Summary of the onCALCULATION methods used in dbSEABED

Chris Jenkins
Institute of Arctic & Alpine Research (INSTAAR)
University of Colorado at Boulder
Boulder CO, 80309-0450

9 June 2004 (rev. 15 May 2005; 21 April 2006)

Introduction

The module onCALCULATE performs a small amount of modeling to extend the outputs of dbSEABED to reasonable estimates of sea-floor properties. This is particularly useful for geoacoustic and other physical properties that have no practical mappable data distribution based on actual analyses. The modeling is based on theoretical or empirical relations that are documented below. The chosen relations may be replaced by others in the future as further physical properties research is published and as onCALCULATION results are validated. Users of dbSEABED may choose whether to use these lower accuracy estimates in mappings or to work with map data coverages that are less reliable because they contain fewer data.

A set of principles have guided the selection of relationships and their implementation:
 a. The methods should be transparent and well documented, not complex;
 b. They may be built on extracted or parsed parameter inputs but not on values that are themselves onCALCULATED;
 c. They might apply only to certain sections of the input parameter range;
 d. They preferably are published relationships, but if not, then
 e. They should be supported by the analysis of a substantial amount of data from a wide range of sediments.

1. Grain size/Sorting from Gravel:Sand:Silt:Clay and Gravel:Sand:Mud Ratios

Gravel:Sand:Silt:Clay and Gravel:Sand:Mud (GSSC, GSM) ratios are in effect short grain size-fraction histograms for the sediments. An estimate of average (AvGRZ) and standard deviation (SD) grain size can be made from them as follows: Each class is assigned a central grain size value based on examinations of large USGS and other datasets in Microsoft[TM] Excel[®]. These (GSSC(M)) class central values result: -3, 2, 5, 7, (8) in phi.

A weighted mean and weighted standard deviation are formed across the GSSC or GSM classes, leading to an estimate of the average grain size and sorting of the sediment. A method of validation and uncertainty calculation is available by comparison of the results for samples where a mean/sorting is already measured.

2. Hydrographic Chart Bottom Type code

This code, described in United Kingdom Hydrographic Office (UKHO, 2005) and National Ocean Service (NOS, 1997), has the form "Cy.S.Co". It is essentially the same as the U.S. NOS codes. The calculation is mostly a matter of assigning textural classes in front-significant order based on the (GSSC(M)) ratios, but also with special classes "R", "Wd", where rock and weed memberships are significant. Thus, the output codes are minimal codes.

3. Folk and Shepard Classifications

These have been implemented following the schemes in Poppe and Polloni (2000).

4. P-wave Velocities for Consolidated Materials Based on Time-Average Model

This calculation is performed only where there is an indication of cementation or consolidation in the material, usually expressed by measured or parsed shear strength greater than 50 kPa or porosity less than 35 percent, and where the porosity has been measured. Then:

$$mVp = (1 - Poros) / VelSol + Poros / VelFlu$$

where Poros is the fractional porosity of the material and VelSol and VelFlu are the solid and fluid phase P-wave velocities. The constants are VelSol = 5,000, VelFlu = 1,520 (these are measured values, different from those optimized for models such as Biot Theory; see Thorsos and others (2001)). The relation is associated with data over the whole range of porosities (figure 5). The time average model is attributed to Wyllie and others (1963).
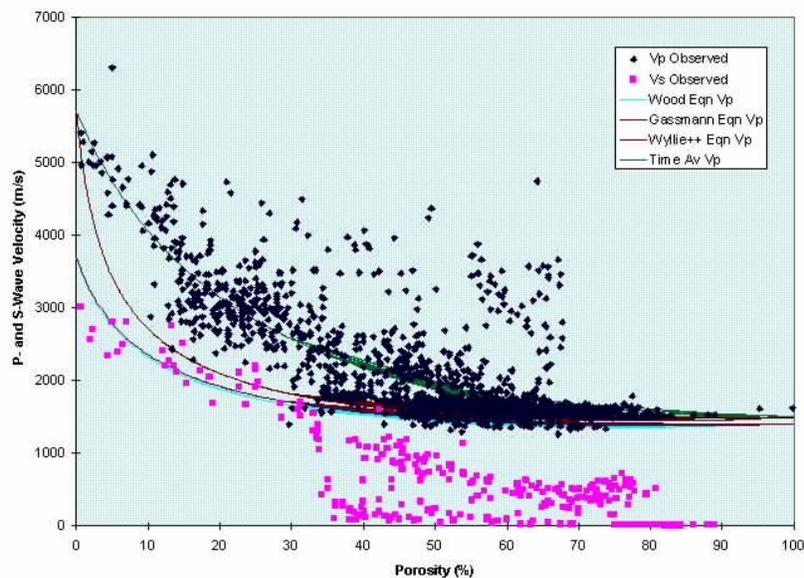

Figure 1. *The distribution of sediments by their porosity and P- and S-wave velocity values. Several separate populations are apparent. For P-wave velocities, the loose sediments with low velocities from 34 percent porosity and follow the Gassman function; consolidated sediments follow the time-average relation; apparently cemented sediments with anomalously high velocities for porosity. The S-wave populations have yet to be explained.*

5. Porosity Based on Mud Content of Loose Sediments

A compilation of many published analysis (fig. 6) results supports the empirical relationship:

$$mPor = 0.4 * mud + 43$$

for mud greater than 7 percent. It appears to hold equally for terrigenous and carbonate sediments. Figure 6 illustrates the relationship for sediments of the Mississippi-Alabama-Florida (MAFLA) shelf.
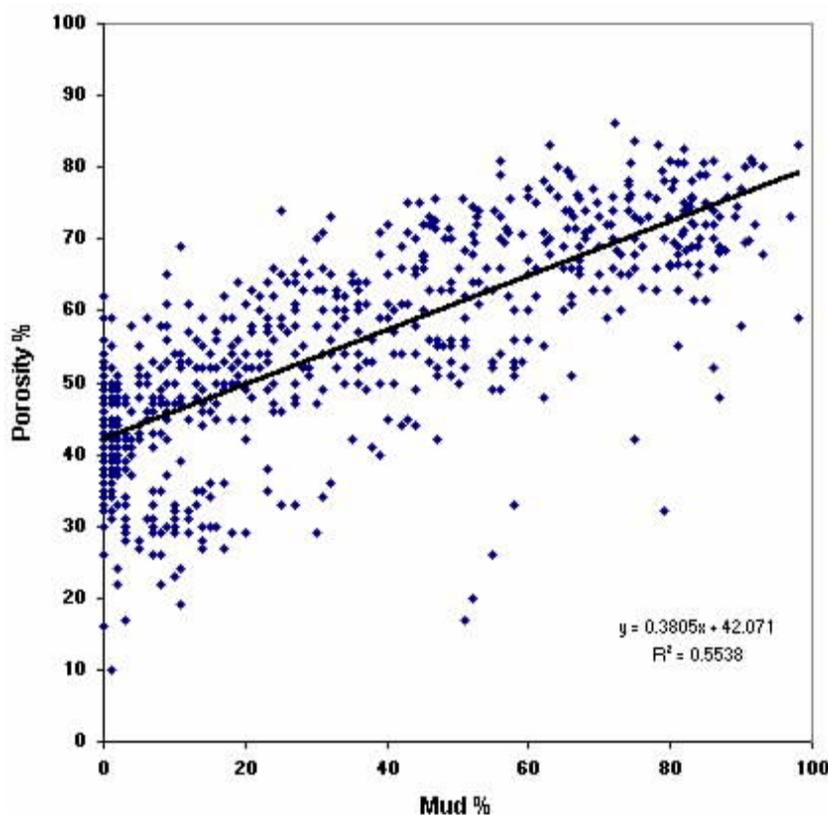

Figure 2. Empirical data supporting the mud percent to porosity relation where mud fraction is >7 percent. The plotted data are a mix of terrigenous, carbonate, loose, and consolidated samples from the Mississippi-Alabama-Florida (MAFLA) shelf.

6. Porosity Based on Average Grain size

Richardson and Briggs (1993) proposed a relation between porosity and average grain size (AvGrsz, phi units) based on their measurements of muddy and sandy sediments. The relation is inverted for the onCALCULATION, and is applied only in the range AvGrsz > 0 phi:

$$Por = 26.92 + 5.92 * AvGrsz.$$

The form is less accurate than methods where the percent of mud is known, and is not used in those cases.

7. Coarse Fraction and the P-wave Velocity

Related to the porosity-mud fraction function is another between coarse fraction and p-wave velocity (V_p):

$$mV_p = 0.0009 * SpG + -0.14 * SpG + 8.56 * SpG + 1512.76$$

where SpG is the percent coarse fraction. This polynomial is a poor fit and further work is required.

8. Wood-Gassman Equation for P-wave Velocity in Loose Sediments

This method of estimating V_p is applied to sediments with no evidence of consolidation. It depends on assumed values for some acoustic constants of the sediments:

   (a) The bulk moduli K for solid, fluid, frame ($Ko1_{Sol}$, $Ko1_{Flu}$ and $Ko1_{Fra} = 3.6*10^{10}$, $2*10^9$ and $4*10^8$, MKS units) and
   (b) The rigidities for solids and frame ($Rigid_{Sol}$, $Rigid_{Fra}$, $= 2.2*10^7$, $1*10^7$).

The sediment bulk modulus (K) and density are

   $Ko1 = (1-fPor)/Ko1_{Sol} + fPor/Ko1_{Flu}$
   $SedDens = (1-fPor) * Den_{Sol} + fPor * Dens_{Flu}$

The p-wave velocity (V_p) is calculated as:

   $Q_{gass}=Ko1_{Flu}*(Ko1_{Sol}-Ko1_{Fra})$
   $[fPor*(Ko1_{Sol}-Ko1_{Flu})]$
   $K_{gass}=Ko1_{Sol}*(Ko1_{Fra}+Q_{gass})/(Ko1_{Sol}-Q_{gass})$
   $V_{p(gass)}=(K_{gass}+4/3 * Rigid_{Fra}/SedDens)$

(Gassmann, 1951). $V_{p(gass)}$ is output as the estimate of V_p.

The Wood-Gassmann relation is one of several that have been proposed between porosity and acoustic velocities. As can be seen on figure 5, the relation has an associated population of data ranging only between 35-80 percent porosity. In the dbSEABED onCALCULATION it is applied only where porosity is known and greater than 35 percent, and where there is no indication of consolidation.

9. Roughness from Grain Protrusion for Gravels and Coarser Sediments

Kirchner and others (1990) offer a method for the calculation of grain protrusion (PnKir) above a sediment surface:

$$En_{Kir} = 0.5 * (Dn_{Kir}-D50_{Kir}+(Dn_{Kir}+D50_{Kir}) * cos(F100n_{Kir}))$$
$$Pn_{Kir}=En_{Kir} + pi*D50_{Kir}/12$$

where $D50_{Kir}$ and Dn_{Kir} are the median and nth percentile grain sizes and $F100n_{Kir}$ is the friction angle with a test grain of the 100-nth grain size percentile. In onCALCULATION, the estimation is done only using the central and the coarsest grain sizes (CSESTsz; from either the parsed

(PRS) or extracted (EXT) results) for $D50_{Kir}$ and Dn_{Kir}. Pn_{Kir} is output as an estimate of roughness.

10. Roughness Metric from Outsized Clasts

This metric was employed as an early measure of seabed roughness; it is based on an idealized arrangement of the sediment clasts and particles. The coarsest grain size is logged from previous processing of grain size analysis and descriptive data inputs or is estimated from the average plus two times the SD (sorting) where both are known. The vertical roughness is estimated as half the clast size (D) with allowance for natural oblateness:

$$dZ = 0.5D * CSF$$

where CSF is the Corey Shape Factor to account for non-sphereicity. (In naturally worn materials CSF is about 0.7; see, for example, Jimenez and Madsen, 2003.) The spacing of the clast grain size is assessed as half the repeat distance implied by the fractional linear abundance PL of the outsized clast with size D. Linear abundance is related to areal and volume (most common) abundances PA and PV as: $PL = PA^{1/2}$, $PL = PV^{1/3}$. The clast protrusion and half-spacing are output as the vertical and horizontal roughness scales.

11. Critical Shear Stress (CSS)

If the material shows evidence of consolidation, then the critical shear stress (CSS, N/m) is set equal to the reported shear strength (kPa). Whitehouse and others (2000, p. 27) discuss the relation, which is interim in the onCALCULATION.

For loose sediments, the functions related to grain size (AvGRZ) were investigated on the basis of data from many studies (figure 7). This work was done in conjunction with Institute Warnemuende (IOW) in Germany. The conclusions were

(i)   With fine-grained loose sediments where density or porosity are known, use the relationship of Mitchener and others (1996, in Whitehouse and others (2000)); else

(ii)   For those sediments use a generalized value of 0.5 N/m; and

(iii)   For loose coarse grained sediments use a log-linear relationship as shown in figure 3,

$$\log_{10}(CSS) = \log_{10}[1.04 - AvGRZ * 0.6].$$

Bioturbation and bioconsolidation were not recognized in the estimation process for fine sediments, though they can be important (see Black and others, 2002). A correction of minor importance compared to the overall uncertainties is applied in the onCALCULATION.
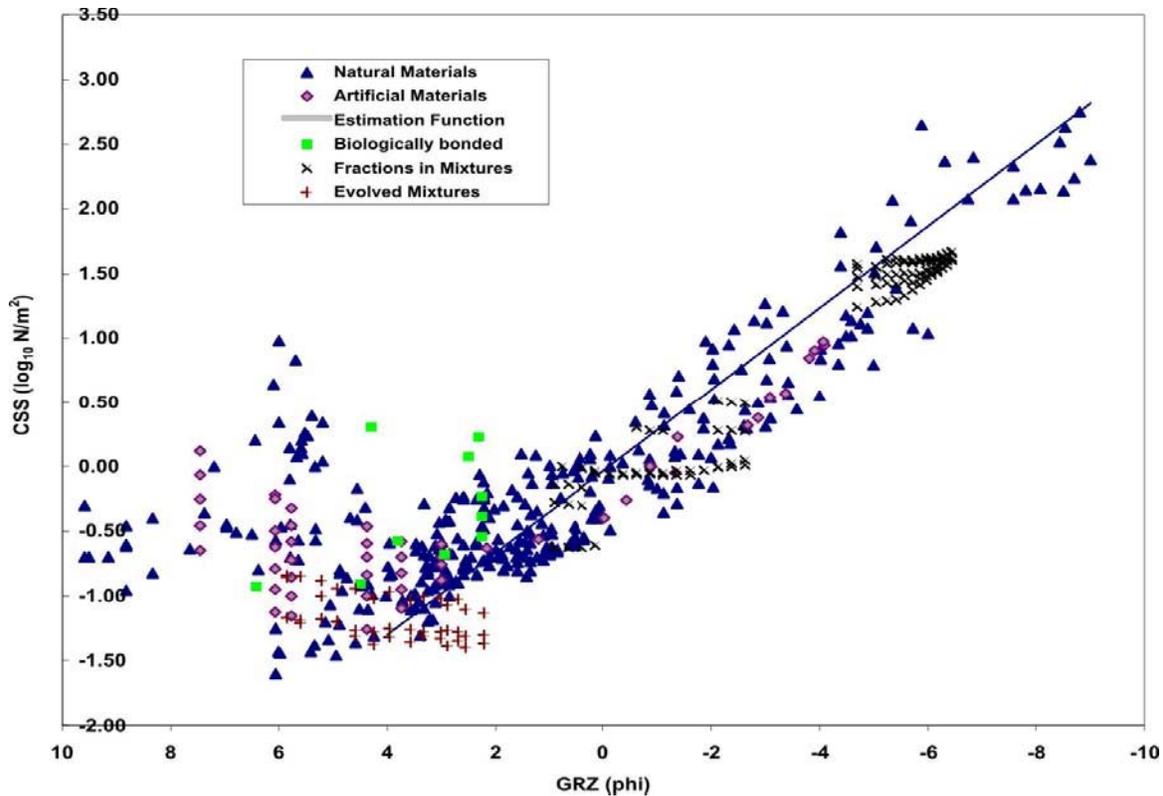
Figure 3. *A compilation of critical shear stress results by sediment grain size over the gravel to clay range. More than 24 references were used referring to marine and river sediments and field and laboratory experiments on unaltered and manipulated natural sediments.*

References Cited

Black, K.S., Tolhurst, T.J., Paterson, D.M., and Hagerthey, S.E., 2002, Working with natural cohesive sediments: Journal of Hydraulic Engineering, v. 128, no. 1, p. 2-8.

Gassmann, F., 1951, Elastic waves through a packing of spheres: Geophysics, v. 16, no. 673-685.

Jimenez, J.A., and Madsen, O.S., 2003, A simple formula to estimate settling velocity of natural sediments: Journal of Waterway, Port, Coastal and Ocean Engineering, March/April 2003, p. 70-78.

Kirchner, J.W., Dietrich, W.E., Iseya, F., and Ikeda, H., 1990, The variability of critical shear stress, friction angle, and grain protrusion in water-worked sediments: Sedimentology, v. 37, p. 647-672.

National Ocean Service (NOS), 1997, Chart no. 1, United States of America, Nautical chart symbols, abbreviations and terms: U.S. National Ocean Service [Chart].

Poppe, L.J., Eliason, A.H., Fredericks , J.J., Rendigs, R.R., Blackwood, D., and Polloni, C.F., 2000, Grain size analysis of marine sediments: methodology and data processing, *in* Poppe, L.J., and Polloni, C.F., eds., USGS east-coast sediment analysis; procedures, database, and georeferenced displays: U.S. Geological Survey Open-File Report 00-358, one CD-ROM.

Richardson , M.D., and Briggs, K.B., 1993, On the use of acoustic impedance values to determine sediment properties: Proceedings of Instuments of Acoustics, v. 15, p. 15-24.

Thorsos, E.I., Williams, K.L., Jackson, D.R., Richardson, M.D., Briggs, K.B., and Tang, D., 2001, An experiment in high-frequency sediment acoustics; SAX99: IEEE Journal of Oceanic Engineering, v. 26, p. 4-25.

United Kingdom Hydrographic Office (UKHO), 2005, Chart symbols and abbreviations: Chart BA 5011 [Booklet], UK Hydrographic Office, 38 p.

Whitehouse, R., Soulsby, R., Roberts, W., and Mitchener, H., 2000, Dynamics of estuarine muds; A manual for practical applications: London, Thomas Telford, 209 p.

Wyllie, M., Gardner, G., and Gregory, A., 1963, Studies of elastic wave attenuation in porous media: Geophysics, v. 27, p. 569-589.