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## IRIS Earthquake Browser (IEB) Tutorial

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**URLs for this tutorial:** <http://web.ics.purdue.edu/~braile/new/IEB.Tutorial.pdf>  
<http://web.ics.purdue.edu/~braile/new/IEB.Tutorial.docx>

**1. Introduction:** Objectives – Using the **IRIS IEB** (*Iris Earthquake Browser*) for exploring earthquakes around the world, illustrating the functions and options of the IEB, the relationship of earthquakes to plate tectonics, and the statistics of earthquakes. For a quick look at recent earthquake activity, open the **IRIS Seismic Monitor** (URL below). You can enlarge to page size. Seismic Monitor is a useful and attractive viewer for up-to-date EQ information. The USGS “last 7 days” lists (below, and links in these websites) are useful locations for finding out about recent earthquakes. The websites are updated within minutes of recent events. Additional useful links for earthquake information are listed below.

**IRIS Seismic Monitor:** <http://www.iris.edu/seismon/>

**IRIS Earthquake Browser (IEB):** <http://ds.iris.edu/ieb/>. Earthquake Browser Information:  
[http://www.iris.edu/hq/files/publications/brochures\\_onepagars/doc/DMC7.pdf](http://www.iris.edu/hq/files/publications/brochures_onepagars/doc/DMC7.pdf)



### Additional earthquake monitoring and information sites:

Real Time Interactive Earthquake Map: <https://seismo.berkeley.edu/seismo.real.time.map.html>

USGS earthquakes map (real time map similar to Seismic Monitor and IEB, used below): <http://earthquake.usgs.gov/> (you can link to a map and list of recent earthquakes – you can adjust the list, map, and settings for time and views) and new site: <https://www.usgs.gov/natural-hazards/earthquake-hazards>.

Animated map of worldwide earthquakes January 1, 2001 – December 31, 2015: <https://www.youtube.com/watch?v=Ed0tGlfJHiY>

You can find lists of significant earthquakes, search for earthquakes (by date and location range), and view earthquake maps at: <http://earthquake.usgs.gov/earthquakes/>.

Lists and significant EQs: <https://earthquake.usgs.gov/earthquakes/browse/>.

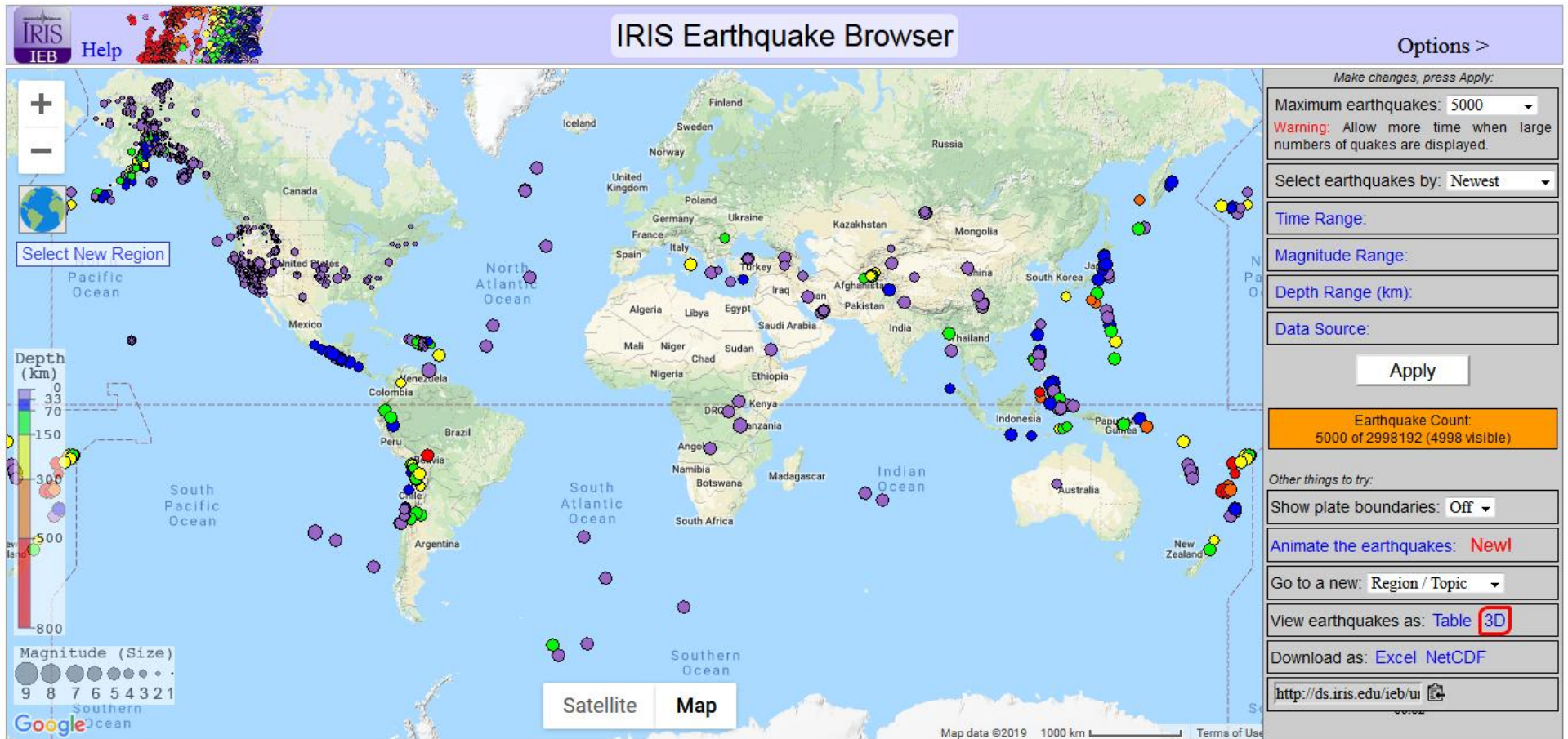
Main page for USGS EQ information (new): <https://www.usgs.gov/natural-hazards/earthquake-hazards>

USGS July 2019 Ridgecrest, California earthquake: [https://www.usgs.gov/news/update-magnitude-7.1-earthquake-southern-california?qt-news\\_science\\_products=7#qt-news\\_science\\_products](https://www.usgs.gov/news/update-magnitude-7.1-earthquake-southern-california?qt-news_science_products=7#qt-news_science_products)

**2. Using the IEB:** In this tutorial, we will use the **IRIS Earthquake Browser** (IEB) to explore earthquake activity. The IEB is a powerful and easy to use tool with an effective map interface and a comprehensive and accurate catalog of historical earthquake information.

**a. Using the IEB (<http://ds.iris.edu/ieb/>):** Some basic instructions for using the IEB are given here. To use the IEB, go to the website listed here. If the map image shows a selected region, click on **deselect region** and then zoom out (minus sign at upper left) and scroll until the world region is visible (similar to *Figure 1*). When making significant changes in the map (dragging, zooming) or using large numbers of events in the plot, the response time for changes is sometimes a few seconds or tens of seconds, so be patient. One suggestion to speed up the response time is to limit the view to a very small number of events (such as 100 or 1000; see **Display at most:** in the upper right hand corner of the screen) when dragging the map for a different view, or zooming in or out, **then, when you have the map that you want, increase the number of events to display** (maximum is 25000). The basic IEB map display, with 5000 events shown (representative events; not all that are included in the IEB earthquake catalog) is shown in *Figure 1*. There is also a **Help file** (see link in upper left corner of the page) for additional instructions and information about the IEB.

The IEB map in *Figure 2* shows the result of selecting a region (**Select a Region** dialog box; **the region selection control is only available with the Firefox, Internet Explorer and Safari web browsers**) that includes northern Japan and the Kamchatka peninsula, then selecting **Zoom to Region** and 5000 event to display. The **Magnitude Range** was also changed to include EQs of magnitude 4 to 10 (there has never been a magnitude 10 earthquake in historical time, although the magnitude scale does not have an upper limit, so we usually use 10 as a maximum in searches).



**Figure 1.** IEB map of the world with 5000 recent events (epicenters are shown by dots) shown. Note scale at lower right, magnitude legend (size of dot is proportional to magnitude,  $M$ ) at lower left, color code for depth of the earthquake (focal depth) shown at the left hand side of the map, and the zoom scale - + and - scale at the upper left hand side of the map). The **Select a Region** dialog box (in upper left area of the map) allows you to select a rectangular area of the map for detailed analysis and display of events. The **Table** button (lower right) allows you to download a table of earthquake information for the events on the map. The **Apply** button applies changes to the map (number of events, **Prioritize**, Options [**Time**, **Magnitude**, **Depth Range**]) after scrolling, zooming or changing numbers of events or options.

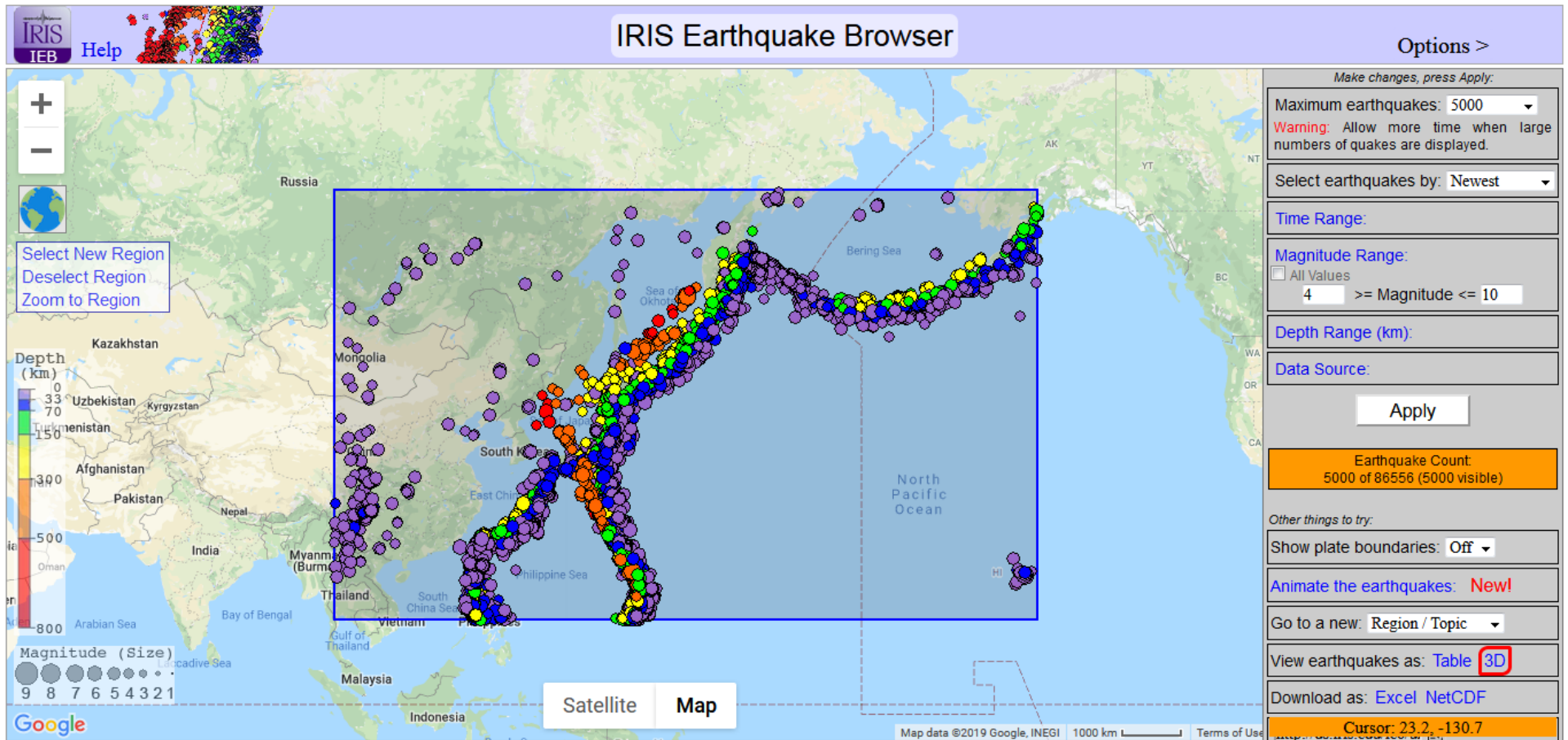
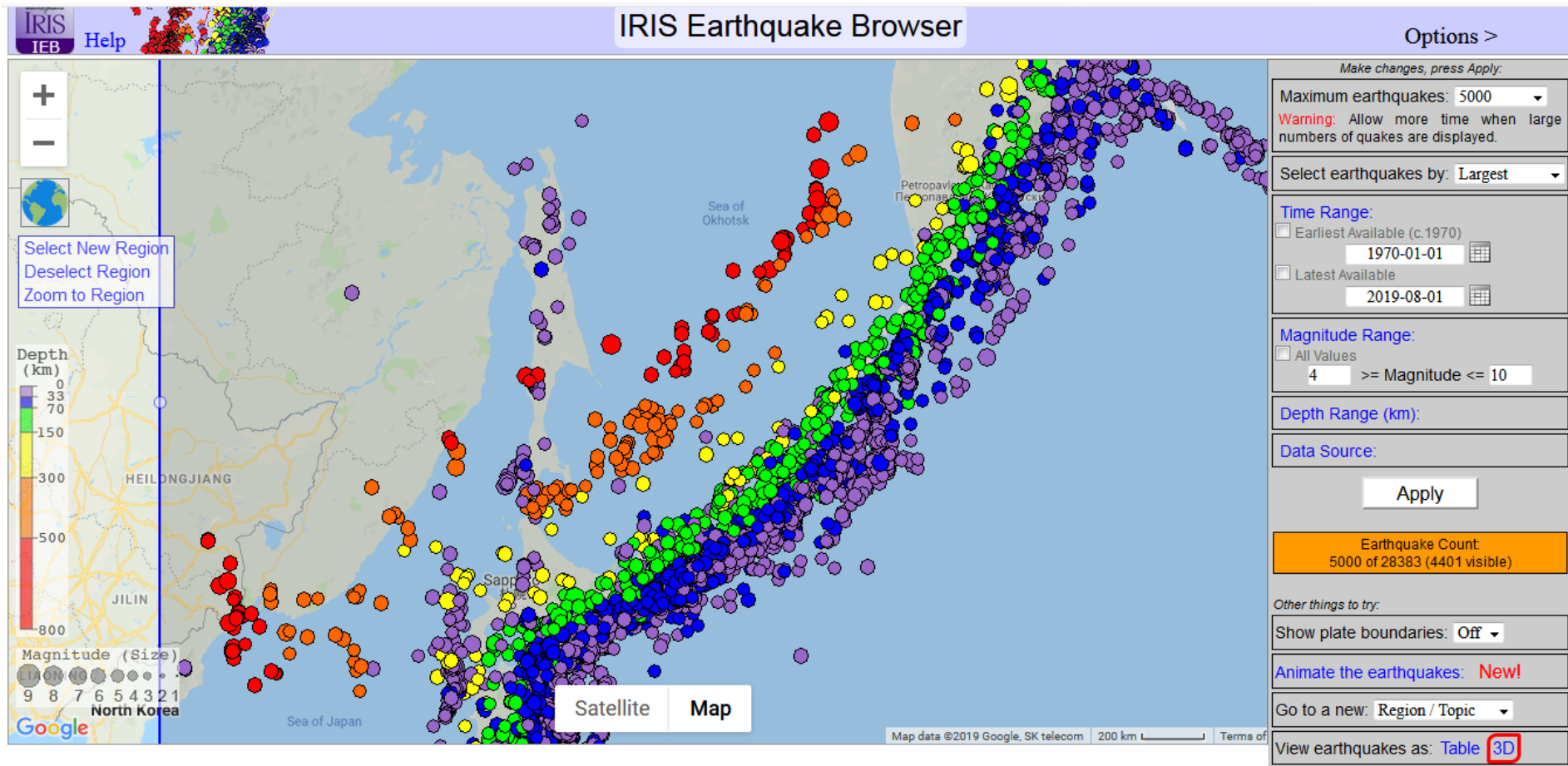


Figure 2. IEB map of the selected area with 5000 recent events shown.

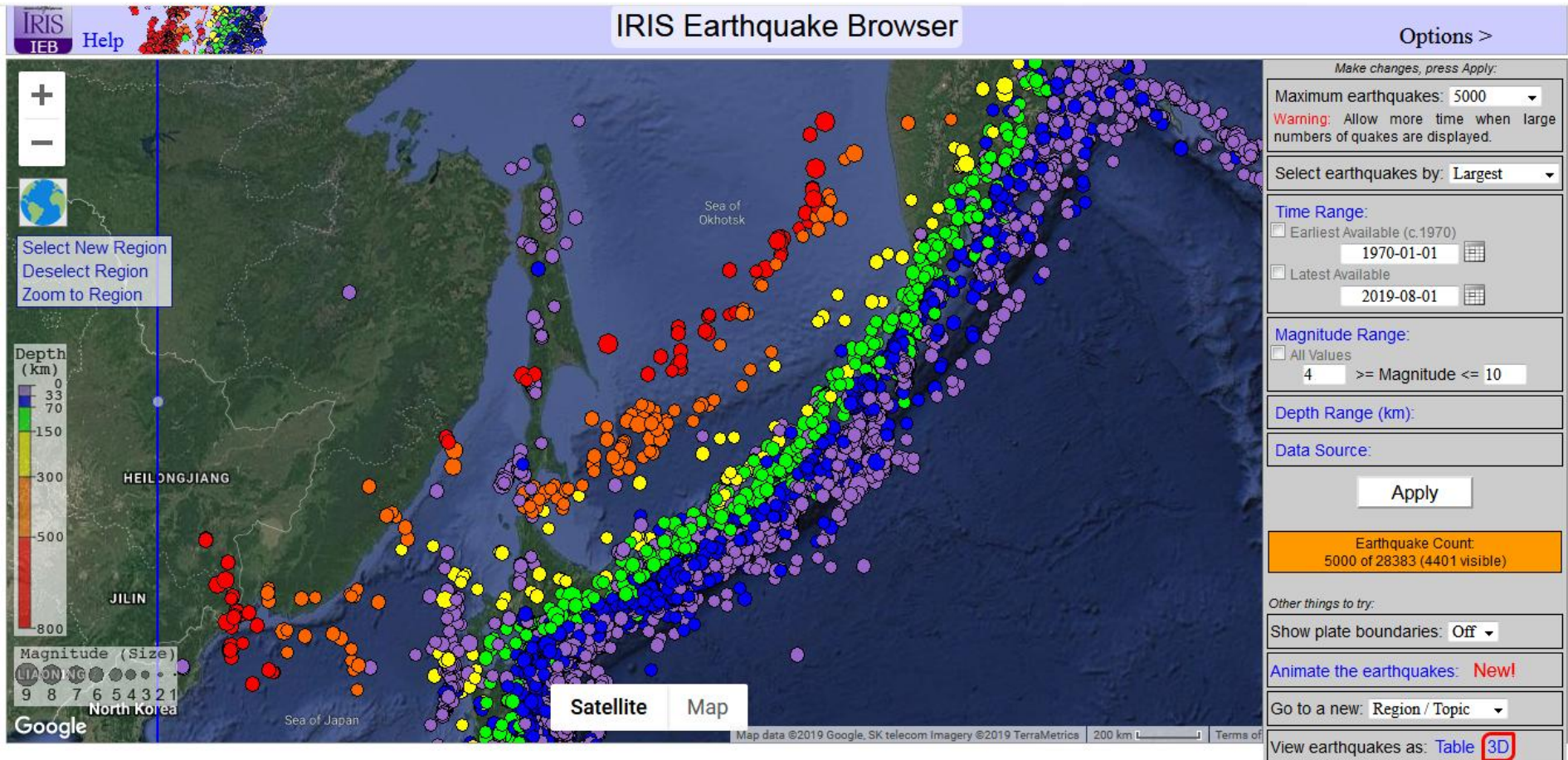
In Figure 3, we show the result of zooming in farther (the + button on the upper left), setting the **Prioritize** option to **Larger Events** (when there are greater than 5000 events in the selected area, plot more of the larger events as they are more significant than smaller events), and setting the **Time Range** to 1970 to 2019 (~50 years). The **Magnitude Range** is also set to M 4 to M 10, For worldwide earthquakes, the catalog of events may not be complete for magnitudes smaller than about 3. For earthquakes in a region where there are many seismograph stations, such as California, smaller events are likely to be recorded routinely. Then we selected **Apply** to obtain the map shown in Figure 3. Note that the number of events displayed (representative events within our selected area) is **5000**, although the **Earthquake count** dialog box (on the right) indicates that there was a total of **86,556 M4+** earthquakes in the area during the **1970 to 2019** time period. This detail of event size and number of events in a given time period will be useful to us later.





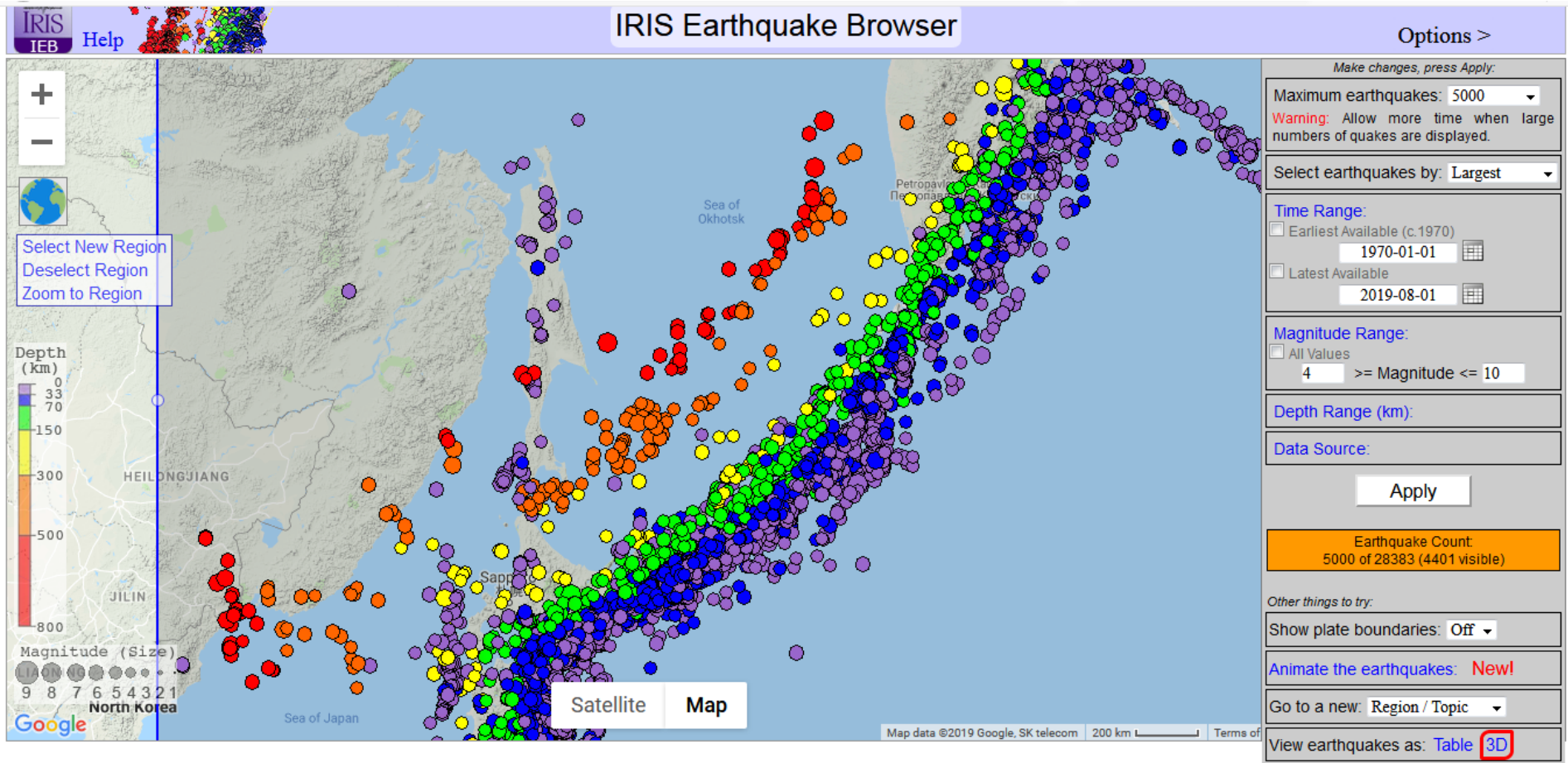
**Figure 3.** IEB map of the selected area with 5000 (out of 28383) M4+ events shown from the 1970-2019 time period. Note the color code of the plotted events. The colors generally go from purple to blue to green to yellow to orange to red as we go from the SE to NW across the earthquake zone. This color code indicates that the events describe a NW dipping zone of earthquake foci (hypocenters, including the depth of focus of the earthquake) – a pattern that is characteristic of a subduction zone (dipping slab of lithosphere in convergent plate boundaries).

**Figure 4** shows the same map as in **Figure 3**, except using the **Satellite** view base map option of the IEB. **Figure 5** shows the same map as in **Figure 3**, except using the **Terrain** view base map option of the IEB.



**Figure 4.** IEB map of the selected area from **Figure 3**, shown with the *Satellite* view option (selected from options at the bottom of the map on the web page). Note the bathymetry data for the oceans shows a deep sea trench (dark shaded area of bathymetry; at the convergence of two plates) near the shallow earthquakes in the Kamchatka/Sea of Okhotsk area.





**Figure 5.** IEB map of the selected area from **Figure 3**, shown with the **Terrain** map view option (selected from options at the bottom of the web page).

**b. The Frequency-Magnitude relation for earthquakes:** The Frequency-Magnitude relation (also called the Gutenberg-Richter relation, named after two seismologists who first suggested it) describes the frequency of earthquakes (how often they occur) in relation to their magnitude (how large they are). This relation has been known for over 70 years and is found to be characteristic of earthquake occurrences for the world and for seismically active regions of varying sizes. Recent Frequency-Magnitude data for the world is summarized in **Figure 6** from the USGS (web site no longer available; also see <https://earthquake.usgs.gov/earthquakes/browse/stats.php>).

## Frequency of Occurrence of Earthquakes

Magnitude	Average Annually
8 and higher	1 <sup>1</sup>
7 - 7.9	15 <sup>1</sup>
6 - 6.9	134 <sup>2</sup>
5 - 5.9	1319 <sup>2</sup>
4 - 4.9	13,000 (estimated)
3 - 3.9	130,000 (estimated)
2 - 2.9	1,300,000 (estimated)

<sup>1</sup> Based on observations since 1900.

These numbers have been recently updated, based on data from the [Centennial catalog](#) (from 1900 to 1999) and the [PDE](#) (since 2000).

<sup>2</sup> Based on observations since 1990.

## Magnitude vs. Ground Motion and Energy

Magnitude Change	Ground Motion Change (Displacement)	Energy Change
1.0	10.0 times	about 32 times
0.5	3.2 times	about 5.5 times
0.3	2.0 times	about 3 times
0.1	1.3 times	about 1.4 times

This table shows that a magnitude 7.2 earthquake produces 10 times more ground motion than a magnitude 6.2 earthquake, but it releases about 32 times more energy. The energy release best indicates the destructive power of an earthquake. See: [How much bigger is a magnitude 8.7 earthquake than a magnitude 5.8 earthquake?](#)

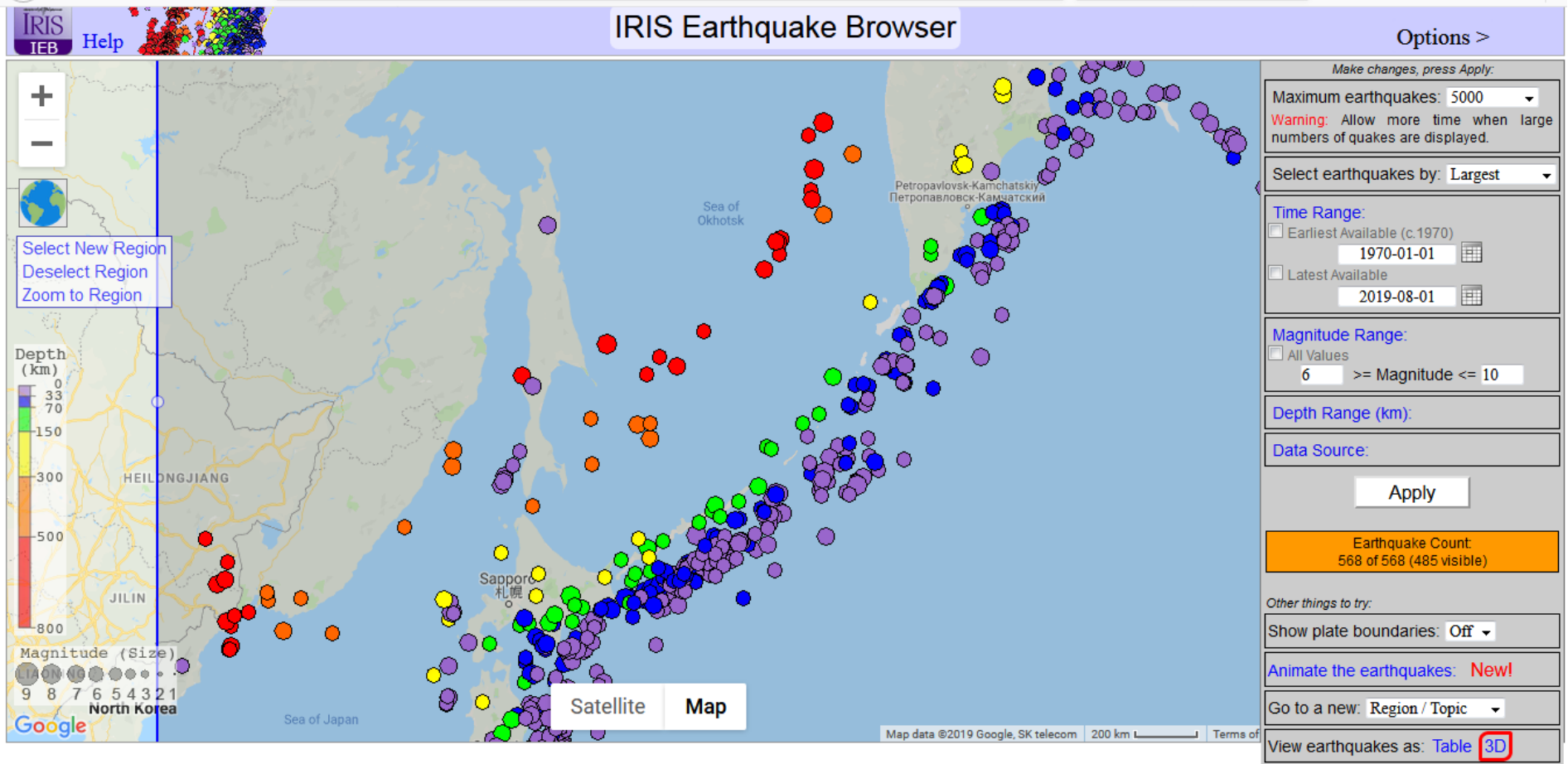
The USGS estimates that several million earthquakes occur in the world each year. Many go undetected because they hit remote areas or have very small magnitudes. The NEIC now locates about 50 earthquakes each day, or about 20,000 a year.

As more and more seismographs are installed in the world, more earthquakes can be and have been located. However, the number of large earthquakes (magnitude 6.0 and greater) has stayed relatively constant. See: [Are Earthquakes Really on the Increase?](#)

**Figure 6.** Left – Frequency of occurrence of earthquakes for the world. Right – Magnitude versus ground motion and energy. From the USGS – (<http://earthquake.usgs.gov/earthquakes/eqarchives/year/eqstats.php>).

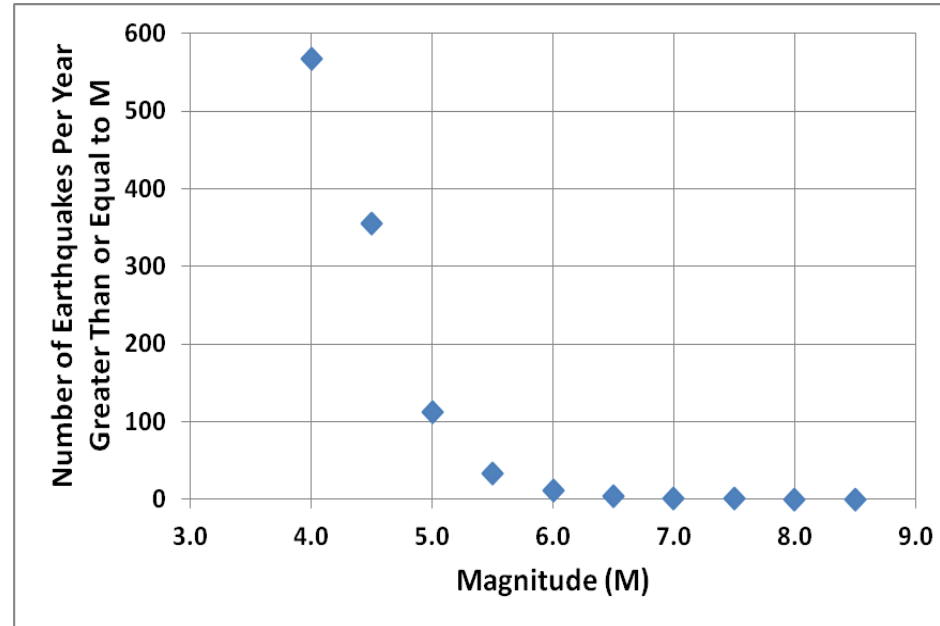
**c. Calculating and plotting a Frequency-Magnitude relation for the Kamchatka area:** We can calculate and plot a Frequency-Magnitude relation for the Kamchatka area (shown in *Figures 3 to 5*) using the IEB. The procedure is to select an area (a specific region such as the Kamchatka area shown in *Figures 3 to 5*), and a time period (we have chosen 1970-2019 – approximately a 50 year time period, because data in the earthquake catalog are fairly accurate for this time period and we would like to have a relatively long time period in order to determine a relationship that is representative of the area). Then, using the IEB, we determine the number of earthquakes of magnitude greater than or equal to 4 (M4+) that occurred in that area from 1970 to 2019. *Figure 3* shows the result. We then repeat the sorting process for magnitudes (M+) of 4.5, 5.0, 5.5, 6.0, etc., until there are no earthquakes in the selected area of that size or greater. **Set the maximum magnitude at 10 for all of these sorts so that you obtain the number of events greater than or equal to the minimum magnitude (such as M4+).** An additional example of the process, for magnitudes greater than equal to 5.0 (M5+) is shown in *Figure 7*. The resulting Table of earthquakes for the Kamchatka area is shown in *Figure 8a*. We then convert the number of events (for the approximately 50 year time period) to the number of events per year (see last column in the Table shown in *Figure 8a*) and plot the data (*Figure 8b*).





**Figure 7.** IEB map of the selected area with 568 M6+ events (note the **Magnitude Range** option on the right) shown from the 1970-2019 time period.

Magn.(M)	Num of M+	Num/yr
4.0	28383	567.660
4.5	17759	355.180
5.0	5624	112.480
5.5	1690	33.800
6.0	586	11.720
6.5	168	3.360
7.0	61	1.220
7.5	22	0.440
8.0	6	0.120
8.5	1	0.020

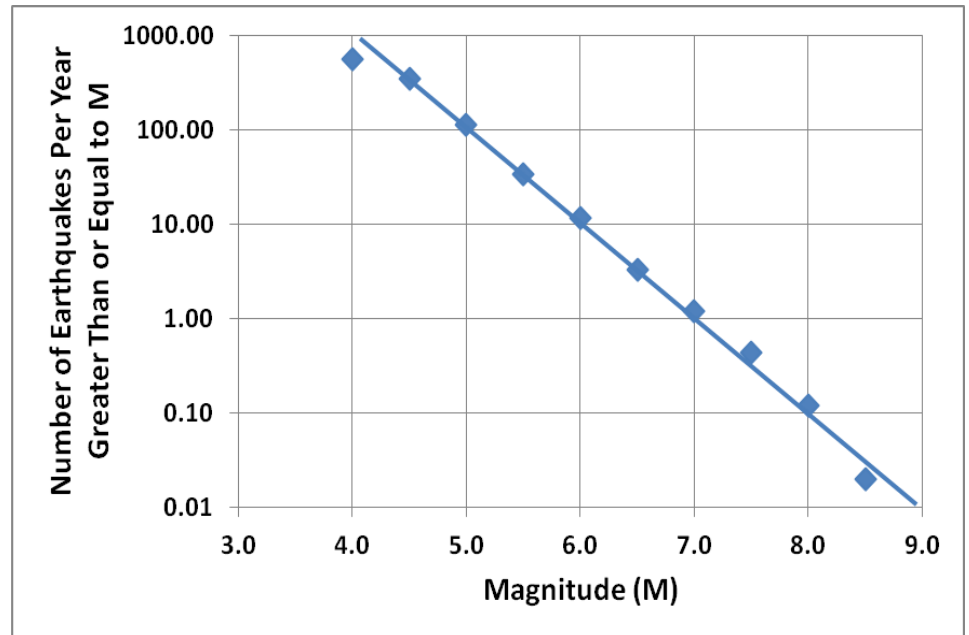


**Figure 8a.** Above, Left – Table of earthquake frequency (Kamchatka area shown in **Figures 3 to 5**, for the time period 1970 – 2019 (August 1), numbers of earthquakes for the values of magnitude  $M = 4+$  (magnitude 4 and greater), 4.5+, 5.0+, 5.5+, ... , 8.5+). The third column in the Table lists the number of earthquakes **per year** (we have used an approximate time period of 50 years for this calculation) for each magnitude cutoff value. **Figure 8b.** Above Right – Graph of the number of events per year of  $M+$  for the cutoff magnitudes. The data are plotted on a linear scale. Because the number of events per year ranges over more than four orders of magnitude, the data for  $M+$  values greater than 6 appear to plot on the zero line (Number per year = 0).

Because the number of events (and number of events per year) varies greatly with the minimum magnitudes ( $M+$ ) selected, we choose to use a **logarithmic scale** for the y-axis and re-plot the data in the graph from **Figure 8b** (see **Figure 9**). Note that the data now display an almost perfect straight line relationship. This relation can be used to make a very useful probability statement (based on past history) of how often earthquakes of a given size or larger, will occur in the selected area. For example, during the past fifty years, we observe that there has been an average of almost 12  $M6+$  (magnitude 6 or greater) earthquakes per year in the selected area. The average time between  $M6+$  events determined by this method is about one twelfth of a year, or about 30 days, for the  $M6+$  magnitude for the selected area) and is called the **recurrence interval**. Therefore, we can reasonably confidently forecast that there will be about twelve  $M6+$  earthquakes per year (or about one  $M6+$  event every 30 days, on the average) in this area in the future. As a simple test of this forecast, a search for earthquakes of magnitude  $M6+$  for the same area for the past 12 months (August 1, 2018 to July 31, 2019) found that there were 10  $M6+$  earthquakes ( $M6+$ ) in that year – not far off from the longer term forecast of 12  $M6+$  events. Of course, the statistical determination of the recurrence interval will be more accurate in areas with good seismograph coverage and over and long time periods.

This method works well (in a statistical sense) for nearly all magnitudes and for regions of the Earth from relatively small areas to the whole world (as illustrated in **Figure 6**).

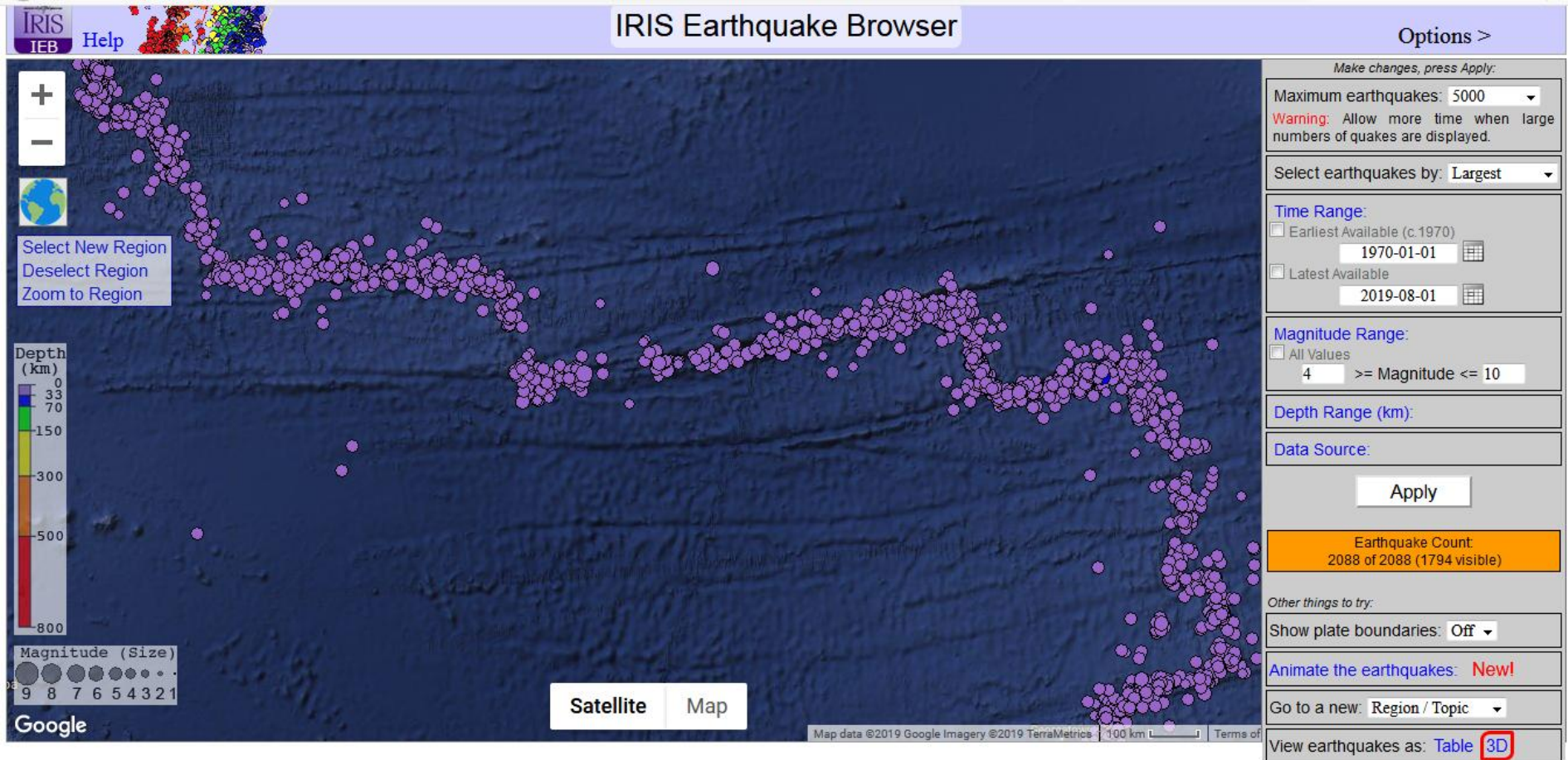
**Figure 9.** Right – Frequency-Magnitude graph (Kamchatka area shown in **Figure 3**, for the time period 1970-2019, numbers of earthquakes for the values of magnitude  $M = 4+$  (magnitude 4 and greater), 4.5+, 5.0+, 5.5+, ... , 8.5+ are shown on the graph; data are the same as in **Figure 8a**, left) using a logarithmic scale for the vertical axis. Note that the number of earthquakes for  $M4+$  is below the expected line, probably because the smaller magnitude earthquakes are not always observed (and their location and magnitude determined) from seismograph recordings. Also note that the data point for the  $M8.5+$  events is also slightly below the “best fit” line, probably because there has been only one  $M8.5+$  earthquake in the 50-year period. It would be expected that it would take a much longer time of observations to accurately determine the recurrence time for this area for events of magnitude 8.5 or greater.



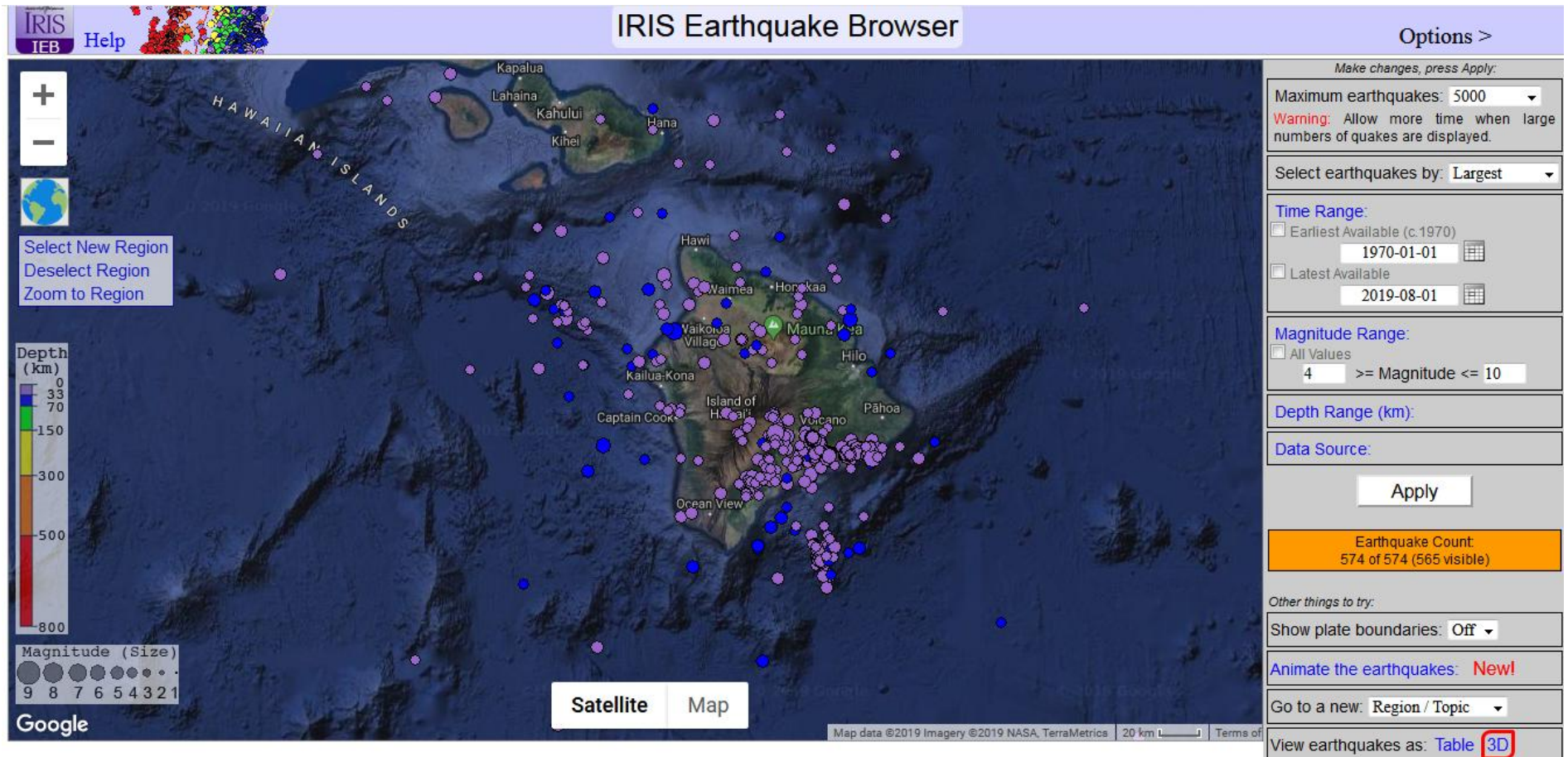
**d. Using the IEB to characterize earthquake activity of plate boundaries or other areas:** The IEB can be used to select (zoom in) and view earthquake activity associated with plate tectonic boundaries or other areas of seismicity. For example, the Kamchatka area and its earthquake activity is a good example of convergent plate boundary earthquakes. Mid-ocean ridge (divergent plate boundaries) and transform boundary earthquake activity for an area of the Atlantic Ocean is illustrated in **Figure 10**. Earthquakes associated with volcanic activity near the Island of Hawaii are illustrated in the image shown in **Figure 11**.

Maps of plate boundaries of the world and global earthquakes are shown for reference in **Figures 20 to 24**, below.





**Figure 10.** Earthquakes associated with mid-ocean ridges and transform faults of the Atlantic Ocean. The bathymetry is used as the base map for this IEB image. The ridge segments trend almost north-south. The transform faults that offset the mid-ocean ridge segments are almost east-west.

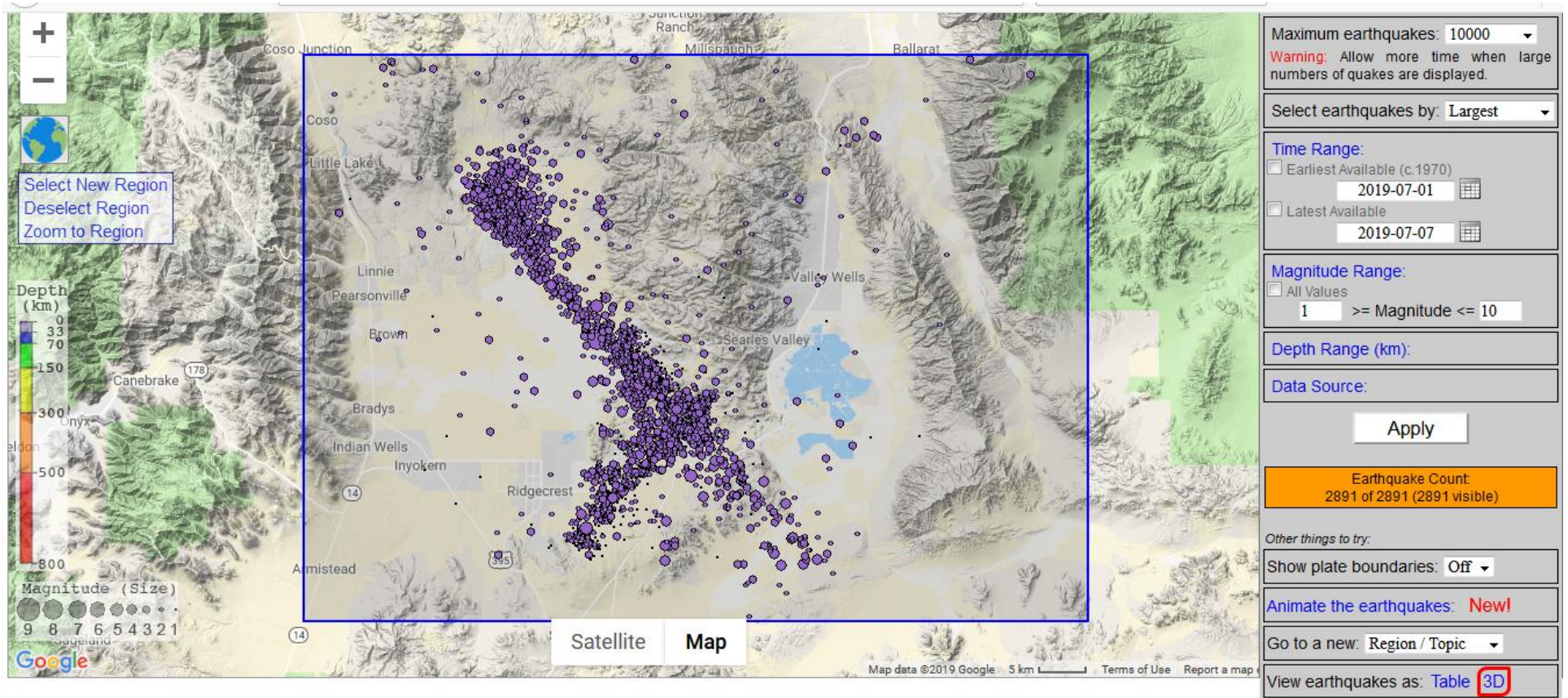


**Figure 11.** Earthquakes associated with volcanic activity on and near the Island of Hawaii. The bathymetry is used as the base map for this IEB image. Note the earthquake epicenters that extend south from the island. Many of these events are associated with the submarine volcano known as Loihi (about 2 km below sea level) that will likely be the next Hawaiian island (in a few tens of thousands or hundreds of thousands of years!). Another area of active seismicity is in the southeastern area of the island which corresponds to the area of active volcanic eruptions from late April to September of 2018. A summary of this activity is available at: [https://www.nps.gov/havo/planyourvisit/upload/PrelimSum\\_LERZ-Summit\\_2018\\_508.pdf](https://www.nps.gov/havo/planyourvisit/upload/PrelimSum_LERZ-Summit_2018_508.pdf).

**e. Using the IEB animation option and the July 2019 Ridgecrest, California earthquake sequence:** An interesting earthquake sequence occurred near Ridgecrest in southern California in July of 2019 (**Figure 12**) that provides an excellent opportunity to illustrate the use of the IEB animation option. After a time of relatively quiet earthquake activity, the sequence began with an M6.4 earthquake on July 4, 2019 and associated aftershocks. That event was followed by an M7.1 earthquake at 3:19:53 on July 6, 2019 (UTC time which would be 7 hours earlier in PDT in



California, or 8:19:53 P.M. on July 5). After the occurrence of the M7.1 event, and its associated aftershocks, the M6.4 event on July 4 would generally be considered a foreshock. The July 2019 Ridgecrest earthquake activity is shown in **Figure 12** from an IEB image for events of M1+ for the time period (UTC time) of July 1 – 7, 2019. There were 2891 M1+ earthquakes in this time period. A **Table** of earthquake activity for this time period for events of M4.5 or greater is shown in **Figure 13**. Note that all of the earthquakes have a depth of the focus of 12 km or less. The relatively shallow earthquake activity is common for Western U.S. events, probably due to relatively hot crust and upper mantle of that region. Additional information from the USGS on the July 2019 Ridgecrest earthquakes can be found at: <https://www.usgs.gov/media/images/2019-ridgecrest-earthquake-sequence-july-4-2019-july-16-2019-0>. An additional interesting update analysis, including discussion of the two fault zone directions evident in the seismicity map (**Figure 12**) of the July 2019 Ridgecrest earthquake sequence can be found at: <https://temblor.net/earthquake-insights/ridgecrest-earthquake-shut-down-cross-fault-aftershocks-9249/>.



**Figure 12.** IEB view of earthquakes from the July 2019 Ridgecrest sequence. Earthquakes shown are 2891 magnitude 1 and larger events from July 1-7, 2019



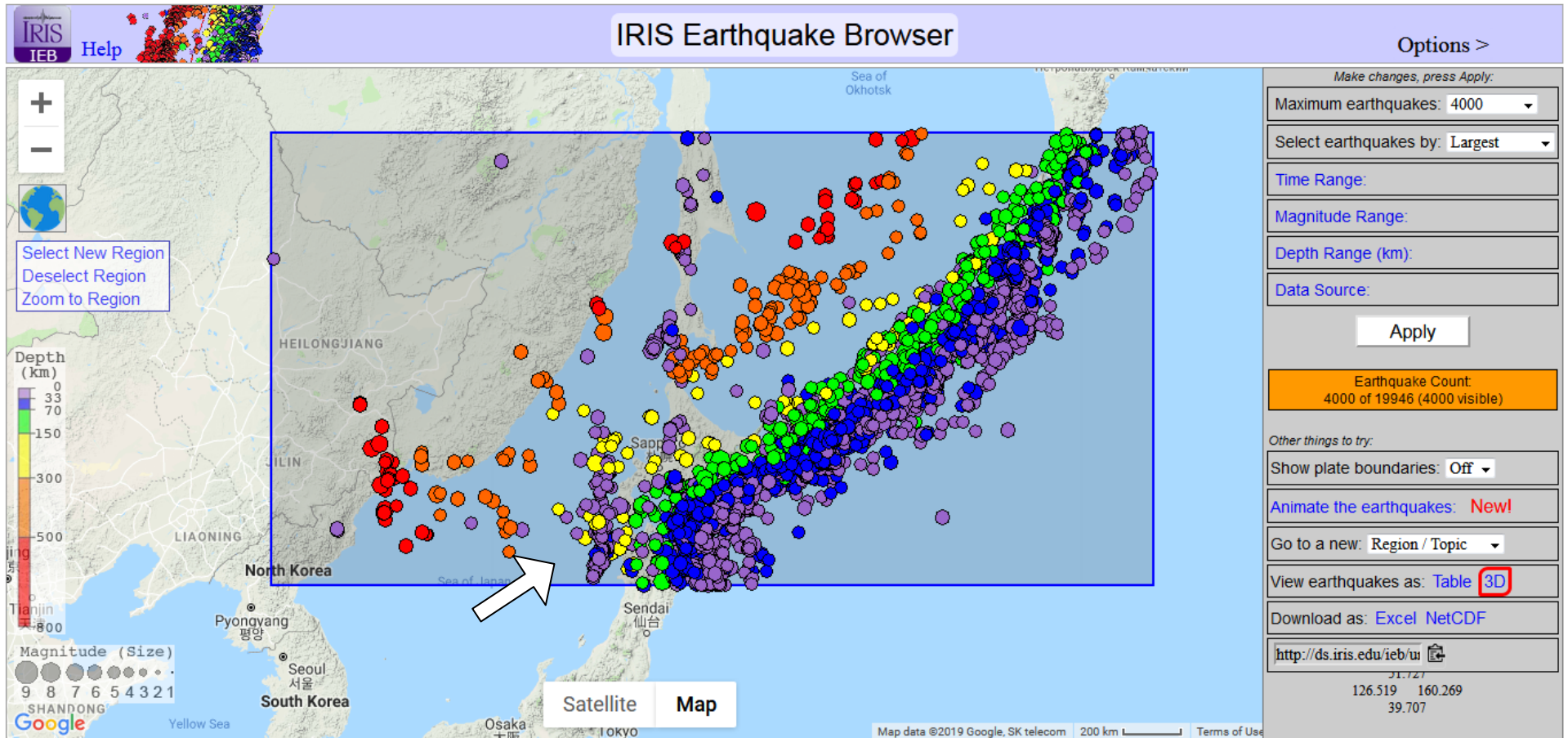
Year	Month	Day	Time UTC	Mag	Lat	Lon	Depth km	Region	IRIS ID	Timestamp
2019	7	4	17:33:49	6.4	35.7052	-117.506	10.7	CENTRAL CALIFORNIA	<a href="#">11056847</a>	1562261629
2019	7	4	18:39:44	4.6	35.6013	-117.597	2.8	CENTRAL CALIFORNIA	<a href="#">11056825</a>	1562265584
2019	7	4	18:56:06	4.7	35.716	-117.56	1.9	CENTRAL CALIFORNIA	<a href="#">11056822</a>	1562266566
2019	7	4	19:21:32	4.5	35.6715	-117.4788	5.2	CENTRAL CALIFORNIA	<a href="#">11056842</a>	1562268092
2019	7	5	11:07:53	5.4	35.7603	-117.575	7	CENTRAL CALIFORNIA	<a href="#">11057796</a>	1562324873
2019	7	6	3:16:32	4.9	35.7253	-117.5535	0.9	CENTRAL CALIFORNIA	<a href="#">11058873</a>	1562382992
2019	7	6	3:19:53	7.1	35.7695	-117.5993	8	CENTRAL CALIFORNIA	<a href="#">11058875</a>	1562383193
2019	7	6	3:22:03	4.6	35.9217	-117.729	8.2	CENTRAL CALIFORNIA	<a href="#">11058874</a>	1562383323
2019	7	6	3:22:17	4.9	35.748	-117.5457	3.9	CENTRAL CALIFORNIA	<a href="#">11088193</a>	1562383337
2019	7	6	3:22:27	4.8	35.6172	-117.4275	8.4	CENTRAL CALIFORNIA	<a href="#">11088216</a>	1562383347
2019	7	6	3:22:35	5.1	35.6167	-117.4302	9.3	CENTRAL CALIFORNIA	<a href="#">11088882</a>	1562383355
2019	7	6	3:22:48	5	35.891	-117.7365	9.1	CENTRAL CALIFORNIA	<a href="#">11060785</a>	1562383368
2019	7	6	3:23:19	4.8	35.861	-117.6778	6.8	CENTRAL CALIFORNIA	<a href="#">11088170</a>	1562383399
2019	7	6	3:23:34	4.5	35.5685	-117.5165	10.8	CENTRAL CALIFORNIA	<a href="#">11088177</a>	1562383414
2019	7	6	3:23:50	4.8	35.8032	-117.6178	11.4	CENTRAL CALIFORNIA	<a href="#">11058932</a>	1562383430
2019	7	6	3:25:27	4.6	35.8607	-117.6708	10.3	CENTRAL CALIFORNIA	<a href="#">11058963</a>	1562383527
2019	7	6	3:27:07	4.5	35.9138	-117.7258	8	CENTRAL CALIFORNIA	<a href="#">11058945</a>	1562383627
2019	7	6	3:29:32	4.5	35.9028	-117.7115	3.2	CENTRAL CALIFORNIA	<a href="#">11060333</a>	1562383772
2019	7	6	3:32:46	4.5	35.8903	-117.7303	6.2	CENTRAL CALIFORNIA	<a href="#">11060109</a>	1562383966
2019	7	6	3:36:16	4.6	35.9028	-117.7338	7.3	CENTRAL CALIFORNIA	<a href="#">11059109</a>	1562384176
2019	7	6	3:47:53	5.4	35.903	-117.7458	3.4	CENTRAL CALIFORNIA	<a href="#">11058952</a>	1562384873
2019	7	6	3:50:59	5	35.9002	-117.7057	6.6	CENTRAL CALIFORNIA	<a href="#">11059175</a>	1562385059
2019	7	6	4:07:04	5	35.5553	-117.5237	5.6	CENTRAL CALIFORNIA	<a href="#">11059137</a>	1562386024
2019	7	6	4:13:06	4.7	35.5887	-117.6153	5	CENTRAL CALIFORNIA	<a href="#">11058907</a>	1562386386
2019	7	6	4:18:55	5.4	35.9102	-117.6848	7.4	CENTRAL CALIFORNIA	<a href="#">11059038</a>	1562386735
2019	7	6	4:36:55	5	35.9	-117.7377	1.9	CENTRAL CALIFORNIA	<a href="#">11058937</a>	1562387815
2019	7	6	6:01:51	4.6	35.9112	-117.7388	5.1	CENTRAL CALIFORNIA	<a href="#">11058902</a>	1562392911
2019	7	6	8:32:57	4.6	35.639	-117.4913	3.1	CENTRAL CALIFORNIA	<a href="#">11059154</a>	1562401977
2019	7	6	9:28:28	4.9	35.898	-117.7272	4	CENTRAL CALIFORNIA	<a href="#">11059153</a>	1562405308
2019	7	6	9:29:20	4.7	35.8815	-117.7173	5.6	CENTRAL CALIFORNIA	<a href="#">11059313</a>	1562405360
2019	7	6	9:30:41	4.5	35.9098	-117.7323	4.2	CENTRAL CALIFORNIA	<a href="#">11059312</a>	1562405441

2019	7	6	13:06:55	4.5	35.9283	-117.705	2.4	CENTRAL CALIFORNIA	<a href="#">11059589</a>	1562418415
2019	7	6	23:50:41	4.5	35.8235	-117.663	6.5	CENTRAL CALIFORNIA	<a href="#">11060418</a>	1562457041

**Figure 13.** Table of earthquakes shown in **Figure 12** that are of magnitude 4.5 or greater. There are two “main shocks” in the sequence – the first is a magnitude 6.4 event on July 4, 2019, and the second is a magnitude 7.1 event on July 6, 2019. After the M7.1 event occurred, the first large event (M6.4 on July 4, 2019) is generally viewed as a “foreshock”. The Table was generated using the **Table** option on the IEB lower right on **Figure 12**. The events were ordered by time using the **Timestamp** option in the IEB table result and then converted to an Excel file.

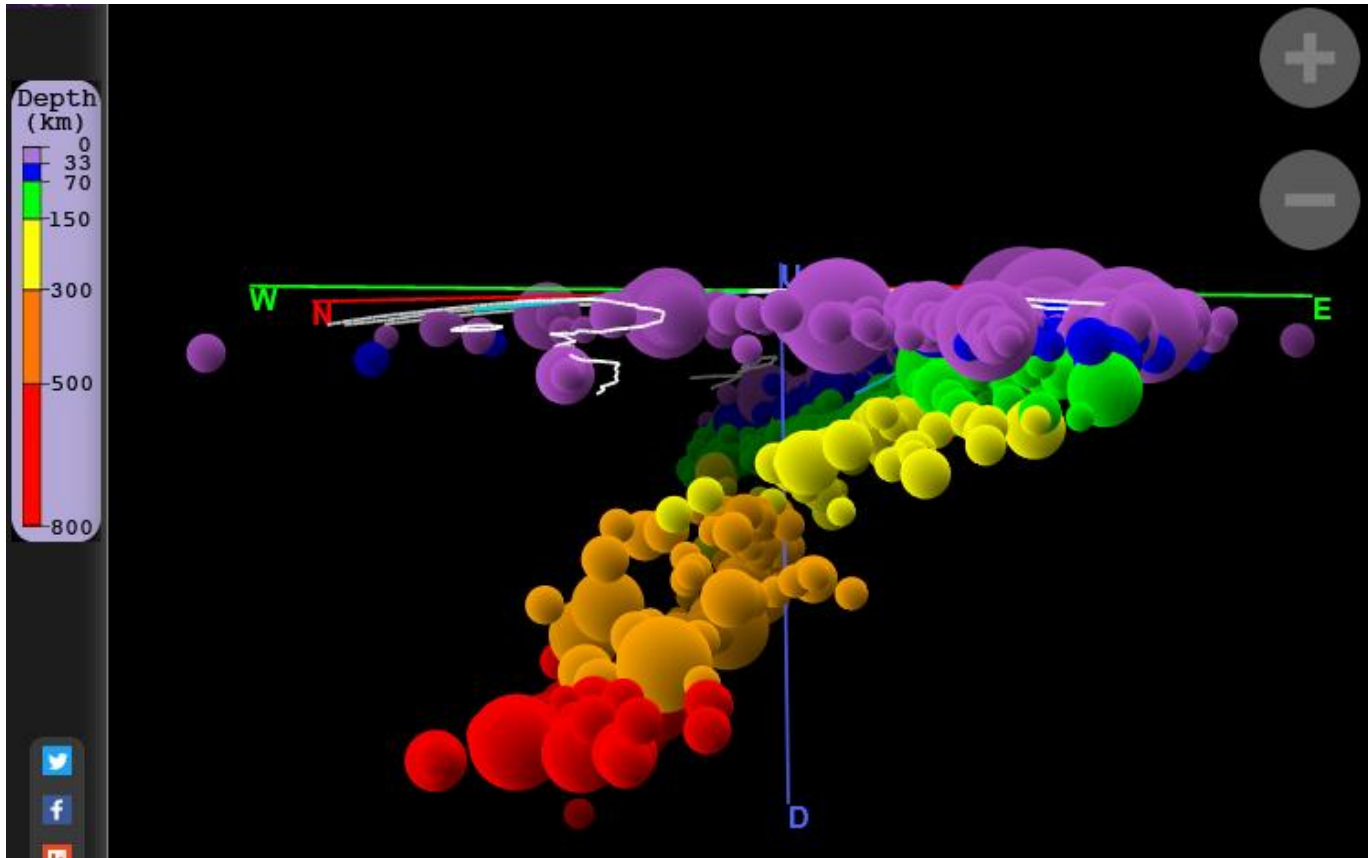
The IEB can be used to view earthquake activity through time. To use this option, **select a region** (such as that shown in **Figure 12** for the July, 2019 earthquakes), **time range**, and **magnitude range**, as described above. Then click on the **Animate the Earthquakes** button in the **Options** menu on the right side of the screen. An **Animate the Earthquakes** dialog box will appear. At the bottom of the dialog box, a large blue dot and a graph of earthquake activity through time will appear. Clicking on the **large right arrow** in the dialog box will cause the earthquake epicenters to appear through time. The large **blue dot** will move to the right below the graph of earthquake activity through time to show the progression with time. You can control the **speed** with the **up and down arrows** in the dialog box. It’s possible to capture a screen image of the animation to produce a video that you can save to view at any time. An example is the IEB screen captured video of the July, 2019 earthquake sequence (events in **Figure 12**) that can be accessed at: **Ridgecrest earthquake video**, 28.0 MB: <http://web.ics.purdue.edu/~braile/new/Video.2019.Ridgecrest.EQ.wmv>. The screen image video was captured with the free software called **Free Cam 8**.

**f. Using the IEB animation option and 3-D viewer for the Kamchatka area:** An additional feature of the IEB is a 3-D viewer. Using the 3-D viewer allows viewing earthquake hypocenters (location of the epicenter, such as Latitude and Longitude, and depth) with the ability to rotate the view to better visualize the locations of the earthquakes in three dimensions. To use the 3-D viewer (after earthquakes for a region have been accessed for an area as illustrated above) select the **3D** option at the lower right in the **Options** list. The 3-D viewer is most useful for earthquakes in a relatively small area or earthquake patterns that are evident in both surface location and depth. An excellent example is viewing a dipping slab of lithosphere in a subduction zone a feature that was already highlighted (in 2-D) in the Kamchatka area in **Figures 3-5**. In **Figure 14**, we show relatively straight segment of the subduction zone that trends southwest to northeast. Note the color codes for depth of the earthquakes from purple for shallow events to red for the deepest events. **Figure 15** shows a 3-D view of the hypocenters as if viewing them from a large distance from a location about 300 km below the surface of the Earth.



**Figure 14.** Epicenters of 4000 earthquakes in the Kamchatka subduction zone. Note color code indicating depth of the earthquakes. The white arrow shows the direction of the view in the subsurface that produces the 3-D view in Figure 14.

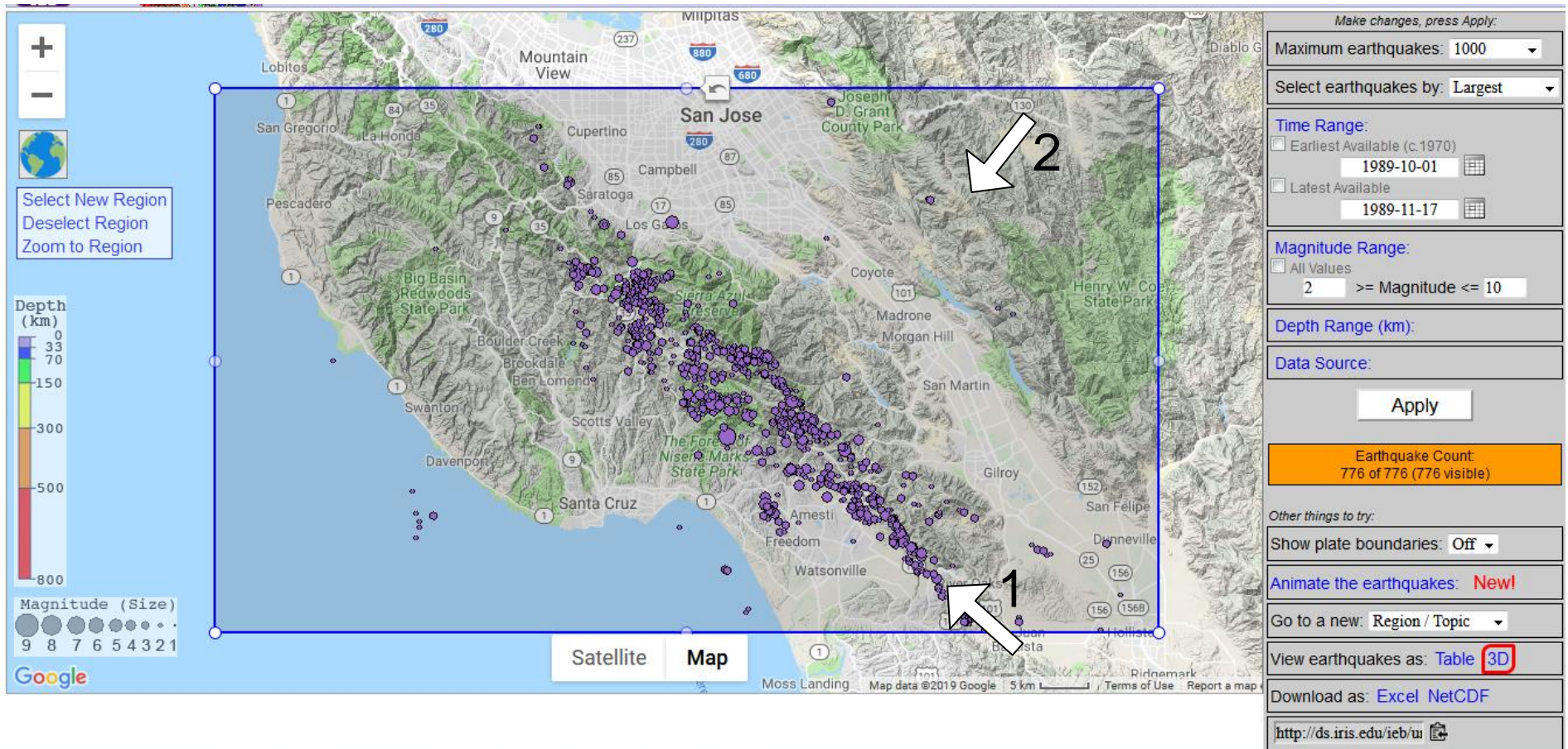




**Figure 15.** IEB 3-D view of earthquake hypocenters from **Figure 14**. By moving the cursor on the IEB 3-D screen view, the earthquake locations are projected onto a vertical cross section equivalent to viewing the hypocenters projected onto a vertical plane. It takes some time to obtain the “best” 3-D view and you can move the cursor around to explore different views. The approximate direction of the view (on the Earth’s surface) is shown by the large arrow on the IEB map on **Figure 14**. The Earth’s surface is approximately indicated by the green and red lines near the top of the image. Note the color code (and scale on the left) of the hypocenters with purple events being shallowest (from 0 to 33 km deep) and red events deepest (greater than 500 km deep). The size of the spheres is proportional to the magnitude. The direction of the view is from the southwest to the northeast (see arrow on **Figure 14**). Note that the subducted lithospheric slab (approximately indicated by the dipping zone of earthquakes) is evident from the alignment of the hypocenters and has an angle of dip of about 45 degrees.

**g. Using the IEB animation option and 3-D viewer for the October 1989 Loma Prieta earthquake:** Using the 3-D viewer for the Ridgecrest events is definitely possible, but the intersection of the two fault zones and length of the NW trending fault zone results in a somewhat complicated 3-D view. A better example of the capability of the **3-D viewer** is illustrated by the relatively straight fault zone (related to the San Andreas fault

system) associated with the M6.9 October 18 (UTC time), 1989 Loma Prieta earthquake in central California. That earthquake is also known and the “World Series earthquake” because it occurred at 5:04 p.m. October 17 local time, just as the third game of the 1989 World Series baseball game at Candlestick Park between the San Francisco Giants and the Oakland A’s was beginning. **Figure 16** shows the IEB image for earthquake epicenters for magnitude 2 and above from October 1 to November 17, 1989 in the central California area. A video of the Loma Prieta earthquake activity for this time period from the **IEB animation option** (using the same IEB options and screen capture software as described in **section e.**, above) is at: <http://web.ics.purdue.edu/~braile/new/Video.1989.LomaPrieta.EQ.wmv> (13.5 MB).



**Figure 16.** IEB image of epicenters of the Loma Prieta earthquakes of magnitude 2 and greater (776 earthquakes; a small number of the epicenters shown on the map are not near the faulted area and are not likely related to the main shock earthquake or its aftershocks) for the time period October 1 to November 17, 1989. A **Table** showing events of magnitude 4.0 and above is shown in **Figure 17**.

The M6.9 Loma Prieta earthquake was preceded by two moderate earthquakes (an M5.3 event in June of 1988 and an M5.4 event in August of 1989 that were located within 5 km of the eventual M6.9 Loma Prieta main shock epicenter) considered to be foreshocks, and seismologists had identified the area as a location that would likely produce a large earthquake. See the Wikipedia website ([https://en.wikipedia.org/wiki/1989\\_Loma\\_Prieta\\_earthquake](https://en.wikipedia.org/wiki/1989_Loma_Prieta_earthquake)) for additional information, and be sure to view the **ground shaking animation** that is linked to that page). U.S. Geological Survey documents related to the Loma Prieta earthquake are also available: (initial report summary: <https://earthquake.usgs.gov/earthquakes/events/1989lomaprieta/>; access to an extensive catalog of photographs of ground faulting and damage to structures: <https://pubs.usgs.gov/dds/dds-29/>; and an extensive USGS Professional Paper containing technical data and analysis of the earthquake and related damage: <https://pubs.usgs.gov/pp/pp1550/>).

The earthquake resulted in 63 deaths, including 42 people who were crushed to death by collapse of the Interstate 880 Cypress Viaduct (see photo in *Figure 17*). In addition, there were 3757 people injured and the quake caused about 6 billion dollars (1988 dollars) in building, road and property damage. Despite these large numbers, the injuries and fatalities were very likely reduced because interest in the baseball game (both teams from the San Francisco Bay area) caused rush hour traffic to be reduced (fewer vehicles on the 880 Cypress Viaduct and other roads) and more people in their homes for the game.

Year	Month	Day	Time UTC	Mag	Lat	Lon	Depth km	Region	IRIS ID	Timestamp
1989	10	18	0:04:14	6.9	37.0608	-121.7895	19.0	CENTRAL CALIFORNIA	<a href="#">3124823</a>	624672254
1989	10	18	0:07:08	5.1	37	-121.9	14	CENTRAL CALIFORNIA	<a href="#">3124842</a>	624672428
1989	10	18	0:07:44	5	37	-121.9	14	CENTRAL CALIFORNIA	<a href="#">3124845</a>	624672464
1989	10	18	0:08:20	4.8	37	-121.9	14	CENTRAL CALIFORNIA	<a href="#">3124855</a>	624672500
1989	10	18	0:08:53	4.3	37	-121.9	14	CENTRAL CALIFORNIA	<a href="#">3124866</a>	624672533
1989	10	18	0:09:57	4	37	-121.9	14	CENTRAL CALIFORNIA	<a href="#">3124869</a>	624672597
1989	10	18	0:11:47	4.2	37	-121.9	14	CENTRAL CALIFORNIA	<a href="#">3124875</a>	624672707
1989	10	18	0:12:37	4.6	37	-121.9	14	CENTRAL CALIFORNIA	<a href="#">3124885</a>	624672757
1989	10	18	0:13:02	4.6	37	-121.9	14	CENTRAL CALIFORNIA	<a href="#">3124892</a>	624672782
1989	10	18	0:15:10	5	37	-121.9	14	CENTRAL CALIFORNIA	<a href="#">3124902</a>	624672910
1989	10	18	0:16:51	4.2	37	-121.9	14	CENTRAL CALIFORNIA	<a href="#">3124910</a>	624673011
1989	10	18	0:17:26	4	37	-121.9	14	CENTRAL CALIFORNIA	<a href="#">3124920</a>	624673046
1989	10	18	0:19:12	4.1	37	-121.9	14	CENTRAL CALIFORNIA	<a href="#">3124933</a>	624673152
1989	10	18	0:25:03	5	36.9434	-121.8801	6.3	CENTRAL CALIFORNIA	<a href="#">3124974</a>	624673503
1989	10	18	0:30:40	4.2	37.0787	-121.9696	5	CENTRAL CALIFORNIA	<a href="#">3124991</a>	624673840
1989	10	18	0:38:27	4.3	37.1319	-122.0055	18.6	CENTRAL CALIFORNIA	<a href="#">3125031</a>	624674307



1989	10	18	0:41:22	4.8	37.181	-121.8775	1	CENTRAL CALIFORNIA	<a href="#">3125054</a>	624674482
1989	10	18	0:45:38	4	36.8636	-121.7983	15.2	CENTRAL CALIFORNIA	<a href="#">3125067</a>	624674738
1989	10	18	2:15:48	4.4	36.9777	-121.7575	3	CENTRAL CALIFORNIA	<a href="#">3125318</a>	624680148
1989	10	18	2:26:06	4.1	36.9982	-121.8	16.7	CENTRAL CALIFORNIA	<a href="#">3125342</a>	624680766
1989	10	18	3:23:55	4	37.1272	-122.0285	21.7	CENTRAL CALIFORNIA	<a href="#">3125569</a>	624684235
1989	10	18	4:16:32	4.1	37.0219	-121.9204	15.5	CENTRAL CALIFORNIA	<a href="#">3125681</a>	624687392
1989	10	18	4:17:35	4	37.1683	-121.9185	16	CENTRAL CALIFORNIA	<a href="#">3125694</a>	624687455
1989	10	18	4:50:25	4.6	37.0859	-122.0517	8.1	CENTRAL CALIFORNIA	<a href="#">3125771</a>	624689425
1989	10	18	5:18:33	4.5	36.9641	-121.8391	18.3	CENTRAL CALIFORNIA	<a href="#">3125810</a>	624691113
1989	10	18	6:39:09	4.6	36.9052	-121.738	9	CENTRAL CALIFORNIA	<a href="#">3125972</a>	624695949
1989	10	18	10:22:03	4.3	36.9324	-121.8593	10.6	CENTRAL CALIFORNIA	<a href="#">3126201</a>	624709323
1989	10	19	9:53:49	4.3	36.8856	-121.7706	13.6	CENTRAL CALIFORNIA	<a href="#">3127874</a>	624794029
1989	10	19	10:14:34	4.6	36.9231	-121.859	13	CENTRAL CALIFORNIA	<a href="#">3127902</a>	624795274
1989	10	20	0:18:19	4.2	37.0208	-122.0047	19.3	CENTRAL CALIFORNIA	<a href="#">3128773</a>	624845899
1989	10	21	0:49:42	4.4	37.0193	-121.8724	17.9	CENTRAL CALIFORNIA	<a href="#">3129988</a>	624934182
1989	10	21	22:14:55	4.5	37.0022	-121.9827	17.6	CENTRAL CALIFORNIA	<a href="#">3131028</a>	625011295
1989	10	22	14:24:35	4.1	36.9597	-121.9741	26	CENTRAL CALIFORNIA	<a href="#">3131606</a>	625069475
1989	10	25	1:27:25	4.6	37.0423	-121.8709	15	CENTRAL CALIFORNIA	<a href="#">3134797</a>	625282045
1989	10	25	13:00:41	4.1	36.8603	-121.7066	18.7	CENTRAL CALIFORNIA	<a href="#">3135343</a>	625323641
1989	10	25	22:01:48	4	36.9721	-121.8109	22.7	CENTRAL CALIFORNIA	<a href="#">3135848</a>	625356108
1989	10	26	9:01:28	4	37.0107	-121.9361	22.2	CENTRAL CALIFORNIA	<a href="#">3136255</a>	625395688
1989	10	30	11:17:12	4.1	37.0335	-121.8638	22.2	CENTRAL CALIFORNIA	<a href="#">3141633</a>	625749432
1989	11	1	8:03:17	4.4	37.0554	-121.8895	17.3	CENTRAL CALIFORNIA	<a href="#">3109269</a>	625910597
1989	11	2	5:50:10	4.5	37.0127	-121.8601	15.5	CENTRAL CALIFORNIA	<a href="#">3111524</a>	625989010
1989	11	5	1:30:41	4	37.0421	-121.974	23	CENTRAL CALIFORNIA	<a href="#">3116004</a>	626232641
1989	11	5	13:37:32	4.2	37.0237	-121.9729	24.3	CENTRAL CALIFORNIA	<a href="#">3116698</a>	626276252
1989	11	7	23:42:36	4.4	37.1672	-122.0478	20.8	CENTRAL CALIFORNIA	<a href="#">3119863</a>	626485356

**Figure 17.** Table of earthquakes of magnitude 4.0 or greater from October 1 to November 17, 1989 that are part of the Loma Prieta earthquake sequence.

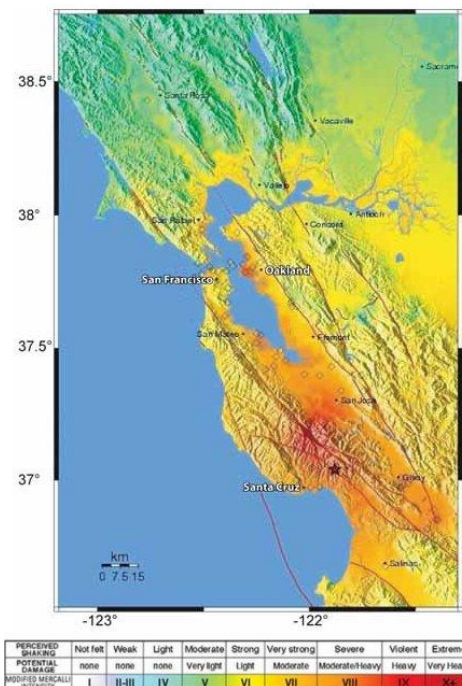
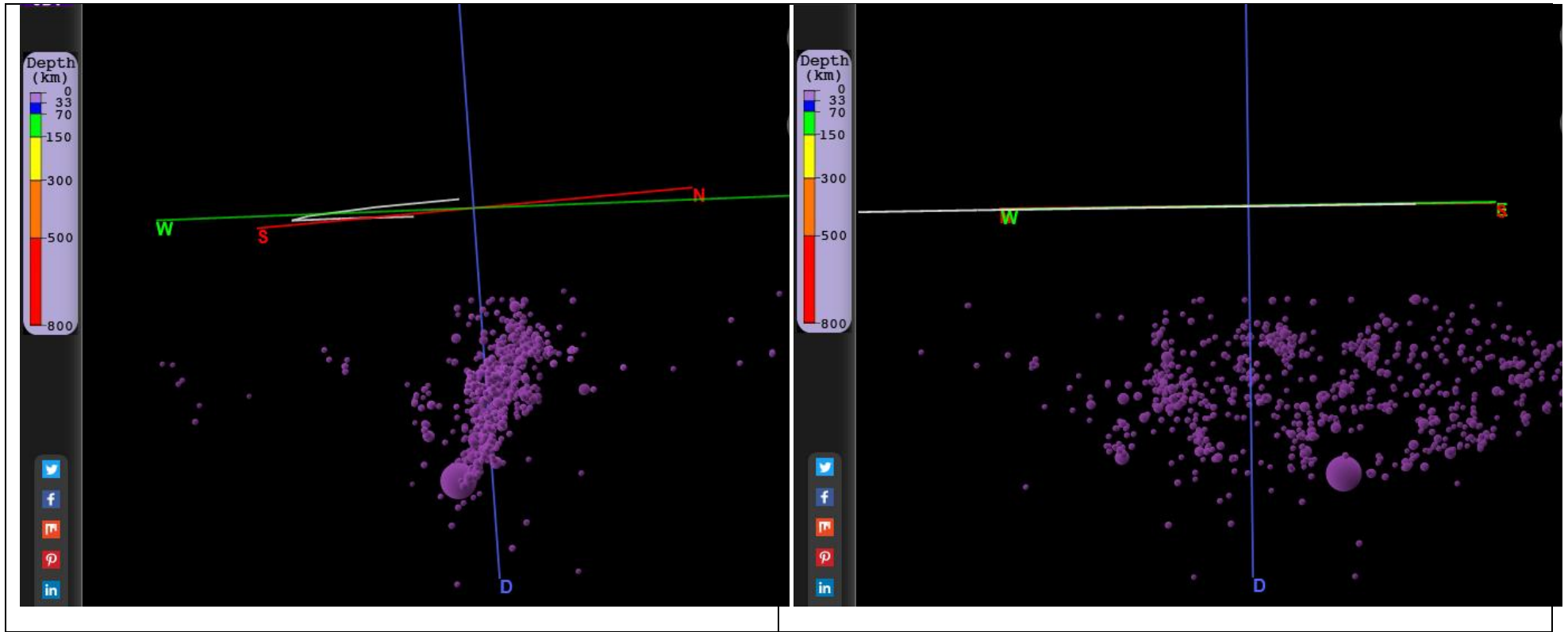


Image and photos from the 1989 October 18, Loma Prieta earthquake web pages on Wikipedia ([https://en.wikipedia.org/wiki/1989\\_Loma\\_Prieta\\_earthquake](https://en.wikipedia.org/wiki/1989_Loma_Prieta_earthquake)): from left to right: shake map of ground shaking intensity (color code is Modified Mercalli intensity); photo of the collapsed Interstate 880 Cyprus Viaduct, Oakland, California; damage to townhouses in the Marina district of San Francisco, illustrating “soft first story” failure.



**Figure 18.** Shake map for the Loma Prieta earthquake and photos of damage caused by M6.9 the Loma Prieta earthquake.

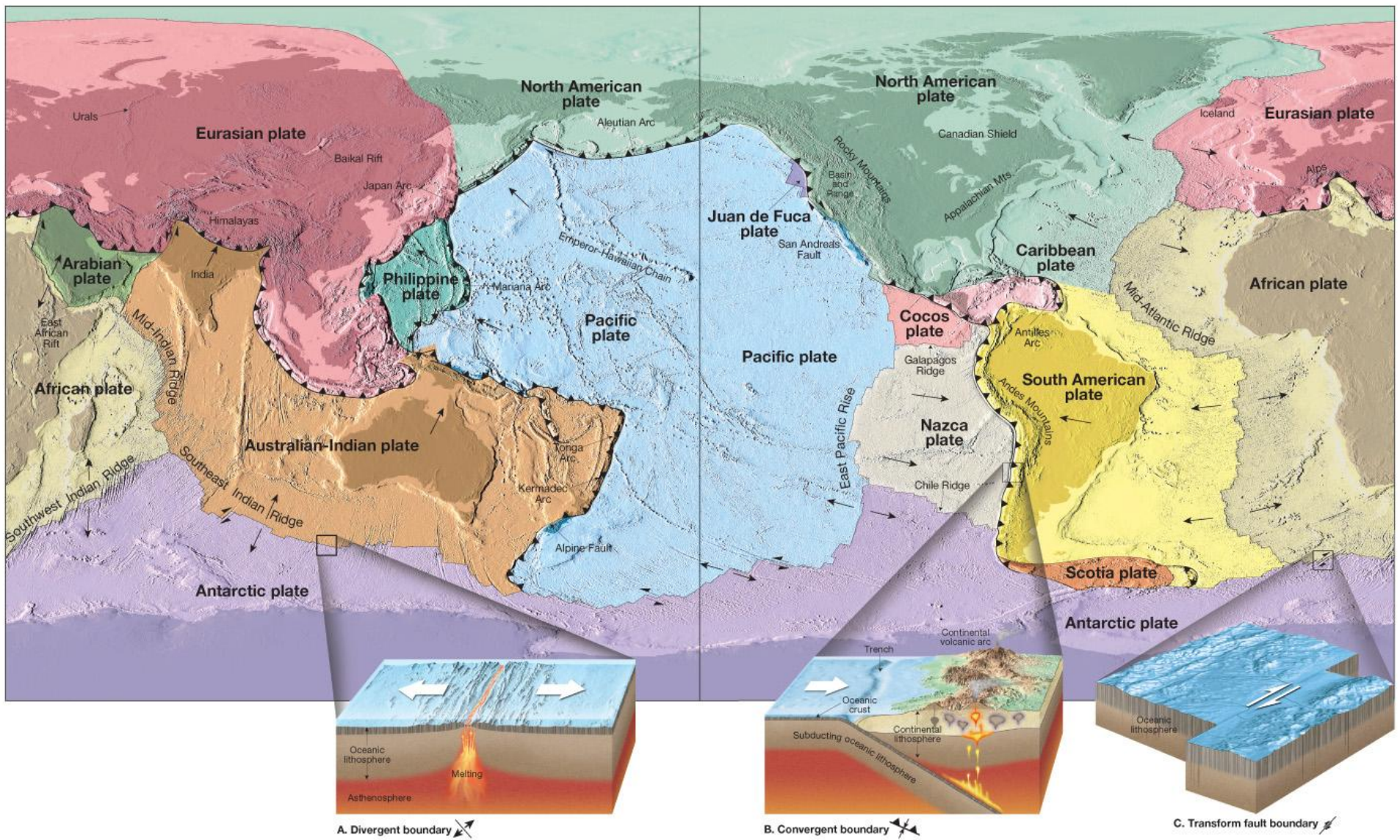
The **IEB 3-D viewer** option was used to create two 3-D views (**Figure 19**) for the hypocenters of the 1989 Loma Prieta earthquake sequence. The main shock earthquake (M6.9) occurred near the largest depth (19 km) of the majority of earthquakes in the sequence. The two 3-D views are described in **Figure 19** and correspond to views along the fault plane and from a distance looking toward the fault plane as shown by the arrows in **Figure 16**. The **Figure 19** caption describes the views. As is the usual case with large earthquakes, the aftershocks approximately identify the area of the fault plane that ruptured, and the magnitude of the earthquake and energy released is directly related to the area of the fault plane that slipped .



**Figure 19.** IEB 3-D view of earthquake hypocenters for the Loma Prieta area earthquakes (10/1/1989 – 11/17/1989). The map view of epicenters is shown in **Figure 16**. **Left Image:** view from a depth of about 10 km from southeast to northwest (corresponding to the direction of **arrow number 1** in **Figure 16**). The red and green lines near the top of the image approximately represent the Earth's surface. Most of the earthquakes were at a depth of 5-25 km. The dot size is proportional to the magnitude of the event. The large dot is the 10/18/1989 M6.9 main shock event at a depth of 19 km. The view is approximately along the Loma Prieta earthquake fault plane so the hypocenters are projected along that plane showing that the majority of events in this sequence were on or close to the fault plane which dips steeply to the southwest. **Right Image:** View of the hypocenters from northeast to southwest (corresponding to the direction of **arrow number 2** in **Figure 16**) showing the earthquakes along the fault plane (a total distance of about 75 km). The dot size is proportional to the magnitude of the event. The large dot is the 10/18/1989 M6.9 main shock event at a depth of 19 km.

**3. Earthquakes and Plate Tectonics:** Some useful plate tectonic maps are provided below. Earthquakes and active volcanoes are associated with the plate boundaries.

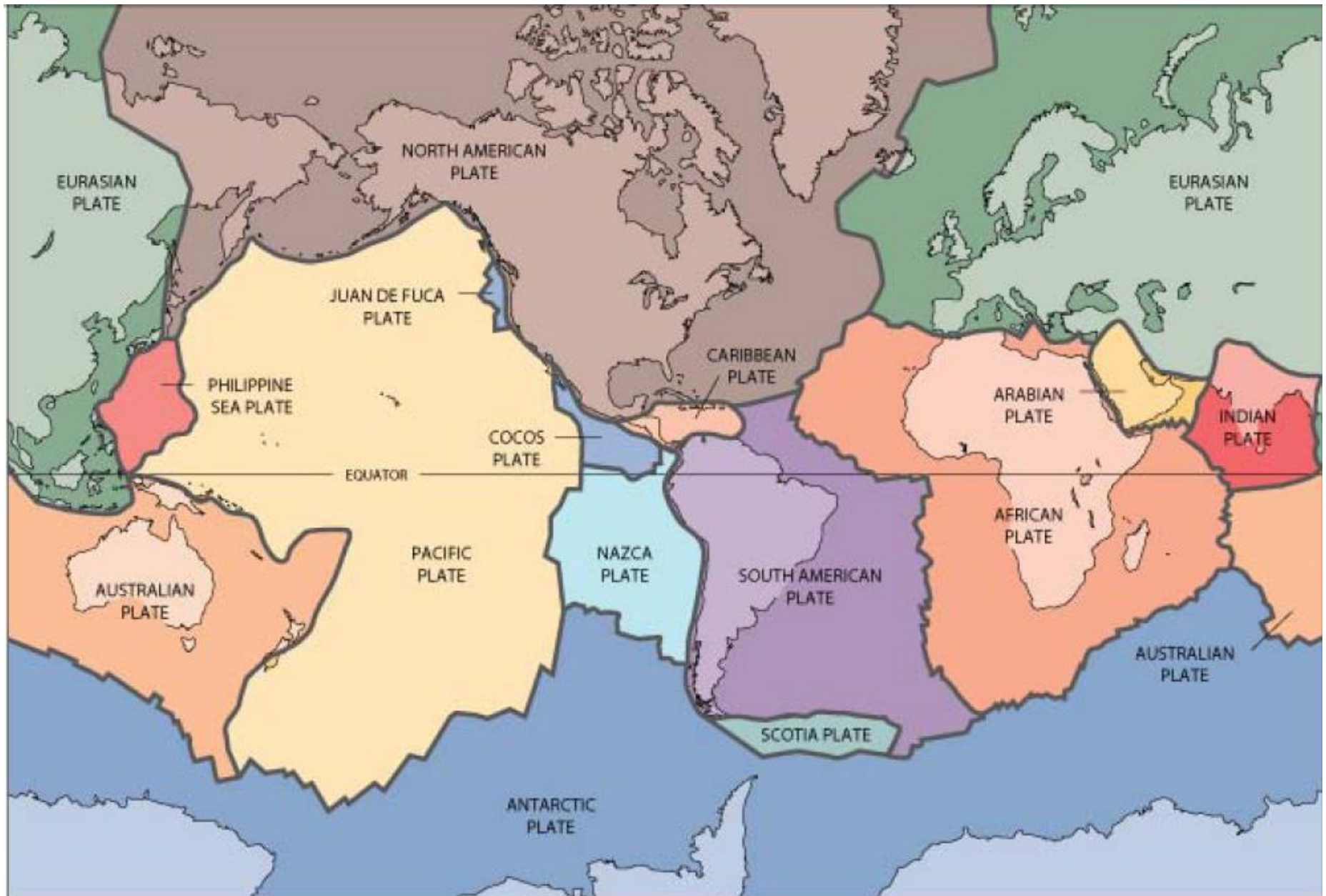




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**Figure 20.** Plate tectonic map of the world including indication of the types of plate boundary, (Figure 5.8 from *Foundations of Earth Science*, 6<sup>th</sup> Edition, Lutgens and Tarbuck, Pearson Prentice Hall publishers, 2011).





**Figure 21.** Plate tectonic map of the world from *This Dynamic Earth* online version (<https://pubs.usgs.gov/gip/dynamic/dynamic.html>). *This Dynamic Earth* is a very useful summary of plate tectonics. At this web page, each **chapter** can be opened by clicking on the links under the **Contents** heading. There is also link to the *This Dynamic Planet* map (can be downloaded) and the *This Dynamic Planet: A Teaching Companion*.



## Major Plate Boundaries

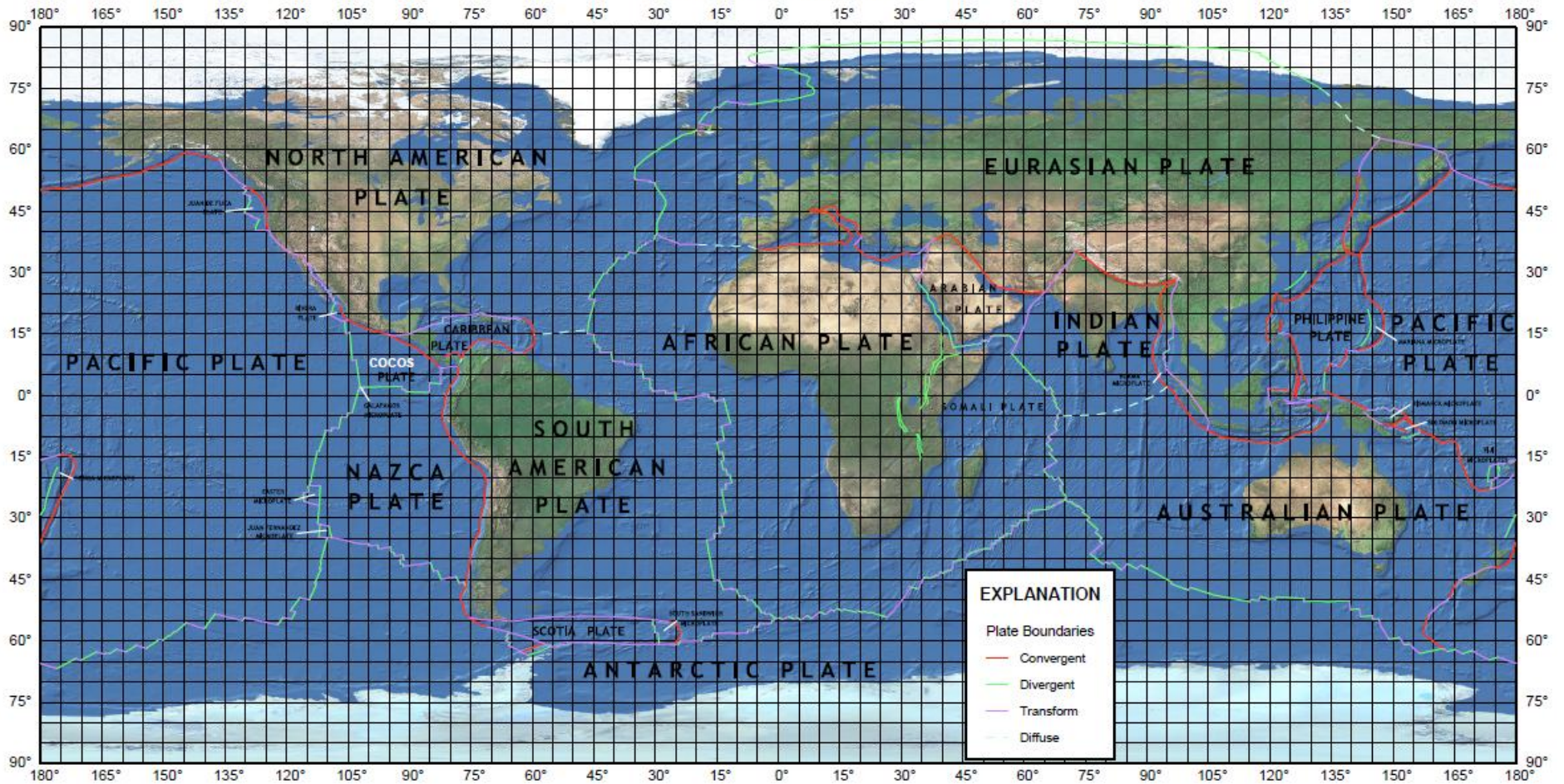
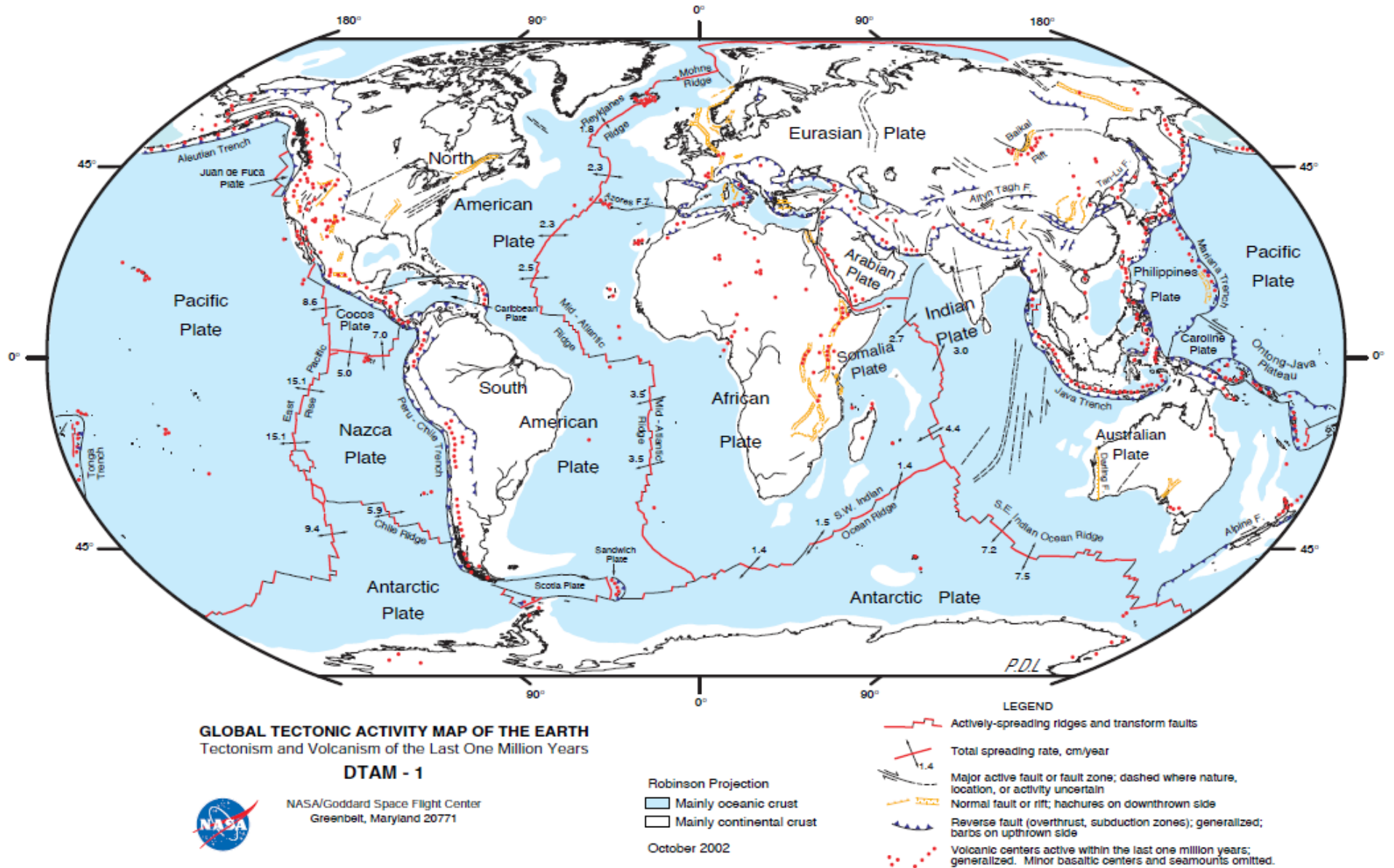
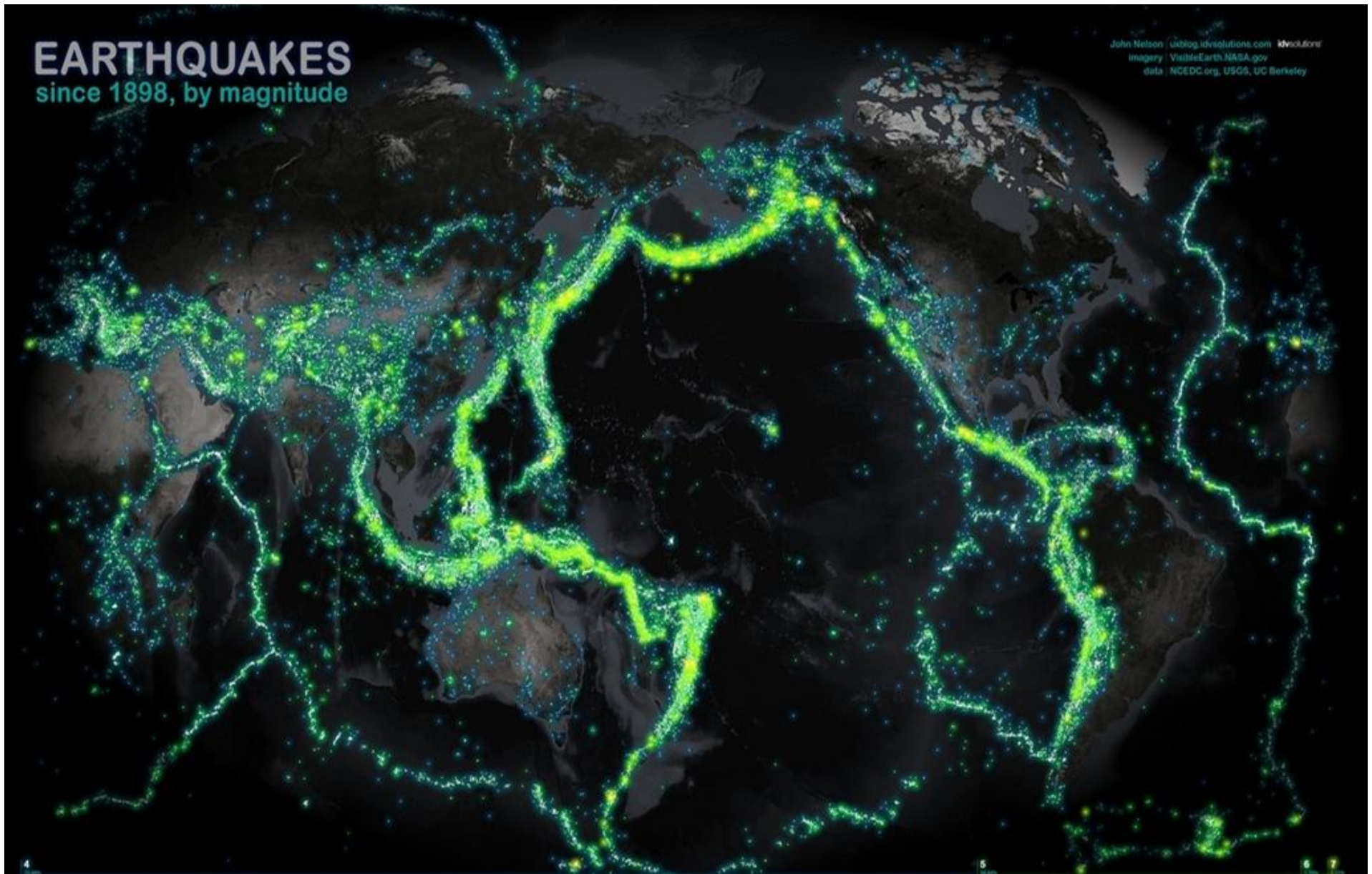


Figure 22. Plate tectonic map of the world – no longer available from the USGS website.



**Figure 23.** Plate tectonic map of the world (from NASA) - ([https://leclercf.files.wordpress.com/2011/11/media\\_httpwwwglobalch\\_ogilb-scaled1000.jpg](https://leclercf.files.wordpress.com/2011/11/media_httpwwwglobalch_ogilb-scaled1000.jpg) or [https://globalchange.umich.edu/globalchange1/current/lectures/evolving\\_earth/tectonic\\_map.jpg](https://globalchange.umich.edu/globalchange1/current/lectures/evolving_earth/tectonic_map.jpg))





**Figure 24.** Magnitude 4 and larger earthquakes from 1898 to 2012 (John Nelson, IDVsolutions). The display of epicenters used here is sometimes called the “firefly” method in that each epicenter dot shown has a brightness proportional to the magnitude (energy released) of the earthquake. The fault zones and plate boundaries therefore show up brightest in areas where large numbers of large earthquakes have occurred.