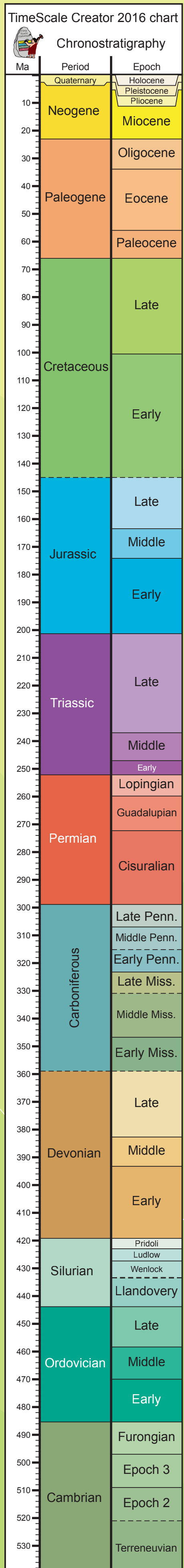
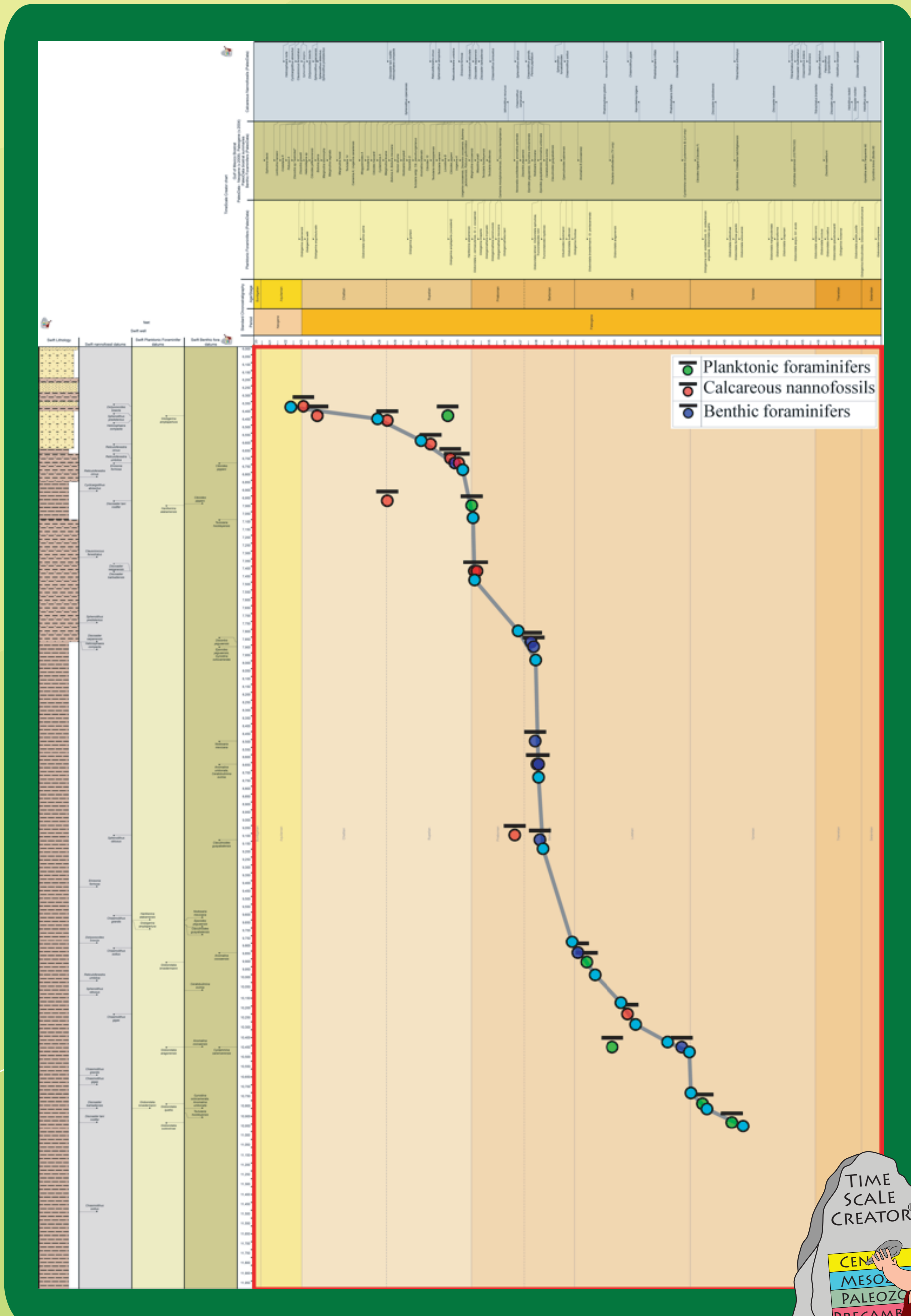


TimeScale Creator Manual

Section 4

TSC Crossplot



www.timescalecreator.org

This Manual is divided into 5 sections, each section is independent of the others and can be used on its own.

Section 1: Reference of TSCreator Features and Datapack Formats
Section 2: Hands-on Exercises for using TSCreator and how to make datapacks
Section 3: TSC Makers: Online tools to create lithology, transect and curve datapacks.
Section 4: Crossplot, convert outcrop or well datapacks from meters or feet to age datapacks in Ma or Ka.
Section 5: Online TSCreator display systems. Not yet fully functional.

Important websites for TimeScale Creator

TSCreator main website https://timescalecreator.org

Datapack Makers (Transect, Lithology, Curve Maker)

https://timescalecreator.org/tscmaker/

TSC Lite

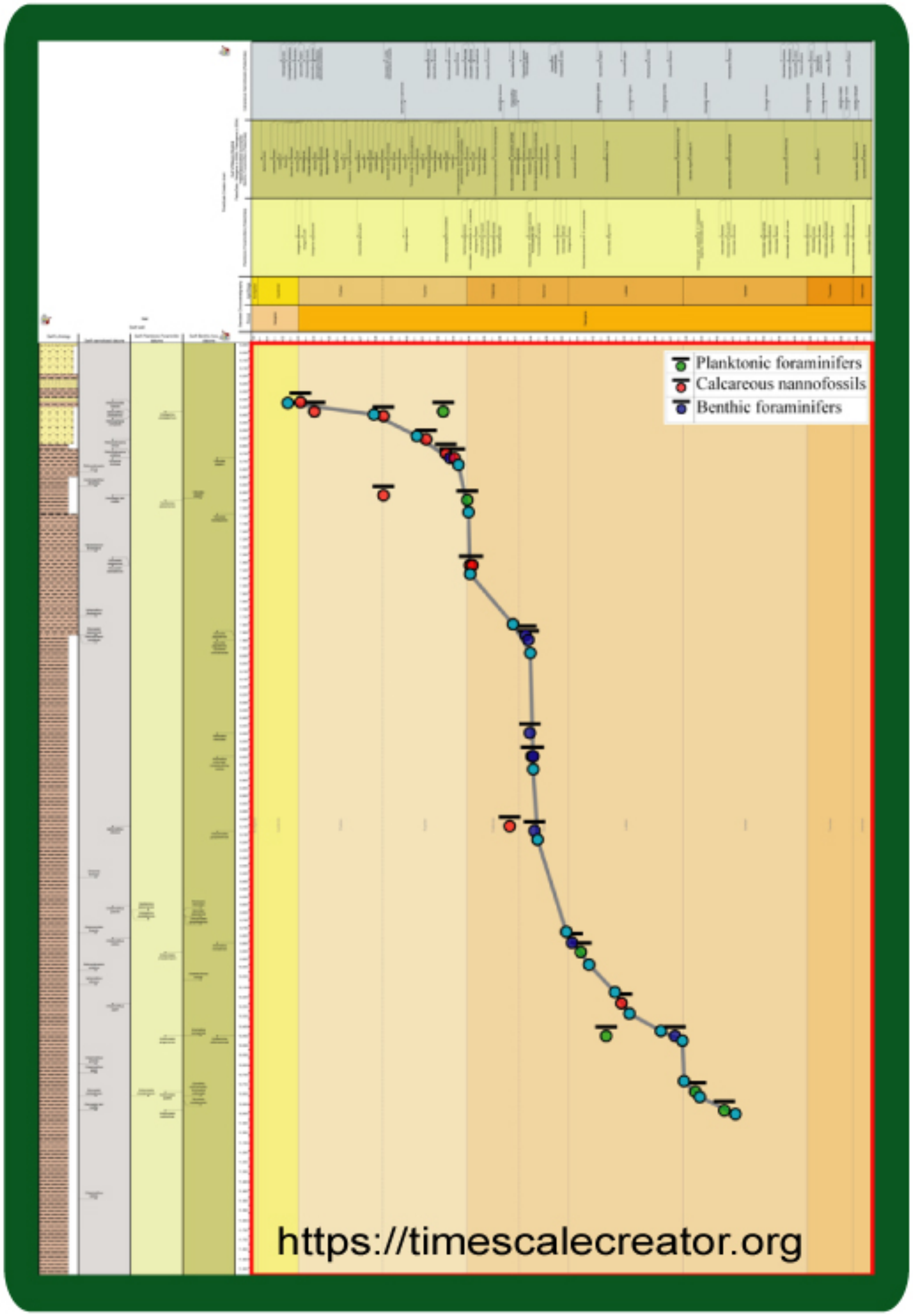
https://timescalecreator.org/tsclite/index/index.php

Online TimeScale Creator (testing site):

http://show.timescalecreator.com:3000/

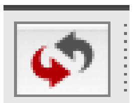
Table of Contents for Section 4

Crossplot and Depth-Age Conversion Tutorial



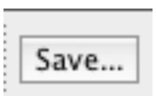
Crossplot Tools – Quick Guide

Top Tool bar:

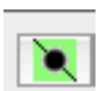


Refresh. Refreshes the crossplot window. Use after autoplotting marker points to enlarge the points.

Zoom. Zoom in or out, View at 100%. Enlarge plot to fill the whole window.

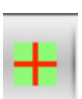


Saves the image of the plot as an svg file.



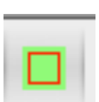
Selector for **Model Points.** Click tab and then double click where you want your model points. Single click will delete your previous point.

Selector for **Marker Points.** Click tab and then double click where you want your marker points. Single click will delete your previous point.

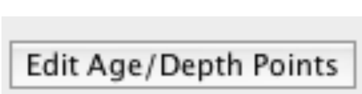


Show/Hide cross hairs. The cross-hairs give precision when aligning events that are on both the Depth and Age axes. The ability to fix either depth (pressing Y key) or age (pressing X key) on the cross-hairs is useful when zooming in/out to retain positions. Press the key again to release the cross-hair.

Show age/depth pop-ups.



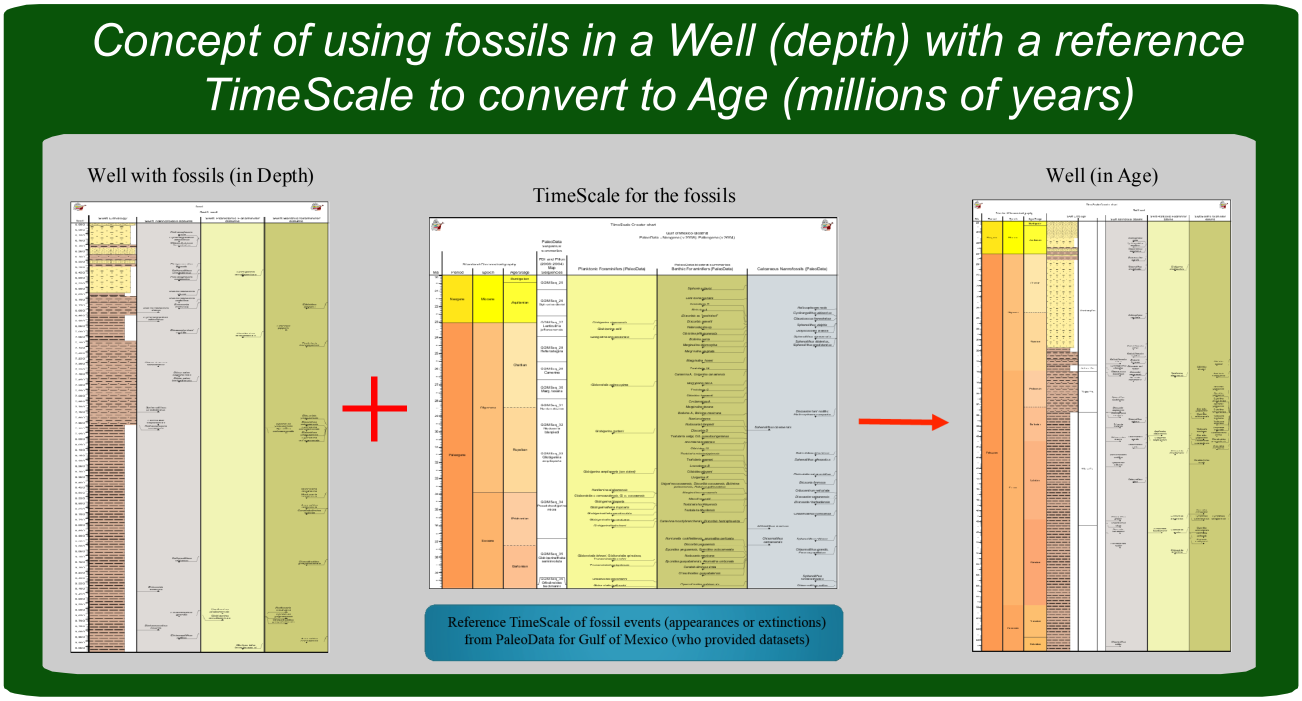
Show/Hide plot bounding box



Edit your marker/model points. Add color, names etc. Save the marker/model points as a txt file to reload at a later time.

Crossplot and Depth-to-Age Conversion

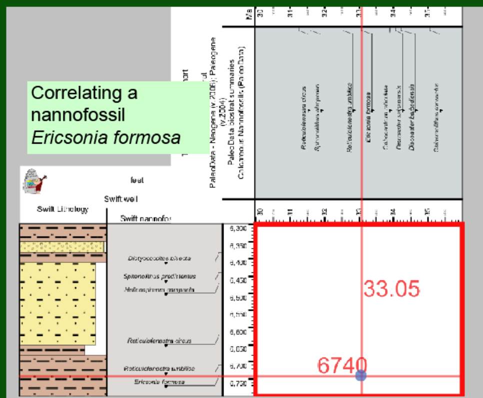
We wish to view a well or outcrop in "depth", then to convert it to geologic age using a reference time scale.

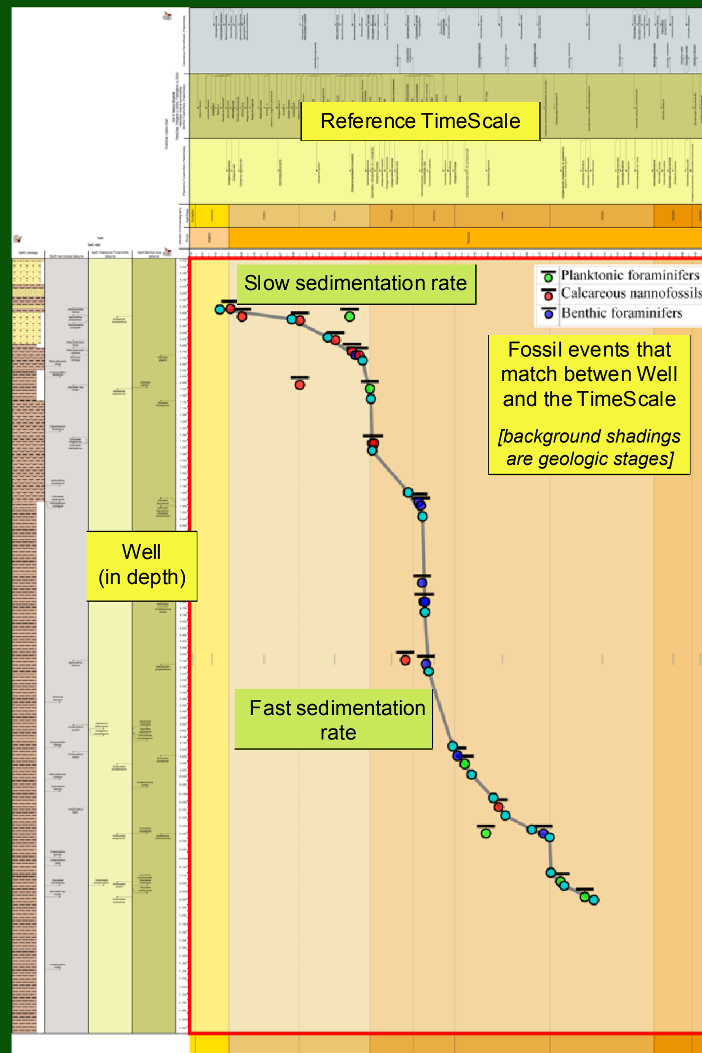


A common visual-method for such a conversion is a crossplot of the well/outcrop (Y-axis) and the Reference time scale (X-axis).

In TSCreator, we can display these two independent datasets. The user can select any age (or depth) span, scaling factor, and which columns to show on each axis. Events that are common to both the well/outcrop and to the reference time scale are selected or auto-plotted (colored dots in the figure on the next page).

The user assigns a series of depth-to-age trends (lines in the figure on the next page), which are used to make the depth-to-age conversion – our desired "Well (in Age)" as shown in the figure above.

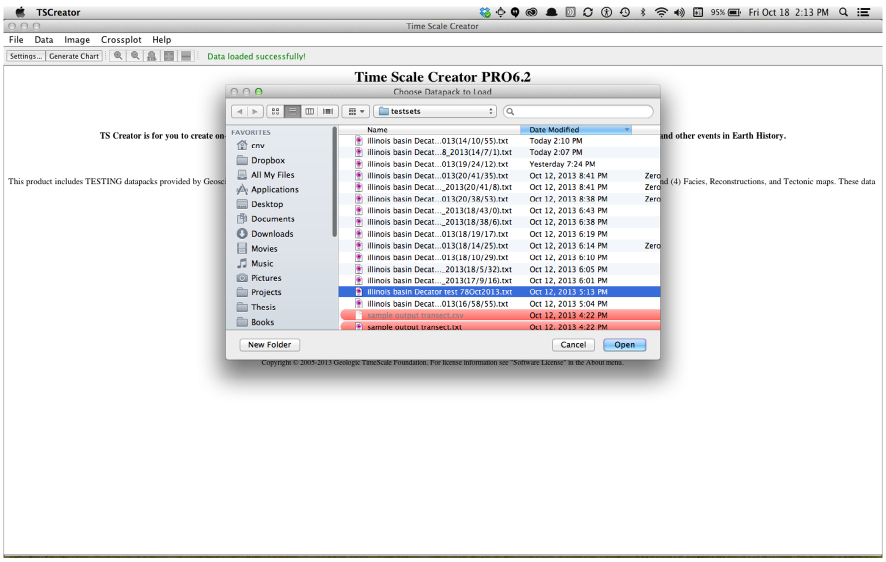

Correlating a nannofossil *Ericsonia formosa*
33.05
6740


Reference TimeScale
Slow sedimentation rate
Planktonic foraminifers
Calcareous nannofossils
Benthic foraminifers
Fossil events that match betwen Well and the TimeScale
[background shadings are geologic stages]
Well (in depth)
Fast sedimentation rate

Crossplot and Depth-to-Age Conversion – Step-by-Step Demo

If you do more than one well, you have to quit the TS-Creator and reload the program between wells

Step-1: Add any additional "Age Reference Scale" datapacks and "Well in Depth" datapacks

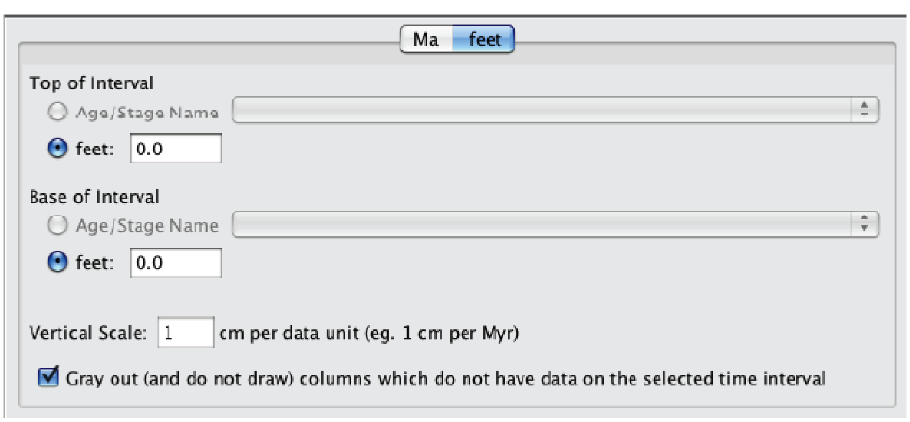


For our reference- "age" datapacks, select **REPLACE** DATA WITH DATAPACK (for the completely stand-alone one, such as the PaleoStrat Gulf of Mexico biostratigraphy scales and generalized regional stratigraphy): Replace with "***Gulf_of_Mex_ReferenceTimeScale_PaleoData.txt***").

To load the "depth-scale" wells, under "File" menu, select "***Add Datapack***" and select the appropriate depth file. For this demo, find and open "***GoM_Swift_well for CrossPlot demo.txt***", the depth file for the facies and biostratigraphy of an onshore "*GoM Swift*" well (provided by PaleoData).

Go to settings:

A separate column menu for that outcrop/well (in "feet" in our example) appears in the age-selection menu ("Time Interval columns"). The corresponding interval-selection menu in *TSCreator* appears as below. Our "Swift" well had units of "feet", therefore we have a choice of "Ma" (for the internal age set) and "**ft**" (for the loaded depth set) to set scales for each separate plot.



Dual-column display mode

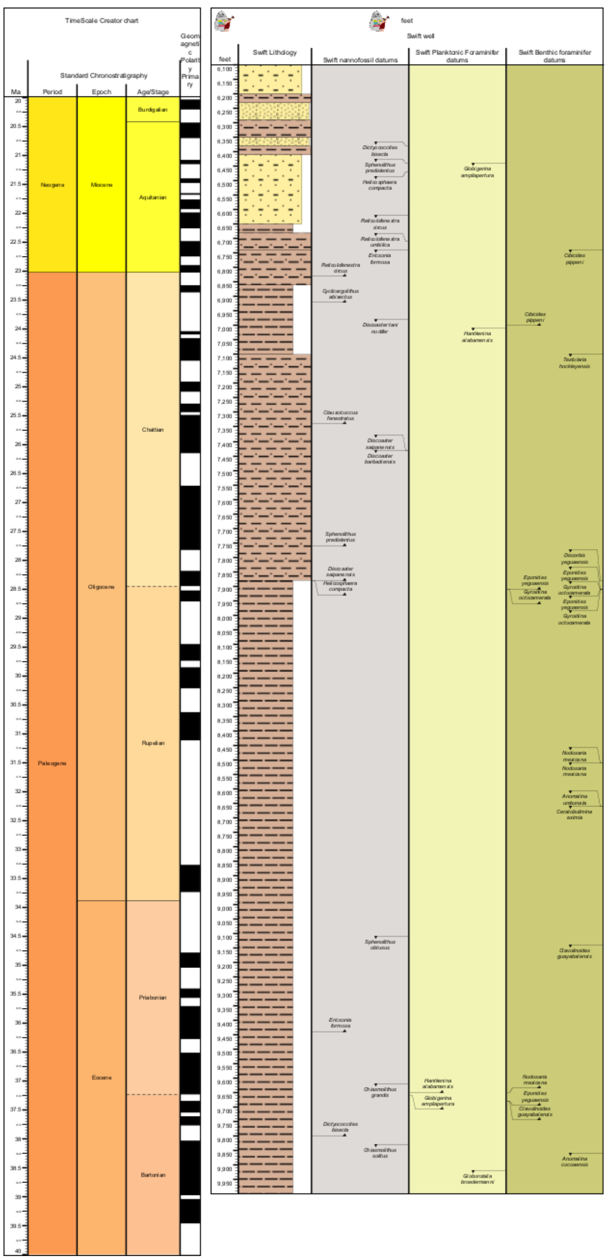
for depth and age

OPTIONAL: Dual-column display

A non-crossplot, dual-column display can be generated by selecting both the “Ma” and the “ft” tabs. For this initial view, we will select an Age interval of early Miocene (**20 Ma**) to middle Paleocene (**60 Ma**) and **3** for the vertical scale for our age set. The **Swift well** has a **depth** range from **6140 ft** to **12000 ft**. Choose an appropriate scaling for the depth axis (e.g., **0.02** cm per ft).

The dual-column display that is generated is shown below. On the left is our “age” dataset spanning Lower Miocene to Early Paleogene. On the right is a visualization of the stratigraphy by depth in Swift well.

Dual-column display for the demo well file

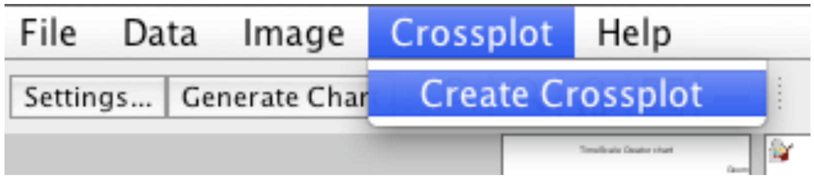


The Swift-display (right-hand columns) shows the different kinds of lithology that appear in the well (claystone, sandstone, etc.) and the various microfossils that appear – in this well, there are a few recorded first appearance datums (FAD), but mainly the last appearance datums (LAD) of calcareous nannofossils, benthic foraminifers and planktonic foraminifers.

Our task is now to convert the depths of the Swift well “feet” into a corresponding age in “Ma”. To do this, we will compare the microfossils in the Swift well with reference microfossil-scales in the Gulf of Mexico datapack. Therefore, we wish to use a cross-plot to pick a series of corresponding depths-in-Swift-well to ages-of-events in the Gulf of Mexico datapack.

Step-2: Open the Crossplot window

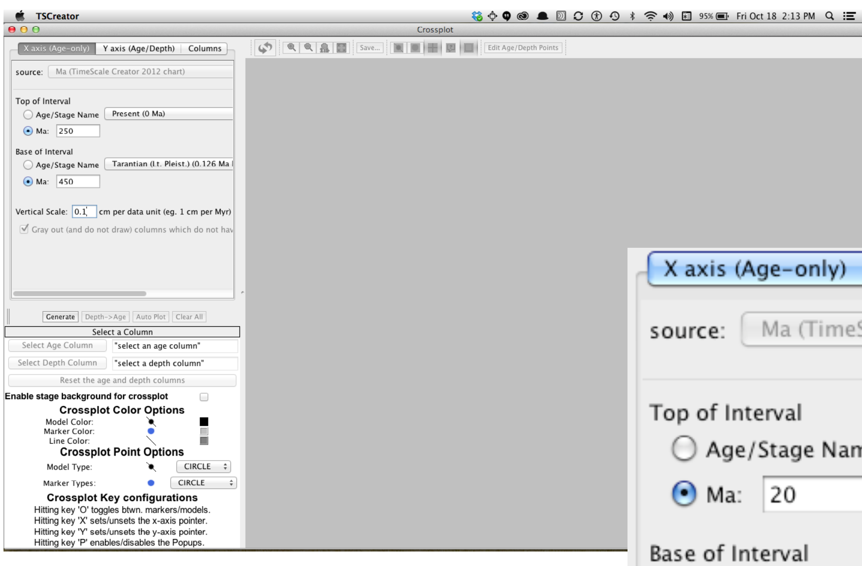
Under "*Crossplot*" menu, select "*Create Crossplot*".

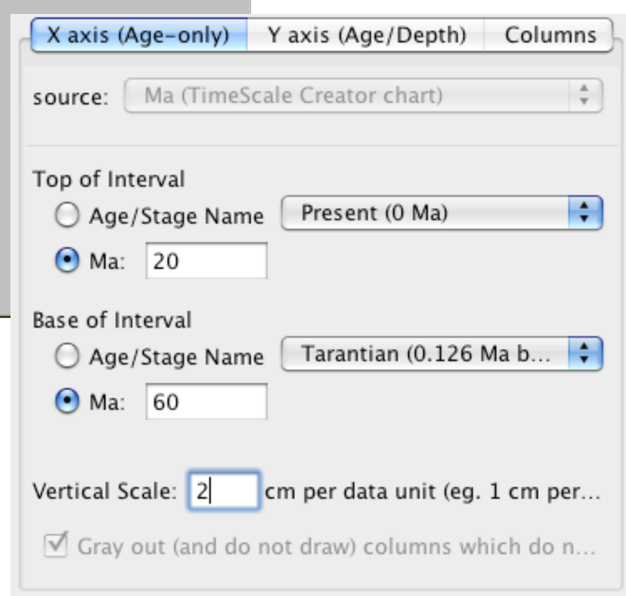


Crossplot window

The crossplot menu appears in a new window.

Step 3: X-axis (=Age) – set Top/Base and scale

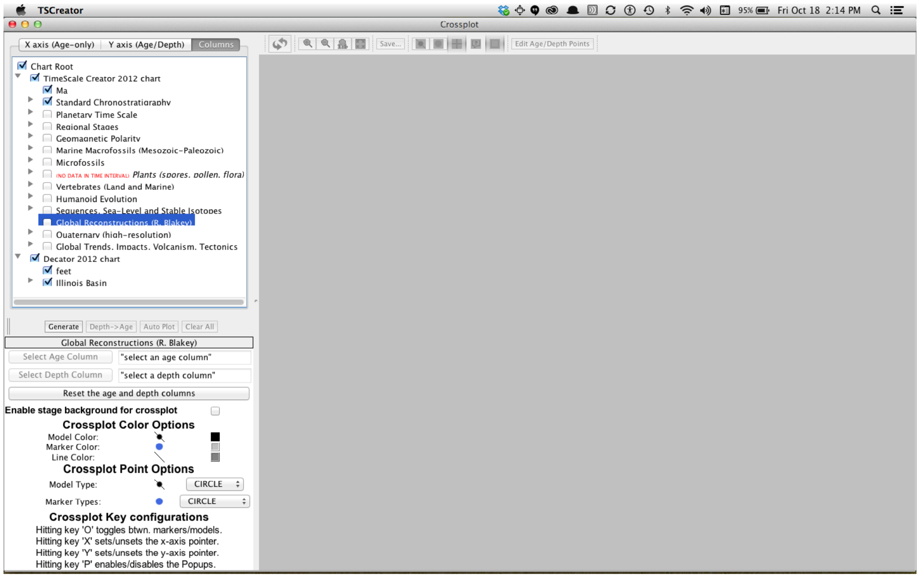




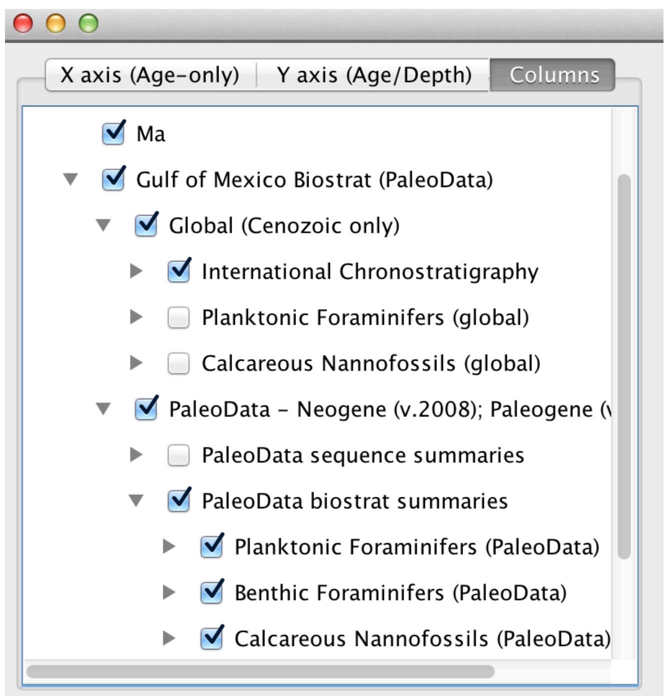
Choosing the top and base of the time interval

Using the LEFT tab (**X-axis**), select an appropriate "Age" interval on the age axis and a scale for the "age" axis. In the Figure above, the interval from **20 to 60** Ma, and a scale of **2** cm/myr is chosen.

Then, under the *Columns* tab, we select the reference stratigraphic scales to be cross-plotted.

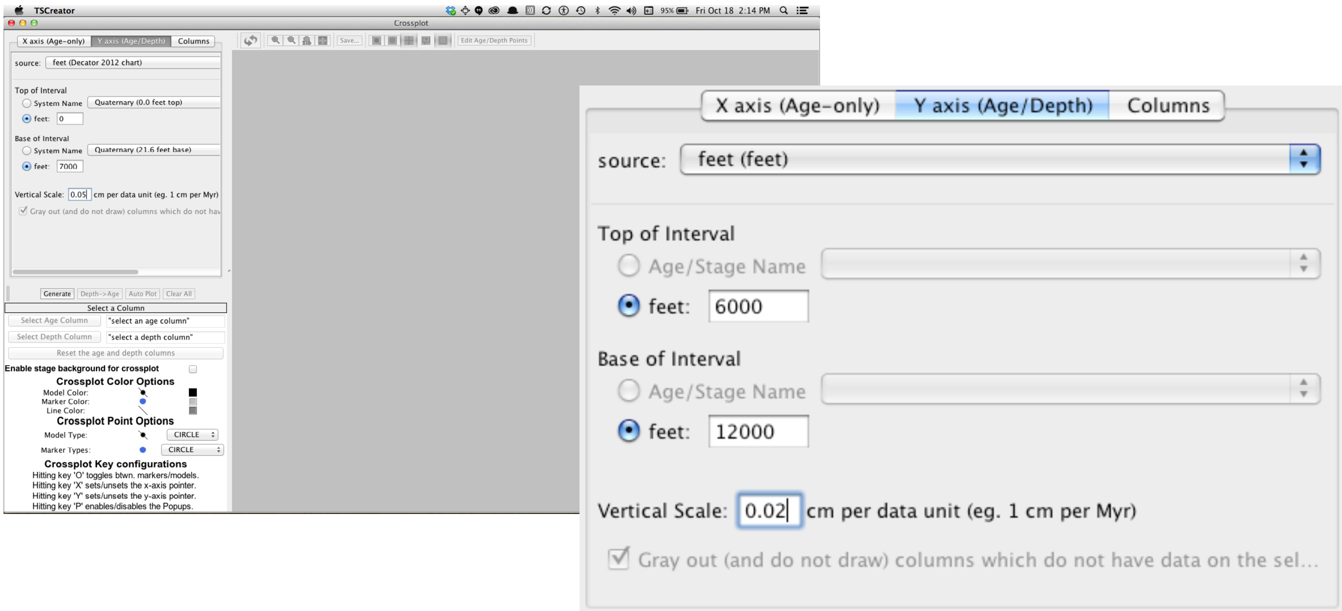


In this demo example, microfossils from the PaleoData Inc's biostratigraphy datapack for the Gulf of Mexico are selected:



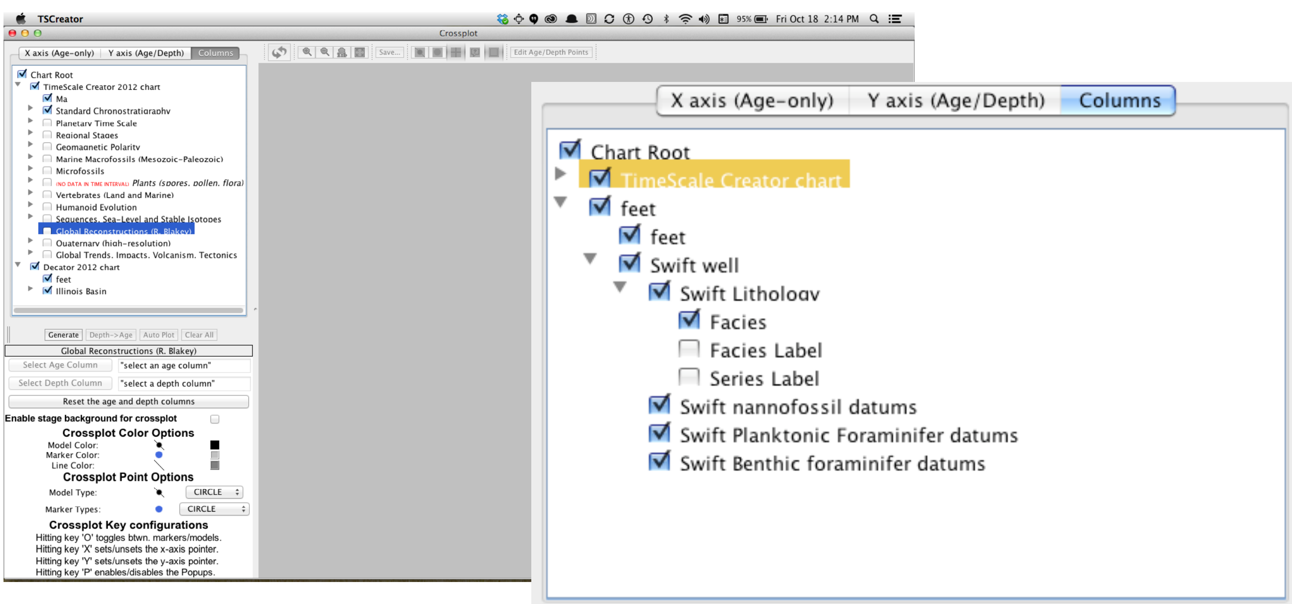
Selecting stratigraphic columns for cross-plotting on the age-axis [*NOTE: This used PaleoData*.]

Step-4: Y-axis (depth) – Set Interval top/base and scale



Using the CENTER tab (**Y-axis**), select an appropriate depth interval for the depth axis to be displayed and a corresponding scale. For the Swift well, we set the top and bottom to be **6000 ft** and **12000 ft**, respectively; then choose a scale of **0.02** cm/ft.

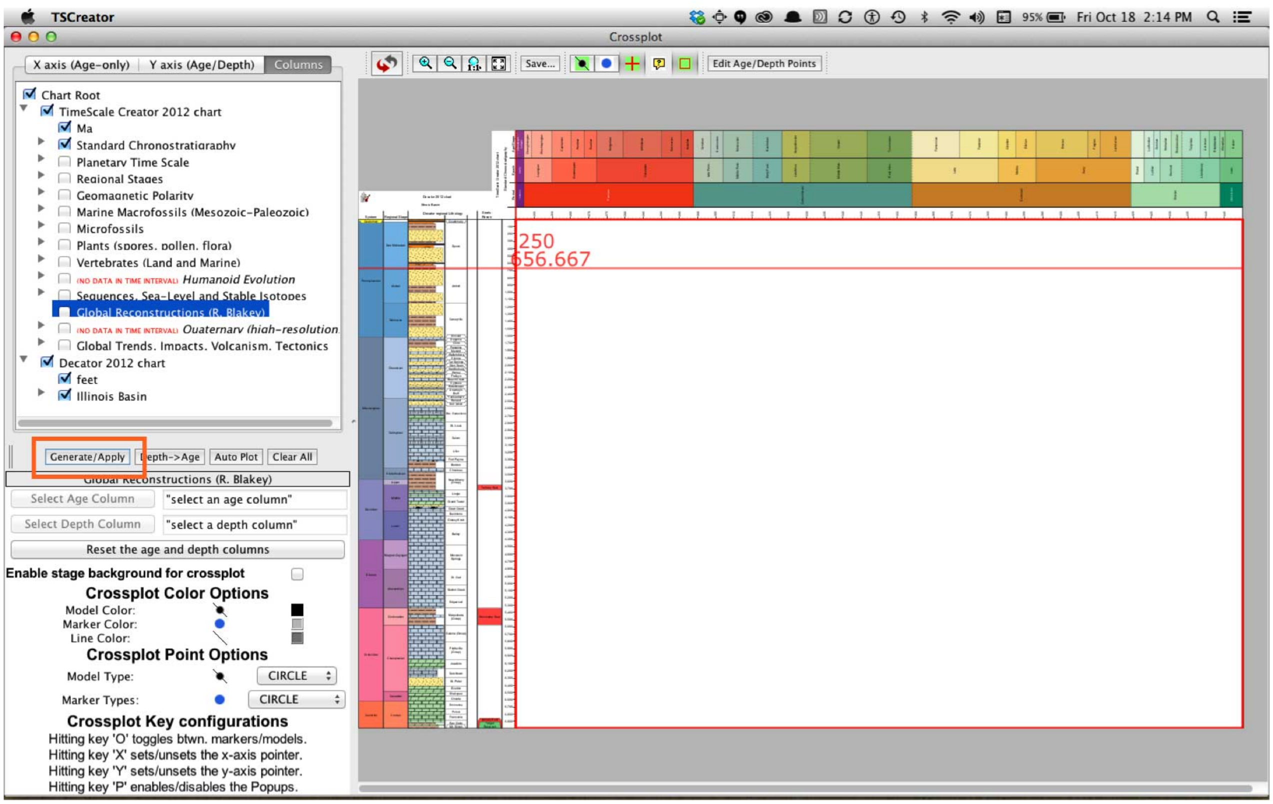
Using the RIGHT-most tab, "*Columns*", choose the appropriate columns for the depth axis to be crossplotted for your initial view.



For this Swift well, choose the Lithology and the different microfossil columns – calcareous nannofossils, benthic and planktonic foraminifers as shown below.

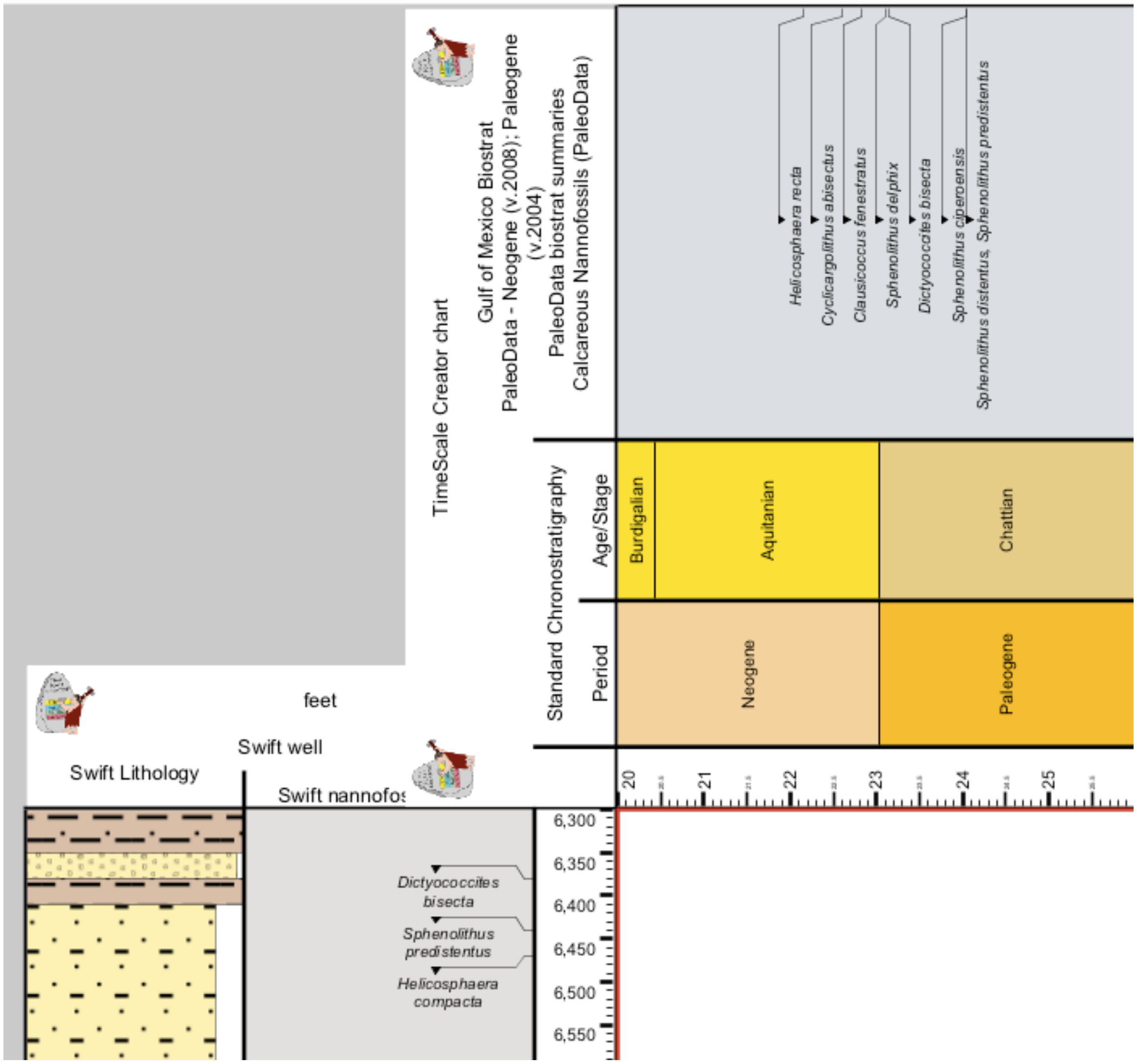
Step 5: Generate the crossplot

The crossplot display is generated by clicking on the '*Generate'* button at the bottom of the crossplot window. Below is an example of the entire Paleozoic of Nanjing, China versus GTS2012:



The crossplot window has an Age-scale as the X-axis and Depth-scale as the Y-axis of the crossplot. A screenshot for a part of the crossplot window is shown below.

NOTE: At any time, you can reset any interval within the Age or Depth sets with a higher-magnification ("vertical scale") to see and correlate details. The placement of reference-correlation or age-model points are retained when zooming in/out, or when selecting a sub-interval for either depth or age.



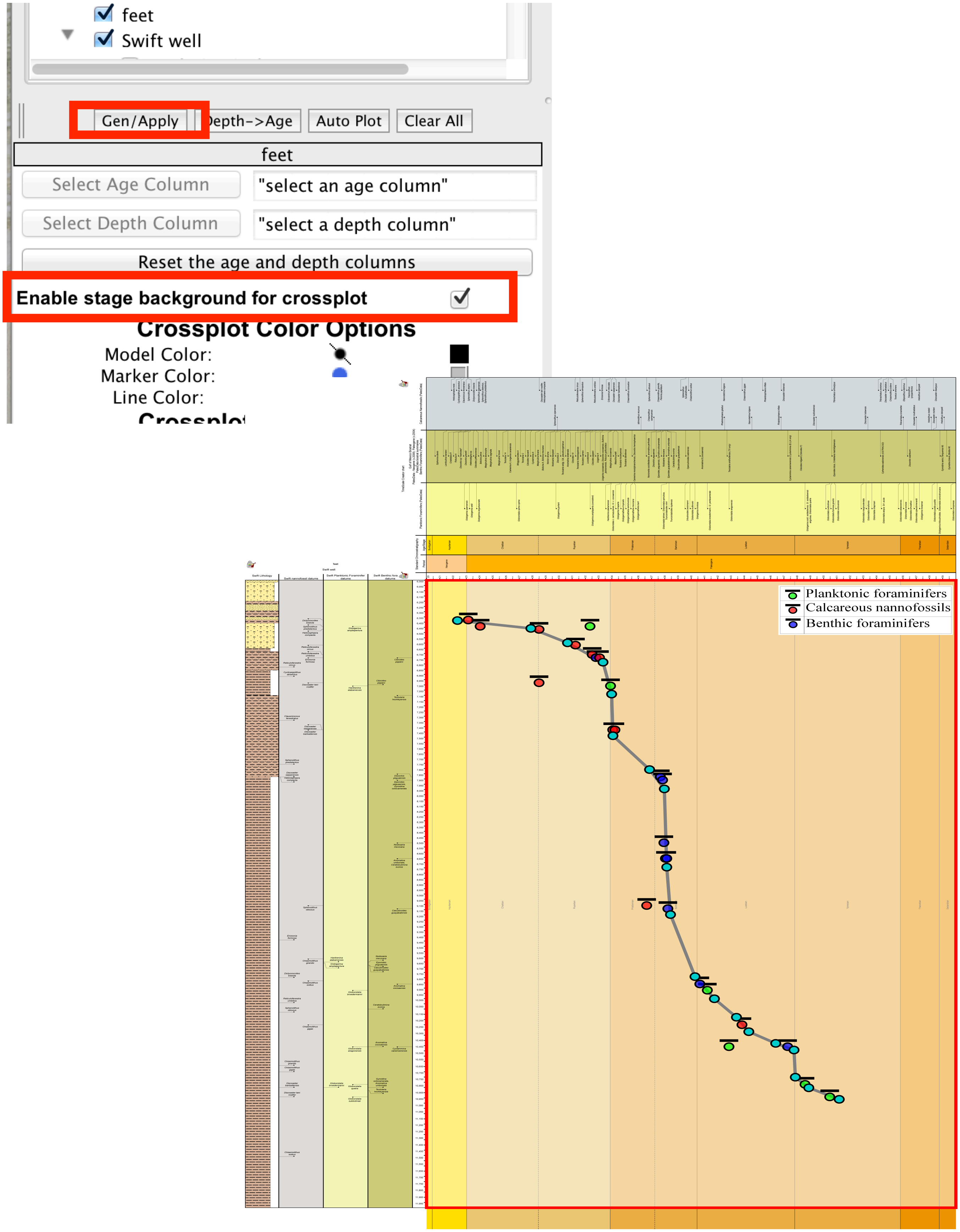
Crossplot window for the demo Swift well

In the subset shown in the Figure, the Y-axis has the Swift-well lithology and the various appearances/disappearances of calcareous nannofossils and the X-axis has the geologic stages and the calcareous nannofossil biostratigraphy for Gulf of Mexico (part of PaleoData sets in that datapack).

<u>Special Feature -- Enabling the stage background:</u>

Clicking on ***'Enable Stage Background'***, then clicking GENERATE adds the background colors for geologic stages according to their position on the X-axis reference Age columns. The figure below shows the depth-age conversion model with the enabled stage background (shades of brown for Paleogene stages, and a yellow for the youngest Neogene stage).

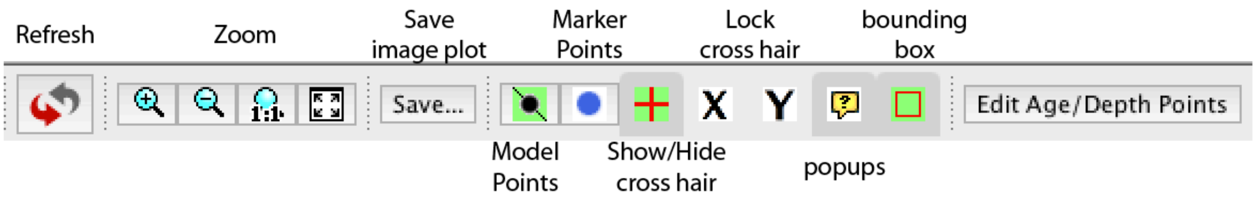
You can enable the background colors at any time.



Crossplot with stage background

Crossplot tools:

Top tool bar:



Keyboard shortcuts:

Crossplot Key Configurations

Hitting key 'O' toggles btwn. markers/models.
Hitting key 'X' locks/unlocks the vertical Age line.
Hitting key 'Y' locks/unlocks the horizontal Depth line.
Hitting key 'P' enables/disables the Popups.

There is a menu of the main tools at the top of the crossplot window; and a set of keyboard shortcuts.

- The cross-hairs give precision when aligning events that are on both the Depth and Age axes.
- The ability to **fix** either depth or age on the cross-hairs (Pressing X or Y keys) is useful when zooming in/out to retain positions, or to force a hiatus (no change in depth, but a jump in age).

There are two types of points– "**Marker points**" used for a visual display of correlation events, and the "**Depth-Age Model points**" that fix our conversion from depth to time. Typically, one first identifies all the various "Marker points", then uses a subset of these to make a subjective "curve fit" (a series of linear segments and perhaps interpreted hiatuses) for the "Depth-Age model".

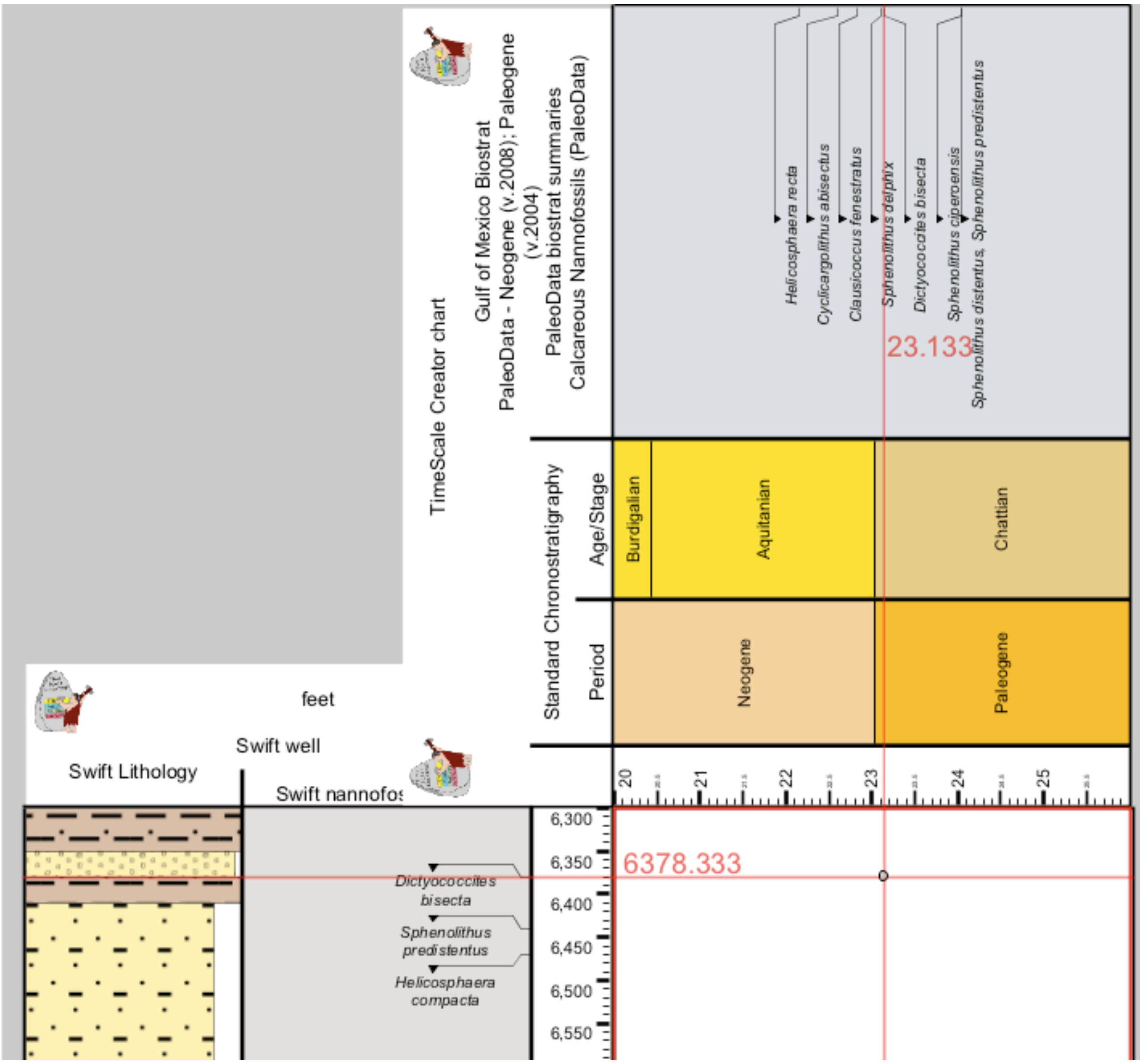
NOTE: Double-clicking adds a point; a Single-click removes it

Step 6: Choosing and editing depth-age points in the crossplot window

To choose points (**markers**) that will guide the depth-age model, we identify the same events that appear both on the age and the depth axis, then place a marker at the corresponding depth and age intersection. For our Swift well, our depth-age model is obtained by correlating the microfossils. Thus, we locate those microfossils that are found on both the depth and the age axes.

There are two ways: (1) the **manual** comparison of events on the depth and the age axes, and (2) an **automated** matching of items that have the same names in those two suites (either by selecting which columns in each to correlate, or a totally auto-match of all events found in any column). But, the automated routines function ONLY if the names in both the depth and the age sets are identical (although in later versions we will try to add synonym usage). We will summarize the manual comparison first to show the methods and flexibility (*next 4 pages*), then the options for automated matching.

METHOD 1 – MANUAL MATCHING



Correlating a nannofossil *Dictyococcites bisecta*

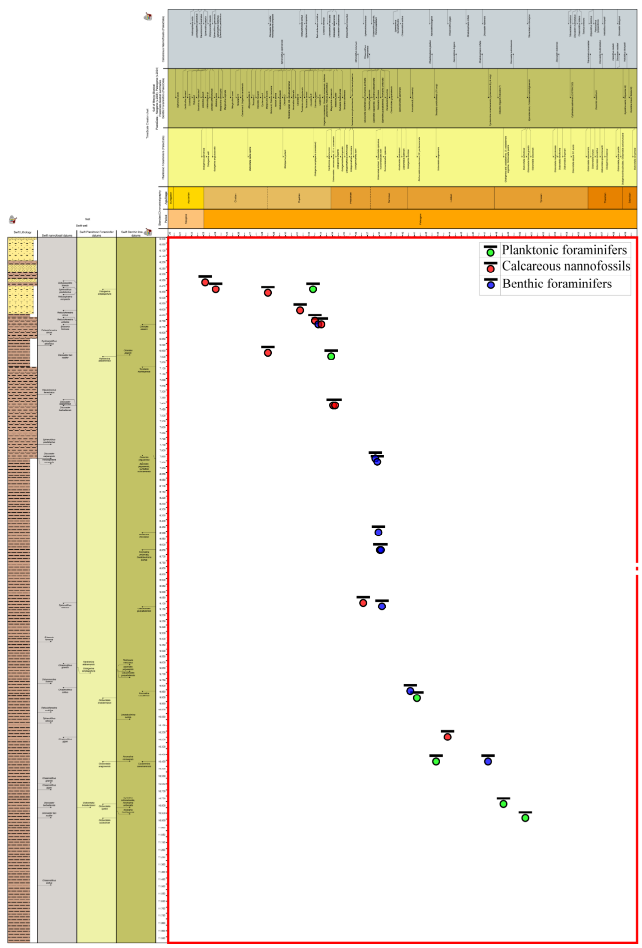
Select marker points  **in the top tool bar.**

NOTE: Double-clicking adds a point; a Single-click removes it

To fix the age coordinate of the event once the cross-hair is on it, press the shortcut '**X'** to lock that age-crosshair. Similarly, the level of depth of the same event once the cross-hair is on it can be fixed by pressing the shortcut '**Y**' to lock that cross-hair. Once this pair of age and the depth coordinates are fixed, a marker-point can be placed by double-clicking and the point will automatically be on the intersection of the cross-hairs. *[A single-click on a previous marker-point will remove it.]*

Try using this method for: ***Dictyococcites bisecta, Sphenolithus predistentus, Reticulofenestra circus.***

Crossplot with reference points for the Swift demo well



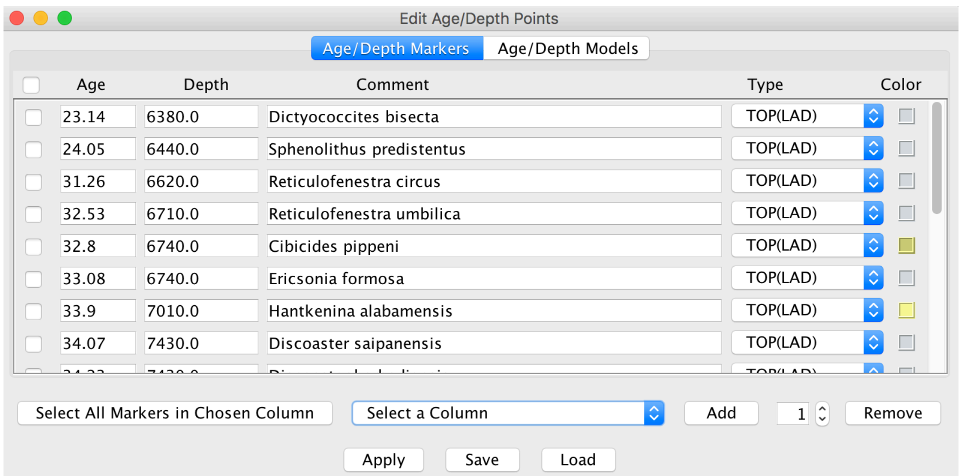
In order to distinguish between different kinds of microfossils, different colors can be assigned to their markers. Also, to differentiate between FADs and LADs of different events, different symbols are given to the FADs and LADs. This is done in the **Edit Age/Depth Points** Menu in the top tool bar.

In the above figure, the calcareous nannofossils have been correlated with red circles, the benthic foraminifers with blue circles, planktonic foraminifers with green circles. LADs of events have a bar at the top of the circle. Similarly, FADs of events have a bar at the bottom of the circle.

The ability to distinguish between different events makes it convenient to choose “priority” points while choosing a depth-age model.

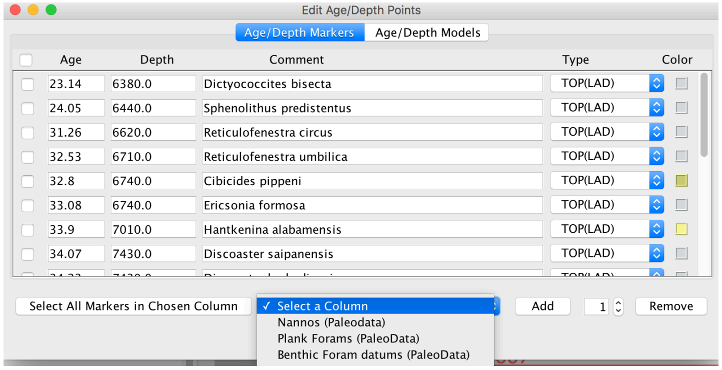
Editing points in the crossplot window:

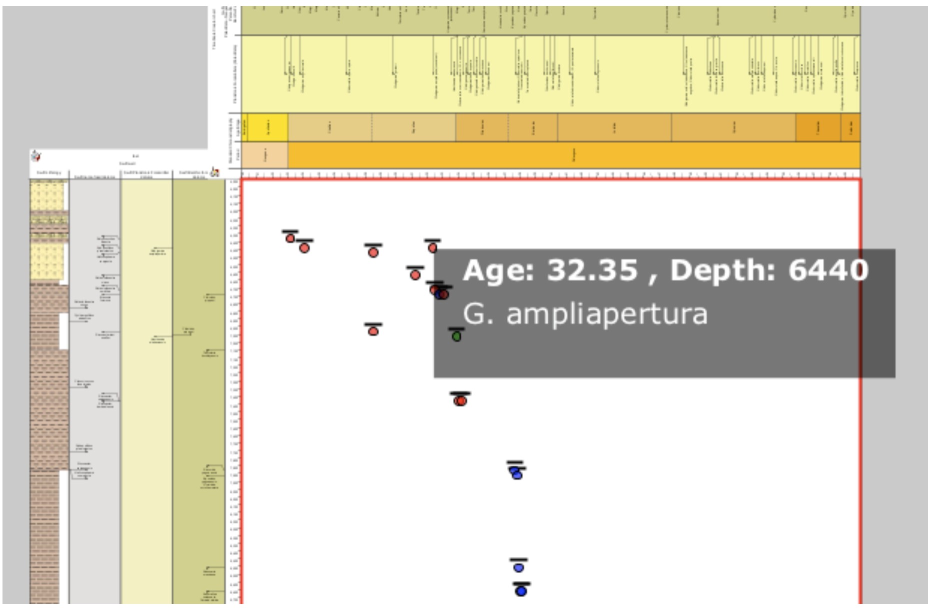
The points chosen in the crossplot window can be edited by choosing the ‘Edit Age/Depth points’ option in the crossplot window. Open **Age/Depth Markers** Tab.



Editing the points

- ***NOTE: Upon making any changes, one must click “Apply”, then move the mouse-pointer onto the Cross-plot display to see those changes.***
- You can select a point and then remove it. ***However, make sure that you “applied” all your other changes, before removing a point, otherwise your changes will not be accepted.***
-
- The age and depth **coordinates** for the chosen points can be changed or made more precise (e.g., type in an exact age for a nannofossil FAD).
- Points can be **added** to the crossplot.
- A **comment** (such as the name of the fossil) can be attached to the chosen point, and this will appear in the popup as shown in the figure below.
- A different **symbol** can be attached to the chosen point by specifying whether the chosen point is an FAD or an LAD or neither.
- Different **colored** symbols can be assigned to the chosen points, clicking on the color in the edit window allows choosing a color from the color palette.
- If you want to make color changes to a whole group of markers, then go to *Select a Column*, choose your column and click *Select All Markers in Chosen Column*. All chosen markers will show a check mark. You can then change the color on just one of them and the change is applied to all of them.





Popup associated with a point

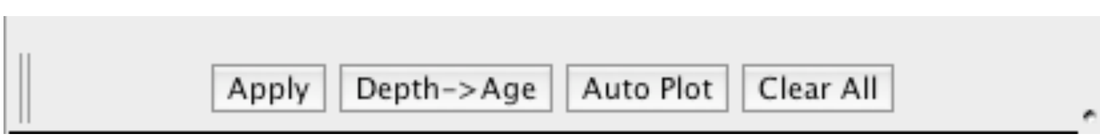
Press **"P"** to open the pop-up function for the marker points.

****

METHOD #2 -- Automatch/autoplot features:

The marker points in the crossplot window can be also generated by using the Autoplot option instead of manually choosing the marker points. This matches similar names in the selected Depth and in the Age columns.

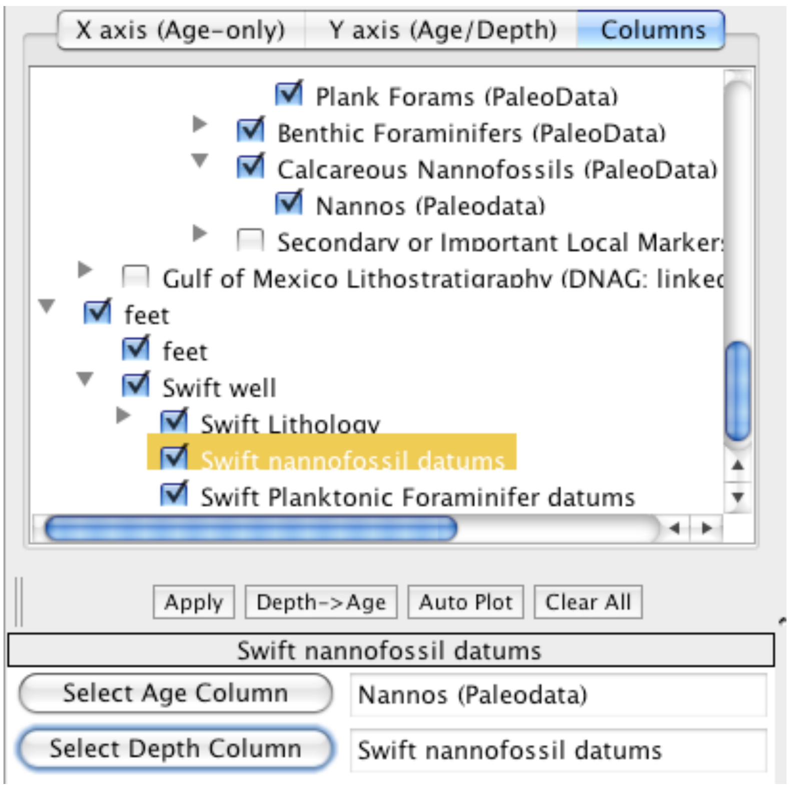
'Autoplot' button in the crossplot panel chooses the markers in the crossplot window.



Autoplot button for crossplot

For autoplotting marker points, the columns that need to be crossplotted can be chosen using the "Select" **Age/Depth Column** menus (bottom of figure) in the menu:

NOTE: You must **HIGHLIGHT** the **desired column** in the well and reference time scale (not just the directory, as shown below), THEN, click the "Select Age Column" button below. Each will load the selected columns – in the example below, you see that "*Nannos (Paleodata)*" is the selected item next to the "***Select Age Column***" button, and "*Swift nannofossil datums*" is the selected column next to the "***Select Depth Column***" button.

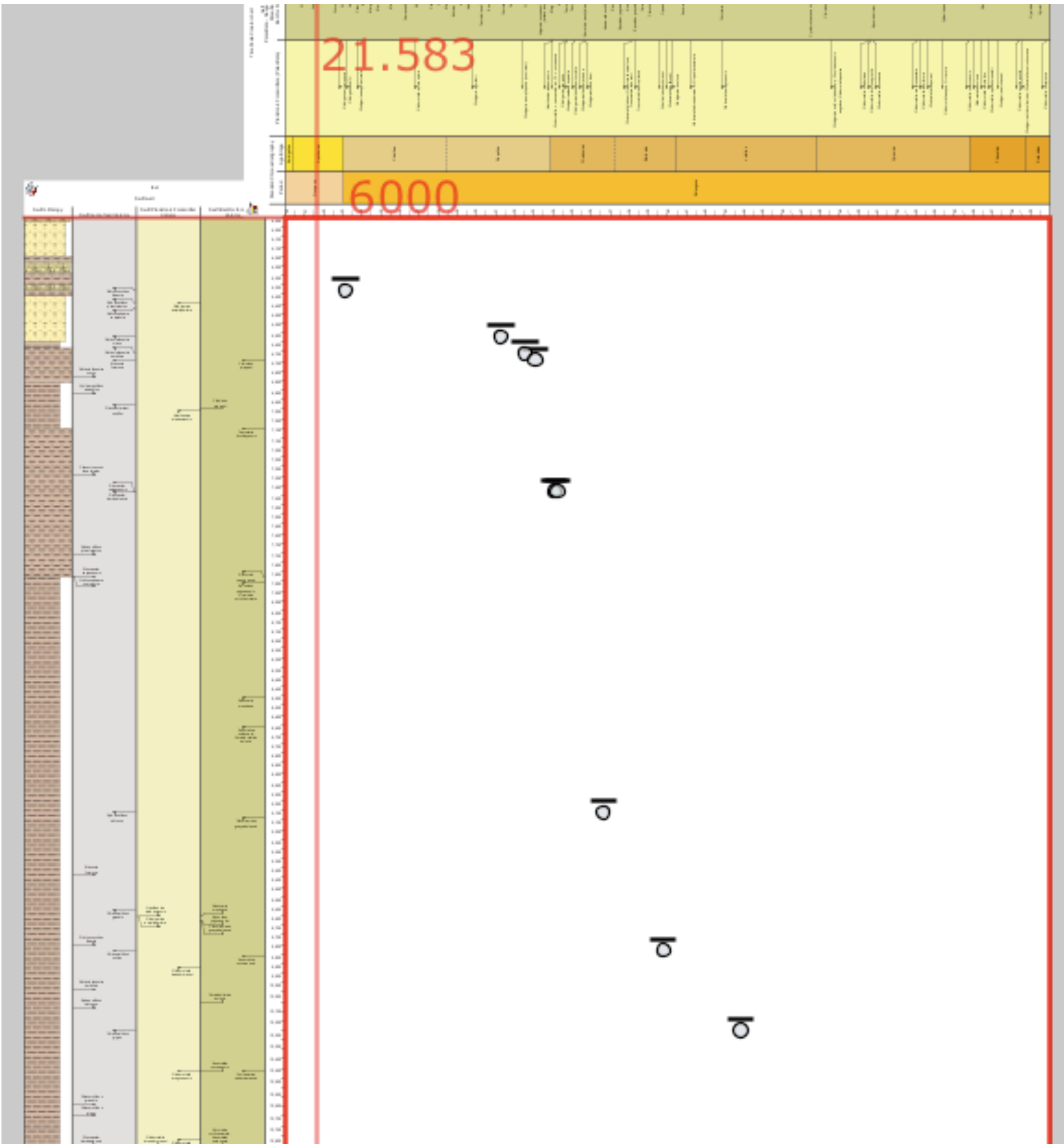


Selecting columns for autoplotting – NANNOFOSSIL set

After choosing the age and depth columns for crossplotting, the "**Auto Plot**" button generates matching marker points in the crossplot window. *NOTE: These are displayed only when your Mouse is moved over the depth-age window that refreshes that window.* Be patient.

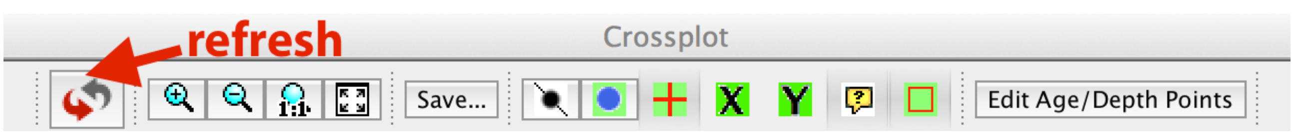
Repeat this procedure – match the Age, and the Depth columns for Planktonic Forams and for Benthic Forams; followed by AutoPlot each time. You now have an extensive set of markers.

One can also use auto plot without choosing any columns, then the whole internal database will be searched for matches. *In this case* ***do not autoplot twice***.

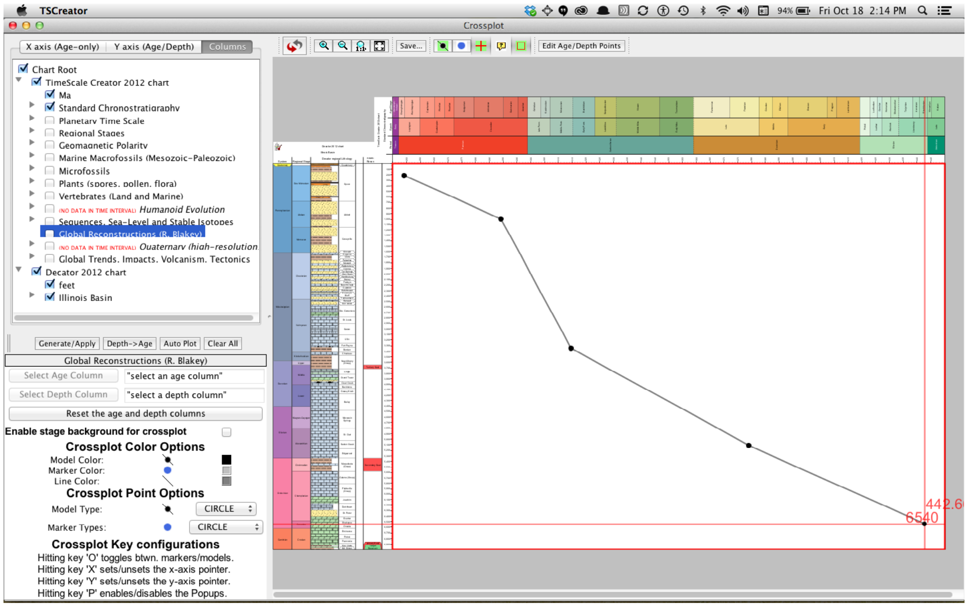


Marker points for **nannofossils** (*Swift-well and PaleoData Nannos*) using autoplot

If your marker points are tiny, then refresh the crossplot. And move your mouse into the crossplot pane.



****



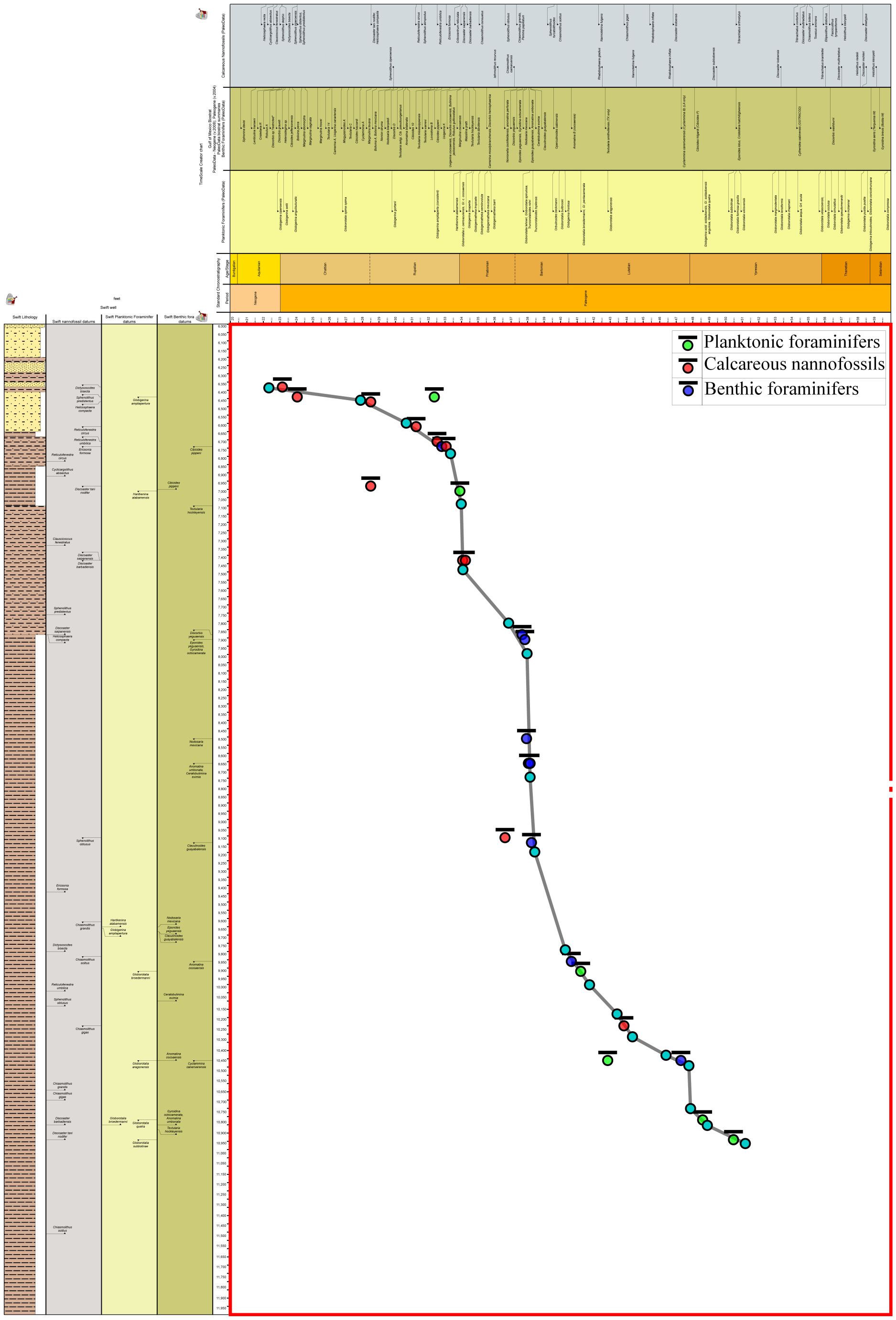
Step-7: Creating a depth-age model

Now, we add control-points (with line segments) for a "Depth-Age Model":

Select depth-age model coordinates  in Top Tool bar

A depth-to-age conversion model can be created either by joining the selected "model" markers or by using them as guidelines to select new points and joining them by a piecewise linear curve. Crossplot capability forces the slope of the depth-age curve to be positive – the geologic history is not allowed to be upside-down.

Double-clicking plots a new point, and single-clicking removes the point from the depth to age model.

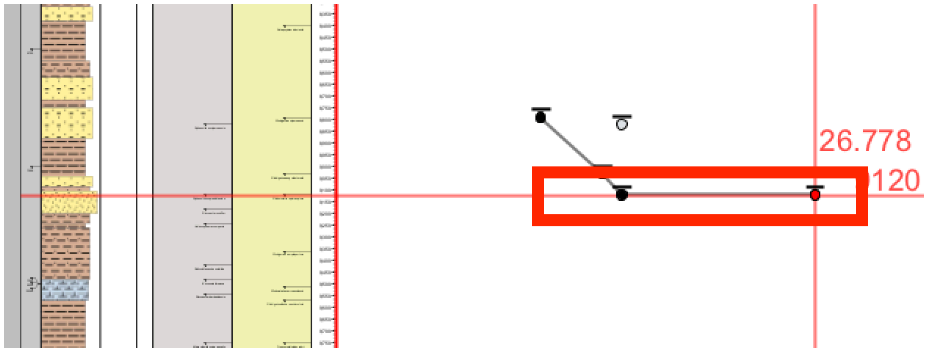


Choosing a depth-age conversion model *(Swift well; Nannos, Planktonic and Benthic Forams)*

Special Case: Hiatus

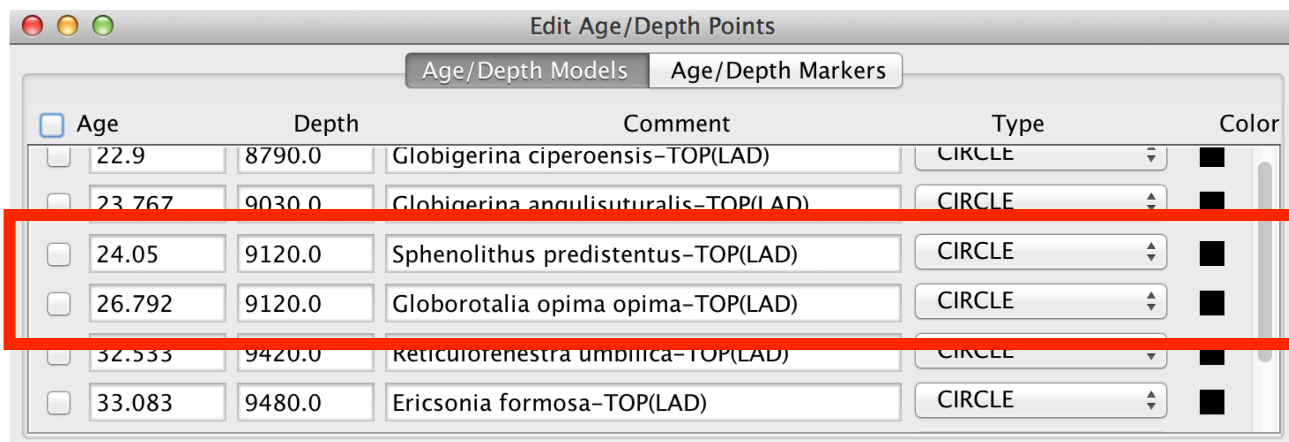
For this exercise use the Slope GardenBanks GB840 well.

To create a Hiatus (a time interval with no preserved rock record), one LOCKS the Depth-crosshair (click **Y**) at the level where there is an unconformity; then double-clicks to add Age-points at the Beginning and Ending of that time-gap. Then, release that Depth-lock (click **Y** again) to continue to enter Depth-Age control points.



These 2 points at the same depth level, but different age levels indicate a hiatus.

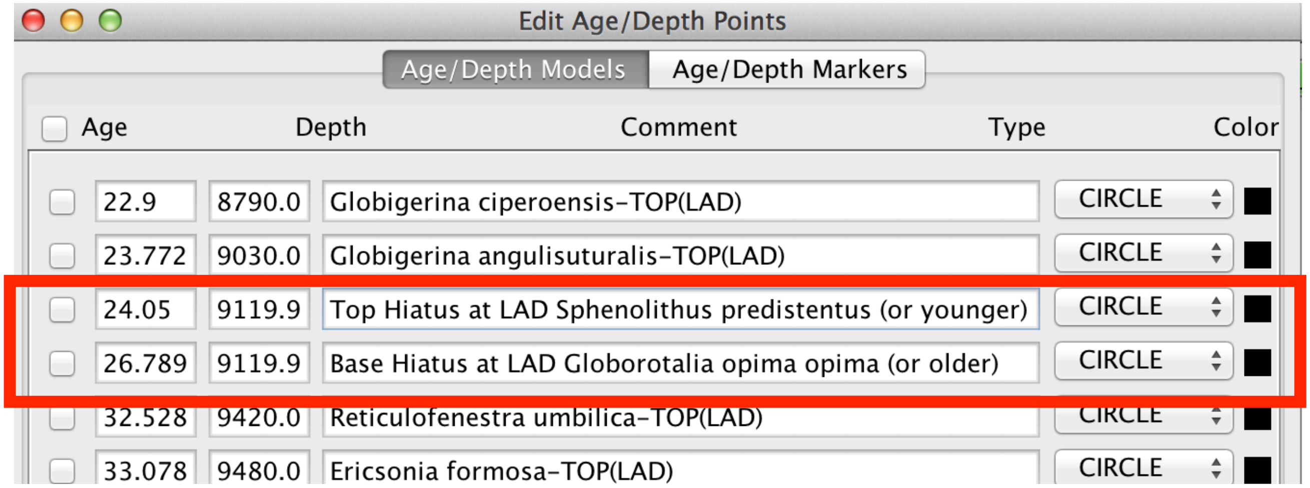
Open **Edit Age/Depth Points** and you will see that the LADs of *Globorotalia opima opima* and *Sphenolithus predistentus* occur at the same depth, but different times. The hiatus spans at least the time from 26.79 – 24.05 Ma, however, the 2 fossils have their last occurrence just slightly below the hiatus, therefore rename these markers to Top and Base Hiatus and make the base of the hiatus just slightly higher than the level of the fossils (in this case 9119.9ft). See figures below:



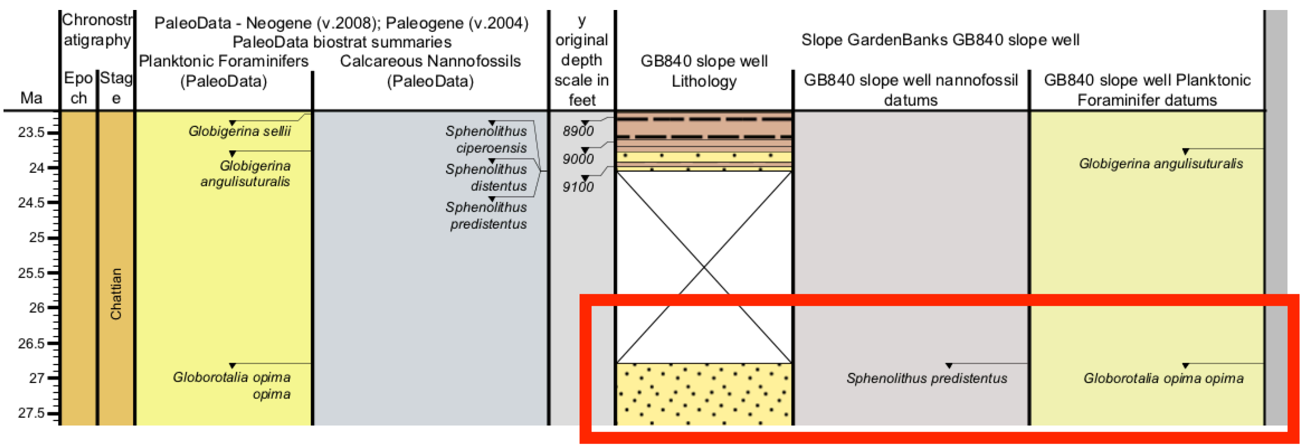
Edit Age/Depth Points

Age/Depth Models | Age/Depth Markers

Age	Depth	Comment	Type	Color
22.9	8790.0	Globigerina ciperoensis-TOP(LAD)	CIRCLE	
23.767	9030.0	Globigerina angulisuturalis-TOP(LAD)	CIRCLE	
24.05	9120.0	Sphenolithus predistentus-TOP(LAD)	CIRCLE	
26.792	9120.0	Globorotalia opima opima-TOP(LAD)	CIRCLE	
32.533	9420.0	Reticulofenestra umbilica-TOP(LAD)	CIRCLE	
33.083	9480.0	Ericsonia formosa-TOP(LAD)	CIRCLE	



After applying the changes and generating the Depth >Age conversion, the hiatus and the 2 fossils will be displayed correctly for the converted well. This method establishes the minimum amount of time for the hiatus.



OPTIONAL: Loading and saving reference points and models:

The points chosen in the crossplot window can be saved and later reloaded to the crossplot system. On clicking on the *'Edit Age/Depth points'* option in the crossplot window, *'Save'* option appears in the crossplot window.

This ability to re-load a previous Depth-Age model enables one to resume at a later time, or send to a colleague, or to modify one's earlier choices.

The Saved file format is a simple tab-delimited text-one (see next Figure) that can be also revised in Excel.

COMMENT	format version: 1.5				
COMMENT	date: Sun Mar 04 19:38:13 EST 2012				
COMMENT	AGE-DEPTH MODEL POINTS.				
CDTINFO	AGE	DEPTH	NOTE	COLOR	TYPE
MODEL	22.333	6385	This is an "Age/Depth M	#00cccc	CIRCLE
MODEL	27.883	6460	This is an "Age/Depth M	#00cccc	CIRCLE
MODEL	30.65	6598.3	This is an "Age/Depth M	#00cccc	CIRCLE
MODEL	33.333	6783.3	This is an "Age/Depth M	#00cccc	CIRCLE
MODEL	33.983	7088.3	This is an "Age/Depth M	#00cccc	CIRCLE
MODEL	34.083	7486.7	This is an "Age/Depth M	#00cccc	CIRCLE
MODEL	36.85	7810	This is an "Age/Depth M	#00cccc	CIRCLE
MODEL	37.967	7995	This is an "Age/Depth M	#00cccc	CIRCLE
MODEL	38.15	8743.3	This is an "Age/Depth M	#00cccc	CIRCLE
MODEL	38.433	9196.7	This is an "Age/Depth M	#00cccc	CIRCLE
MODEL	40.283	9790	This is an "Age/Depth M	#00cccc	CIRCLE
MODEL	41.75	10002	This is an "Age/Depth M	#00cccc	CIRCLE
MODEL	43.417	10178	This is an "Age/Depth M	#00cccc	CIRCLE
MODEL	44.35	10317	This is an "Age/Depth M	#00cccc	CIRCLE
MODEL	46.383	10428	This is an "Age/Depth M	#00cccc	CIRCLE
MODEL	47.767	10492	This is an "Age/Depth M	#00cccc	CIRCLE
MODEL	47.867	10752	This is an "Age/Depth M	#00cccc	CIRCLE
MODEL	48.883	10853	This is an "Age/Depth M	#00cccc	CIRCLE
MODEL	51.183	10963	This is an "Age/Depth M	#00cccc	CIRCLE

File of Saved Depth-Age model points

The contents for each column are described by the headers, which are part of the file. The first column "*CDTINFO*" indicates if the point is a control on the Depth-Age "Model" (as shown above) or a "Marker" display point. [In the above example, no fossil names were input as Note comments; therefore the default "This is an ..." comment was recorded.]

If the "Autoplot" option is used to choose the "marker" points, the name of the taxa being correlated becomes the default Note comments.

****

Step 8: Conversion from depth to age:

1: Create the conversion file

Clicking on the ***'Depth -> Age'*** button in the crossplot panel converts the Depth file to an Age file.

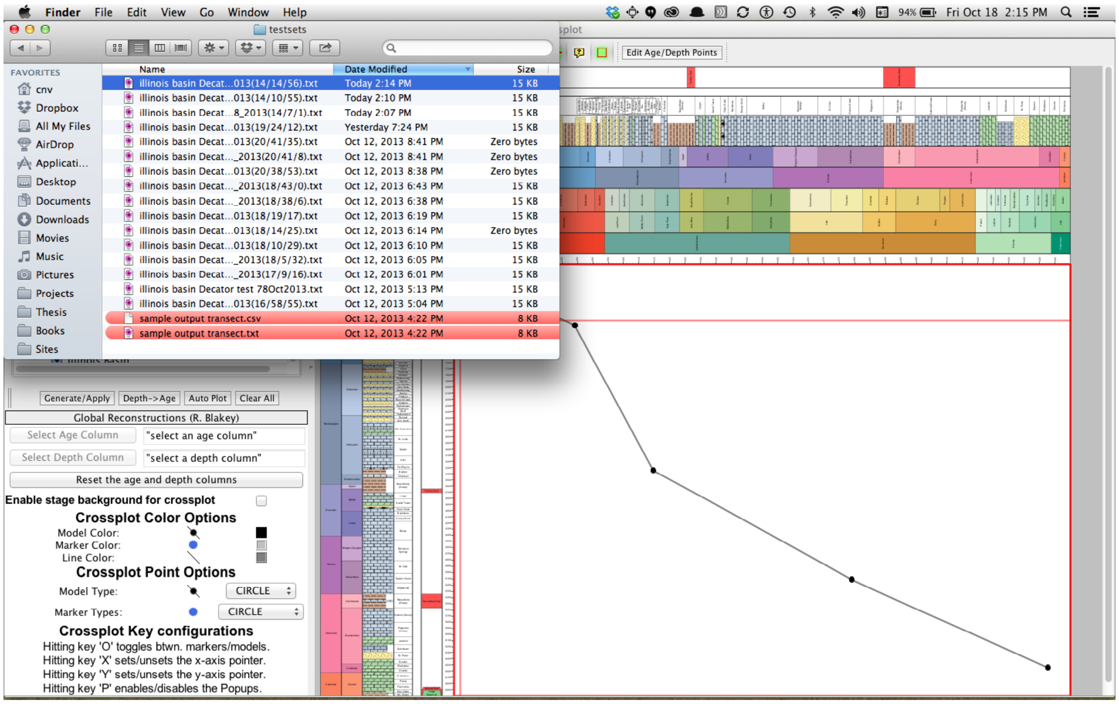
Note on File Format: The program will ask you to save the converted file. The Depth-Age conversion of the well data is also automatically loaded onto the TSCreator memory. This automatically ADDS the converted (depth-to-age) column set to the "age" suite, and plots the set at the TOP of the Cross-plot.

format version:	1.2	
date:	1/18/2012	
age units:	ma	
AgeConverterA	ageconvert-interpolate	
	6385	22.333
	6460	27.883
	6598.333	30.65
	6783.333	33.333
	7088.333	33.983
	7486.667	34.083
	7810	36.85
	7995	37.967
	8743.333	38.15
	9196.667	38.433
	9790	40.283
	10001.667	41.75
	10178.333	43.417
	10316.667	44.35
	10428.333	46.383
	10491.667	47.767
	10751.667	47.867
	10853.333	48.883
	10963.333	51.183

Depth-age conversion TEXT (.txt) file that is generated with an added date-time

2: Visual display of the converted file

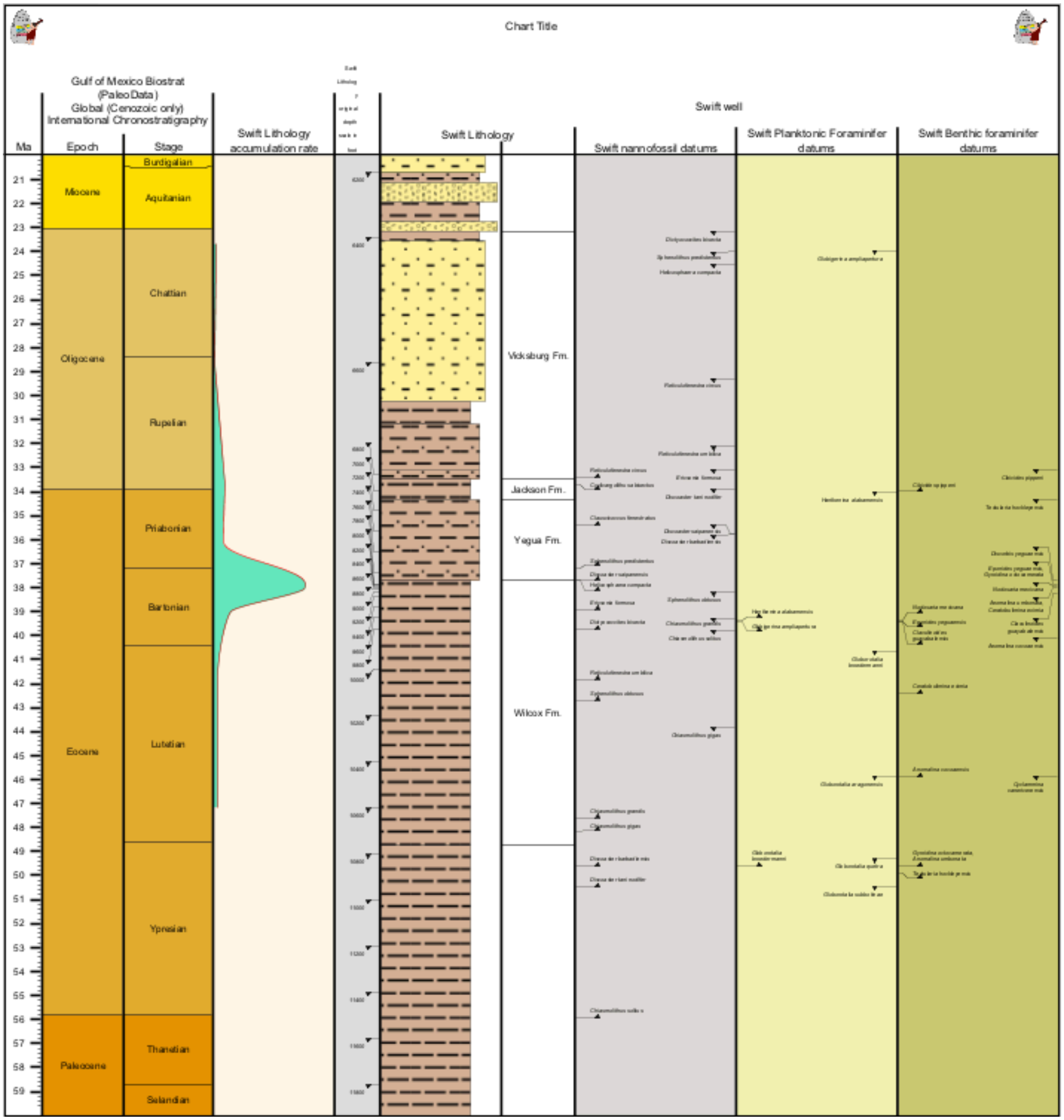
The depth-to-age file is automatically loaded onto the main user interface.



[NOTE: If one decides to apply a different depth-age model, then this suite is replaced with the new one; although the saved-output will be retained with its unique name-date-time stamp, in case one wishes to recover (or compare) earlier models.]

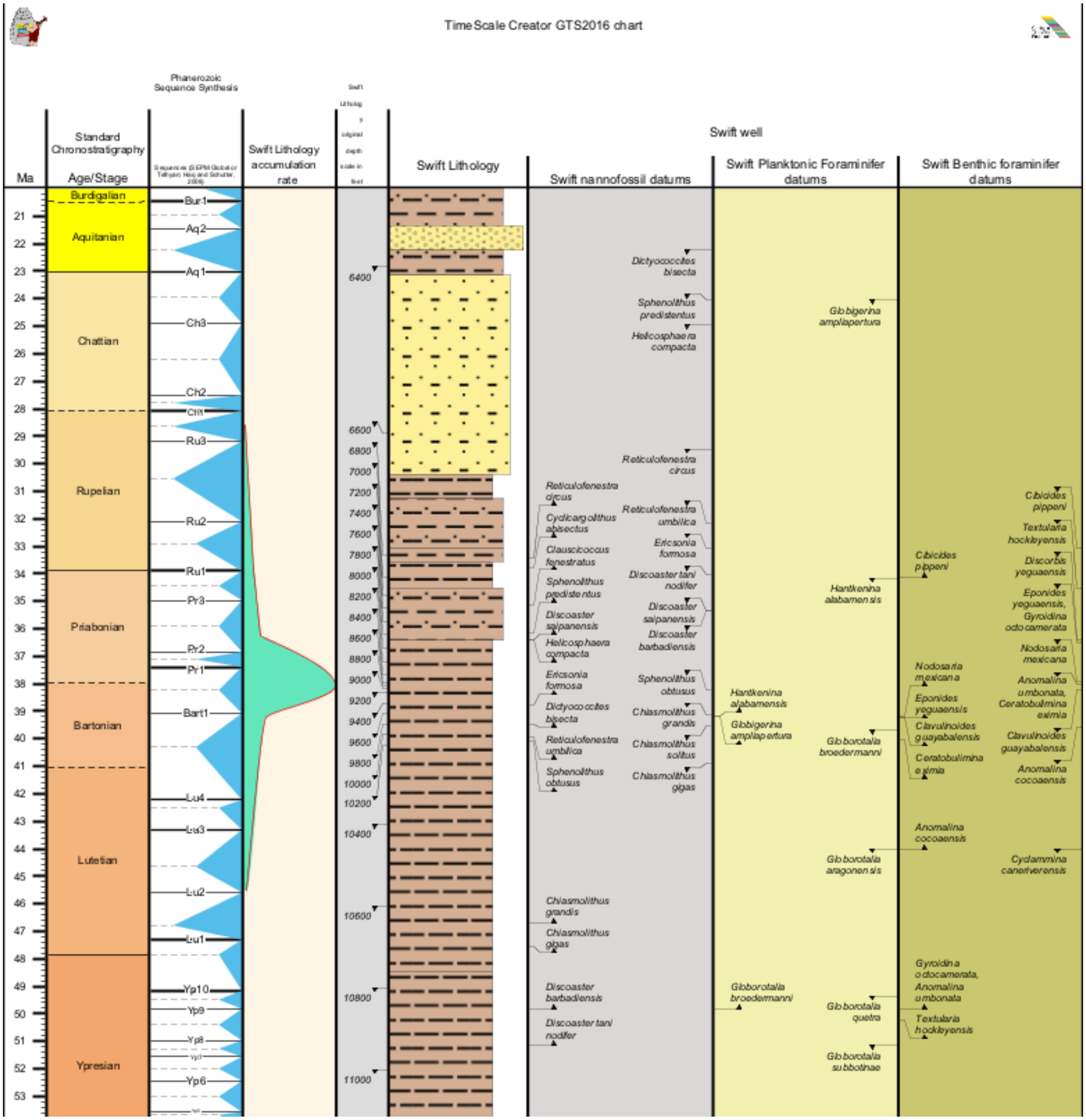
Return to the main TS-Creator window. In the '*Settings*' options for the "Ma" suite, under the 'Columns' tab, you will see that the depth-to-age converted file has appeared at the bottom of the column-menu. The program also generates a new chart with the depth-age converted columns added to the reference columns.

To see the variation of sediment-accumulation with time, a feet-scale column and a sediment accumulation column is automatically added to your converted file. Feet labels which are close together indicate rapid pulses of accumulation, such as the ones below at the Bartonian/Priabonian boundary.



Depth-to-age converted demo well

The Swift well, as converted from depth to age, can be compared with any other stratigraphic data. For example, select the age models for global sea-level sequences to understand the link between facies trends and sea-level variations (next figure):



Comparison with global sequences of sea-level change

OTHER ITEMS

Datapacks (in meters/feet)

To flag that a dataset is an outcrop/well with depth-varying information (biostratigraphy, petrophysical logs, lithological variations etc to the *TimeScale Creator*, one adds an initial "flag" that the units for the ENTIRE suite of columns are in "***feet***" or "***meters***"; but not in "Ma".

Well format (meters or feet increase downwards)

age units:	m	***<- Or, "feet", etc.***
interval column:		Formations of Fujian

Outcrop format (meters or feet increase upward)

Outcrop:	ON	
age units:	m	***<- Or, "feet", etc.***
interval column:		Formations of Fujian

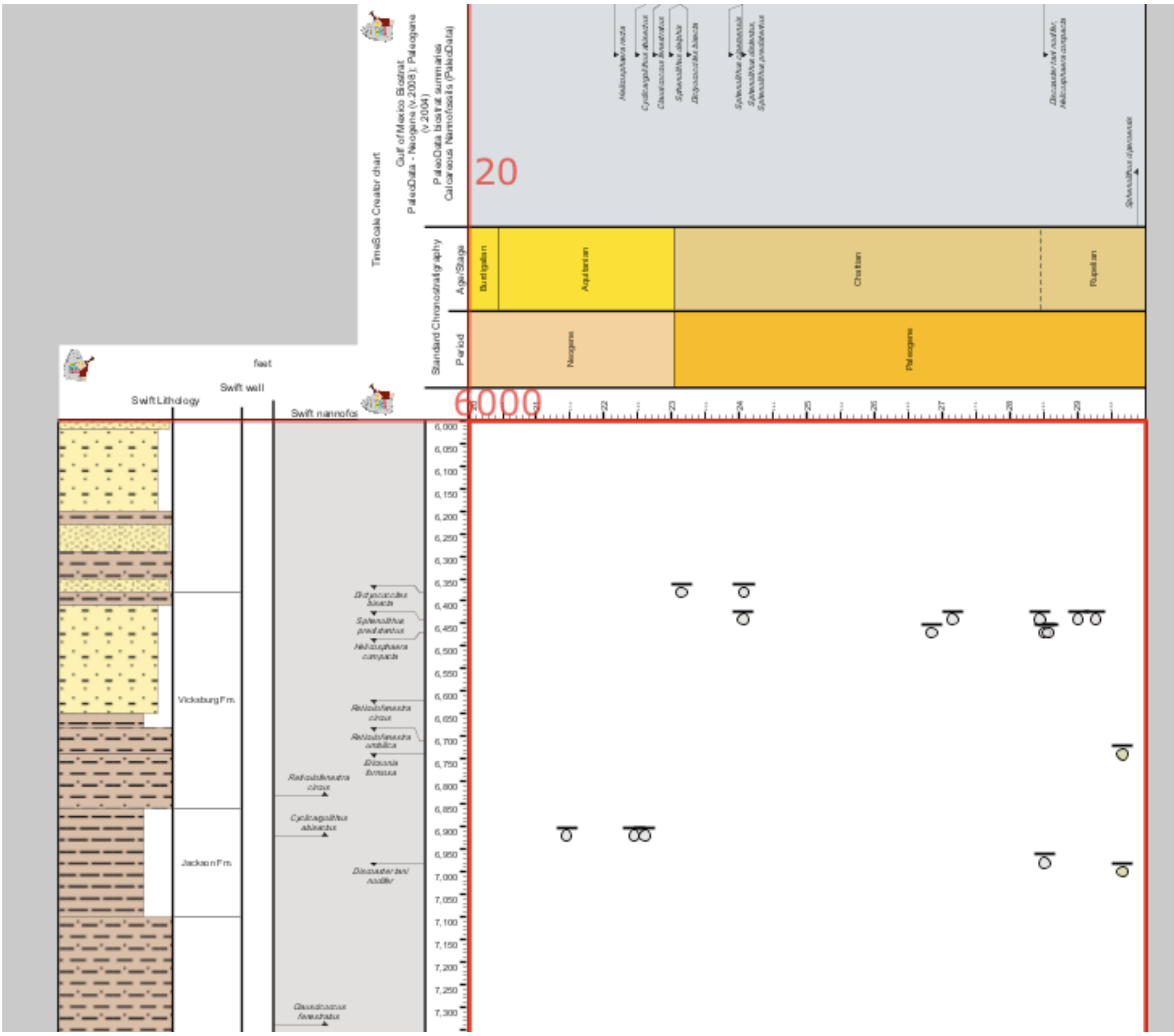
One can also specify a block-format column in that dataset to be used in the Settings user-interface to be the "pull-down" choices for "setting age" instead of the default "stages".

Autoplot with general search

The "Autoplot" option can be used without choosing individual age and individual depth columns. On using the "Autoplot" option without choosing the appropriate age and depth columns, the "Autoplot" feature plots all the points that match any within the entire suite of columns in the loaded and/or internal age-datapacks.

For our Swift well that was used as demonstration, if we had loaded a more extensive Gulf of Mexico reference datapack (available for download from the TSCreator website), then selecting "*Autoplot*" with this "use all" default, would give a "cloud" of points that had been matched with all of the various subsets of both the internal and loaded datapacks – Paleo-Data Inc, Shell, BOEM, etc. – each of which have slightly different calibrations for some of the zone markers. Therefore, one gets an array for each of the taxa correlations (see next figure).

If using autoplot without choosing column, then **do not click autoplot twice**.

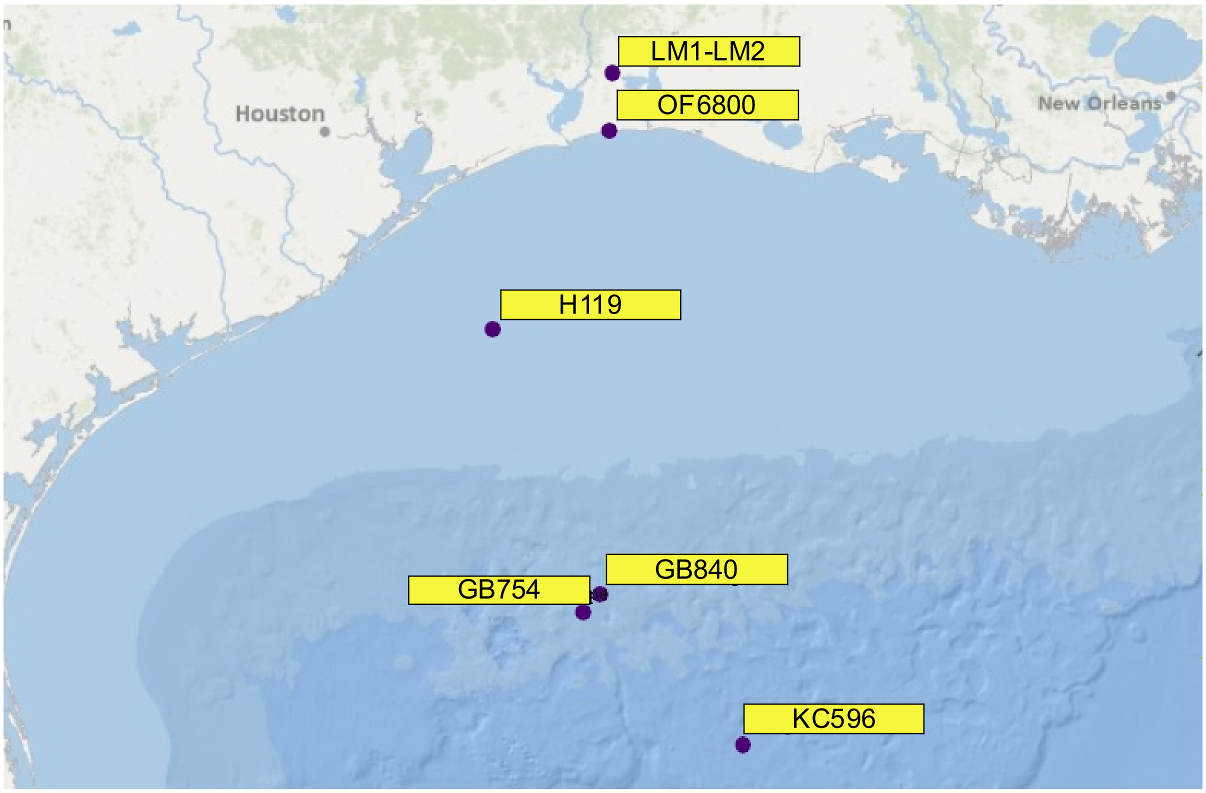


Result of using Autoplot for a larger Gulf of Mexico suite of reference time scales (PaleoData, BOEM, Shell, etc.) without choosing specific reference-age columns from those choices. Multiple potential age assignments are shown for some markers, because these groups have different opinions on calibrations and scaling to geologic age.

IMPORTANT: You must quit TS-Creator and reload the program before starting a new well conversion. *This will be fixed in later versions*.

Gulf of Mexico

Crossplot exercise

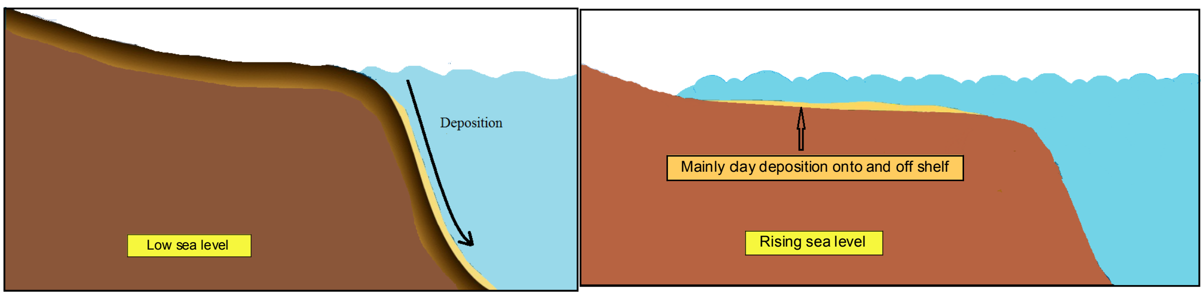


TimeScale Creator *www.timescalecreator.org*

Deciphering Major Depositional Sequences in the Gulf of Mexico during the Oligocene and Miocene by Converting a Transect of Wells (*in depth*) into a Standard Geologic Time Scale (*in age*)

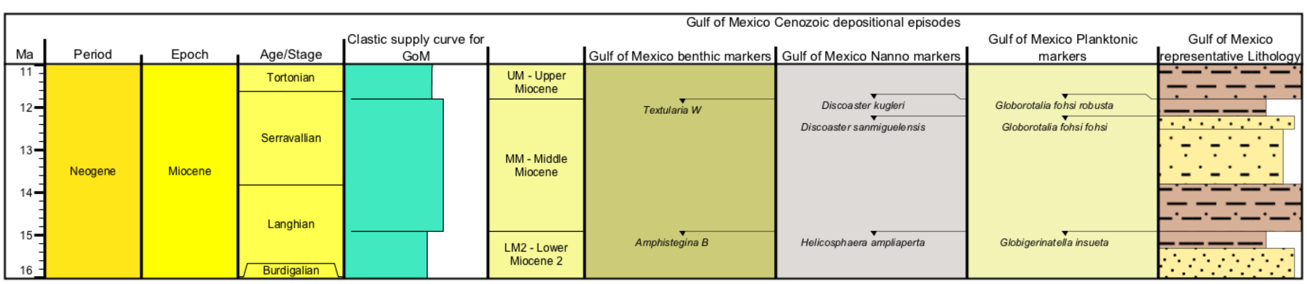
Background

The main offshore oil-gas reservoirs in the Gulf of Mexico are sand-rich fans that develop during lowstands in sea level. During these lowstands, the shelf is either exposed or has deposits of clay interlayered with sandy storm beds. In contrast, the influx of sands during highstands are captured in inland beaches. Therefore, highstand deposits consist of relatively condensed clay-rich intervals in both the deep Gulf and on majority of the shelves that are flooded below storm wave-base.



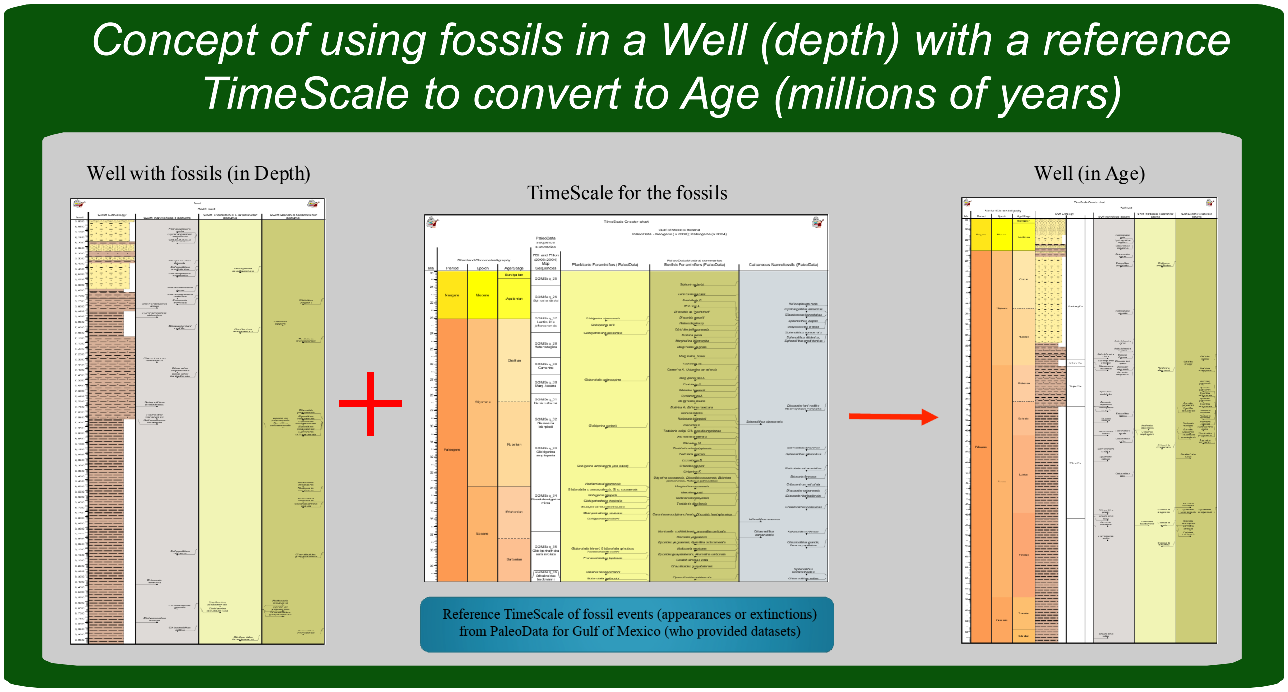
Our goal

We will use a transect of wells drilled on the present onshore to slope to basin to identify pulses of sand-rich sediment into the Gulf of Mexico basin during the Eocene through middle Miocene epochs of the Cenozoic (ca. 50 through 5 million years ago). These will give us an indication of the major lowstand and highstand trends during this interval, and also the ages for targets of future hydrocarbon exploration. Such a large-scale generalization requires looking at the main patterns, rather than relying only on a single well.



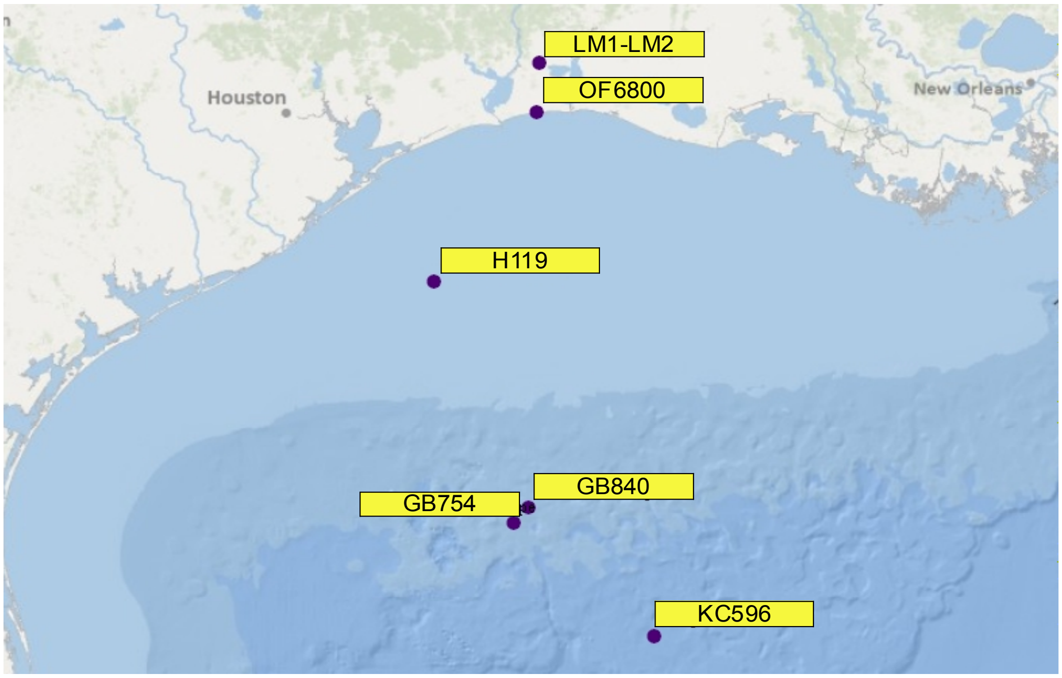
Example of an idealized generalized Middle Miocene basinal sequence. The lowstand sand-rich deposits are bound by clay-rich transgressive and highstand intervals. Highest occurrences (extinctions) of microfossil marker fossils are used to assign the clay-rich intervals to the geologic time scale.

Each of our wells (*see map on next page*) has facies interpretations of clay/sand and rare carbonates from the combination of downhole logs and well cuttings. In addition, each well has been analyzed for different types of microfossils; mainly benthic foraminifers, planktonic foraminifers and calcareous nannofossils. We will use the last occurrences of these fossils to convert the stratigraphy of each well (depth) to a standard geologic time scale (age) via a cross-plot procedure. This will enable us to visually identify the major trends.



<u>Our data sets and analysis</u>

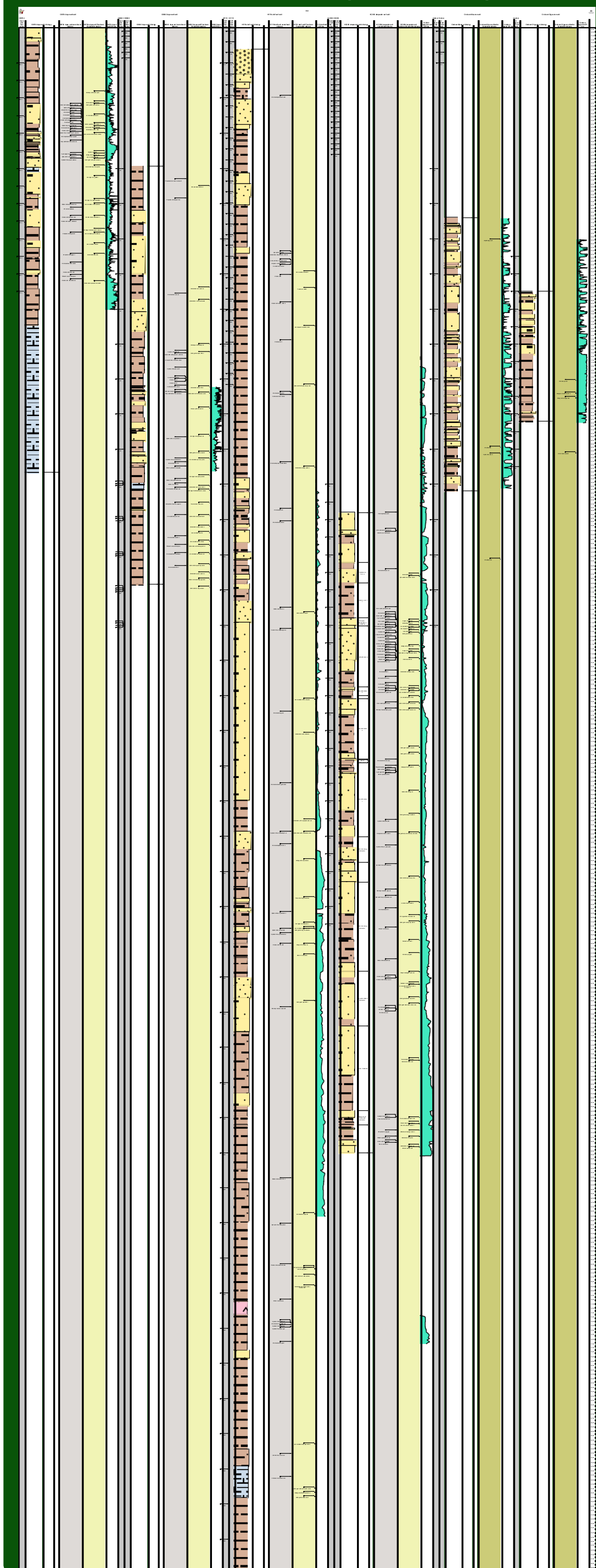
The majority of our downhole well data for this suite has been provided by PaleoData (New Orleans), which also compiled a timescale of the main Gulf of Mexico marker fossils, by John Snedden (Institute of Geophysics at University of Texas at Austin), and by the USA government Bureau of Offshore Energy Management (BOEM). The data from each well has been repackaged as TSCreator-formatted files by Sribharath Kainkaryam (formerly at Purdue University; now at Schlumberger in Houston, who did a major part of this project) and James Ogg (Purdue University). The crossplot and depth-to-age conversion routines within the TSCreator package were developed at Purdue by Adam Lugowski (now at Univ. Calif. Santa Barbara) and by Nag Varun Chunduru (now part of the Silicon Valley groups in San Francisco).



The data sets for all wells have been "trimmed" to be the Eocene-Miocene interval, with the later deposits removed. The modern "Onshore" wells were originally at a mid-shelf location during the Oligocene-Miocene; but are now buried beneath the modern coastal plain as global sea levels fell and the Texas coastline advanced during the Pliocene-Pleistocene. The modern "Shelf" well (H119) has the thickest accumulation of Oligocene-Miocene deposits, because it received both thick sands during each lowstand and the greatest amount of clays during highstands.

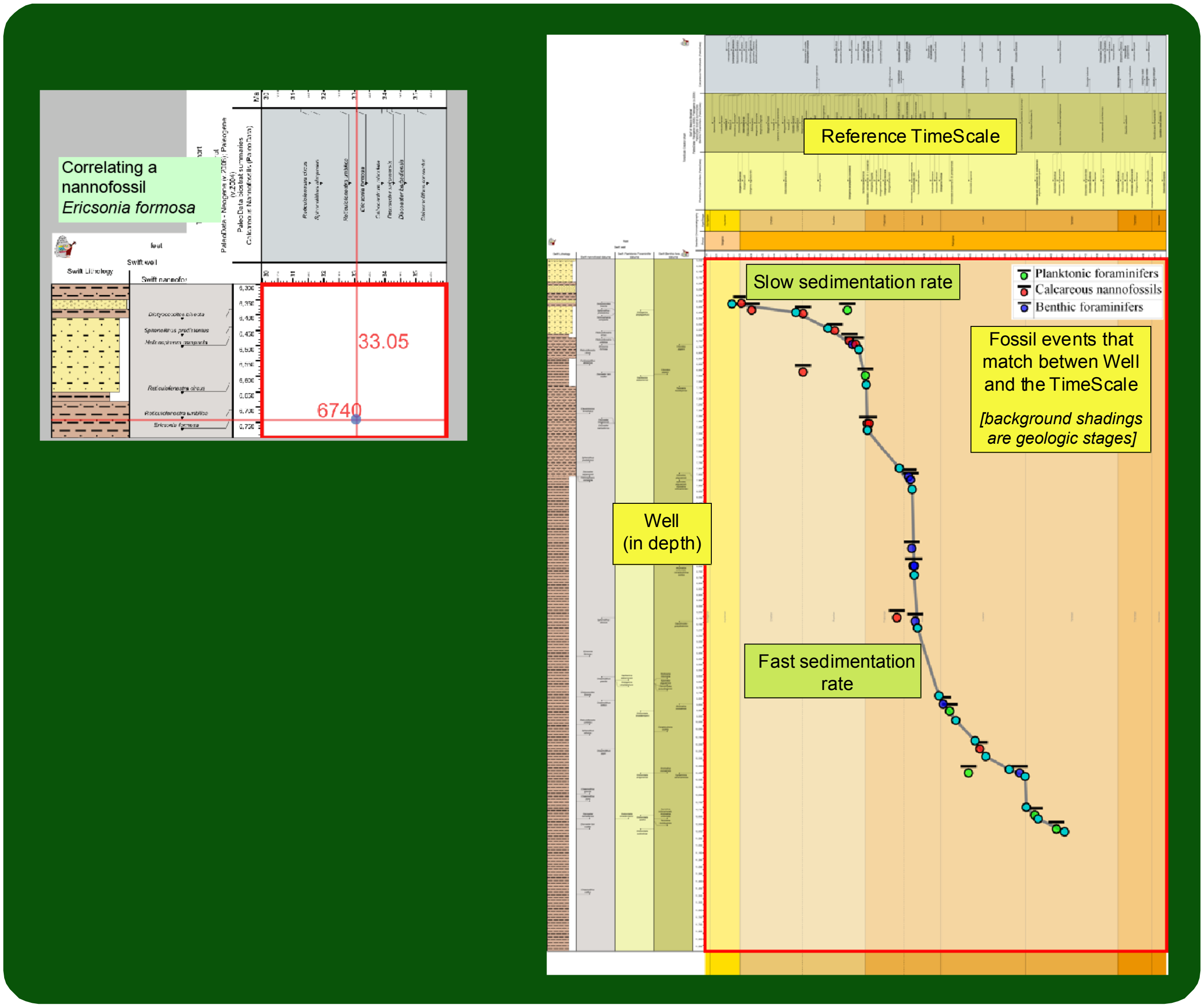
Well name	**Present geographic location**	**Top of interval (ft)**	**Bottom of interval (ft)**	**TSCreator-formatted data file**
Onshore Louisiana Miocene LM	Onshore	7150	9598	*Onshore Louisiana Miocene LM-depth.txt*
Onshore Louisiana Oligocene OF6800	Onshore	9100	12000	*Onshore Louisiana Oligocene OF6800-depth.txt*
Shelf Highland Island HI119	Continental shelf	3000	25000	*Shelf Highland Island HI119-depth.txt*
Slope GardenBanks GB840	Continental slope	4500	11500	*Slope GardenBanks GB840-depth.txt*
Slope GardenBanks GB754	Continental slope	3000	7500	*Slope GardenBanks GB754-depth.txt*
Deepwater Keathley Canyon KC596-deepwater	Deepwater well	9500	19500	*Deepwater Keathley Canyon KC596-depth.txt*

Suite of wells (in depth)



If one plots all of these wells "by depth" (*see figure on next page*), then it is only apparent that the present "Shelf" well H119 (Highland Island) region has the greatest thickness of accumulation during this time interval. Therefore, we will correlate the fossils in each well to a reference time scale to convert the well-depth into a standard time-scaling:

Below is an example of Depth to Age conversion using a Cross-Plot matching of microfossil levels (left) to reference time scale of those events (top). The LEFT figure shows one event (6740 ft in well = 33.05 Ma in time scale); and the RIGHT figure shows a composite of all fossil events in that well that had matching events in the reference time scale.



The estimated smoothed line-fit to the depth-age points for those microfossil events is our best guess of how much time has passed within the sediment intervals. It is always the case that real data has some scatter, perhaps because of reworking, mis-identification, sample spacing or other artifacts.

Notice in the middle of the above example that the line-fit is nearly vertical in the upper part of the clay. This implies that this very-thick clay actually accumulated in only a very brief interval of time – essentially, an anomalous pulse of clay arrived at the site for some reason.

In contrast, the sand-rich interval at the top has a series of microfossils that span a relatively long time period. Therefore, these sands accumulated quite slowly compared to the underlying clay; and perhaps even contain some hiatuses.

Our steps:

1. Using the tutorial-manual as a guide, convert each of the wells along a generalized shallow-to-deep transect from depth (in "feet" for the wells in Gulf of Mexico) to the geologic timescale (in millions of years ago "Ma") by using depth-to-age conversion process.
2. Assemble these converted wells according to increasing distance from the shoreline to create a transect scaled to geologic time.
3. Identify the main depositional episodes from the timing of widespread sand-rich and clay-rich horizons. Interpret the implications for the main sea-level variations that affected the sedimentation of the Gulf of Mexico region during Oligocene and Miocene epochs.

Microfossil Markers

The reference points corresponding to microfossils/nannofossils that guide the choice of depth-to-age conversion model can be picked using two different ways – Manual correlation, or by Auto-plot correlation. Both these methods are described in the tutorial-manual on depth-to-age conversion using crossplot. Manual correlation is suggested for choosing reference points, as it helps in understanding biostratigraphic correlations better.

For Part 2 to reduce ambiguities in the choice of the depth-to-age conversion model, we list a suggested suite of the microfossils and nannofossils to guide the choice of the depth-to-age conversion for each well.

Depending on the available data in a well, we recommend the following "relatively more reliable guide fossils" to be primary correlation controls for the offshore wells. In order from youngest to oldest, with Nannofossils in *italics* and Planktonic Foraminifers in **bold**:

Middle Miocene
- **Globorotalia fohsi robusta**
- *Sphenolithus heteromorphus*
- *Helicosphaera ampliaperta*

Early Miocene
- *Triquetrorhabdulus carinatus*

Oligocene-Miocene boundary interval
- **Globigerina ciperoensis**
- *Sphenolithus ciperoensis*

Late Oligocene
- *Sphenolithus predistentus*
- **Globorotalia opima opima**

To distinguish between marker points for different kind of biostratigraphic information, it is convenient to use different colors for nannofossils and planktonic foraminifers. Also, the name of the species can be used as a comment for the microfossils/nannofossils. As explained in the tutorial-manual, this annotation appears as a popup when the mouse passes over that point on a cross-plot. Another advantage of the annotation process is that you can make a note about the reliability of a particular species for the purposes of correlation.

Well data sets and suggested scalings:

Each well datapack contains a suite of columns: Depth in feet, Depth in meters, Downhole log (usually Gamma, but sometimes Spontaneous potential for older wells), the interpreted Lithology column from the logs and cuttings, and Biostratigraphy (depending upon the well, it will have benthic foraminifers, planktonic foraminifers, and calcareous nannofossils – and these columns have standardized color coding).

Time span for the biostratigraphy observed in the wells: The wells that are a part of the current dataset span Miocene and Oligocene epochs, as the objective is to understand the depositional episodes during Miocene and Oligocene epochs. Thus, the top of the time interval for the crossplot is used as the top of Messinian stage – **5.33 Ma** and the bottom of the time interval for the crossplot is used as the base of the Lutetian stage –**50 Ma**. A scaling value of **3 cm/Myr** is suggested to avoid over-crowding of microfossil datums.

Depth ranges for the wells: The top and bottom for each well is listed in the table below the map (above). A vertical-scale value of **0.02 cm/feet** is suggested for most sets; but you can adjust as needed.

****

Part 1: Convert each of the wells along a generalized shallow-to-deep transect from depth (in "feet" for the wells in Gulf of Mexico) to the geologic timescale (in millions of years ago "Ma") by using depth-to-age conversion process.

To create a transect scaled to geologic time, each individual well is to be converted to the geologic timescale. [*NOTE: We suggest the "quick" Method #2 of auto-matching to rapidly correlate the different microfossils*.]

The recommended set are **Shelf-well HI119; Slope-well GB754, and Deep-Basin-well KC595,** because those have the most detailed biostratigraphy and show the main trends from near-shore to far offshore.

The optional set that would enhance your results are the Slope-well GP840 (reproduces some of the features of GB754), and the two Onshore wells which only span limited intervals with mainly benthic foraminifers of relatively low resolution.

1. We will use the same ***Gulf_of_Mex_ReferenceTimeScale_PaleoData.txt*** reference microfossil time scale for the Gulf of Mexico as was used in the Swift-well tutorial – Open TS-Creator, load this "age" file. This can be as a "*Replace datapack*" instead of "*Add datapack*".
2. Locate the folder consisting of the depth .txt files for the wells. Load your first well (e.g., *Shelf Highland Island HI119-depth.txt*).
3. Use the crossplot with appropriate time-interval and depth-interval and vertical scaling factors (see above; but you'll need to adjust for each well according to its sediment thickness).

4. Convert EACH well from depth to geologic timescale as explained in the tutorial-manual in. Some suggested marker fossils to guide the choice of depth-to-age conversion model are listed for each well at the end of this document. Using your marker points, add your preferred set of depth-to-age conversion points and associated line-fit. **Note:** For some wells, at the end of this document we've suggested some possible hiatuses that might be present based on those markers (*think about why there might be a hiatus at these levels when you plot them*). SEE BELOW FOR QUESTIONS TO ANSWER FOR EACH WELL.
5. Convert EACH well (depth) to stratigraphy (age). Check if this conversion seems reasonable. SAVE A PRINTOUT/SCREENSHOT of your Converted well.
6. Save your age-converted output for that well in a folder for later access. Label the .txt output for your convenient use in Part 2.
7. Once you finished your first conversion **QUIT THE PROGRAM** and reload it **(very important)**. REPEAT the process for the other wells. Complete **Shelf-well HI119; Slope-well GB754, and Deep-Basin-well KC595**; and the other three are optional.

Based on the depth-to-age conversions, answer the following questions:

a. If any of the marker points (microfossil events) has a significant deviation from the chosen depth-to-age model, can you suggest the reasons behind the deviation?
b. A steeper slope indicates higher sedimentation rate. The latest TSCreator version automatically plots a sedimentation rate curve next to your converted well. What is the average sedimentation rate for your well? When are the time intervals where the sedimentation rates are anomalously high? When are these anomalously low (or a hiatus)?

Some guidance to individual wells

REQUIRED SUBSET:

1. Shelf-well HI119

Shelf Highland Island HI119	Continental shelf	3000	25000	*Shelf Highland Island HI119-depth.txt*

Suggested main Marker Nannofossil/planktonic foraminifer fossils for Age model

Nannofossils:

Discoaster kugleri
Discoaster sanmiguelensis
Sphenolithus heteromorphus
Sphenolithus ciperoensis
Sphenolithus predistentus

Forams:

Globorotalia fohsi robusta
Globorotalia fohsi barisanensis
Globigerinoides sicana
Praeorbulina glomerosa
Globigerina ciperoensis
Globorotalia opima opima
Globigerina angulisuturalis

There are some special items to note.

(1) **Late-Oligocene cluster**. There is a cluster of nannofossil and foraminifer LAD matches at ~24-27 Ma and depth of about 15600-15800. There are different possibilities for this situation. For example, there may be a hiatus that caused artificial termination of ***Globigerina angulisuturalis*** (~24Ma) to be at the same level as LAD of ***Globorotalia opima opima*** (~27 Ma), but this would require that the "higher" observed LAD of ***Sphenolithus ciperoensis*** would be reworking. Think about it. We suggest assuming that there is no reworking, and therefore connect the LADs of ***Globorotalia opima opima*** and ***Sphenolithus ciperoensis*** in our age model, and therefore consider the "below line" LADs of the cluster with ***Globigerina angulisuturalis*** to be a preservation or sampling artifact. However, as in many cases in biostratigraphy, there is not a unique answer in this situation!

(2) Early **Miocene scaling**. Between the planktonic foraminifer ***Globigerinoides sicana*** (~14.5 Ma) and the nannofossil ***Sphenolithus ciperoensis*** (~24 Ma), the only depth-age constraint is the observed highest common occurrence in Gulf of Mexico of the planktonic foraminifer ***Praeorbulina glomerosa*** (~15 Ma). What does this suggest about the changes in average sedimentation rates, assuming that the ***Praeorbulina glomerosa*** is a reliable age-control point?

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2. Slope-well GB754

Slope GardenBanks GB754	Continental slope	3000	7500	*Slope GardenBanks GB754-depth.txt*

Suggested main Marker Nannofossil/planktonic foraminifer fossils for Age model

Nannofossils:

Coccolithus miopelagicus
Discoaster sanmiguelensis
Helicosphaera ampliaperta
Triquetrorhabdulus carinatus
Cyclicargolithus abisectus
Sphenolithus ciperoensis
Sphenolithus predistentus

Forams:

Globorotalia fohsi robusta
Globorotalia fohsi fohsi
Globorotalia fohsi barisanensis
Globigerina ciperoensis
Globorotalia kugleri
Globigerina angulisuturalis
Globorotalia opima opima

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3. Deep-basin-well KC596

Deepwater Keathley Canyon KC596-deepwater	Deepwater well	9500	19500	*Deepwater Keathley Canyon KC596-depth.txt*

Suggested main Marker Nannofossil/planktonic foraminifer fossils for Age model

Nannofossils:

Discoaster kugleri
Discoaster sanmiguelensis
Helicosphaera ampliaperta
Triquetrorhabdulus carinatus
Cyclicargolithus abisectus
Helicosphaera recta
Spenolithus delphix
Dictyococcites bisectus
Sphenolithus ciperoensis
Sphenolithus predistentus

Forams:

Globorotalia fohsi robusta
Globorotalia fohsi fohsi
Globorotalia peripheroacuta
Globigerinoides sicanus
Catapsydrax dissimilis
Globorotalia kugleri
Globigerina angulisuturalis
Globigerina ciperoensis ciperoensis
Globorotalia opima opima

OPTIONAL SUBSETS:

4. Slope-well GB840 = verification and enhancement of Slope-well GB745

Suggested main Marker Nannofossil/planktonic foraminifer fossils for Age model

Nannofossils:

Sphenolithus heteromorphus
Triquetrorhabdulus carinatus
Sphenolithus ciperoensis
Sphenolithus predistentus

Forams:

Globorotalia fohsi fohsi
Globorotalia fohsi barisanensis
Catapsydrax dissimilis
Globigerina ciperoensis
Globigerina angulisuturalis
Globorotalia opima opima

A special item to note -- The LAD of the planktonic foraminifer *Globorotalia opima opima* (~26.8 Ma) and nannofossil ***Sphenolithus predistentus*** (~27.3 Ma) occur at the same depth of 9100 ft. Assuming that this is not an artifact of sample spacing, what does this imply?

5. Shelf-well Onshore Miocene = clay-rich versus storm-bed-rich (?) clay/sand alternations

Suggested main Marker fossils for Age model = only Benthic Foraminifers

Amphistegina B
Cristellaria A
Siphoninia davisi
Cristellaria R

6. Shelf-well Onshore Oligocene = clay-rich versus storm-bed-rich (?) clay/sand alternations

Suggested main Marker fossils for Age model = only Benthic Foraminifers

Bolivina perca
Marginulina idiomorpha
Marginulina vaginata
Cibicides hazzardi

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__**Part 2: Creating a time transect:**__ We will assemble these converted wells by increasing distance from the shoreline to create a transect scaled to geologic time:

1. **Restart** the TimeScale Creator "
2. Replace the reference age datapack with the Gulf of Mexico – '*Gulf_of_Mex_ReferenceTimeScale_PaleoData.txt*'
3. Load the depth-to-age converted files with the increasing distance from the ancient shoreline. HI119, GB754, KC596.
4. After loading all the depth-to-age converted files, for each well -- click on '*Settings*' to choose the columns– lithology (deselect the 'Facies Label' and 'Series Label' options), and biostratigraphy. Don't plot the logs.
5. Make a one-page printout of this transect for use in Part 3:

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__**Part 3: Identification of depositional episodes and sea level interpretations**__

Your plot of wells scaled to geologic time in increasing order of distance from the ancient shoreline enables you to identify the main depositional episodes from the timing of widespread sand-rich and clay-rich horizons. Increase in sea-level results in flooding that leads to a widespread deposition of shale. Similarly, a decrease in sea-level leads to deposition of sand-rich sediment into the basins. During lowstands, the outer shelf (which is now our "onshore" wells in the present Texas-Louisiana margin location) was affected more by storm deposits resulting in interbedded sands and clays. We will interpret your results to deduce the main sea-level variations that affected the sedimentation of the Gulf of Mexico region during Oligocene and Miocene epochs.

In general, one is looking for widespread clay-rich horizons (highstands) and the widespread sand-rich intervals (lowstands) for sea-level variations. Depending upon your results, there will be either 4 or 5 main sequences within your analyzed suite.

Questions:

1. Examine the trends seen across the transect at ~15 Ma and ~23 Ma. Does your data suggest a clay-rich interval followed by a sand-rich interval? At ~23 Ma near the beginning of the Miocene, there is a global cooling event and widespread drop in sea-level. Therefore, the deeper waters in the Gulf of Mexico received an increased influx of sand-rich sediments.

2. After you've tentatively identified the main trends and possible clay-sand-clay packages, mark these with "red-pencil" boxes. What are the ages of the lowstand sand deposits?

3. Using the TSCreator internal database, turn on the long-term trends in global sequences. Which of these are indicated in your independently analyzed datasets?