operation and we have assumed a Gaussian error model, the seismic data given in Equation (1.4) are also Gaussian distributed.

For the time-discretized seismic data $\mathbf{d}_{obs}$, this gives us the multi-normal distribution

$$\mathbf{d}_{obs} \sim \mathcal{N}_{n_d} \left(\boldsymbol{\mu}_d, \mathbf{\Sigma}_d \right), \tag{1.16}$$

where

$$\begin{aligned} \boldsymbol{\mu}_d &= \mathbf{G}\boldsymbol{\mu}_m, && (1.17) \\ \mathbf{\Sigma}_d &= \mathbf{G}\mathbf{\Sigma}_m\mathbf{G}^T + \mathbf{\Sigma}_e. && (1.18) \end{aligned}$$

where all vectors and matrices are time-discretized.

This means that the simultaneous distribution for $\mathbf{m}$ and $\mathbf{d}_{obs}$ is Gaussian, and that the distribution for $\mathbf{m}$ given $\mathbf{d}_{obs}$ can be obtained analytically using standard theory for Gaussian distributions:

$$\begin{aligned} \boldsymbol{\mu}_{m|d_{obs}} &= \boldsymbol{\mu}_m + \mathbf{\Sigma}_m\mathbf{G}^T\mathbf{\Sigma}_d^{-1}(\mathbf{d}_{obs} - \boldsymbol{\mu}_d) && (1.19) \\ \mathbf{\Sigma}_{m|d_{obs}} &= \mathbf{\Sigma}_m - \mathbf{\Sigma}_m\mathbf{G}^T\mathbf{\Sigma}_d^{-1}\mathbf{G}\mathbf{\Sigma}_m, && (1.20) \end{aligned}$$

where $\boldsymbol{\mu}_d$ is the expected observation, that is, the seismic response of $\boldsymbol{\mu}_m$, and $\mathbf{\Sigma}_{d,m}$ is the covariance matrix between logarithmic parameters and observations. See Buland and Omre (2003) for a detailed description on how to compute these.

The computations given in Equations (1.19) and (1.20) involves the inverse of $\mathbf{\Sigma}_d$. Given an inversion volume with n cells, this matrix has $n_\theta^2 n^2$ elements, and for any reasonably sized volumes,

inverting this matrix is forbiddingly time consuming. However, the covariance function for a homogeneously correlated spatial variable is diagonalised by a 3D Fourier transform (Christakos (1992)), and in this domain the inversion problem can be solved independently for each frequency component. This reduces the complexity of the computations dramatically, and the calculation time becomes $\mathcal{O}(n \log n)$. This is illustrated in Figure 1.1. Details can be found in Buland et al. (2003)

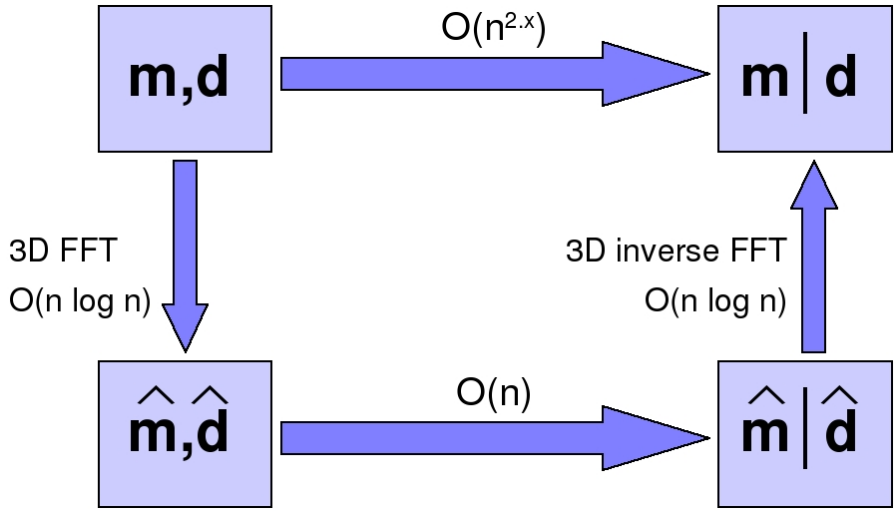

Figure 1.1. The problem is transformed to the Fourier domain, solved in this domain, and back-transformed to time domain. This reduces the problem from a $\mathcal{O}(n^{2.x})$ to a $\mathcal{O}(n \log n)$ process.

This seems to require that $\mathbf{d}$ is stationary, which would imply that the wavelet must be the same everywhere. However, we can divide out the wavelet from Equation 1.12 to obtain

$$\mathbf{d}' = \mathbf{ADm} + \mathbf{e}', \tag{1.21}$$

where $\mathbf{d}'$ is the data divided by the wavelet, and $\mathbf{e}'$ is the error divided by the wavelet. The details of how we do this division is given in Section 2.6.1. Note that we now assume that the noise after division, $\mathbf{e}'$ is stationary. Since we assume that a seismic response only depends on the reflections in that trace, this division can be done trace by trace. This assumption relies on a rather smooth seismic response, so the lateral variations in the wavelet should be smooth. We have chosen to restrict the local wavelet changes to only allow local temporal shift and amplitude scaling.

We can also work around the stationary noise assumption, and allow $\mathbf{e}'$ to vary laterally. This is done by utilising the nature of a Bayesian solution, which always is a tradeoff between the prior and the posterior with noise free data. By finding the posterior for a minimal noise, we can then interpolate between this solution and the prior to find an appropriate solution for the local noise level. When doing this, we ignore the lateral correlation, so we require constant noise level in each trace, since the conditional correlations inside a trace are much stronger than between traces. See Section 2.6.2 for details.

1.4.1 Facies probabilities

To calculate facies probabilities from inverted elastic parameters we must first establish a link between the elastic parameters from inversion and facies. There are several ways to do this, and we have listed the four most realistic in Table 1.1.

First, we may establish the link using a rock physics models. This way we avoid any alignment problems, but we get no frequency control and get to use no correlation information from the

Table 1.1. Different methods for establishing a relation between elastic parameters and facies.

Approach	Frequency control	Inversion correlation	Alignment	Predictions
Rock physics	No	No	Yes	Optimistic
Low-pass filtered elastic well logs	Yes	No	Yes	Optimistic
Inversion	Yes	Yes	No	Pessimistic
Parameter filtered elastic well logs	Yes	Yes	Yes	Realistic

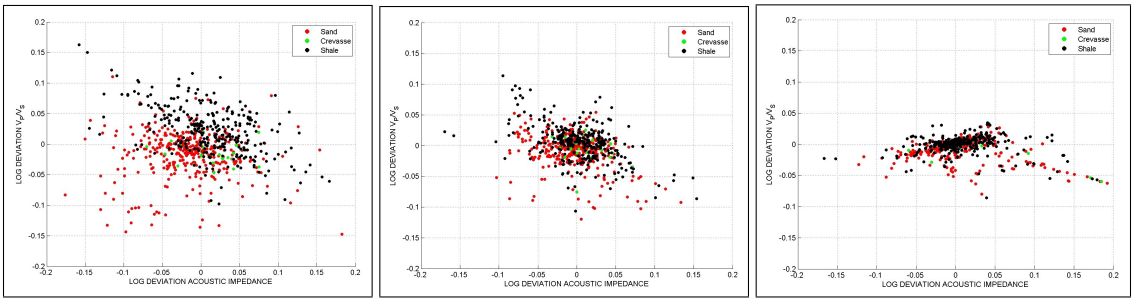

Figure 1.2. Acoustic impedance residuals calculated from blocked raw logs plotted against corresponding V_p/V_s residuals (left), the same plot, but with logs high-cut frequency filtered to 40Hz (middle), and the same logs but filtered using frequency and correlation information from inversion (right).

inversion. A prediction obtained this way tends to be too optimistic, but if there are no well logs available, this is our only option.

Second, we may filter the elastic well logs using a low-pass filter, and use these filtered logs and facies logs to make a density estimation of $p(\boldsymbol{\mu}_{m|d_{obs}}|f)$, where f is the facies. This gives us frequency control and proper alignment, but again there are no correlation information from the inversion included, and the predictions become to optimistic. The frequency filtering of well logs is illustrated in Figure 1.2.

Third, we may set up the probability density for an elastic responds given the facies directly from the inverted elastic parameters. This way we get both frequency control and correlation information included, but we get no alignment information, and the predictions become to pessimistic.

Finally, we may establish the density using elastic parameters from well logs, but filter these using frequency and correlation information obtained from the inversion. Since we only use well logs to establish the density estimates, we get no alignment problems, and in total, this gives us realistic facies predictions. How the inversion-based filtering differs from the pure frequency-based filtering mentioned above is illustrated in Figure 1.2.

The link between facies and elastic parameters that we eventually are interested in is $p(f_i|\boldsymbol{\mu}_{m|d,i})$, where f_i is the facies at location i and $\boldsymbol{\mu}_{m|d,i}$ is the inversion result at the same location. To establish this link, we must first establish a link between the well logs $\mathbf{m}$ and the expectation given the seismic data $\boldsymbol{\mu}_{m|d_{obs}}$. We get this by combining Equation 1.13 and Equation 1.19:

$$\begin{aligned}\boldsymbol{\mu}_{m|d_{obs}} &= \boldsymbol{\mu}_m + \boldsymbol{\Sigma}_m \mathbf{G}^T \boldsymbol{\Sigma}_d^{-1}(\mathbf{d}_{obs} - \boldsymbol{\mu}_d) \\ &= \boldsymbol{\mu}_m + \boldsymbol{\Sigma}_m \mathbf{G}^T \boldsymbol{\Sigma}_d^{-1}(\mathbf{G}\mathbf{m} + \mathbf{e} - \mathbf{G}\boldsymbol{\mu}_m) \\ &= \boldsymbol{\mu}_m + \mathbf{F}(\mathbf{m} - \boldsymbol{\mu}_m) + \mathbf{e}^*, \end{aligned} \tag{1.22}$$

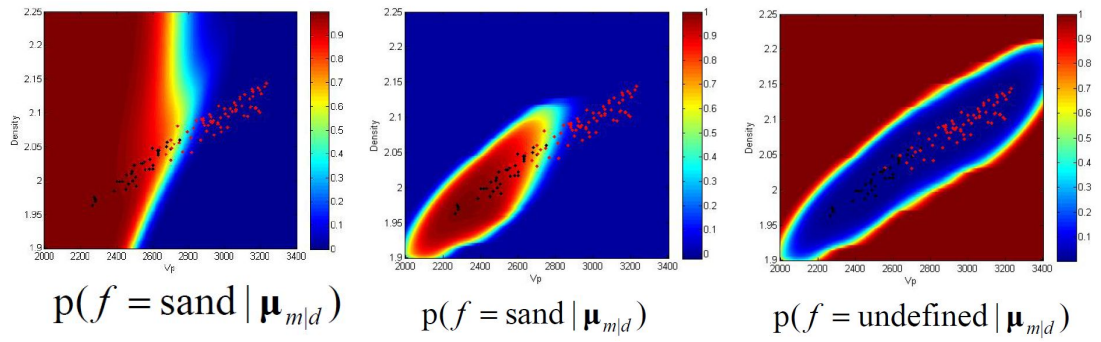

Figure 1.3. To the left, the posterior sand probability calculated without undefined facies. In the middle, the sand probability when undefined facies is introduced. To the right, the posterior probability for undefined facies.

where

$$\mathbf{F} = \boldsymbol{\Sigma}_m \mathbf{G}^T \boldsymbol{\Sigma}_d^{-1} \mathbf{G} \tag{1.23}$$

$$\mathbf{e}^* \sim \mathrm{N}(0, \boldsymbol{\Sigma}_{e^*}) \tag{1.24}$$

$$\boldsymbol{\Sigma}_{e^*} = \boldsymbol{\Sigma}_m \mathbf{G}^T \boldsymbol{\Sigma}_d^{-1} \boldsymbol{\Sigma}_e \boldsymbol{\Sigma}_d^{-1} \mathbf{G} \boldsymbol{\Sigma}_m. \tag{1.25}$$

The operator $\mathbf{F}$ is used to filter the well logs and obtain an estimate of the expected inversion values $\mathbf{m}^*$. For each facies, we then do a density estimation of $p(\boldsymbol{\mu}_{m|d_{obs}}|f)$ for each possible facies value f using $\mathbf{m}^*$ and facies logs. The density estimation is done using a kernel smoothing approach, and by using the distribution of $\mathbf{e}^*$ as our kernel, we get an unbiased estimate of this distribution.

Finally, we find the facies probability:

$$p(f = j|\boldsymbol{\mu}_{m|d_{obs}}) = \frac{p(\boldsymbol{\mu}_{m|d_{obs}}|f = j)p(f = j)}{\sum_i p(\boldsymbol{\mu}_{m|d_{obs}}|f = i)p(f = i)}, \tag{1.26}$$

where $p(f = i)$ is the prior probability of facies i. This probability is then computed for each facies and each cell in the grid, with $\boldsymbol{\mu}_{m|d_{obs}}$ given by the inversion results.

Far away from wells, the estimates will not be reliable, and we introduce an undefined facies to show such areas. Denoting the likelihood of this undefined facies $p(u)$, the facies probabilities are now calculated as

$$p(f = j|\boldsymbol{\mu}_{m|d_{obs}}) = \frac{p(\boldsymbol{\mu}_{m|d_{obs}}|f = j)p(f = j)}{\sum_i p(\boldsymbol{\mu}_{m|d_{obs}}|f = i)p(f = i) + p(u)}, \tag{1.27}$$

where $p(u)$ is uniform over the area, and low compared to the likelihood for facies when we are close to data. In Figure 1.3 the effect of the undefined facies in a reservoir consisting of sand and shale is illustrated. The three figures show cross plots of well observations of ρ against V_p combined with a probability map shown as a Colo coded map.

In the left figure, we show the probability of sand before the undefined facies has been introduced. Note how combinations of ρ and V_p which are far away from any well observations, as for instance (V_p, ρ) = (2000m/s, 2.25g/cm^3), may still lead to a facies prediction of sand equal to one. This is not realistic.

In the middle figure, the undefined facies has been introduced, and whenever we get far away from combinations of ρ and V_p for which we have no well observations, the probability for sand now decreases to zero. This does not mean that there is no chance of finding sand at the current spot, only that we have no data support to tell us what facies we might find. Similarly, the probability of finding shale will also be zero.

In the right figure, we show the probability of the undefined facies. This is zero around well observations, and gradually increases to one as the distance to observations increase. The probability of shale may be extracted from these figures since $p(\text{sand}) + p(\text{shale}) + p(\text{undefined}) = 1$.

2 Implementation

Whereas the general model was explained in Chapter 1 we explain a bit more of the actual implementation details here.

The estimation routines implemented in CRAVA are based on straightforward and commonly used techniques. This gives fast and robust estimation, although we may run into problems if the number of data points is too small, or the data quality is too low. The quality of an estimation result is never better than the quality of the data it is based on.

2.1 Estimating optimal well location

The positioning uncertainty between well data and seismic data is often significant. To overcome this, the well may be moved to the location with maximum correlation between the seismic data and the reflection coefficients calculated from the well data. The relation between the seismic data and reflection coefficients is linear; so linear covariance is a good measure. The optimal well location is found by searching for the location with highest covariance in a lateral neighbourhood around the original well location, where the well is allowed to be shifted vertically in each target position. The moving of wells is triggered by a command in the model file, and it is done prior to the estimation of wavelets, noise, correlations and background model.

2.2 Estimating the prior model

The prior model for the Bayesian inversion is defined in equation (1.10), and consists of the expectations of the elastic parameters V_p, V_s, and ρ collected in the vector $\boldsymbol{\mu}_m$, and their spatial correlation structure collected in the covariance matrix $\boldsymbol{\Sigma}_m$. These expectations and covariances must be given prior values before the inversion.

2.2.1 Background model

The expectation $\boldsymbol{\mu}_m$ is usually referred to as the background model. As the seismic data do not contain information about low frequencies, a background model is built to set the appropriate levels for the elastic parameters in the inversion volume. To identify this level, we can plot the frequency content of the seismic traces in the available wells, and identify lowest frequency for which seismic data contains enough energy to carry information.

In Figure 2.1, we have plotted the frequency content in the seismic data in two different wells. The green curve gives the frequency content in the near stack and the blue curve gives the frequency content in the far stack. These plots show that the seismic data contain little energy below 5–6Hz, and the purpose of the background model is to fill this void.

The estimation of the background model is made in two steps. First, we estimate a depth trend for the entire volume, and then we interpolate well logs into this volume using kriging. The estimation will by default contain information up to 6Hz, but this high-cut limit can be adjusted using the `<high-cut-background-modelling>` keyword.

When identifying the depth trend, it is important that the wells are appropriately aligned. The alignment is defined by the time interval surfaces specified as input, or alternatively, the correlation direction surface. It is important that the alignment reflects the correlation structure (deposi-

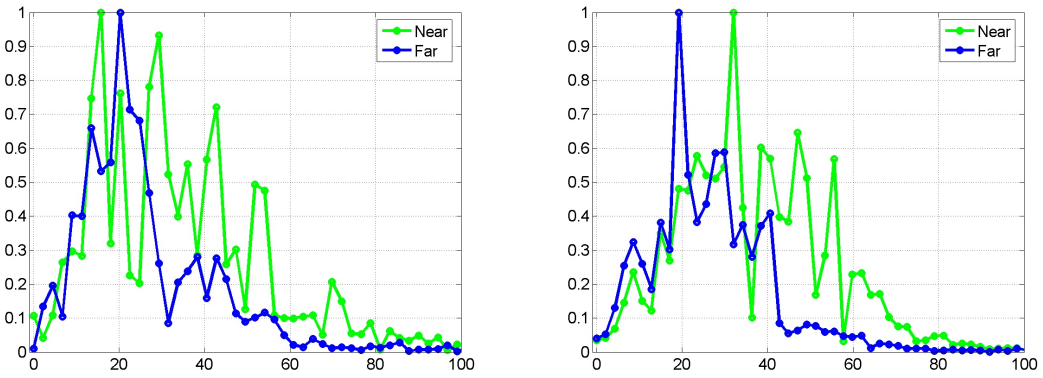

Figure 2.1. The frequency content of the seismic traces in two different wells. The frequency content of the near and far stacks are shown as green and blue curves respectively.

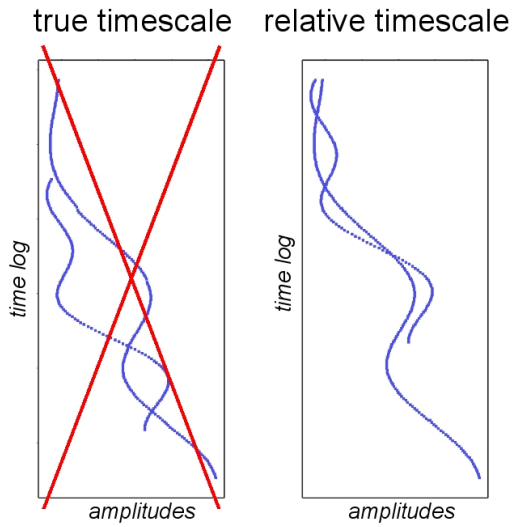

Figure 2.2. Well logs aligned according to true time scale (left) and according to stratigraphic depth (right).

tion/compaction), and if the time surfaces are either eroding or on-lapped, one should consider specifying the correlation direction separately using the `<correlation-direction>` keyword.

In Figure 2.2, we show two well logs aligned according to deposition and according to the true time scale. Evidently, an incorrect trend will be identified if the true vertical depth is used. The size of the error will depend on the stratigraphy.

Assuming properly aligned wells, the trend extraction starts by calculating an average log value for each layer. This average is calculated for the V_p, V_s, and ρ well logs and is based on all available wells. The estimation uses a piecewise linear regression, rather than the more straightforward arithmetic mean or moving average, as these measures are sensitive to the amount of data available. The piecewise regression has the additional advantage that it can give trend estimates also outside the interval for which we have data available.

For the linear regression we require a minimum of 10 data points behind each estimate. In addition, we require that the minimum number of data points must also be at least $5*N_{wells}$. This way we ensure that data points from different time samples are always included. Alternatively, the regression would reduce to an arithmetic mean whenever there are 10 or more wells available. If we enter a region with no data points available at all, the minimum requirements are doubled.

To get the right frequency content in the depth trends, the regression values are eventually fre-

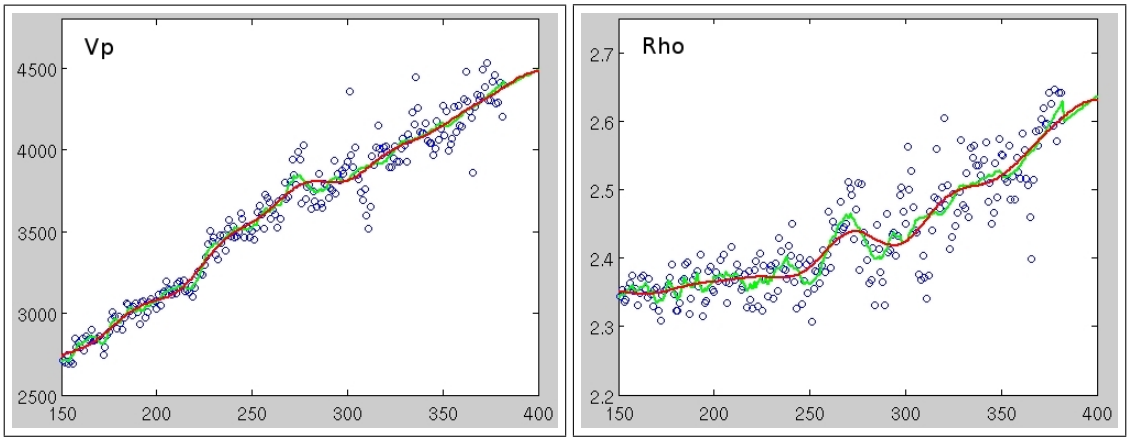

Figure 2.3. Well log values plotted against grid layer number for V_p (left) and ρ (right). The blue circles show log values, the green curve is a piecewise linear regression of the these values, and the red curve is the regression values filtered to 6Hz.

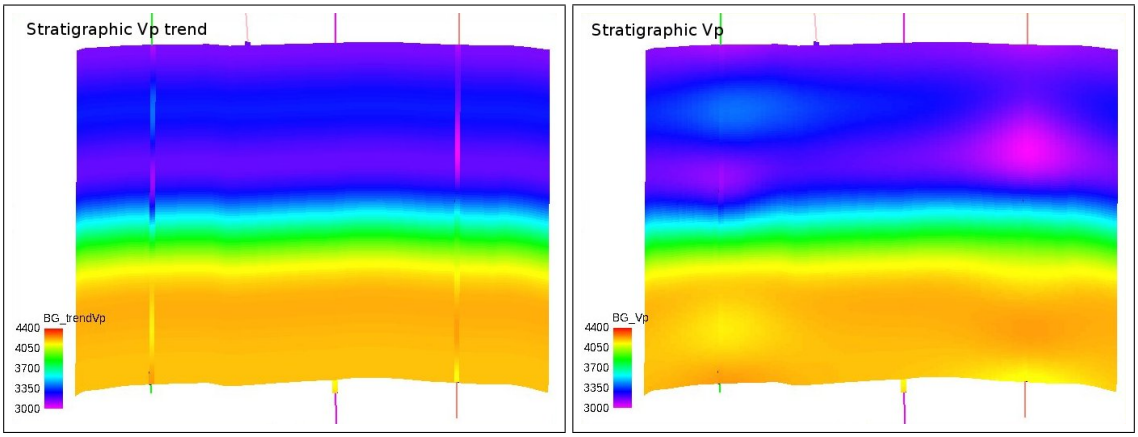

Figure 2.4. V_p depth trend (left) and final background model (right). Well logs of V_p, high-cut filtered to 6Hz, are shown for comparison.

quency filtered to 6Hz.

The trend extraction process is illustrated in Figure 2.3 for the V_p and ρ logs of a field with six wells. Note that the plots are oriented with layers as abscissa and log values as ordinate. The blue circles represent log values from any wells, the green curve is the piecewise linear regression of these values, and the red curve is the frequency filtered log that will be used as a depth trend. Note that the green curve is slightly erratic, especially, as we enter the region (below reservoir) where there are no data points available. This shift, which is clearly observed for the density, arises as we stabilise the estimate by requiring twice as many data points behind each estimate.

When the inversion volume has been filled with the depth trend, we interpolate it with 6Hz filtered well logs, to ensure that the background model will match in wells. A cross section of the resulting background model for V_p is illustrated in the right part of Figure 2.4. To the left is the corresponding depth trend. For comparison the well logs of V_p has plotted in both illustrations. Note how the wells influence the volume in a region around the well.

Ideally, the background model should be as smooth as possible, and a Gaussian variogram model with relatively long ranges may seem an obvious choice. This model is too smooth, however, and should be omitted as it often give parameter over- and undershooting away from wells.

2.2.1.1 Multizone background model

Multizone background model is achieved by doing a `<multiple-intervals>` inversion and with estimating background models activated. The surfaces are set under `<output-volume>`. When estimating the multizone background model the reservoir is divided into several horizontal zones defined by surfaces in the inversion volume. In each zone, a local backround model is made by estimating a depth trend for the zone volume, then kriging well logs to the depth trend. The settings for interval uncertainty and erosion priority are set under `<multiple-intervals>`. The background model in each zone contains frequencies up to 6Hz, but the frequency content is higher in the transitions between the zones. These higher frequencies will, however, contain information about the locations of the zones; hence they contain important prior information. Higher uncertainty gives smoother background models with lower frequency.

2.2.1.2 Background model from rock physics

When rock physics models are used, the background model is generated using these. Each facies is defined as a `<rock>` possibly containing trends using the rock physics template model described in Section 3.5. The resulting background model is generated as a weighted average of the rock models, where the weights are the corresponding facies `<prior-probabilities>`.

If well logs are available, the elastic parameters in the background model, i.e. the expectations, and the corresponding precision/variance, can be modelled from data, respectively. Moreover, if there exist appropriate reference parameters, like two-way-time and/or stratigraphic depth, it is also possible to model the elastic parameters as 1- or 2-dimensional functions of the provided reference parameters. In principle, these reference parameters can be almost anything, as long as they provide some underlying structure to the problem at hand. Also, note that it is possible to combine different models, in the sense that we might model the trend as constant while the variance is a two dimensional surface that depends on a 2-dimensional reference parameter, see subsection 3.5.2.3 for more details.

The expectation is fitted using a modified version of a standard local linear regression implementation with a Gaussian kernel. In short, what distinguishes this implementation from those more commonly used, is that it will provide more stable estimates outside the main support of data. This is achieved by gradually increase the bandwidth in the kernel as the method extrapolate away from the main support of the observations. This happens, however, at just the right rate to make a smooth transition to a standard linear model in regions far away from the centre of the observations. The bandwidth aims at, in all locations, to give a 'effective sample sizes', i.e. the total weight of the kernel at a given point, that matches that in the main support of the data, with a bandwidth set to optimize the asymptotic properties (limiting minimize mean square error), under the assumption that the observations are uniformly distributed over the domain.

The estimated variances are a weighted averages between the estimated global variance and estimates from a standard implementation of a kernel smoother with a Gaussian kernel. The weights, used in the mixture, are the effective sample sizes. The selected bandwidth is kept fixed and is the same as used to estimate the expectation inside the main support of the data. This construction removes a rather undesirable feature of the standard kernel smoother, which estimates a variance that is too low, or zero, in regions with few observations.

2.2.2 Covariance

Since we model the covariance structure as separable, we have collapsed the full time dependent covariances between parameters into one parameter covariance matrix $\Sigma_{0,m}$, a lateral correlation vector $\nu_m(\xi)$, and a temporal correlation vector $\nu_m(\tau)$.

We estimate the correlations by first blocking the wells into the grid, and then do standard corre-

lation estimation using

$$\mathrm{Cov}(X,Y) = \frac{\sum(x_i - \bar{x})(y_j - \bar{y})}{\sqrt{n-1}}, \text{ with } X, Y \in \{\ln V_p, \ln V_s, \ln \rho\} \tag{2.1}$$

The parameter covariance matrix is simply estimated by using the covariances at time lag 0. When rock physics models are used, the parameter covariance matrix is calculated from the expectation vector and parameter covariance matrix for each rock model weighted with the corresponding prior facies probability using standard statistical models. If trends are included in the rock physics models, the parameter covariance matrix is calculated in each reservoir position. The resulting parameter covariance matrix is then calculated as the average over these coveraince matrices.

In Figure 2.5, we show cross plots of the parameter residuals ($x_i - \bar{x}$) for a sample field. The depicted distributions look similar to bivariate normal distributions, which supports the normal distribution assumptions made in Equation 1.10. If there are no V_s logs available, the prior V_s variance will be set equal to twice the V_p variance, and their covariance will be set equal to zero.

The temporal correlation is estimated from the remaining lags in the well logs as depicted in Figure 2.6. The temporal correlation will be a weighted average of the estimates made for all three elastic parameters.

While the covariance matrix and the temporal correlation can be readily estimated from well data, this is not the case for the lateral correlation, unless there are a large number of wells available. The lateral correlation is therefore normally chosen parametric. There is an option in CRAVA to estimate the lateral correlation from seismic data, but these estimates are not made relative to stratigraphy and tend to grossly underestimate the correlation. Using a parametric correlation function is therefore encouraged. In Figure 2.7, we have depicted an exponential correlation function and the lateral correlation structure this kind of function gives rise to.

2.2.3 Likelihood model

As with the prior model for the elastic parameters, we have also collapsed the full time dependent error covariance matrix into a noise covariance matrix $\Sigma_{0,e}$, a lateral correlation vector $\nu_e(\xi)$, and a temporal correlation vector $\nu_e(\tau)$.

The lateral correlation is difficult to estimate and is chosen equal to that for the elastic parameters, that is, we use $\nu_e(\xi) = \nu_m(\xi)$. The temporal correlation is partly estimated from wavelet derivatives and partly white noise. By default, a 10% white noise fraction is assumed.

For the noise covariance matrix, the noise for a single angle gather can be either specified in the model file using the `<signal-to-noise>` keyword or it can be estimated. A noise estimate is found by generating synthetic seismic data (see next section) using the wavelet optimally shifted in each well, and subtracting this from the seismic data. The remaining part is assumed to be noise, and we measure the noise energy from this.

The correlation between the noise in different angle stacks is hard to estimate and is therefore chosen parametric. Typically, an exponential correlation functions with a range of 10° is used. In most cases this implies that the noise in the angle stacks are treated as independent of each other.

2.3 Estimating wavelets

The implemented wavelet estimation uses the approach of spectral division, see White (1984). In this approach an estimate of the cross-correlation between data and reflection coefficients, and an estimate of the auto-correlation of reflection coefficients are used to estimate the wavelet. The methodology requires that the reflection coefficients are known, thus wavelets are estimated at well locations. The cross-correlation between data and reflection coefficients is found by convolv-

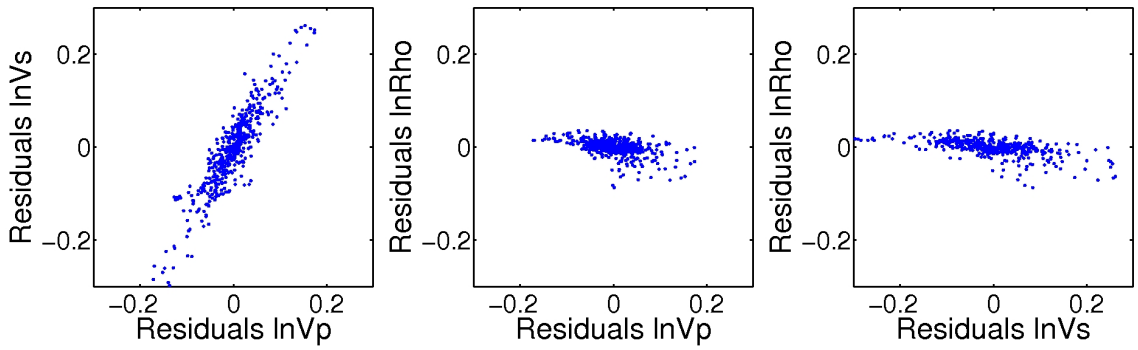

Figure 2.5. Cross plots of logarithmic parameter residuals. From such plots the parameter correlations may be estimated.

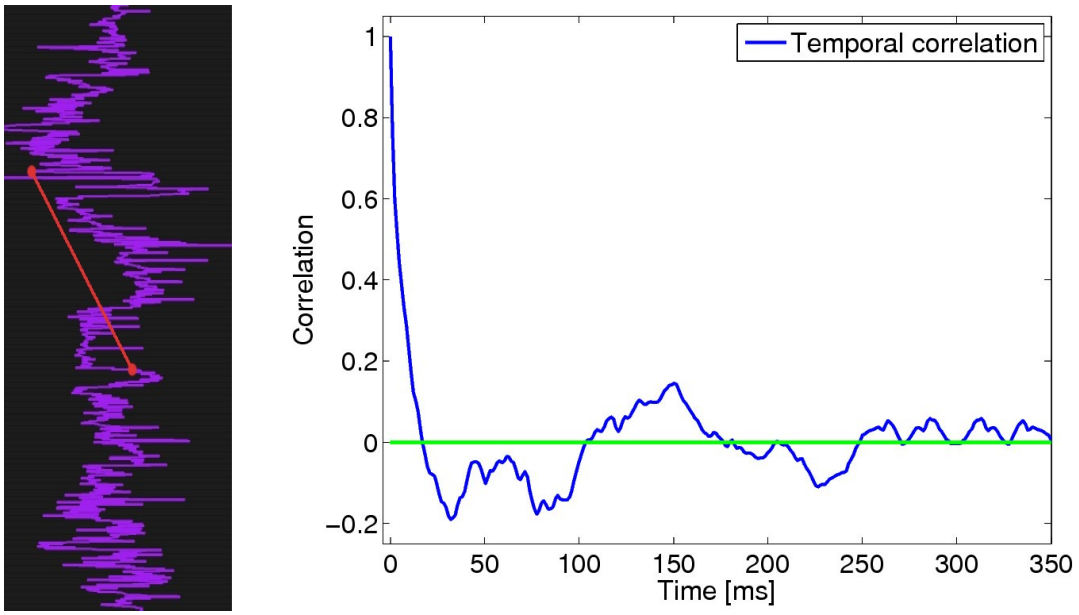

Figure 2.6. We obtain the temporal covariance by measuring the covariance between all pairs of points in the well log (left). The resulting temporal correlation function (right).

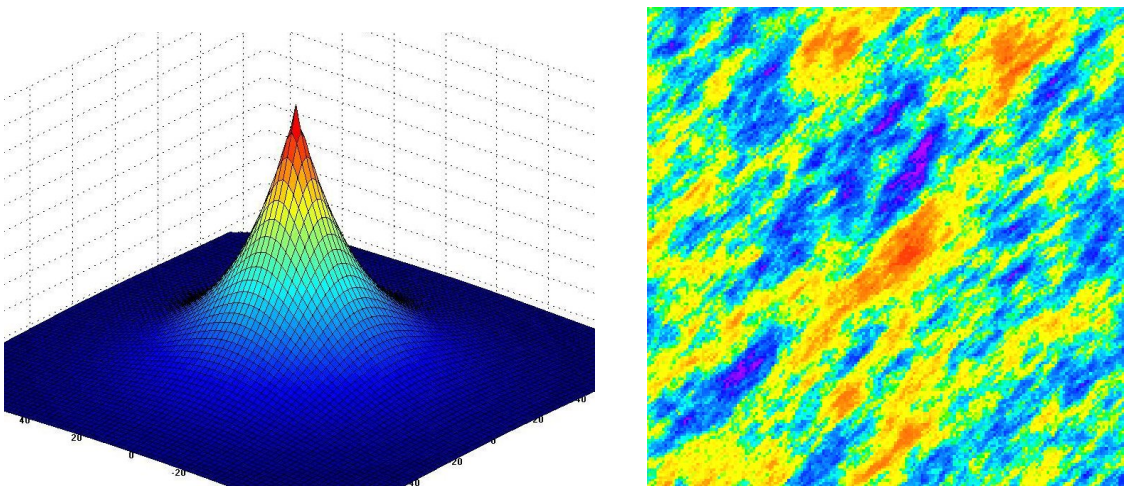

Figure 2.7. Parametric lateral correlations. A two-dimensional exponential correlation function (left). The lateral correlation structure resulting from an anisotropic exponential correlation function having an azimuth of 45° degrees (right).

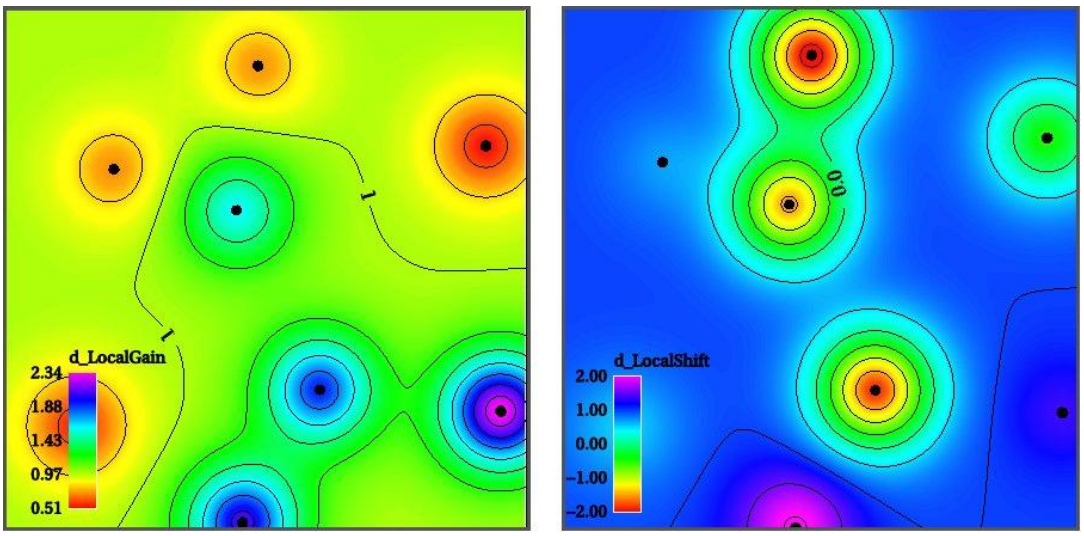

Figure 2.8. The local scale and shift maps involved when using local wavelets

ing the data with the reflection coefficients, and tapering the result. The auto-correlation of the reflection coefficients are found similarly by convolving the reflection coefficients with themselves and then applying a taper to the result. The tapering is performed in order to avoid spurious correlations at large lags.

Using the standard convolutional relation for seismic data,

$$\mathbf{d} = \mathbf{w} * \mathbf{c} + \mathbf{e}, \tag{2.2}$$

where $\mathbf{d}$ is the seismic amplitude data, $\mathbf{w}$ is the wavelet, $\mathbf{c}$ the reflection coefficients, and $\mathbf{e}$ is the noise. We see that convolving the data with reflection-coefficients, transforming to the Fourier domain, and take the expectation we get

$$d(\omega)\bar{c}(\omega) = w(\omega)|c(\omega)|^2 \tag{2.3}$$

Note that the convolution has disappeared, and the equation can be solved for each frequency ω. We recognise the left hand side as the spectre of the cross-correlation between data and reflection coefficients. And the left hand side as the wavelet multiplied with spectre of the auto-correlation of the reflection coefficients. This can be obtained by dividing the spectre of the cross-correlation with the spectre of the auto-correlation.

Tapering of the estimated cross-correlation and auto-correlation is required in order to stabilise the estimate. In Crava a Papoulis taper is used. Tapering is equivalent to a local smoothing in the frequency domain, thus the resulting wavelet estimate will behave smoothly in Fourier domain.

We find the optimal vertical shift for each well. The global wavelet is then found by taking the arithmetic average of the zero-phase wavelets, weighted by the number of samples used from each well.

When using local wavelets, we find the optimal shift and/or scale of the global wavelet at each well location. Optimal here means minimising the noise energy. We then use kriging to interpolate this between wells, with a shift of 0 and a scale of 1 as the mean level outside the well control area. This is illustrated in Figure 2.8.

Local noise is estimated using the local noise energies from above. We always use local shift when estimating the noise, but only use local scale if it is used in the inversion. If local scale is used, the noise is divided by this. A noise scaling factor is then computed in each well, and kriged as above.

2.4 Estimating 3D wavelet

The expression for the wavenumber representation of the point-spread function given in Equation 1.8 has only one unknown element, namely the 1D pulse $w_0(\omega)$. The functions $\tilde{\alpha}_1$ and $\tilde{H}$ are given as input, together with the average velocity V_0. The elements needed for the conversion from depth to time are also input to CRAVA. That is the reference depth Z_0, and reference time surface T_0. The theory for the estimation of the 1D pulse is given in Georgsen et al. (2010a), and with more details in Georgsen et al. (2010b).

As for the 1D wavelet, the pulse is estimated from wells. Using reflection coefficients from well logs, time gradients estimated from seismic data around wells and depth gradients computed from time gradients by using the reference time surface and average velocity given, a matrix K can be constructed forming a linear regression model for the seismic data as

$$\mathbf{d} = \mathbf{K}\mathbf{w}_0 + \mathbf{e}. \tag{2.4}$$

The least squares estimate for $\mathbf{w}_0$ is

$$\widehat{w}_0 = (\mathbf{K}'\mathbf{K})^{-1}\mathbf{G}'\mathbf{d}. \tag{2.5}$$

2.5 Using FFT for inversion

As previously stated, Equation 1.12 separates when transformed into the Fourier domain. After this transformation, the equation becomes

$$\tilde{\mathbf{d}}(\omega, \mathbf{k}) = \mathbf{G}(\omega)\tilde{\mathbf{m}}(\omega, \mathbf{k}) + \tilde{\mathbf{e}}(\omega, \mathbf{k})) \tag{2.6}$$

The tilde denotes the 3D Fourier transform, with temporal frequency ω, and lateral frequency vector $\mathbf{k} = (k_x, k_y)$. Due to the separation, we now have a set of n small equations, where n is the number of grid cells in the inversion volume. Everything is still normally distributed, so the solution to this equation follows the pattern from Equation 1.19 and Equation 1.20. We still must invert a data covariance matrix, but whereas this matrix had dimension $(n \cdot n_\theta)^2$ before the Fourier-transform, the matrix we must invert here is reduced to dimension n_θ^2, where n_θ is the number of angle stacks. Since the time for a matrix inversion is almost cubic in size, it is much faster to invert n of these small matrixes than the one large. After solving for $\tilde{\mathbf{m}}(\omega, \mathbf{k})$, we do the inverse transform of this to obtain the distribution for $\mathbf{m}$. The same does of course hold when we are using local wavelets that are divided out in advance, Equation 1.21. For full details, see Buland et al. (2003).

2.6 A note one local wavelet and noise

As shown, even though the use of FFT-transform requires stationarity, we are able to work around this. Wavelets can be made local since these can be divided out before solving the equations, and locally higher noise levels can be approximated by interpolating the low-noise solution and the prior distribution.

2.6.1 Local wavelet - dividing out the wavelet

A simple division of data by wavelet can easily be done in the Fourier domain, where the convolution reduces to a multiplication, and the division can be done one frequency at a time. However, this is very unstable for frequencies where the wavelet is very weak or not present, and some sort of stabilisation is needed.

In CRAVA this is done in two ways. First, we set an upper and lower cutoff frequency for the wavelet, default set to 5 and 55 Hz. Furthermore, for frequencies that fall below 10% of the average amplitude, we set the amplitude to 10% of average before doing the division.

2.6.2 Local noise

Local noise is implemented by first finding the solution using the minimum noise level, to fulfil the stationarity requirements of the FFT algorithm. We then interpolate the values for each locations between the prior and this minimum noise posterior. When doing this interpolation, we ignore correlation between locations. This is not a problem as long as the noise varies slowly and smoothly.

For each location $\mathbf{x}$ the adjusted estimate $\tilde{\boldsymbol{\mu}}_{m|d_{obs}}(\mathbf{x})$, is found from the inversion result $\boldsymbol{\mu}_{m|d_{obs}}(\mathbf{x})$ by a linear relation,

$$\tilde{\boldsymbol{\mu}}_{m|d_{obs}}(\mathbf{x}) = \boldsymbol{\mu}_m(\mathbf{x}) + \mathbf{H}_{\mathbf{x}} \left(\boldsymbol{\mu}_{m|d_{obs}}(\mathbf{x}) - \boldsymbol{\mu}_m(\mathbf{x}) \right), \tag{2.7}$$

The matrix $\mathbf{H}_{\mathbf{x}}$ is a shrinkage matrix, i.e. the adjusted estimate is always closer to the prior mean than the inversion result. The matrix $\mathbf{H}_{\mathbf{x}}$ depends on the local error variance $\boldsymbol{\Sigma}_e^x$ and error variance used in the inversion $\boldsymbol{\Sigma}_e^0$.

To find the shrinkage matrix we first identify a matrix $\mathbf{G}_0$ which maps the local prior distribution to the local posterior distribution when it is observed with the noise Σ_e^0, that is,

$$\mathbf{d}(\mathbf{x}) = \mathbf{G}_0 \mathbf{m}(\mathbf{x}) + \mathbf{e}_0,$$

where $\mathbf{e}_0 \sim N\left(\mathbf{0}, \Sigma_e^0\right)$. The inversion of this expression is a linear relation

$$\boldsymbol{\mu}_{m|d_{obs}} = \boldsymbol{\mu}_m + \mathbf{P}(\Sigma_e^0)\left(\mathbf{d}_{obs} - \boldsymbol{\mu}_d\right) \tag{2.8}$$

where $\mathbf{P}(\Sigma_e^0) = \boldsymbol{\Sigma}_m \mathbf{G}_0^T \left(\mathbf{G}_0 \boldsymbol{\Sigma}_m {\mathbf{G}_0}^T + \boldsymbol{\Sigma}_e^0 \right)^{-1}$.

We then define the shrinkage matrix to be:

$$\mathbf{H}_{\mathbf{x}}(\Sigma_e^{\mathbf{x}}, \Sigma_e^0) = \mathbf{P}(\Sigma_e^{\mathbf{x}}) \mathbf{P}(\Sigma_e^0)^{-1}. \tag{2.9}$$

This removes the effect of the standard inversion and add the effect of the locally adapted inversion. The matrix $\mathbf{P}(\Sigma_e^0)$ is not invertible, but since the local noise always is larger than the noise in the inversion the product in expression 2.9 is always well defined.

2.7 Memory handling

Since the grids needed by CRAVA can become very large, we try to keep the number of grids kept simultaneously in memory as small as possible. This implies that some allocated grids will be used for more than one purpose. Both padded and unpadded grids are used in CRAVA, The amount of memory needed by padded and unpadded grids are denoted s_p and s_u respectively.

CRAVA also has an option to use disk space for intermediate storage of grids. This will reduce the memory consumption with a factor of at least 2 in realistic cases, but will also increase the computation time by a factor of almost 3.

2.7.1 Grid allocation with all grids in memory

If intermediate disk storage is not used, the grid memory allocation will go as follows:

1. Background grids for Vp, Vs and density, 3 grids.
2. If the background model is to be estimated, another 3 grids are allocated for estimation, but destroyed before any other allocations.
3. Seismic grids, n_θ. If well optimisation is used, this will come before background grids.
4. Possibly prior facies probability grids, indicated by I_p, n_f unpadded grids.

5. Prior covariance, 6 grids.

6. If relative facies probabilities or local noise, a copy of background indicated by I_b, 3 grids.

7. **Peak:** At this stage, CRAVA reaches its first memory peak. Minimum memory in use is 10 grids, typical situation with three seismic grids and facies modelling requires 15 grids.
   Memory usage: $P_1 = (9 + n_\theta + I_b * 3) * s_p + I_p * n_f * s_u$.

8. The posterior distribution is computed into the background and prior covariance grids, and seismic residuals are computed into the seismic grids. Thus, the inversion requires no extra grids. (But we needed a copy of the background for local noise or facies.)

9. After the inversion, the seismic grids are released, taking us off peak down to a base level:
   Memory usage: $P_{\text{base}} = (9 + I_b * 3) * s_p + I_p * n_f * s_u$.

10. If simulation is used:

    a. Simulated grids are allocated, 3 grids.

    b. If secondary elastic parameters are requested as output (AI, $\mu\rho$, etc.), indicated by I_s, a computation grid is allocated, 1 grid.

    c. If kriging is used, indicated by I_k, 1 unpadded grid, not concurrent with computation grid.

11. **Peak:** New possible peak, since the number of grids now allocated may be larger than the released seismic grids.
    Memory usage: $P_2 = (12 + I_b * 3 + I_s) * s_p + (I_p * n_f + \max(0, I_k - I_s)) * s_u$.

12. New release of grids, back to P_{base}.

13. If facies probabilities:

    a. 3D histograms of elastic parameters per facies are created, each of size 2MB, n_f special grids.

    b. Facies probability grids are created, including for undefined, $n_f + 1$ unpadded grids.

14. **Peak:** New possible peak, since the new memory allocated may be larger than the released seismic grids and/or the simulation+computation/kriging grids.
    Memory usage: $P_3 = (9 + I_b * 3) * s_p + (I_p * n_f + n_f + 1) * s_u + 2 * n_f$.

15. Can now release all grids related to facies probability, memory down to $9 * s_p$.

16. Eventual kriging of prediction allocates 1 unpadded grid.

17. Everything released.

The maximum memory usage is thus the largest of the actual peaks. The maximum number of allocated padded grids will occur at either P_1 or P_2, whereas the largest number of other grids are allocated at P_3.

2.8 Implementation of the rock physics template model

The rock physics template model is very flexible, and requires an equally flexible implementation. There are four main elements:

1. Fluids.

2. Solids.

3. Rocks.

4. Dry-rocks.

We handle these by a dual set of corresponding classes, the distribution classes and the sample classes. We have the set of DistributionFluid, DistributionSolid etc. base classes. These describe the prior distribution for different elements. From these, we can generate samples of the element. These samples are of base classes Fluid, Solid etc., and correspond directly to the Distribution-classes.

Under the base classes, we have a set of derived classes, based on different rock physics models for mixing. These aoos exist on both distribution and sample version. Thus, the tree-like structure of a rock physics template model is mirrored here, with each prior distribution being built as a tree of Distribution... objects, and capable of generating a sample that is a similar tree of sample objects. The sample tree computes it properties as it is built, so the top level knows the resulting elastic parameters.

A feature of the rock physics implementation is that we can update a sample to generate a new sample. This new sample will be highly correlated with the initial sample. This is utilised to generate synthetic well data (for filtering), and when doing 4D modelling. In order to do this updating, each sample stores all the quantiles for the randomly drawn parameters in the sample. When updating a sample, each quantile u is perturbated to a quantile u_p as follows:

$$x = \Phi^{-1}(u) \tag{2.10}$$

$$x_p = x + \epsilon \tag{2.11}$$

$$u_p = \Phi(x_p). \tag{2.12}$$

Here, ϵ is normally distributed with expectation 0, and a variance based on the desired correlation. This sampling models the realtion between the existing and new value as a Gaussian pair copula, with a given correlation parameter.

The correlation parameter is controlled in different ways, depending on whether we are generating synthetic wells or setting up a 4D model. In the former case, we use a constant correlation for all random parameters in the sample-tree. This correlation is tuned to obtain the desired correlation between neighbouring samples. In the 4D setting, each random parameter is assigned a yearly correlation (on the distribution level). From this, the correlation for the relevant time step is computed and used for updating. By setting most parameters perfectly correlated, this allows us to update only parameters that are changing in a 4D setting, such as saturation.

2.9 Facies probabilities

How facies probabilities are calculated depends on the input to CRAVA. If facies probabilities from rock physics is requested, CRAVA will make synthetic wells from the rock physics models. If rock physics is not used and there are real wells supplied in the input, CRAVA will make use of these. In both cases, the wells are filtered and used to make a smooth probability distribution from the histogram of observed values.

2.9.1 Trends

With rock physics, it is also possible to have zero, one or two trends. Trend minimum and maximum values are specified by the user. If the maximum trend value is equal to the minimum value, this is interpreted as having no trend. Each trend axis is divided in 20 bins. Since the grids

in general are very large, it is advantageous to keep the number of dimensions low. When there are either one or two trend dimensions, CRAVA will automatically reduce the three elastic dimensions to the two components that are best resolved by seismic. By minimizing the expression

$$\min_{\mathbf{v}} = \frac{\mathbf{v}^T \mathbf{\Sigma}_{m|d} \mathbf{v}}{\mathbf{v}^T \mathbf{\Sigma}_m \mathbf{v}} \tag{2.13}$$

once, the best resolved feature is found. The second best feature is found by minimizing the same expression but with the additional constraint of being uncorrelated to the first component. This amounts to choosing the eigenvectors of $\mathbf{\Sigma}_m^{-1}\mathbf{\Sigma}_{m|d}$ sorted in increasing order of the corresponding eigenvalues. However, the use of trends will increase the number of numerical grids in use in CRAVA:

1. With real wells and no rock physics: the wells are filtered and a 3D grid (where the three dimensions represent the three elastic parameters) is filled with the observed values.

2. If facies probabilites from rock physics is requested:

   a. With no trend, a 3D grid is filled with values from the synthetic wells.

   b. With one trend, the three elastic dimensions are reduced to two dimensions and 20 (the number of bins in the trend dimension) 2D grids (actually 3D grids where only two dimensions are in use) are filled.

   c. With two trends, the three elastic dimensions are reduced to two dimensions and $20^2 = 4000$ (the number of bins in the trend dimension) 2D grids (actually 3D grids where only two dimensions are in use) are filled.

2.9.2 Synthetic wells

When rock physics is used, 10 synthetic wells, each of minimum length 100 bins, is simulated per combination of trend parameters. If no trends are used, 10 such wells are simulated. The synthetic wells are made as follows:

1. If the length of the well is less than 100 bins, draw one of the relevant facies from a uniform distribution (no correlation with the facies above).

2. Draw a facies length from a geometric distribution with expectation 10 ms.

3. Generate a well sample of this length by calling the functionality described in section 2.8 and add this piece to the well.

2.9.3 Well filtering and smoothing

The final probability distribution is smoothed with the seismic uncertainty. This uncertainty is calculated using the prior and posterior spatial covariance for the elastic parameters in the well. For both real and synthetic wells, the distribution of the error in the inversion is calculated as

$$\mathbf{\Sigma}_{e^*,w} = \mathbf{\Sigma}_{m,w|d} - \mathbf{\Sigma}_{m,w|d}\mathbf{\Sigma}_{m,w}^{-1}\mathbf{\Sigma}_{m,w|d} \tag{2.14}$$

Each well is filtered independently. The bins in the probability grids (one per facies) are then filled with the values from the wells and a Gaussian distribution with covariance in the elastic dimensions from the well filter is created. The facies probability grids are then convoluted with the Gaussian distribution by FFT. This gives $\hat{p}(\hat{\mathbf{m}}_i|f_i,\mathbf{z})$.

2.9.4 Calculating facies probabilities

The final lithology prediction is computed as

$$\hat{p}(f_i|\hat{m}_i, z) = \frac{\hat{p}(\hat{\mathbf{m}}_i|f_i, \mathbf{z})p(f_i|\mathbf{z})}{\Sigma_{f_i}\hat{p}(\hat{\mathbf{m}}_i|f_i, \mathbf{z})p(f_i|\mathbf{z})} \tag{2.15}$$

The `<uncertainty-level>` is part of the input to CRAVA and specifies the likelihood for undefined lithologies. This value is scaled according to the size of the grid, but will result in a high probability for undefined facies if the relevant point is not close to one of the modes in the distribution.

3 User guide

In this chapter, we describe how to build a CRAVA model file. The model file mainly follows the XML format, but we also use the character '#' for commenting, meaning that the rest of the line after such a character is read as comment. XML files are built with start and end tags, encapsulating either tags or values. All model files start with `<crava>`, and end with `</crava>`. An example of a model file is given in Appendix A.

3.1 Basic inversion

A primary ability for CRAVA is to run simple first-pass inversions. In this section, we describe how to build a model file for a simple inversion. We focus on how to get the key information into the program, whereas more detailed controls are discussed later, in Section 3.2. The key information elements for a CRAVA inversion run is:

- Seismic data.
- Wavelet.
- Signal/noise ratio.
- Inversion volume.
- Background model.
- Correlation structures.

Since CRAVA is designed to estimate any information that is not given, well data must also commonly be included.

3.1.1 Survey information

All information regarding the seismic data is gathered under the `<survey>` tag. This includes the file names for seismic data files, wavelet information and signal-to-noise ratio for each angle gather. As an example, it may look like this:

```
<crava>
<survey>
  <segy-start-time>             2500.0 </segy-start-time>
  <angle-gather>
    <offset-angle>                16.0 </offset-angle>
    <seismic-data>
      <file-name>  seismic/Cube16.segy </file-name>
    </seismic-data>
  </angle-gather>
  <angle-gather>
    <offset-angle>                28.0 </offset-angle>
    <seismic-data>
      <file-name>  seismic/Cube28.segy </file-name>
```

```
    </seismic-data>
  </angle-gather>
</survey>
</crava>
```

The seismic data can be given on SegY-format, with a common offset time specified by the keyword <segy-start-time> if the offset is different from 0. The first value is used to represent the interval from start-time to start-time + time-step, so with a start-time of 100ms, and 4ms sampling, the first value is used in the grid cell covering the interval 100-104ms. If we use seismic data of another format than SegY, the <segy-start-time> command is not used. The file format is detected automatically by CRAVA.

For each available angle, the rest of the information is gathered under an <angle-gather> tag, one for each offset. The actual angle is given by <offset-angle>.

3.1.1.1 Seismic data

The name of the seismic data file is given with <file-name>, as seen in Section 3.1.1. Naturally, seismic data is always required when running an inversion. By default, CRAVA recognises four SegY formats; Seisworks, Charisma, SIP and IESX, see Table 3.1.

Table 3.1. SegY formats recognised by Crava

Name	X	Y	IL	XL	CoordScal	CoordSys
SeisWorks	73	77	9	21	71	UTM
Charisma	73	77	5	21	71	UTM
IESX	73	77	221	21	71	UTM
SIP	181	185	189	193	71	UTM

You are also allowed to define your own format using the <segy-format> command. A standard format is given by <standard-format>. Possible arguments are 'seisworks', 'iesx', 'charisma' or 'SIP'. Modifications to the chosen standard format can be given by the following commands: <location-x>, <location-y>, <location-il>, <location-xl> and <bypass-coordinate-scaling>. For more information on how to use this, see <segy-format> in the reference manual chapter.

Other file formats recognised by CRAVA are storm, Sgri and crava.

3.1.1.2 Wavelet

To invert the seismic data, we need a wavelet for each angle. This wavelet can be read from file, using the <wavelet> and <file-name> commands like this:

```
<angle-gather>
  <offset-angle>     16.0 </offset-angle>
  <seismic-data>
    <file-name>  seismic/Cube16.segy </file-name>
  </seismic-data>
  <wavelet>
    <file-name>  wavelets/wavelet16.txt </file-name>
  </wavelet>
</angle-gather>
```

We can read wavelets on JASON and NORSAR format.

The Ricker wavelet is implemented in CRAVA, and can be used by the command <ricker>. The peak frequency is given as argument.

If the <wavelet> command is not given, or given without <file-name>, the wavelet is estimated. See Section 2.3 for how this is done. If the wavelet is given on file, but not scaled, the command <scale> should be used if the scale is known, otherwise, the scale can be estimated by using the <estimate-scale> command. If none of these are specified, the wavelet will be used as it is on file.

3.1.1.3 Signal/noise ratio

This ratio is given with <signal-to-noise-ratio>. If this command is not given, the ratio is estimated. Note that we define the signal to noise ratio as the data variance divided by the error variance, where the data variance is model variance plus error variance.

3.1.2 Inversion volume

The volume used for inversion is given horizontally by a rectangle, and vertically bounded by a top and base surface. It is defined by the command <output-volume> under <project-settings>. It is possible to perform either single or multiple interval inversion.

3.1.2.1 Single interval inversion

The output volume for single interval inversion is set by one top and one base surface by the keyword <interval-two-surfaces> or <interval-one-surface> where a top surface and thickness are given. Typically, it may look something like this:

```
<crava>
<project-settings>
  <output-volume>
    <utm-coordinates>
      <reference-point-x>  403050.0   </reference-point-x>
      <reference-point-y> 7211900.0   </reference-point-y>
      <length-x>              500.0   </length-x>
      <length-y>              500.0   </length-y>
      <angle>                  23.627 </angle>
      <sample-density-x>       50.0   </sample-density-x>
      <sample-density-y>       50.0   </sample-density-y>
    </utm-coordinates>

    <interval-two-surfaces>
      <top-surface>
        <time-file>   horizons/FlatTop_3100ms.storm </time-file>
      </top-surface>
      <base-surface>
        <time-file>   horizons/FlatBase_3600ms.storm </time-file>
      </base-surface>
      <number-of-layers> 125 </number-of-layers>
    </interval-two-surfaces>
  </output-volume>
</project-settings>
</crava>
```

3.1.2.2 Multiple interval inversion

To perform multiple interval inversion one must define several surfaces in the <multiple-intervals>. Here one defines one top surface and several base surfaces (one for each interval). In addition one must set the <erosion-priority> which defines which surface to be used when two surfaces intersect. All the base surfaces need to be given a unique priority. The surface with highest priority is given erosion priority two (top surface has priority one), while the surface with lowest priority is given priority n, where n is equal to the number of surfaces.

The inversion is done separately for each interval and finally combined to a final grid, which consist of the first top surface and the last base surface. The resolution used in the output grid is taken from the smallest resolution from all intervals. One can also set the <uncertainty> for all base surfaces, this is used to smooth results across border when they are merged to a final grid. To represent uncertainties between intervals a beta distribution with parameters $\alpha = \beta = 2$ is used. The distribution is symmetric around its center, being the surface between the intervals. The limits in the Beta distribution, given by the keyword <uncertainty>, is the distance of the uncertainty in ms in each direction from the surface.

Each interval given in <multiple-intervals> are defined by a name. This name is used as a reference when other interval based settings are set. These are <vp-vs-ratio>, <correlation-direction>, <parameter-autocovariance>, <prior-probabilities> and <volume-fractions>.

It may look something like this:

```
<crava>
<project-settings>
  <output-volume>
    <utm-coordinates>
      <reference-point-x>  403050.0   </reference-point-x>
      <reference-point-y> 7211900.0   </reference-point-y>
      <length-x>              500.0   </length-x>
      <length-y>              500.0   </length-y>
      <angle>                  23.627 </angle>
      <sample-density-x>       50.0   </sample-density-x>
      <sample-density-y>       50.0   </sample-density-y>
    </utm-coordinates>

    <multiple-intervals>
      <top-surface>
        <time-file>   horizons/FlatTop_3100ms.storm </time-file>
      </top-surface>
      <interval>
        <name>IntervalA</name>
        <base-surface>
         <time-file>horizons/BaseA.storm</time-file>
         <erosion-priority>2</erosion-priority>
          <uncertainty>60</uncertainty>
     </base-surface>
     <number-of-layers>100</number-of-layers>
      </interval>
      <interval>
     <name>IntervalB</name>
        <base-surface>
```

```
          <time-file>horizons/BaseB.storm</time-file>
          <erosion-priority>4</erosion-priority>
           <uncertainty>40</uncertainty>
      </base-surface>
      <number-of-layers>120</number-of-layers>
  </interval>
    </multiple-intervals>
  </output-volume>
</project-settings>
</crava>
```

3.1.2.3 Lateral extent

The lateral extent of the inversion volume is specified by the command <area-from-surface>, <utm-coordinates>, or <inline-crossline-numbers>. The command <utm-coordinates> describes a rectangle, which may be rotated relative to the seismic data. It has the following parameters, which must all be specified:

- <reference-point-x> is the UTM x-coordinate of one corner of the area.
- <reference-point-y> is the UTM y-coordinate of the same corner.
- <length-x> is the extent of the area along the local x-axis.
- <length-y> is the extent of the area along the local y-axis.
- <angle> is the angle between the direction of the UTM x-axis and the local x-axis. Positive angles are counterclockwise.
- <sample-density-x> is the length of one grid cell along the local x-axis.
- <sample-density-y> is the length of one grid cell along the local y-axis.

If the grid has the same rotation as the SegY volume read as input, output SegY volumes will have correct in-lines and cross-lines. Otherwise, these numbers are just counting from the initial corner. The command <area-from-surface> contains only one parameter, <file-name>, the name of a storm surface file defining the lateral extent of the inversion volume. The last way to define the inversion area is by the command <inline-crossline-numbers>. By this command, the following parameters can be used:

- <il-start> is the starting inline number.
- <il-end> is the ending inline number.
- <xl-start> is the starting crossline number.
- <xl-end> is the ending crossline number.
- <il-step> is the inline interval.
- <xl-step> is the crossline interval.

The parameters <il-start> and <xl-start> must be set if this command is used, the other parameters are optional. If they are not given, the numbers are taken from the Segy file containing the first seismic cube.

The area commands may be skipped altogether. The area will then be taken from the first input seismic data file, and defined as the smallest rectangle that covers all traces.

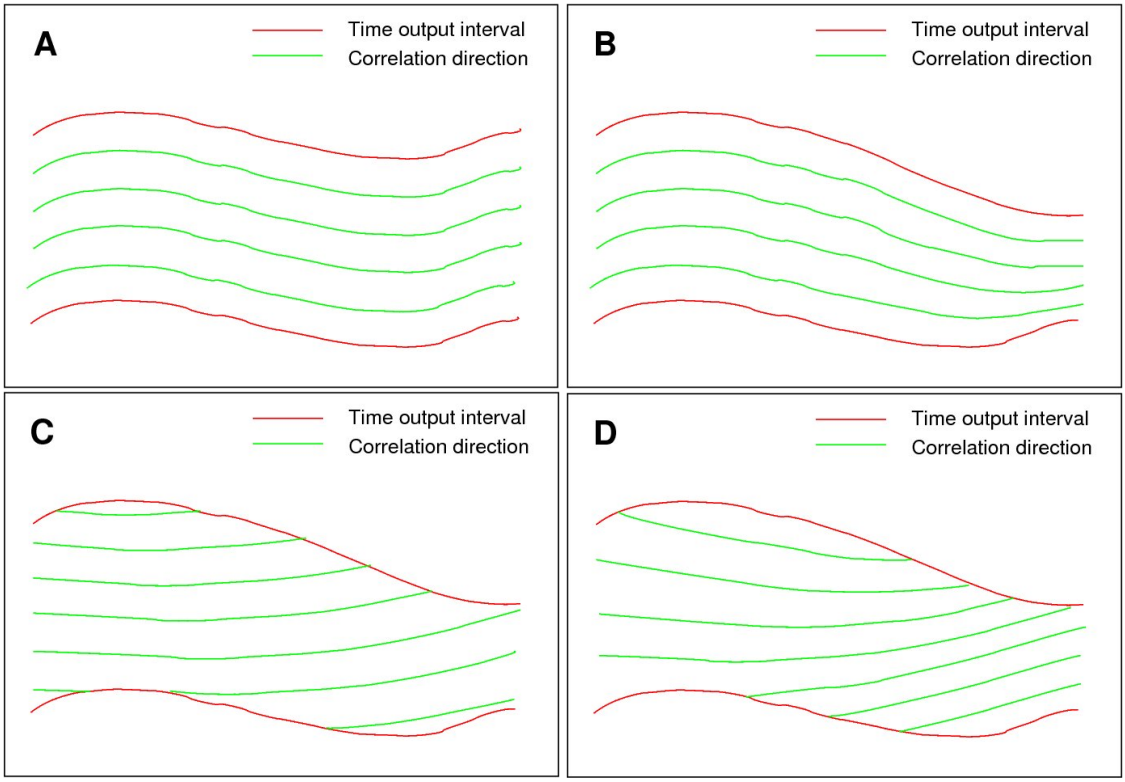

Figure 3.1. The layer structure of a (A) parallel top and base, (B) top- and base-conform compaction grid (C) Uniform correlation structure in a cut grid (D) Compactional correlation structure in a cut grid.

3.1.2.4 Top and base surfaces

The vertical extent is normally given by a top and a base surface in time, under the command `<interval-two-surfaces>` , as shown in Section 3.1.2.1. The file name for the top surface is given under command `<top-surface>`, `<time-file>`, and the base surface is given similarly under `<base-surface>` , `<time-file>`. The file format is binary storm, ASCII Irap or a Multicolumn ASCII format (file with five columns, x, y, z, IL and XL). Top and base time values for the inversion interval can be given as constants instead of files, by using the command `<time-value>`.

These surfaces also define the default lateral correlation direction for the elastic parameters, with the correlation being parallel to the top surface at the top, and base surface at the base. Between this, we create a top- and base-conform grid, so that the number of grid cells in each trace is constant, although the interval thickness may vary. This is shown in part B of Figure 3.1. The inversion may be unstable if the resolution varies too much in different traces, so we recommend that no trace interval is larger than twice the shortest interval. The number of layers between top and base is given by the command `<number-of-layers>` .

By specifying a correlation surface, the correlation direction can be independent of the interval surfaces, see part C of Figure 3.1 and Section 3.1.3.2. If this is done, there are no restrictions on the differences in interval thickness.

The more flexible approach where a compactional correlation structure is specified independent of the interval of interest (see part D of Figure 3.1) is currently not implemented.

If only one surface is known, the command `<interval-one-surface>` can be used to invert an interval with top and base parallel to this surface. See Section 4.2.1.2 in the reference guide for more details. Note that depth conversion and correlation surfaces will not be available in this mode, so the lateral correlation will be parallel to this surface, as illustrated in part A of Figure 3.1.

3.1.2.5 Depth conversion

The <output-volume> command is also where the depth conversion is specified. Additional information for depth conversion has only to be given under <interval-two-surfaces>, since the lateral area is the same. To do a depth conversion, one of the following must be given:

- Reference surface in depth (either top or base), and a velocity cube.
- Both top and base surface in depth. In this case, we assume constant velocity along each trace, computed from the time and depth surfaces.
- Both top and base surface in depth, and a velocity cube. In this case, we use the cube for relative velocity in a trace, and scale it to match the interval length.

Reference surfaces in depth are given with the tags <depth-file> under <top-surface> and/or <base-surface>. The velocity cube can be read from file with the command <velocity-field>. Alternatively, the command <velocity-field-from-inversion> can be used to specify that V_p from inversion should be used for velocity. With depth conversion, the <interval-two-surfaces> command may look like this:

```
<interval-two-surfaces>
  <top-surface>
    <time-file>      FlatTop_3100ms.storm </time-file>
    <depth-file>     FlatTop_3100ms.storm </depth-file>
  </top-surface>
  <base-surface>
    <time-file>      FlatBase_3600ms.storm </time-file>
    <depth-file>     FlatBase_3800ms.storm </depth-file>
  </base-surface>
  <velocity-field>   velocity.storm </velocity-field>
  <number-of-layers>            125 </number-of-layers>
</interval-two-surfaces>
```

3.1.3 Prior model

Since seismic data only contain information about relative elastic parameters, the absolute level needs to be set with a background model. In a Bayesian inversion setting, the background model is the prior expectation. We also need the prior covariance, which is given by the covariance of the parameters, the lateral correlation and the temporal correlation, as described in Section 1.4. In the model file, all this is gathered under the <prior-model> command, which may look something like this:

```
<crava>
<prior-model>
  <background>
    <vp-file>      input/background/CravaBgVp.storm  </vp-file>
    <vs-file>      input/background/CravaBgVs.storm  </vs-file>
    <density-file> input/background/CravaBgRho.storm </density-file>
  </background>
  <lateral-correlation>
    <variogram-type> genexp </variogram-type>
    <power>       1 </power>
    <angle>       0 </angle>
    <range>    2500 </range>
```

```
    <subrange> 2500 </subrange>
  </lateral-correlation>
</prior-model>
</crava>
```

3.1.3.1 Background model

The background model is given under the <background> command. It can be given from file, using <vp-file>, <vs-file> and <density-file>. These files should either be on Storm, crava, Sgri or SegY format. Alternatively, constant values can be used for background model, specified with <vp-constant>, <vs-constant> and <density-constant>. Any combinations of files and constants are also accepted. If none of these are given, the background model will be estimated.

Multiinterval (Multizone) background model is achieved by doing a <multiple-intervals> inversion and with estimating background models activated. The surfaces are set under <output-volume>. It is not possible to use multiinterval background with a single interval/zone inversion directly. To achieve this, one must first run Crava in estimation mode with <multiple-intervals> and estimate a background model, where the written background model must then be used as input in a single interval inversion. The multiinterval background model will follow the other setting for multiinterval inversion, like <correlation-direction>, <erosion-priority> and <uncertainty>. In each interval, a local background model is created by estimating a depth trend for the zone volume, then interpolating well logs into the depth trends using kriging. The full multiinterval background model is then made by joining the local background models in all the intervals.

3.1.3.2 Covariances

As shown in Section 1.4 the prior covariance structure for the elastic parameters consists of three parts:

1. A 3x3 covariance matrix for point-wise covariance between the parameters. May be read from ASCII file using the command <parameter-correlation>.
2. A temporal correlation vector, length equal to number of layers in grid, n_t. May be read from ASCII file using the command <temporal-correlation>.
3. A lateral correlation structure. May be given as a parametric variogram using the command <lateral-correlation>.

By default, the two first are estimated from well data, and the lateral correlation structure is set to a isotropic exponential variogram with range 1000. The reason for the latter choice is that this is hard to estimate, see Section 2.2.2 for details. The most common to override is the lateral correlation, where the variogram used for petro-physical modelling is a good choice.

3.1.4 Well data

Unless all information about wavelet, signal to noise and correlations are specified, well data are needed for estimation. Wells are given with the command <well-data>, and may look like this:

```
<crava>
<well-data>
  <log-names>
    <time>    TWT  </time>
    <dt>      DT   </dt>
    <dts>     DTS  </dts>
    <density> RHOB </density>
```

```
  </log-names>
  <well>
    <file-name> input/logs/ed6406_3-3_cut.rms    </file-name>
  </well>
  <well>
    <file-name> input/logs/ed6506_12-3_cut.rms   </file-name>
  </well>
  <well>
    <file-name> input/logs/ed6506_12-8_cut.rms   </file-name>
  </well>
  <well>
    <file-name> input/logs/ed6506_12-S4H_cut.rms </file-name>
  </well>
</well-data>
</crava>
```

There are two main elements here. The first is a well log interpretation, given by <log-names>, which tells CRAVA which headers to look for. The following logs are needed:

- Two way time log, specified with <time>.
- V_p log, either given by <vp> or <dt>. The latter is used for DT-logs.
- V_s log, either given by <vs> or <dts>. The latter is used for DTS-logs.
- Density log, given by <density>.

In addition, if facies probabilities are computed, a facies log is needed. This is specified with the tag <facies>.

The wells are given with the command <file-name> under <well>, which is given once for each well. The reason for this is that additional information may be given for each well. Well files should be on NORSAR or RMS-format.

Each well may be moved to its optimal location using <optimize-position> under <well>, taking the arguments <angle> and <weight> which allow the user to assign different weights to the different angle gathers for each well. The maximum allowed offset and vertical shift for moving wells is specified in <maximum-offset> and <maximum-shift> under <well-data>, with default values of 250 m and 11 ms, respectively.

The command <synthetic-vs-log> tells whether the V_s log is synthetic. If not specified, it will be detected from rank correlation with V_p. The command <filter-elastic-logs> is used to do multi-parameter-filtering of the elastic logs in this well after the inversion.

3.1.5 I/O settings

Two commands are used to specify the directory for input files. <top-directory> gives the working directory for the model file. The command <input-directory> is used to specify directory name for root directory for input files. The name is given relative to <top-directory>.

Under <advanced-settings>, the command <use-intermediate-disk-storage> can be used to limit the memory usage when running large CRAVA jobs. A built-in smart-swap is then activated. The option has largest effect on Microsoft Windows.

Under <project-settings>, <io-settings> and <other-output>, the command <error-file> writes all errors to a separate file, in addition to the log file. The command <task-file> writes all tasks to a separate file, in addition to the log file.

3.1.6 Output

Output is controlled under <io-settings> under <project-settings>. Here, you may set the output directory using <output-directory>, and you may also specify a prefix for all output files using <file-output-prefix>.

Except for the log file which is placed directly under the output directory, all files output by crava are placed in sub-directories. These sub-directories are

```
output-directory / wells
                 / background
                 / wavelets
                 / seismic
                 / velocity
                 / correlations
                 / inversionresults
```

There are two main output formats: Grid output, controlled by <grid-output>, and well output controlled by <well-output>. The output section may look something like this:

```
<crava>
<project-settings>
  <io-settings>
    <file-output-prefix> CRAVA_ </file-output-prefix>
      <grid-output>
        <format>
          <segy>       yes </segy>
        </format>
        <domain>
          <time>       yes </time>
          <depth>      yes </depth>
        </domain>
        <elastic-parameters>
          <vp>         yes </vp>
          <vs>         yes </vs>
          <density>    yes </density>
          <background> yes </background>
        </elastic-parameters>
      </grid-output>
      <well-output>
        <wells>         yes </wells>
        <blocked-wells> yes </blocked-wells>
      </well-output>
  </io-settings>
</project-settings>
</crava>
```

3.1.6.1 Grid output

Different elastic parameters can be given as grid output. In addition, the estimated background model may be written as grids. This is controlled by the <elastic-parameters> command under <grid-output>. See Section 4.2.3.4.3 for a full list of possible grids. If this command is not used, V_p, V_s and density will be written. Output of original and synthetic seismic data can be given by the <seismic-data> command. Other grids can be requested for output by the command

<other-parameters>, for example correlations.

The grid format may be controlled using <format>. Here the yes/no parameters <storm>, <segy>, <sgri>, <crava> and <ascii> can be used to decide if grids should be written on storm- (RMS), segy-, Sgri-, crava- or ASCII-format. You may choose several formats for one run; all grids will be written on all selected formats. The Segy format can be controlled by the <segy-format> command, in the same way as for input data, described in Section 3.1.1.1. Note that correlation grids make sense only in storm format. Default output format is storm. The crava format is a binary format only to be used with CRAVA. It can be read and written from CRAVA, and is useful if the output from a CRAVA run should be used as input to another CRAVA run because the format is fast to read.

By using the <domain> option, output may be written in time domain <time> or depth domain <depth> (requires parameters set under <output-volume>, see Section 3.1.2.5), or both. Again, correlation grids only make sense in time domain, which is default.

3.1.6.2 Well output

Some versions of filtered elastic parameters (V_p, V_s and density) in wells can be generated by the <well-output> command. The wells can be given in two different formats, RMS or NORSAR. This is controlled by the <format> command. The logs written are

- Raw elastic logs.
- Elastic logs filtered to background frequency.
- Elastic logs filtered to seismic frequency.
- Elastic logs filtered with facies prediction filter (if available).
- Facies log (if available).

The wells can either be written with original sampling density, using <wells>, or matching the internal grid resolution, using <blocked-wells>.

3.1.7 Actions

The final information that is needed for a CRAVA run is what the run is supposed to do. This is controlled by <actions>. The <mode> keyword defines the purpose of this run and should be set to "inversion" when doing inversion. Other options are "estimation", see Section 3.3 and "forward", see Section 3.7. When inversion is chosen, <inversion-settings> can be used to control basic aspects of the inversion. It may look something like this:

```
<crava>
<actions>
  <mode>                    inversion </mode>
  <inversion-settings>
    <prediction>                  yes </prediction>
    <simulation>
      <seed>                   150570 </seed>
      <number-of-simulations>      10 </number-of-simulations>
    </simulation>
  </inversion-settings>
</actions>
</crava>
```

The command <prediction> can be used to turn predictions on or off. By default, the prediction will be generated. A number of full frequency stochastic realisations of the inversion can be obtained by specifying <number-of-simulations> under <simulation>. The seed for the random generator can also be given here, with the <seed> command. Changing the seed will give a new set of realisations.

The command <kriging-to-wells> can be used to krige realisations to well data. By default, this is done if the <simulation> command is used.

3.1.8 Standard formats for input and output

3.1.8.1 3D-grid

Crava can read and write the following 3D grid formats: SegY, Storm, Sgri (NORSAR) and crava (internal) . On output, the format is controlled by a <format> keyword. On input, the program automatically detects the format, although it may need help to correctly read SegY formats, using the <segy-format> keyword. The default output format is storm.

3.1.8.2 Surfaces

The standard format for reading and writing surfaces is binary storm, but CRAVA can also read Roxar ASCII surfaces (formerly known as ASCII Irap classic) and Multicolumn ASCII surfaces (see example below). In addition some surfaces related to 3D-inversion are read as sgri (NORSAR). On input, the surface format will be automatically detected. For writing we currently support Roxar Ascii and Storm binary.

3.1.8.2.1 Multicolumn Ascii example The multicolumn ascii file is a text file with five columns, and each columns needs ta have a header name: X or UTMX; Y or UTMY; IL or Inline; XL or Crossline; Z, TWT or Attribute. The order of the columns is arbitrary. The file might also have some text before the header-row. This surface is based segy-geometry and must follow the corresponding seismic cube, as the reference point, angle and area are taken from the geometry. We require even sampling in the file, but we do not require as fine sampling as in the seismic. It is for example possible to give only the four corners of the surface. Base on this a segy geometry will be required for using multicolumn ascii files. The standard missing value is defined as -999.25.

A file may look like:

X	Y	Inline	Crossline	Attribute
455380.0	6799690.0	2100.0	5600.0	2467.05737
447256.0	6799789.0	2100.0	5640.0	2480.06712
447393.0	6811038.5	2120.0	5600.0	2549.43453
455517.0	6810939.5	2120.0	5640.0	2338.12905

3.1.8.3 Wavelets

Wavelets are either on JASON or NORSAR format, both for reading and writing. Auto-detect is used on reading, use <format3> for writing. The default output format is JASON.

3.1.8.4 Wells

For reading we support wells on RMS, NORSAR and LAS format. For writing we currently support RMS and NORSAR. Auto-detect is used on reading; use <format2> to control writing. The default output format is RMS.

3.2 Advanced inversion options

Although CRAVA is mainly intended as a simple and fast inversion tool, there are still some options to control the inversion, and to access more sophisticated approaches. Most of these are covered here, see also Section 4.2.4 for details about <advanced-settings>.

3.2.1 Non-stationary wavelet and noise

Although the FFT-algorithm which is at the core of CRAVA requires stationarity, this does not mean that the entire inversion has to be stationary, as discussed in Section 2.6. We allow lateral variations in wavelet amplitude, wavelet shift and signal to noise ratio.

The local wavelet transformations fit well within the core framework of CRAVA, but the local noise requires some approximations, as explained in section Section 2.6.2. This means that local noise only improves the final result if the local variations are substantial. We do not recommend using local noise if the variation in noise level is less than 15%.

Unlike the basic level, where parameters that were not specified automatically got estimated, the use of local wavelets or local noise must be explicitly triggered. For wavelets, this is done with the <local-wavelet> command under <wavelet>. There are four alternatives: <local-wavelet>:

1. <shift-file> gives a file name for a map giving the local shifts.
2. <estimate-shift> will estimate a local shift map when set to "yes".
3. <scale-file> gives a file name for a map giving the local scale.
4. <estimate-scale> will estimate a local scale map when set to "yes".

Naturally, the shift can not be both given and estimated, the same holds for scale. Note that you may choose to use only shifts, omitting both scale keywords, or use only scale.

The local noise is triggered similarly, by using one of two commands under <angle-gather>:

1. <local-noise-scaled> gives a file name for a map with the local scaling of the signal to noise ratio.
2. <estimate-local-noise> estimates the local scaling of the signal to noise ratio if set to "yes".

3.2.2 PS-seismic and reflection approximations

By default, CRAVA assumes that the input seismic data are PP, but PS data can also be used. For both cases, we use the linearised Aki-Richards approximation, see Equation 1.1. The type of seismic data is indicated by using the <type> command under<seismic-data>. Here, <type> should be either "pp" or "ps". Note that PS data must also be aligned in PP-travel time, as no such alignment is done internally by CRAVA.

Instead of using the default reflection approximation, the user may supply the parameters to compute the reflections. We always assume that for a given angle and seismic type, the reflections can be computed from the equation

$$\begin{aligned} c(\mathbf{x},t,\theta) = & \, a_{Vp}(\theta)\frac{\partial}{\partial t}\ln V_p(\mathbf{x},t) \\ & + a_{Vs}(\mathbf{x},t,\theta)\frac{\partial}{\partial t}\ln V_s(\mathbf{x},t) \\ & + a_{\rho}(\mathbf{x},t,\theta)\frac{\partial}{\partial t}\ln \rho(\mathbf{x},t). \end{aligned} \tag{3.1}$$

The coefficients a_{Vp}, a_{Vs} and a_{ρ} can be read from file, using the <reflection-matrix> command under <advanced-settings>. This file should have one line for each seismic data file, and each

Table 3.2. Default intervals for valid well log values.

	Min	Max
V_p	1300	7000
V_s	200	4200
ρ	1.4	3.3

Table 3.3. Default intervals for valid well log variances.

	Min	Max
Var(ln(V_p))	$5 * 10^{-4}$	$250 * 10^{-4}$
Var(ln(V_s))	$10 * 10^{-4}$	$500 * 10^{-4}$
Var(ln(ρ))	$2 * 10^{-4}$	$100 * 10^{-4}$

line should have the three coefficients for one set of seismic input data. The order of the lines should be the same as the order of the seismic data in the `<survey>` command.

3.2.3 Well quality checks

Well logs are often faulty, and CRAVA has some safety mechanisms to detect this. The primary mechanism is to detect extreme values, and set these undefined. The default upper and lower bounds accepted in well logs are shown in Table 3.2. These can be overridden using the command `<allowed-parameter-values>` under `<well-data>`. Here, `<minimum-vp>`, `<minimum-vs>`, `<minimum-density>` and the corresponding maximum values can be given.

Some logs may stay within reasonable values, but have too much or too little variation, also indicating that something is wrong. We therefore calculate the variance of the logarithm of the log minus the background, and if this is outside reasonable bounds, an error is triggered. The default bounds shown in Table 3.3 can be overridden with `<allowed-parameter-values>`, using `<minimum-variance-vp>`, and so forth.

3.2.4 Generate synthetic seismic from inversion data

It is possible to generate synthetic seismic by a forward modelling with the V_p, V_s and density resulting from the inversion. This is done by the command `<synthetic>` under `<seismic-data>` under `<grid-output>`, `<io-settings>`, in command `<project-settings>`.

3.3 Estimation

As mentioned, CRAVA can estimate many of the needed parameters. There are several commands that control the estimation behaviour for wavelets, noise and background model. Note that the correlations will always be estimated as explained in Section 2.2.2 from all available well logs, and do not have any further controls.

3.3.1 Estimation mode

If you only want to do the estimation, in order to check the quality of the estimates, you can use "estimate" in the `<mode>` command. Using this, CRAVA will perform the initial model building tasks and estimate needed information, but terminate once all information needed for inversion is estimated. When running in estimation mode, you can also control the main estimation aspects using the `<estimation-settings>` command. This allows you to control which of the main estimation tasks should be carried out, setting yes or no for `<estimate-correlations>`, `<estimate-wavelet-or-noise>` or `<estimate-background>`. Parameters with a "no" will not be estimated unless needed for other estimations. Note that in estimation mode, all estimated pa-

rameters are written to file, regardless of output settings.

3.3.2 Wavelet and noise estimation

Wavelets and noise are estimated together. These parameters will only be estimated from wells that are vertical or close to vertical, since this allows comparing synthetic seismic from well logs with one or a couple of traces, and thus reduces alignment issues. The angle limit can be controlled by the <maximum-deviation-angle> command under <well-data>. In addition, wells can be excluded individually, by setting <use-for-wavelet-estimation> to "no" under <well>.

By default, the wavelet and noise are estimated in the region between the top and base surface for the inversion area. This may be limited using the <wavelet-estimation-interval> command under <survey>, where a separate set of restricting surfaces are given with <top-surface> and <base-surface>. Since these are under <wavelet>, they can be different for each angle.

Some wavelet estimation options are also found under the command <advanced-settings> given under <project-settings>. These are

- <wavelet-tapering-length> which controls the length of the wavelet (in ms).
- <minimum-relative-wavelet-amplitude> which finds the wavelet length, by setting the cut-off size for edge peaks relative to centre peak.
- <maximum-wavelet-shift> which controls how far the wavelet can be shifted locally, see Section 2.3.

Prior information for local wavelet modelling is given by the <local-wavelet> command under <prior-model>. Here, lateral correlation is specified as a 2D variogram for the lateral correlation in local wavelet modelling by the command <lateral-correlation>.

Output of wavelets is controlled by the <wavelet-output> command under <io-settings>. Two different formats can be specified, JASON and NORSAR. Estimated wavelets for each well is written by the <well-wavelets> command. The command <global-wavelets> writes global wavelets for each seismic angle. If local wavelet is requested, the command <local-wavelets> writes estimated local wavelet shift and scale surfaces.

Output of estimated local noise surface is given by the command <local-noise> given under <io-settings> and <other-output>.

3.3.3 Background model estimation

The background model is estimated as a low frequency vertical trend. The trend is given in relative depth in the inversion volume, so the trend value along the top and base surface is constant. At well locations, the trend is kriged to the well logs. By default, all wells are used for background model estimation, but can be excluded by specifying "no" for <use-for-background-trend> under <well> for individual wells.

The background estimation can be controlled by some commands under <background>. These are:

- <velocity-field> takes an external velocity field, typically from migration, and uses as V_p background, kriged to low frequency V_p well logs.
- <lateral-correlation> gives a variogram for the kriging. Larger ranges extends the influence of well data further away from wells.
- <high-cut> allows specification of a maximum frequency for the background model.

3.3.4 Prior correlations

Prior correlations between V_p, V_s and density, and autocorrelation are estimated. they can be written to file by the command <prior-correlations> under <project-settings>, <io-settings> and <other-output>.

3.4 3D wavelet

Instead of the traditional 1D wavelet a 3D wavelet can be used in CRAVA. This wavelet is constructed by a 1D pulse and a 3D wavelet filter based on illumination vectors. The use of a 3D wavelet is invoked by the keyword <wavelet-3d>.

The 1D pulse used to construct the 3D wavelet, can be specified by the <file-name> keyword. If a file is not specified, this pulse is estimated. Either way, a filter file must be given by the keyword <processing-factor-file-name>. This filter contains the amplitude effects related to the illumination vectors and is given on Sgri format. One or two filters are given. The first, and necessary, contains frequency-independent amplitude effects, while the second, if given, contains frequency-dependent amplitude effects.

For noise estimation in the 3D wavelet setting, a propagation filter file is given by the keyword <propagation-factor-file-name>. At present, this is not used. The keyword <stretch-factor> can be given, but is not used since the stretch factor is automatically calculated from the offset angle.

When estimating the 1D pulse, seismic data from a neighbourhood of the well can be used. The distance from the well, specified in meters, that data are collected is given by the commands <estimation-range-x-direction> and <estimation-range-y-direction>. The default is that only data from the well position are used.

When 3D wavelet is used, certain parameters related to the mapping between time and depth are needed. This occurs since the illumination vectors relates to depth, while CRAVA works in time. These settings are given under keyword <time-to-depth-mapping-for-3d-wavelet> in <project-settings>. A reference depth for the target area must be specified under the keyword <reference-depth>. This depth represents a constant surface which in time normally will refer to a variable surface due to varying velocity above this depth. This reference surface is given by <reference-time-surface> and can be given on Storm- or Sgri-format. The parameter <average-velocity> refers to the average velocity in the target area which is needed for the estimation of the pulse.

3.5 Rock physics

The idea behind the rock physics template is to be able to model the density and elastic properties of a fluid-filled <rock> in a very flexible way, by selecting from and possibly combining many different rock physics theories. In order to do this, we need some basic building blocks. The basic building blocks here are <fluid>, <solid>, <dry-rock> (a solid with porosity, but no fluid) and <rock> (a combination of solid and fluid).

In CRAVA, the rock physics models are used for generating the background model and covariance matrix used in the prior model, and for generating synthetic wells used for facies estimation.

3.5.1 Structure of the rock physics template

The base structure of the rock physics template consists of the elements <reservoir>, <evolve>, <predefinition>, <rock> and <trend-cube>, each of which contains sub-elements.

The sub-elements will be basic building blocks (e.g. <solid>, <fluid>, <dry-rock>), properties

(e.g. temperature, pore-pressure, density, etc) and theories.

3.5.1.1 Reservoir

<reservoir> contains reservoir properties, such as pressure, temperature, porosity, fluid saturation, lithology, etc. Reservoir properties given under the keyword <reservoir> are parameters common for fluids, solids, dry rocks and rocks. For models that depend on these parameters, the values given under reservoir can be used, although they may be overridden locally. The elements in <reservoir> are defined by labels to be referred to with the <reservoir-variable> statement. Hence, they must be unique. After <reservoir>, the command <variable> follows. Below is an example of how <reservoir> can be defined:

```
<reservoir>
  <variable>
    <label> temperature </label>
    <value> 50 </value>
  </variable>

  <variable>
    <label> porosity </label>
    <gaussian>
      <mean> 0.5 </mean>
      <variance> 0.1 </variance>
    </gaussian>
  </variable>
</reservoir>
```

3.5.1.2 Evolve

<evolve> controls the time development of the reservoir variables. Under the keyword <evolve>, <reservoir-variable>, <one-year-correlation> and <vintage> are given. <reservoir-variable> needs to be the label of one of the variables defined in <reservoir>. <one-year-correlation> defines the correlation between the reservoir variable at two following years. <vintage> is repeated for each vintage of the time development. In <vintage>, <distribution> and <vintage-year> are given. <distribution> is the distribution of the reservoir variable at the given vintage, and it needs to be one of the distributions given under <value-assignments>. <vintage-year> is the year of the given vintage of the reservoir variable. Below is an example with <evolve> for the reservoir variable porosity:

```
<evolve>
  <reservoir-variable> porosity </reservoir-variable>
  <one-year-correlation> 0.7 </one-year-correlation>
  <vintage>
    <distribution>
      <beta>
        <mean> 0.1 </mean>
        <variance> 0.01 </variance>
      </beta>
    </distribution>
    <vintage-year> 2000 </vintage-year>
  </vintage>
```

```
  <vintage>
    <distribution>
      <beta>
        <mean> 0.08 </mean>
        <variance> 0.01 </variance>
      </beta>
    </distribution>
    <vintage-year> 2002 </vintage-year>
  </vintage>
</evolve>
```

3.5.1.3 Predefinitions

<predefinitions> is used for specifying and calculating the elastic properties of basic building blocks, being <solid>, <fluid> or <dry-rock>, or elements and mixtures of these. It will typically use properties specified under <reservoir>.

Each time a building block is defined, it is given a unique identifying name using the <label> keyword. This is followed by a keyword specifying which theory we use for building this element, and inside that keyword block, the required parameters for the theory are given.

Inside the theory block, the required parameters for the theory are given. The theories are used for calculating the bulk and shear moduli. In addition, they are implicitly used for calculating the density using the arithmetic average of the constituent densities.

If we want to use an element that is already defined, we can use the keyword <use> instead of <label>, followed by the unique name of the element. Thus, we can easily reuse elements once they are defined.

The significant difference between elements in <reservoir> and <predefinitions> is that each element in <reservoir> defines a single property, while it defines an object with several properties in <predefinitions> (e.g. bulk modulus, shear modulus and density). These objects are typically used as inputs to various theories for calculating the effective properties of a mixed material.

```
<predefinitions>
  <solid>
    <label> quartz </label>
    <tabulated>
      <bulk-modulus> 37 </bulk-modulus>
      <shear-modulus> 44 </shear-modulus>
      <density> 2.65 </density>
    </tabulated>
  </solid>
  <fluid>
    <label> brine </label>
    <batzle-wang-brine>
      <pore-pressure> 20 </pore-pressure>
      <temperature> 60 </temperature>
      <salinity> 0.05 </salinity>
    </batzle-wang-brine>
  </fluid>
</predefinitions>
```

3.5.1.4 Rock

<rock> contains the final composition of the rock, and will typically use details specified in <reservoir> and <predefinitions>. The <rock> command is followed by either <label> or <use>. If <label> is used, the next keyword is a theory.

The rocks to be used in the facies estimation, need to correspond to the facies given in <facies-probabilities>.

Example:

```
<rock>
  <label> effective rock </label>
  <gassmann>
    <dry-rock>
      <use> quality sand </use>
    </dry-rock>
    <fluid>
      <use> brine </use>
    </fluid>
  </gassmann>
</rock>
```

3.5.1.5 Trend cubes

<trend-cube> contains the trend cubes that can be used for defining a trend on the variables. Each variable defined by a trend may be related to one or two trend cubes. These trend cubes may for example be related to time and depth, and they need to be defined in the entire inversion volume.

3.5.2 Value assignments in the rock physics template

All the properties and function parameters can use previously assigned values defined in <reservoir>, or be assigned values directly in <predefinitions>. The possible types of value assignments are value, trend or distribution.

3.5.2.1 Value

The simplest form of deterministic value assignment is a single value. For the variables in <reservoir>, the value is given by the command <value>, while it may be given directly for the variable commands of <predefinitions>. Below is an example for each of these cases:

```
<reservoir>
  <variable>
    <label> temperature </label>
    <value> 40 </value>
  </variable>
</reservoir>

<predefinitions>
  <solid>
    <label> clay </label>
    <tabulated>
      <bulk-modulus> 21 </bulk-modulus>
      <shear-modulus> 7 </shear-modulus>
      <density> 2.6 </density>
    </tabulated>
  </solid>
```

```
</predefinitions>
```

3.5.2.2 Distributions

The rock physics template supports the distribution functions <gaussian>, <beta> and <beta-end-mass> for assigning probabilistic values to a variable. Whenever several building blocks use the same stochastic variable defined under <reservoir>, the same sample of the variable is used for all the building blocks. The required input variables for the different distributions are given in Section 4.6.

Examples:

```
<reservoir>
  <variable>
    <label> total-porosity </label>
    <gaussian>
      <mean> 0.25 </mean>
      <variance> 0.05 </variance>
    </gaussian>
  </variable>

  <variable>
    <label> bulk-quartz </label>
    <beta>
      <mean> 63000000 </mean>
      <variance> 30000 </variance>
      <lower-limit> 10000000 </lower-limit>
      <upper-limit>100000000</upper-limit>
    </beta>
  </variable>
</reservoir>
```

3.5.2.3 Assigning trends to the rock physics variables

The values of the variables may be given by a trend. The trends are named <trend-1d> or <trend-2d>, with the 1d and 2d endings telling if the property values should be related to one or two trend cubes. These trend cubes may for example be related to time and depth, and they need to be defined in the entire inversion volume. If the trend is to be used, trend cubes must be given on the same level as <reservoir> using the command <trend-cube> following the example below. If the trend represent a mean or a variance (as in for example the background model), these can be estimated from data by specifying either <mean> or <variance> in addition to using the command <estimate>. Note that if the model is 1-dimensional, it is necessary to specify the reference parameter, see the examples below. The estimation methods are version of standard kernel smoothing (local linear regression for the mean and a weighted kernel smoothing for the variance). Note that the mean and variance does not need to have the same dimensionality, see the examples below.

```
<reservoir>
  <variable>
    <label> temperature </label>
    <trend-1d>
      <file-name> trend1d.txt </file-name>
      <reference-parameter> time </reference-parameter>
    </trend-1d>
```

```
  </variable>

  <variable>
    <label> porosity </label>
    <trend-2d>
      <file-name> trend2d.txt </file-name>
      <reference-parameter-first-axis> time
      </reference-parameter-first-axis>
      <reference-parameter-second-axis> depth
      </reference-parameter-second-axis>
    </trend-2d>
  </variable>
</reservoir>

<trend-cube>
  <parameter-name> time </parameter-name>
  <file-name> trendCubeTime.txt </file-name>
</trend-cube>

<trend-cube>
  <parameter-name> depth </parameter-name>
  <file-name> trendCubeDepth.txt </file-name>
</trend-cube>

<vp>
  <gaussian>
    <mean>
      <trend-2d>
        <estimate>yes</estimate>
      </trend-2d>
    </mean>
    <variance>
      <trend-1d>
       <estimate>yes</estimate>
        <reference-parameter>twt</reference-parameter>
      </trend-1d>
    </variance>
  </gaussian>
</vp>

<vp>
  <gaussian>
    <mean>
      <trend-1d>
        <estimate>yes</estimate>
        <reference-parameter>twt</reference-parameter>
      </trend-1d>
    </mean>
    <variance>
```

```
      <estimate>yes</estimate>
    </variance>
  </gaussian>
</vp>
```

3.6 Facies prediction

An important feature in CRAVA is the ability to create facies probabilities. This requires that <mode> is set to "inversion", and is triggered by the <facies-probabilities> command under <inversion-settings>.

The facies probabilities are computed based on the inversion results and a distribution for inversion values given facies computed from filtered well logs, where the filter is defined by the inversion. See Section 1.4.1. Probability volumes will be computed for all facies seen in wells, and if the command <facies-probabilities-with-undef> is used, an additional undefined probability cube is also generated, indicating areas where the inversion values are too far away from well data to make reliable predictions.

Except from the trigger in <inversion-settings>, all parameters related to facies probabilities are given under <facies-probabilities> under <prior-model>. Here is an example:

```
<crava>
<prior-model>
  <facies-probabilities>
    <use-vs>                          yes </use-vs>
    <use-prediction>                  yes </use-prediction>
    <use-absolute-elastic-parameters> yes </use-absolute-elastic-parameters>
    <estimation-interval>
      <top-surface-file>  input/horizons/facies_top.storm  </top-surface-file>
      <base-surface-file> input/horizons/facies_base.storm </base-surface-file>
    </estimation-interval>
    <prior-probabilities>
      <facies>
        <name>          sand </name>
        <probability>    0.4 </probability>
      </facies>
      <facies>
        <name>         shale </name>
        <probability>    0.6 </probability>
      </facies>
    </prior-probabilities>
  </facies-probabilities>
</prior-model>
</crava>
```

If <use-absolute-elastic-parameters> is set to 'yes', facies probability is computed based on inverted parameters including background model. If the distribution for elastic parameters for each facies is constant over the inversion volume, using absolute values is more stable. However, if there are trends in the elastic parameters, the relative values are more robust. The default is to use relative values.

The interval to use for facies probability calculations can be set with <estimation-interval>,

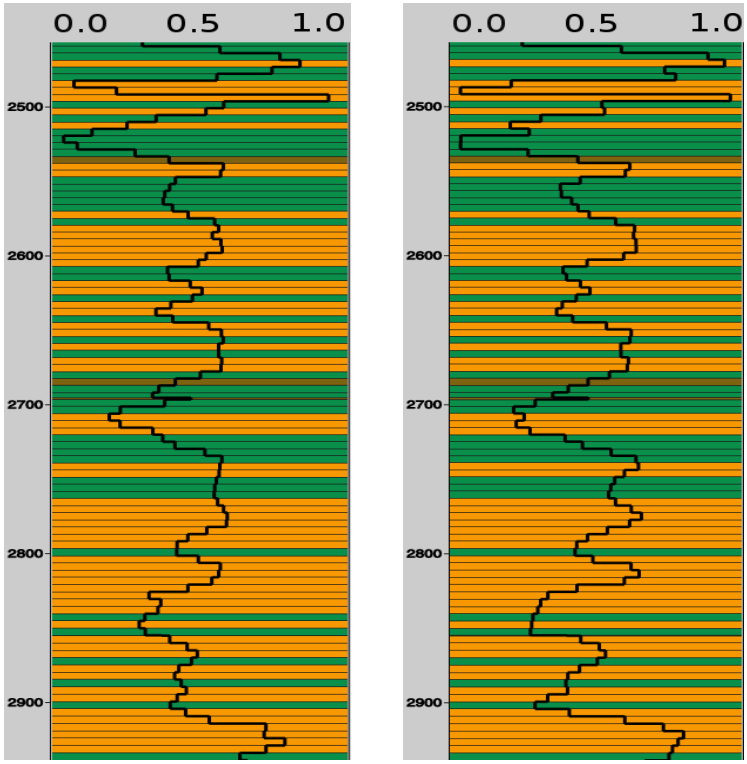

Figure 3.2. A sample facies probability estimation. The black curve gives the probability of sand in a well containing sand (orange), shale (green) and crevasse (brown). In the left figure the well was not included in the facies probability estimate whereas it was included in the right figure.

similar to estimation interval for wavelets. Parallel to the wavelet case, wells may also be excluded using the `<use-for-facies-probabilities>` command under `<well>`.

3.6.1 Prior probabilities

In order to get reliable probabilities, we need good prior probabilities. By default, CRAVA computes the average fraction of each facies in the relevant interval of the wells. This can be overridden using the `<prior-probabilities>` command, which allows specification of these. Note that probabilities must be given for each facies. Probabilities can either be given globally, with `<probability>`, or as a full 3D trend, using `<probability-cube>`. The latter takes a grid file as argument, and the corresponding grid must cover the inversion volume. A prior value for undefined facies is set with the command `<uncertainty-level>`.

3.6.2 Output parameters

Facies probabilities can be written to file by using the command `<facies-probabilities>` or `<facies-probabilities-with-undef>` given under `<project-settings>`, `<io-settings>`, `<grid-output>` and `<other-parameters>`. `<facies-probabilities>` gives probabilities for the existing facies that sum up to one. This is recommended for use in RMS. `<facies-probabilities-with-undef>` includes probability for undefined facies, and this cube will be the most correct one. `<facies-likelihood>` writes the likelihood for inverted seismic for each facies, $p(m|f)$, while `<seismic-quality-grid>` writes a grid kriged from values for fit between facies probabilities and facies observed in each of the wells.

Rock physics distributions can be written by the command `<rock-physics-distributions>` under `<io-settings>` and `<other-output>`. The distributions are written per facies, with V_p, V_s and density as axes. The density axis is scaled by a factor of 1000, to make zooming easier in RMS, and

in order to have sufficient resolution in SEGY. The density is scaled by a factor 1 000 000, again for SEGY convenience.

3.7 Forward modelling

A minor functionality in CRAVA is that it can do forward modelling, showing what seismic response the program would expect from a given set of elastic parameters. This is triggered by using "forward" as <mode>. In this mode, we generate synthetic seismic data from the given background volumes. A file for forward modelling looks like this:

```
<crava>
<actions>
  <mode> forward </mode>
</actions>

<survey>
  <angle-gather>
    <offset-angle>  0 </offset-angle>
    <wavelet>
      <file-name> wavelets/ricker.txt      </file-name>
    </wavelet>
  </angle-gather>

  <angle-gather>
    <offset-angle> 10 </offset-angle>
    <wavelet>
      <file-name> wavelets/rickershift.txt </file-name>
    </wavelet>
  </angle-gather>
</survey>

<prior-model>
  <earth-model>
    <vp-file>      background/Vp.storm  </vp-file>
    <vs-file>      background/Vs.storm  </vs-file>
    <density-file> background/Rho.storm </density-file>
  </earth-model>
</prior-model>

<project-settings>
  <output-volume>
    <!-- Lateral dimensions are extracted from the volume for Vp -->
    <interval-two-surfaces>
      <top-surface>
        <time-file> horizons/top.irap  </time-file>
      </top-surface>
      <base-surface>
        <time-file> horizons/base.irap </time-file>
      </base-surface>
      <number-of-layers>           250 </number-of-layers>
```

```
    </interval-two-surfaces>
  </output-volume>

  <io-settings>
      <grid-output>
        <format>
          <segy> yes </segy>
        </format>
      </grid-output>
  </io-settings>

</project-settings>
</crava>
```

Note that no seismic files are given under <survey>, as these are now computed. No wells are used, since nothing can be estimated here. We need the angles to generate seismic data for, the corresponding wavelets, the elastic parameters (given as earth model), and the volume. Instead of using one of the commands defining volume, the volume can be taken from V_p. The output format can be controlled using <io-settings>, as can input- and output-directory. Other input will be ignored.

4 Model file reference manual

The numbering shows the command grouping. A command with no sub-numbering expects a value to be given, otherwise, it is only a grouping of other commands.

File names are currently given with a path relative to the directory settings in <project-settings>-<io-settings>-<input/output/top-directory>. If these are not given, the path will always be relative to the working directory.

All commands are optional, unless otherwise stated. A necessary command under an optional is only necessary if the optional is given.

Standard grid formats for surfaces and 3D grids are given in Section 3.1.8.

4.1 `<actions>` (necessary)

Description: Controls the main purpose of the run.
Argument: Elements specifying the main purpose

4.1.1 `<mode>` (necessary)

Description: Inversion: Invert seismic input data to elastic parameters and/or facies probabilities. Needs seismic data and volume, all other missing data will be estimated. Forward: Create seismic response from background model. Not able to estimate anything. Estimation: Checks input data and performs estimation of lacking information for inversion, but stops before inversion.
Argument: 'inversion', 'forward' or 'estimation'

4.1.2 `<inversion-settings>`

Description: Controls aspects of the inversion. Only valid with the `<mode>` 'inversion' above.
Argument: Elements controlling the inversion
Default:

4.1.2.1 `<prediction>`

Description: Controls whether predicted elastic parameters will be generated.
Argument: 'yes' or 'no'
Default:

4.1.2.2 `<simulation>`

Description: Controls aspects of the simulation of elastic parameters.
Argument: Elements controlling the simulation of elastic parameters

4.1.2.2.1 `<seed>`

Description: A number used to initialise the random generator. Running a model file with a given seed will give the same simulation results each time.
Argument: Integer
Default: 0

4.1.2.2.2 <seed-file>

Description: An ASCII-file with a number used to initialise the random generator. Running a model file with a given seed will give the same simulation results each time.
Argument: File name
Default: Using 0 as seed

4.1.2.2.3 <number-of-simulations>

Description: Integer value giving the number of stochastic realizations to generate.
Argument: Integer
Default: 0

4.1.2.3 <kriging-to-wells>

Description: Should the realizations be kriged to well data?
Argument: 'yes' or 'no'
Default: 'yes' if not the <simulation> command is used.

4.1.2.4 <facies-probabilities>

Description: Should facies probabilities be estimated?
Argument: 'yes' or 'no'
Default: 'no'

4.1.3 <estimation-settings>

Description: Controls what will be estimated. Only valid with the <mode> 'estimation'. Note that these commands can only turn off estimations - a parameter that is given will not be estimated even if it says so here.
Argument: Elements controlling what to estimate
Default:

4.1.3.1 <estimate-background>

Description: If 'no', background will not be estimated unless needed for other estimation.
Argument: 'yes' or 'no'
Default: 'yes'

4.1.3.2 <estimate-correlations>

Description: If 'no', correlations will not be estimated unless needed for other estimation.
Argument: 'yes' or 'no'
Default: 'yes'

4.1.3.3 <estimate-wavelet-or-noise>

Description: If 'no', wavelets and/or noise will not be estimated unless needed for other estimation.
Argument: 'yes' or 'no'
Default: 'yes'

4.2 <project-settings> (necessary)

Description: Controls inversion volume, output and advanced program settings.
Argument: Elements controlling inversion volume, output and advanced program settings
Default:

4.2.1 `<output-volume>` **(necessary)**

Description: Defines the core inversion volume. All grid output will be given in this volume.
Argument: Elements defining the core inversion volume.
Default:

4.2.1.1 `<interval-two-surfaces>`

Description: One way to give the top and bottom limitations. Must be used if output in depth domain is desired. This, `<multiple-intervals>` or `<interval-one-surface>` must be given.
Argument:
Default:

4.2.1.1.1 `<top-surface>` **(necessary)**

Description: File name(s) for top surface file(s).
Argument: Elements controlling the top surface
Default:

####### 4.2.1.1.1.1 `<time-file>`

Description: File name for standard surface file giving top surface in time. This or `<time-value>` must be given.
Argument: File name
Default:

####### 4.2.1.1.1.2 `<time-value>`

Description: Value giving the top time for the inversion interval. This or `<time-file>` must be given.
Argument: Value
Default:

####### 4.2.1.1.1.3 `<depth-file>`

Description: File name for standard surface file giving top surface in depth.
Argument: File name
Default:

4.2.1.1.2 `<base-surface>` **(necessary)**

Description: File name(s) for base surface file(s).
Argument: Elements controlling the base surface
Default:

####### 4.2.1.1.2.1 `<time-file>`

Description: File name for standard surface file giving base surface in time. This or `<time-value>` must be given.
Argument: File name
Default:

####### 4.2.1.1.2.2 `<time-value>`

Description: Value giving the base time for the inversion interval. This or <time-file> must be given.
Argument: Value
Default:

4.2.1.1.2.3 <depth-file>

Description: File name for standard surface file giving base surface in depth.
Argument: File name
Default:

4.2.1.1.3 <number-of-layers>

Description: Integer value giving how many layers to use between top and base surface.
Argument: Integer
Default:

4.2.1.1.4 <velocity-field>

Description: File name for standard 3D grid file. Gives more detailed depth conversion information. Without this, constant velocity per trace is used. If only one depth surface is given, this is used to compute the other. Otherwise, the depth interval will always match both surfaces, but the velocity field is scaled and used for internal depth computations. Can not be used with <velocity-field-from-inversion>.
Argument: File name
Default:

4.2.1.1.5 <velocity-field-from-inversion>

Description: If given, velocity field from inversion is used for depth conversion. See <velocity-field> for details on how this is done. Can not be used with <velocity-field>.
Argument: 'yes' or 'no'
Default:

4.2.1.2 <interval-one-surface>

Description: Using this command gives parallel top and base of inversion interval. This, <multiple-intervals> or <interval-two-surfaces> must be given.
Argument: Elements for parallel top and base inversion interval
Default:

4.2.1.2.1 <reference-surface>

Description: File name for standard surface file. The top and base surfaces for the inversion interval will be parallel to this.
Argument: File name
Default:

4.2.1.2.2 <shift-to-interval-top>

Description: Value giving the distance from reference surface to top surface. This value is added to the reference surface to create the top surface.

Argument: Value
Default:

4.2.1.2.3 `<thickness>`

Description: Value giving the thickness of the inversion interval. This value is added to the top surface to create the base surface.
Argument: Value
Default:

4.2.1.2.4 `<sample-density>`

Description: Value giving the thickness of a layer in the inversion interval. The thickness should be divisible by this value.
Argument: Value
Default:

4.2.1.3 `<multiple-intervals>`

Description: One way to give the top and bottom limitations of the inversion intervals. Must be used if output in depth domain is desired. This, `<interval-one-surface>` or `<interval-two-surfaces>` must be given.
Argument:
Default:

4.2.1.3.1 `<top-surface>` **(necessary)**

Description: File name(s) for top surface file(s).
Argument: Elements controlling the top surface
Default:

4.2.1.3.1.1 `<time-file>`

Description: File name for standard surface file giving top surface in time. This or `<time-value>` must be given.
Argument: File name
Default:

4.2.1.3.1.2 `<time-value>`

Description: Value giving the top time for the inversion interval. This or `<time-file>` must be given.
Argument: Value
Default:

4.2.1.3.1.3 `<depth-file>`

Description: File name for standard surface file giving top surface in depth.
Argument: File name
Default:

4.2.1.3.2 `<interval>` **(necessary)**

Description: Repeatable command: defines an inversion interval.
Argument: Elements controlling the interval.
Default:

4.2.1.3.2.1 `<name>` (necessary)

Description: Inversion interval name. Must be unique.
Argument: String
Default:

4.2.1.3.2.2 `<base-surface>` (necessary)

Description: Base surface
Argument: File name
Default:

4.2.1.3.2.2.1 `<time-file>`

Description: File name for standard surface file giving top surface in time. This or `<time-value>` must be given.
Argument: File name
Default:

4.2.1.3.2.2.2 `<time-value>`

Description: Value giving the top time for the inversion interval. This or `<time-file>` must be given.
Argument: Value
Default:

4.2.1.3.2.2.3 `<depth-file>`

Description: File name for standard surface file giving top surface in depth.
Argument: File name
Default:

4.2.1.3.2.2.4 `<erosion-priority>` (necessary)

Description: Priority of the base surface file for this interval. The top surface file and all base surface files in the inversion intervals need to given different priority.
Argument: Int
Default:

4.2.1.3.2.2.5 `<uncertainty>`

Description: Uncertainty of the base surface file for this interval. Used to smooth relaisations across zone borders. Uncertainty on the lowest base surace will be ignored.
Argument: Value
Default: 10

4.2.1.3.2.3 <number-of-layers>

Description: Number of layers for the interval
Argument: Int
Default: Use resolution from seismic data.

4.2.1.4 <area-from-surface>

Description: Inversion area can be defined by a surface. Then the name of the surface is given in this command. Other ways to define inversion area are by the commands <utm-coordinates> or <inline-crossline-numbers>. If none of these commands are used, the area is defined by the first seismic data file, or from Vp if we do forward modelling.
Argument:
Default:

4.2.1.4.1 <file-name>

Description: File name for standard surface file.
Argument: File name
Default:

4.2.1.4.2 <snap-to-seismic-data>

Description: Find the smallest rectangular IL-XL box enclosing the entire surface and do the inversion using these IL-XL values. This allows a user to specify an inversion area in UTM and get the inversion volume aligned with seismic data.
Argument: 'yes' or 'no'
Default: 'no'

4.2.1.5 <utm-coordinates>

Description: Describe area by UTM coordinates.
Argument:
Default:

4.2.1.5.1 <reference-point-x>

Description: Value giving the x-coordinate of a corner of the area.
Argument: Value
Default:

4.2.1.5.2 <reference-point-y>

Description: Value giving the y-coordinate of a corner of the area.
Argument: Value
Default:

4.2.1.5.3 <length-x>

Description: Value giving the area length along the rotated x-axis.
Argument: Value
Default:

4.2.1.5.4 <length-y>

Description: Value giving the area length along the rotated y-axis.
Argument: Value
Default:

4.2.1.5.5 <sample-density-x>

Description: Cell size along the rotated x-axis.
Argument: Integer
Default:

4.2.1.5.6 <sample-density-y>

Description: Cell size along the rotated y-axis.
Argument: Integer
Default:

4.2.1.5.7 <angle>

Description: Orientation of the azimuth.
Argument:
Default:

4.2.1.5.8 <snap-to-seismic-data>

Description: Find the smallest rectangular IL-XL box enclosing the entire UTM specified area and do the inversion using these IL-XL values. This allows a user to specify an inversion area in UTM coordinates and get an inversion volume aligned with seismic data. Keywords <sample-density-x> and <sample-density-y> are not needed when snapping is activated.
Argument: 'yes' or 'no'
Default: 'no'

4.2.1.6 <inline-crossline-numbers>

Description: Describe area by inline and crossline numbers. il-start and xl-start must be given if this command is used, the other variables are optional. The numbers which are not specified are taken from the SegY file containing seismic data. The command is only working if seismic data are given on SegY format.
Argument:
Default:

4.2.1.6.1 <il-start>

Description: Start value for inline.
Argument:
Default:

4.2.1.6.2 <il-end>

Description: End value for inline.
Argument:
Default:

4.2.1.6.3 `<xl-start>`

Description: Start value for crossline.
Argument:
Default:

4.2.1.6.4 `<xl-end>`

Description: End value for crossline.
Argument:
Default:

4.2.1.6.5 `<il-step>`

Description: Step value for inline.
Argument:
Default:

4.2.1.6.6 `<xl-step>`

Description: Step value for crossline.
Argument:
Default:

4.2.2 `<time-to-depth-mapping-for-3d-wavelet>`

Description: Defines the mapping between pseudo-depth and local time in the target area for 3D wavelet.
Argument: Reference depth, velocity and time surface for mapping
Default:

4.2.2.1 `<reference-depth>`

Description: Holds the z-value for the reference depth for target area
Argument: Depth in meter
Default:

4.2.2.2 `<average-velocity>`

Description: Holds the average velocity in the target area
Argument: Velocity in meter/second
Default:

4.2.2.3 `<reference-time-surface>`

Description: File name for the time surface corresponding to the reference depth. Standard surface format.
Argument: File name
Default:

4.2.3 `<io-settings>`

Description: Holds commands that deal with what output to give and where, and where to find input.
Argument: Elements controlling output and input
Default:

4.2.3.1 <top-directory>

Description: Directory name giving the working directory for the model file. Must end with directory separator.
Argument: Directory name
Default:

4.2.3.2 <input-directory>

Description: Directory name, relative to <top-directory>, for root directory for input files. Must end with directory separator.
Argument: Directory name
Default:

4.2.3.3 <output-directory>

Description: Directory name, relative to <top-directory>, for root directory for output files. Must end with directory separator.
Argument: Directory name
Default:

4.2.3.4 <grid-output>

Description: All commands related to output given as grids are gathered here.
Argument: Elements controlling output given as grids
Default:

4.2.3.4.1 <domain>

Description: Commands specifying which domain output should be in.
Argument: Elements controlling the output domain
Default:

4.2.3.4.1.1 <depth>

Description: Should output come in depth domain? Requires information under <interval-two-surfaces>.
Argument: 'yes' or 'no'
Default: 'no'

4.2.3.4.1.2 <time>

Description: Should output come in time domain?
Argument: 'yes' or 'no'
Default: 'yes'

4.2.3.4.2 <format>

Description: Control of the format of output grids.
Argument: Elements controlling the format of output grids
Default:

4.2.3.4.2.1 <segy-format>

Description: Information about the segy format. By default CRAVA recognises SeisWorks, IESX, SIP and Charisma, see Table 3.1.

Argument: Elements containing information about the segy format.
Default:

4.2.3.4.2.1.1 `<standard-format>`

Description: Giving the starting format for modifications.
Argument: 'seisworks', 'iesx', 'charisma' or 'SIP'
Default: 'seisworks'

4.2.3.4.2.1.2 `<location-x>`

Description: The byte location for the x-coordinate in the trace header.
Argument: Integer
Default:

4.2.3.4.2.1.3 `<location-y>`

Description: The byte location for the y-coordinate in the trace header.
Argument: Integer
Default:

4.2.3.4.2.1.4 `<location-il>`

Description: The byte location for the inline in the trace header.
Argument: Integer
Default:

4.2.3.4.2.1.5 `<location-xl>`

Description: The byte location for the crossline in the trace header.
Argument: Integer
Default:

4.2.3.4.2.1.6 `<bypass-coordinate-scaling>`

Description: Indicates whether coordinate scaling information should be used.
Argument: 'yes' or 'no'
Default:

4.2.3.4.2.1.7 `<location-scaling-coefficient>`

Description:
Argument: Integer
Default:

4.2.3.4.2.2 `<segy>`

Description: Should grid output come as segy?
Argument: 'yes' or 'no'
Default:

4.2.3.4.2.3 <storm>

Description: Should grid output come as storm?
Argument: 'yes' or 'no'
Default: 'yes' if <format> command is not given.

4.2.3.4.2.4 <crava>

Description: Should grid output come in crava binary format?
Argument: 'yes' or 'no'
Default:

4.2.3.4.2.5 <sgri>

Description: Should grid output come as storm sgri?
Argument: 'yes' or 'no'
Default:

4.2.3.4.2.6 <ascii>

Description: Should grid output come as storm ascii?
Argument: 'yes' or 'no'
Default:

4.2.3.4.3 <elastic-parameters>

Description: Controls which elastic grid parameters to output. All are 'yes' or 'no'.
Argument: Elements controlling which elastic parameters to output
Default: If this command is not given, vp, vs and density are written.

4.2.3.4.3.1 <vp>

Description:
Argument: 'yes' or 'no'
Default:

4.2.3.4.3.2 <vs>

Description:
Argument: 'yes' or 'no'
Default:

4.2.3.4.3.3 <density>

Description:
Argument: 'yes' or 'no'
Default:

4.2.3.4.3.4 <lame-lambda>

Description:
Argument: 'yes' or 'no'
Default:

4.2.3.4.3.5 <lame-mu>

Description:
Argument: 'yes' or 'no'
Default:

4.2.3.4.3.6 <poisson-ratio>

Description:
Argument: 'yes' or 'no'
Default:

4.2.3.4.3.7 <ai>

Description:
Argument: 'yes' or 'no'
Default:

4.2.3.4.3.8 <si>

Description:
Argument: 'yes' or 'no'
Default:

4.2.3.4.3.9 <vp-vs-ratio>

Description:
Argument: 'yes' or 'no'
Default:

4.2.3.4.3.10 <murho>

Description:
Argument: 'yes' or 'no'
Default:

4.2.3.4.3.11 <lambdarho>

Description:
Argument: 'yes' or 'no'
Default:

4.2.3.4.3.12 <background>

Description:
Argument: 'yes' or 'no'
Default:

4.2.3.4.3.13 <background-trend>

Description:
Argument: 'yes' or 'no'
Default:

4.2.3.4.4 <seismic-data>

Description: Controls which seismic data parameters to output. All are 'yes' or 'no'.
Argument: Elements controlling which seismic data to output
Default:

4.2.3.4.4.1 <original>

Description: Write original seismic data to file.
Argument: 'yes' or 'no'
Default:

4.2.3.4.4.2 <synthetic>

Description: Generate synthetic seismic from the inverted data.
Argument: 'yes' or 'no'
Default:

4.2.3.4.4.3 <residuals>

Description: Residuals computed by taking the original seismic and subtracting the synthetic seismic. This means that these parameters are a matched set.
Argument: 'yes' or 'no'
Default: 'no'

4.2.3.4.4.4 <synthetic-residuals>

Description: This keyword is obsolete. Use <residuals> instead, they give the same residuals.
Argument: 'yes' or 'no'
Default: 'no'

4.2.3.4.4.5 <fourier-residuals>

Description: Residuals computed in the actual inversion. Will not add up to original seismic data when combined with synthetic seismic, due to some filtering and numerical imprecision. These are written per interval if <multiple-intervals> is used.
Argument: 'yes' or 'no'
Default: 'no'

4.2.3.4.5 <other-parameters>

Description: Controls which other parameters to output. All are 'yes' or 'no'.
Argument: Elements controlling which other to output
Default:

4.2.3.4.5.1 <facies-probabilities>

Description: Write facies probabilities to file.
Argument: 'yes' or 'no'
Default: 'yes' if facies estimation is requested and <facies-probabilities-with-undef> is not specified

4.2.3.4.5.2 `<facies-probabilities-with-undef>`

Description: Write facies probabilities with undefined value to file.
Argument: 'yes' or 'no'
Default: 'no'

4.2.3.4.5.3 `<facies-likelihood>`

Description: Write likelihood for inverted seismic for each facies, $p(m|f)$.
Argument: 'yes' or 'no'
Default: 'no'

4.2.3.4.5.4 `<time-to-depth-velocity>`

Description: Write time-to-depth velocity to file.
Argument: 'yes' or 'no'
Default:

4.2.3.4.5.5 `<extra-grids>`

Description: Temporary, will be replaced. Currently triggers writing of

- Estimated background files in extended versions (go above and below inversion volume).
- Estimated background files in standard volume.

Argument: 'yes' or 'no'
Default:

4.2.3.4.5.6 `<correlations>`

Description: These are the posterior correlations between vp, vs and density after inversion.
Argument: 'yes' or 'no'
Default:

4.2.3.4.5.7 `<seismic-quality-grid>`

Description: Quality grid kriged from values for fit between facies probabilities and facies observed in each of the wells.
Argument: 'yes' or 'no'
Default:

4.2.3.4.5.8 `<rms-velocities>`

Description: Original RMS velocity travel time data
Argument: 'yes' or 'no'
Default:

4.2.3.4.5.9 `<trend-cubes>`

Description: Trend cubes used for trends in rock physics models
Argument: 'yes' or 'no'
Default:

4.2.3.5 <well-output>

Description: Collects all output that can be given in well format. Wells contain logs for vp, vs and density, each of these in four versions: Raw, filtered to background frequency, filtered to seismic frequency and seismic resolution. In addition, the facies log is written if found.
Argument: Elements collecting output given in well format
Default:

4.2.3.5.1 <format>

Description: Controls well formats used for output. Default is RMS.
Argument: Elements controlling the formats used for output
Default:

4.2.3.5.1.1 <rms>

Description: Controls if wells are written on RMS format.
Argument: 'yes' or 'no'
Default:

4.2.3.5.1.2 <norsar>

Description: Controls if wells are written on NORSAR format.
Argument: 'yes' or 'no'
Default:

4.2.3.5.2 <wells>

Description: Writes wells following original sampling density.
Argument: 'yes' or 'no'
Default:

4.2.3.5.3 <blocked-wells>

Description: Writes wells sampled to internal grid resolution.
Argument: 'yes' or 'no'
Default:

4.2.3.5.4 <blocked-logs>

Description: Not currently active.
Argument:
Default:

4.2.3.6 <wavelet-output>

Description: Collects all output that can be given for wavelets.
Argument: Elements controlling wavelet output
Default:

4.2.3.6.1 <format>

Description: Controls wavelet formats used for output. Default is JASON.
Argument: Elements controlling the formats used for output

Default:

4.2.3.6.1.1 <jason>

Description: Controls if wavelets are written on JASON form, being 'wlt' format.
Argument: 'yes' or 'no'
Default: 'yes'

4.2.3.6.1.2 <norsar>

Description: Controls if wavelets are written on NORSAR form, being 'swav' format.
Argument: 'yes' or 'no'
Default: 'no'

4.2.3.6.2 <well-wavelets>

Description: Writes estimated wavelets for each well used for wavelet estimation. Note: These wavelets are not optimally shifted, but aligned for easy comparison.
Argument: 'yes' or 'no'
Default: 'no'

4.2.3.6.3 <global-wavelets>

Description: Writes global wavelets for each seismic angle.
Argument: 'yes' or 'no'
Default: 'no'

4.2.3.6.4 <local-wavelets>

Description: Writes estimated local wavelet shift and scale surfaces. Can only be written when <local-wavelet> is requested.
Argument: 'yes' or 'no'
Default:

4.2.3.7 <other-output>

Description: Controls output that is neither standard grid nor well.
Argument: Elements controlling output
Default:

4.2.3.7.1 <extra-surfaces>

Description: Temporary, will be replaced. Currently writes:

- Top and base surface for constant thickness interval used for log filtering and facies probabilities.
- Top and base surface for extended inversion interval computed from correlation surface.
- Top and base surface for background estimation interval (larger than inversion interval).

Argument: 'yes' or 'no'
Default:

4.2.3.7.2 <prior-correlations>

Description: Write prior correlation files.
Argument: 'yes' or 'no'
Default:

4.2.3.7.3 <local-noise>

Description: Writes estimated local noise surface. Can only be written when <local-noise-scaled> or <estimate-local-noise> is requested.
Argument: 'yes' or 'no'
Default:

4.2.3.7.4 <rock-physics-distributions>

Description: Writes rock physics distribution per facies, in a vp, vs, and density grid. That is, the x-axis is Vp values, y-axis is Vs values and z-axis is density values. The value in each cell is the probability density of this set of elastic values for this facies. The probability density is scaled by a factor of 1000000. The physical density values (z-axis) are scaled by a factor of 1000. Only available when facies probabilities are computed.
Argument: 'yes' or 'no'
Default: 'no'

4.2.3.7.5 <error-file>

Description: Writes all errors to a separate file, in addition to the log file.
Argument: 'yes' or 'no'
Default: 'no'

4.2.3.7.6 <task-file>

Description: Writes all tasks to a separate file, in addition to the log file.
Argument: 'yes' or 'no'
Default: 'no'

4.2.3.7.7 <rock-physics-trends>

Description: Writes rock physics trends estimated in <trend-1d> and <trend-2d> to file. Only available when the trends are estimated.
Argument: 'yes' or 'no'
Default: 'no'

4.2.3.8 <file-output-prefix>

Description: Common prefix added to all files written in the run. Identifies the run.
Argument: String
Default:

4.2.3.9 <log-level>

Description:
Argument: String. Possible values are error, warning, low, medium, high.
Default: Low

4.2.4 `<advanced-settings>`

Description: A collection of different commands that control advanced aspects of the program control.

Argument: Commands controlling advanced aspects of the program control

Default:

4.2.4.1 `<number-of-threads>`

Description: The number of threads to use for parallelization. If a positive number is given, that particular number of threads is requested. If a negative number is given all available threads minus that number is requested. For instancne, by specifying -1, all minus one threads will be used.

Argument: Value

Default: All available

4.2.4.2 `<fft-grid-padding>`

Description: Controls the padding size, can be used to optimize memory or improve visual results. Padding should be at least one range laterally, and a wavelet length vertically to avoid edge effects.

Argument: Elements controlling the padding size

Default:

4.2.4.2.1 `<x-fraction>`

Description: Value telling how large the padding in the x-direction should be relative to the x-length.

Argument: Value

Default: 0.0

4.2.4.2.2 `<y-fraction>`

Description: Value telling how large the padding in the x-direction should be relative to the y-length.

Argument: Value

Default: 0.0

4.2.4.2.3 `<z-fraction>`

Description: Value telling how large the padding in the x-direction should be relative to the thickness.

Argument: Value

Default: 0.0

4.2.4.3 `<use-intermediate-disk-storage>`

Description: When running under Windows with less physical memory than the program requires, this activates a built-in smart-swap. It is more efficient to use this smart-swapping than the built-in windows paging system. Linux/Unix swap is so efficient that this option has little effect there. If you run Crava on a machine that you share with other users, it can be wise to use this if you know that Crava will need most of the memory.

Argument: 'yes' or 'no'

Default:

4.2.4.4 <vp-vs-ratio>

Description: Value of Vp/Vs ratio used in reflection matrix. By default, the Vp/Vs ratio is estimated from the background model.
Argument: Value OR a list of intervals with corresponding values.
Default: Not set

4.2.4.4.1 <interval>

Description: Repeatable command. Defines the Vp/Vs ratio for the relevant interval. The Vp/Vs-ratio must be specified for either all or none of the intervals defined in <multiple-intervals>.
Argument: Name and Vp/Vs-ratio for the interval.
Default:

4.2.4.4.1.1 <name>

Description: Name of the relevant inversion interval defined in <multiple-intervals>.
Argument: String
Default:

4.2.4.4.1.2 <ratio>

Description: Value of Vp/Vs ratio used in reflection matrix for this interval. By default, the Vp/Vs ratio is estimated from the background model.
Argument: Value
Default: Not set

4.2.4.5 <vp-vs-ratio-from-wells>

Description: If this command is given, the Vp/Vs ratio used in the reflection matrix will be estimated from well data. By default, the ratio is taken from the background model. If the keyword <wavelet-estimation-interval> has also been specified, the estimate will be limited to that interval.
Argument: 'yes' or 'no'
Default: 'no'

4.2.4.6 <maximum-relative-thickness-difference>

Description: Value giving the limit of how small the minimum interval thickness can be relative to maximum. If this gets too low, the transformation to stationarity for the FFT-algorithm gives strange results.
Argument: Value
Default: Default is 0.5, which is acceptable. Slightly smaller seems to work as well.

4.2.4.7 <frequency-band>

Description: This command controls the frequency band of the inversion, so high and/or low frequencies can be filtered away. This ought to be done by the wavelet, but can be done here.
Argument: Elements controlling the frequency band of the inversion
Default:

4.2.4.7.1 <low-cut>

Description: Value setting the minimum frequency affected by the inversion.
Argument: Value

Default: 5.0

4.2.4.7.2 <high-cut>

Description: Value setting the maximum frequency affected by the inversion.
Argument: Value
Default: 55.0

4.2.4.8 <energy-threshold>

Description: If the energy in a trace falls below this threshold relative to the average, the trace is interpolated from neighbours.
Argument: Value
Default: 0.0

4.2.4.9 <wavelet-tapering-length>

Description: Value giving the length of the wavelet to be estimated in ms. For a 1D wavelet this is the width of the Papoulis taper used, when tapering of auto-correlation of reflection coefficients, and cross-correlation of reflection-coefficients and seismic data, before doing the spectral division. Increasing this value will give less bias (i.e. less energy at low frequencies), but larger variance in the estimate (i.e. secondary oscillations). For a 3D wavelet this gives the length of the source-wavelet, by dividing this length by the vertical sampling interval we find the the number of parameters that is estimated by the least-squares approach in the 3D-wavelet.
Argument: Value
Default: 200.0

4.2.4.10 <minimum-relative-wavelet-amplitude>

Description: Value giving the ratio between the smallest relevant amplitude and the largest amplitude of peaks on an estimated wavelet. Edge peaks below this ratio are removed.
Argument: Value
Default: 0.05

4.2.4.11 <maximum-wavelet-shift>

Description: Value controlling how much the wavelet is allowed to be shifted when doing estimation of wavelet or noise.
Argument: Value
Default: 11.0

4.2.4.12 <minimum-sampling-density>

Description: Threshold value for minimum sampling density allowed.
Argument: Value
Default: 0.5 ms

4.2.4.13 <minimum-horizontal-resolution>

Description: Threshold value for minimum horizontal resolution allowed.
Argument: Value
Default: 5 m

4.2.4.14 <white-noise-component>

Description: In order to stabilise the inversion, we need to interpret some of the noise as white. This value controls the fraction.
Argument: Value between 0 and 1.
Default: 0.1

4.2.4.15 <reflection-matrix>

Description: The file should be a 3 by number of seismic data cubes ascii matrix. The first column is the factor used for vp for each cube setting (angle and ps/pp) when computing the reflection coefficients. The second and third are for vs and density.
Argument: File name
Default: Linearised Aki-Richards.

4.2.4.16 <kriging-data-limit>

Description: Integer value giving the limit for the amount of well data used to krige each point. A high value gives a smoother and more exact field, but takes more time.
Argument: Integer
Default: 250

4.2.4.17 <seismic-quality-grid>

Description: Input parameters for seismic quality grid if it is set to yes under <seismic-quality-grid> in <grid-output>.
Argument:
Default:

4.2.4.17.1 <range>

Description: Range from wells. Outside this range the facies probabilities are estimated from seismic data with a weighing given in <value>.
Argument: Value
Default: 2000

4.2.4.17.2 <value>

Description: The value of weighing of seismic-data between wells.
Argument: Value between 0 and 1.
Default: An average of all fit values from wells.

4.2.4.18 <debug-level>

Description: Gives debug messages and output. Not intended for use except on request by NR.
Argument: Integer value 0, 1 or 2.
Default: 0

4.2.4.19 <smooth-kriged-parameters>

Description: Tells whether we should smooth borders between kriging blocks or not.
Argument: yes or no
Default: no

4.2.4.20 <rms-panel-mode>

Description: Disables some checks that are unnecessary when running from RMS.

Argument: yes or no
Default: no

4.2.4.21 `<guard-zone>`

Description: Changes the amount of data that will be required outside the interval of interest. The guard zone contains data that will contribute to the inversion results in the interval of interest, and reducing the guard zone is therefore discouraged.
Argument: Value
Default: 100ms

4.2.4.22 `<3d-wavelet-tuning-factor>`

Description: Allows tuning of the 3D wavelet estimation. A large value forces better fit of wavelet, while a smaller value gives smaller secondary peaks in wavelet.
Argument: Value
Default: 50

4.2.4.23 `<gradient-smoothing-range>`

Description: Controls smoothing of the gradient used in 3D wavelet estimate and 3D inversion. This should be of the order of the horisontal extent of the 3D wavelet.
Argument: Value
Default: 100

4.2.4.24 `<estimate-well-gradient-from-seismic>`

Description: If 'yes', the well gradient used for 3D wavelet estimation is estimated from seismic. Otherwise this is taken from the correlation direction.
Argument: yes or no
Default: no

4.2.4.25 `<write-ascii-surfaces>`

Description: Surfaces are written on the same format at output grids. If this is set to 'yes' then all surfaces will also be written on ascii-format.
Argument: yes or no
Default: no

4.3 `<survey>` (necessary)

Description: All information about the seismic data is collected here.
Argument: Elements containing information about the seismic data
Default:

4.3.1 `<angular-correlation>`

Description: 1D variogram. Gives the noise correlation between survey angles.
Argument: 1D variogram, see Section 4.7.
Default:

4.3.2 `<segy-start-time>`

Description: Global start time for segy cubes. This is used if no individual time is given for a segy-cube.
Argument: Value

Default: 0

4.3.3 `<angle-gather>` (necessary)

Description: Repeatable command, one for each seismic data cube.
Argument: Elements containing information about the different seismic data cubes
Default:

4.3.3.1 `<offset-angle>` (necessary)

Description: This is the angle for the seismic data cube.
Argument: Value
Default:

4.3.3.2 `<seismic-data>` (necessary)

Description: Information about the seismic data cube.
Argument: Elements containing information about the seismic data cube
Default:

4.3.3.2.1 `<file-name>` (necessary)

Description: File name for the seismic data cube of one of the standard 3D formats, see Section 3.1.8. The file type will be automatically detected.
Argument: File name
Default:

4.3.3.2.2 `<start-time>`

Description: Value giving the start time for this segy file. If not given, the start time is taken from `<segy-start-time>`.
Argument: Value
Default:

4.3.3.2.3 `<segy-format>`

Description: Information about the segy format. By default, CRAVA recognises SeisWorks, IESX, SIP and Charisma. See Table 3.1.
Argument: Elements containing information about the segy format
Default:

4.3.3.2.3.1 `<standard-format>`

Description: Giving the starting format for modifications.
Argument: 'seisworks', 'iesx', 'charisma' or 'SIP'
Default: 'seisworks'

4.3.3.2.3.2 `<location-x>`

Description: The byte location for the x-coordinate in the trace header.
Argument: Integer
Default:

4.3.3.2.3.3 `<location-y>`

Description: The byte location for the y-coordinate in the trace header.
Argument: Integer
Default:

4.3.3.2.3.4 `<location-il>`

Description: The byte location for the inline in the trace header.
Argument: Integer
Default:

4.3.3.2.3.5 `<location-xl>`

Description: The byte location for the crossline in the trace header.
Argument: Integer
Default:

4.3.3.2.3.6 `<bypass-coordinate-scaling>`

Description: Indicates whether coordinate scaling information should be used.
Argument: 'yes' or 'no'
Default:

4.3.3.2.3.7 `<location-scaling-coefficient>`

Description:
Argument: Integer
Default:

4.3.3.2.4 `<type>`

Description: Indicating the type of seismic data. Note that if both pp and ps cubes are used, these must be aligned.
Argument: 'pp' or 'ps'
Default: 'pp'

4.3.3.3 `<wavelet>`

Description: Information about the wavelet for this angle and seismic type. If not given, the wavelet will be estimated.
Argument: Elements containing information about the wavelet and seismic type
Default:

4.3.3.3.1 `<file-name>`

Description: File name for wavelet file on JASON or NORSAR format. Can not be given together with ricker. If neither file-name nor ricker is given, wavelet is estimated.
Argument: File name
Default:

4.3.3.3.2 `<ricker>`

Description: Use Ricker wavelet. Can not be given together with file-name. If neither file-name nor ricker is given, wavelet is estimated.

Argument: Peak frequency
Default:

4.3.3.3.3 `<scale>`

Description: Wavelet read from file or ricker wavelet is multiplied by this. Has no meaning when wavelet is estimated.
Argument: Value
Default:

4.3.3.3.4 `<estimate-scale>`

Description: Should global scale be estimated?
Argument: 'yes' or 'no'
Default:

4.3.3.3.5 `<local-wavelet>`

Description: The amplitude and shift of the wavelet may be modified locally by 2D fields for shift and scale values. This is handled here.
Argument: Elements modifying the amplitude and shift of the wavelet
Default:

4.3.3.3.5.1 `<shift-file>`

Description: File name for standard surface file giving the local shift for the wavelet. Not allowed when wavelet is estimated.
Argument: File name
Default:

4.3.3.3.5.2 `<scale-file>`

Description: File name for standard surface file giving local scale for the wavelet. Not allowed when wavelet is estimated.
Argument: File name
Default:

4.3.3.3.5.3 `<estimate-shift>`

Description: Should a local shift be estimated? Not allowed with `<shift-file>`, but can be used both with given and estimated wavelet.
Argument: 'yes' or 'no'
Default:

4.3.3.3.5.4 `<estimate-scale>`

Description: Should a local scale be estimated? Not allowed with `<scale-file>`, but can be used both with given and estimated wavelet.
Argument: 'yes' or 'no'
Default:

4.3.3.4 `<wavelet-3d>`

Description: Information about the 3D-wavelet for this angle and seismic type. If not given, a 1D-wavelet is assumed.

Argument: Elements containing information about the 3D-wavelet

Default:

4.3.3.4.1 `<file-name>`

Description: File name for the 1D-wavelet file. This 1D-wavelet will define the 3D-wavelet in combination with the filter given in `<processing-factor-file-name>`. If not given, the 1D-wavelet is estimated.

Argument: File name

Default:

4.3.3.4.2 `<processing-factor-file-name>`

Description: File name for 3D-wavelet damping factor filter file. The 3D-wavelet is defined by the 1D-wavelet and the filter. The 1D-wavelet is either given in `<file-name>` or estimated. In either case this filter file must be given.

Argument: File name for the amplitude scalings in the wavenumber filter.

Default:

4.3.3.4.3 `<propagation-factor-file-name>`

Description: File name for 3D-wavelet correction filter file. This is used to set up the noise model for the 3D-wavelet.

Argument: File name for the correction factors in the wavenumber filter.

Default:

4.3.3.4.4 `<stretch-factor>`

Description: Stretch factor for 3D-wavelet. The pulse is stretch with this factor.

Argument: Value > 0.0

Default: 1.0

4.3.3.4.5 `<estimation-range-x-direction>`

Description: Range for area around the well in x-direction where data are used in 3D wavelet estimation.

Argument: Value >= 0.0

Default: 0.0

4.3.3.4.6 `<estimation-range-y-direction>`

Description: Range for area around the well in y-direction where data are used in 3D wavelet estimation.

Argument: Value >= 0.0

Default: 0.0

4.3.3.5 `<match-energies>`

Description: If 'yes', signal to noise ratio and wavelet scaling will be set to match model values with empirical values. Not a common estimator.

Argument: 'yes' or 'no'
Default:

4.3.3.6 <signal-to-noise-ratio>

Description: Value for the signal to noise value. If not given, this will be estimated.
Argument: Value
Default:

4.3.3.7 <local-noise-scaled>

Description: Name of standard surface file with local noise.
Argument: File name
Default:

4.3.3.8 <estimate-local-noise>

Description: Can not say 'yes' here if <local-noise-scaled> is given.
Argument: 'yes' or 'no'
Default:

4.3.4 <wavelet-estimation-interval>

Description: Controls the time interval used for wavelet estimation by a top and base surface.
Argument: Elements controlling the time interval used for wavelet estimation
Default: By default, estimation is done from all available seismic and well data.

4.3.4.1 <top-surface>

Description: File name for standard surface file, or a constant value, giving the top of the time interval used for wavelet estimation.
Argument: Elements controlling the top surface.
Default:

4.3.4.1.1 <time-file>

Description: File name for standard surface file giving the top of the time interval used for wavelet estimation. This or <time-value> must be given.
Argument: File name
Default:

4.3.4.1.2 <time-value>

Description: Value giving the top time used the wavelet estimation. This or <time-file> must be given.
Argument: Value
Default:

4.3.4.2 <base-surface>

Description: File name for standard surface file, or a constant value, giving the base of the time interval used for wavelet estimation.
Argument: Elements controlling the base surface.
Default:

4.3.4.2.1 <time-file>

Description: File name for standard surface file giving the base of the time interval used for wavelet estimation. This or <time-value> must be given.
Argument: File name
Default:

4.3.4.2.2 <time-value>

Description: Value giving the base time used the wavelet estimation. This or <time-file> must be given.
Argument: Value
Default:

4.3.5 <time-gradient-settings>

Description: The prior standard deviation of the gradients are given, as well as the minimum distance for where gradient lines should not cross each other
Argument: The standard deviation and the minimum distance
Default:

4.3.5.1 <distance>

Description: The minimum lateral distance for where the gradient lines should not cross. The distance is equal for both x- and y-direction.
Argument: Value
Default: 100 m

4.3.5.2 <sigma>

Description: The prior standard deviation of the gradient. Equal for both x- and y-gradients
Argument: Value
Default: 1 ms/m

4.3.6 <travel-time>

Description: Travel time data
Argument: Elements controlling travel time data
Default:

4.3.6.1 <rms-data>

Description: Elements controlling the RMS velocities
Argument:
Default:

4.3.6.1.1 <file-name>

Description: File name for the RMS velocities
Argument:
Default:

4.3.6.1.2 <standard-deviation>

Description: Standard deviation of the RMS data
Argument:
Default:

4.3.6.2 `<horizon>`

Description: Repeated command, one for each horizon file.
Argument: Elements controlling the horizon data
Default:

4.3.6.2.1 `<file-name>`

Description: File name for the travel time horizon
Argument:
Default:

4.3.6.2.2 `<horizon-name>`

Description: Horizon name used to identify the travel time horizon in different time lapses
Argument:
Default:

4.3.6.2.3 `<standard-deviation>`

Description: Standard deviation of the travel time horizon
Argument:
Default:

4.3.6.3 `<lateral-correlation-stationary-data>`

Description: 2D variogram for the lateral correlation in the stationary data calculated in the travel time inversion.
Argument: 2D variogram, see Section 4.7.
Default: General exponential variogram with angle=0, range=50, subrange=50 and power=1.

4.3.7 `<gravimetry>`

Description: Elements controlling gravimetric data
Argument:
Default:

4.3.7.1 `<data-file>`

Description: File name for the gravimetric response and standard deviation
Argument:
Default:

4.3.8 `<vintage>`

Description: Vintage of seismic time lapse data
Argument: Elements controlling the vintage
Default:

4.3.8.1 `<year>`

Description: The year the seismic data were collected
Argument: Integer value
Default:

4.3.8.2 <month>

Description: The month the seismic data were collected. Can not be specified unless the corresponding year is specified
Argument: Integer value
Default:

4.3.8.3 <day-of-month>

Description: The day the seismic data were collected. Can not be specified unless both the corresponding year and month are specified
Argument: Integer value
Default:

4.4 <well-data>

Description: All information about the well data is collected here.
Argument: Elements containing information about the well data
Default:

4.4.1 <log-names>

Description: CRAVA needs to find the time, vp, vs, density and possibly facies logs. The name of these logs in the well files are given here. Note that log names are not case sensitive.
Argument: Name of logs
Default:

4.4.1.1 <time>

Description: Name of the TWT log
Argument: String
Default:

4.4.1.2 <vp>

Description: Name of the vp log. May not be given if <dt> is given.
Argument: String
Default:

4.4.1.3 <dt>

Description: Name of the inverse vp log. May not be given if <vp> is given.
Argument: String
Default:

4.4.1.4 <vs>

Description: Name of the vs log. May not be given if <dts> is given.
Argument: String
Default:

4.4.1.5 <dts>

Description: Name of the inverse vs log. May not be given if <vs> is given.
Argument: String
Default:

4.4.1.6 <density>
Description: Name of the density log.
Argument: String
Default:

4.4.1.7 <porosity>
Description: Name of the porosity log. Leave empty if porosity is not included.
Argument: String
Default:

4.4.1.8 <facies>
Description: Name of the facies log.
Argument: String
Default:

4.4.1.9 <x-coordinate>
Description: Name of the x-coordinate log.
Argument: String
Default:

4.4.1.10 <y-coordinate>
Description: Name of the y-coordinate log.
Argument: String
Default:

4.4.1.11 <relative-x-coordinate>
Description: Name of the relative x-coordinate log. Can not be given together with <x-coordinate> or <y-coordinate>.
Argument: String
Default:

4.4.1.12 <relative-y-coordinate>
Description: Name of the relative y-coordinate log. Can not be given together with <x-coordinate> or <y-coordinate>.
Argument: String
Default:

4.4.2 <well>
Description: Repeatable command, one for each well. Contains information about the wells.
Argument: Elements containing information about the wells
Default:

4.4.2.1 <log-names>
Description: The name of log headings for this well file are given here. Same arguments as for the common <log-names> above.
Argument: Name of logs
Default: Log names that are not given here are taken from the common <log-names> above.

4.4.2.1.1 <time>

Description: Name of the TWT log
Argument: String
Default:

4.4.2.1.2 <vp>

Description: Name of the vp log. May not be given if <dt> is given.
Argument: String
Default:

4.4.2.1.3 <dt>

Description: Name of the inverse vp log. May not be given if <vp> is given.
Argument: String
Default:

4.4.2.1.4 <vs>

Description: Name of the vs log. May not be given if <dts> is given.
Argument: String
Default:

4.4.2.1.5 <dts>

Description: Name of the inverse vs log. May not be given if <vs> is given.
Argument: String
Default:

4.4.2.1.6 <density>

Description: Name of the density log.
Argument: String
Default:

4.4.2.1.7 <porosity>

Description: Name of the porosity log. Leave empty if porosity is not included.
Argument: String
Default:

4.4.2.1.8 <facies>

Description: Name of the facies log.
Argument: String
Default:

4.4.2.1.9 <x-coordinate>

Description: Name of the x-coordinate log.
Argument: String
Default:

4.4.2.1.10 <y-coordinate>

Description: Name of the y-coordinate log.
Argument: String
Default:

4.4.2.1.11 <relative-x-coordinate>

Description: Name of the relative x-coordinate log. Can not be given together with <x-coordinate> or <y-coordinate>.
Argument: String
Default:

4.4.2.1.12 <relative-y-coordinate>

Description: Name of the relative y-coordinate log. Can not be given together with <x-coordinate> or <y-coordinate>.
Argument: String
Default:

4.4.2.2 <file-name>

Description: File name for a well file. RMS or Norsar format.
Argument: File name
Default:

4.4.2.3 <use-for-wavelet-estimation>

Description: Should this well be used for wavelet estimation?
Argument: 'yes' or 'no'
Default:

4.4.2.4 <use-for-background-trend>

Description: Should this well be used for background trend estimation?
Argument: 'yes' or 'no'
Default:

4.4.2.5 <use-for-facies-probabilities>

Description: Should this well be used for facies probability estimation?
Argument: 'yes' or 'no'
Default:

4.4.2.6 <use-for-rock-physics>

Description: Should this well be used to calibrate rock physics models?
Argument: 'yes' or 'no'
Default:

4.4.2.7 <synthetic-vs-log>

Description: Is the Vs log in this well synthetic? Will be detected from Vp correlation if not specified here.
Argument: 'yes' or 'no'
Default:

4.4.2.8 <filter-elastic-logs>

Description: Should we multi-parameter-filter the elastic logs in this well after the inversion?
Argument: 'yes' or 'no'
Default:

4.4.2.9 <optimize-position>

Description: Repeatable command, one for each offset angle used for estimating optimised well location for this well.
Argument: Elements controlling optimisation of well location
Default:

4.4.2.9.1 <angle>

Description: Offset angle used for estimating optimised well location
Argument: Value
Default:

4.4.2.9.2 <weight>

Description: Weight of the offset angle given in <angle>
Argument: Value
Default: 1

4.4.3 <high-cut-seismic-resolution>

Description: This frequency is used to filter wells down to seismic resolution. Only used to generate output logs for QC.
Argument: Value
Default:

4.4.4 <allowed-parameter-values>

Description: Sometimes there are faulty values in well logs. Here, trigger values for error detection can be controlled. These fall in two categories: Actual log values that are wrong, or logs that have extremely low or high variance when the background model is subtracted.
Argument: Elements controlling trigger values for error detection
Default:

4.4.4.1 <minimum-vp>

Description: Value for the smallest legal vp value.
Argument: Value
Default: 1300 m/s

4.4.4.2 <maximum-vp>

Description: Value for the largest legal vp value.
Argument: Value
Default: 7000 m/s

4.4.4.3 <minimum-vs>

Description: Value for the smallest legal vs value.
Argument: Value
Default: 200 m/s

4.4.4.4 <maximum-vs>

Description: Value for the largest legal vs value.
Argument: Value
Default: 4200 m/s

4.4.4.5 <minimum-density>

Description: Value for the smallest legal density value.
Argument: Value
Default: 1.4 g/cm^3

4.4.4.6 <maximum-density>

Description: Value for the largest legal density value.
Argument: Value
Default: 3.3 g/cm^3

4.4.4.7 <minimum-variance-vp>

Description: Value for the smallest legal variance in the vp log after the background is subtracted and logarithm is taken.
Argument: Value
Default: 0.0005

4.4.4.8 <maximum-variance-vp>

Description: Value for the largest legal variance in the vp log after the background is subtracted and logarithm is taken.
Argument: Value
Default: 0.0250

4.4.4.9 <minimum-variance-vs>

Description: Value for the smallest legal variance in the vs log after the background is subtracted and logarithm is taken.
Argument: Value
Default: 0.0010

4.4.4.10 <maximum-variance-vs>

Description: Value for the largest legal variance in the vs log after the background is subtracted and logarithm is taken.
Argument: Value
Default: 0.0500

4.4.4.11 <minimum-variance-density>

Description: Value for the smallest legal variance in the density log after the background is subtracted and logarithm is taken.
Argument: Value
Default: 0.0002

4.4.4.12 <maximum-variance-density>

Description: Value for the largest legal variance in the density log after the background is subtracted and logarithm is taken.
Argument: Value

Default: 0.0100

4.4.4.13 <minimum-vp-vs-ratio>

Description: Value for the smallest Vp/Vs-ratio regarded as likely.
Argument: Value
Default: 1.4

4.4.4.14 <maximum-vp-vs-ratio>

Description: Value for the largest Vp/Vs-ratio regarded as likely.
Argument: Value
Default: 3.0

4.4.5 <maximum-deviation-angle>

Description: Value for the maximum deviation angle of a well before it is excluded from estimation based on vertical wells (such as wavelet and signal to noise).
Argument: Value
Default: 15

4.4.6 <maximum-rank-correlation>

Description: If the correlation between vp and vs logs exceed this value, the vs log is considered to be synthetic, and not counted as additional data in estimation.
Argument: Value close to, but less than 1.
Default: 0.99

4.4.7 <maximum-merge-distance>

Description: Value giving the minimum distance in time between well log entries before they are merged to one observation.
Argument: Value
Default: 0.01

4.4.8 <maximum-offset>

Description: Value giving the maximum allowed offset for moving wells in meters.
Argument: Value
Default: 250

4.4.9 <maximum-shift>

Description: Value giving the maximum allowed vertical shift for moving wells.
Argument: Value
Default: 11.0

4.4.10 <well-move-data-interval>

Description: Defines an interval for estimation of facies probability given elastic parameters.
Argument: Elements defining estimation interval
Default: Everywhere facies and elastic logs are present.

4.4.10.1 <top-surface-file>

Description: File name for standard surface file giving the top of the estimation interval.
Argument: File name
Default:

4.4.10.2 <base-surface-file>

Description: File name for standard surface file giving the base of the estimation interval.
Argument: File name
Default:

4.5 <prior-model>

Description: This command defines the prior model for elastic parameters and possibly also facies.
Argument: Elements defining prior models for elastic parameters and facies
Default:

4.5.1 <background>

Description: Contains information about the background model or how to estimate it. Note that either all parameters must be given, or all must be estimated.
Argument: Elements containing information about the background model
Default:

4.5.1.1 <ai-file>

Description: File name for 3D grid file, giving background AI. Can not be given together with <vp-file> or <vp-constant>.
Argument: File name
Default:

4.5.1.2 <si-file>

Description: File name for 3D grid file, giving background SI. Can not be given together with <vs-file> or <vs-constant> or <vp-vs-ratio-file>.
Argument: File name
Default:

4.5.1.3 <vp-vs-ratio-file>

Description: File name for 3D grid file, giving background Vp/Vs. Can not be given together with <vs-file> or <vs-constant>.
Argument: File name
Default:

4.5.1.4 <vp-file>

Description: File name for 3D grid file, giving background vp. Can not be given together with <vp-constant>.
Argument: File name
Default:

4.5.1.5 <vs-file>

Description: File name for 3D grid file, giving background vs. Can not be given together with <vs-constant>.
Argument: File name
Default:

4.5.1.6 <density-file>

Description: File name for 3D grid file, giving background density. Can not be given together with <density-constant>.
Argument: File name
Default:

4.5.1.7 <vp-constant>

Description: Value, used for constant vp background. Can not be given together with <vp-file>.
Argument: Value
Default:

4.5.1.8 <vs-constant>

Description: Value, used for constant vs background. Can not be given together with <vs-file>.
Argument: Value
Default:

4.5.1.9 <density-constant>

Description: Value, used for constant density background. Can not be given together with <density-file>.
Argument: Value
Default:

4.5.1.10 <velocity-field>

Description: File name for 3D grid file giving a velocity field used as base for vp in background estimation. Can not be used if the background parameters are given.
Argument: File name
Default:

4.5.1.11 <lateral-correlation>

Description: 2D variogram for the lateral correlation in the elastic parameters in the estimated background model, used for kriging of wells. Can not be used if the background parameters are given.
Argument: 2D variogram, see Section 4.7.
Default:

4.5.1.12 <high-cut-background-modelling>

Description: Value giving the maximum frequency in the estimated background model. Can not be used if the background parameters are given.
Argument: Value
Default: 6.0 Hz

4.5.1.13 <filter-multizone-background>

Description: Filter multizone background model. The filtering is done after the interval grids are resampled to one grid and uses the filter value from <high-cut-background-modelling>.
Argument: 'yes' or 'no'
Default: 'yes'

4.5.1.14 <segy-header>

Description: Repeatable, optional command: Separate segy-header for each background file if they are given in segy-format.

Default: Read from segy file

4.5.1.14.1 <parameter>

Description: Reapeatable command: Specifies which background parameters uses the following <segy-format>.
Argument: ai, si, vp, vs, vp-vs-ratio or rho/density
Default:

4.5.1.14.2 <segy-format>

Description: Information about the segy format. By default, CRAVA recognises SeisWorks, IESX, SIP and Charisma. See Table 3.1.
Argument: Elements containing information about the segy format
Default:

4.5.1.14.2.1 <standard-format>

Description: Giving the starting format for modifications.
Argument: 'seisworks', 'iesx', 'charisma' or 'SIP'
Default: 'seisworks'

4.5.1.14.2.2 <location-x>

Description: The byte location for the x-coordinate in the trace header.
Argument: Integer
Default:

4.5.1.14.2.3 <location-y>

Description: The byte location for the y-coordinate in the trace header.
Argument: Integer
Default:

4.5.1.14.2.4 <location-il>

Description: The byte location for the inline in the trace header.
Argument: Integer
Default:

4.5.1.14.2.5 <location-xl>

Description: The byte location for the crossline in the trace header.
Argument: Integer
Default:

4.5.1.14.2.6 <bypass-coordinate-scaling>

Description: Indicates whether coordinate scaling information should be used.
Argument: 'yes' or 'no'
Default:

4.5.1.14.2.7 <location-scaling-coefficient>

Description:
Argument: Integer
Default:

4.5.2 <earth-model>

Description: Contains inverted seismic data used for forward modelling.
Argument: Vp, vs and rho used for forward modelling.
Default:

4.5.2.1 <vp-file>

Description: File name for 3D grid file, giving vp.
Argument: File name
Default:

4.5.2.2 <vs-file>

Description: File name for 3D grid file, giving vs.
Argument: File name
Default:

4.5.2.3 <density-file>

Description: File name 3D grid file, giving density.
Argument: File name
Default:

4.5.2.4 <ai-file>

Description: File name for 3D grid file, giving AI. Can not be given together with <vp-file> .
Argument: File name
Default:

4.5.2.5 <si-file>

Description: File name for 3D grid file, giving SI. Can not be given together with <vs-file2> or <vp-vs-ratio-file2>.
Argument: File name
Default:

4.5.2.6 <vp-vs-ratio-file>

Description: File name for 3D grid file, giving Vp/Vs. Can not be given together with <vs-file2>.
Argument: File name
Default:

4.5.2.7 <segy-header>

Description: Repeatable, optional command: Separate segy-header for each background file if they are given in segy-format.
Default: Read from segy file

4.5.2.7.1 <parameter>

Description: Reapeatable command: Specifies which background parameters uses the following

<segy-format>.
Argument: ai, si, vp, vs, vp-vs-ratio or rho/density
Default:

4.5.2.7.2 <segy-format>

Description: Information about the segy format. By default, CRAVA recognises SeisWorks, IESX, SIP and Charisma. See Table 3.1.
Argument: Elements containing information about the segy format
Default:

4.5.2.7.2.1 <standard-format>

Description: Giving the starting format for modifications.
Argument: 'seisworks', 'iesx', 'charisma' or 'SIP'
Default: 'seisworks'

4.5.2.7.2.2 <location-x>

Description: The byte location for the x-coordinate in the trace header.
Argument: Integer
Default:

4.5.2.7.2.3 <location-y>

Description: The byte location for the y-coordinate in the trace header.
Argument: Integer
Default:

4.5.2.7.2.4 <location-il>

Description: The byte location for the inline in the trace header.
Argument: Integer
Default:

4.5.2.7.2.5 <location-xl>

Description: The byte location for the crossline in the trace header.
Argument: Integer
Default:

4.5.2.7.2.6 <bypass-coordinate-scaling>

Description: Indicates whether coordinate scaling information should be used.
Argument: 'yes' or 'no'
Default:

4.5.2.7.2.7 <location-scaling-coefficient>

Description:
Argument: Integer
Default:

4.5.3 <local-wavelet>

Description: Contains prior information for local wavelet modelling.
Argument: Elements containing prior information for local wavelet estimation.
Default:

4.5.3.1 <lateral-correlation>

Description: 2D variogram for the lateral correlation in local wavelet modelling.
Argument: 2D variogram, see Section 4.7.
Default:

4.5.4 <lateral-correlation>

Description: 2D variogram for the lateral correlation in the elastic parameters.
Argument: 2D variogram, see Section 4.7.
Default:

4.5.5 <temporal-correlation>

Description: File name for the temporal correlation file. The file is an ascii file. Usually, this file comes from an earlier run of CRAVA. Cannot be used in combination with <temporal-correlation-range>, <parameter-autocovariance> or <multiple-intervals>.
Argument: File name
Default:

4.5.6 <temporal-correlation-range>

Description: Range (ms) in exponential variogram used for temporal correlation. Cannot be used in combination with <temporal-correlation>. This is used for all intervals if <multiple-intervals> is used.
Argument: Value
Default:

4.5.7 <parameter-correlation>

Description: File name for the parameter correlation file. The file is an ascii file, containing covariances between Vp, Vs and density. Cannot be used in combination with <parameter-autocovariance>. This is used for all intervals if <multiple-intervals> is used. It is most common to use a file resulting from an earlier run of CRAVA, and the file might look like this:

```
0.001171   0.000786   0.000046
0.000786   0.001810  -0.000395
0.000046  -0.000395   0.000530
```

Argument: File name
Default:

4.5.8 <parameter-autocovariance>

Description: File name for the parameter autocovariance file OR a list of intervals with a parameter autocovariance for each interval. The file is an ascii file, containing covariance matrices between Vp, Vs and density for each lag. This cannot be used in combination with <parameter-correlation> and <temporal-correlation> or <temporal-correlation-range>. Parameter and temporal correlations are integrated in this autocovariance, where <parameter-correlation> is equal to the first lag. It is most common to use a file resulting from an earlier run of CRAVA, and the first two lags in a file might look like this:

```
dz = 4.32
i = 0:
 0.0026682400  0.0017649470  0.0005514660
 0.0017649470  0.0026489375 -0.0002818111
 0.0005514660 -0.0002818111  0.0007756864

i = 1:
 0.0014685779  0.0008918178  0.0003006959
 0.0010523574  0.0014839220 -0.0002266622
 0.0002532785 -0.0002192851  0.0004530772
```

Argument: File name OR a list of intervals.
Default:

4.5.8.1 <interval>

Description: Commands controlling the correlation directions of the inversion intervals.
Argument: Elements controlling the correlation directions.
Default:

4.5.8.1.1 <name>

Description: Interval name - must correspond to one specified in <name>.
Argument: String.
Default:

4.5.8.1.2 <file-name>

Description: File name for the parameter autocovariance file.
Argument: File name
Default:

4.5.9 <correlation-direction>

Description: Standard surface file giving the single correlation direction for the inversion OR top and base correlation directions OR a list of intervals with elements controlling the correlation directions.
Argument: File name for the top correlation surface and elements controlling the base correlation surface OR a list of inversion intervals with top and base correlation surfaces.
Default:

4.5.9.1 <top-surface>

Description: Standard surface file giving the top correlation direction for the inversion. Cannot be used at the same time as <interval> or with <top-conform> set to 'yes'.
Argument: File name
Default:

4.5.9.2 <base-surface>

Description: Standard surface file giving the base correlation direction for the inversion. Cannot be used at the same time as <interval> or with <base-conform> set to 'yes'.
Argument: File name
Default:

4.5.9.3 <top-conform>

Description: Decides whether the top correlation direction should be equal to the top inversion surface. Cannot be set to 'yes' at the same time as <interval>, nor with a single correlation surface file under <correlation-direction>.
Argument: 'yes' or 'no'
Default: 'no'

4.5.9.4 <base-conform>

Description: Decides whether the base correlation direction should be equal to the base inversion surface. Cannot be set to 'yes' at the same time as <interval>, nor with a single correlation surface file under <correlation-direction>.
Argument: 'yes' or 'no'
Default: 'no'

4.5.9.5 <interval>

Description: Commands controlling the correlation directions of the inversion intervals.
Argument: Elements controlling the correlation directions.
Default:

4.5.9.5.1 <name>

Description: Interval name - must correspond to one specified in <name>.
Argument: String.
Default:

4.5.9.5.2 <single-surface>

Description: Single correlation direction given as a standard surface file. Cannot be used simultaneously with <top-conform>, <base-conform>, <base-surface> or <top-surface>.
Argument: String.
Default:

4.5.9.5.3 <top-surface>

Description: Top correlation direction given as a standard surface file. Cannot be used at the same time as <single-surface>.
Argument: File name.
Default:

4.5.9.5.4 <base-surface>

Description: Base correlation direction given as a standard surface file. Cannot be used at the same time as <single-surface>.
Argument: File name.
Default:

4.5.9.5.5 <top-conform>

Description: Decides whether the top correlation direction should be equal to the top inversion surface. Cannot be set to 'yes' at the same time as <top-surface> is given.
Argument: 'yes' or 'no'

Default: 'no'

4.5.9.5.6 <base-conform>

Description: Decides whether the base correlation direction should be equal to the base inversion surface. Cannot be set to 'yes' at the same time as <base-surface> is given.
Argument: 'yes or 'no'.
Default: 'no'

4.5.10 <facies-probabilities>

Description: Commands controlling the generation of facies probabilities.
Argument: Elements controlling facies probabilities
Default:

4.5.10.1 <use-vs>

Description: Decides whether V_s information is used when computing facies probabilities.
Argument: 'yes' or 'no'.
Default: 'yes'.

4.5.10.2 <use-prediction>

Description: Decides whether sampled inversion logs are used when computing facies probabilities. If not, filtered logs are used.
Argument: 'yes' or 'no'.
Default: 'no'.

4.5.10.3 <use-absolute-elastic-parameters>

Description: Decides whether facies probabilities are generated based on absolute elastic parameters or elastic parameters minus trend (background model).
Argument: 'yes' or 'no'
Default: 'no'

4.5.10.4 <estimation-interval>

Description: Defines an interval for estimation of facies probability given elastic parameters.
Argument: Elements defining estimation interval
Default: Everywhere facies and elastic logs are present.

4.5.10.4.1 <top-surface>

Description: File name for standard surface file, or a constant value, giving the top of the time interval used for facies estimation.
Argument: Elements controlling the top surface.
Default:

4.5.10.4.1.1 <time-file>

Description: File name for standard surface file giving the top of the time interval used for facies estimation. This or <time-value> must be given.
Argument: File name
Default:

4.5.10.4.1.2 <time-value>

Description: Value giving the top time used the facies estimation. This or <time-file> must be given.
Argument: Value
Default:

4.5.10.4.2 <base-surface>

Description: File name for standard surface file, or a constant value, giving the base of the time interval used for facies estimation.
Argument: Elements controlling the base surface.
Default:

4.5.10.4.2.1 <time-file>

Description: File name for standard surface file giving the base of the time interval used for facies estimation. This or <time-value> must be given.
Argument: File name
Default:

4.5.10.4.2.2 <time-value>

Description: Value giving the base time used the facies estimation. This or <time-file> must be given.
Argument: Value
Default:

4.5.10.5 <prior-probabilities>

Description: Prior facies probabilities are given for all facies. Priors can be given as constant numbers or 3D cubes. If this command is not given, prior distribution is estimated from wells.
Argument: Elements controlling facies probabilities OR elements controlling facies probabilities per interval.
Default:

4.5.10.5.1 <facies>

Description: Repeatable command, one for each facies. All facies present in well logs must be given.
Argument: Elements containing information about the facies
Default:

4.5.10.5.1.1 <name>

Description: Name of facies.
Argument: String
Default:

4.5.10.5.1.2 <probability>

Description: Probability for the facies given above. Either this command or <probability-cube> is given, same for all facies.

Argument: Real numbers between 0 and 1. Numbers for all facies must sum to one.
Default:

4.5.10.5.1.3 <probability-cube>

Description: File name for 3D grid file containing prior facies probability for facies with name given above. Either this command or <probability> is given, same for all facies.
Argument: File name
Default:

4.5.10.5.2 <interval>

Description: Repeatable command, one for each interval. All intervals described in <multiple-intervals> must be given here.
Argument: Elements containing information about the prior probabilities per interval.
Default:

4.5.10.5.2.1 <name>

Description: Name of interval. Must correspond to one given in <multiple-intervals>.
Argument: String
Default:

4.5.10.5.2.2 <facies>

Description: Repeatable command, one for each facies.
Argument: Elements containing information about the facies
Default:

4.5.10.5.2.2.1 <name>

Description: Name of facies.
Argument: Facies name
Default:

4.5.10.5.2.2.2 <probability>

Description: Probability for the facies given above.
Argument: Real numbers between 0 and 1. Numbers for all facies per interval must sum to one.
Default:

4.5.10.6 <volume-fractions>

Description: Posterior volume fractions per facies
Argument: Elements controlling volume fractions per facies OR elements controlling volume fractions per facies per interval.
Default:

4.5.10.6.1 <facies>

Description: Repeatable command, one for each facies. All facies present in well logs must be given.
Argument: Elements containing information about the facies

Default:

4.5.10.6.1.1 <name>

Description: Name of facies.
Argument: String
Default:

4.5.10.6.1.2 <fraction>

Description: Posterior volume fraction for the facies given above.
Argument: Real numbers between 0 and 1. Numbers for all facies must sum to one.
Default:

4.5.10.6.2 <interval>

Description: Repeatable command, one for each interval. All intervals described in <multiple-intervals> must be given here.
Argument: Elements containing information about the volume fractions per interval.
Default:

4.5.10.6.2.1 <name>

Description: Name of interval. Must correspond to one given in <multiple-intervals>.
Argument: String
Default:

4.5.10.6.2.2 <facies>

Description: Repeatable command, one for each facies.
Argument: Elements containing information about the facies
Default:

4.5.10.6.2.2.1 <name>

Description: Name of facies.
Argument: Facies name
Default:

4.5.10.6.2.2.2 <fraction>

Description: Posterior volume fraction for the facies given above.
Argument: Real number between 0 and 1. Numbers for all facies per interval must sum to one.
Default:

4.5.10.7 <uncertainty-level>

Description: Value defining how large the undefined probability will be when facies probabilities are computed. This value is scaled and used as likelihood for undefined when facies probabilities are computed.
Argument: Value
Default: 0.01

4.5.11 <rock-physics>

Description: Commands controlling the rock pyhsics prior model
Argument: Elements controlling the rock physics prior model
Default:

4.5.11.1 <reservoir>

Description: <reservoir> contains reservoir properties, such as various pressures, temperature, porosity, fluid saturation, lithology, etc. Reservoir properties given under the keyword <reservoir> are parameters that are common for fluids, solids, dry rocks and rocks. For models that depend on these parameters, the values given under reservoir can be used, although they may be overridden locally. The elements <reservoir> are defined by labels to be referred to with the <reservoir-variable> statement. Hence, they must be unique. After <reservoir>, the command <variable> follows.
Argument:
Default:

4.5.11.1.1 <variable>

Description: Repeated command, one for each reservoir variable. The variable is defined by <label>, followed by a variable, trend or distribution.
Argument: Value, trend or distribution, see Section 4.6
Default:

####### 4.5.11.1.1.1 <label>

Description: Unique label identifying the reservoir variable.
Argument:
Default:

4.5.11.2 <evolve>

Description: Repeated command, one for each reservoir variable that is to be evolved. <evolve> needs to come after <reservoir>, and before <predefinitions>
Argument:
Default:

4.5.11.2.1 <reservoir-variable>

Description: Name of the reservoir variable that is to be evolved. The variable needs to be specified in <reservoir>.
Argument: String
Default:

4.5.11.2.2 <one-year-correlation>

Description: The correlation between the reservoir variables at two following years
Argument: Value
Default: 1

4.5.11.2.3 <vintage>

Description: Repeated command, one for each vintage of the reservoir variable that is to be evolved. Whenever a reservoir variable is being evolved, it needs to be given for all vintages.
Argument:
Default:

4.5.11.2.3.1 `<distribution>`

Description: Distribution of the vintage variable. May also be given by a value or trend. Note that the keyword `<distribution>` is used even though a value or trend is used.
Argument: Value, trend, distribution or variable defined in `<reservoir>`, see Section 4.6
Default:

4.5.11.2.3.2 `<vintage-year>`

Description: Unique year of the vintage. Must be given in ascending order, where the first variable given under `<variable>` is given the year of the first seismic survey
Argument: Integer value
Default:

4.5.11.3 `<predefinitions>`

Description: <predefinitions> is used for specifying and calculating the elastic properties of basic building blocks, being `<fluid>`, `<solid>` and `<solid>`, or elements and mixtures of these. It will typically use properties specified under `<reservoir>`. Under the keyword <predefinitions>, fluids, solids and dry rocks are defined for later use, to make the xml-file more readable. Each time a building block is defined, it is given a unique identifying name using the <label> keyword. This is followed by a keyword specifying which theory we use for building this constituent. However, if we want to use a constituent that is already defined, we use the keyword <use> instead of <label>, followed by the unique name of the element. Thus, constituents can easily be used over and over once they are defined.
Argument:
Default:

4.5.11.3.1 `<fluid>`

Description: Fluids are generally defined by the command <fluid>. The fluid command is followed either by the command <label> to specify a new fluid, or <use> to use a predefined fluid. In the latter case, the fluid is now done; in the former case, the next keyword is the theory used to model the fluid.
Argument:
Default:

4.5.11.3.1.1 `<use>`

Description: To use a fluid that is already defined, we use the keyword <use> followed by the unique name of the fluid element.
Argument: Unique name of the fluid element to be used
Default:

4.5.11.3.1.2 `<label>`

Description: Unique idenitfication of the fluid. Each time a fluid is defined, it is given a unique identifying name using the <label> keyword. The <label> keyword needs to be followed by a keyword specifying which theory we use for building this fluid. The possible theories are listet below.
Argument: String
Default:

4.5.11.3.1.3 `<tabulated>`

Description: The tabulated theory allows specifying properties explicitly. For fluids, the properties can either be specified by the set <density> and <bulk-modulus>, or by the set <density> and <vp>. The correlations between the variables may also be added. If the correlations are not used, the variables are assumed to have zero correlation.
Argument:
Default:

4.5.11.3.1.3.1 `<density>`

Description: Density given in g/cm^3. Needs to be specified
Argument: Value, trend, distribution or variable defined in `<reservoir>`, see Section 4.6.
Default:

4.5.11.3.1.3.2 `<bulk-modulus>`

Description: Bulk modulus given in MPa. One of <bulk-modulus> or `<vp>` needs to be specified.
Argument: Value, trend, distribution or variable defined in `<reservoir>`, see Section 4.6.
Default:

4.5.11.3.1.3.3 `<correlation-bulk-density>`

Description: Correlation between the bulk modulus and density
Argument: Value, trend, distribution or variable defined in `<reservoir>`, see Section 4.6
Default: 0

4.5.11.3.1.3.4 `<vp>`

Description: P-wave velocity given in m/s. One of `<bulk-modulus>` or <vp> needs to be specified.
Argument: Value, trend, distribution or variable defined in `<reservoir>`, see Section 4.6
Default:

4.5.11.3.1.3.5 `<correlation-vp-density>`

Description: Correlation between vp and density
Argument: Value, trend, distribution or variable defined in `<reservoir>`, see Section 4.6
Default: 0

4.5.11.3.1.4 `<reuss>`

Description: Used for calculating the harmonic average of various constituents. Typically used for calculating effective bulk moduli of fluids, then referred to as Wood's theory.
Argument:

Default:

4.5.11.3.1.4.1 <constituent>

Description: Repeated command, one for each constituent of the Reuss model
Argument: <fluid> followed by <volume-fraction>
Default:

4.5.11.3.1.4.1.1 <fluid>

Description: May define a new fluid here, or use a predefined <fluid> from <predefinitions> using the keyword <use> followed by the unique name of the fluid. When a new fluid is defined, follow the construction of <fluid> in <predefinitions>
Argument: <use> or <label> followed by a theory following the lines of <fluid>
Default:

4.5.11.3.1.4.1.2 <volume-fraction>

Description: Volume fraction of the constituent. Must to be specified for all but the last constituents, where it may be calculated to ensure that the sum of the volume fractions of all the constituents is one. If the volume fraction of the last constituent is included, the sum of volume fractions must be one.
Argument: Value
Default:

4.5.11.3.1.5 <voigt>

Description: Used for calculating the harmonic average of various constituents. Typically used for calculating effective bulk moduli of fluids, then referred to as Wood's theory.
Argument:
Default:

4.5.11.3.1.5.1 <constituent>

Description: Repeated command, one for each constituent of the Voigt model
Argument: <fluid> followed by <volume-fraction>
Default:

4.5.11.3.1.5.1.1 <fluid>

Description: May define a new fluid here, or use a predefined <fluid> from <predefinitions> using the keyword <use> followed by the unique name of the fluid. When a new fluid is defined, follow the construction of <fluid> in <predefinitions>
Argument: <use> or <label> followed by a theory following the lines of <fluid>
Default:

4.5.11.3.1.5.1.2 <volume-fraction>

Description: Volume fraction of the constituent. Must to be specified for all but the last constituents, where it may be calculated to ensure that the sum of the volume fractions of all the constituents is one. If the volume fraction of the last constituent is included, the sum of volume fractions must be one.

Argument: Value
Default:

4.5.11.3.1.6 `<hill>`

Description: Used for calculating the average of Reuss and Voigt of various constituents. Note that Hill can be used to calculate the effective bulk modulus of a patchy fluid.
Argument:
Default:

4.5.11.3.1.6.1 `<constituent>`

Description: Repeated command, one for each constituent of the Hill model
Argument: <fluid> followed by <volume-fraction>
Default:

4.5.11.3.1.6.1.1 `<fluid>`

Description: May define a new fluid here, or use a predefined `<fluid>` from `<predefinitions>` using the keyword `<use>` followed by the unique name of the fluid. When a new fluid is defined, follow the construction of `<fluid>` in `<predefinitions>`
Argument: <use> or <label> followed by a theory following the lines of `<fluid>`
Default:

4.5.11.3.1.6.1.2 `<volume-fraction>`

Description: Volume fraction of the constituent. Must to be specified for all but the last constituents, where it may be calculated to ensure that the sum of the volume fractions of all the constituents is one. If the volume fraction of the last constituent is included, the sum of volume fractions must be one.
Argument: Value
Default:

4.5.11.3.1.7 `<batzle-wang-brine>`

Description: The theory of Batzle and Wang used for calculating the brine properties.
Argument:
Default:

4.5.11.3.1.7.1 `<pore-pressure>`

Description: Pressure given in MPa. Needs to be specified.
Argument: Value, trend, distribution or variable defined in `<reservoir>`, see Section 4.6
Default:

4.5.11.3.1.7.2 `<temperature>`

Description: Temperature given in C. Needs to be specified.
Argument: Value, trend, distribution or variable defined in `<reservoir>`, see Section 4.6
Default:

4.5.11.3.1.7.3 `<salinity>`

Description: Fraction of one
Argument: Value, trend, distribution or variable defined in `<reservoir>`, see Section 4.6
Default:

4.5.11.3.1.8 `<span-wagner-co2>`

Description: Interpolation of the reported values from Span and Wagner used for calculating the CO2 properties.
Argument:
Default:

4.5.11.3.1.8.1 `<pressure>`

Description: Pressure given in MPa. Needs to be specified.
Argument: Value, trend, distribution or variable defined in `<reservoir>`, see Section 4.6
Default:

4.5.11.3.1.8.2 `<temperature>`

Description: Temperature given in C. Needs to be specified.
Argument: Value, trend, distribution or variable defined in `<reservoir>`, see Section 4.6
Default:

4.5.11.3.2 `<solid>`

Description: Solids follow the same pattern as fluids, with <solid> as the defining keyword, followed by <label>, and the following keyword defining the theory used. As with fluids, <use> can be used instead of <label>, to use a previously specified solid.
Argument:
Default:

4.5.11.3.2.1 `<use>`

Description: To use a solid that is already defined, we use the keyword <use> followed by the unique name of the solid element.
Argument: Unique name of the solid element to be used
Default:

4.5.11.3.2.2 `<label>`

Description: Unique idenitfication of the solid. Each time a solid is defined, it is given a unique identifying name using the <label> keyword. The <label> keyword needs to be followed by a keyword specifying which theory we use for building this solid. The possible theories are listet below.
Argument: String
Default:

4.5.11.3.2.3 `<tabulated>`

Description: The tabulated theory allows specifying properties explicitly. The properties can either be specified by the set <density>, <bulk-modulus> and <shear-modulus>, or by the set <density>, <vp> and <vs>. The correlations between the variables may also be added. If the correlations are not used, the variables are assumed to have zero correlation.
Argument:
Default:

4.5.11.3.2.3.1 `<density>`

Description: Density given in g/cm^3. Needs to be specified
Argument: Value, trend, distribution or variable defined in `<reservoir>`, see Section 4.6
Default:

4.5.11.3.2.3.2 `<bulk-modulus>`

Description: Bulk modulus given in MPa. One of <bulk-modulus> or `<vp>` needs to be specified.
Argument: Value, trend, distribution or variable defined in `<reservoir>`, see Section 4.6
Default:

4.5.11.3.2.3.3 `<shear-modulus>`

Description: Shear modulus given in MPa. One of <shear-modulus> or `<vs>` needs to be specified.
Argument: Value, trend, distribution or variable defined in `<reservoir>`, see Section 4.6
Default:

4.5.11.3.2.3.4 `<correlation-bulk-shear>`

Description: Correlation between the bulk and shear moduli
Argument: Value, trend, distribution or variable defined in `<reservoir>`, see Section 4.6
Default: 0

4.5.11.3.2.3.5 `<correlation-bulk-density>`

Description: Correlation between the bulk modulus and density
Argument: Value, trend, distribution or variable defined in `<reservoir>`, see Section 4.6
Default: 0

4.5.11.3.2.3.6 `<correlation-shear-density>`

Description: Correlation between the shear modulus and density
Argument: Value, trend, distribution or variable defined in `<reservoir>`, see Section 4.6
Default: 0

4.5.11.3.2.3.7 `<vp>`

Description: P-wave velocity given in m/s. One of `<bulk-modulus>` or <vp> needs to be specified.
Argument: Value, trend, distribution or variable defined in `<reservoir>`, see Section 4.6
Default:

4.5.11.3.2.3.8 `<vs>`

Description: S-wave velocity given in m/s. One of `<shear-modulus>` or <vs> needs to be specified.

Argument: Value, trend, distribution or variable defined in `<reservoir>`, see Section 4.6
Default:

4.5.11.3.2.3.9 `<correlation-vp-vs>`

Description: Correlation between vp and vs
Argument: Value, trend, distribution or variable defined in `<reservoir>`, see Section 4.6
Default: $1/\sqrt{2}$

4.5.11.3.2.3.10 `<correlation-vp-density>`

Description: Correlation between vp and density
Argument: Value, trend, distribution or variable defined in `<reservoir>`, see Section 4.6
Default: 0

4.5.11.3.2.3.11 `<correlation-vs-density>`

Description: Correlation between vs and density
Argument: Value, trend, distribution or variable defined in `<reservoir>`, see Section 4.6
Default: 0

4.5.11.3.2.4 `<reuss>`

Description: Used for calculating the harmonic average of various constituents. Typically used for calculating effective bulk moduli.
Argument:
Default:

4.5.11.3.2.4.1 `<constituent>`

Description: Repeated command, one for each constituent of the Reuss model
Argument: <solid> followed by <volume-fraction>
Default:

4.5.11.3.2.4.1.1 `<solid>`

Description: May define a new solid here, or use a predefined `<solid>` from `<predefinitions>` using the keyword `<use>` followed by the unique name of the solid. When a new solid is defined, follow the construction of `<solid>` in `<predefinitions>`
Argument: <use> or <label> followed by a theory following the lines of `<solid>`
Default:

4.5.11.3.2.4.1.2 `<volume-fraction>`

Description: Volume fraction of the constituent. Must to be specified for all but the last constituents, where it may be calculated to ensure that the sum of the volume fractions of all the constituents is one. If the volume fraction of the last constituent is included, the sum of volume fractions must be one.
Argument: Value
Default:

4.5.11.3.2.5 <voigt>

Description: Used for calculating the aritmetic average of various constituents. Typically used for calculating effective bulk moduli.
Argument:
Default:

4.5.11.3.2.5.1 <constituent>

Description: Repeated command, one for each constituent of the Voigt model
Argument: <solid> followed by <volume-fraction>
Default:

4.5.11.3.2.5.1.1 <solid>

Description: May define a new solid here, or use a predefined <solid> from <predefinitions> using the keyword <use> followed by the unique name of the solid. When a new solid is defined, follow the construction of <solid> in <predefinitions>
Argument: <use> or <label> followed by a theory following the lines of <solid>
Default:

4.5.11.3.2.5.1.2 <volume-fraction>

Description: Volume fraction of the constituent. Must to be specified for all but the last constituents, where it may be calculated to ensure that the sum of the volume fractions of all the constituents is one. If the volume fraction of the last constituent is included, the sum of volume fractions must be one.
Argument: Value
Default:

4.5.11.3.2.6 <hill>

Description: Used for calculating the average og Reuss and Voigt of various constituents.
Argument:
Default:

4.5.11.3.2.6.1 <constituent>

Description: Repeated command, one for each constituent of the Hill model
Argument: <solid> followed by <volume-fraction>
Default:

4.5.11.3.2.6.1.1 <solid>

Description: May define a new solid here, or use a predefined <solid> from <predefinitions> using the keyword <use> followed by the unique name of the solid. When a new solid is defined, follow the construction of <solid> in <predefinitions>
Argument: <use> or <label> followed by a theory following the lines of <solid>
Default:

4.5.11.3.2.6.1.2 <volume-fraction>

Description: Volume fraction of the constituent. Must to be specified for all but the last constituents, where it may be calculated to ensure that the sum of the volume fractions of all the constituents is one. If the volume fraction of the last constituent is included, the sum of volume fractions must be one.
Argument: Value
Default:

4.5.11.3.2.7 `<dem>`

Description: Differential effective medium (DEM) theory is an inclusion based model. One of the constituents acts as the host material while the other constituents are treated as inclusions. In addition to volume fractions of the inclusions, their pore geometry must be specified. Typical use of DEM is mixing two solids, adding vacuum pores to a solid ("later" saturated using Gassmann theory) or adding fluid filled pores in a solid directly. Note that this is an asymmetric model, where interchanging host and constituent typically leads to different solutions. Note that inclusions beyond the first one are optional. The same material can be used in all inclusions, with different geometries. It is also possible to use different materials for the various inclusions.
Argument:
Default:

4.5.11.3.2.7.1 `<host>`

Description: The host of the DEM model
Argument: <solid> followed by <volume-fraction>
Default:

4.5.11.3.2.7.1.1 `<solid>`

Description: May define a new solid here, or use a predefined `<solid>` from `<predefinitions>` using the keyword `<use>` followed by the unique name of the solid. When a new solid is defined, follow the construction of `<solid>` in `<predefinitions>`
Argument: <use> or <label> followed by a theory following the lines of `<solid>`
Default:

4.5.11.3.2.7.1.2 `<volume-fraction>`

Description: Volume fraction of the constituent. Must to be specified for all but the last constituents, where it may be calculated to ensure that the sum of the volume fractions of all the constituents is one. If the volume fraction of the last constituent is included, the sum of volume fractions must be one.
Argument: Value
Default:

4.5.11.3.2.7.2 `<inclusion>`

Description: Repeated command, one for each inclusion of the DEM model
Argument: <solid> followed by <volume-fraction>
Default:

4.5.11.3.2.7.2.1 <solid>

Description: May define a new solid here, or use a predefined <solid> from <predefinitions> using the keyword <use> followed by the unique name of the solid. When a new solid is defined, follow the construction of <solid> in <predefinitions>
Argument: <use> or <label> followed by a theory following the lines of <solid>
Default:

4.5.11.3.2.7.2.2 <volume-fraction>

Description: Volume fraction of the constituent. Must to be specified for all but the last constituents, where it may be calculated to ensure that the sum of the volume fractions of all the constituents is one. If the volume fraction of the last constituent is included, the sum of volume fractions must be one.
Argument: Value
Default:

4.5.11.3.2.7.2.3 <aspect-ratio>

Description: Aspect ratio of the inclusion
Argument: Value, trend, distribution or <reservoir-variable>, see Section 4.6
Default:

4.5.11.3.3 <dry-rock>

Description: Dry rocks are a particular type of solid, as they have a defined porosity, yet no fluids added, so they are not rocks according to the rock-definition in <rock>. In addition to the density and effective elastic moduli for the specified porosity, they also contain information about the effective mineral properties. Dry rocks are specified with <dry-rock>, followed by <label> or <use>. If <label> is given, it is followed by a theory for calculating the effective elastic moduli.
Argument:
Default:

4.5.11.3.3.1 <use>

Description: To use a dry-rock that is already defined, we use the keyword <use> followed by the unique name of the dry-rock element.
Argument: Unique name of the dry-rock element to be used
Default:

4.5.11.3.3.2 <label>

Description: Unique idenitfication of the dry-rock. Each time a dry-rock is defined, it is given a unique identifying name using the <label> keyword. The <label> keyword needs to be followed by a keyword specifying which theory we use for building this dry-rock. The possible theories are listet below.
Argument: String
Default:

4.5.11.3.3.3 <tabulated>

Description: The tabulated theory allows specifying properties explicitly. The properties can either be specified by the set <density>, <bulk-modulus> and <shear-modulus>, or by the set <density>, <vp> and <vs>. The correlations between the variables may also be added. If the correlations are not used, the variables are assumed to have zero correlation.
Argument:
Default:

4.5.11.3.3.3.1 `<density>`

Description: Density given in g/cm^3. Needs to be specified
Argument: Value, trend, distribution or variable defined in `<reservoir>`, see Section 4.6
Default:

4.5.11.3.3.3.2 `<bulk-modulus>`

Description: Bulk modulus given in MPa. One of <bulk-modulus> or `<vp>` needs to be specified.
Argument: Value, trend, distribution or variable defined in `<reservoir>`, see Section 4.6
Default:

4.5.11.3.3.3.3 `<shear-modulus>`

Description: Shear modulus given in MPa. One of <shear-modulus> or `<vs>` needs to be specified.
Argument: Value, trend, distribution or variable defined in `<reservoir>`, see Section 4.6
Default:

4.5.11.3.3.3.4 `<correlation-bulk-shear>`

Description: Correlation between the bulk and shear moduli
Argument: Value, trend, distribution or variable defined in `<reservoir>`, see Section 4.6
Default: 0

4.5.11.3.3.3.5 `<correlation-bulk-density>`

Description: Correlation between the bulk modulus and density
Argument: Value, trend, distribution or variable defined in `<reservoir>`, see Section 4.6
Default: 0

4.5.11.3.3.3.6 `<correlation-shear-density>`

Description: Correlation between the shear modulus and density
Argument: Value, trend, distribution or variable defined in `<reservoir>`, see Section 4.6
Default: 0

4.5.11.3.3.3.7 `<vp>`

Description: P-wave velocity given in m/s. One of `<bulk-modulus>` or <vp> needs to be specified.
Argument: Value, trend, distribution or variable defined in `<reservoir>`, see Section 4.6
Default:

4.5.11.3.3.3.8 `<vs>`

Description: S-wave velocity given in m/s. One of `<shear-modulus>` or <vs> needs to be specified.

Argument: Value, trend, distribution or variable defined in `<reservoir>`, see Section 4.6
Default:

4.5.11.3.3.3.9 `<correlation-vp-vs>`

Description: Correlation between vp and vs
Argument: Value, trend, distribution or variable defined in `<reservoir>`, see Section 4.6
Default: $1/\sqrt{2}$

4.5.11.3.3.3.10 `<correlation-vp-density>`

Description: Correlation between vp and density
Argument: Value, trend, distribution or variable defined in `<reservoir>`, see Section 4.6
Default: 0

4.5.11.3.3.3.11 `<correlation-vs-density>`

Description: Correlation between vs and density
Argument: Value, trend, distribution or variable defined in `<reservoir>`, see Section 4.6
Default: 0

4.5.11.3.3.3.12 `<total-porosity>`

Description: Total porosity of the dry-rock
Argument: Value, trend, distribution or <reservoir-variable>, see Section 4.6
Default:

4.5.11.3.3.3.13 `<mineral-bulk-modulus>`

Description: Mineral bulk modulus, i.e., the bulk modulus of the effective mineral of the dry-rock
Argument: Value, trend, distribution or <reservoir-variable>, see Section 4.6
Default:

4.5.11.3.3.4 `<reuss>`

Description: Used for calculating the harmonic average of various constituents. Typically used for calculating effective bulk moduli.
Argument:
Default:

4.5.11.3.3.4.1 `<constituent>`

Description: Repeated command, one for each constituent of the Reuss model
Argument: <dry-rock> followed by <volume-fraction>
Default:

4.5.11.3.3.4.1.1 `<dry-rock>`

Description: May define a new dry-rock here, or use a predefined `<dry-rock>` from `<predefinitions>` using the keyword `<use>` followed by the unique name of the dry-rock. When a new dry-rock is defined, follow the construction of `<dry-rock>` in `<predefinitions>`
Argument: <use> or <label> followed by a theory following the lines of `<dry-rock>`

Default:

4.5.11.3.3.4.1.2 <volume-fraction>

Description: Volume fraction of the constituent. Must to be specified for all but the last constituents, where it may be calculated to ensure that the sum of the volume fractions of all the constituents is one. If the volume fraction of the last constituent is included, the sum of volume fractions must be one.
Argument: Value
Default:

4.5.11.3.3.5 <voigt>

Description: Used for calculating the aritmetic average of various constituents. Typically used for calculating effective bulk moduli.
Argument:
Default:

4.5.11.3.3.5.1 <constituent>

Description: Repeated command, one for each constituent of the Voigt model
Argument: <dry-rock> followed by <volume-fraction>
Default:

4.5.11.3.3.5.1.1 <dry-rock>

Description: May define a new dry-rock here, or use a predefined <dry-rock> from <predefinitions> using the keyword <use> followed by the unique name of the dry-rock. When a new dry-rock is defined, follow the construction of <dry-rock> in <predefinitions>
Argument: <use> or <label> followed by a theory following the lines of <dry-rock>
Default:

4.5.11.3.3.5.1.2 <volume-fraction>

Description: Volume fraction of the constituent. Must to be specified for all but the last constituents, where it may be calculated to ensure that the sum of the volume fractions of all the constituents is one. If the volume fraction of the last constituent is included, the sum of volume fractions must be one.
Argument: Value
Default:

4.5.11.3.3.6 <hill>

Description: Used for calculating the average of Reuss and Voigt of various constituents.
Argument:
Default:

4.5.11.3.3.6.1 <constituent>

Description: Repeated command, one for each constituent of the Hill model
Argument: <dry-rock> followed by <volume-fraction>

Default:

4.5.11.3.3.6.1.1 <dry-rock>

Description: May define a new dry-rock here, or use a predefined <dry-rock> from <predefinitions> using the keyword <use> followed by the unique name of the dry-rock. When a new dry-rock is defined, follow the construction of <dry-rock> in <predefinitions>
Argument: <use> or <label> followed by a theory following the lines of <dry-rock>
Default:

4.5.11.3.3.6.1.2 <volume-fraction>

Description: Volume fraction of the constituent. Must to be specified for all but the last constituents, where it may be calculated to ensure that the sum of the volume fractions of all the constituents is one. If the volume fraction of the last constituent is included, the sum of volume fractions must be one.
Argument: Value
Default:

4.5.11.3.3.7 <dem>

Description: Differential effective medium (DEM) theory is an inclusion based model. One of the constituents acts as the host material while the other constituents are treated as inclusions. In addition to volume fractions of the inclusions, their pore geometry must be specified. Typical use of DEM is mixing two solids, adding vacuum pores to a solid ("later" saturated using Gassmann theory) or adding fluid filled pores in a solid directly. Note that this is an asymmetric model, where interchanging host and constituent typically leads to different solutions. Note that inclusions beyond the first one are optional. The same material can be used in all inclusions, with different geometries. It is also possible to use different materials for the various inclusions.
Argument:
Default:

4.5.11.3.3.7.1 <host>

Description: The host of the DEM model
Argument: <dry-rock> followed by <volume-fraction>
Default:

4.5.11.3.3.7.1.1 <dry-rock>

Description: May define a new dry-rock here, or use a predefined <dry-rock> from <predefinitions> using the keyword <use> followed by the unique name of the dry-rock. When a new dry-rock is defined, follow the construction of <dry-rock> in <predefinitions>
Argument: <use> or <label> followed by a theory following the lines of <dry-rock>
Default:

4.5.11.3.3.7.1.2 <volume-fraction>

Description: Volume fraction of the constituent. Must to be specified for all but the last constituents, where it may be calculated to ensure that the sum of the volume fractions of all the con-

stituents is one. If the volume fraction of the last constituent is included, the sum of volume fractions must be one.

Argument: Value

Default:

4.5.11.3.3.7.2 `<inclusion>`

Description: Repeated command, one for each inclusion of the DEM model

Argument: <dry-rock> followed by <volume-fraction>

Default:

4.5.11.3.3.7.2.1 `<dry-rock>`

Description: May define a new dry-rock here, or use a predefined `<dry-rock>` from `<predefinitions>` using the keyword `<use>` followed by the unique name of the dry-rock. When a new dry-rock is defined, follow the construction of `<dry-rock>` in `<predefinitions>`

Argument: <use> or <label> followed by a theory following the lines of `<dry-rock>`

Default:

4.5.11.3.3.7.2.2 `<volume-fraction>`

Description: Volume fraction of the constituent. Must to be specified for all but the last constituents, where it may be calculated to ensure that the sum of the volume fractions of all the constituents is one. If the volume fraction of the last constituent is included, the sum of volume fractions must be one.

Argument: Value

Default:

4.5.11.3.3.7.2.3 `<aspect-ratio>`

Description: Aspect ratio of the inclusion

Argument: Value, trend, distribution or <reservoir-variable>, see Section 4.6

Default:

4.5.11.3.3.8 `<walton>`

Description: The Walton (1987) is a contact model for spherical grain packing. It assumes the normal and shear deformation of a two-grain-combination occur simultaneosly. The effective elastic moduli can be modelled assuming no or a very large friction coefficient. The no-slip factor can be used to model friction coefficients between these two extremes.

Argument:

Default:

4.5.11.3.3.8.1 `<solid>`

Description: May define a new solid here, or use a predefined `<solid>` from `<predefinitions>` using the keyword `<use>` followed by the unique name of the solid. When a new solid is defined, follow the construction of `<solid>` in `<predefinitions>`

Argument: <use> or <label> followed by a theory following the lines of `<solid>`

Default:

4.5.11.3.3.8.2 <no-slip>

Description: 0: no friction, 1: high friction and any value between is an arithmetic average between the two extremes.
Argument: Value, trend, distribution or variable defined in <reservoir>, see Section 4.6.
Default:

4.5.11.3.3.8.3 <pressure>

Description: Hydrostatic confining pressure (often substituted with effective pressure).
Argument: Value, trend, distribution or variable defined in <reservoir>, see Section 4.6.
Default:

4.5.11.3.3.8.4 <porosity>

Description: Porosity.
Argument: Value, trend, distribution or variable defined in <reservoir>, see Section 4.6.
Default:

4.5.11.3.3.8.5 <coord-nr>

Description: Average contact points per grain.
Argument: Value, trend, distribution or variable defined in <reservoir>, see Section 4.6.
Default: Defaults to interpolate value from porosity and coordination measurements by Murphy (1982). Note that the dataset by Murphy is between 0.2 and 0.7 porosity, estimated values outside that range are extrapolations.

4.5.11.4 <rock>

Description: <rock> contains the final composition of the rock, and will typically use details specified in <reservoir> and <predefinitions>. The <rock> command is followed by either <label> or <use>. If <label> is used, the next keyword is a theory.
Argument:
Default:

4.5.11.4.1 <use>

Description: To use a rock that is already defined, we use the keyword <use> followed by the unique name of the rock element.
Argument: Unique name of the rock element to be used
Default:

4.5.11.4.2 <label>

Description: Unique idenitfication of the rock. Each time a rock is defined, it is given a unique identifying name using the <label> keyword. The <label> keyword needs to be followed by a keyword specifying which theory we use for building this rock. The possible theories are listet below.
Argument: String
Default:

4.5.11.4.3 <tabulated>

Description: The tabulated theory allows specifying properties explicitly. The properties can either be specified by the set <density>, <bulk-modulus> and <shear-modulus>, or by the set <density>, <vp> and <vs>. The correlations between the variables may also be added. If the correlations are not used, the variables are assumed to have zero correlation.
Argument:
Default:

4.5.11.4.3.1 `<density>`

Description: Density given in g/cm^3. Needs to be specified
Argument: Value, trend, distribution or variable defined in `<reservoir>`, see Section 4.6
Default:

4.5.11.4.3.2 `<bulk-modulus>`

Description: Bulk modulus given in MPa. One of <bulk-modulus> or `<vp>` needs to be specified.
Argument: Value, trend, distribution or variable defined in `<reservoir>`, see Section 4.6
Default:

4.5.11.4.3.3 `<shear-modulus>`

Description: Shear modulus given in MPa. One of <shear-modulus> or `<vs>` needs to be specified.
Argument: Value, trend, distribution or variable defined in `<reservoir>`, see Section 4.6
Default:

4.5.11.4.3.4 `<correlation-bulk-shear>`

Description: Correlation between the bulk and shear moduli
Argument: Value, trend, distribution or variable defined in `<reservoir>`, see Section 4.6
Default: 0

4.5.11.4.3.5 `<correlation-bulk-density>`

Description: Correlation between the bulk modulus and density
Argument: Value, trend, distribution or variable defined in `<reservoir>`, see Section 4.6
Default: 0

4.5.11.4.3.6 `<correlation-shear-density>`

Description: Correlation between the shear modulus and density
Argument: Value, trend, distribution or variable defined in `<reservoir>`, see Section 4.6
Default: 0

4.5.11.4.3.7 `<vp>`

Description: P-wave velocity given in m/s. One of `<bulk-modulus>` or <vp> needs to be specified.
Argument: Value, trend, distribution or variable defined in `<reservoir>`, see Section 4.6
Default:

4.5.11.4.3.8 `<vs>`

Description: S-wave velocity given in m/s. One of `<shear-modulus>` or <vs> needs to be specified.

Argument: Value, trend, distribution or variable defined in <reservoir>, see Section 4.6
Default:

4.5.11.4.3.9 <correlation-vp-vs>

Description: Correlation between vp and vs
Argument: Value, trend, distribution or variable defined in <reservoir>, see Section 4.6
Default: $1/\sqrt{2}$

4.5.11.4.3.10 <correlation-vp-density>

Description: Correlation between vp and density
Argument: Value, trend, distribution or variable defined in <reservoir>, see Section 4.6
Default: 0

4.5.11.4.3.11 <correlation-vs-density>

Description: Correlation between vs and density
Argument: Value, trend, distribution or variable defined in <reservoir>, see Section 4.6
Default: 0

4.5.11.4.4 <reuss>

Description: Used for calculating the harmonic average of various constituents. Typically used for calculating effective bulk moduli.
Argument:
Default:

4.5.11.4.4.1 <constituent>

Description: Repeated command, one for each constituent of the Reuss model
Argument: One of <fluid>, <solid> or <dry-rock>, followed by <volume-fraction>
Default:

4.5.11.4.4.1.1 <fluid>

Description: May define a new fluid here, or use a predefined <fluid> from <predefinitions> using the keyword <use> followed by the unique name of the fluid. When a new fluid is defined, follow the construction of <fluid> in <predefinitions>
Argument: <use> or <label> followed by a theory following the lines of <fluid>
Default:

4.5.11.4.4.1.2 <solid>

Description: May define a new solid here, or use a predefined <solid> from <predefinitions> using the keyword <use> followed by the unique name of the solid. When a new solid is defined, follow the construction of <solid> in <predefinitions>
Argument: <use> or <label> followed by a theory following the lines of <solid>
Default:

4.5.11.4.4.1.3 <dry-rock>

Description: May define a new dry-rock here, or use a predefined <dry-rock> from <predefinitions> using the keyword <use> followed by the unique name of the dry-rock. When a new dry-rock is defined, follow the construction of <dry-rock> in <predefinitions>
Argument: <use> or <label> followed by a theory following the lines of <dry-rock>
Default:

4.5.11.4.4.1.4 <volume-fraction>

Description: Volume fraction of the constituent. Must to be specified for all but the last constituents, where it may be calculated to ensure that the sum of the volume fractions of all the constituents is one. If the volume fraction of the last constituent is included, the sum of volume fractions must be one.
Argument: Value
Default:

4.5.11.4.5 <voigt>

Description: Used for calculating the harmonic average of various constituents. Typically used for calculating effective bulk moduli.
Argument:
Default:

4.5.11.4.5.1 <constituent>

Description: Repeated command, one for each constituent of the Voigt model
Argument: One of <fluid>, <solid> or <dry-rock>, followed by <volume-fraction>
Default:

4.5.11.4.5.1.1 <fluid>

Description: May define a new fluid here, or use a predefined <fluid> from <predefinitions> using the keyword <use> followed by the unique name of the fluid. When a new fluid is defined, follow the construction of <fluid> in <predefinitions>
Argument: <use> or <label> followed by a theory following the lines of <fluid>
Default:

4.5.11.4.5.1.2 <solid>

Description: May define a new solid here, or use a predefined <solid> from <predefinitions> using the keyword <use> followed by the unique name of the solid. When a new solid is defined, follow the construction of <solid> in <predefinitions>
Argument: <use> or <label> followed by a theory following the lines of <solid>
Default:

4.5.11.4.5.1.3 <dry-rock>

Description: May define a new dry-rock here, or use a predefined <dry-rock> from <predefinitions> using the keyword <use> followed by the unique name of the dry-rock. When a new dry-rock is defined, follow the construction of <dry-rock> in <predefinitions>
Argument: <use> or <label> followed by a theory following the lines of <dry-rock>

Default:

4.5.11.4.5.1.4 <volume-fraction>

Description: Volume fraction of the constituent. Must to be specified for all but the last constituents, where it may be calculated to ensure that the sum of the volume fractions of all the constituents is one. If the volume fraction of the last constituent is included, the sum of volume fractions must be one.
Argument: Value
Default:

4.5.11.4.6 <hill>

Description: Used for calculating the average og Reuss and Voigt for various constituents
Argument:
Default:

4.5.11.4.6.1 <constituent>

Description: Repeated command, one for each constituent of the Hill model
Argument: One of <fluid>, <solid> or <dry-rock>, followed by <volume-fraction>
Default:

4.5.11.4.6.1.1 <fluid>

Description: May define a new fluid here, or use a predefined <fluid> from <predefinitions> using the keyword <use> followed by the unique name of the fluid. When a new fluid is defined, follow the construction of <fluid> in <predefinitions>
Argument: <use> or <label> followed by a theory following the lines of <fluid>
Default:

4.5.11.4.6.1.2 <solid>

Description: May define a new solid here, or use a predefined <solid> from <predefinitions> using the keyword <use> followed by the unique name of the solid. When a new solid is defined, follow the construction of <solid> in <predefinitions>
Argument: <use> or <label> followed by a theory following the lines of <solid>
Default:

4.5.11.4.6.1.3 <dry-rock>

Description: May define a new dry-rock here, or use a predefined <dry-rock> from <predefinitions> using the keyword <use> followed by the unique name of the dry-rock. When a new dry-rock is defined, follow the construction of <dry-rock> in <predefinitions>
Argument: <use> or <label> followed by a theory following the lines of <dry-rock>
Default:

4.5.11.4.6.1.4 <volume-fraction>

Description: Volume fraction of the constituent. Must to be specified for all but the last constituents, where it may be calculated to ensure that the sum of the volume fractions of all the con-

stituents is one. If the volume fraction of the last constituent is included, the sum of volume fractions must be one.

Argument: Value

Default:

4.5.11.4.7 `<dem>`

Description: Differential effective medium (DEM) theory is an inclusion based model. One of the constituents acts as the host material while the other constituents are treated as inclusions. In addition to volume fractions of the inclusions, their pore geometry must be specified. Typical use of DEM is mixing two solids, adding vacuum pores to a solid ("later" saturated using Gassmann theory) or adding fluid filled pores in a solid directly. Note that this is an asymmetric model, where interchanging host and constituent typically leads to different solutions. Note that inclusions beyond the first one are optional. The same material can be used in all inclusions, with different geometries. It is also possible to use different materials for the various inclusions.

Argument:

Default:

4.5.11.4.7.1 `<host>`

Description: The host of the DEM model

Argument: One of <fluid>, <solid> or <dry-rock>, followed by <volume-fraction>

Default:

4.5.11.4.7.1.1 `<fluid>`

Description: May define a new fluid here, or use a predefined `<fluid>` from `<predefinitions>` using the keyword `<use>` followed by the unique name of the fluid. When a new fluid is defined, follow the construction of `<fluid>` in `<predefinitions>`

Argument: <use> or <label> followed by a theory following the lines of `<fluid>`

Default:

4.5.11.4.7.1.2 `<solid>`

Description: May define a new solid here, or use a predefined `<solid>` from `<predefinitions>` using the keyword `<use>` followed by the unique name of the solid. When a new solid is defined, follow the construction of `<solid>` in `<predefinitions>`

Argument: <use> or <label> followed by a theory following the lines of `<solid>`

Default:

4.5.11.4.7.1.3 `<dry-rock>`

Description: May define a new dry-rock here, or use a predefined `<dry-rock>` from `<predefinitions>` using the keyword `<use>` followed by the unique name of the dry-rock. When a new dry-rock is defined, follow the construction of `<dry-rock>` in `<predefinitions>`

Argument: <use> or <label> followed by a theory following the lines of `<dry-rock>`

Default:

4.5.11.4.7.1.4 `<volume-fraction>`

Description: Volume fraction of the constituent. Must to be specified for all but the last constituents, where it may be calculated to ensure that the sum of the volume fractions of all the constituents is one. If the volume fraction of the last constituent is included, the sum of volume fractions must be one.
Argument: Value
Default:

4.5.11.4.7.2 `<inclusion>`

Description: Repeated command, one for each inclusion of the DEM model
Argument: One of <fluid>, <solid> or <dry-rock>, followed by <volume-fraction>
Default:

4.5.11.4.7.2.1 `<fluid>`

Description: May define a new fluid here, or use a predefined `<fluid>` from `<predefinitions>` using the keyword `<use>` followed by the unique name of the fluid. When a new fluid is defined, follow the construction of `<fluid>` in `<predefinitions>`
Argument: <use> or <label> followed by a theory following the lines of `<fluid>`
Default:

4.5.11.4.7.2.2 `<solid>`

Description: May define a new solid here, or use a predefined `<solid>` from `<predefinitions>` using the keyword `<use>` followed by the unique name of the solid. When a new solid is defined, follow the construction of `<solid>` in `<predefinitions>`
Argument: <use> or <label> followed by a theory following the lines of `<solid>`
Default:

4.5.11.4.7.2.3 `<dry-rock>`

Description: May define a new dry-rock here, or use a predefined `<dry-rock>` from `<predefinitions>` using the keyword `<use>` followed by the unique name of the dry-rock. When a new dry-rock is defined, follow the construction of `<dry-rock>` in `<predefinitions>`
Argument: <use> or <label> followed by a theory following the lines of `<dry-rock>`
Default:

4.5.11.4.7.2.4 `<volume-fraction>`

Description: Volume fraction of the constituent. Must to be specified for all but the last constituents, where it may be calculated to ensure that the sum of the volume fractions of all the constituents is one. If the volume fraction of the last constituent is included, the sum of volume fractions must be one.
Argument: Value
Default:

4.5.11.4.7.2.5 `<aspect-ratio>`

Description: Aspect ratio of the inclusion
Argument: Value, trend, distribution or <reservoir-variable>, see Section 4.6
Default:

4.5.11.4.8 <gassmann>

Description: Gassmann can be used for calculating the effective elastic properties of rock when substituting one fluid with another. Here, it is restricted to the case of replacing vacuum filled pores with some type of fluid (liquid or gas).
Argument: <dry-rock> and <fluid>
Default:

4.5.11.4.8.1 <fluid>

Description: May define a new fluid here, or use a predefined <fluid> from <predefinitions> using the keyword <use> followed by the unique name of the fluid. When a new fluid is defined, follow the construction of <fluid> in <predefinitions>
Argument: <use> or <label> followed by a theory following the lines of <fluid>
Default:

4.5.11.4.8.2 <dry-rock>

Description: May define a new dry-rock here, or use a predefined <dry-rock> from <predefinitions> using the keyword <use> followed by the unique name of the dry-rock. When a new dry-rock is defined, follow the construction of <dry-rock> in <predefinitions>
Argument: <use> or <label> followed by a theory following the lines of <dry-rock>
Default:

4.5.11.4.9 <bounding>

Description: The Bounding model is a rock physics model describing the stiffness of a rock as a weighting between a Voigt and a Reuss model. High weights in the bounding model indicate a stiff rock, while low weights indicate a soft rock.
Argument: Two rocks, being generated using the Voigt and Reuss models, respectively. Both these models need to be mixed from a solid and an fluid.
Default:

4.5.11.4.9.1 <upper-bound>

Description: The upper bound of the Bounding model needs to be a <rock> mixed from a tabulated solid and a tabulated fluid using the Voigt model. The variables in the tabulated models can not use distributions nor trends.
Argument: <rock>
Default:

4.5.11.4.9.2 <lower-bound>

Description: The lower bound of the Bounding model needs to be a <rock> mixed from a tabulated solid and a tabulated fluid using the Reuss model. The variables in the tabulated models can not use distributions nor trends.
Argument: <rock>
Default:

4.5.11.4.9.3 <porosity>

Description: The porosity of the Bounding model should be the same variable as <volume-fraction> of the fluid in the Reuss and Voigt models where a solid and fluid are mixed, and it should be declared in `<reservoir>`. If the porosity is not the same variable as the volume fractions, <porosity> overrides the volume fractions. The porosity is uncorrelated with the weights.
Argument: Value, trend, distribution or <reservoir-variable>, see Section 4.6
Default:

4.5.11.4.9.4 `<bulk-modulus-weight>`

Description: The bulk modulus K is calculated using the weights and upper/lower bounds from the relation $K = W_K$*upper-bound$+(1 - W_K)$*lower-bound. Higher weigths therefore indicate stiffer rock, while lower weights indicate softer rock.
Argument: Value, trend, distribution or <reservoir-variable>, see Section 4.6
Default:

4.5.11.4.9.5 `<shear-modulus-weight>`

Description: The shear modulus G is calculated using the weights and upper/lower bounds from the relation $G = W_G$*upper-bound$+(1 - W_G)$*lower-bound. Higher weigths therefore indicate stiffer rock, while lower weights indicate softer rock.
Argument: Value, trend, distribution or <reservoir-variable>, see Section 4.6
Default:

4.5.11.4.9.6 `<correlation-weights>`

Description: The correlation between the bulk-modulus weight and shear-modulus-weight.
Argument: Value
Default: 0

4.5.11.5 `<trend-cube>`

Description: Repeated command; one for each trend cube. There can be no more than two trend cubes
Argument:
Default:

4.5.11.5.1 `<parameter-name>`

Description: Name of the parameter in the trend cube. Must coincide with `<parameter-name>`, `<parameter-name-first-axis>` or `<parameter-name-second-axis>`
Argument: String
Default:

4.5.11.5.2 `<file-name>`

Description: File name of the trend cube
Argument: String
Default:

4.5.11.5.3 `<stratigraphic-depth>`

Description: Generates a trend cube following stratigraphy of the inversion area

Argument: 'yes' or 'no
Default: 'no'

4.5.11.5.4 `<twt>`

Description: Generates a trend cube following the two way travel time
Argument: 'yes' or 'no
Default: 'no'

4.5.12 `<rms-velocities>`

Description: Prior information for the RMS data
Argument:
Default:

4.5.12.1 `<above-reservoir>`

Description: Prior information for the RMS data above the reservoir
Argument:
Default:

4.5.12.1.1 `<mean-vp-top>`

Description: Expected value of V_p at the top of the zone above the reservoir, that is, at sea level. A linear trend will be made between this value and the background value at the top of the reservoir.
Argument: Value (m/s)
Default:

4.5.12.1.2 `<variance-vp>`

Description: Variance for V_p in the zone above the reservoir
Argument: Value
Default:

4.5.12.1.3 `<temporal-correlation-range>`

Description: Range (ms) in exponential variogram used for temporal correlation above the reservoir.
Argument: Value
Default:

4.5.12.1.4 `<n-layers>`

Description: Number of layers to be used from t=0 at the surface to the top of the reservoir
Argument: Integer
Default:

4.5.12.2 `<below-reservoir>`

Description: Prior information for the RMS data below the reservoir
Argument:
Default:

4.5.12.2.1 <mean-vp-base>

Description: Expected value of V_p at the base of the zone below the reservoir. A linear trend will be made between this value and the background value at the base of the reservoir.
Argument: Value (m/s)
Default:

4.5.12.2.2 <variance-vp>

Description: Variance for V_p in the zone below the reservoir
Argument: Value
Default:

4.5.12.2.3 <temporal-correlation-range>

Description: Range (ms) in exponential variogram used for temporal correlation below the reservoir.
Argument: Value
Default:

4.5.12.2.4 <n-layers>

Description: Number of layers to be used from the base of the reservoir to the deepest observed time for the RMS velocities in <rms-data>
Argument: Integer
Default:

4.6 Value assignments

All the properties and function parameters can use previously assigned values in <reservoir>, or be assigned values directly in <predefinitions>. The possible types of value assignments are value, trend or distribution. Variables defined in <reservoir> can also be used by the <reservoir-variable> keyword.

4.6.1 <value>

Description: The simplest form of deterministic value assignment is a single value. For the variables in <reservoir>, the value is given by the command <value>, while it may be given directly for the variable commands of <predefinitions>.
Argument: Double
Default:

4.6.2 <trend-1d>

Description: Commands controlling a 1D-trend. Can not be used in combination with <trend-2d>. When <trend-1d> is used, a corresponding trend cube must be given in <trend-cube>
Argument:
Default:

4.6.2.1 <file-name>

Description: Name of the 1D trend file
Argument: String
Default:

4.6.2.2 <reference-parameter>

Description: Name of the trend cube used as reference for the trend. Must be the same as <parameter-name> in one of <trend-cube>
Argument: String
Default:

4.6.2.3 <estimate>

Description: Estimate the 1D trend from well data. The wells used in the estimation are given by <use-for-rock-physics>.
Argument: 'yes' or 'no'
Default:

4.6.3 <trend-2d>

Description: Commands controlling a 2D-trend. Can not be used in combination with <trend-1d>. When <trend-2d> is used, the corresponding trend cubes must be given in <trend-cube>
Argument:
Default:

4.6.3.1 <file-name>

Description: Name of the 2D trend file
Argument: String
Default:

4.6.3.2 <reference-parameter-first-axis>

Description: Name of the trend cube used as reference for the trend corresponding to the first axis of the 2D trend file. Must be the same as <parameter-name> in one of <trend-cube>, but not the same as <reference-parameter-second-axis>
Argument: String
Default:

4.6.3.3 <reference-parameter-second-axis>

Description: Name of the trend cube used as reference for the trend corresponding to the first axis of the 2D trend file. Must be the same as <parameter-name> in one of <trend-cube>, but not the same as <reference-parameter-first-axis>
Argument: String
Default:

4.6.3.4 <estimate>

Description: Estimate the 2D trend from well data. The wells used in the estimation are given by <use-for-rock-physics>. Two trend cubes must be generated or given in <trend-cube>.
Argument: 'yes' or 'no'
Default:

4.6.4 <estimate>

Description: Estimate a constant value from well data. The wells used in the estimation are given by <use-for-rock-physics>.
Argument: 'yes' or 'no'
Default:

4.6.5 <gaussian>

Description: Commands controlling assignment of Gaussian probabilistic values to a variable. Whenever several building blocks use the same stochastic variable defined under <reservoir>, the same sample of the variable is used for all the building blocks.
Argument:
Default:

4.6.5.1 <mean>

Description: Mean value of the Gaussian distribution
Argument: Value or trend
Default:

4.6.5.2 <variance>

Description: Variance of the Gaussian distribution
Argument: Value or trend
Default:

4.6.6 <beta>

Description: Commands controlling assignment of Beta probabilistic values to a variable. Whenever several building blocks use the same stochastic variable defined under <reservoir>, the same sample of the variable is used for all the building blocks.
Argument:
Default:

4.6.6.1 <mean>

Description: Mean value of the Beta distribution
Argument: Value or trend
Default:

4.6.6.2 <variance>

Description: Variance of the Beta distribution
Argument: Value or trend
Default:

4.6.6.3 <lower-limit>

Description: Lower limit of the Beta distribution
Argument: Value
Default: 0

4.6.6.4 <upper-limit>

Description: Upper limit of the Beta distribution
Argument: Value
Default: 1

4.6.7 <beta-end-mass>

Description: Commands controlling assignment of Beta probabilistic values with end mass to a variable. Whenever several building blocks use the same stochastic variable defined under <reservoir>, the same sample of the variable is used for all the building blocks.
Argument:

Default:

4.6.7.1 `<mean>`
Description: Mean value of the Beta distribution with end mass
Argument: Value or trend
Default:

4.6.7.2 `<variance>`
Description: Variance of the Beta distribution with end mass
Argument: Value or trend
Default:

4.6.7.3 `<lower-limit>`
Description: Lower limit of the Beta distribution with end mass
Argument: Value
Default: 0

4.6.7.4 `<upper-limit>`
Description: Upper limit of the Beta distribution with end mass
Argument: Value
Default: 1

4.6.7.5 `<lower-probability>`
Description: Probability in the lower limit of the Beta distribution with end mass
Argument: Value
Default:

4.6.7.6 `<upper-probability>`
Description: Probability in the upper limit of Beta distribution with end mass
Argument: Value
Default:

4.6.8 `<reservoir-variable>`
Description: Use elements defined in `<reservoir>`
Argument: Name of the reservoir variable
Default:

4.7 Variogram
The variograms are given on the following form:

4.7.1 `<variogram-type>`
Description: Either 'genexp' or 'spherical' for general exponential or spherical variogram.
Argument:
Default:

4.7.2 `<angle>`
Description: Value for the azimuth direction. Only for 2D variograms.
Argument:

Default:

4.7.3 `<range>`

Description: Value for the range in the azimuth direction.
Argument:
Default:

4.7.4 `<subrange>`

Description: Value for the range normal to the azimuth direction. Only for 2D variograms.
Argument:
Default:

4.7.5 `<power>`

Description: Value between 1 and 2 for the power of the general exponential variogram. Not allowed for spherical variogram.
Argument:
Default:

All angles are given as mathematical angles in degrees.

A Sample model file

B Test suite overview

This appendix gives an overview of the features that are currently tested in the test suite.

Test \ Case number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Mode																		
Forward	x																	
Estimation - 1D											x				x			
Estimation - 3D																		x
Inversion - prediction		x	x		x	x	x	x	x	x		x	x	x		x	x	
Inversion - simulation				x														
Inversion - kriging			x	x		x												
Inversion - facies prob.									x			x	x	x				
Survey																		
Angle gathers	2	2	2	2	2	2	2	2	2	2	3	3	3	3	3	2	2	2
Estimate global wavelet		x			x						x					x		x
Estimate global SN-ratio		x			x						x					x		x
Estimate local noise								x										
Estimate local scale								x										
Estimate local shift								x										
Wavelet estimation interval											x							
Wells																		
Number of wells		1	1	1	4	4	4	4	1	1	6	6	6	6	1	1	2	3
Only synthetic Vs logs		x														x		
<use-for-facies-probabilities>												x	x					
<synthetic-vs-log>												x						
<filter-elastic-logs>												x	x					
<optimize-position>										x								
<allowed-parameter-values>															x	x	x	x
Prior model																		
Estimate covariance		x			x		x	x	x		x					x	x	
Estimate background		x			x		x			x	x					x	x	
Anisotropic background mod					x	x	x	x			x							
Anisotropic lateral corr					x	x	x	x			x	x	x	x				
Correlation direction							x											
VpVsRho filter									x			x						
VpRho filter													x					
Use prediction (not filter)														x				
Absolute params. for facies									x									
Facies estimation interval												x	x	x				
Output volume																		
Area from UTM	x	x		x	x			x								x	x	
Area from ILXL											x							
Area from surface						x	x											
Area from first angle gather			x						x	x		x	x	x	x			
Snap to seismic data							x											
One surface																x		
Two surfaces	x	x	x	x	x	x		x	x	x	x	x	x	x	x		x	
Constant top and base							x											

Test \ Case number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Depth conversion																		
Vel. field - from file		x														x		
Vel. field - from inversion					x													
Vel. field - from surfaces																		
Number of depth surfaces		2			1											2		
Advanced settings																		
FFT-grid-padding estimated											x							
Intermediate disk storage			x															
Smooth kriged parameters			x															
Well input formats																		
Roxar	x	x	x	x	x	x	x	x	x	x	x	x	x	x		x	x	
Norsar															x			x
Surface input formats																		
STORM BINARY		x	x	x	x	x	x	x		x		x	x	x	x	x		
Roxar ASCII (Irap classic)	x								x		x	x	x	x			x	
Grid input formats																		
STORM BINARY	x	x							x							x		
SEGY		x			x	x	x	x	x		x					x	x	
CRAVA			x	x						x		x	x	x				
SGRI															x			x
Output check of																		
Depth domain		x			x													
Generated seismic data	x																	
Synthetic seismic data		x	x					x										
Pred/sim elastic parameters		x	x	x	x	x	x	x								x	x	
Background		x			x		x				x							
Background trend		x			x		x				x							
Prior correlations		x			x						x							
Posterior correlations		x																
Blocked wells		x			x		x		x	x	x	x	x	x	x			x
Surfaces - top and base		x			x													
Surfaces - help grids							x											
Wavelet - global		x			x			x			x				x			x
Wavelet - well		x			x						x				x			x
Wavelet - local shape								x										
Wavelet - local scale/shift								x										
Local noise								x										

C Release notes

The tags, e.g. CRA-49, are links to the CRAVA project management system called JIRA. Note that access permission is required to be able to open the links.

C.1 Changes from v1.2 to 2.0

New features:

- Rock physics models in CRAVA
  - Tabulated model
  - Bounding model
- User inperface for rock physics models
- Trends in rock physics variables
- Distributions with trends
  - Normal
  - Beta
  - Beta with end mass
- Generate background model from rock physics
- Calculate parameter covariance from rock physics
- Estimate facies probabilities using synthetic wells from rock physics models
- Smoothing values from illumination vector grid. CRA-162
- Create multizone background model. CRA-317, CRA-319, CRA-325

Changes:

- Check that facies probabilities are between 0 and 1. CRA-347
- Adjust estimated wavelet such that it is smooth and the amplitude goes smoothly to zero in frequency domain. CRA-315
- Make CRAVA compile under g++ 4.6.3 (Ubuntu 12.04). CRA-345

Bug fixes:

- If ASCII grid output is requested, STORM grids cannot be imported to RMS CRA-224
- Incorrect guard zone check done before smoothing seismic data in new resampling. CRA-330
- Problems if <seg-start-time> is used when it should not have been. CRA-346
- Failed to open temporal seismic file in crava format for writing. CRA-349
- In new resampling algorithm of seismic data, wrong weights are used when doing interpolation. CRA-350
- CRAVA incorrectly reports that no optimal global wavelet scale has been found. CRA-351
- Some segy files are given the same path twice. CRA-352
- Command <snap-to-seismic-data> did not work when inversion area was selected using <area-from-surface>. CRA-512

C.2 Changes from v1.1 to v1.2

New features:

- Introduce new and more efficient resampling of seismic data. CRA-274
- Add SI (=Vs*Rho) as possible input type for background model. CRA-287
- For forward modelling allow earth model to be input as (AI,SI,Rho) and (AI,Vp/Vs,Rho). CRA-302
- Add new SegY format "SIPX" to list of auto-detected formats.CRA-290
- Added 3D wavelet estimation/inversion. CRA-304, CRA-308, CRA-309

Changes:

- Require seismic data in target zone+guard zone rather than in full inversion grid (simbox). CRA-216
- Cleaned test suite and findgrammar for <TAB> and trailing blanks, and added "no trailings blanks" as requirement for passing test suite. CRA-275, CRA-276
- Use one wavelet (200ms) as default when estimating vertical padding size. Previous default was half a wavelet (100ms). CRA-300
- Ensure that we log the parameter values of all parameters available under the `<advanced-settings>` keyword. CRA-307

Bug fixes:

- Fixed problem identifying the lateral geometry of seismic data. CRA-277
- Vp and Vs were reported as input data types for background model in logFile.txt when AI and Vp/Vs were used. CRA-288
- An incorrect grid size estimate made inversion runs stop even for medium sized grids. CRA-292
- Fixed crash when the `<filter-elastic-logs>` option was used. CRA-310
- Removed memory leaks in test suite using Purify. CRA-265.

C.3 Changes from v1.0 to v1.1

New features:

- Allow background model to be specified with AI and/or V_p/V_s, as a complement to V_p, V_s, and ρ. Specify files for these parameters with keyword `<ai-file>` and `<vp-vs-ratio-file>`. CRA-214
- Allow users to specify V_p/V_s for use in the reflection matrix. Use keyword `<vp-vs-ratio>`. CRA-219
- Remove certain QC checks when CRAVA is run from Irap RMS, as Irap RMS will perform these tests. Activated with keyword `<rms-panel-mode>`. CRA-221
- When seismic data is given in SegY format, write the IL-XL range of data to the log file. CRA-230, CRA-267
- Create synthetic residuals which add up to original seismic when added to synthetic seismic. Activated with `<synthetic-residuals>`. CRA-234
- If the `<rms-panel-mode>` mode has been requested and facies probabilities are not requested, well logs will not be (multi-parameter) filtered. CRA-242
- Allow V_p/V_s to be estimated from wells. Activated with keyword `<vp-vs-ratio-from-wells>`. If `<wavelet-estimation-interval>` has been specified, this interval will also be used for the V_p/V_s estimate. CRA-247
- If automatic SegY format detection fails, list trace header locations of known formats as well as their associated CRAVA-names. CRA-259
- Give a warning if prior or posterior parameter correlations exceed one. To avoid this situation completely, some recoding is required. This is left for a later release (see CRA-257). CRA-261

- When specifying an area as UTM coordinates or surface, choose as inversion area the smallest IL-XL box that encloses the specified area. Activated with keyword `<snap-to-seismic-data>`. CRA-266
- Allow (some) traces to have bogus IL-XL information in header. If encountered, the IL-XL values are set to undefined. CRA-269
- Write IL-XL values for well start positions whenever possible. This makes it easy to do inversion around a given well. CRA-270

Changes:

- When the prior correlation between V_p and V_s cannot be estimated from well data it is set to $1/\sqrt{2} \approx 0.7$. CRA-220
- Made blocking of facies deterministic. If a cell has the same facies count for n different facies, the cell value becomes facies_to_choose $= (k+1) \ \% \ n$, where k is the layer number. This used to be randomly chosen, so that identical runs could give different facies predictions. CRA-249
- Changed the computation of SegY geometry, and improved error messages. The new version should be more accurate and robust.

Bug fixes:

- Fixed crash in background modelling when there were (unrealistically) few layers in grid. CRA-200
- Background volumes of AI and/or V_p/V_s containing undefined values caused troubles. The fix is to set such undefined values to global mean. CRA-222
- Removed bugs in estimation of wavelet norm, which indirectly led to ringing in inversion results. CRA-223
- Number of allocated grids were incorrectly counted when estimating total memory requirement for CRAVA. CRA-251
- Fixed crash when interval was specified with option `<interval-one-surface>`. Wavelets had not been transformed prior to constant thickness inversion. Also, a wavelet polarity bug was fixed. New test cases 16 and 17 were added to avoid future constant thickness and wavelet polarity related bugs. CRA-252, CRA-253
- For short wells, deviation angles were incorrectly estimated due to an 10ms sample requirement. Also, the angle was calculated between well start and well end instead of for trajectory tangents.
- Fixed crash when project directory could not be created. This was a bug in the throw/catch system of NRLib. CRA-256
- Fixed several bugs encountered when using 3D prior facies probability volumes. CRA-272
- Fixed bug with interpolation of Storm-grids used for input.

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