KEY TO NUMERICAL CODE FOR GLACIAL VARVE ANALYSIS

INSTRUCTIONS

Version: August 1, 2008

The numerical coding of varves is an attempt to quantify individual varve characteristics with 2-digit numbers, which lends itself to non-parametric statistical and graphical analysis of varve sequences. The characteristics cover summer and winter layer (see below) characteristics as well as special features. If nothing else, the numerical coding system forces the user to make observations on the internal structure of individual varves and to look for features that might otherwise get overlooked. Effective use of the coding system requires practice and the development of a consistent usage of code numbers.

Here, as in most glacial lacustrine varve studies, the **"summer" layer** refers to the silty clay to sandy **melt season layer** and is the bottom unit of a varve's annual couplet. The **"winter" layer** refers to the upper, usually very clayey, **non-melt season layer** of the varve. The most important aspect of glacial varve analysis or counting is the recognition of distinct nearly pure clay beds as winter layers along with the overall pattern of bedding and grain size in the varve that help define annual layering.

Identifying features with the coding system relies heavily on visually recognizing the contrast between light and dark units in partially dried cores and using darkness contrast as a relative indicator of clay content with lighter tones representing coarser sediment and darker tones representing finer sediment. This works well on gray varves but may not always work with other colors or in varves with mixed colors, especially where red sediments are involved. Cores must be partially dried and scraped carefully for a clear view or thin sections must be prepared (not logistically reasonable for thick varves) to facilitate accurate identification of intra-annual features!! The system will not work on wet or very moist cores because moister tends to obscure contrasts in grain size that allow the detailed identification of subtle varve features in the summer layer according to grain size.

Steps in coding varves are given below. The first four steps are applied to all varves and pair a type of summer layer with a type of winter layer, providing an overall categorization of a varve's sediment type and general bed characteristics. Step 5 is to indicate more details on features that occur within the varve's fundamental summer and winter layers and may not have very much to do with the dominant annual characteristics of glacial varve deposition. Step 6 is to make annotations concerning uncertainties in measurement and core conditions related to coring deformation or recovery. A more detailed flow chart is on the next page and a separate EXCEL spreadsheet has been provided for recording code numbers. Features absent from a varve should be left blank on the spreadsheet. A sheet of icons is also provided to make assigning numerical values easier.

STEP 1: Pick a number for a summer layer type in either the silty clay to clayey silt (10-16) or silt to fine sand categories (20-29). 1 to 3 different summer layer types usually prevail in a varve sequence. The number categorizes the overall makeup of the summer layer, which does ***not*** include separate fine muddy units at the top or base of the summer layer (bedding arrangements 30 and 32).

STEP 2: Pick numbers (up to 9) that apply in the Bedding Arrangements list (30-44) for summer layers. Features 30-44 are normally a part of glacial varves and when they occur in a varve section they often occur repeatedly or prominently in groups of varves in a sequence.

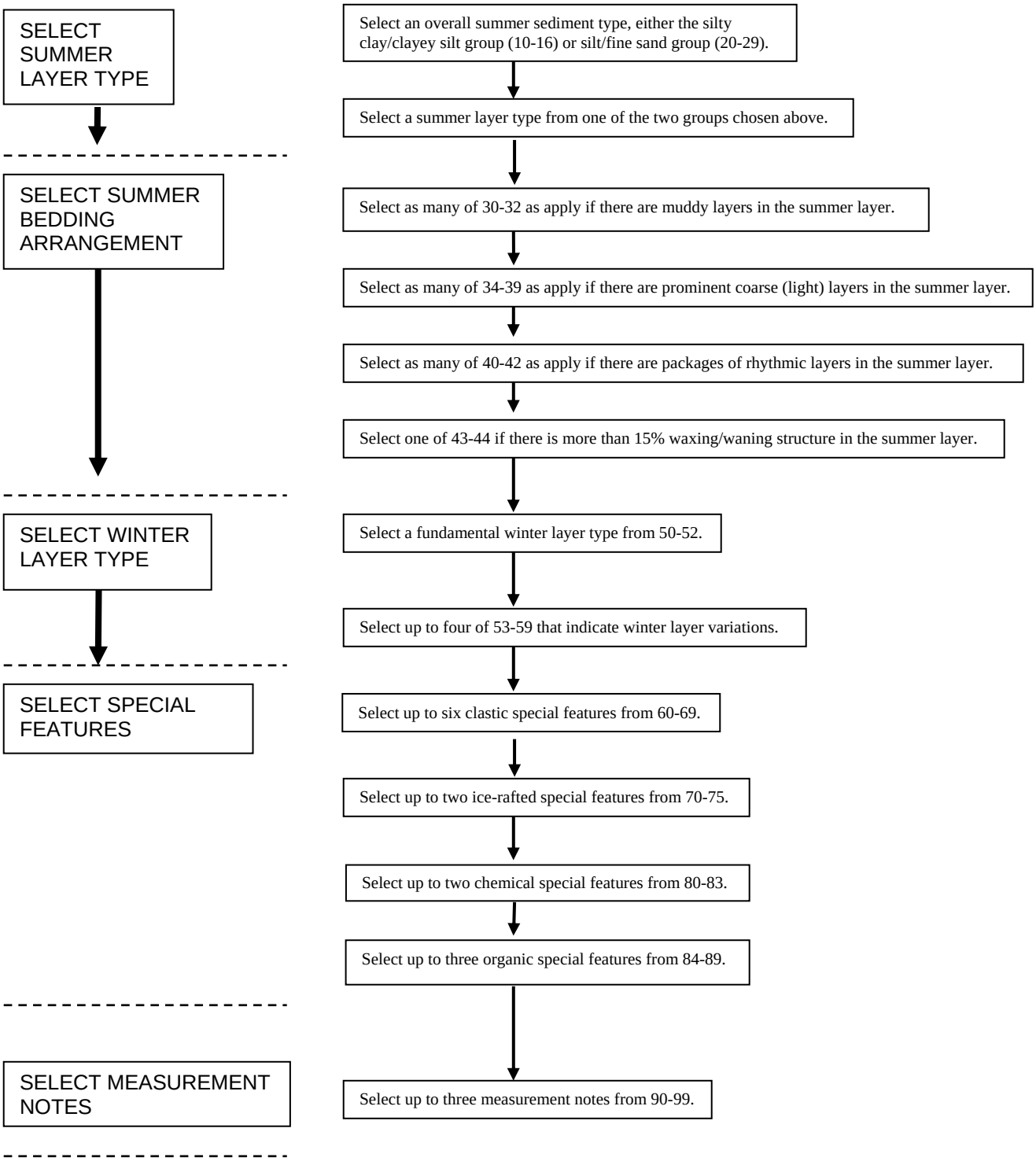
STEP 3: Pick a number for a winter layer type (50-52). 1 to 2 different winter bed types usually prevail in a single varve sequence.

STEP 4: Pick numbers (up to 4) that apply in the Variations list (53-59) for winter layers.

STEP 5: Pick all numbers that apply in the Special Features lists (60-89: Clastic, Ice-Rafted, Chemical/Organic). Special Clastic Features 60-69 occur in glacial varves somewhat infrequently and are not generally repeated very often throughout an entire varve sequence.

STEP 6: Pick any numbers (up to 3) that apply in the Measurement Notes list (90-99).

VARVE CHARACTERIZATION FLOW CHART



SUMMER (MELT SEASON) LAYER CHARACTERISTICS (10-44)

SUMMER SEDIMENT / LAYER TYPES:

Clayey silt to silty clay (usually relatively thin summer layers as compared to the silt to fine sand units below**) Note: Gradation in summer layers is identified as two types: 1) gradation of the summer layer that is a single bed in which individual laminae cannot be defined, and 2) a summer layer in which gradation is in the form of well defined laminae or thin beds (bed stack) that either increase or decrease in coarseness upward. Grading should not include separate distinct muddy units that may occur at the beginning, end, or within the summer layer.**

10 = summer layer is a very thin (<3 mm), usually thinner than winter bed. The thinness of these layers makes the identification of bedding arrangements difficult.
11 = summer layer with single solid tone and massive with no apparent internal layering.
12 = summer layer is bedded with layers that are non-gradational from bottom to top of summer layer.
13 = summer layer with simple normal grading and little or no apparent internal bedding.
14 = summer layer is bedded with stacks of layers that form a normally gradational package from bottom to top.
15 = summer layer with simple reverse grading and little or no apparent internal bedding.
16 = summer layer is bedded with stacks of layers that form a reversely gradational package from bottom to top.

Silt to fine sand (often relatively thick summer layers as compared to the clayey units above) **Note: Gradation in summer layers is identified as two types: 1) gradation of the summer layer that is a single bed in which individual laminae cannot be defined, and 2) a summer layer in which gradation is in the form of well defined laminae or thin beds (bed stack) that either increase or decrease in coarseness upward. Grading should not include separate distinct muddy units that may occur at the beginning, end, or within the summer layer.**

20 = summer layer is a very thin (<3 mm), usually thinner than winter bed. Recorded ignoring 30-32. The thinness of these layers makes the identification of bedding arrangements difficult.
21 = summer layer with single solid tone and massive with no prominent internal layering. Recorded ignoring 30-32.
22 = summer layer is bedded with stack of layers that are non-gradational from bottom to top of summer layer. Recorded ignoring 30-32.
23 = summer layer with simple normal grading and little or no apparent internal bedding (does not include 32).
24 = summer layer is bedded with stack of layers that form a normally gradational package from bottom to top (does not include 32).
25 = summer layer with simple reverse grading and little or no apparent internal bedding (does not include 30).
26 = summer layer is bedded with stack of layers that form a reversely gradational package from bottom to top (does not include 30).
27 = summer layer with initial reverse grading followed by normal grading and little or no apparent internal bedding (does not include 30 or 32).
28 = summer layer is bedded with stack of layers that form an initially reverse graded package followed by a normal graded package from bottom to top (does not include 30 or 32).
29 = summer layer is initially normal graded with reverse grading above. Summer grading is in the form of either: 1) a single bed with no apparent internal laminations, 2) two beds with no apparent internal laminations, one bed normally graded and the other reverse graded, or 3) a stack of beds that are initially normal graded and then reverse graded.

SUMMER BEDDING ARRANGEMENTS:

Prominent Fine Layers

30 = summer layer has distinct bedded or non-bedded fine-grained unit at bottom apart from grading identified as 25, 26, 27, or 28. This unit is distinct from and siltier than the underlying winter layer and appears to mark low sediment input and current velocity at the beginning of the melting season.
31 = summer layer has distinct bedded or non-bedded fine-grained unit in middle.
32 = summer layer has distinct bedded or non-bedded fine-grained unit at top separate from its winter layer and apart from grading identified as 23, 24, 27, or 28. This unit is non-gradational with the winter layer above and siltier than the winter layer. It appears to represent reduced sediment input and weakened current velocity at the end of the melting season.

Prominent Coarse Layers

34 = summer layer with no prominent coarse layers. (Relatively rare in thicker varves.)
35 = summer layer with a prominent coarse (light) layer at its bottom. Recorded immediately above 30, if 30 is present. This layer can typically represent the beginning of the melting season layer in ice-distal or valley side varves.
36 = summer layer with only one prominent coarse (light) layer in its middle.
37 = summer layer with 2 prominent coarse (light) layers in its middle.
38 = summer layer with 3 or more prominent coarse (light) layers in its middle.
39 = summer layer with a prominent coarse (light) layer at its top. Recorded immediately below 32, if 32 is present. This unit may represent the end of the melting season layer.

Rhythmic (diurnal?) Layers (record all 3 of 40-42 for summer layer with rhythmic layering throughout) **Note: The very regularly repeated layering of some internal rhythmic packages is highly suggestive of diurnal variation in sediment input and /or sediment dispersal. These units are most prominent in ice-proximal varves.**

40 = summer layer with package of laminated highly rhythmic beds at bottom, may be in unit recorded as 30.
41 = summer layer with package of laminated highly rhythmic beds in middle, may be in unit recorded as 31.
42 = summer layer with package of laminated highly rhythmic beds at top, may be in unit recorded as 32 but should not be in base of winter layer (see 59).

Waxing/Waning Structure **Note: Waxing/waning structures are grain size differences in the melting season layer that occur gradationally with no sharp boundaries between beds of different grain size. Caution should be used in interpreting waxing/waning structure in that its accurate recognition is highly dependent on core preparation and in some cases it could be the result of coring-induced shock of the sediment.**

43 = summer layer that is 15-50% waxing (coarsening) and waning (fining) structure (cycles).
44 = summer layer that is >50% waxing (coarsening) and waning (fining) structure (cycles).

WINTER (NON-MELT SEASON) LAYER CHARACTERISTICS (50-59) (Also see SPECIAL FEATURES)

LAYER TYPES:

50 = winter layer is very thin (<3 mm) or a clay parting. These layers are sometimes silty and their thinness makes the identification of winter bed variation features (below) difficult.
51 = winter layer is not gradational with summer layer below (diatactic varve), summer/winter transition over 1 mm or less.
52 = winter layer is gradational over more than 1 mm with underlying summer layer below (symmict varve).

VARIATIONS:

53 = winter layer with two separate colors (dark over light, or gray over red) due to compositional, not grain size differences.
54 = winter layer with two separate colors (light over dark, or red over gray) due to compositional, not grain size differences.
55 = winter layer is muddy and silty throughout.
56 = winter layer has faint muddy silty zone or parting in middle. This may represent a weak melting or stream/storm runoff event after the initiation of winter clay deposition.
57 = winter layer has one prominent light silty or sandy parting. This may represent a melting or stream/storm runoff event after the initiation of winter clay deposition.
58 = winter layer has two or more prominent light silty or sandy partings. These may represent two or more melting or stream/storm runoff events after the initiation of winter clay deposition.
59 = winter layer has rhythmic (diurnal?) silty layers or partings in its base, i.e. rhythmic layering occurs after the initiation of winter clay deposition. If the rhythmic layering is still in the summer layer (prior to initiation of clay deposition) it should be designated as 32.

SPECIAL FEATURES (60-89) – in addition to summer and winter layer characteristics

CLASTIC FEATURES:

60 = isolated bedding plane depression or scour mark at top of winter layer
61 = isolated bedding plane depression or scour pit in or at top of summer layer
62 = entire top of winter layer is scoured or eroded.
63 = varve containing a folded or contorted layer or debris layer produced by soft sediment deformation associated with translational mass movement.
64 = layers in varve are deformed by load deformation or have water escape structures that do not appear to be associated with significant translational movement.
65 = brecciated layer in varve
66 = prominent, relatively thick (>0.5 cm), graded sand to clayey bed in summer layer, or graded sandy bed in winter layer (false couplet). In summer layer should be simultaneously recorded as one of 35-39.
67 = rippled or crossbedded sand, could simultaneously be recorded as 66 or 68.
68 = medium sand to gravelly layer or parting, could simultaneously be recorded as 66 or 67.
69 = diamicton layer, either due to ice rafting or mass flow.

ICE-RAFTED DEBRIS:

70 = summer layer is >50% rafted debris.
71 = ice-rafted clasts and pellets of diamicton or rock flour (silt) are <50% of varve and occur throughout but mostly in summer layer.
72 = ice-rafted clasts and pellets of diamicton or rock flour (silt) are <50% of varve and occur evenly distributed in summer and winter layers.
73 = ice-rafted clasts and pellets of diamicton or rock flour (silt) are <50% of varve and occur throughout but mostly in top of summer through winter layer.
74 = ice-rafted clasts and pellets of diamicton or rock flour (silt) are <50% of varve and occur throughout but have a conspicuous concentration in top of winter layer.
75 = isolated outsized clast (dropstone).

CHEMICAL/ORGANIC FEATURES:

80 = calcium carbonate concretion or cement layer.
81 = beds with oxidized Fe/Mn or Fe/Mn oxide accumulation.
82 = Fe/Mn nodule or concretion.
83 = oxidation banding cutting across bedding.
84 = thin dark brown to black, organic or oxide lamination on top of winter layer.
85 = black to dark bluish-gray color in sediment due to elevated organic content.
86 = plant fossil(s), may be oxidized.
87 = macroscopic bioturbation.
88 = shell, shells, or shell debris of bivalves or gastropods.
89 = fish fossil remains (scale or bone)

MEASUREMENT NOTES AND UNCERTAINTIES (90-99)

90 = measured as one varve but this couplet may be two varves.
91 = measured as separate varve but this couplet may be a varve with couplet above. Always used with 92 for couplet above.
92 = measured as separate varve but this couplet may be a varve with couplet below. Always used with 91 for couplet below.
93 = crack in core.
94 = fault in core, accurate measurement unimpeded.
95 = core deformation, bedding warped during coring, accurate measurement unimpeded.
96 = core deformation, deformed by coring or naturally folding/contorted bed, accurate measurement is not likely.
97 = core join in this varve.
98 = core thickness, not a couplet measurement. This is the core thickness of a space measured in core or of sediment not included in a varve measurement.
99 = other comment: Make a written note with a core designation and image number for later reference. This may be a feature not covered by the present code.