CASMI
Creating A Stress Map Interactively

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1. Introduction

CASMI is a software tool for generating publication quality stress maps. It has a graphical user interface and is the interactive, stand-alone cousin of CASMO with a wider range of functionality. CASMI version 2.0 includes the World Stress Map database release 2008. The CASMI software can freely be distributed under the terms of a 2-clause BSD licence, see the Info.

CASMI uses Perl/Tk for its graphical user interface, where all the settings for the desired stress maps are made. This interface also calls the C-shell and AWK scripts that automatically generate the stress maps by using GMT (the Generic Mapping Tools).

CASMI version 2.0 comes with ABSOLUTELY NO WARRANTY.

1.1. System Requirements

CASMI runs under Unix-like systems such as Linux. In addition to a running X Window System generally needed for graphical user interfaces under Unix, CASMI depends on the following software packages:

- Gmake (the GNU make utility)

- Perl (version 5.6.1 or higher)

- Perl/Tk (the perl module Tk.pm; version 800.023 or higher)

- Csh (the C-shell)

- Gawk (the GNU Project's implementation of AWK)

- GMT (the Generic Mapping Tools; version 3.4.1 or higher)

- ImageMagick

- Ghostscript

Problems may occur with older versions of Perl, Perl/Tk, or GMT. The `convert` program (from the ImageMagick software suite) is used to convert the map files generated by GMT in PostScript format to GIF. It is needed to display stress maps in CASMI's graphical user interface. Alternatively, you can also view created stress maps manually by a PostScript previewer like Ghostscript (`$ gs casmi-output.ps`).

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1.2. Installation

It is assumed that all GMT commands are in your PATH environment variable, such that `$ <GMT_command>` will work. You then do the following:

1. Unpack CASMI in a directory of your choice:
   `$ tar -xvvzf casmi.tar.gz`

2. Move into the CASMI directory:
   `$ cd casmi`

3. Run the configuration script:
   `$ csh ./configure_script`

4. Build the smoothing routines:
   `$ cd smooth`
   `$ make clean; make`

5. Add the CASMI directory to your PATH environment variable:
   `$ export PATH=$PATH:<path_to_CASMI_directory>` (for bash-like shells)
   `$ set path = ( $path <path_to_CASMI_directory> )` (for csh-like shells)
   Also add the appropriate line into your shell startup file, such as `~/.bashrc` or `~/.cshrc`, respectively.

6. You start CASMI by:
   `$ casmi`

1.3. General Information

The stress maps display the orientations of the maximum horizontal compressional stress S_H. The length of a stress symbol represents its data quality, with A being the highest quality and E the lowest. A-quality means that the orientation of S_H is accurate to within $\pm 15°$, B-quality to within $\pm 20°$, C-quality to within $\pm 25°$, and D-quality to within $\pm 40°$. For the most methods these quality classes are defined through the standard deviation of S_H. In general, A-, B- and C-quality stress indicators are considered reliable for the use in analyzing stress patterns and the interpretation of geodynamic processes. D-quality data are considered to yield questionable tectonic stress orientations [Zob92, SMH+03]. E-quality data records do not provide sufficient information or have standard deviations greater than 40°. These data records are mainly for well bores, contain no stress information, but are only kept for book keeping purposes that these data have been processed. The abbreviations for tectonic regimes used here are: "NF" for normal faulting, "SS" for strike-slip faulting, "TF" for thrust faulting, and "U" for an unknown regime.

More information on the data and stress maps can be found at the World Stress Map (WSM) website: www.world-stress-map.org .

Usage

In a number of menus in CASMI, there is the choice between "yes" and "no" at the top. The map will only be affected if "yes" is selected. Sometimes there are several choices and a User Defined button at the bottom followed by other entries. For example File → Page Settings → Page Size: If you don't like the predefined paper sizes and enter your own paper sizes, you also have to press the User Defined button. Otherwise those changes will have no effect. Any selection in a window must be confirmed by pressing the Apply or the Ok button. Apply leaves the window open, Ok closes it. Cancel closes the window without saving any changes.

The map will be generated by pressing the Make Map! menu button. It will take some time, so don't press this button twice or otherwise the map will be generated twice. Messages will be directed to the shell from where you have started CASMI. If you save your settings or your map you have to type the filename extension explicitly.

CASMI creates a number of files in the current working directory (where `$ casmi` is started), called `casmi-output.gmt`, `casmi-output.ps`, etc. Those are overwritten when a new map is generated, and they are deleted when CASMI is quit. It also creates three temporary directories in your home directory (`$HOME`) called `.casmi-Temp`, `.casmi-Temp1`, and `.casmi-Temp2`. In these directories the extracted data and other temporary files are stored.

CASMI doesn't check your entries. For example, if a pen size shall be given and instead of a (sensible) number you enter "sometext" this will be accepted. However, GMT will give you error messages and the map will possibly be damaged. If you need help with any GMT command you get all necessary information by `$ man <GMT_command>`.

1.4. Reference

If you use the stress maps in publications, please quote the World Stress Map (WSM) database:

Reinecker, J.; O. Heidbach, M. Tingay, B. Sperner, and B. Müller (2005): The 2005 release of the World Stress Map (available online at www.world-stress-map.org).

In addition, please reference the usage of CASMI:

Heidbach, O., Kurfeß, D., Höhne, J. (2008). CASMI – An interactive software tool for stress map plotting using the 2008 release of the World Stress Map data base (available online at www.world-stress-map.org).

The stress maps were created using the Generic Mapping Tools (GMT) by P. Wessel and W.H.F. Smith [WS91]. The used plate boundaries are courtesy of Peter Bird's digital model for plate boundaries PB2002 [Bir03]. CASMI's basic scripts were written by Veronika Wehrle and Stefan Hettel.

2. File menu

2.1. Page Settings

The Page Settings window allows the user to change the page parameters of the map. These are the page size, orientation, margins.

You can change the width of the map via Plot Width or by the page width. Its height will then be determined by the map range you have selected. Left Margin and Page Size will determine the page width. If the Bottom Margin of the page is too small, the WSM release information text will not appear.

Note that some other page parameters can be changed by menu Extras → Change GMT Defaults. For example, if you want to prepare a map for a poster with a known paper colour, you could set the page background colour to this colour.

2.2. Save Map As

This allows you to save the map in several formats (GIF, PDF, PS). The extension has to be typed in the File name field. The displayed image always appears in the current working directory as `casmi-output.ps` and `casmi-output.gif`. These files will be removed when CASMI is closed.

2.3. Save Stress Data (ASCII)

The selected stress data (in file `StressData.select` in the current working directory) will be copied to the given filename. Data format is like the WSM format:
longitude latitude azimuth type quality regime depth sitecode

2.4. Save/Load Plot Settings

These menu items allow you to save your settings to a file. This allows you to adjust the settings for several geographic ranges in your interest like "whole Earth", "Europe", "Romania", for example.

Note that the file selector first starts with the root directory ("/"). If you close it and start it another time, it will pop up with the current working directory. This is a bug in the module `Tk::FileSelect` which cannot be changed at the moment. The filename extension `.cas` can make it easier to recognize your files, but you can use any filename you want. Note that the extension must be typed as well.

Defaults for CASMI

CASMI will look in your home directory for a file called `casmi_defaults.cas`. In this file all the default settings of your parameters are stored. This may become very useful if you don't like the default colour palette table or other things. You can change this default file either directly with a text editor or by using CASMI, File → Save Plot Settings and overwriting your `~/casmi_defaults.cas` file. If there is no such file in your home directory, CASMI will use its internal defaults.

3. Data Parameters menu

This menu allows you to control the output of the stress data. Also user supplied data can be plotted. Such data must be in WSM format.

From the data a `*.prep` file will be created. If you add new data to your database you must delete the old `*.prep` file to see this new data plotted.

3.1. WSM Stress Data

You can choose the data that is to be included in the stress map. The data can be filtered by quality (A–D, and E where only the location, not the S_H azimuth is valid), depth range, regime, and indicator type. For a detailed explanation of the different methods/types and qualities please see the description of the WSM data at the WSM website.

FMS type events

The button for selecting data resulting from Single Focal Mechanism solutions (FMS) is not located under the Type selection. You find it under FMS type events, where you can additionally filter out subsets of FMS type data that you consider to be strongly influenced by plate boundaries. FMS type data is subdivided into 7 subsets in terms of the plate boundary type located next to the individual data point. For each of these 7 subsets you can (1) exclude all events within a certain distance from the plate boundary, (2) exclude events with the corresponding regime within a certain distance from the plate boundary, or (3) exclude PBE events (possible Plate Boundary Events) as defined by the WSM team.

So-called Plate Boundary Events might occur near weak transform plate boundaries and might have a higher error for the stress azimuth. You will find more information on the criteria for FMS data to be flagged as PBE by the WSM team in the appendix A or at the World Stress Map website (www.world-stress-map.org).

Please pay attention to the following two points: (1) The regime abbreviations here are more general than in the Regime selection above: "SS" means SS, NS, and TS, while "NF" means NF and NS, and "TF" means TF and TS. (2) While normally you select things in CASMI by pressing a button, here you deselect (exclude) data by pressing the buttons. This way you can generate a 3-stage filter for each of the 7 subsets. For example, you select "exclude all events < distance of 100 km", "exclude SS events < 200 km" *and* "exclude PBE events" for the CTF subset: Then FMS data near continental transform faults will not include data flagged as PBE by the WSM team, it will not include SS, NS, and TS events within 200 km range from the transform fault, and it will not include any data within 100 km from the plate boundary. When you deselect (release) the Focal Mechanism solutions, Single (FMS) button, all these plate boundary filters do not have any effect, as no FMS data at all will be included in the stress map.

If you choose a depth range, e.g. from 4.5 km to 10 km, you also have to select the Depth → User Defined button, otherwise data from all depths will be plotted.

3.2. Symbols WSM

This menu allows you to change the appearance of the WSM stress symbols.

3.3. Stress Legend

Here the position and size of the stress legend can be selected. It is not possible to give an explicit size of the legend. As a guideline, use "middle" for an A4, "huge" for an A0 map.

3.4. User Stress Data

It is also possible to provide your own dataset for plotting, by the Select your data file button. It must have the same format as the WSM data. The options are the same as for regular WSM data.

3.5. Symbols User Data

The same functionality as menu item Symbols WSM, but concerning the data provided as User Stress Data.

4. Map Parameters menu

4.1. Set Range and Projection

Here you select the map area and projection. "rectangular" means that instead of west/east/north/south you enter the lower left (south/west) and upper right corner (north/east) instead. This is useful for those projections where lines of constant latitude/longitude are not straight lines. Minutes and seconds can be given via the normal GMT syntax (lat:mm:ss). The "Orthographic" projection shows the Earth as seen from space, and the "Mollweide" projection shows the whole Earth. For both projections the area selected has only the effect of setting some defaults like the central meridian or the projection centre. Those defaults can also be changed explicitly by the Change

Defaults button. If your map range includes minutes or seconds, you may have to set those defaults by hand (as the C-shell scripts can't use their normal arithmetic on minutes/seconds).

There is also a Whole Earth button included. Remember that it is not possible to plot over the horizon using cylindrical projections. The "Orthographic" and the "Mollweide" projection set the range to the whole Earth internally.

Change (Projection) Defaults

Except for "Mercator" the other projections need some extra variables. These are the Projection Center, two Standard Parallels and the Central Meridian.

The defaults for the Standard Parallels are the upper third for the Upper and the lower third for the Lower Parallel. The default for the lat/lon of the Projection Center is given by the centre of the selected area. The default for the Central Meridian is 0 Longitude (Greenwich). If the map range includes minutes and seconds check if the defaults are sensible.

Projection	Proj. Center		Standard Parallels		C. Meridian
	Longitude	Latitude	Upper	Lower	
Albers Conic Equal Area	x	x	x	x	
Lambert Conic Conformal	x	x	x	x	
Lambert Azi. Equal Area	x	x			
Orthographic	x	x			
Mollweide					x

4.2. Map Attributes

A number of parameters control the appearance of the map. (Pen) Size is given in points, Color in red/green/blue (0–255/0–255/0–255) or a grey value: 0(black)–255(white). You can use the arrow keys to navigate in the entries.

- Coastline Resolution: The -D switch in GMT. This really depends on the scale of your map.

- Minimum Lake/Island Size: The minimum feature size (km^2) of lakes and islands. This is influenced by the next item:

- Coastline Level:

    - 1: Only continent-sea boundaries (i.e. neither lakes nor islands are plotted)
    - 2: also lakes, islands (with a certain minimum size)

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- 3: also islands in lakes, lakes in islands
- 4: also lakes in islands in lakes and vice versa

- Coastlines: Colour and pen size of the coastlines. Colour of continents and oceans. Write "no" into the fields if no colour for ocean/continent shall be used (e.g. topography plot with coastlines). If you want to plot bathymetry write "no" for Ocean Fill Color.

- Political Boundaries: Pen size and colour.

- Plate Boundaries: Pen size and colour. The data file for the plate boundaries can be changed in Extras → Change Files/Directories. If you use the default plate boundary file for a publication, please reference Peter Bird's updated digital model for plate boundaries [Bir03].

4.3. Topography

This window allows you to plot topography. The options also apply to any other grid file you would like to plot. The default topography file is `DATA/dtm5.grd` with the colour palette table `topo_col.cpt`. Both can be changed in Extras → Change Files/Directories. The scale bar will require careful use if not to produce ugly results.

- Contours: You can choose to contour the topography by setting the Contour Interval, the Annotation Interval, and the Pen Attributes. Here the full pen attributes are given: width/colour/texture.

- Illumination: Illuminated topography looks better, but also takes a little longer to generate. The Direction of Light counts the angle (in degrees) positive from north, e.g. 90 means light from east. The Normalisation Factor is for the intensity, a value between 0 and 1. The smaller this value is, the less is the illumination effect. Other possible values are "default" (which defaults to -Nt) or "e<factor>" which uses a Laplace distribution. See GMT's `grdgradient` -N option for details.

- Scale: A lot of try and error will be necessary to produce good looking results. The position of centre/top for "horizontal" scale (or centre/left for "vertical" scale) in the selected units (cm/inches) with respect to the lower left corner of the map can be given. The clearance rectangle is underlain beneath the scale. You can give either a colour or "no" which means that no clearance rectangle will be produced. Note that up to now the rectangle will be clipped at map boundaries.

4.4. Map Title

If you want to title your map, here's the place to go. You can enter any title you like, but note that it must be in parentheses if it's longer than one word. Octal escape characters are allowed and necessary if you want to use any special characters like the german "ä". If you use octal escape sequences but they aren't plotted, please see if in your `.gmtdefault` WANT_EURO_FONT is set to TRUE.

For the position of the label there are three possibilities: "Centered" is the normal position centred above the map, "Upper Left" means the upper left corner of the map or explicit placing via x/y coordinates. Don't be disturbed by the word "default" if you choose "Upper Left". The real default means centred.

4.5. Map Information

Here you can enter the gridline spacing, annotations for it, and the map scale. The default position for the map scale is not very fortunate as it collides with the WSM labeltext. So normally you will have to enter the lon/lat coordinates of the scale as well. The pen size of the scale label can be changed in `.gmtdefaults` → Label_font_size.

The info string contains information about the projection used. Its location at the lower right corner of the map cannot be altered.

4.6. Overview Map

The proposed range of the overview map is 10 degrees greater than the range of the map. This may not work if the range contains minutes or seconds. Four positions are possible. The width of the overview map is either "default" (1/4 map width) or can be set explicitly. Several other attributes can be given for the overview map.

5. Extras menu

5.1. Change Files/Directories

Here some data files can be changed. If you want to change the defaults for those files (and not only the files for this session) you can save your changes in `~/casmi_defaults.cas` (see section 2.4). The PostScript settings mean the following: If you want to append more PostScript to your map later, (i.e., you can plot it but not

print it) you have to change it from "no" to "yes". This is equivalent to ending the last GMT command with an -O option.

5.2. Change GMT Defaults

Nothing that is done here couldn't also be done directly in your `.gmtdefaults` file. However, if you don't want to change your `.gmtdefaults`, you can do it here, as the parameters are set locally via `gmtset`.

5.3. Smoothing the data

For general information about the smoothing of stress data and the program used, please see the dissertation of Veronika Wehrle [Weh98].

CASMI also provides an interface to the program `smooth` of V. Wehrle. Three methods are provided by this program:

- Smoothing stress data (menu item: Plot smoothed data). This is a useful first step also to see how the different parameters affect the algorithm.

- Smoothing and gridding stress data (menu item: Plot gridded smoothed data). This is useful to plot averages over the stress field.

- Calculating trajectories (menu item: Plot smoothed trajectories). This is an advanced feature. Please have a look into the reference above to make sure you understand what you are doing here.

Each of the three smoothing menu windows is actually two windows in one. The left half is for plotting the information. It will be used after the right half, which generates this information. First to this right half:

All three windows have the same options for smooth. If the (right) Smooth WSM Stress Data button is pressed, `smooth` is called through the shell with the options provided. Then only those WSM data will be smoothed that is selected in the Data Parameters → WSM Stress Data menu. That means that all of the applied data filters in the Select WSM Stress Data window do take effect. E.g., if you only select A quality data of type FMS, only those points will be used for `smooth`.

There is an additional data filter in the smoothing menu windows: Range W/E/S/N. Only those data records are passed to `smooth` that are within this region (+ the search Radius for smoothing). By default it is set to the range that you have selected in the

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Map Parameters → Set Range and Projection menu window. You may want to change this to decrease boundary effects of the smoothed stress field.

You can also do this manually (and thereby filter data by other criteria or give your own data, for example) by saving the selected data (File → Save Stress Data (ASCII)) and then selecting this as a new input file (Change Smooth Input File button). When you press the Smooth data from given Input File button, only this data is handed over to `smooth`. Please pay attention: When you press the Smooth WSM Stress Data button, the input filename information is overwritten. So do *not* press the Smooth WSM Stress Data button between Change Smooth Input File and Smooth data from given Input File! Besides, the input file for `smooth` must be in lat/lon format! That means, you will have to change the columns 1 and 2 manually as the "Saved Stress Data" will be in lon/lat format. Do this via `awk` or:

```
$ perl -i.lonlat -p -e 's/^(.*?)\s+(.*?)\s+(.*)$/$2 $1 $3/g' <data.dat>
```

This will save the original data and swap the first two columns if whitespace is the separator.

Depending on the size of selected data the program `smooth` will take time (most for trajectories, least for simply smoothed data). The default output file for `smooth` is `casmi-smooth.sdat` for smoothed data, `casmi-smooth.grdm` for gridded maps, and `casmi-smooth.trjs` for trajectories.

The left Ok/Apply button is for plotting the gained smoothed stress orientations. This means you can select different colours/textures for your smoothed data without calling `smooth` again.

Options for smoothing

Parameter	possible values / *default value*	Explanation
Input File	*wsm.dat*	Format for input file:
		latitude longitude azimuth type quality ...
Output File	*casmi-smooth.sdat*	for smoothed data
	casmi-smooth.grdm	for gridded data
	casmi-smooth.trjs	for trajectories
Lambda (λ)	12	Controls the degree of smoothing. Smoothing is emphasized for high λ, fidelity to the data for small λ.

Parameter	possible values / *default value*	Explanation
Neighbours (N)	*(none)*	Either a number of neighbours (N) or a search radius (R) must be given for the smoothing. For non-isotropically distributed data a search radius is normally the better choice but see the reference for more information.
Radius (R)	*100*	Search radius in km.
Quality Weighting	*y1/0.75/0.5/0.25*	If you want no quality weighting, insert "n".
Range	*(the map range)*	Defines from which range WSM stress data is taken for smoothing.
Weight Method	twf	tricubic weight function
	pdf/n	power distance weight function, n being the power
	Together with a search radius R the following can be used:	
	ntwf	number normalized tricubic weight function
	npdf/n	number normalized power distance weight function
	nbtwf	number and bin normalized tricubic weight function
	nbpdf/n	number and bin normalized power distance weight function
	Together with N neighbours the following can be used:	
	rtwf	rescaled tricubic weight function
	rpdf/n	rescaled power distance weight function
Ignore Option	*n/3*	Applied when calculating trajectories/gridded maps via the search radius.
	A datapoint is not calculated	
	n/α	if less than α datapoints lie within search radius.
	w/α	if the sum of all weights (distance × quality) $< \alpha$.
	$q\alpha$	if the sum of all quality weights is less than α.
Iterations	*10*	Maximum number of iterations before the program stops.
Deviation	*[no]*	Calculate sort of average deviation when writing gridded maps or trajectories; the average deviation is written in the 4th column of outfile.grdm and in the 3rd column of outfile.trjs. Additional information is given in column 5 to 7.

Parameter	possible values / *default value*	Explanation
Robustness	*[no]*	Robustness checking of smoothed data (BETA).
Verbose	*[no]*	Verbose mode for smooth.

5.4. Relative Plate Motions

This dialog allows you to plot trajectories of relative plate motions in the map. You can choose between various plates (but of course not all possible pairs are included). If your pair is not in the list, you will have to include the relevant information in the file `Scripts2.4/RotationPoles.info`. The relevant information for that is the rotation pole and the angular velocity and a pair number. Then you can use this number in the dialog.

5.5. Other Data

As an option, you can also plot point data (like measurement locations), names data (cities), text data (any text you like) and polygon data (faults).

The formats are as follows:

- Point data must be in the format:
  one line header, data: longitude latitude [symbol size]

  If the symbol size is in the third column just enter the symbol type. A list of GMT symbol types is available by `$ man psxy`.

- Names data format:
  one line header, data: longitude latitude label [justify]

- Text data format:
  one line header, data: longitude latitude size angle font no justify text

  This is equivalent to the file format expected from `pstext` (see: `$ man pstext`).

- Polygon data format:
  one line header, data: longitude latitude; separate multiple segments with ">"

  Without doubt this is the most useful feature here as it allows you to plot faults and other interesting geological information.

5.6. CMT Solutions

This menu item allows you to plot CMT (Centroid Moment Tensor) solutions. Note that the file format must be in Harvard CMT solution format for `psmeca`:
lon lat depth mrr mtt mpp mrt mrp mtp iexp name

You can obtain such solutions at: http://www.seismology.harvard.edu/CMTsearch.html
.

These solutions also allow non-double-couple components. If these are strong, you will probably not recognize the beach ball appearance. Note that the number of header lines should be correct or at least not small otherwise GMT will complain.

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A. Possible Plate Boundary Event (PBE) assignment

Plate boundaries are characterized by faults with preferred orientations and presumably include major faults with a low coefficient of friction which can be easily reactivated. Thus, the derivation of stress orientations from a single focal mechanism is not always an unambiguous matter, because of its dependence on the mechanical behaviour of the involved fault zone. In the case of weak faults the angle between the principal stress axes and the P-B-T axes is theoretically as large as 90° (McKenzie, 1969). The scientific debate about the strength of plate boundary faults – whether they are weak or strong – is ongoing (e.g. Provost and Houston, 2004). Users should be aware that stress orientations derived from single focal mechanism solutions (FMS) along weak plate boundaries might have a higher degree of uncertainty. Thus, FMS data records that are located near plate boundaries have been flagged as Possible Plate Boundary Events (PBE) if they fulfill the following criteria:

1. The event is located within a critical horizontal distance relative to the closest plate boundary segment. The critical distances depend on the types of plate boundaries. We estimated them by means of statistical analysis as being 45 km for continental transform faults, 80 km for oceanic transform faults, 70 km for oceanic spreading ridges, and 200 km for subduction zones. A detailed description of this statistical analysis is part of a manuscript that has been submitted to the Tectonophysics Special Issue on Frontiers of Stress Research (Heidbach et al., in review, to be published in early 2009).

2. The angle between the strike of the nodal plane and the strike of the plate boundary is smaller than 30°.

3. The tectonic regime of the FMS reflects the plate boundary kinematics, i.e. thrust faulting (TF, TS) near subduction zones, strike-slip faulting (SS, NS, TS) near oceanic and continental transforms, and normal faulting (NF, NS) near oceanic spreading ridges.

Stress data records that are flagged as PBEs are not down-ranked in quality, but keep their C-quality in the WSM database. By default they are not plotted on stress maps created with CASMO (Heidbach et al., 2004) or CASMI (Heidbach & Höhne, 2008; Heidbach et al., 2008). For each data record additional information is available in the database which helps the user to evaluate the influence of plate boundary kinematics on the stress orientation at a specific location (distance from and type of the plate boundary). Please contact the WSM team if you have any questions or comments.

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