DigitSeis v1.5 Manual

July 2020

This manual is provided to complement the DigitSeis v1.5 package for digitization of analog seismograms available on the http://www.seismology.harvard.edu/research/DigitSeis.html

DigitSeis manuals and supplementary materials prepared by Katelyn Lee for the Harvard Seismology Group.

For more information on the Harvard Seismology Group, please visit: http://www.seismology.harvard.edu/index.html.

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and by the Miller Institute for Basic Sciences at the University of California, Berkeley.

DigitSeis uses two functions that were not written by the authors nor are built-in functions that come with MATLAB. Permissions from the functions' authors to include them in the DigitSeis package were obtained prior to inclusion. The individual functions can be obtained from sources below.

`rgb2hsv_fast.m`

This function was written by Dr. Alexander Ihlow (Technische Universitat Ilmenau), and is available at http://www.mathworks.com/matlabcentral/fileexchange/15985-fast-rgb2hsv/content/rgb2hsv_fast.m.

`writesac.m`

This function was written by Dr. David Yang (Los Alamos National Laboratory). The latest version of this function was obtained from the author, but it can also be found included in the Seismic Analysis Code (SAC) distribution, at http://ds.iris.edu/ds/nodes/dmc/forms/sac/.

Contents

About

DigitSeis is an image processing tool that fits a digital line to the traces appearing on analog seismograms[1] in both time and location spaces. It takes a high-resolution digital scan of an analog seismogram and then allows the user to create a digital copy of the traces, which can then be extracted as time series in the `.SAC` format. This allows for old analog data to be treated like modern digital time series, and opens up a veritable wealth of data which was previously both relatively inaccessible and had little use with regard to modern techniques.

DigitSeis is a MATLAB based software and uses automated image-processing algorithms to extract data where possible. However, it still requires human input and supervision for the purposes of correction and monitoring. This comprehensive manual extensively covers the tools DigitSeis includes and the methods for using them to most effectively digitize analog seismograms.

1.1 Manual Organization

This comprehensive manual for DigitSeis is arranged chronologically and moves through the tools and features available at each step in the digitization process. There are six major steps involved in digitizing the image of an analog seismogram:

[1] For more information on analog seismograms, see About Analog Seismograms.

These steps are also listed in the table of contents, along with each of their subsections. With this format in mind, and because many of the tools in DigitSeis recur in multiple steps, please note that tools are only described in-depth in the section for the step they first occur within. Further, tips relevant to specific tools and steps are included with the details of those steps, and tips relevant to DigitSeis as a whole are included in Tips for Using DigitSeis.

> Specific tips can be found in boxes such as this throughout this manual.

For users that are working with seismograms for the first time, going through the section below on analog seismograms before beginnning any other steps is highly recommended. An understanding of the parts of seismograms is crucial when using DigitSeis, and this manual is generally written for users already somewhat familiar with key pieces.

> To troubleshoot, start with the step the problem occurred in. If a solution cannot be found in that section, consider reading through the prior section(s), overall tips, or the Troubleshooting guide found at http://seismology.harvard.edu/research/DigitSeis/DigitSeis1.5/troubleshoot.html.

1.2 Analog Seismograms

When using DigitSeis, it's important to have familiarity with the three types of objects in an analog seismogram: traces, time marks, and noise. These parts are each highlighted in Figure 1-1.

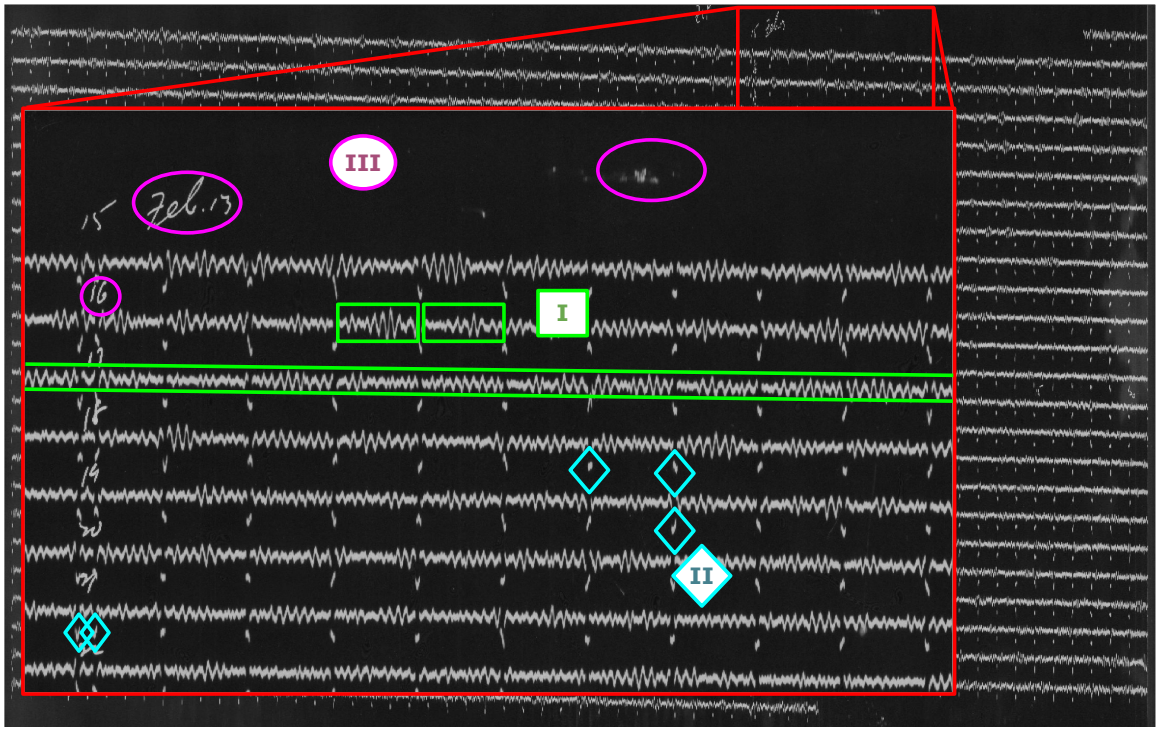

Figure 1-1: A zoomed view of an analog seismogram with examples of key parts highlighted. (I) Traces, highlighted in green squares, make up most of the data in an image; (II) time marks, highlighted in blue diamonds, define segments of time; (III) Noise, highlighted in pink circles, is any extraneous data.

Traces are the longer segments in a seismogram, and are interspersed with time marks. The word "trace" can refer to individual objects (for example, the two smaller green boxes in Figure 1-1), or to an entire line of data from the seismogram. In general, "trace" refers to individual objects in the classification step, when each object is considered separately, and refers to entire lines in the digitization step and beyond, once whole digitized traces for each line have been created.

Noise is any object that isn't a time mark or a trace. This is data that is present in the image, but is irrelevant to the final product — digitized and timed traces. Noise can include stains and handwriting; in particular, hours and dates are frequently written between traces and must be classified as noise. Classifying objects as noise masks them in the digitization step, so noise objects can be resolved either by classification

as noise or by masking.

Time marks are generally set at minute intervals in traces, and are necessary to calculate timing once traces have been digitized. They can come in a few different shapes and forms. The most common type of time mark used by the Harvard-Adam Dziewonski observatory (HRV) appears as a small amount of the trace offset from the rest, as in Figure 1-1. These types of time marks can either be offset above (Figure 1-2, II), or below (Figure 1-2, I) the traces.

> A good way to check the directionality of the time marks is to look at the top or bottom of the record. If the time marks aren't present above the top line, they are below the traces. Alternatively, if the time marks aren't present below the bottom line, they are above the traces. The same strategy can be used to find which hour labels correspond to which traces.

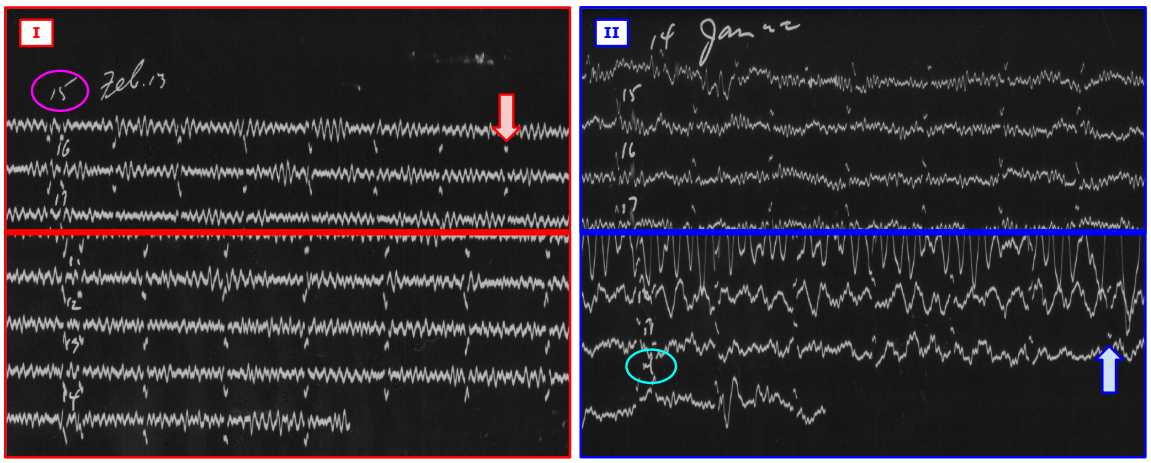

Figure 1-2: The top and bottom of two analyses in DigitSeis. (I) A seismogram with time marks below traces, and (II) a seismogram with time marks above traces. Both images have hour labels above traces (circled).

DigitSeis is optimized for time marks with width and offset. However, there are other types of time marks that are less prevalent[2]. In particular, seismograms with gap time marks (where traces are timed by gaps at minute intervals) and streak time marks (where traces are vertically smeared at minute intervals) are somewhat prevalent — these are shown in Figure 1-3.

[2] DigitSeis was developed by the Harvard Seismology group, and so is optimized for types of analog seismograms scanned in the HRV Seismogram Archival Project.

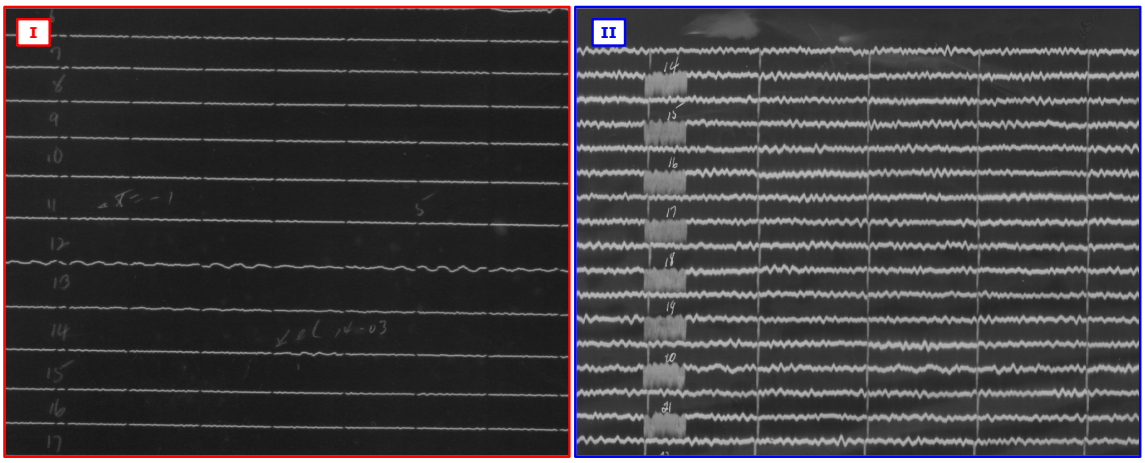

Figure 1-3: Analyses with other types of time marks. (I) An image with gap time marks, and (II) an image with streak time marks.

There are some features available in DigitSeis to aid in digitization of analog seismograms with gap time marks[3]. However, DigitSeis has not yet been optimized for streak time marks. If necessary, images with streak time marks may be digitized by masking or otherwise removing the time marks[4], then treating the removed spaces as gap time marks.

In addition to traces, time marks, and noise, there are a few common features in analog seismograms that sometimes require attention for proper digitization, listed below.

- **Paper Edges.** The edges of paper seismograms frequently create objects that need to be masked so they don't interfere with trace objects. This can be dealt with early in the classification process by zooming into a thin column encompassing the paper edge, then masking all objects close to that edge.

  > The Remove Region of Pixels tool creates a closed plane figure by connecting line edges with a straight line. If the ends of the line are defined at the top and bottom of the image, just inside the page edge, a straight line closes the region and cleanly removes the page edge.

- **Hour Marks.** Hour marks can differ significantly seismogram to seismogram. It is important to remain aware of the type of hour mark present in a given analysis so that the appropriate adjustments can be made. To name a few,

[3] Procedure for gap traces is discussed in each relevant section.

[4] In some instances, DigitSeis may be unable to automatically classify streak time marks; if this is the case, they must be removed before loading the image to DigitSeis.

hour marks indicated by two close time marks[5] are dealt with automatically, hour marks (and time marks in general) as gap traces sometimes require deletion (due to interference from extra gaps), and hour marks as extended time marks require consideration for positioning of time bars relevant to time mark edges.

- **Multiple Records.** Often, two records are present on one image, as shown in Figure 1-4. It is recommended to crop out one record at a time and work with each record separately, to avoid complications with timing[6].

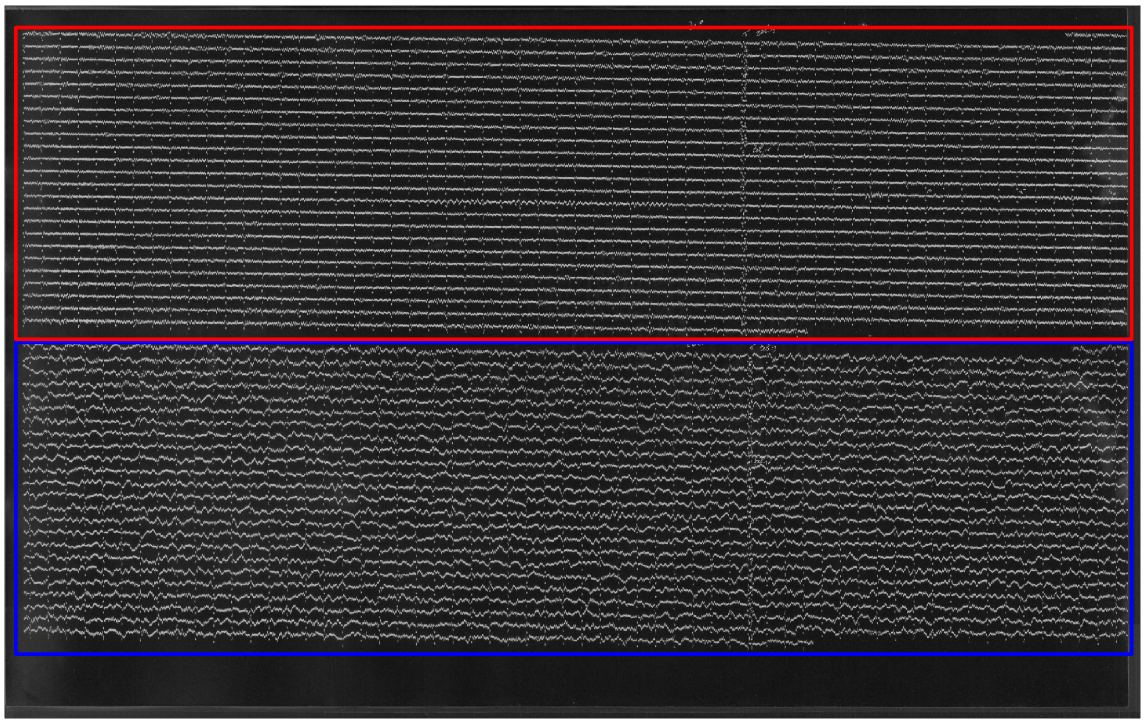

Figure 1-4: An image containing two records. In this case, the two records are for different components, and have been boxed in different colors for emphasis. The upper record, boxed in red, was used to generate the majority of examples and figures in the DigitSeis v1.5 documentation.

- **Stains and Handwriting.** Few analog seismograms are pristine. Some of the most common noise objects on images are from stains and handwriting. It is important to note that handwriting does not need to be preserved, and can

[5] This type of hour mark is present in the example seismogram, and some are visible in Figure 1-2 and Figure 1-1.

[6] The **Segment Trace** option in the plus menu for timing allows for an analysis with two records to be timed most accurately.

be completely masked out if desired. Further, stains tend to be darker[7] than traces, and so can often be removed by lowering binary threshold in the affected area using the Small Region Analysis tool in the classification step.

- **Calibration Pulses.** Calibration pulses are a common feature in analog seismograms, and can sometimes include sudden but uniform waves. Often, these result in thin lines that may not be classified as objects by DigitSeis. Ensure that the parts of individual calibration pulses are combined to avoid extra trace zero lines in the digitization stage[8].

[7] Less intense in pigment. Because images appearing in DigitSeis are white-on-black, markings that might be "lighter" on the original paper actually appear darker in DigitSeis.

[8] Combination of component objects is important for all objects; calibration pulses are particularly prone to separation.

1.3 Tips for Using DigitSeis

One of the best ways to learn to use DigitSeis is simply to use it. Many scanned images of analog seismograms are available at http://www.seismology.harvard.edu/HRV/scanned_images.html for downloading and digitization — practicing with many analyses helps operators acclimate to using DigitSeis and develop personal techniques for best digitization. However, there are a few tips that are generally helpful for navigating DigitSeis.

- **Saving.** While working through the digitization of a seismogram, keeping multiple save files — each for an important step — is highly recommended. Mistakes are inevitable, and it is sometimes difficult to backtrack without losing progress entirely. If `.mat` files for the analysis at each step are saved and organized, it's easy to go back to any step and minimize loss of progress in the case of a mistake. More information can be found in the section on saving.

- **Plus Menus.** In the left sidebar of the main DigitSeis window, each major action has a button and an adjacent plus menu. Though DigitSeis could probably be used successfully without interacting with the plus menus, the options available are worth looking through. They allow for customizations, corrections, and shortcuts that can drastically simplify steps in many common circumstances. Some of the plus menu options may seem perplexing upon first use of DigitSeis, but once some familiarity with the basic features has been developed, the plus menus can become an invaluable ally.

  It is important to note that changes made within plus menus are immediately applied. Simply selecting **Close** after changing settings implements the changes for the current analysis[9]. The **Save** option, however, sets the values in the chosen plus menu as defaults for all future use. See below for more information on defaults.

- **Zoom and Aspect Ratio.** Navigation tools are available in nearly every DigitSeis window and are extremely useful. More information is provided in the section on navigation, but one good-to-know feature is the zoom tool's ability to select a region of any size or aspect ratio. This disregard to scale applies to all selection-type tools in DigitSeis, and allows for examination of the exact region of interest. The changes in scale can be disorienting initially, but frequent practice allows users to take full advantage of this feature.

[9] It should be noted, however, that changes made in small windows, such as the Small Region Analysis window or the Overlap Analysis window, are only applied when **Apply** is selected. Selecting **Close** in small image windows does not apply changes made.

- **Tool Similarity.** There are a number of tools in DigitSeis whose usages are quite similar. They may have similar icons, and also tend function similarly. For example, all icons with a single coloured circle are object-selectors, and all icons with a certain shape involve drawing a region. Then, any tips and tricks known in regards to application using one tool can be applied similarly to all sibling-tools. For more details on tool types, see Tools in DigitSeis below.

- **Common Mouse Commands.** Many of DigitSeis's tools take advantage of right-clicks and double-clicks in similar ways. With this in mind, double-clicking and right-clicking are valid as very quick troubleshooting strategies if anything seems stuck. Double-clicking often acts as a confirmation, while right-clicking usually ends a process. These commands are common to certain common structures in DigitSeis — for example, all crosshairs are dismissed by a right-click, and all adjustable selection boxes are confirmed by double clicking within.

- **DigitSeis Defaults.** The default settings for DigitSeis on a machine running Mac OS X are contained in a file called `defaultDigitSeis.mat` created in the user's home directory. For Windows, this file appears in the desktop. Deleting this file restores original defaults, and causes a new `defaultDigitSeis.mat` file to be created in either the home directory or desktop the next time DigitSeis is opened. Otherwise, the current version of the default settings file loads the most recently saved settings to DigitSeis.

- **Step Order** Though use of DigitSeis sometimes may seem to follow a twisting path through different tools and windows, it is based on a core skeleton of steps leading into steps in a specific order. Thus, doing steps out of order can sometimes draw errors. Many of these step combinations have been tested and debugged, however, it is good to keep in mind that deviating from the usual step order can sometimes produce unusual effects.

DigitSeis is a software in progress, and is always evolving. For this reason, there are a few features included that may not seem to have a use in the current version. This is simply a sign of a feature to come — not all features available in DigitSeis v1.5 necessarily have a use, and that is simply part of the growing process of the software.

1.4 Tools in DigitSeis

There are many tools in DigitSeis that are structured similarly. These similar structures require many of the same commands, and so it is helpful to be able to recognize sibling tools[10] in order to utilize knowledge of any single tool towards any of the others. A few key tool types are listed below.

- **Crosshairs.** Yellow[11] crosshairs that extend over the whole image are used to select specific items. After the icon for a crosshairs tool is selected, the crosshairs immediately appear to follow the mouse in the image. Once the intended item(s) have been selected, right-clicking dismisses the crosshairs. All tools with icons featuring a single colored circle are crosshairs tools.

- **Adjustable box.** Adjustable boxes (and lines[12]) can appear in different colors, but always have colored lines with white borders and small squares as control points. Once an adjustable box encompasses the desired region, double-clicking within the box acts as a confirmation for the tool or the next step for the tool. To remove an adjustable box entirely, press the backspace or delete key.

- **Drawn region.** Drawn regions (and lines[13]) are created by clicking and dragging the mouse to create a region. The region is closed by a straight line between endpoints of the line drawn, creating a completed edge. The effects of the drawn region are implemented immediately after the mouse is released to complete the drawing. All tools with icons featuring an outline of a blob[14] are drawn region tools.

- **Toggle.** Some tool icons are the tools themselves — simply clicking these toggle-type tools enacts the change intended. Most toggle tools switch between two options upon clicking.

- **Navigation.** The four navigation tools — Zoom In, Zoom Out, Pan, and Show Whole Image — are powered mostly by MATLAB, as opposed to being designed specifically for DigitSeis. More information can be found in the Navigation section.

[10] Some, but not all, similar tools also have similar icons.
[11] The Check Time Point tool features a pink crosshairs.
[12] The time mark measuring tools function as adjustable lines. Note that double-clicking has no effect on adjustable lines.
[13] The Remove Line of Pixels tool functions as a drawn line. Note that it is treated as a line only — there is no edge completion.
[14] In a loose shape similar to a sideways heart or a squished kidney bean.

Tools which change the appearance of the cursor (with the exception of crosshairs tools) can be dismissed by either clicking the tool's icon again or by selecting another tool. Because it can sometimes be difficult to recall which tool was last selected[15], selecting and unselecting the Pan tool, which uses a hand as its alternate cursor, can be helpful to return to a neutral cursor[16].

There are a few tools which may take advantage of more than one of these tool types — these may act as hybrids of the types. For a full list of tools in DigitSeis and their types, see Appendix B: Tools.

[15] Many tools use the same alternate cursor, a cross.
[16] A neutral cursor is necessary for some right-click functions, such as setting absolute time.

Installing DigitSeis and Other Resources

2.1 Packages and Resources Available

DigitSeis is available at http://www.seismology.harvard.edu/research/DigitSeis.html. It is provided as a `.zip` file containing a standalone package for either Mac OS X or Windows[1] and so does not require installation of MATLAB[2].

DigitSeis v1.5 can be downloaded either as a bundle containing DigitSeis, this manual, and an example image of an analog seismogram[3], or as individual files. For a more compact download, a QuickStart manual is available as an individual file.

Also available at http://www.seismology.harvard.edu/research/DigitSeis.html are tutorial videos (contained in Online Documentation) and a list of frequent errors and solutions for troubleshooting (contained in Troubleshooting). The videos walk through the main processes for digitizing an analog seismogram, in particular the example seismogram provided, and the Troubleshooting guide provides possible step-by-step solutions for problems frequently encountered by new users of DigitSeis.

[1] The Windows version of DigitSeis is for 64-bit Windows operating system. A 32-bit version is not provided, but inquiries can be directed to the contacts available online.
[2] For MATLAB source codes, please contact the Harvard Seismology Group.
[3] This image is used for the majority of examples in this manual and the online tutorial videos.

2.2 Installing for Mac OS X

> A video is provided online as a walkthrough for installing DigitSeis on Mac OS X.

DigitSeis v1.5 is contained in a `.zip` file (downloaded either as part of the Mac bundle or as a single download), which, when unzipped, creates the folder **DigitSeis**[4]. This folder, as shown in Figure 2-1, contains a folder called **resources**, a `README.txt` file with instructions for installation, and two click-to-run shell scripts: `RunDigitSeis.sh` and `RunInstaller.sh`.

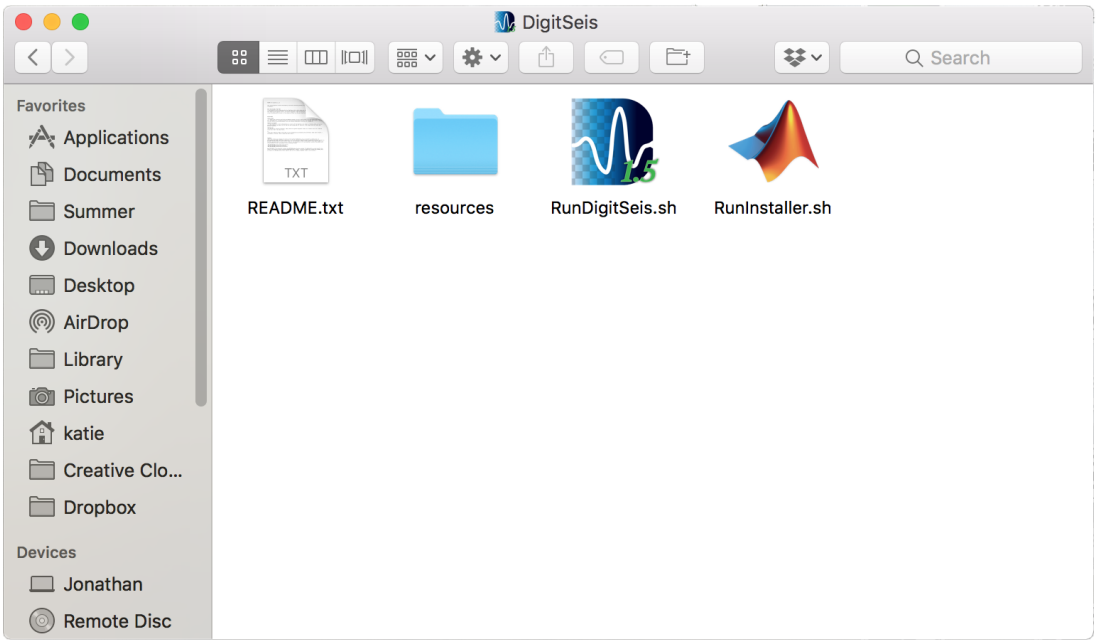

Figure 2-1: DigitSeis folder containing a folder called **resources**, a `README.txt` file with instructions for installation, the DigitSeis installer, and the script to run DigitSeis itself.

Before DigitSeis can be started, the proper MATLAB runtimes[5] must first be installed. This is done by first running the `RunInstaller.sh` script. To allow it to run, right-click the script and select **Open**, or **Open With** and then **Terminal** to ensure the file opens in the correct program. This usually triggers a warning (Figure 2-2) that the script is from an unknown developer. Clicking the **Open** option allows the

[4] Do not move any of the files from this folder. Some of the processes that allow DigitSeis to run rely on the positioning of other files in the folder.

[5] These allow for DigitSeis to be run as a standalone package.

script to run — this should open a Terminal window that begins the installation process. The installation takes a few minutes, and when it is complete, the window displays a `[Process Complete]` message, after which it can be closed.

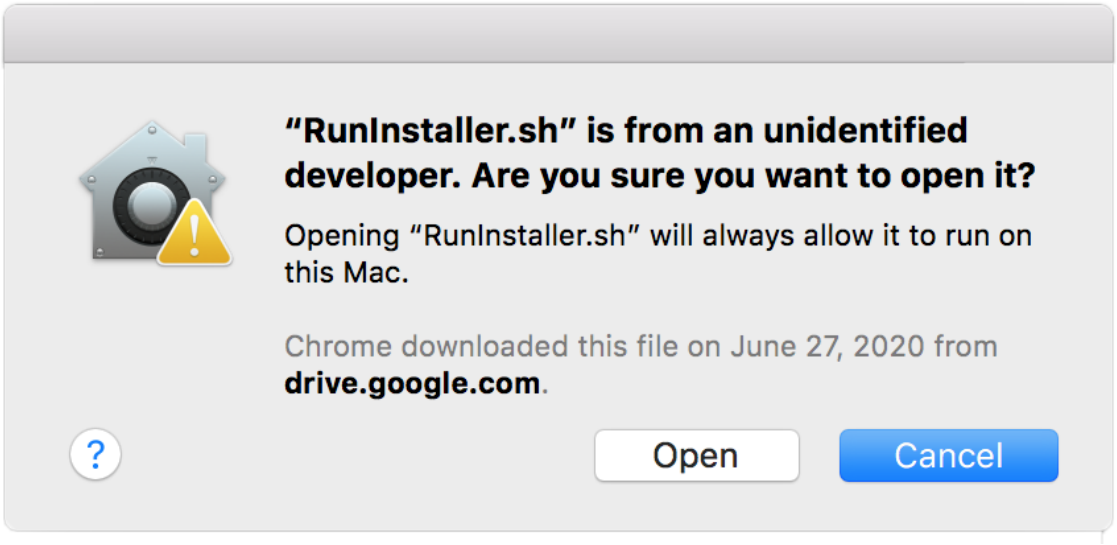

Figure 2-2: Warning appearing before running DigitSeis scripts in Mac OS X.

Once the Installer has been run, DigitSeis itself can be started. Right-click the script `RunDigitSeis.sh` and then select either **Open** or **Open With** as with the installer to allow it to run[6]. After bypassing the warning (Figure 2-2), a Terminal window runs DigitSeis opens. It may take a moment to load. The first window to appear allows for selection of either English or Japanese language — this selection applies to all future uses of DigitSeis[7]. After this, DigitSeis is ready to load an image.

> If any errors arise while attempting to install DigitSeis, or DigitSeis cannot be installed, see the troubleshooting guide at http://www.seismology.harvard.edu/research/DigitSeis/DigitSeis1.5/troubleshoot.html.

When opening DigitSeis after the inital installation, click `RunDigitSeis.sh` to initialize the program. This opens a Terminal window that runs DigitSeis. Once the user quits DigitSeis by closing all windows[8] , the window displays a `[Process Complete`, after which it can be closed.

[6] Once the warning has been bypassed by selecting to **Open** the file, DigitSeis can be opened in the future simply by clicking `RunDigitSeis.sh`.

[7] Language can be changed in the information window of an analysis. More in-depth information can be found in the Analysis Information section.

[8] Selecting **Quit DigitSeis** in the menubar does not quit DigitSeis. To quit, close all windows.

2.3 Installing for Windows

A video is provided online as a walkthrough for installing DigitSeis on Windows.

If any errors arise while attempting to install DigitSeis, or DigitSeis cannot be installed, see the troubleshooting guide at http://www.seismology.harvard.edu/research/DigitSeis/DigitSeis1.5/troubleshoot.html.

DigitSeis was developed for, compiled for, and primarily tested on the Mac OS X operating system[9]. A Windows version is available, but it has not been extensively tested[10]. There are differences in appearance and known cosmetic issues, such as text in messages being cut off and buttons having some overlap. Please note that this software remains primarily a Mac OS X software, and that as a result, support for the Windows version may be limited.

DigitSeis v1.5 for Windows is installed using the file `InstallDigitSeis.exe`, which is available in the DigitSeis bundle for Windows or as an individual download. Administrator privileges may be required to run DigitSeis on Windows. To install DigitSeis, run this script and follow directions given by the installer "wizard"[11]. In this process, select an installation location for the program folder, and, if desired, specify the desktop shortcut to be created.

This installation requires an internet connection to allow for the software to download the necessary open-use MATLAB runtimes[12]. Keep in mind that as a result of these downloaded files, the final application size for DigitSeis is larger than might initally appear from the installer size. If internet connection is not available during installation, a significantly larger installer that includes the runtimes can be downloaded instead[13].

In order for DigitSeis to operate properly, the user must have permission to read

[9] This manual, the images within, and the videos provided online also represent an OS X environment, unless otherwise specified.

[10] It has been confirmed that the software is usable and analyses can be processed, however, the testing was for a limited number of analyses.

[11] Dependent upon the machine and version of Windows used, a user confirmation window asking for permission to make changes may appear. Select in the affirmative to continue the installation.

[12] Internet connection is not required for further use of DigitSeis once it has been installed.

[13] This file is available in the Online Documentation in association with the tutorial for installing DigitSeis for Windows.

and write to the folders where the program is installed and where images are read in from. When opening DigitSeis for the first time, an inital window allows for selection of either English or Japanese language — this selection applies to all future uses of DigitSeis[14]. After this, DigitSeis is ready to load an image.

[14] Language can be changed in the information window of an analysis. More in-depth information can be found in the section on Analysis Information.

2.4 Uninstalling

2.4.1 Mac OS X

To uninstall DigitSeis on Mac OS X, simply delete the **DigitSeis** folder (Figure 2-1). Then, search for `defaultDigitSeis.mat` and delete it if it exists in other folders. If MATLAB is not independently present on the computer, go to the Applications folder and remove MATALB and/or MATLAB RunTime folders. All other dependencies for DigitSeis are contained the DigitSeis folder[15], so once the trash has been emptied, all files are removed.

2.4.2 Windows

To uninstall DigitSeis on Windows, the uninstaller script (created when the program is first installed) must be run. This script can be found in the directory `uninstall/bin/win64/`, starting from the directory in which the runtimes were originally installed. In this directory the user should find an uninstaller in the form of an executable. After this, remove any DigitSeis folders, shortcuts, and `defaultDigitSeis.mat`. Empty the trash to fully uninstall and completely remove DigitSeis.

[15] This is not the case if the user has set environmental variables and moved the MATLAB runtime folder as detailed in `README.txt`.

Loading and Preparing Images

3.1 Loading Images

Upon opening DigitSeis[1], a window allowing for starting file type selection opens, as in Figure 3-1.

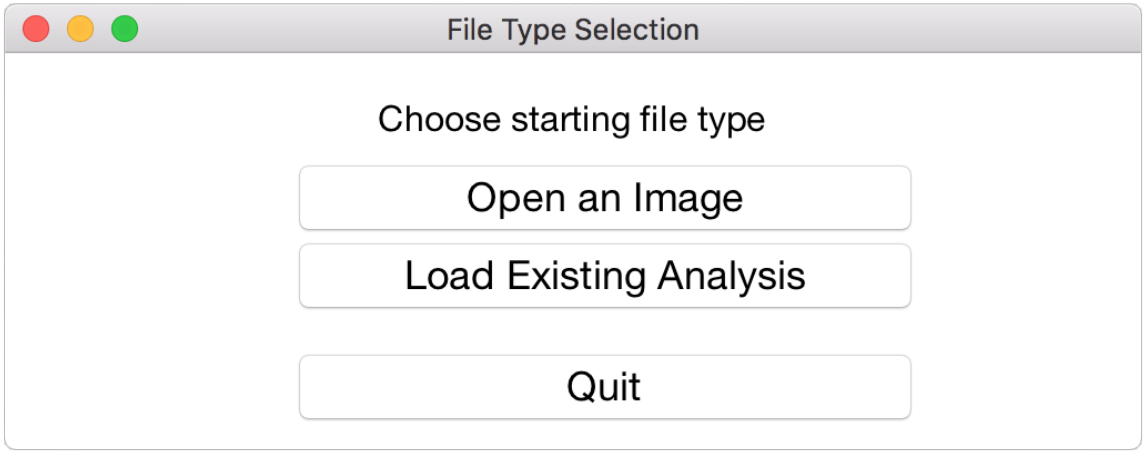

Figure 3-1: File Type Selection window.

To continue work on an existing analysis, load a `.mat` file by selecting **Load Existing Analysis**. The analysis opens in the main DigitSeis window[2], and the user can pick up from where the loaded analysis was saved.

To upload a new image[3], select **Open an Image**. The image may take some time to load as it is converted to the proper format. Once it is loaded, the main DigitSeis

[1] The first time DigitSeis is opened, language selection begins first. However, in all subsequent launches of DigitSeis, the File Type Selection window opens immediately.

[2] To continue classification, simply press the **Classify Objects** button, and the Classification window opens where it was last left.

[3] DigitSeis works with all image formats supported by the MATLAB function `imread`, which are detailed at https://www.mathworks.com/help/matlab/import_export/supported-file-formats.html.

window opens, and the image should be visible and contain light-coloured traces over a dark background, as in Figure 3-2.

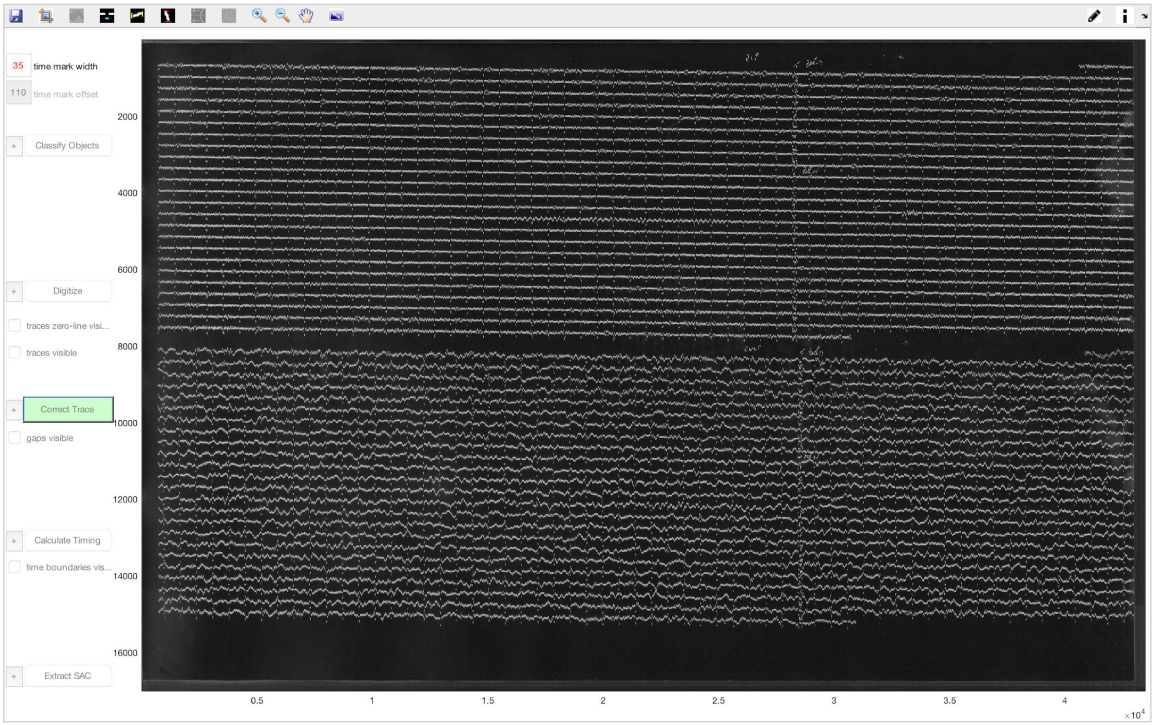

Figure 3-2: Main DigitSeis window upon first loading an image.

Once either **Open an Image** or **Load Existing Analysis** are selected, the selection cannot be changed without closing DigitSeis. If the wrong option is mistakenly selected and then cancelled, or **Quit** is selected, the current DigitSeis program quits and a new instance of DigitSeis must be opened to begin.

> For help if the main DigitSeis window or the Language Selection window[4] do not open, see the online troubleshooting guide.

[4] The Language Selection window only opens the first time DigitSeis is launched.

3.2 Saving and Undoing

3.2.1 Saving

Many of the processes DigitSeis carries out are time-consuming, and some actions are irreversible. For these reasons, it is a good idea to save analyses frequently[5] to avoid having to redo long steps and to minimize work lost if a mistake is made. Saving an analysis as a `.mat` file also allows for work to essentially be paused and later be resumed by loading the existing analysis from the saved `.mat` file as described in the Loading Images section.

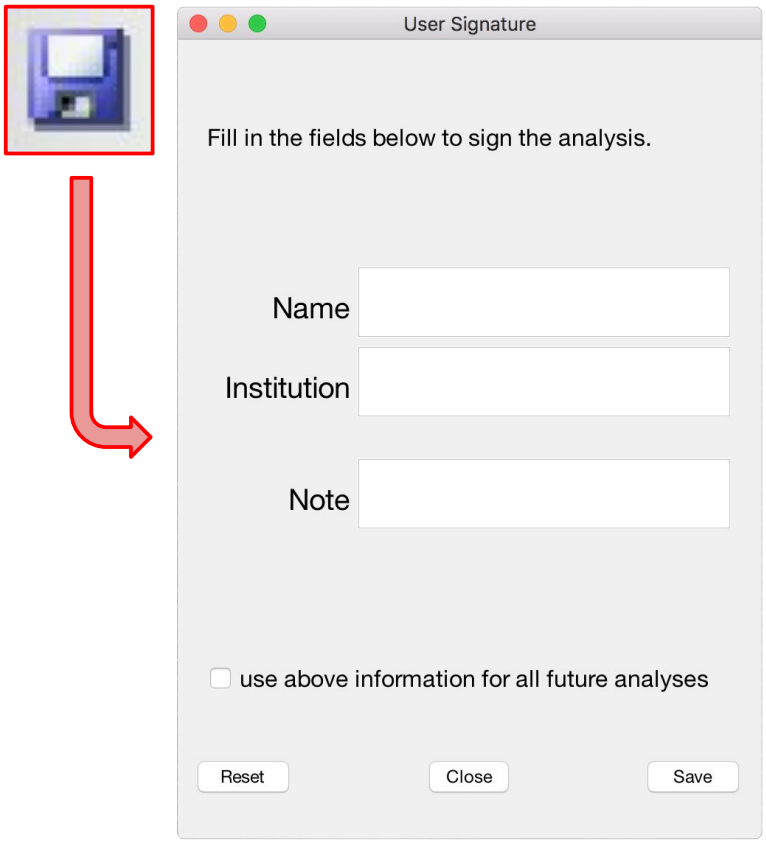

Figure 3-3: Save icon and initial window for signing analysis.

To save an analysis as a `.mat` file, select the save icon, in the top left corner of the main DigitSeis window (and also the Classification window), as circled in Figure 3-3. The first time an analysis is saved, a window (Figure 3-3) opens where the user can

[5] If a DigitSeis window is closed without saving, a warning window opens to give the user the opportunity to go back and save.

input information to "sign" the analysis. This information allows for better organization of analyses, where applicable.

Once the **User Signature** window has been saved and closed, the standard save window for the user's operating system opens to allow for file naming and choice of save location. Once the user signature has been completed once for an analysis, all future saves go directly to the operating system's standard save window.

> Throughout the process of digitizing an image, save files at key points with different names so it is possible to return to any point if need be. After completing any time- or effort-intensive task, be sure to save the analysis.

3.2.2 Analysis Information

To access the user signature and other information for the analysis after it has been created, clicking the **Information** icon at the top right of the main DigitSeis window opens the **DigitSeis Analysis Information** window (Figure 3-4).

In this window, language selection can also be switched by clicking the button labeled with the current language in the lower right corner of the window. Doing so reopens the window for language selection, and, if the language is changed, the main DigitSeis window closes and reopens in the selected language.

3.2.3 Undoing

DigitSeis has an undo function. However, it is limited and so users should remain cautious in maintaining up-to-date saves in case of a mistake. The undo button can be found in the toolbar in both the main DigitSeis window and the Classification window, as well as in smaller windows intended for manipulating specific parts of images.

The undo button changes from greyed-out to green when a previous action can be undone. Selecting the undo button can only undo *one* previous action — the last action carried out on the image. Further, an undone action cannot be redone. The undo button becomes unavailable if the last action is not undoable or if the action was already undone.

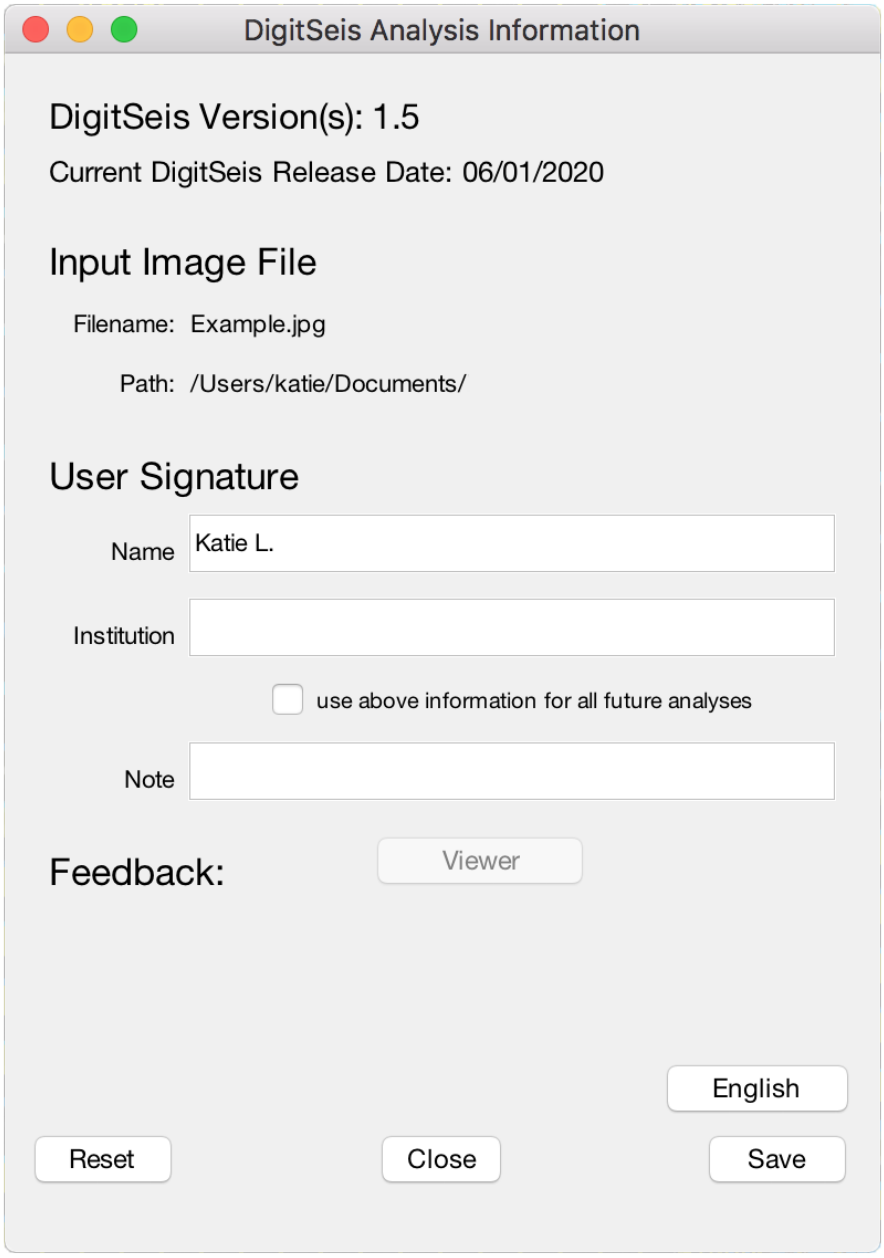

Figure 3-4: DigitSeis Analysis Information Window.

3.3 Navigating Within Images

Many intermediate steps in the process of digitization require close examination of certain parts of images. To navigate within an image, there are four tools available in the toolbar of all DigitSeis windows (Figure 3-2 and Figure 3-5): Zoom In, Zoom Out, Pan, and Show Whole Image.

Figure 3-5: Navigation tools found in the toolbar of all DigitSeis image windows. From left to right: Zoom In, Zoom Out, Pan, and Show Whole Image.

After clicking its icon, the Zoom In function can be used both by simply clicking the image to zoom in increments or by clicking and dragging to create a box that then zooms to fill the entire window. The image does not stay to scale, and zooms as soon as the box is created. To use the Zoom Out function, simply click on the image after selecting the icon, and the image zooms out in increments.

The Pan function transforms the cursor into a hand when selected, and allows for clicking and dragging to pan the image. To stop using Zoom In, Zoom Out, or Pan, either click the icon again or simply click another tool to start using it. Further, double-clicking with any of those three navigation tools selected causes the window to zoom out to the full image. The window can also be zoomed out to view the full image by clicking the Show Whole Image icon.

> The Show Whole Image tool doesn't end use of most other DigitSeis tools. For example, if the Zoom In tool is active, using Show Whole Image doesn't deactivate it — the cursor could still be used to zoom in directly after Show Whole Image is used.

> Though secondary versions of the navigation tools appear in the top right corner of most DigitSeis windows when the cursor is in that area, using them is not recommended. The navigation tools in the top toolbar are intended to work with DigitSeis whereas those in the top right corner are part of MATLAB and do not necessarily interact properly with all DigitSeis features.

3.4 Cropping Images

A video is provided online as a walkthrough for cropping an image and measuring time mark dimensions.

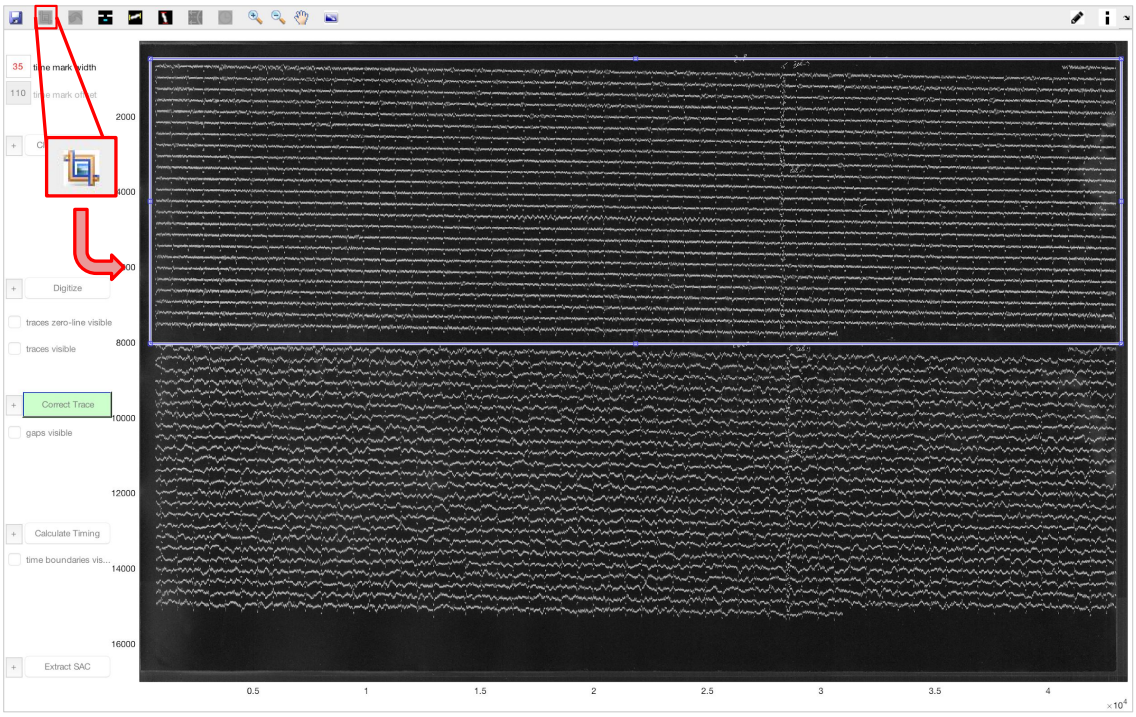

Figure 3-6: Main DigitSeis window with area to be cropped selected in blue. The crop icon in top left corner has been emphasized.

To make the digitization process as efficient as possible, new images should be cropped to minimize space without data. Many of DigitSeis's processes act on the image as a matrix, so a smaller amount of unecessary space significantly expedites much of the digitization.

Click the crop icon at the top left of the main DigitSeis window, next to the save icon to begin cropping (Figure 3-6). Selecting this icon allows the user to click and drag on the image to create an adjustable box outlined in blue. This box can be adjusted to encompass the area of the image to be retained after cropping, or can be deleted by pressing the backspace or delete button. To finish cropping, simply double click anywhere within the box.

3.5 Measuring Time Mark Dimensions

A video is provided online as a walkthrough for cropping an image and measuring time mark dimensions[6].

Before object classification can begin, properties of the time marks in the seismogram must first be indicated so that DigitSeis can properly identify them. To measure time mark width and offset, there are two tools available in the toolbar of the main DigitSeis window (Figure 3-2 and Figure 3-7).

Figure 3-7: Tools available in the toolbar of the main DigitSeis window for measuring and defining time mark properties. From left to right: Time Mark Direction, Measure Width, and Measure Height.

3.5.1 Images With Time Marks

After selecting one of the tools, click and drag to draw a line. Once created, the line is labeled with its vertical or horizontal component in number of pixels — the Measure Width tool creates a yellow line that measures horizontal distance while the Measure Offset tool creates a red line that measures vertical distance. The ends of individual lines can be adjusted, and to clear all lines, press the backspace or delete button.

The adjustable lines created by the measurement tools are coloured, outlined in white, and have square-shaped control points. Other lines and boxes of this type function similarly in regards to size adjustment and removal[7].

To measure a specific time mark, zoom in until it is large enough to be accurately measured. Offset should be measured to account for trace thickness, so vertical distance should be found with a line from the bottom of the trace to the bottom of the

[6] This video does not cover gap traces.
[7] See Tools in DigitSeis for more information on tool similarity.

time mark or from the top of the trace to the top of the time mark (as in Figure 3-8). Time mark length can simply be found by measuring horizontal distance using a line spanning a time mark end-to-end.

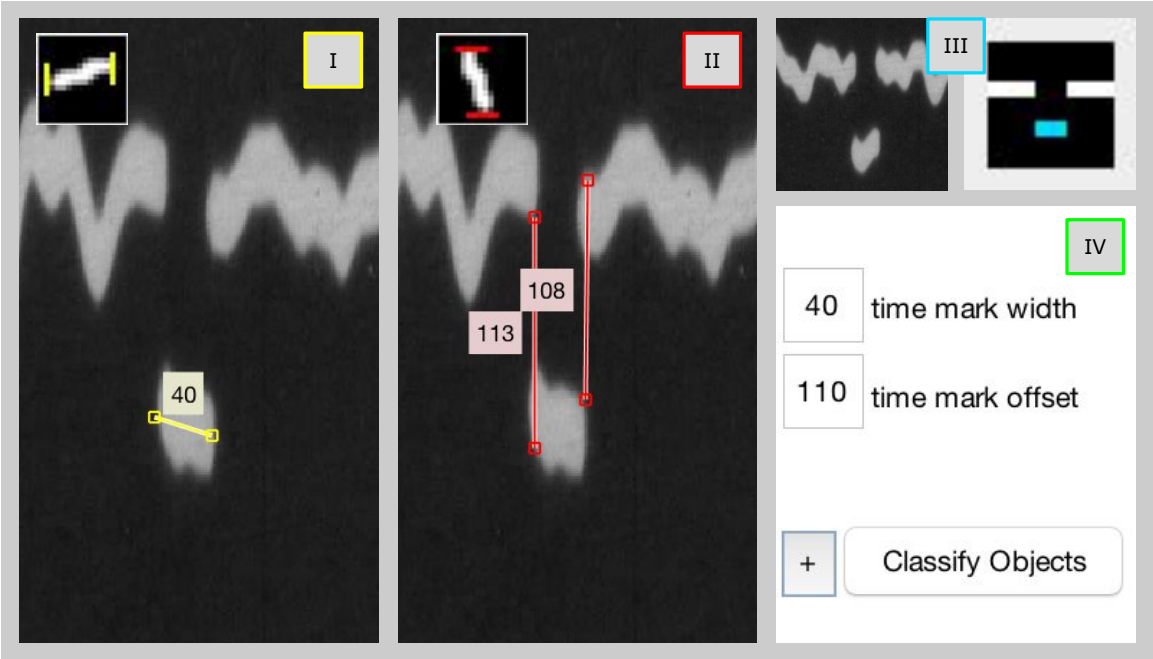

Figure 3-8: Using time mark dimension measuring tools. (I) Tool for measuring only horizontal distance for width, (II) tool for measuring only vertical distance for offset, (III) toggle indicating time marks are below traces for the image, and (IV) fields in left sidebar for inputting time mark dimensions.

> Since time marks can differ even within the same seismogram, it's a good idea to measure a few different time marks and estimate averages for height and width.

When time mark dimensions have been determined, they can be input to fields in the left sidebar, as in Figure 3-8. Though default values may already be present, the **Classify Objects** button does not become available until the **time mark width** field has been confirmed (by at the least clicking to edit the field and pressing enter, if no changes to default numbers are necessary).

Before beginning classification, also ensure that the Time Mark Direction icon (Figure 3-7 and Figure 3-8) displays a time mark in the correct orientation. Pressing the icon toggles between the orientations — time marks above traces or time marks below traces.

3.5.2 Images Without Time Marks

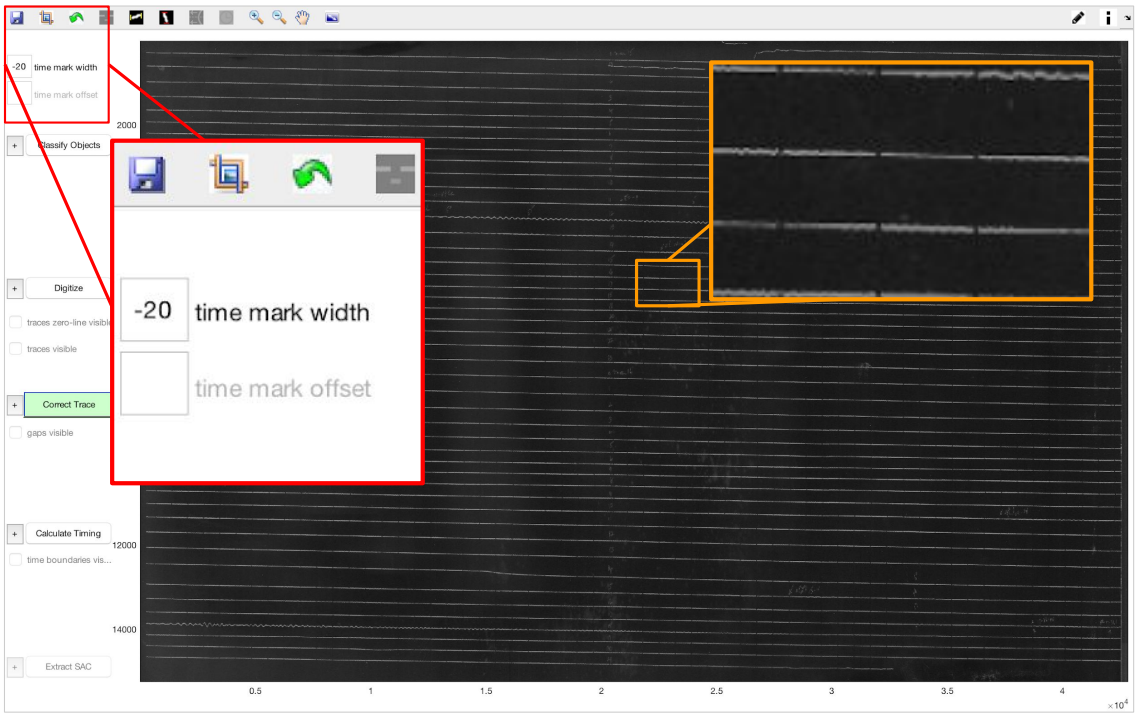

Figure 3-9: Inputting time mark dimensions for a seismogram shown with gaps for time marks.

Some seismograms don't have time marks, and instead have gaps in traces to represent time (Figure 3-9). To set time mark dimensions for an image without time marks, set the **time mark width** field to zero or a negative number. This causes the **time mark offset** field to become unavailable. Further, if the time mark width is set as a number less than zero, any object with an x-range (horizontal-only distance) less than the absolute value of the width set is classified as noise[8]. In the case of gap traces, the time mark orientation icon is greyed out.

> When working with gap traces, setting a negative width with an absolute value slightly less than the horizontal extent of the shortest trace is recommended. This eliminates any non-trace objects — because there are no time marks in a seismogram with gaps for time marks, traces are the only necessary objects.

[8] Noise is anything that appears on the image but isn't pertinent data. See more in About Analog Seismograms.

Classifying Objects

4.1 Goals of Object Classification

> A video is provided online as a walkthrough for the basics of classification.

During the classification process, DigitSeis automatically converts the image to a binary format and creates objects based upon non-empty adjacent pixels[1]. These objects are classified into three categories: Traces, time marks, and noise.

Traces are the longer segments of line in an image. They are interrupted by time marks, which may appear above, below, or as gaps in the traces and each mark a time interval of a minute in the seismogram. Noise is any other object, and does not contribute to digitization. See About Analog Seismograms for more information on the parts of seismograms. One significant source of noise is the handwriting often used to label traces on an analog seismogram. These hour and date labels must be separated from the traces and masked or classified as noise.

Object classification is mostly automated, but requires human input to check the accuracy of classifications. This is particularly crucial for images with smudges, stains, or which otherwise contain a lot of noise or inaccuracies. Then, when an image is digitized, the correctly sorted objects can be effectively compiled into digitized traces and later, when time is calculated, the appropriate objects are labeled as time marks to create accurate intervals. Classification sets up the image for the rest of the digitization process.

[1] Pixels adjacent on a diagonal are considered adjacent by DigitSeis

4.2 Settings for Classification

4.2.1 Initial Settings

Before classification begins, there are some settings that can be customized to make the automated classification as effective as possible. These settings can be found in the plus menu to the left of the **Classify Objects** button (Figure 4-1).

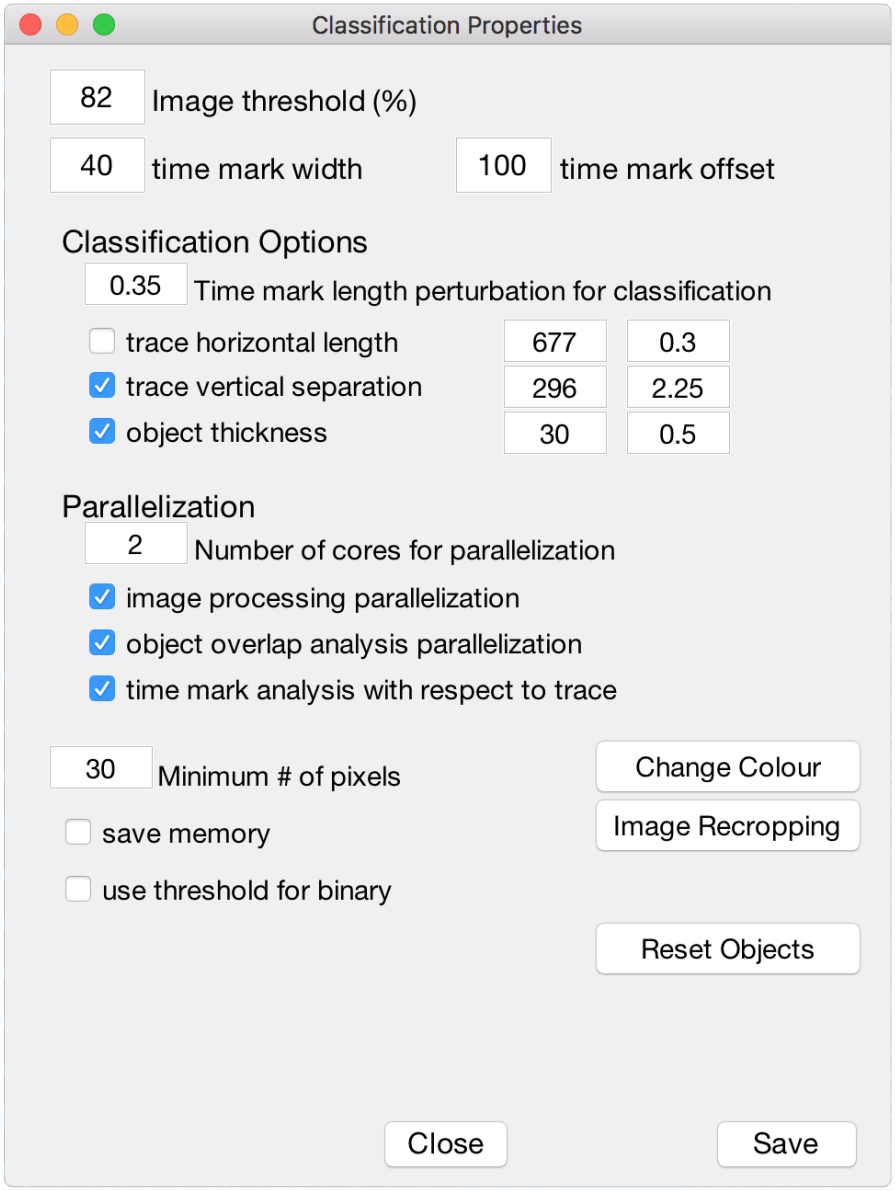

Figure 4-1: Plus menu for object classification settings.

- **Image threshold.** The number in this field represents the minimum intensity value (threshold) of a pixel in the image for it to be included in classified objects. Higher values include fewer pixels and thus exclude darker[2] parts of objects. This effect is demonstrated in Figure 4-2.

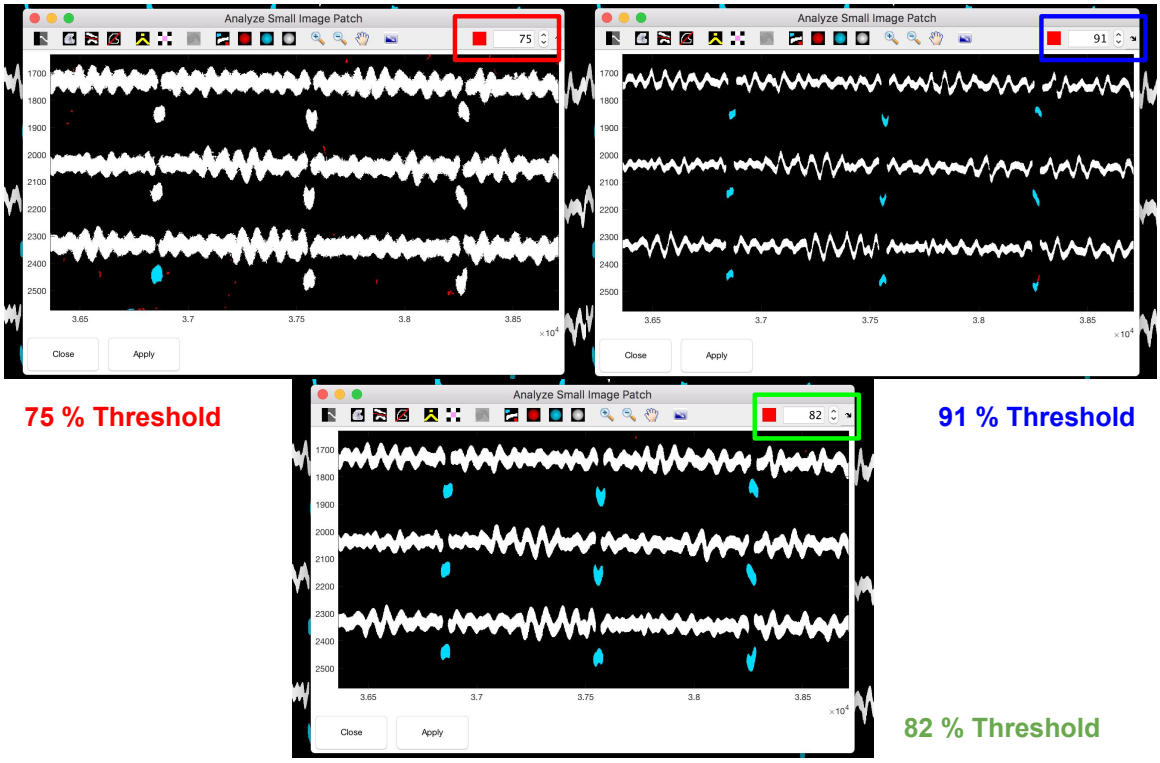

Figure 4-2: Effect of changing image threshold. Classification of same section at 75, 82, and 91 percent in a Small Region Analysis Window.

Image threshold does not apply in general to the Classification window unless **use threshold for binary** below is checked. When it isn't checked, the number specified instead acts as the default in the small-image windows (the Small Region Analysis window is displayed in Figure 4-2, where the threshold can be easily changed). The **use threshold for binary** option is not recommended, because it can slow down the classification process significantly.

> Generally, threshold values of 80 to 85 are fairly appropriate. Very clear images and thick lines tend to be better for higher threshold values.

[2] Since the images are converted to white traces on a black background, lines that appear heavier and darker on the original paper seismogram are actually brighter in DigitSeis.

- **Time mark width and offset.** These fields are interchangeable with the **time mark width** and **time mark offset** fields in the left sidebar. See Measuring Time Mark Dimensions for more information.

- **Time mark length perturbation for classification.** The value for time mark length perturbation determines how much variance in time mark dimensions objects classified as time marks are allowed. A larger value results in a larger range of object dimensions leading to classification as time marks.

  > If, after classification, many time marks seem to be misclassified, try increasing time mark length perturbation and reclassifying.

- **Properties to check for.** When classifiying objects, only certain properties are considered (for example, time mark width and offset are always considered). Checking the box of any of the following three properties includes that property during classification. The first field following the name of each property is the value (in pixels) specified for that property; the second field is the perturbation allowed for the property.

  - *Trace horizontal length.* The horizontal length of traces, the long segments in between time marks. However, trace lengths tend to be very variable and the existing algorithm tends to be reasonably robust in regards to this property, so it is not usually necessary.

  - *Trace vertical separation.* The vertical spacing between "rows" of traces. This aids in classifying objects with incorrect vertical spacing as noise rather than traces.

  - *Object thickness.* The thickness (vertical extent) of time marks and traces. This aids in classifying too-thin objects as noise — increasing the object thickness property helps to reduce the number of small noise objects incorrectly classified as traces.

- **Number of cores for parallelization.** To reduce the calculation time for large tasks, multiple cores can be parallelized to split the calculations and more effiently carry out the process of classification. The default number of cores depends on the number of cores available on the machine used, but if there is reason for concern about a potential merge error or availability of cores, it can be reduced.

- **Processes to parallelize.** Parallelization for certain processes can be toggled on or off. Image conversion to binary, detection of potential overlapping objects, and checks of time marks against gaps in traces can all be optionally parallelized. They are all parallelized by default.

- **Minimum number of pixels.** This value specifies the minimum number of pixels needed to define an object. Selecting a higher value helps to remove small noise objects altogether — with fewer unnecessary objects, processes that check against all objects in the classification window are completed faster.

- **Save memory.** Checking the **save memory** box saves as much memory as possible throughout classification. This significantly slows classification processes.

- **Use threshold for binary.** A more complex default algorithm is normally used to calculate the binary image, but if this option is selected, the threshold value specified in the **Image Threshold** field is used for the entire image. This is a significantly more time-intensive choice.

- **Change Colour.** The default colour scheme is white for traces, blue for time marks, and red for noise (Figure 4-3). By clicking the **Change Colour** button, a different existing scheme can be selected, or a custom scheme can be created. To create a custom colour scheme, click one of the squares next to an object type. A window to choose a new colour opens, and a custom colour can be selected for that object type.

- **Image Recropping.** Images are cropped at the beginning in part because once classification, digitization, and/or timing have been done, the image cannot be recropped. For this reason, the crop icon greys out as soon as classification has begun. However, if recropping is necessary (at the expense of any work done on steps in classification and after), this button allows for it.

- **Reset Objects.** If, for whatever reason, the classification is not sufficiently accurate and the automated classification needs to be run again, this button can be selected to reset all current classifications. This allows for selection of different settings and reclassification.

Changing any of the settings and simply clicking **Close** to close the window applies the settings to only the current analysis. To apply the chosen settings to the current and all future analyses, click **Save** before closing the window. Any changes made to default settings are saved in the `defaultDigitSeis.mat` file, as described in the

section regarding DigitSeis defaults.

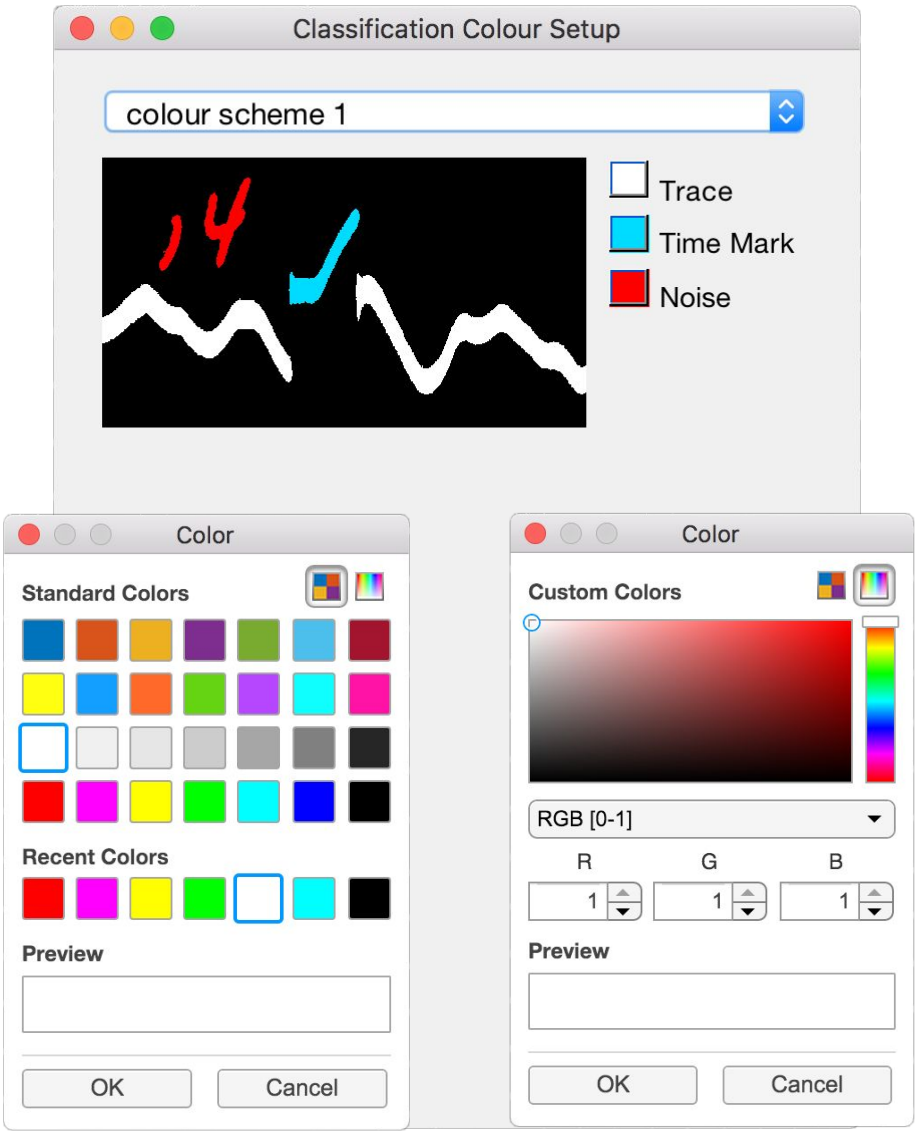

Figure 4-3: Classification Colour Setup window and the two custom colour selection windows.

It is a good idea to run the automatic classification once before changing settings. If there's time to be running the classification process a couple times, seeing the results of the process with default settings helps determine what settings might need to be customized.

4.2.2 Additional Settings

After objects have been automatically classified, settings for classification can still be opened in the classification window, with the addition of a second page of settings regarding small analysis windows (Figure 4-4).

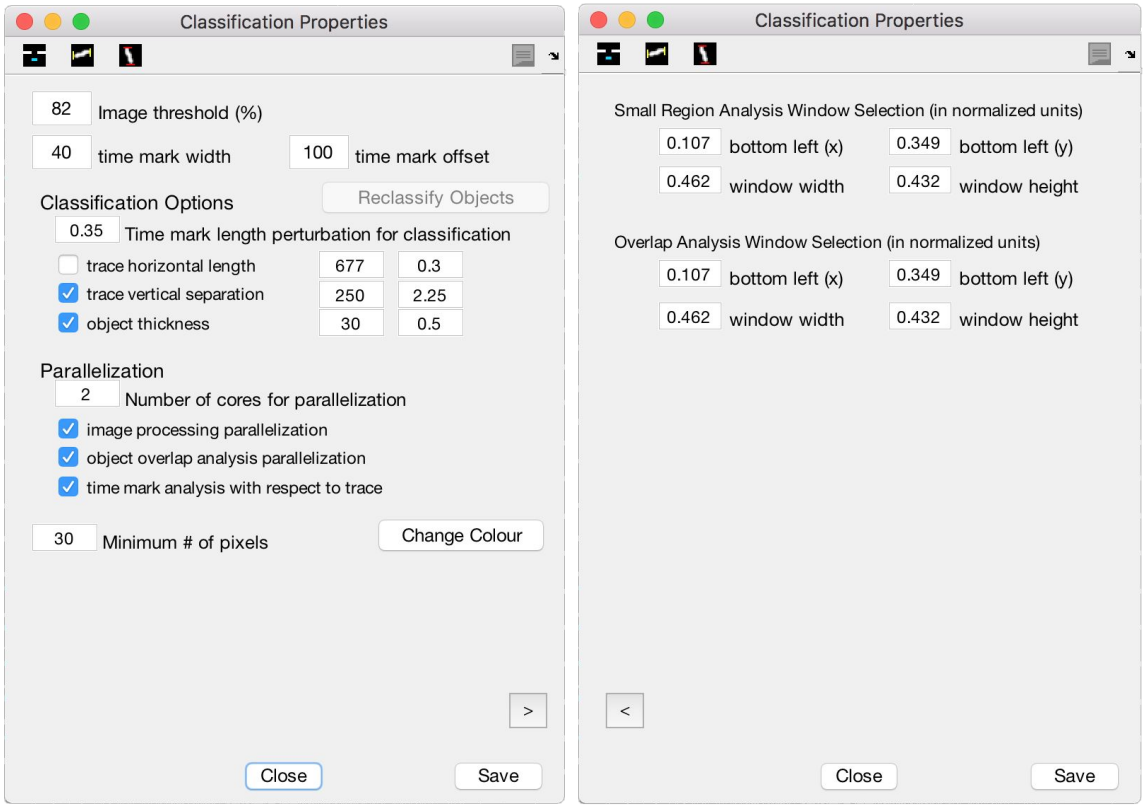

Figure 4-4: Settings for classification available within classification window.

The secondary plus menu for classification includes the time mark measuring and offset direction tools at top, an option to reclassify all objects automatically, and a second page of settings regarding analysis window sizes and positions. The second page allows for changes to default placement and size of the Small Region Analysis window and the Overlap Analysis window. Whenever a new window for either of these functions is opened, it opens in the position and size specified in the plus menu.

> Many of the settings in DigitSeis's plus menus make much more sense once some time has been spent working through images with the basic tools provided. The default settings are meant to be sufficient for the majority of situations, so use of caution when playing with settings is recommended.

4.3 Classification Tools

4.3.1 Basic Classification Tools

Once **Classify Objects** has been selected, DigitSeis begins automated classification of the objects in the image. This process takes some time. After it has finished, the main DigitSeis window closes and the classification window opens[3], as shown in Figure 4-5.

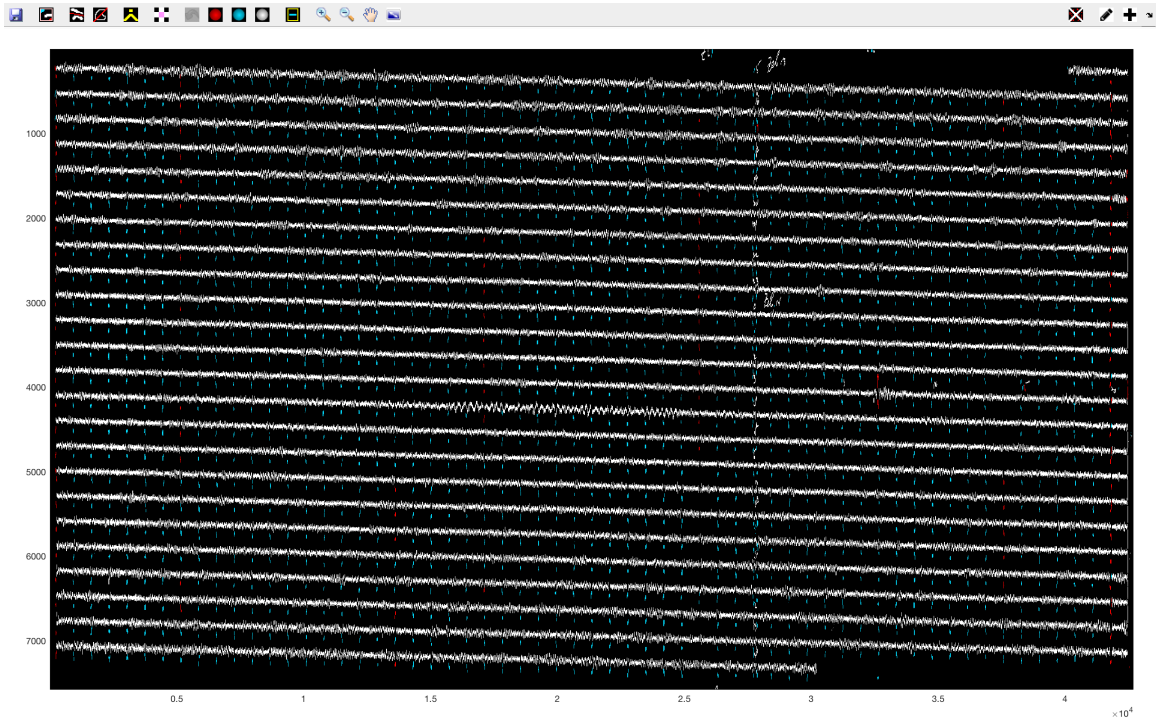

Figure 4-5: Classification window after automatic object classification.

For accurate digitization, the traces, time marks, and noise must all be accurately classified. As noted, the majority of objects should already be classified accurately. However, the image must be checked and corrected where necessary, using the tools available in the toolbar (Figure 4-6).

Save. See Saving.

Small Region Analysis. See Small Region Analysis below.

[3] Closing the classification window reopens the main DigitSeis window. Then, **Classify Objects** can be pressed again to reopen the classification window and resume progress.

Figure 4-6: Icons in classification window toolbar. From left to right: Row 1: Save, Small Region Analysis, Remove Line of Pixels, Remove Region of Pixels, Combine Objects, Overlap Analysis; Row 2: Undo, Classify as Noise, Classify as Time Mark, Classify as Trace, Show Time Marks, Zoom In, Zoom Out, Pan, Show Whole Image; Row 3: Remove Noise Objects, Add Note, Show Plus Menu.

- **Remove Pixels.** There are two tools that can be used to mask pixels in an image. These tools remove pixels, such that they cannot be considered part of any objects in the classification view. Note that pixel removal can be undone either with the Undo tool or with the Unmask Region tool in the Small Region Analysis window.

  > When separating objects with Remove Pixels tools, keep in mind that objects are not considered separate unless they share no adjacent pixels, and that diagonally adjacent pixels are considered adjacent.

   *Remove Line of Pixels.* Click and drag to mask the drawn line of pixels.

   *Remove Region of Pixels.* Click and drag to mask a drawn region of pixels. A straight line between the endpoints of the line drawn is used to complete the region.

  > Because the Remove Region of Pixels tool is completed with a straight line endpoint-to-endpoint if used to create an incomplete shape, it can be used to mask areas with straight edges. Drawing brackets or incomplete circles is effective for creating these straight edges.

 **Combine Objects.** To combine multiple objects into a single object, Combine

Objects introduces crosshairs which can be used to target objects to combine. After an object has been selected, it is highlighted in yellow; any number of objects can be selected. To complete use of the tool and combine all objects selected into one object, right-click anywhere.

The Combine Objects tool is useful for objects with gaps that have caused "breakage" of one object into two or more. Combining those objects into the single object they should be minimizes chances of inaccurate trace identification in the digitization step.

To un-combine objects, mask then unmask any part of the combined object. Note that this happens any time an object that has been combined is modified, so removing pixels from a combined object un-combines them.

 **Overlap Analysis.** See Overlap Analysis below.

 **Undo.** See Undoing.

- **Classify Object.** The three type of objects — traces, time marks, and noise — are each represented by a colour. In the default colour scheme[4], traces are white, time marks are blue, and noise is red. Selecting the appropriate colour from the icons introduces crosshairs which can be used to target objects to classify using the selected colour. To release the crosshairs after the desired objects have been defined, right-click anywhere.

   *Classify as Noise.*

   *Classify as Time Mark.*

   *Classify as Trace.*

 **Show Time Marks.** Selecting this icon highlights all defined time marks by creating yellow squares around them. This is helpful for quick identification of the time marks in the image and allows for potential missing or extra marks to be easily found and corrected.

- **Navigation.** See Navigating Within Images.

   *Zoom In.*

[4] The default colour scheme is used throughout the documentation for DigitSeis.

 *Zoom Out.*

 *Pan.*

 *Show Whole Image.*

 **Remove Noise Objects.** Deleting all noise objects (red in the default colour scheme) saves memory and increases speed of many processes impacting the entire image. However, some caution should be exercised to avoid removing traces or time marks that may be misidentified as noise.

 **Add Note.** The pencil icon allows for creation of note symbols, which are pink stars. Clicking the icon introduces a dotted crosshairs that is then used to select a location for the note symbol. If desired, a comment can be added to a specific symbol by right clicking it and choosing **Comment**. Symbols can also be individually deleted by right clicking each star and choosing **Delete**.

> Unlike the usual crosshairs-type tools, the dotted crosshairs cannot be dismissed by right-clicking. However, they are dismissed as soon as a note has been added, and it is simple to delete extra notes.

 **Show Plus Menu.** See Additional Classification Settings.

4.3.2 Small Region Analysis

> A video is provided online as a walkthrough for using the Small Region Analysis tool and the features it includes.

The **Small Region Analysis** window allows for selection and closer examination of a small region of the seismogram. Once the small region analysis icon has been selected, click and drag to create a box[5] encompassing the region desired. Then, double click inside the box to open the **Small Region Analysis** window, as displayed in Figure 4-7.

Most of the tools in the **Small Region Analysis** window are identical to those in the classification window. However, there are some that are more unique to the smaller window (Figure 4-8).

[5] This process is similar to the process for cropping the image.

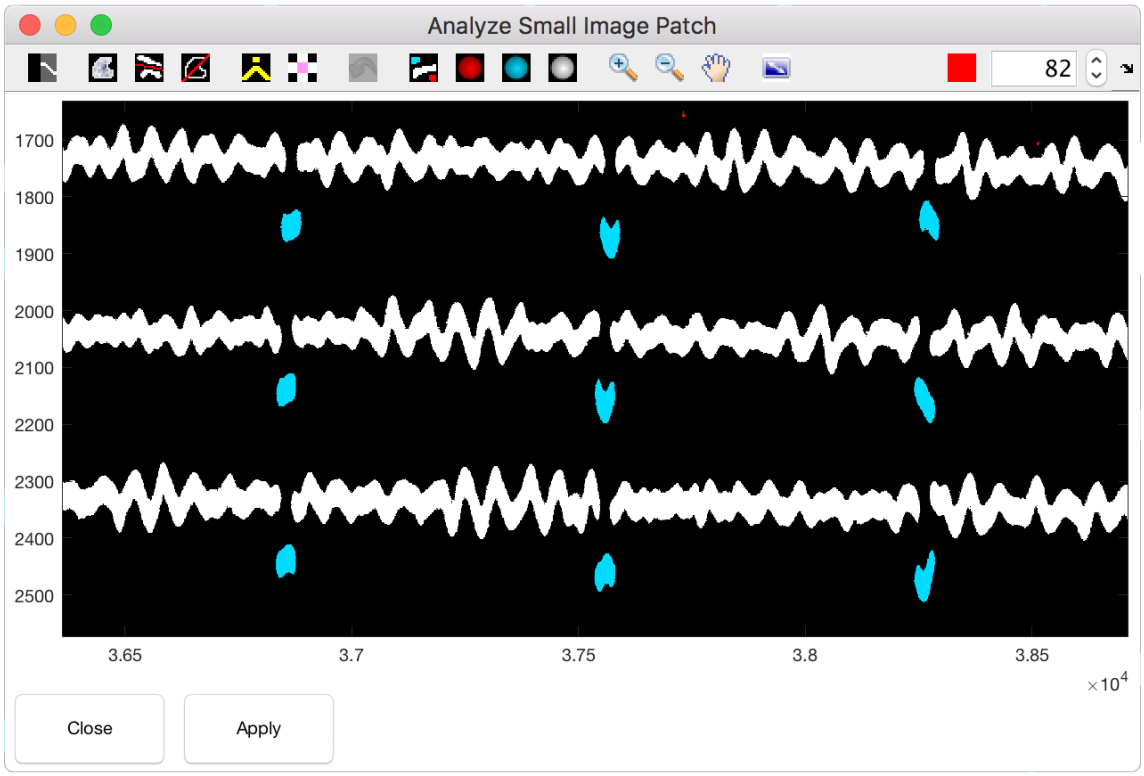

Figure 4-7: Small Region Analysis window.

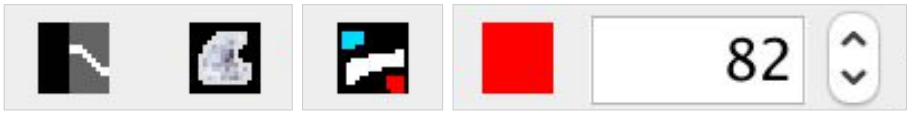

Figure 4-8: Special tools in the Small Region Analysis window. From left to right: Display original image, Restore a region to orginal image, Display classification, and Change binary threshold.

Show Original Image. Clicking this icon cycles between the original image (Figure 4-9), without the classification colouring, and the original image with masking. Masking is any area and/or any pixels that have been removed using the pixel removal tools. The masked original image allows for an accurate visual of excluded areas to most accurately ensure proper masking.

Unmask. The Unmask tool is essentially the opposite of the Remove Pixels tools. A region is drawn, and the area within that region is restored to the original image.

This tool is helpful for any mistakes regarding masking that have been made and are no longer in the reach of the Undo tool. Though the Small Region Analysis window automatically removes masking in the region it encompasses, any masking mistakes made while in the window can be reversed with the area restoration tool.

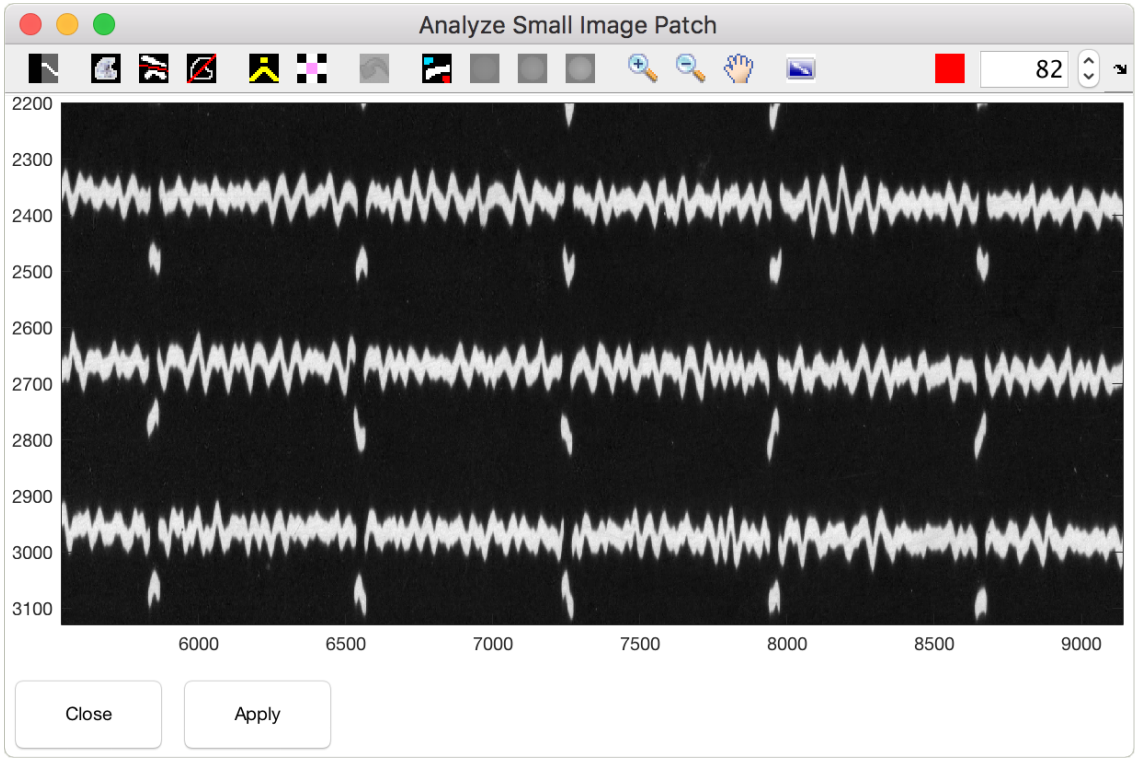

Figure 4-9: Small Region Analysis window displaying the original image.

Show Classification. Clicking this icon cycles between the classified image and the masked original image. It is useful for observing the effects of masking on the automatic classification of an object.

Recalculate Classification. The binary threshold feature allows for reevaluation of pixels as part of objects, as shown in Figure 4-2. The number can be changed either with the arrows or by typing, and then the new threshold is applied by clicking the red square. Changes can only be viewed when the window is displaying the classified image.

> When changing the binary threshold, it's a good idea to make the changes in increments and observe the new classification each time, decreasing increment size as the classification becomes more desirable. Then, it becomes very easy to see the ideal threshold for both clarity and accuracy.

Once appropriate changes have been made within the window, **Apply** can be selected to apply the changes to the section of the image[6]. **Close** can also be selected if no changes are desired, or to cancel undesirable changes made within the window.

> When the Small Region Analysis window is opened, objects within it are reclassified. For example, if time marks in one area seem to be classified as noise for no particular reason, opening the area in the small window may solve the problem without any user input — the Small Region Analysis window might reclassify them as time marks automatically.

> If the colour-coded classified image is unclear, or a certain spot seem unusual, the Small Region Analysis window is perfect for inspecting the possible anomaly. It is easy to use to view the original image and check for anything unusual, and simply closing the window without applying changes maintains the original classification if no changes are desired.

4.3.3 Overlap Analysis

> A video is provided online as a walkthrough for classifying overlapping traces.

The other small window openable in the classification window is the Overlap Analysis window. It allows for the classification of objects that overlap one another. Once the icon is selected, a crosshairs is introduced that is used to select a single object. That object is then opened alone in the Overlap Analysis window, as in Figure 4-10.

Like the Small Region Analysis window, many of the tools available are the same as those present in the classification. The tools unique to the Overlap Analysis window (Figure 4-11) aid specifically with resolving issues regarding overlap.

[6] The undo function is effective for undoing a single instance of changes caused by the **Small Region Analysis** window. As long as no actions are carried out after applying the changes from the window, all changes from the most recent application can be removed.

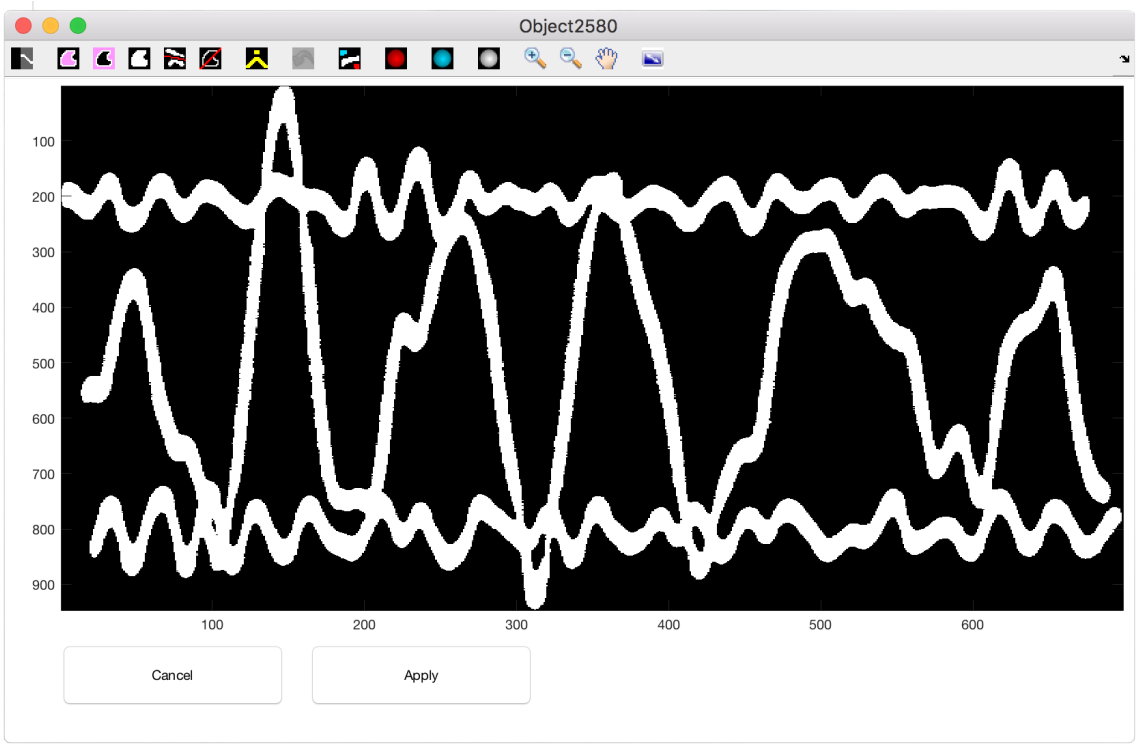

Figure 4-10: Overlap Analysis window.

Figure 4-11: Special tools in the Overlap Analysis window. From left to right: Add Overlap, Remove Overlap, and Add Pixels.

Add Overlap. This tool works much like the other drawn region tools. The area selected is highlighted in pink (shown in Figure 4-12), and becomes a sort of intersection for objects in DigitSeis. To fully separate overlapping objects, use the Combine Objects tool to select the parts of each individual object. The overlapping regions can be counted towards multiple objects.

When Combine Objects is used in the Overlap Analysis window, changes made in the window may cause combined objects to un-combine, so combining objects only after defining all overlapping regions is recommended. Note that, until combined, the overlapping regions act as masked regions, so be wary that classifying or combining objects early can create multiple objects, and, since the Overlap Analysis window contains only one object, detached parts may disappear.

Remove Overlap. The opposite of defining pixels as overlapping regions. This tool removes pixels from already existing overlapping regions.

Add Pixels. This tool adds pixels to objects. Caution should be exercised when using this tool, to avoid falsely adding nonexistent data. It can be used to recover pixels that may have been removed in separating objects.

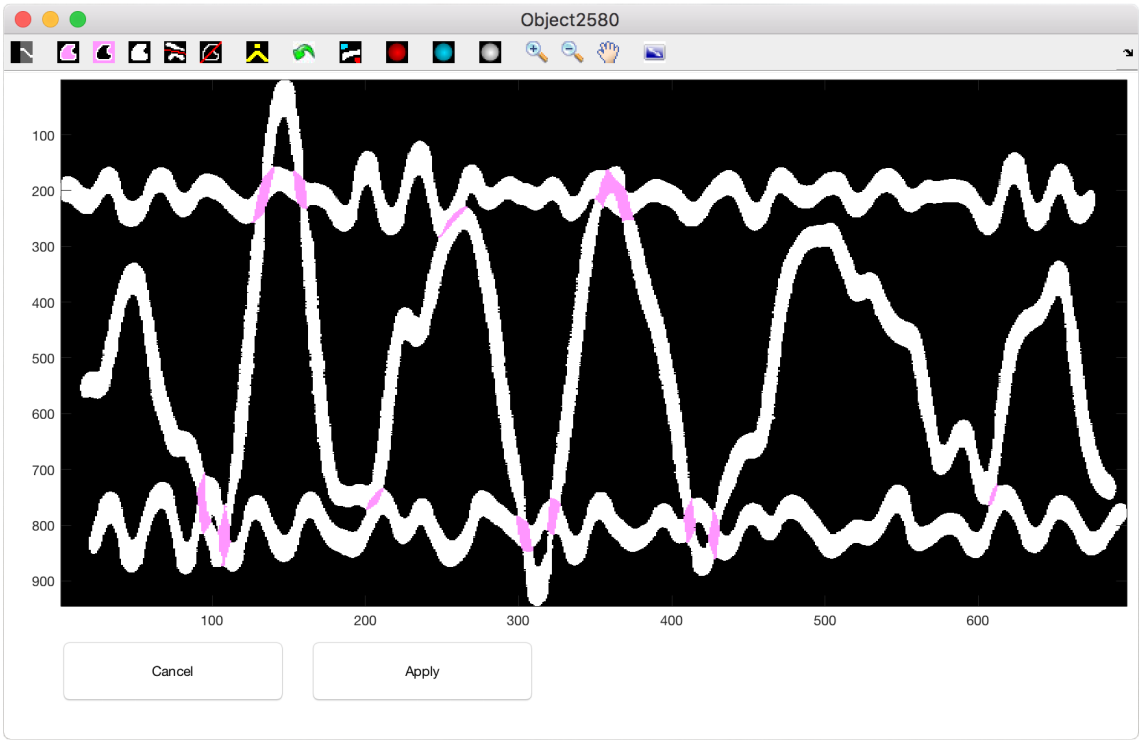

Figure 4-12: Overlap Analysis window, with regions defined as overlapping.

If a seismogram has two traces very close to one another, such that they've been classified as the same object but do not actually overlap significantly, the Overlap Analysis tool can be used to neatly separate them. Define an overlapping region to the edge of one trace in the region the traces are attached, then only assign the "overlap" to the one trace. This separates the traces without requiring removal of pixels.

Note that regions defined as overlapping *must* be combined into another object before applying the Overlap Analysis window. If they are created, but not combined, the regions defined as overlapping are considered masked regions in the image as a whole, and thus appear as gaps.

If a seismogram has traces that are very thin and overlap many other traces, rather than sorting through all possible overlapping regions, simply use the Small Region Analysis tool to remove the thin traces from around the others. These types of traces are often simpler and easier to contend with manually in the digitization step[7], so even though simply removing them seems counter-intuitive, it is much more time-effective to manually include them later.

[7] Thin traces are particularly difficult because thin lines as objects are often not thick enough or bright enough to be properly detected in either the classification or the digitization processes.

Digitizing and Correcting Traces

After all the objects in an image have been classified, the traces can be digitized. Closing the classification window reopens the main DigitSeis window, where the **Digitize** button in the left sidebar can be selected, thus beginning the process to automatically digitize the traces. This process takes some time, but once it has completed, the digitized traces appear in the main DigitSeis window as in Figure 5-1.

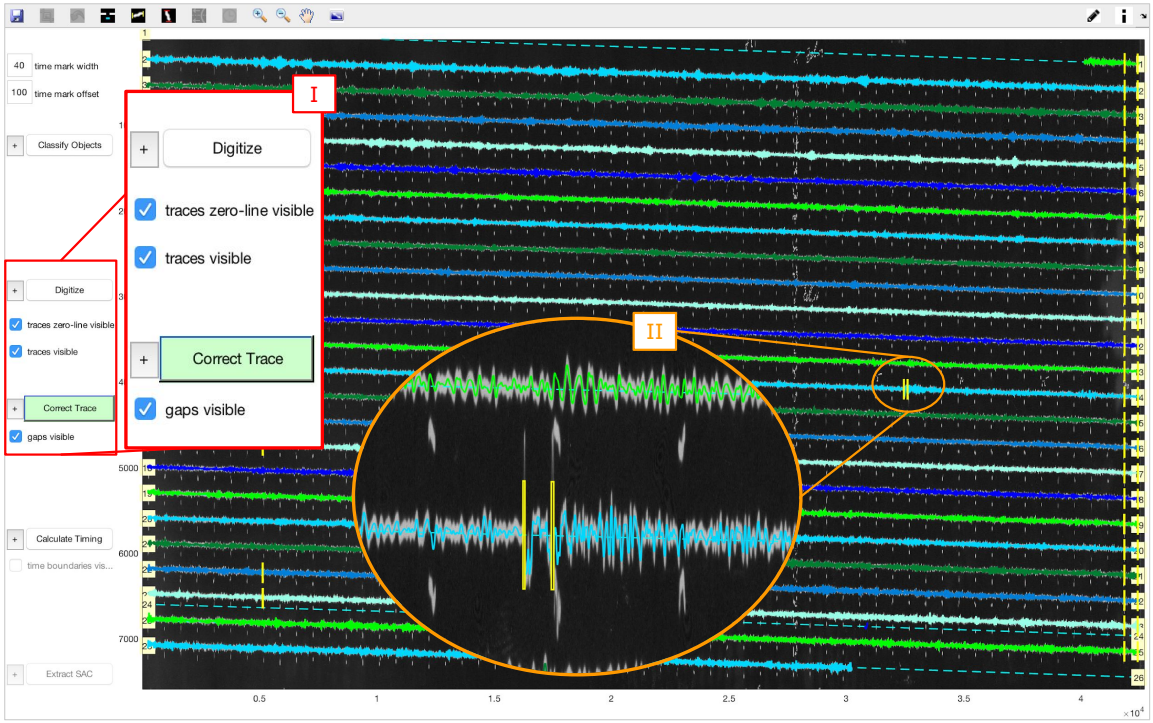

Figure 5-1: Main DigitSeis window after automated digitization. At left (I), the sidebar contains options for displaying zero-lines, traces, and gaps, and for correcting traces. A zoomed in view of the digitized traces (II) displays correctable gaps, indicated in yellow.

Beneath the **Digitize** button in the left side bar, there are two checkboxes that can be used to toggle digitized traces and zero lines on and off. The digitized traces are coloured and follow the traces in the image. The zero lines are dotted lines through

the traces and are numbered top-to-bottom by default. The number of zero lines should match with the number of traces in the image — this can be checked using features in the digitization plus menu, accessible to the left of the **Digitize** button.

In general, large issues with the digitized traces (missing or extra zero lines, misattributed objects) are corrected using the digitization plus menu. Smaller, trace-specific issues (gaps, specific issues with the digitization of a trace, digitization of overlapping traces removed in the classification phase) are corrected using **Correct Trace** in the left sidebar.

> If there appear to be a lot of problems with the digitized traces, consider going back to fix objects in the classification stage. The more accurate the classification is, the more smoothly digitization goes.

5.1 Settings for Digitization

Unlike the settings for classification, most of the settings for digitization can and should be used *after* the traces have been automatically digitized. The settings in the plus menu for digitization (Figure 5-2) are generally helpful for ensuring traces are correct and in order.

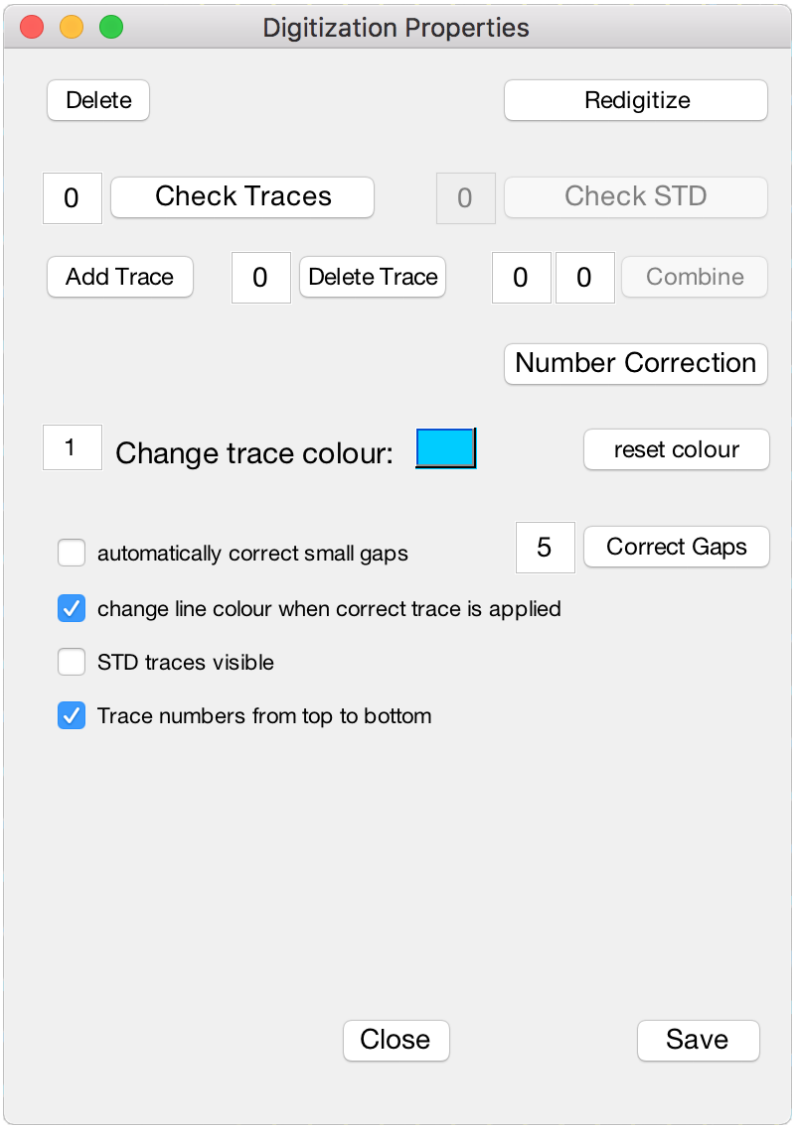

Figure 5-2: Plus menu for digitization settings.

- **Delete digitized traces.** The **Delete** button in the top left of the window deletes all the digitized traces and zero lines. If the digitization isn't satisfac-

tory and something need be changed in the classification window, this can be used to remove the undesireable digitized traces without redigitizing right away.

- **Redigitize traces.** The **Redigitize** button in the top right of the window, like the **Delete** button, deletes all the digitized traces and zero lines. However, unlike the **Delete** function, it also immediately digitizes the traces in the image again. This is useful as essentially a reset on the digitization step.

- **Check traces and standard deviation.** Each trace can be inspected individually by pressing **Check Traces** or **Check STD**, or by inputting the number of the trace in the fields to the left of those buttons. These features can only be used when digitized traces or STD (standard deviation) traces are visible — digitized traces are toggled on and off in the left sidebar, and STD traces are toggled on and off below in the plus menu.

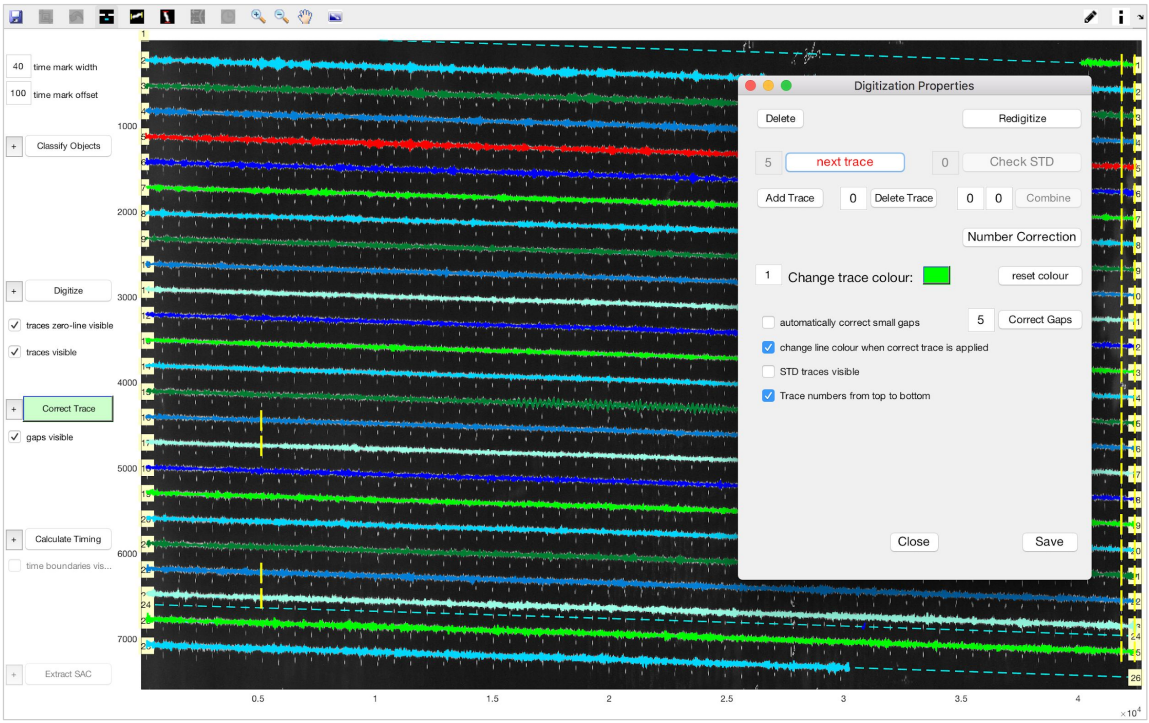

Figure 5-3: Main DigitSeis window and digitization plus menu with a trace highlighted for checking.

Inputting a trace number highlights that specific trace in red in the image. Pressing the buttons allows for every trace in the image to be accounted for; after a button is pressed once, it transforms into a **next trace** button and, when pressed, cycles through and highlights each trace one at a time (Figure 5-3).

> As soon as the traces have been digitized, check through each trace using the **Check Trace** button, to make sure that the correct number of traces have been digitized.

- **Add Trace.** If a trace is missing a digitized trace entirely, to add a trace, click the **Add Trace** button. This introduces crosshairs that can be used to create a large red point at which a new zero line is to be created. To finish this process, right click with the red point in the desired position, and a new zero line through that point is aligned with the others in the image.

- **Delete Trace.** If there is an extra trace[1], it can be deleted using the **Delete Trace** button. Enter the extra trace's number in the field to the left of the button and then click the button to delete.

- **Combine Traces.** If a trace has been broken up into two digitized traces, this tool can be used to merge them into one. Enter the numbers of the two traces to combine in the fields to the left of the button, then press **Combine Traces** to merge their data.

- **Number Correction.** See Trace Number Correction below.

- **Trace Colour.** The colours of individual traces can be customized using **Change trace colour** — by selecting a trace, entering its number, and clicking the colour displayed to edit it. Colours can also be reset to default by clicking **reset colour**.

- **Automatically correct gaps.** DigitSeis can fix small gaps in traces by interpolating over a fairly small distance. As long as it's a small enough gap, this type of fix can be sufficiently accurate. To automatically correct gaps before digitizing the traces, check the box next to **automatically correct small gaps**, and then when the traces are digitized, small gaps are corrected automatically.

  To automatically correct gaps once the traces have been digitized, choose a horizontal extent for gap size[2] (in pixels[3]) and click **Correct Gaps**. If some gaps are to be excluded (for manual correction), select **Yes** when asked to deselect

[1] This is fairly common, and is easily identifiable by a zero line that doesn't appear to line up with a digitized trace.
[2] Any size larger than half of the time mark width originally indicated is prohibited.
[3] Most measurements in DigitSeis, unless otherwise specified, refer to pixels.

gaps, and then deselect the gaps that are not to be corrected. The deselected gaps are displayed in grey, and selected gaps in white. Click and drag to create boxes to select or deselect gaps, then click **Finish** to correct eligible gaps. Otherwise, select **No** and all eligible gaps are corrected.

> It tends to be easy to manually correct a small number of gaps, so unless the number of small gaps to be corrected is very large, using **Correct Gaps** to wholesale correct gaps is often unnecessary.

- **Line Colour after Correct Trace.** By default, after **Correct Trace** has been applied to a digitized trace, that trace changes colour to show that it has been modified. This effect can be toggled on or off using this checkbox in the plus menu.

- **Standard deviation traces.** To see the standard deviation traces[4], check this box.

- **Trace directionality.** If the traces are going from bottom to top (but are still left to right), check this box. If traces have already been digitized, changing this setting causes redigitization.

[4] Digitized traces are calculated by averaging vertical position per horizontal position for each pixel classified in the trace. Standard deviation traces display the extent of the object in one direction.

5.2 Trace Number Correction

Clicking **Number Correction** opens a new window where individual objects can be assigned to different traces, as shown in Figure 5-4. This window may take some time to load, and automatically closes the main DigitSeis window.

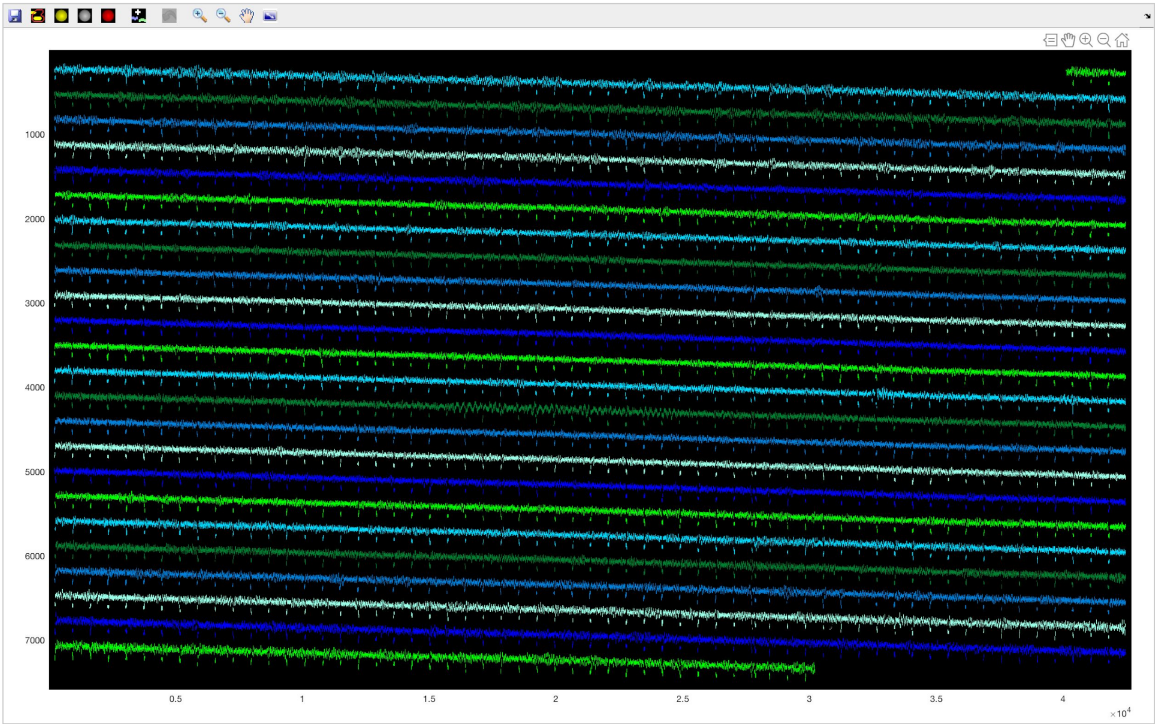

Figure 5-4: Trace number correction window.

This window introduces some new features (Figure 5-5); the base controls for these features are similar to that in previous windows, however, the specific usages are quite different.

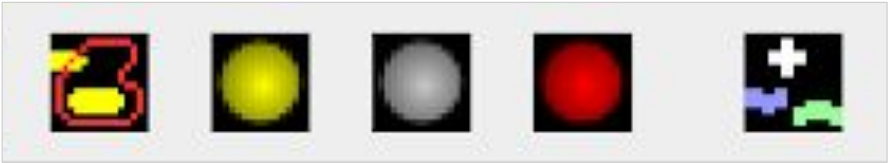

Figure 5-5: Icons for special tools in the trace number correction window. From left to right: Select Objects in Region, Renumbering Selection, Renumbering Deselection, Classify as Noise, and Combine Lines.

 **Select Objects in Region.** This tool functions similarly to other region-

drawing tools. However, it does not cut off at the borders of the region drawn; only complete objects can be selected. Any object that is in any part within the region drawn is selected by this tool. The selected objects are indicated in yellow.

Renumbering Selection. Clicking this icon introduces a crosshairs that allows for selection of individual objects to be reassigned. Selected objects are recoloured in yellow. To end selection, right-click anywhere in the image.

Renumbering Deselection. Clicking this icon introduces a crosshairs that allows for selection of objects that are not assigned a trace. Selected objects are recoloured in grey. To end selection, right-click anywhere in the image. In general, objects that are not assigned a trace function as noise.

> This tool is usually used to un-indicate areas accidentally selected in yellow. All objects in yellow are treated as a single object by the combination tool, so re-classifying accidentally selected traces with the remove trace assignment tool prevents unwanted objects from being combined. However, it is important to note that leaving an object in grey also leaves it without a trace assignment, so any objects in grey should be eventually recombined with the proper trace.

Classify as Noise. See Classify Objects.

Combine Lines. This tool works similarly to the Combine Objects tool in the classification step. However, where the Combine Objects tool selects single objects, this tool instead selects defined groups of objects. Clicking the icon introduces a crosshairs that can be used to select groups of objects to combine into a single trace.

The group of all yellow objects and also objects of the same colour in one line (existing numbered traces) are considered single groups. Grey objects whose trace assignment has been removed and noise objects cannot be combined with any others. The groups to be combined are all highlighted with an off-white colour, and right-clicking finishes the reclassification.

Once the desired changes to trace assignment have been made, simply close the Trace Number Correction window. The main DigitSeis window may take some time to reload, but reflects the changes made to trace numbers in the Trace Number Correction window.

5.3 Settings for Correcting Traces

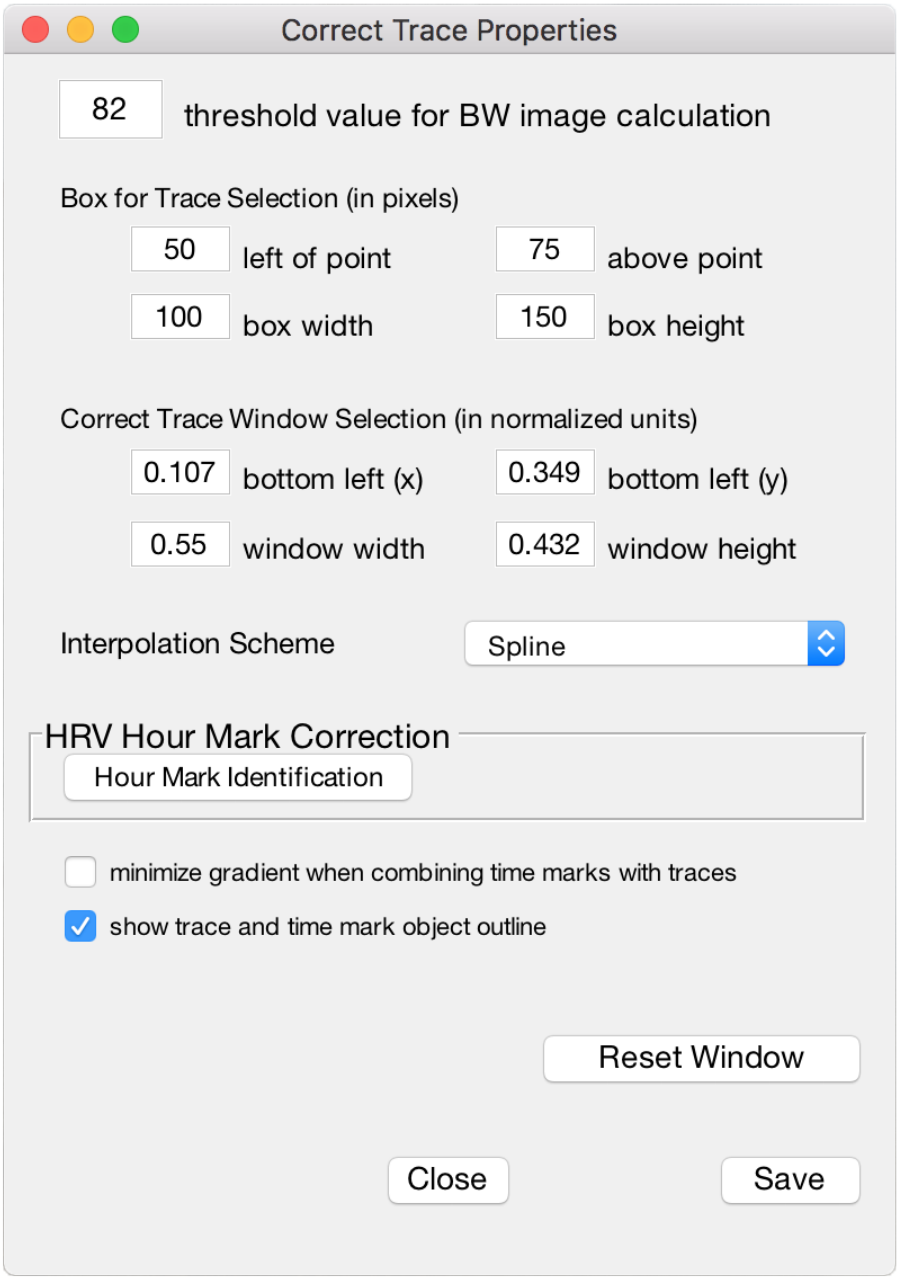

Figure 5-6: Plus menu for trace correction settings.

After issues involving mutliple traces and the image as a whole are resolved, the Correct Trace tool can be used to resolve gaps and single trace-specific issues. Gaps in the digitized traces are made visible with yellow boxes if the **gaps visible** checkbox

beneath **Correct Trace** is checked. For the most complete possible results, the number of gaps should be minimized by correcting those gaps where possible. There are a few settings relevant specifically to the trace-correcting stage.

- **Image Threshold.** See Image Threshold in classification settings. Setting this threshold value makes it the default for new Correct Trace windows.

- **Box for trace selection properties.** Unlike some similar tools, boxes to select areas for the Correct Trace window are created using crosshairs. Using crosshairs to initiate Correct Trace helps ensure that the correct trace has been selected. If a box is generated in the wrong place initially[5], moving it to another trace causes an error when changes are applied because the changes apply to the trace selected by the crosshairs, not the trace(s) the box encompasses. In the case of large, overlapping traces, a Correct Trace window may need to encompass multiple zero lines and so the base trace must be specified in this way.

  Additionally, there is a default size (and a default position relative to the location selected with the crosshairs) for boxes created by the **Correct Trace** tool. The values specified are for the position of top left corner relative to the point initially selected and for the total size of the box.

  > For an image with many gaps, immediate appropriately sized selections are invaluable. As a rule of thumb, setting the distance above the point to slightly less than the vertical gap between traces and the height of the box to double that (if the gap is 50 pixels, a box with a height of 80px and a top corner 40px above the point) is very reasonable.

- **Correct trace window properties.** Like the Small Region Analysis and Overlap Analysis windows, the Correct Trace window's default size and position can be specified to user preference.

- **Interpolation Scheme.** See Line Generation through Points. When a trace is too thin or dark to be digitized automatically, it is manually digitized using a line defined by user-created control points. The line generated can be set to **Spline** (default), which creates a sort of polynomial regression, or **Linear**, which essentially simply connects the dots.

[5] If a box is generated in the wrong place, it can be deleted by pressing the delete or backspace key. This may result in DigitSeis executing as if the Correct Trace window had been opened, causing it to prevent further action in the main window. In this case, opening and closing the plus menu restores functionality in the main window.

> The linear interpolation scheme is highly unideal in most situations. It's an unrealistic representation of the waves actually present in most traces, and thus should not be used in the great majority of situations.

- **HRV Hour Marks.** DigitSeis was developed by the Harvard Seismology Group, and thus is frequently used for HRV seismograms. The **Hour Mark Identification** button creates correct trace windows around time marks identified as consistent with the scheme most commonly used for HRV analog seismograms and automatically corrects related issues.

> This is not usually necessary; hour marks represented by two close time marks are generally dealt with correctly without intervention. The second time mark is generally disregarded, and, when absolute time is set, hours should be properly identified regardless.

- **Minimize gradient.** When this box is checked, time marks are as closely matched to their associated traces as possible, regardless of indicated offset.

- **Show object outlines.** The Correct Trace window functions very similarly to classification windows. However, since the immediate goal when correcting traces is to create accurate traces, exact shapes of objects when masking become important. When in the original image view, if the **show object outlines** box is checked, the outlines of detected objects are visible (blue for time marks and yellow[6] for traces) so that effects of masking becomes immediately apparent.

- **Reset window.** Closes and reopens main DigitSeis window. This is sometimes necessary to resolve "dead ends" in DigitSeis options[7].

> A common semi-dead end occurs when Correct Trace is aborted before the Correct Trace window can be opened, usually by deleting the selection box before double-clicking. This is normally resolvable without the **Reset window** button, by opening and closing the Correct Trace plus menu.

[6] Traces are normally indicated with white, but because the lines in the original image view are white, the trace outline is yellow for visibility.

[7] DigitSeis is intended to move through steps in a certain order. When that order is deviated from, a sort of "dead end" can occasionally be reached, where options become unavailable because they would not normally follow a given step. See more on intended order in Tips for Using DigitSeis.

5.4 Gaps Requiring Correction

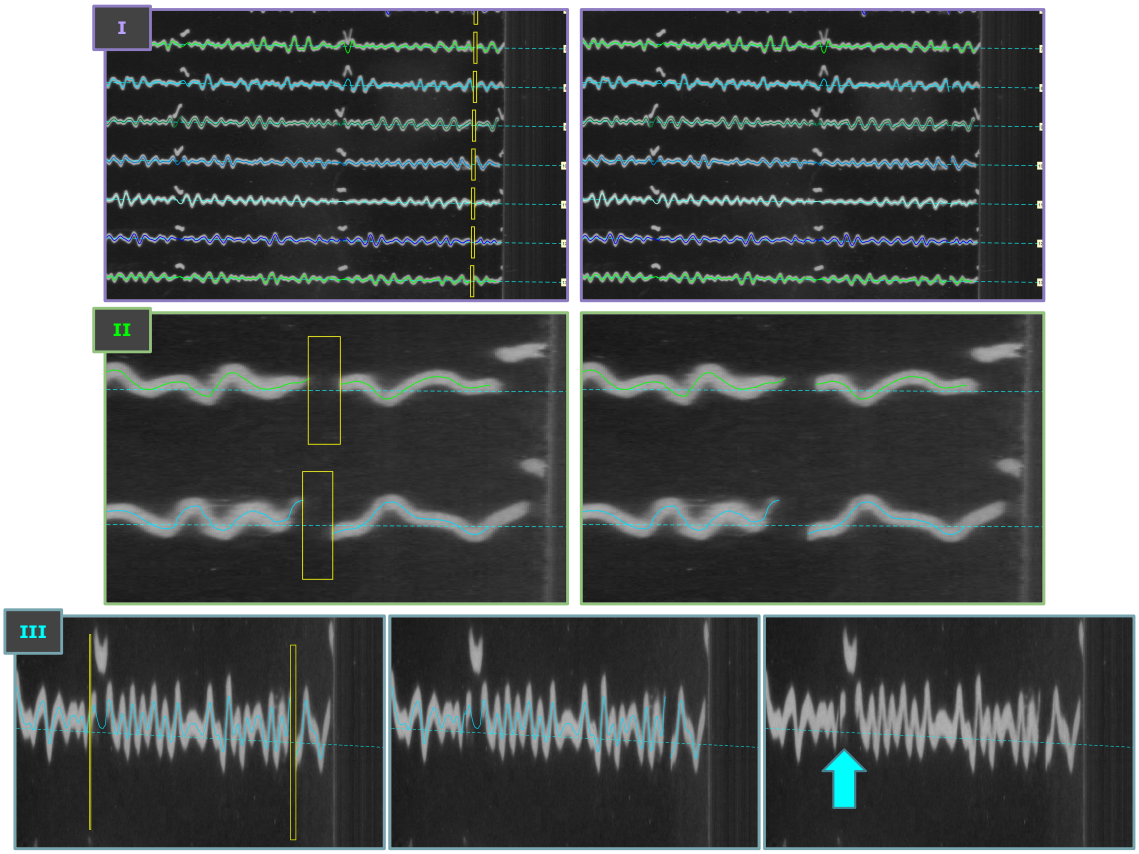

Figure 5-7: Portions of images containing gaps that do not need correction. (I) An example of a vertical line of gaps near the edge of an image, (II) a zoomed in view of missing data due to a gap, and (III) examples of both small and large gaps.

Analog seismograms are rarely pristine — gaps in data caused by damage to the physical record itself, by the scanning process, or by the original instrumentation are all fairly common. It is unnecessary to correct these gaps because the image simply lacks the data to complete them. Gaps of this type are displayed in Figure 5-7. In particular, gaps in the original record are very prevalent near the edges of images; methodical, vertical lines of gaps near the page edge are very common.

To examine whether a gap exists in the original record, it is sometimes necessary to hide the yellow boxes highlighting the gaps by unchecking the **gaps visible** box in the left sidebar. For smaller gaps, as in Figure 5-7, III, even the digitized trace can make it difficult to observe a gap in the original record. However, gaps small enough to be hidden by the digitized traces are often small enough to correct without manufacturing data.

A very small gap can usually be fixed by lowering the binary threshold of the relevant portion of the image. If the ends of the gap are close enough, lowering the binary threshold merges separate objects and closes the gap. If the gap cannot be closed without extreme reduction in the binary threshold, to the detriment of other areas of the trace, it should be left alone.

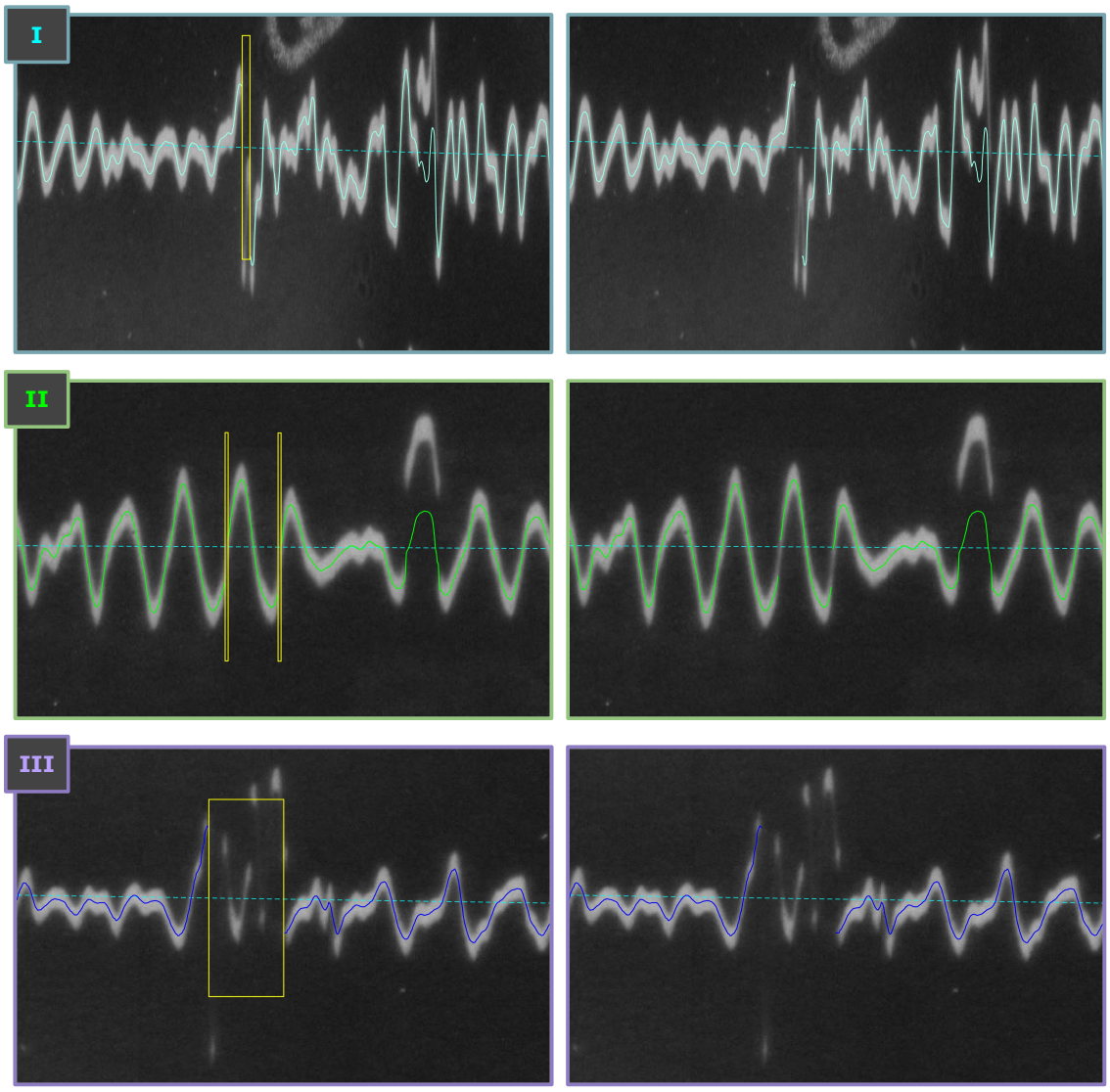

Figure 5-8: Portions of images containing gaps that require correction. (I) An example of a gap caused by part of an object classified as noise, (II) examples of gaps caused by too-thin lines, and (III) an example of a gap caused both by the thin, dark lines and by the misclassification of a time mark.

Gaps are also sometimes created in the digitization process, often due to misclassification in the classification step. Usually, this is due to portions of objects being misclassified as noise (and subsequently masked in the digitization process) or parts of very thin lines being missed entirely because they may be too dark to count towards any object. In some images, correctable gaps are common near time marks. In cases such as those, shown in Figure 5-8, Correct Trace is used to resolve the gaps.

> One way to reduce gaps during digitization is ensuring that objects which have been separated are combined either by using the Combine Objects tool or by changing the binary threshold in a Small Region Analysis window during the classification step.

5.5 Correct Trace Tools

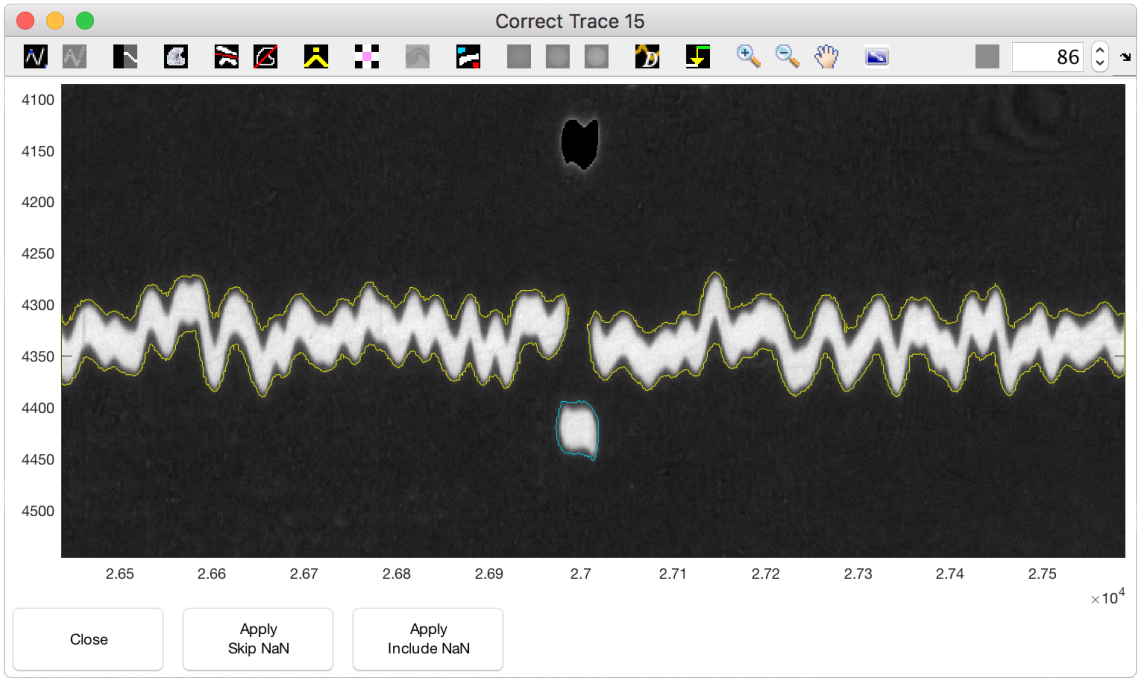

Figure 5-9: Correct trace window.

To begin correcting a trace, click the **Correct Trace** button in the left sidebar. This introduces a crosshairs that can be used to select the trace that needs correcting[8]. Once a point has been selected, a red-outlined adjustable box appears to encompass the area requiring correction. Double-clicking inside the box opens the Correct Trace window, shown in Figure 5-9.

> It is helpful for gaps to be toggled on while correcting the traces, to make it as easy as possible to identify regions that require correction. However, sometimes they must be togged off to more easily see and compare the original image and the digitized traces.

[8] The trace selected is determined by the zero line nearest to the point indicated.

5.5.1 Basic Correct Trace Tools

A video is provided online as a walkthrough for the basics of using the Correct Trace function.

In most cases, the Correct Trace window can be used essentially as a small-portion reclassification window. DigitSeis creates digitized traces by first identifying trace and time mark objects, then finding an appropriate line through each[9], and lastly integrating the trace information from the time marks to the larger body of traces[10]. If objects composing a trace were not classified adequately in the classification step, such as in Figure 5-10, the Correct Trace Window provides a shortcut to fixing classification errors without reopening the Classification window.

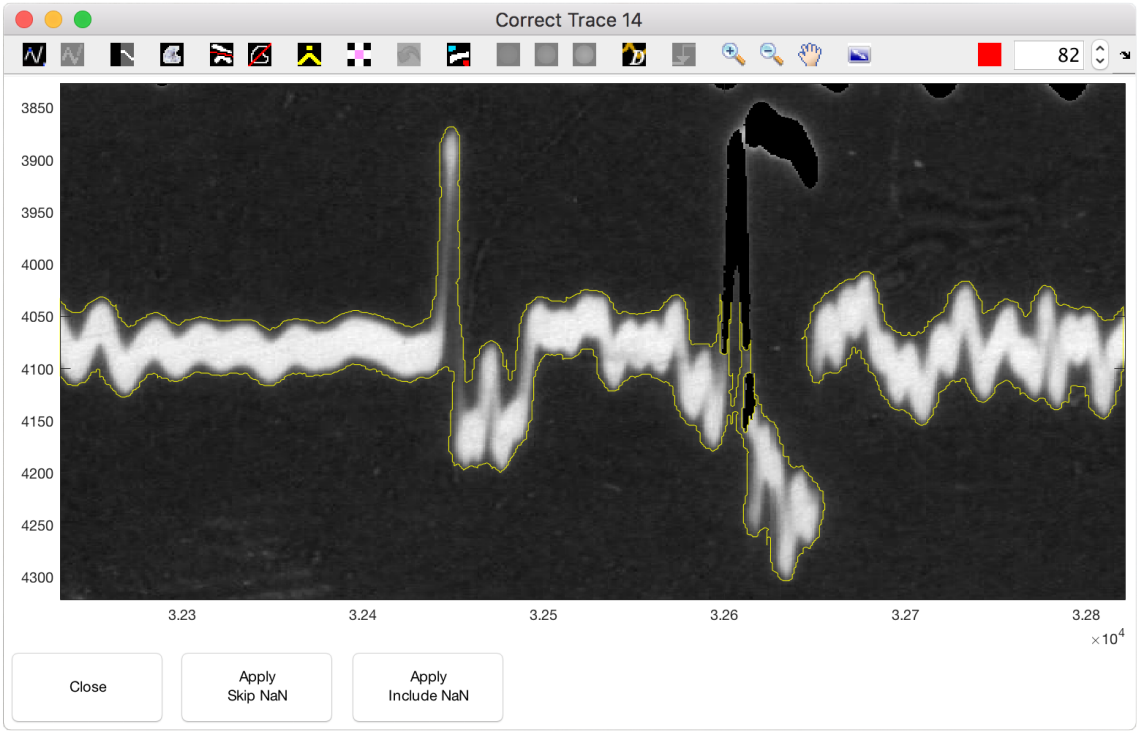

Figure 5-10: Correct trace window displaying a trace that requires correction. The steepness of the line caused part of the trace to be incorrectly masked, and the time mark at bottom must be separated from the trace. The Unmask and Remove Pixels tools available in the Correct Trace window, in combination with some adjustment to the binary threshold, allow for proper classification.

[9] In general, this is done by averaging vertical extent at each point along the horizontal axis.

[10] The most common type of time mark is created when a small part of the trace is offset vertically, so removing that offset creates a smooth overall trace. Gap time marks are simply bridged over.

In some instances, even properly classified objects do not create accurately digitized traces. In such cases, the Correct Trace window allows the user to make changes to classification and then immediately view the redigitized trace. Then, even if many small adjustments need be made to allow for accurate automatic digitization[11], those adjustments can be made and viewed without necessitating complete redigitization[12].

> The Show Object Outlines feature displays loose classification atop the original image. This is helpful for instances where a gap has occurred despite accurate classification in a non-complex region (Figure 5-9), or when only simple changes need be made. However, the Show Classification tool is often necessary to use in more complicated situations as in Figure 5-10.

Excluding line-generation tools, nearly all of the tools available in the Correct Trace window are introduced earlier in the digitization process, in the various windows within the classification step. There are, however, two unique tools to basic trace correction (Figure 5-11).

Figure 5-11: Icons for special tools in the Correct trace window. At left, Digitize trace. At right, Manually set vertical offset.

Digitize Trace. After using the other tools to resolve issues with the trace, the **Digitize trace** button is used to create the digitized line for the selection encompassed in the window. This trace appears as a purple line. A digitized trace must be present for the corrected trace to be applied to the image as a whole.

Set Vertical Offset. This icon only becomes available once the trace in the window has been digitized. It allows for manual adjustment of vertical offset of

[11] There are some cases which are too extreme to be automatically digitized. These can be corrected using the line generation through points feature in the Correct Trace Window

[12] Changes made in the Classification window only appear after the image has been redigitized.

time marks in the selection, as displayed in Figure 5-12, to increase the accuracy of time mark integration to the traces. It also allows for gradient minimization, to most effectively merge the digitized time mark and trace.

Once the digitized trace in the **Correct Trace** window is satisfactory, it can be applied to the image as a whole either with or without NaN values[13]. Applying the corrected trace with NaN values[14] causes any gaps in the small window to be applied to the greater image, even if they did not exist prior to "correction[15]". Applying a corrected trace without NaN values allows any existing trace, from either the **Correct Trace** window or the original digitization to take precedence over any gaps.

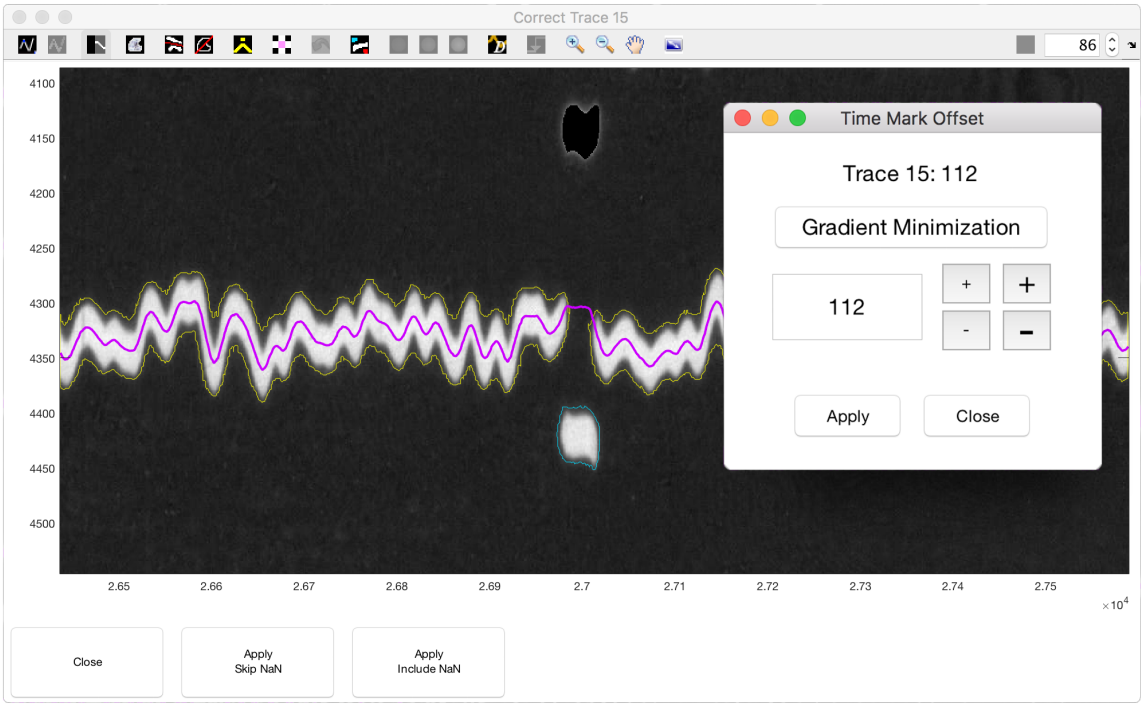

Figure 5-12: Options for manually setting time mark offset in Correct trace window.

Application without NaN values is generally the more conservative option, because it ensures that, if a region ever had an associated digitized trace, it does not become a gap. Application including NaN values is a good way to force-create gaps if manual digitization is intended, or to ensure the trace created in correct trace lacks gaps.

[13] The window can also be simply closed to avoid making any changes.
[14] NaN values are parts of the image that don't have any associated digitized trace.
[15] Applying a Correct Trace window without digitizing any trace creates a gap in the area selected.

5.5.2 Line Generation through Points

> A video is provided online as a walkthrough for use of the point-to-point interpolation function within the Correct Trace window.

Some traces are too thin or too dark to be properly digitized automatically. Instead, they must be digitized manually through point-to-point interpolation (Figure 5-13). In particular, traces with very large amplitudes that overlap other traces generally cannot be digitized automatically. Thus, the manual line generation tool is critical for digitizing some of the most sought-after data on major seismic events.

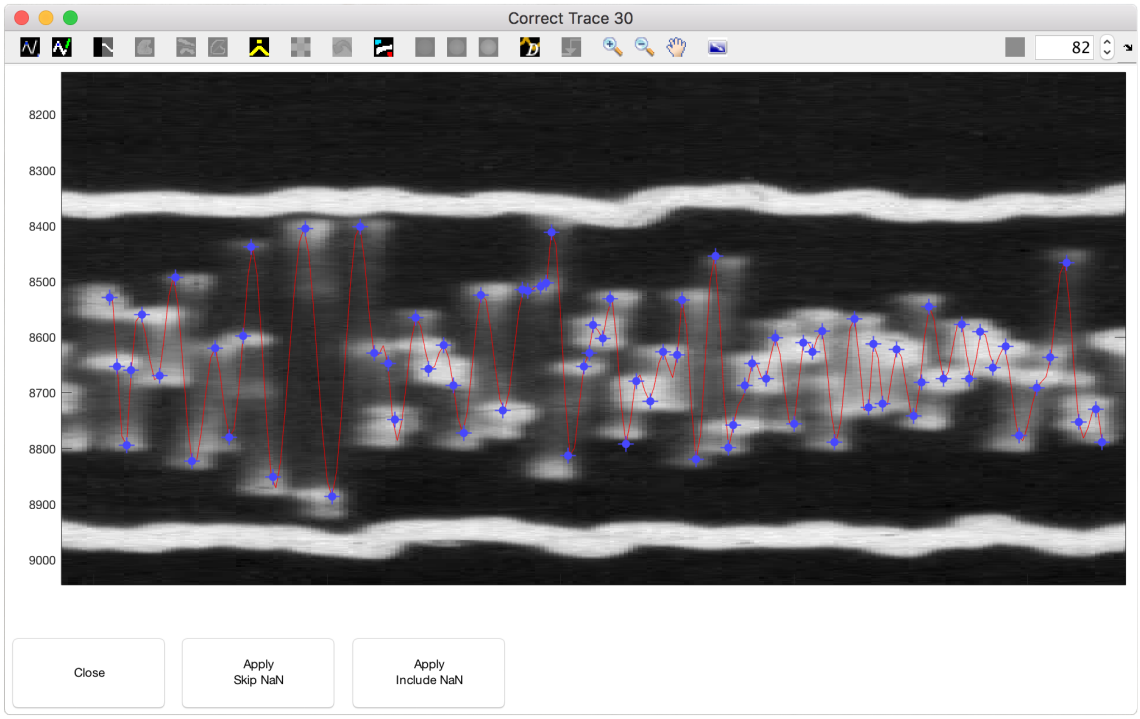

Figure 5-13: Correct trace window for line generation through points, in an extreme case. The digitized trace could not possibly be otherwise generated for this trace.

> Use the original image view rather than the masked view when manually creating a digitized trace. It is easier to match the trace as exactly as possible from this view, because parts of the large-amplitude traces that are frequently hidden by overlap are most apparent in the original image view.

Clicking the first icon in the toolbar, the point-creation tool, introduces a crosshairs that can be used to lay points to generate a single object. Right-clicking indicates

the object is complete, and generates a line. To correct the generated line, points can be dragged to adjust positioning, deleted altogether by right-clicking and selecting **Delete**, or added by selecting the icon again and clicking to create points anywhere within the horizontal extent defined by the two end points of the object.

> If an object is accidentally finished early, simply move a point to the intended endpoint, then add points as needed between the endpoints. The regression line updates point-by-point, so this strategy can also be used to observe immediate effect of an added point. As long as endpoints have been defined, points can be added to an existing object.

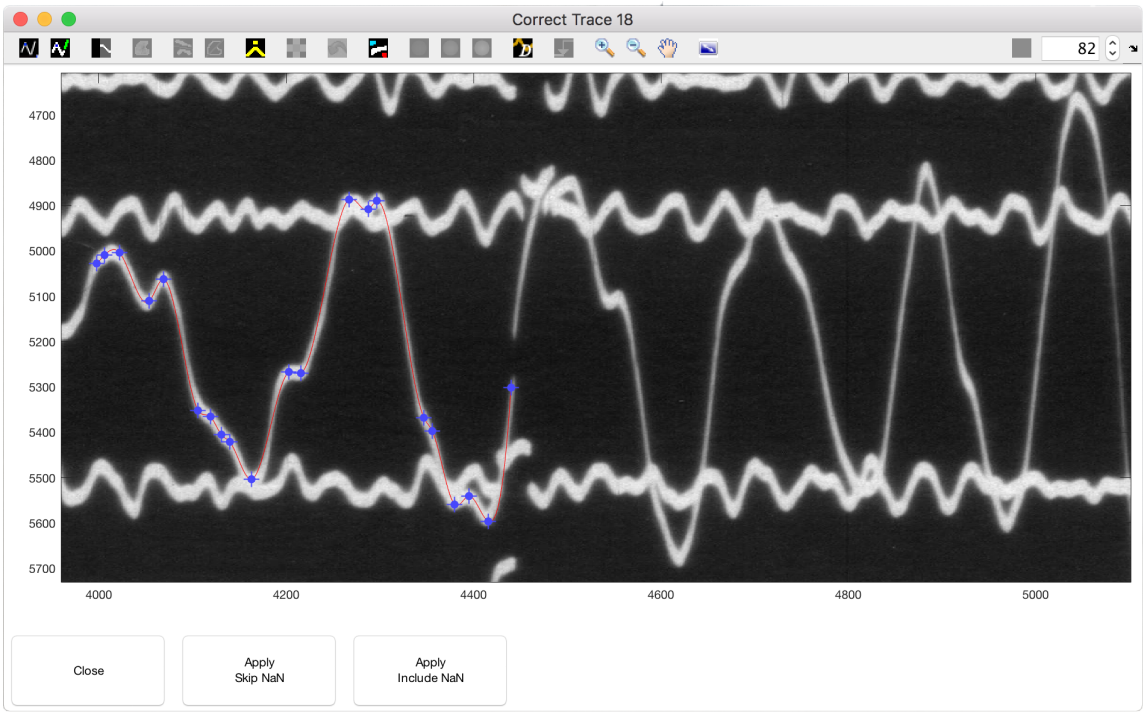

Figure 5-14: Correct trace window for line generation through points. A line has been generated for one object out of three in the displayed image.

When using spline interpolation, the line generated essentially maxes out at a quintic regression for each subset of five consecutive points in an image. This means that adjusting a point impacts (at most) the line spanning two to three points to its right and left. Further, due to the nature of spline interpolation, points very close together or which imply extreme vertical change tend to create very extreme curves, which occasionally can only be remedied by moving a line slightly off the trace in the image. This type of error is inevitable.

The regression scheme works best when points are alternated up and down, as sort-of indicators of crude troughs and crests. With this in mind, if a peak in the image is asymmetrical, using two very close points instead of a single point is much more effective in guiding the asymmetry. If only one point is used, it throws the up-down nature of the line out of period, whereas two points instead act as a quick up-down intermission to the larger up-down pattern.

To create a new object (as necessary in Figure 5-14), select the point-creation icon and click the crosshairs anywhere outside the horizontal extent of currently existing objects. Any points added in a single point-creation "session" that do not overlap any other objects are grouped together to create one object. Note that for proper classification, each time mark and trace must be created as a separate object.

To create overlapping objects, as is sometimes necessary to ensure time marks integrate properly, add a "dummy" endpoint that does not overlap any other objects, and, once the object is complete, move it to its overlapping position. The objects remain separate but are now overlapping.

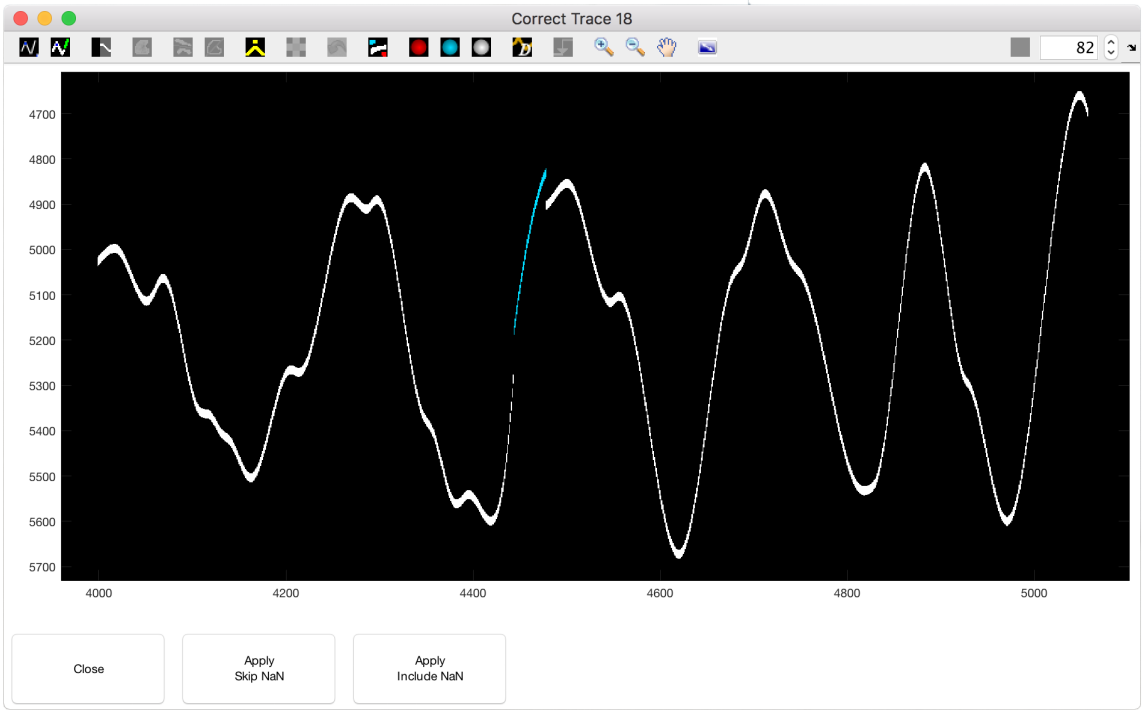

Figure 5-15: Correct trace window for line generation through points, after the objects have been classified.

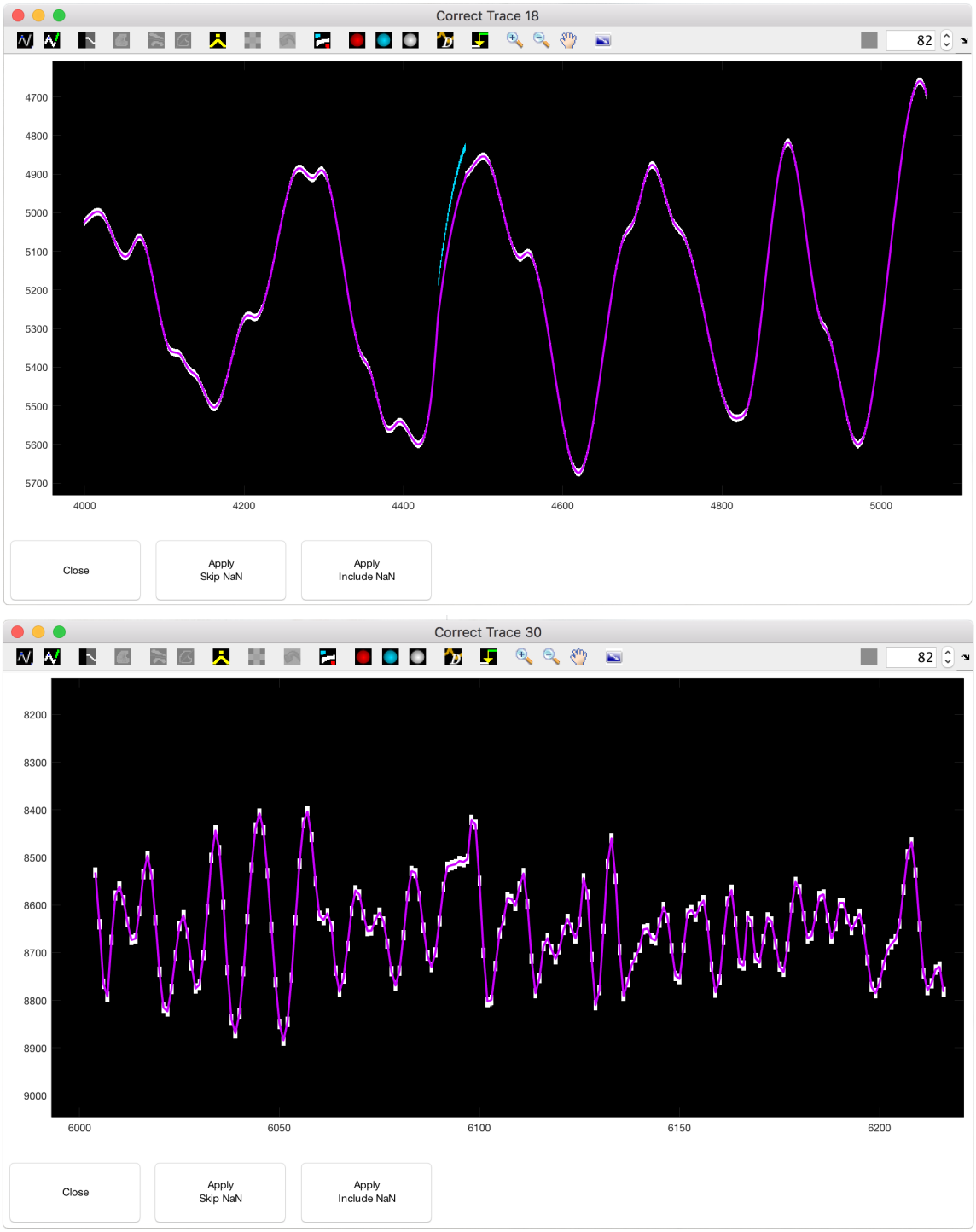

Figure 5-16: Correct trace window for line generation through points, after the digitized trace has been generated. At top, a simple case, and at bottom, a more extreme case are shown.

Once all desired objects have been created and optimally adjusted, the Classify Point Objects icon, to classify the created objects, can be clicked. This process takes a moment, and results in dashed lines that are classified as either traces or time marks, as in Figure 5-15. The created objects can be reclassified using the object classification tools if necessary. When all objects are as desired, the Digitize Trace icon can be selected to create the digitized trace.

> Increasing overlap and decreasing offset between time marks and traces usually helps to resolve gaps caused by insufficient integration. It is sometimes inevitable that an endpoint need be extended beyond the visible end of an object in the original image in order to bring the edges of the two objects close enough to integrate.

Then, as with basic trace correction, the final digitized trace (as in Figure 5-16) can be applied to the image as a whole by choosing one of the application methods. This process is extremely time-intensive, so saving extremely frequently between digitization of small sections at a time is highly recommended.

> When using the manual line generation tool, the digitization traces should nearly always be applied using **Skip NaN**, because objects generated manually usually do not extend all the way to the ends of the window, and so create gaps at the edges of the selection if applied including NaN.

Timing

After all traces in the image have been digitized as accurately as possible, timing can begin. This step associates each point in the digitized traces with an absolute point in time, ultimately allowing for observation of seismic waves over time. It is the final step in the digitization process itself. At this point, the main DigitSeis window appears as in Figure 6-1.

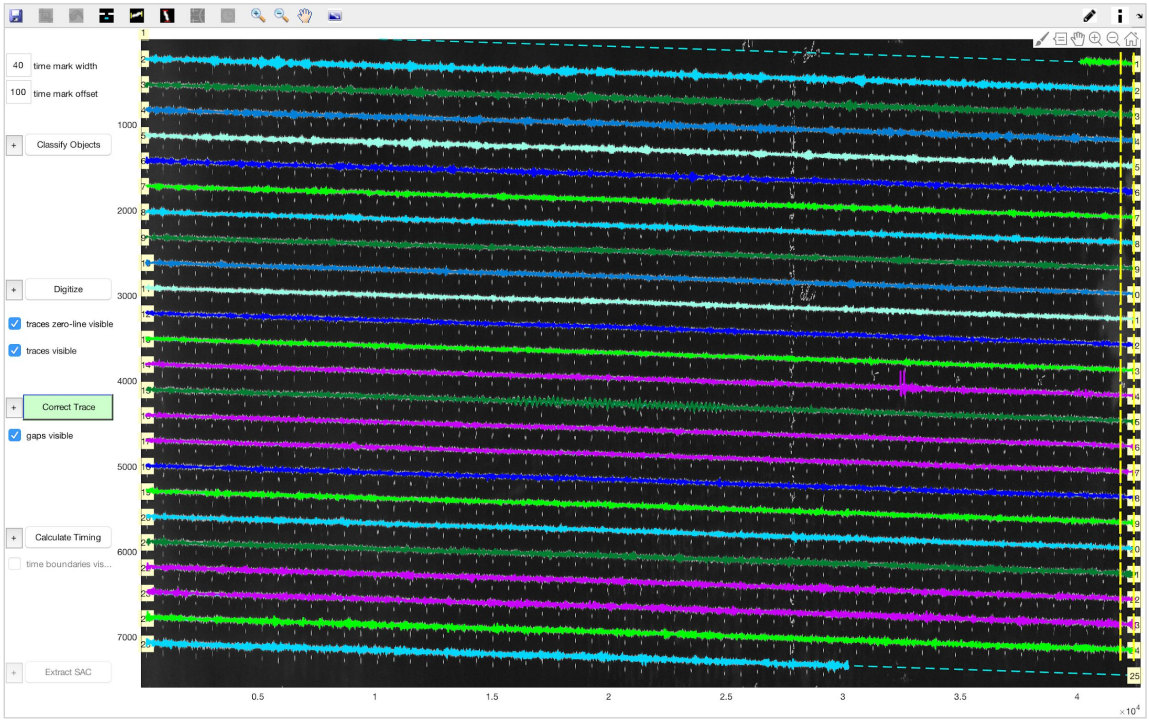

Figure 6-1: Main DigitSeis window with digitization complete, but prior to timing.

6.1 Settings for Timing

Settings for timing (Figure 6-2) are applicable both before and after time bars[1] have been calculated. The timing process is relatively quick, however, so recalculation of timing can be done and redone fairly painlessly as needed.

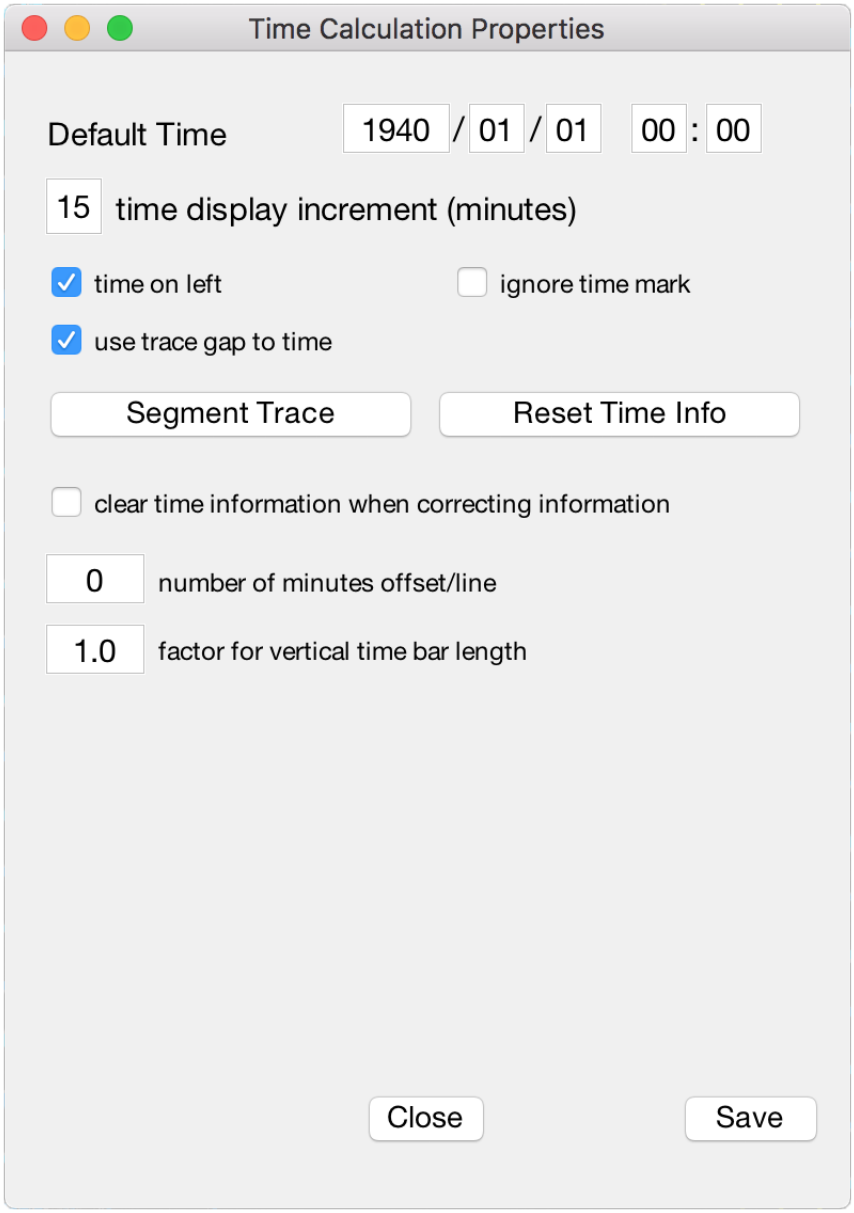

Figure 6-2: Plus menu for timing settings.

[1] Time bars are the vertical bars near time marks that mark either minute intervals or the ends of traces.

- **Default time.** The default time, in YYYY/MM/DD HH:MM form, is automatically suggested when setting time for a time bar in the image.

  > If digitization is done thoroughly, absolute time should only need be applied once[2], so default time rarely need be changed. Modifying default time is helpful in the case where many time recalculations are anticipated.

- **Time display increment.** Time display increment is the interval, in minutes, that absolute time is displayed after it has been applied. This is useful to check that times line up — in general, 15-minute time marks should align vertically, and any offsets are likely due to missing or extra timebars.

- **Time on left.** Time bars are normally set to the rightmost end of time marks, but checking this box instead sets them to the left. This setting is useful for extra long time marks used to indicate hours — if the time marks' edges align to the left, time bars should also be aligned left.

- **Use trace gap to time.** For gap traces, this option should be selected.

- **Ignore time mark.** If selected, this option causes time marks to be ignored when timing. It becomes unavailable if time marks are not present in the image.

- **Segment Trace.** The segment trace option allows for the total group of traces in a single image to be broken into segments. Once the **Segment Trace** button is selected, the main window transforms to display only gaps, marked by two pink lines at their endpoints. Right-clicking a gap reveals the option to set that gap as an end time: the first pink bar serves as the end for the series prior to the gap, and the second serves as the beginning for the series following the gap.

  If the traces in an image are segmented, an instance of absolute time must be set for each segment to calculate absolute time for the whole image. As long as at least one time bar has an absolute time manually specified in each segment, the timing can be calculated.

  > Though a single analysis with multiple records could be handled without **Segment Trace**, it is the most effective way to divide and time two records accurately.

[2] For a standard, full, single seismogram.

- **Reset Time Info.** This button clears all time information currently present in the analysis.

- **Clear time info after editing.** If this box is checked, time information is cleared automatically whenever other aspects of the analysis are edited[3].

- **Minutes offset per line.** For the majority of seismograms, each minute from the start of the traces to the end is represented by a time mark present in the image. However, there are instances[4] where the end of each line is not continuous with the beginning of the next, and a uniform number of time marks have been lost in between. That number of lost time marks can be input as the minutes offset per line, after which the specified offset is applied to every line.

- **Time bar length.** This setting controls the vertical height of the time bars in the image. Longer or shorter time bars can be set for ease of personal accessibility.

[3] Through reclassification, redigitization, or additonal trace correcting.

[4] For example, if an image has been split in half such that part of each trace is missing and the end of one line is not continuous with the beginnning of the next, the time marks in the other half of the image are not accounted for in either image alone.

6.2 Setting Absolute Time

A video is provided online as a walkthrough for setting timing on an image.

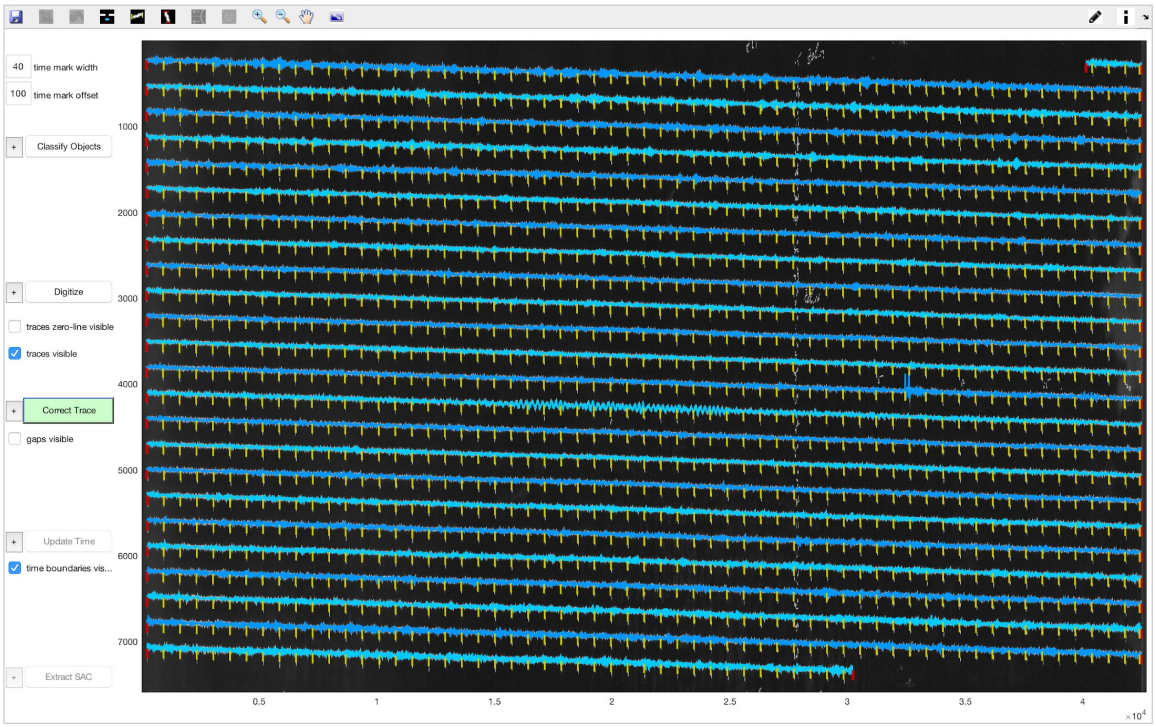

Figure 6-3: Main DigitSeis window after calculating time.

To calculate timing, click the **Calculate Timing** button in the left sidebar. This assigns time bars to the classified time marks. Yellow time bars indicate minute intervals within traces, and red time bars indicate the ends of traces, as in Figure 6-3.

The space between each pair of consecutive time bars in an image is one minute of time. This is relative time. To set absolute time, right click a time bar with known time, and select **Set Time**.

On most seismograms, hours have been manually labeled, making it simple to determine absolute time for an hour mark[5]. Enter that time in the window that appears (Figure 6-4), and select **OK**. After setting at least one absolute time per segment[6],

[5] Year and day are usually indicated in the file name or in other information for the image, though day is also frequently handwritten on analog seismograms.

[6] Most images have only one segment. An image only has more than one segment if the Segment Trace feature was used.

the **Calculate Time** button in the left sidebar updates to an **Update Time** button, which, when clicked, applies the absolute time to the image as a whole.

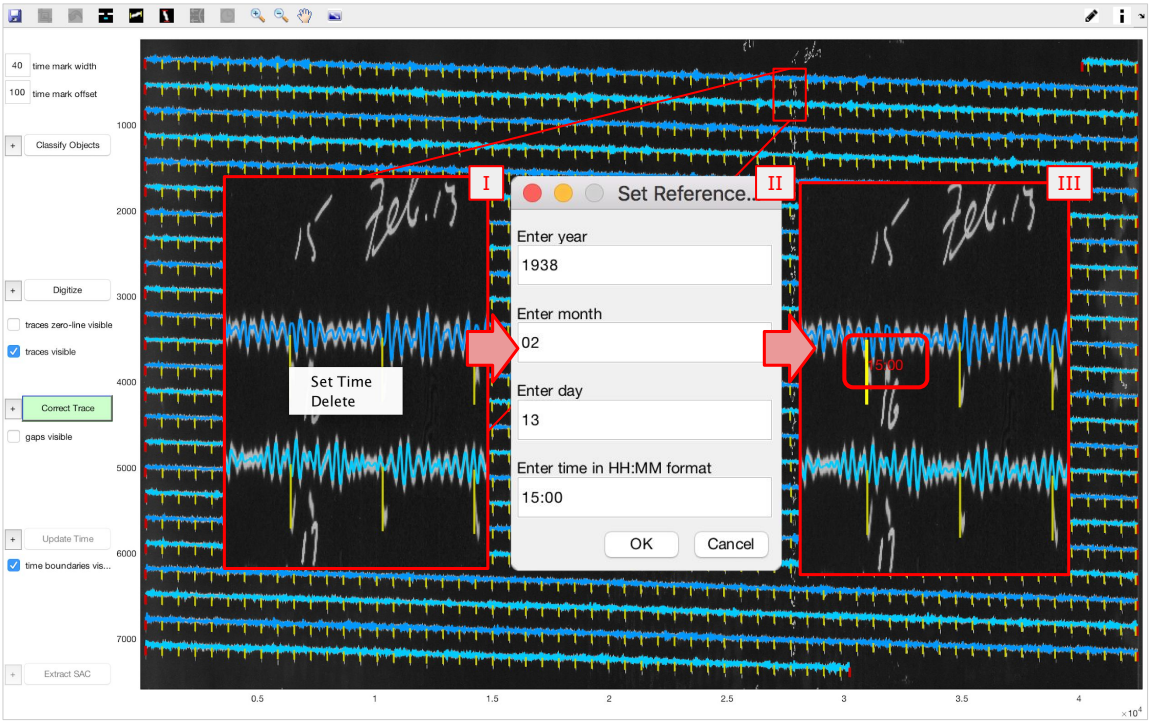

Figure 6-4: Main DigitSeis window while setting time. Zoomed views shown in center are (I) the right-click options for a timebar, (II) the window for setting absolute time of selected time bar, and (III) the set absolute time appearing in red once set.

> As in the figure above, it is usually easiest to set absolute time directly at an hour time mark. For the average seismogram, this normally only need be done at one point — in the example, it was done for the topmost hour time mark.

6.3 Correcting Time

Usually, markers at 15-minute intervals on a correctly timed seismogram line up vertically, as in Figure 6-5. However, if there is an error in timing, they may instead appear offset. A single offset, where the "column" of 15-minute markers appears broken or partially shifted over, is generally caused by a single missing or extra time bar in the trace where the "break" appears. Because time marks line up vertically, find the missing or extra time mark by comparing the trace with the break to others. If there's an extra, right-click and delete it[7]. Then, recalculate the timing.

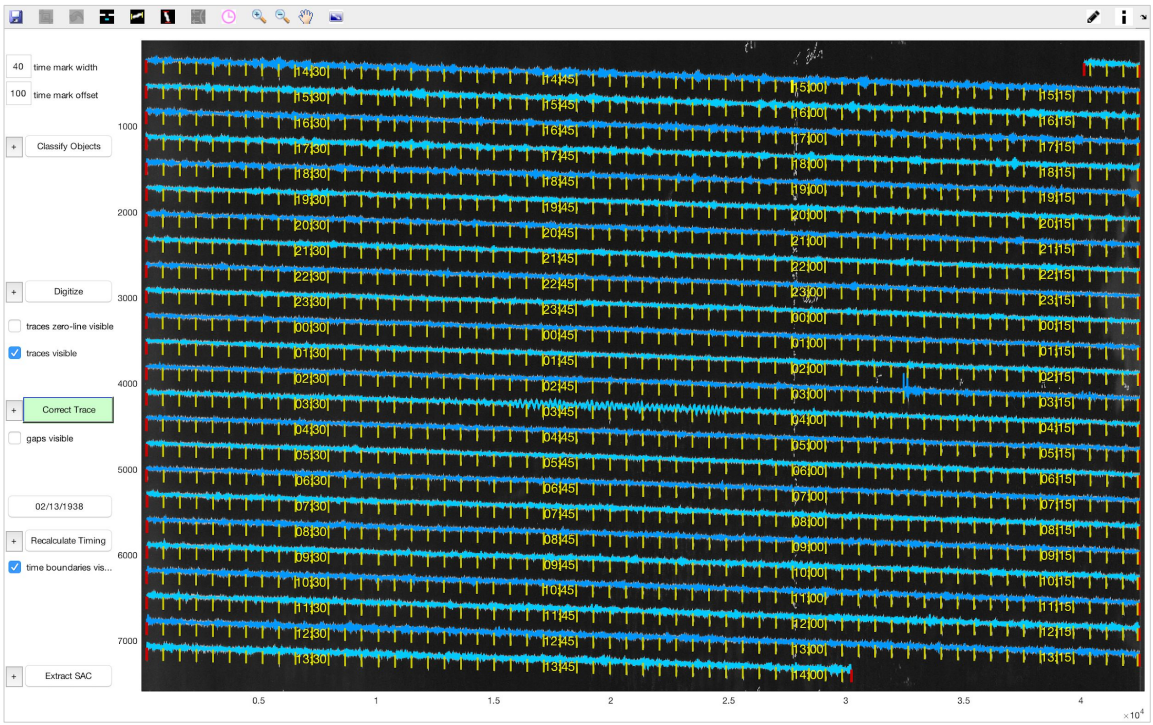

Figure 6-5: Main DigitSeis window after time has been set. Time markers at 15-minute intervals line up.

Sometimes, small portions of traces may not contain labeled time marks. For this reason, the Check Time Point tool becomes available in the main toolbar once time has been calculated, and can be used to ensure time is accurate in all portions of the image. Selecting the Check Time Point icon[8] introduces a pink crosshairs, which

[7] This is a common issue for analog seismograms — the method of recording sometimes causes wraparound, where the data on the end of one trace is repeated at the beginning of the next. Depending on how many of the time marks were "wrapped around", it might be necessary to delete an entire column of time marks on one edge of the image.

[8] The Check Time Point icon is a pink clock. See Appendix B: Tools for an image of the icon.

then can be used to select a specific point. Then, that point is labeled with its time, allowing the user to confirm accuracy of timing.

If a time mark or segment of trace is missing, manually set another point of absolute time on the trace with the missing time mark. DigitSeis generally evaluates timing trace by trace and top to bottom, so another absolute time point on a trace applies to that trace and others below it which don't have manually set absolute time bars.

> Each trace is checked first for any manually set time bar. If it has one, the trace is timed with respect to that time bar. If not, it is timed with respect to another trace that does have a manually set time bar. For this reason, at last resort, a very problematic analysis with regards to timing could be resolved with a manually set absolute time bar on every trace.

If, rather than single offsets at various traces, the column of time markers is not a column but is regularly offset by the same amount at each trace, the Minutes offset per line setting in the plus menu for timing can be set to account for a regular offset.

Additionally, it is possible to move individual time bars by clicking and dragging. This should be done with caution, however, to avoid mistiming errors caused by misplaced time bars.

Extracting SAC Files

7.1 Settings for Extracting Files

Once the timing is complete and accurate, the digitization process is complete! The complete, digitized traces can be exported as SAC files[1] to a folder of choice. Ensure that the complete analysis, in `.mat` file form, is also saved, in the event that the SAC files are lost or changes are needed.

Most of the settings for exporting SAC files (Figure 7-1) are related to data organization.

- **SAC Data Interpolation.** These parameters describe at what intervals the data is sampled to create SAC files.

- **Time Correction.** The number input in the time correction field is the time offset for all times set for the image. This type of correction is applied when there is a known clock error.

- **Trace Zero Line Correction.** This feature allows for correction of trace zero lines using a quadratic function. Correction of trace zero lines can also be carried out after SAC files can be extracted, so it isn't usually necessary to apply correction using this feature.

- **Record Information.** Information regarding the station at which the seismogram originated from can be recorded in these fields. This information is used to label the SAC files.

- **Save information in text file.** Checking this box saves information from the analysis in ASCII text format when it is exported.

[1] Seismic Analysis Code.

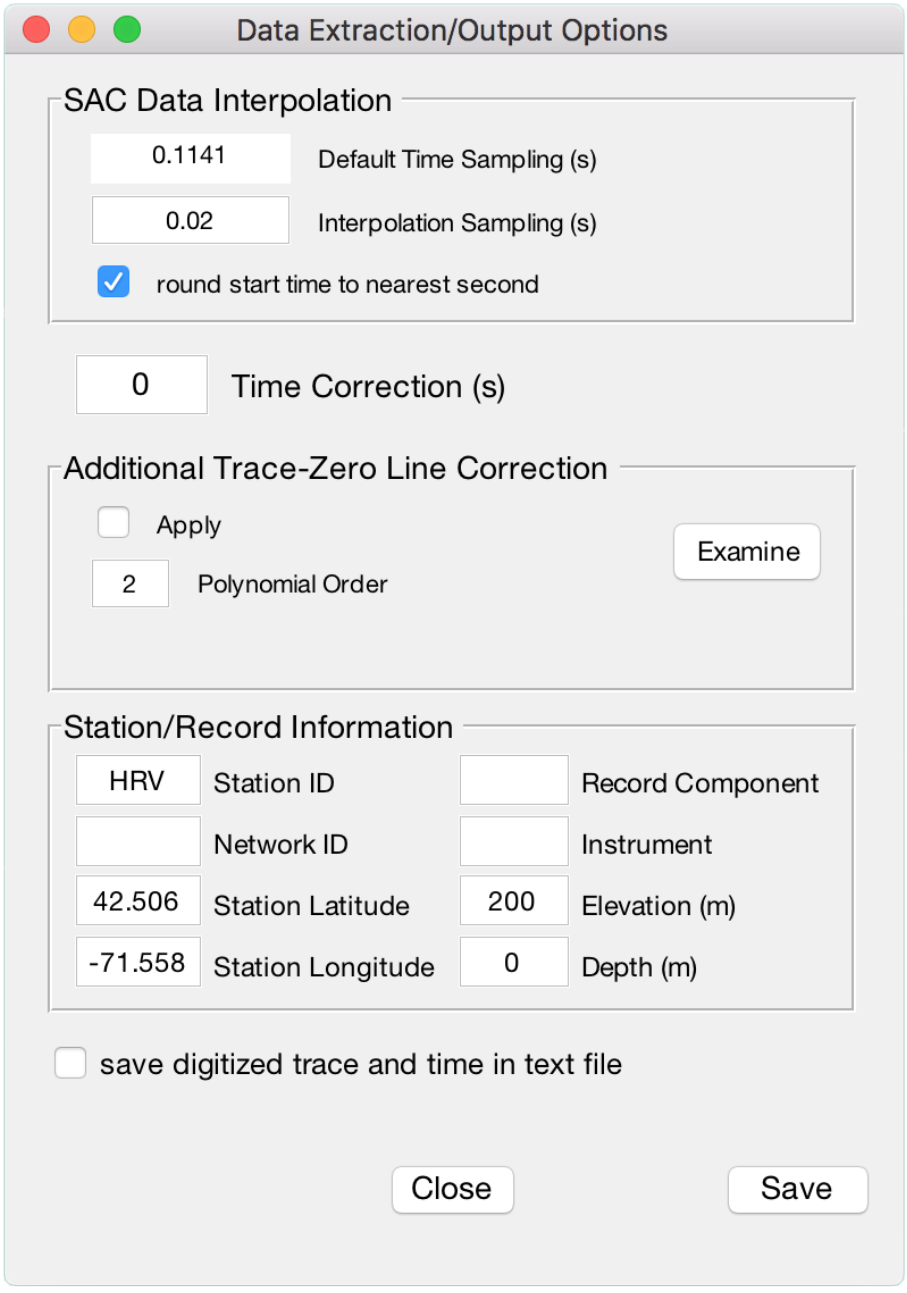

Figure 7-1: Plus menu for SAC file extraction settings.

7.2 Extracting and Saving Files

A video is provided online as a walkthrough for generating `.SAC` or `.txt` files from the completed analysis.

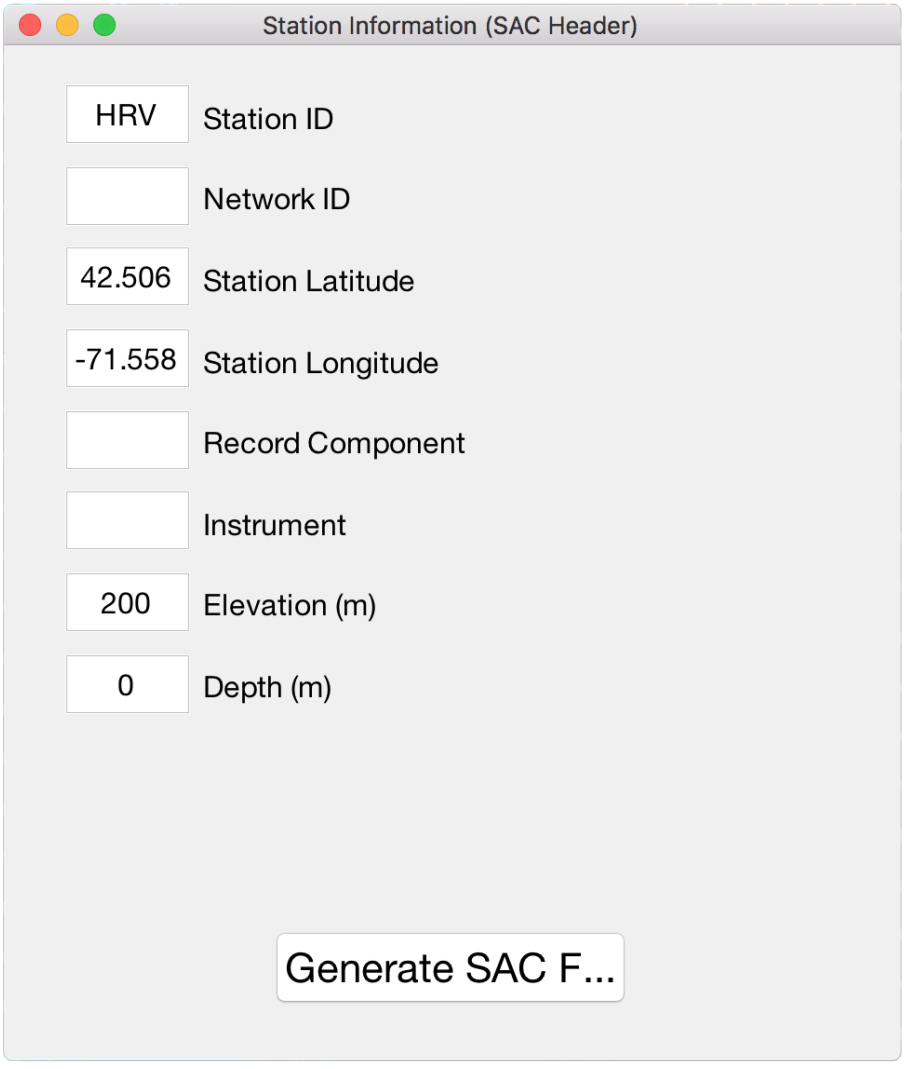

Figure 7-2: Window for setting station information before extracting SAC files.

Clicking the **Extract SAC** button at the bottom of the left sidebar opens the window shown in Figure 7-2. The information from the plus menu is included in the window, so if station information was previously specified[2], it should already be present in the

[2] Station information for HRV is the default.

SAC Header window. Once that information has been verified, click **Generate SAC Files** to begin the operating system's saving process and save the created SAC files to a selected folder.

If **Save information in text file** is checked in the SAC Extraction plus menu, **Extract SAC** in the left sidebar is replaced by **Extract TXT**. Clicking this option allows for naming and saving of two separate text files — one for trace information, and one for timing information.

> In addition to `.txt` or `.SAC` files, it is a good idea to keep a copy of the `.mat` file for the analysis in its most complete state, in case it becomes necessary to make changes or to re-extract other file types.

Appendices

DigitSeis Windows

A list of the DigitSeis windows and the tools available in the toolbar of each. Windows are listed in step-order.

Main DigitSeis Window

 Save

 Crop

 Undo

 Time Mark Direction

 Measure Width

 Measure Height

 Check Time Point

 Zoom In

 Zoom Out

 Pan

 Show Whole Image

 Add Note

 Show Information

Classification Window

 Save

 Small Region Analysis

 Remove Line of Pixels

 Remove Region of Pixels

 Combine Objects

 Overlap Analysis

 Undo

 Classify as Noise

 Classify as Time Mark

 Classify as Trace

 Show Time Marks

 Zoom In

 Zoom Out

 Pan

 Show Whole Image

 Remove Noise Objects

 Add Note

 Show Plus Menu

Classification Window: Small Region Analysis Window

 Show Original Window

 Unmask Region

 Remove Line of Pixels

 Remove Region of Pixels

 Combine Objects

 Overlap Analysis

 Undo

 Show Classification

 Classify as Noise

 Classify as Time Mark

 Classify as Trace

 Zoom In

 Zoom Out

 Pan

 Show Whole Image

 Recalculate Classification

Classification Window: Overlap Analysis Window

 Show Original Window

 Add Overlap

 Remove Overlap

 Add Pixels

 Remove Line of Pixels

 Remove Region of Pixels

 Combine Objects

 Undo

 Show Classification

 Classify as Noise

 Classify as Time Mark

 Classify as Trace

 Zoom In

 Zoom Out

 Pan

 Show Whole Image

Trace Number Correction Window

 Save

 Select Objects in Regions

 Renumbering Selection

 Renumbering Deselection

 Classify as Noise

 Combine Lines

 Undo

 Zoom In

 Zoom Out

 Pan

 Show Whole Image

Main DigitSeis Window: Correct Trace Window

 Create Point

 Classify Point Objects

 Show Original Window

 Unmask Region

 Remove Line of Pixels

 Remove Region of Pixels

 Combine Objects

 Overlap Analysis

 Undo

 Show Classification

 Classify as Noise

 Classify as Time Mark

 Classify as Trace

 Digitize Trace

 Set Vertical Offset

 Zoom In

 Zoom Out

 Pan

 Show Whole Image

 Recalculate Classification

Tools

This appendix contains a full list of the tools available in DigitSeis's toolbars. Table B.1 contains each tool's icon, the name used to describe it in this manual, its type, and the windows(s) it can be found in.

Table B.1: Tools available in DigitSeis.

Icon	Name	Type	Window(s)
	Save	Other	Main Classification Trace Number Correction
	Crop	Adjustable Box	Main
	Undo	Other	All
	Time Mark Direction	Toggle	Main
	Measure Width	Adjustable Line	Main
	Measure Height	Adjustable Box	Main
	Zoom In	Navigation	All
	Zoom Out	Navigation	All
	Pan	Navigation	All

Icon	Name	Type	Window(s)
	Show Whole Image	Navigation	All
	Add Note	Other	Main Classification
	Show Information	Other	Main
	Small Region Analysis	Adjustable Box	Classification
	Remove Line of Pixels	Drawn Line	Classification Small Region Analysis Overlap Analysis Correct Trace
	Remove Region of Pixels	Drawn Region	Classification Small Region Analysis Overlap Analysis Correct Trace
	Combine Objects	Crosshairs	Classification Small Region Analysis Overlap Analysis Correct Trace
	Overlap Analysis	Crosshairs	Classification Small Region Analysis Correct Trace
	Classify as Noise	Crosshairs	Classification Small Region Analysis Overlap Analysis Trace Number Correction Correct Trace

Icon	Name	Type	Window(s)
	Classify as Time Mark	Crosshairs	Classification Small Region Analysis Overlap Analysis Correct Trace
	Classify as Trace	Crosshairs	Classification Small Region Analysis Overlap Analysis Correct Trace
	Show Time Marks	Toggle	Classification
	Remove Noise Objects	Other	Classification
	Show Plus Menu	Other	Classification
	Show Original Image	Toggle	Small Region Analysis Overlap Analysis Correct Trace
	Unmask Region	Drawn Region	Small Region Analysis Correct Trace
	Show Classification	Toggle	Small Region Analysis Overlap Analysis Correct Trace
	Recalculate Classification	Other	Small Region Analysis Correct Trace
	Add Overlap	Drawn Region	Overlap Analysis
	Remove Overlap	Drawn Region	Overlap Analysis
	Add Pixels	Drawn Region	Overlap Analysis

Icon	Name	Type	Window(s)
	Select Objects in Region	Drawn Region	Trace Number Correction
	Renumbering Selection	Crosshairs	Trace Number Correction
	Renumbering Deselection	Crosshairs	Trace Number Correction
	Combine Lines	Crosshairs	Trace Number Correction
	Create Point	Crosshairs	Correct Trace
	Classify Point Objects	Other	Correct Trace
	Digitize Trace	Other	Correct Trace
	Set Vertical Offset	Other	Correct Trace
	Check Time Point	Crosshairs	Main

Seismograms Featured in Figures

This appendix contains descriptions of each seismogram featured in figures in this manual, and also Table C.1, which lists the seismogram(s) used in each figure. All seismograms used to generate images for this manual are available through the HRV Seismogram Archival Project, at http://www.seismology.harvard.edu/HRV/archive.html.

- **Standard Example.** Long period analog seismogram, Z component, recorded February 13–14, 1938 (`s1418_1938_0213_0214_lp_zew_f`). Included with DigitSeis bundles.

- **Overlap Example.** Long period analog seismogram, Z component, recorded March 25–26, 1937 (`s1094_1937_0325_0326_lp_zew_f`).

- **High-Amplitude Example.** Long period analog seismogram, Z component, recorded September 27–28, 1937 (`s1279_1937_0927_0928_lp_zew_f`).

- **Dense Example.** Short period analog seismogram, Z component, recorded July 18–19, 1937 (`s1208_1937_0718_0719_sp_z_f`).

- **Gap Time Marks.** Analog seismogram, NW component, recorded January 5–7, 1934 (`s0140_1934_0105_0107_ms43_nw_f`).

- **Streak Time Marks.** Long period analog seismogram, Z component, recorded February 19–20, 1946 (`s4389_1946_0219_0220_lp_z_f`).

- **Secondary Example.** Long period analog seismogram, NS component, recorded January 22–24, 1938 (`s1396_1938_0122_0124_lp_ns_f`).

Table C.1: Seismogram(s) featured in each figure in this comprehensive DigitSeis manual. Figures not featuring specific seismograms are not listed.

Figure	Seismogram(s)
Figure 1-1	Standard Example
Figure 1-2	Standard Example Secondary Example
Figure 1-3	Gap Time Marks Streak Time Marks
Figure 1-4	Standard Example
Figure 3-2	Standard Example
Figure 3-6	Standard Example
Figure 3-8	Standard Example
Figure 3-9	Gap Time Marks
Figure 4-2	Standard Example
Figure 4-5	Standard Example
Figure 4-7	Standard Example
Figure 4-9	Standard Example
Figure 4-10	Overlap Example
Figure 4-12	Overlap Example
Figure 5-1	Standard Example
Figure 5-3	Standard Example
Figure 5-4	Standard Example
Figure 5-7	Standard Example
Figure 5-8	Standard Example
Figure 5-9	Standard Example
Figure 5-10	Standard Example
Figure 5-12	Standard Example
Figure 5-13	Dense Example
Figure 5-14	High-Amplitude Example
Figure 5-15	High-Amplitude Example
Figure 5-16	Dense Example High-Amplitude Example
Figure 6-1	Standard Example
Figure 6-3	Standard Example
Figure 6-4	Standard Example
Figure 6-5	Standard Example