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An Integrative Technique to Create a Digital Tectonic Activity Map (DTAM) of the Earth

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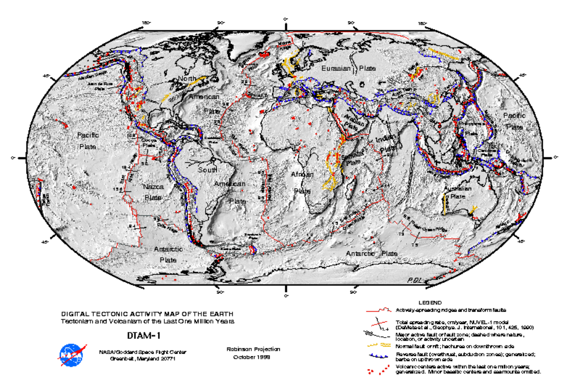
Abstract

A digital tectonic and volcanic map of the world was created which integrates numerous remotely sensed and GIS databases (Fig. 1). This integrative technique made it possible to analyze data differentiated by spatial and temporal resolutions. The remotely sensed data ranged from 9 kilometers to 30-meters resolution. The GIS datasets ranged in scale from 1:1,000,000 to 1:24,000. In both cases, the numbers represent global and regional scales of analysis, respectively. The scope of the digital database was the geologic present. The “geologic present” is restricted to geological events that have taken place in the last million years. The data, totaling 5 gigabytes, integrated satellite sea-surface altimetry, volcanoes, seismicity, Very Long Baseline Interferometry (VLBI), ground base records, and a digital terrain model. The digital database used the convention of viewing analytical outputs as a composite map. This is an artifact from the electronic stacking of geographic events as layers. This capacity is found in all geographic information systems. This tectonic activity database may be used to produce maps highlighting geological activities with user-defined ranges of time, locality, severity, and topography. The database can be easily modified to facilitate the inclusion of additional supplementary information (e.g., geologic or geomorphic maps) and new seismic or volcanic observations.



(Fig. 1)

Purpose

Traditional views of tectonics via geology maps and textbooks have focused on schematic plate maps, seismicity bordering plate boundaries, and plate reconstructions (Minster et al, 1978). However, they fail to present the synoptic view of tectonic activity in a global context during the past one million years. This Digital Tectonic Activity Map (DTAM) addresses global tectonism as an interactive data tool for the researcher and student in Earth Sciences. The datasets involved are seismicity, volcanism, bathymetry, topography, and geodetic VLBI. The DTAM depicts recognized geological structures and crustal differences between continental and oceanic lithosphere. This paper will focus on the integration of discrete tectonic datasets into this new visualization tool.

The usage of discrete, co-registered data layers overlain on a digital terrain model has great utility. The DTAM represents tectonic activity from the recent geological past as an objective and realistic global map. It allows the analytical manipulation of data layers independently or with newly acquired data for correlation. The DTAM also enables synoptic views of remote geographic areas that lack accessibility, and tectonic activity can also be displayed at the intra-plate level where the continental craton is generally assumed to be inactive. We leave it up to the user to find the best usage of these tectonic datasets as either geodetic control for their tectonic studies or find regional patterns for intercomparisons with known geological features at the mesoscopic scale.

The integration of the datasets is being stressed because of the differences in data structure and because it accommodates the large amount of data that is presently archived in the GIS format (Mattikalli et al., 1995). The other half of the problem is the increasing size of the raster based data. There is a limited number of systems that can accommodate both types of data at a reasonable cost in training and time. Integration between commercially available software increases the efficiency of vector to raster conversions (Mattikalli, 1995). As a basic example, the coordinate system for the raster based data starts in the upper left pixel as an origin point. The vector data, x/y coordinate strings (polygons, lines, and points), is referenced in the bottom right corner. By utilizing an integration technique, these differences are appropriately handled with minimal confusion for the researcher. Thus, this paper targets the initial construction of one global dataset in which the data formats used (text, vector, and raster) could be fully integrated to operated as a digital tool for analysis.

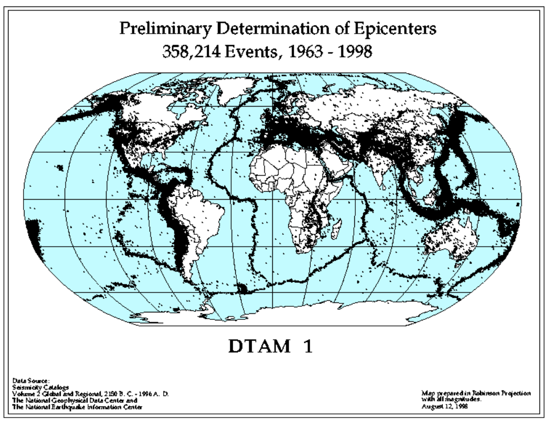
Equipment and Software

All work was completed on a Silicon Graphic Indigo2 computer. The computer's CPU was a MIPS R4400 chip. The FPU was a MIPS 4000 floating point co-processor. The Indigo2 system contained 128 megabytes of RAM, 2 gigabytes hard disk, and peripherals that included: CD-ROM, tape reader, and 18 gigs external disk space. The commercially available GIS software called "ARCVIEW," and “PCI” were used. The data, in the form of ASCII text files, was also manipulated by the UNIX commands: “awk," “cp,” and "sed" (Gilly, 1992).

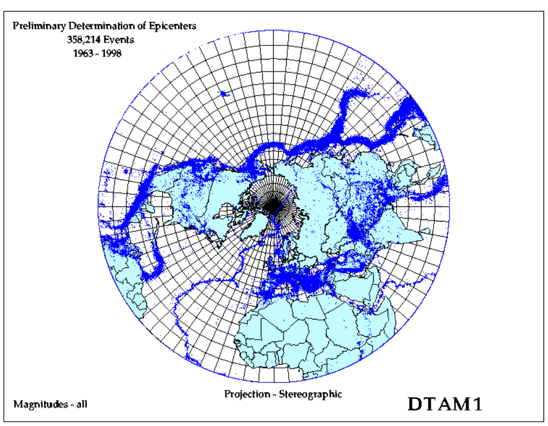
Data acquisition

Seismology is one of the main foundations of modern tectonic theory. Its scope has expanded greatly in recent decades. This expansion has produced an array of data that now gives interpretive insight at greater scales. The new digital databases require new manipulation techniques due to increases in data size and attribution. A geographic information system offers the appropriate algorithms for data manipulation and the ability to produce analytical outputs (Jensen, 1986).

A commercially available geographic information system (GIS) and image processing software reduced the processing time. They also functioned as the database managers. Global seismicity data compiled from NOAA covering the interval 1963-1998, with three different magnitude ranges (mb): > 3.5, < 3.5, and all detectable magnitudes was the first dataset used. Epicenter locations were acquired from a CD-ROM set supplied by the National Geophysical Data Center (NGDC). We have combined these developments to produce three new maps (Figs. 2, 3, and 4) of global seismicity covering the 35 year period 1963-1998. These maps are presented as examples of GIS applied to geophysics. The VLBI map (Fig. 5) has also been included.



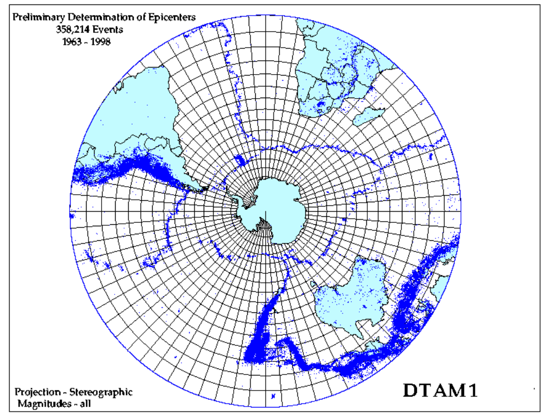
(Fig. 2)



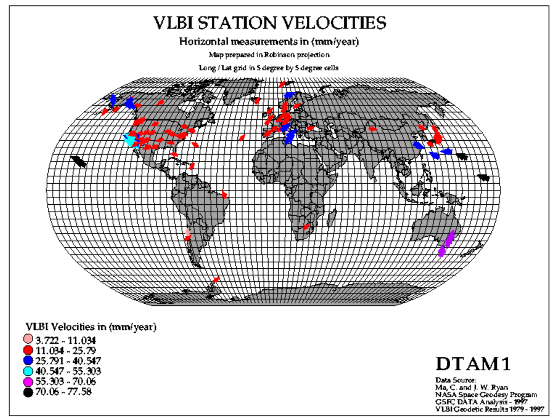
(Fig. 3)

(The images and data are available for the interested researcher at the following websites. Please note that the images are a product of the DTAM project and that the data will be in an unprocessed format.)

The websites are:
http://denali.gsfc.nasa.gov/dtam/
http://dtam.gsfc.nasa.gov/



(Fig. 4)



(Fig. 5)

The data that was made available from the National Geophysical Data Center and National Earthquake Information Center in Boulder, Colorado was instrumental in the creation of the displayed seismicity maps. The three seismicity maps were compiled to develop a digital tectonic activity map (DTAM) of the world (Yates et al., 1998). The seimicity data was acquired via CD-ROM from the National Geophysical Data Center and the National Earthquake Information Center.

The CD-ROM was volume 2 of global and regional data between the time periods of 2150 B.C. - 1996 A.D. Using the interface called, "GEOVU," contained on the disk, the preliminary determination of epicenters were extracted. Initially, there was a formatting problem because the column of data overlapped. This was corrected by acquiring the data for the center's FTP site. The data is now archived on our ftp site and is available using the following commands:

```
>ftp ltpftp.gsfc.nasa.gov
>login: anonymous
>password: (your email address)
>cd pub/people/brianm
>get pdeto98.eq
>quit
```

The size of the data set was 24 megabytes. This is too large for standard spreadsheet programs. Also, all of the data was not needed. The data came in a column, tab-delineated format. The column headings were: **Numeric month, Numeric day of the month, Numeric hour of the day, Numeric minute, Numeric second, Year, Latitude, Longitude, Depth, Magnitude, Local magnitude, Surface magnitude, Unspecified magnitude and Number of stations**. These columns were numbered as fields 1 to 14, respectively. Using the UNIX command "'cp,"' a copy was made of the original data:

```
cp pdeto98.eq Table 1
```

Table 1 is now the data set used. If it becomes corrupted in any way, work can begin from the original data set.

Methodology

The text data was manipulated using the following steps. The columns of data needed were: Longitude, Latitude, Year, Depth, and Magnitude. The following UNIX command, typed at the UNIX prompt, was used to subset the text file to extract only the data identified as requisite for analysis:

```
awk '(print $8, $7, $6, $9, $10)' Tablel > Table2
```

"Tablel" is an arbitrary name given to the data set only to show a starting point before a subset of the data was produced. The "$ number" after the "print" parameter places the desired columns, in the order listed, in the newly created file called "Table2." It is important to note positions 8,7,6,9, and 10 are reflective of their positions in "Tablel." They have acquired the new positions 1,2,3,4, and 5 in "Table2." Next, it was necessary to extract only the data that was between 1963 to 1998. The following conditional construct in "awk" was used:

```
awk 'if ($3 > 1962) print $0)' Table2 > Table3
```

The "Print $0" means to print the entire record if the conditional statement is satisfied. As a result, from Table2, all records in which the year is greater that "1963" exist in text file called, "Table3." The same command was used to extract only the records, from Table3, with magnitudes greater than three:

```
awk '( if ($5 > 3) print $0)' Table3 > Table4
```

The columns in Table4 have lost their "tab delineation." They are now separated by spaces. The ARCVIEW software accepts column data separated by commas, therefore, the following command was used to substitute the spaces with commas:

```
sed 's/ /,/g' Table4 > Table5
```

The result is now Table5 with the five columns: Longitude, Latitude, Year, Depth and Magnitude. There were a total of 200,855 records all with magnitude greater than 3 and between the years 1964 and 1998. Open Table5 in the system's text editor. The Silicon Graphics computer text editor is called, "jot."' Once Table5 is open, add the following header to the file: **Longitude, Latitude, Year, Depth, Magnitude**

It is important that spaces are not added between the commas. Save the file as "Table5.txt"' with the new header. "Table5.txt" is now ready for importing into ARCVIEW. Open ARCVIEW. Once the interface has appeared, click on the word "Project" in the blue bar. In the menu that opens, click on "add table." Another interface will open. Under "List Files of Type:" click on the "Delineated Text (*.txt)." "Table5.txt" should appear. Click on it and press "OK." "Table5.txt"' will appear with the column headings in place. Next, click on "new" in the untitled box. Viewl will appear.

Under the word EDIT there is a gray box with a plus sign. That will add a new theme. Click the button and the interface will open to the ARCVIEW directory. This location contains base maps. Open the directory called MAPS, then WORLD. To the left, all available data sets will appear. Open the file “world30.shp" first, then open "cntry94.shp." In the blue bar, execute the following pathway:

View -> Properties -> Projection -> Type - > Robinson

The Robinson Projection was chosen because the distortion in shape and area are low, and the scale is constant along latitudes. It also has utility as a "'general use" map. The countries and ocean grid should have change shape into a Robinson projection. Next, in the blue bar execute the following pathway: **View -> Add Event Theme**

Once the interface appears, load "'Table5.txt" and click "OK." Table5.txt should be loaded with the world in Robinson projection and will appear as dots once the Table5.txt theme is turned on. The "information tool," (it looks like this **i**) can be used to discern any individual record. The query builder can utilize Boolean logic to accomplish spatial analysis for the whole data set. Each record will have five attributes. The attributes are the five columns established with the "awk"' command. This procedure was repeated for magnitudes "less than or equal to three," and for "all magnitudes."

The raster data was manipulated with the following steps in order to establish a database with a real world coordinate system. To calculate the upper left and lower right boundaries (UL and LR, respectfully), it is important to note that they don't change in the software automatically. To use a worldview, the bounds must be set using calculated projection boundary points. When using the PCI software for any given projection, the corners may not “reproject.” The projection bounds are equi-rectagular, but the LONG/LAT bounds are not. It's not obvious what the LONG/LAT of the bounds would be in the commercially available software. Thus, the bound parameters are derived from:

Earth-circumference = 2 * PI * earth-radius
= 2 * 3.14159 ….* 6370997.0
= 40030154.742485

and 40030154.742485 / 2.0 = 20015077.371
(for equi-rectagular projections)
and 40030154.742485 / 4.0 = 10007538.686
(for polar stereographic projections)
("Normal Sphere" (EO19) is the software’s internal representation for the earth radius.) (PCI, 1997).

So the bounds for:
- Robinson

Upper Left: -20015077.371 E 10007538.686 N
Lower Right: 20015077.371 E -10007538.686 N

- Polar Stereographic

Upper Left: -10007538.686 E 10007538.686 N
Lower Right: 10007538.686 E -10007538.686 N

Actual description of bounds:
- Robinson

Upper Left: -PI radians +PI/2 radians
Lower Right: +PI radians -PI/2 radians

- Polar Stereographic

Upper Left: -PI/2 radians +PI/2 radians
Lower Right: +PI/2 radians -PI/2 radians

The data sets that are important can now be added as layers. In order to exchange data that could be text, raster or vector, it is important to maintain the same coordinate system throughout the process. Operating from a base map with a neutral projection is one way to stop conflicts between projections or in slow processing time. The exchange between the GIS software ARCVIEW and Arc/Info to the PCI is accomplished by the command: UNGENERATE (ESRI, 1996). The exchange between PCI to any of the ARC products is accomplished by the command: VECWRITE (PCI, 1997). This exchange has purpose. It allows the data formats to be manipulated in the software with the greatest algorithms for that particular format. It is the integration of the data sets, regardless of scale or format, that allows robust analysis to produce global products.

CONCLUSION

The DTAM is a useful tool in terms of its application and its realistic portrayal of global tectonics. It provides an important asset for both the researcher and student in the cartographically impoverished arena of global-scale tectonics. This methodology of GIS integration can be replicated by anyone with the appropriate expertise and tools. The authors are willing, however, to make this interactive data tool open to the community for its usage and feedback. DTAM’s development into an interactive GIS has been highlighted here. But the real usage will be in the future when the Earth Science users may interact freely with it or its derivative data products. The DTAM will allow a more synoptic understanding global tectonics in terms of activity in the geological present (i.e. Holocene Epoch) for studies ranging from neotectonics to natural hazards.

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