CRESCENT Seed Grant Report

# Assuring Continuity Between a 3D Community Fault Model in the Cascadia Region and the SCEC CFM and Integration of Foundational Datasets for CFM Development

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**Final Technical Report**

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## Summary

We worked to ensure that the southern portion of the CRESCENT Community Fault Model (CFM) is continuous with the northern portion of the CFM developed for the Statewide California Earthquake Center (SCEC), both in the onshore forearc region and in the offshore splay fault region off the accretionary wedge. We examined the USGS National Seismic Hazard Model (NHSM) fault section database, the USGS Quaternary Fault and Fold database, and the California Geological Survey Fault Activity Map as well as primary data sources such as the National Archive of Marine Seismic Surveys, hypocentral catalogs and CASIE21 data. From those sources we developed a set of 3D fault representations for the CRESCENT southern border region which are geometrically and kinematically compatible with neighboring 3D fault representation in the latest iteration of the SCEC CFM. In addition to fault trace, generalized fault dip and cross-sectional fault information, the fault model is constrained by contiguous bounding surfaces, e.g., topographic and base of seismicity (i.e., seismogenic thickness) surfaces. These bounding surfaces were developed to cover both the CRESCENT and the SCEC regions and have been shared with the CRESCENT CFM group.
The model also includes an updated subduction zone interface which is scheduled to be included in upcoming SCEC CFM evaluations and revisions. The complete model is delivered in the format of the SCEC CFM to ensure compatibility with popular 3D CAD software..
With development and delivery of ten border crossing faults and three regional, foundational surfaces, as well as facilitating in person collaboration and training with a CRESCENT CFM group member we reached all objectives of the project proposal as funded in our seed grant. Currently, we do not have immediate plans for further development with this project and rather focus on implementing related updates with the SCEC CFM. We publish the results on a dedicated web resource and maintain continued contact with the CRESCENT CFM development team. Additionally, we presented this work at the CRESCENT 2025 Annual Meeting, and the CRESCENT 2025 Partnership and Application workshop.

## 1. Background and the SCEC CFM

For CRESCENT, the Community Fault Model (CFM) working group is tasked to develop a comprehensive three-dimensional model of onshore and offshore crustal faults in the upper plate of the Cascadia subduction system as well as the megathrust plate boundary fault. Similarly, for SCEC, CFM v.7.0 is an object-oriented, three-dimensional representation of active faults in California and adjacent offshore basins. For each fault object, the SCEC CFM provides triangulated surface representations (t-surfs) in several resolutions, fault traces in several different file formats (shapefiles, GMT plain text, and GoogleEarth kml), and complete metadata including references used to constrain the surfaces. The CFM faults are defined based on all available data including surface traces, seismicity, seismic reflection profiles, well data, geologic cross sections, and various other types of data and models. The CFM serves SCEC as a unified resource for physics-based fault systems modeling, strong ground-motion prediction, and probabilistic seismic hazards assessment (e.g., UCERF3).
Since last year, SCEC has transitioned to a California statewide center and has presented its first version of a fault model which is expanded to include central and northern California (Plesch et al., 2023). This means the current and future SCEC CFM is neighboring and overlapping the domain of the CRESCENT CFM in development. Neighboring 3D fault models present a great opportunity to better understand the broader plate boundary structure but present risks of inadvertent mismatches and incompatibilities in the fault structure that may be introduced in the border area. CRESCENT explicitly recognizes this concern in its CFM1 priority of the RFP. In this report, we present several products to assure continuity and compatibility between the neighboring CFMs. Such consistency is critical for any application of the fault models in the

border area, from dynamic rupture modeling, strong ground motion predictions, seismic hazard assessment to policy making and reducing planning uncertainties in affected communities.

## 2. Completed Work

We developed and delivered three regional, foundational surfaces and ten border crossing faults. using a variety of datasets and methods as detailed below. All surfaces and fault representations are made available as triangulated surfaces in t-surf format, surface traces in plain text, kml, and shapefile formats, and a metadata spreadsheet that provides key information about the fault representations. All are packaged as a zip archive that can be easily uploaded to a CRESCENT managed data repository when available, an open online code repository such as Github, or on request to the CFM development team.

## 3. Regional Surface Products

For use with this study and the wider CRESCENT community, we developed and shared three regional surfaces covering the western U.S. including Cascadia: a topographic/bathymetric surface, a seismogenic depth surface and megathrust/plate interface surface. All surfaces are provided in the same t-surf format and coordinate system.

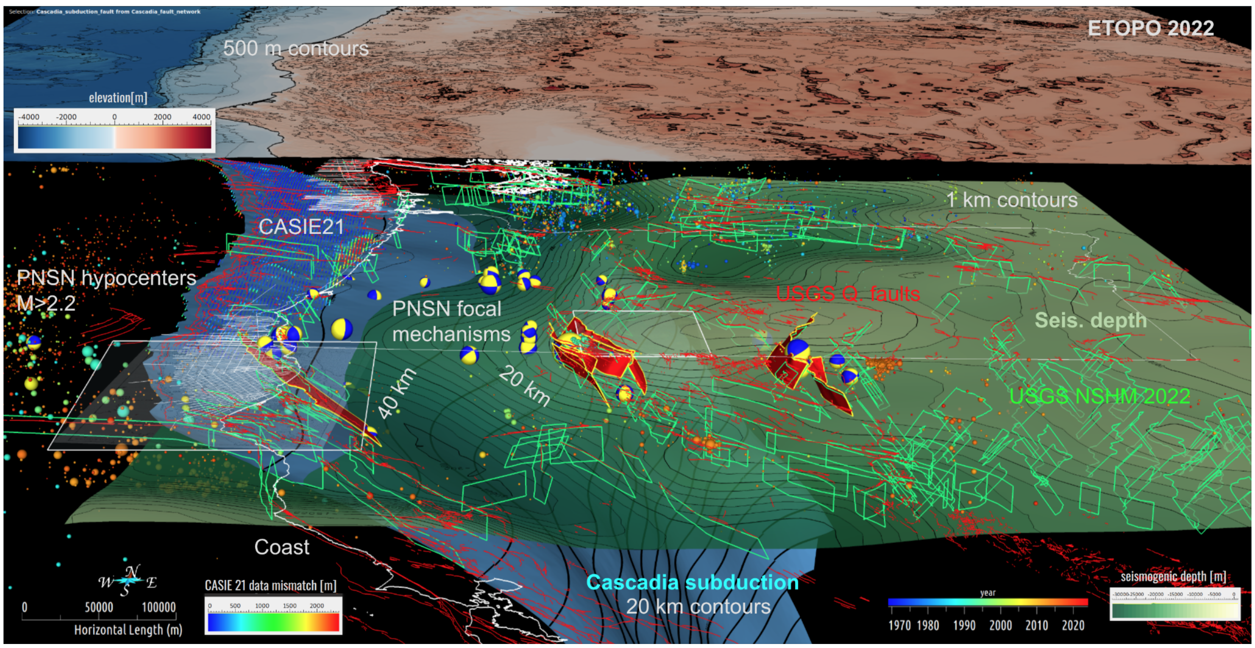

*Fig.1: Perspective view of the CRESCENT region, datasets relevant to CFM development and regional surfaces constructed. Topography/bathymetry surface (ETOPO 2022, NOAA, 2025) is offset vertically for illustration. The seismogenic depth surface (label Seis. depth, Zeng et al., 2022) is transparent. The surface labeled Cascadia subduction is merged from Hayes (2018) and CASIE21 data (Carbotte et al., 2024). The CASIE21 grid of the base of the accretionary wedge is color contoured by its mismatch with the merged surface. USGS Q. (red traces): USGS Quaternary Fault and Fold database (California Geological Survey, 2024; Oregon State University, 2024), USGS NSHM 2022 (green outlines): National Seismic Hazard Model Fault Section Database (NSHM, Hatem et al., 2021), PNSN hypocenters and focal mechanisms ("beachball" symbols): Pacific Northwest Seismic Network (2025). Red fault surfaces and other content: see Fig. 2*

### *3.1. Topography/Bathymetry*

For use as an upper bound for CFM purposes we developed a contiguous topographic-bathymetric surface derived from ETOPO 2022 (NOAA, 2022) covering the Western U.S. Specifically, we downloaded all relevant tiles of the 15 arc second resolution surface ETOPO 2022 product, mosaiced those into a single dataset in GeoTIFF format with GIS software (QGIS), cropped this large map for the CRESCENT region, and projected the cropped map into our preferred reference system (CRS, UTM Zone 11, WGS 84). This resulted in a ca. 400 m resolution topographic-bathymetric surface suitable for use in a 3D modeling environment.

### *3.2. Lower Seismogenic Depth*

For use as a lower bound for CFM purposes we developed a contiguous surface from the dataset provided by Zeng et. al (2022) covering the Western U.S. The dataset has a nominal resolution of ca. 8 km. We projected the provided source shapefile into our preferred CRS and developed a closely matching surface at 20 km resolution in our modeling environment. This is the surface which defines the lower limit of all fault surfaces we developed for this project except for where the subduction zone interface surface is shallower.

### *3.3. Megathrust-Plate Interface*

We developed a single, contiguous surface of the Cascadia megathrust below the accretionary wedge and the deeper subduction zone plate interface by merging datasets developed for the CASIE21 imaging project and by Hayes (2018). Specifically, we used the Casie21-R2T-PlateBdy_medflt-surface-mask grid by (Carbotte et al. 2024) and the cas_depth shapefile holding structure contours by Hayes (2018). From those input datasets we used SKUA-GOCAD to interpolate a smooth surface using discrete-smooth interpolation (via the software's SnS workflow, Mallet, 1992). Since there is overlap at the transition between the base of the accretionary wedge and the seismologically characterized upper limit of the subduction zone, we computed the misfit of the interpolated surface with the input data. The misfit is generally small (median of 138 m for the CASIE21 mapping) and reaches maximum values of 2 km to 5 km in a small area offshore northern Oregon (Fig. 1) following there the 20 km depth contour of Hayes (2018).

## 4. Fault surface updates

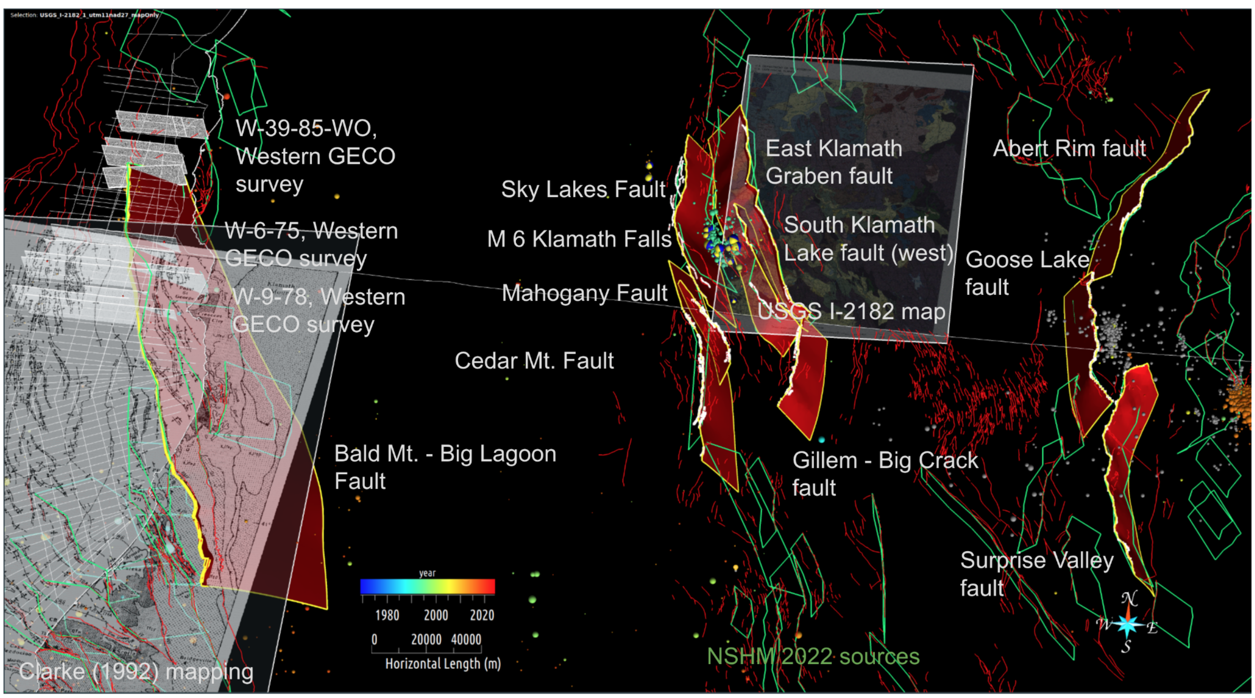


*Fig. 2: Perspective view looking north of the study region at the border between California and Oregon. The 10 fault representations crossing the border which are considered in this project are shaded red with a yellow outline. White rectangles outline scanned, georeferenced maps (Fig. 2 in Clarke, 1992; USGS I-2182 geologic map by Sharrod and Pickthorn, 1992). Filled vertical rectangles offshore show utilized 2d seismic reflection lines of the surveys labeled (NAMSS, Kluesner et al., 2024). Yellow fault traces with white vertices show detailed fault traces (Qfaults, USGS, 2025) selected for fault modeling. Hypocenters of the M 6.0 1993 Klamath Falls sequence are labeled. See Fig. 1 for other content.*

All updated fault surfaces extend to the topographic/bathymetric level. We employ the reproducible fault surface modeling method by Riesner et al. (2017) to generate 3D fault surface representations.

### *4.1. Bald Mt. - Big Lagoon thrust*

The Bald Mt. - Big Lagoon thrust is recognized in NSHM 2023 as a seismic source and can be traced from the onshore Eel River basin in northernmost CA into the offshore Eel River basin and further into Oregon (Qfaults). It is the largest, recognized seismic source in the accretionary wedge above the megathrust in this area crossing state borders. We used existing mapping (Qfaults, USGS, 2025; Clarke, 1992), the availability of seismic reflection surveys collected in the National Archive of Marine Seismic Surveys (NAMSS) and hypocentral locations of earthquakes determined by the Pacific Northwest Seismic Network (PNSN) to generate an updated 3D fault representation. In particular, we focused on how the onshore/nearshore portion of the fault may connect to offshore mapping in Oregon and if the fault may be traced further north into offshore Oregon.

Clarke's (1992, Fig. 2) mapping of the fault in onshore and offshore northernmost CA is adopted by Qfaults (USGS, 2025) and NSHM 2023 (Hatem et al., 2021) but is unmapped approaching the CA-OR border where Qfaults and NSHM 2023 identify a continuation of the fault into southernmost OR. Clarke (1992, Fig. 9 AA', Fig. 2) interprets tentatively, blind fault fragments along strike of the fault in this otherwise unmapped portion. In order to validate this interpretation we retrieved 2D reflection seismic amplitude and navigation data of Western GECO surveys (W-6-75, W-9-78, lines W75-548, W75-546, W-546A, W75-542, W-542A, W75-540) archived by NAMSS, analyzed the relationship between navigation data and SEGY binary header information for each line, and loaded the resulting profiles at their precise location into our modeling environment. Both, seafloor morphology and disruptions of reflector continuity, allowed for Clarke's (1992) tentative fault mapping which results in a rather linear continuation of the offshore CA portion of the fault into existing mapping in OR. Thus, we adopt an updated fault trace which has a more linear strike offshore.

In order to assess the northern extent of the fault as mapped, we retrieved additional 2D seismic data (Western GECO W-39-85-WO, lines WO-4116, WO-4124, WO-4126, WO-4130) acquired in this area. Whereas line WO-4130 shows evidence of thrust faulting at the fault location as mapped, lines farther north do not, thus confirming the currently mapped northern extent of the fault.

We adopt an average dip of 35° from NSHM 2023 and select 22 events with hypocentral location (PNSN) which surround the fault down dip. 13 of those are excluded due to hypocentral depths either below the megathrust at this location or very close to the seafloor.

To generate the surface, we used as weighted constraints the updated fault trace (weight 1000), the orientation and dip of the NSHM surface (weight 10) and the selected hypocenters (weight 1). The generated fault surface extends at depth to the megathrust/subduction interface offshore and onshore to the seismogenic depth surface.

### *4.2. Klamath Graben - Cedar Mt. fault system*

The Cedar Mt. fault zone extends across the CA-OR border into the Klamath Graben, a substantial extensional structure which hosted the M 6.0 1993 Klamath Falls sequence - including the largest, recorded crustal earthquake in Oregon.

We provide updated fault surfaces for use with the CFM of the Cedar Mt. fault zone consisting of the Cedar Mt. fault and the Mahogany fault, and parts of the Klamath Graben including the Sky Lakes fault, the East Klamath Graben fault and the South Klamath Lake fault (west). Additionally, we updated the Gillem-Big Crack fault as it approaches the border just south of Klamath Graben.

All updates closely follow the Qfault traces at the surface.

Departing from NSHM 2023 and following USGS Qfaults and CGS FAM we represent the Cedar Mt. fault zone with two faults, a main east dipping Cedar Mt. fault and an antithetic, west dipping Mahogany fault. We adopt 60° average dips for both consistent with the Qfaults database. The northern limit of the updated Cedar Mt. fault follows NSHM recognizing that mapped Qfault traces assigned to the Sky Lakes fault zone in Oregon directly connect to traces assigned to the Cedar Mt. fault in California across the border. Additionally, the northern extension is more consistent with the mapped extent of the antithetic, closely related Mahogany fault. To the south, the updated Cedar Mt. fault zone extends to include mapped surface rupture of the fault during the 1978 M 4.6 Stephens Pass earthquake (FAM). The Mahogany fault representation is truncated by the larger Cedar Mt. fault. For both the Cedar Mt. and the Mahogany fault we used the surface trace (weight 100), a downdip contour (weight 1), and a reduced constant gradient (roughness) constraint (weight 0.01) as input to generate the surfaces.

The Sky Lakes fault constitutes the westernmost bounding fault of the Klamath Graben fault system and is associated with the M 6.0 1993 Klamath Falls earthquake sequence (Dreger et al., 1993; Braunmiller et al., 1993). In our update, we largely follow the NSHM 2023 representation of the fault but extend it 7 km farther north following mapped Qfault traces assigned to the western boundary of the Klamath Graben and 13 km to the south to the limit of mapped Qfault traces assigned to the Sky Lakes fault zone. Additionally, we use main shock nodal planes of Braunmiller et al. (1993) and PNSN to constrain fault orientation at 9 km depth. Inputs for surface generation consist of the detailed fault trace (weight 1000), a downdip contour (weight 0.1), and nodal plane orientations (weight 1000 for M 6.0 main shocks, and 100 for two other large events).

The west-dipping East Klamath Graben fault constitutes the easternmost, bounding fault of the graben. We follow NSHM 2023 in dip and extent and replace the smaller South Klamath Lake fault (east) with an updated East Klamath Graben fault. Surface inputs are the detailed surface trace (weight 1000) and multiple downdip contours (weight 100) preserving the more segmented character of the fault near the surface. The South Klamath Lake fault (west) is a smaller, antithetic, east-dipping fault which extends to the south to the State border. We updated the fault to follow east dipping traces at its southern termination (Sherrod and Pickthorn, 1992) rather than west dipping traces used previously. Inputs were traces where mapped (weight 100) and a downdip contour (weight 10). The fault is truncated at depth against the larger East Klamath Graben fault.

Updates to the Gillem - Big Crack fault follow NSHM 2023 and include a 4 km extension to the north across the State border to link to the faults at the eastern Klamath Graben at depth. Other than detailed fault surface traces (weight 1000), the orientation of the NSHM representation (weight 100) was used as input.

*4.3. Abert Rim, Goose Lake, and Surprise Valley faults*

The Goose Lake fault crosses the state border and is related to the Abert Rim fault in Oregon and the Surprise Valley fault in California. The area has ongoing seismic activity with a 2004 M 4.4 event as the largest, recent earthquake.

The update of the Goose Lake follows the extent and overall dip of the NSHM 2023 fault. Additionally, it uses six hypocenters which align with the fault. Final inputs were the detailed fault trace (weight 1000), the orientation of the NSHM fault (weight 100) and the selected hypocenters (weight 1).

To the north of the Goose Lake fault, the Abert Rim fault continues along strike across a 19 km gap of diffuse extension. While the update follows the overall orientation of the NSHM 2023 fault, it extends it both farther to the north and to the south. To the south, eight hypocenters define a plane into which the dipping fault projects nearly perfectly for ca. 15 km reducing the gap to the Goose Lake fault substantially at depth. To the north, we include the northern section of the Abert Rim fault as mapped by Qfaults and an additional hypocenter which can be associated with this northern extension. In total, inputs are the detailed fault trace (weight 1000), a downdip contour (weight 10) and the hypocenters (weight 10).

To the south of the west dipping Goose Lake fault, the Surprise Valley fault overlaps for 15 km and dips to the east. The update follows both the extent and variable orientation of NSHM 2023. Input constraints are a detailed fault trace (weight 1000) and orientation (weight 1000). In addition, five selected hypocenters which occurred close to the dipping fault were used (weight 100).

## 5. In person visit and software training of CRESCENT CFM group member

We organized and facilitated a three-day visit (10/16/2024 to 10/18/2024) of CRESCENT CFM group researcher Dr. Rebecca Fildes (WWU) to the SGER group at EPS Harvard University which shares responsibility for developing the SCEC CFM. The visit was designed to relay a closer, shared understanding of the CFM development process and included remote meetings with the larger SCEC and CRESCENT CFM groups. Of particular focus was introduction and training in methods of fault construction with software tools like MOVE and SKUA-GOCAD. This included demonstrations of the tools in various settings as well as hands-on modeling of splay faults in Cascadia.

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