Using DDMs to Teach Petrology

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Summary

In this session we will examine how to utilize Dynamic Digital Maps (DDMs) in undergraduate petrology courses to bring inaccessible and exciting volcanic field areas to the students in the classroom and to engage the students in authentic research experiences. A DDM is a stand-alone "presentation manager" computer program that contains interactive maps, analytical data, digital images and movies. They are essentially complete geologic maps in digital format, available on CD-ROM and the web at http://ddm.geo.umass.edu/. We have developed two different kinds of exercises that use DDMs to provide field-based context for undergraduate research projects in petrology. In one, the students use the DDM of the Tatara-San Pedro volcanic complex of the Andes Mountains of central Chile to develop a group research poster on part of the volcano's evolution, to present to the class, modeled after what would be presented at a national meeting. The second exercise focuses on the Springville Volcanic field, where the students try to understand the magma evolution using both field relations and quantitative modeling skills. The open-source code, web-enabled, cross-platform DDM-Template and its Cookbook currently in progress will enable petrologists to create their own customizable DDMs for any field area of interest.

Supporting documents available at these URLs:

DDM.TSP: http://www.uwm.edu/Course/422-302/TSPproject

DDM.SVF: http://ddm.geo.umass.edu/ddmsvfex

Introduction

Geology is a natural science with a fundamental grounding in fieldwork. The field provides a natural laboratory and the most realistic environment in which to learn. But what happens when we have to teach about geologic features and processes in a location remote from their field setting? When located in western Massachusetts, how does one present the fledgling igneous petrologist with a volcanic problem that has some realistic field basis? Or similarly, when in Wisconsin, how does one present volcanic arc rocks in a way that the students feel the data they are required to evaluate has some down-to-earth foundation that allows them to form a hypothesis based on their field relations? Ideally there is no substitute for a geologic fieldwork, where students make their own observations and then formulate and test their hypotheses. In fact, several studies have recognized and quantified the value of field trips and geologic observations in the field for undergraduate geology majors (e.g. Munn et al., 1995; Huntoon et al., 2001). Many recent publications by national scientific organization (e.g. NRC, 1996; NRC, 2000; NSF, 1996) have emphasized the need for more inquiry-directed science teaching and learning in the classroom, and engaging students in authentic research experiences. Recognizing the need for quality field experiences and inquiry-based research experiences in our petrology courses, we created a way to overcome the geographic challenges and introduce 'field-based' petrology research into our courses by bringing the field to the student using Dynamic Digital Maps (DDMs).

Data for realistic field based problems, from areas that were previously inaccessible to the student, can now be brought to them through use of Dynamic Digital Maps (DDMs). DDMs are complete geologic maps presented in digital formats such as on CD-ROM or on the www. They can contain detailed high quality color maps along with field photos, analytical data, movies and animations. DDMs offer a variety of options to engage students in authentic research experiences and to circumvent the inaccessibility of field research. Instruction with activities that use DDM has the potential to impact student learning by reinforcing concepts though discovery, and by improving problem solving, visualization and computational skills. The power of DDM is in the tools it provides for rapid analysis and visualization of large geologic data sets. Investigations with DDMs allow students to identify physical and spatial relationships by constructing multiple representations of data in the form of maps, tables, charts and layouts.

In this session we will describe how the two of us have used different Dynamic Digital Maps (Condit, 1995a, 2000) as a source for class projects in petrology courses, and report on the impact on student learning. These DDMs provided our students with the "field-based" information they needed to select samples whose analyses they could use to test their own hypothesis on how these rocks formed petrogenetically. The main purpose was to have students actively engaged in authentic research with essential field based grounding. In the case of the Springerville volcanic field (DDM.SVF, Condit, 1995b), which is an intraplate continental field, the problem was to select a pair of lava flows based on field relations that might be related by fractional crystallization, and then to run the mass-balance model on the pair to test it. In the case of the Tatara-San Pedro volcanic complex, which is a Chilean subduction-zone related arc volcano, the problem was to develop a research project to study some aspect of the evolution of the volcano. The students conducted the research in collaborative groups. Both DDMs include analytical data sets, which could be used for modeling. These DDMs can be downloaded from http://ddm.geo.umass.edu/ and additional data sets described below, along with class exercises can be downloaded from http://www.uwm.edu/Course/422-302/TSPproject (DDM.TSP) and http://ddm.geo.umass.edu/ddmsvfex (DDM.SVF).

RESEARCH EXPERIENCE IN PETROLOGY UTILIZING DYNAMIC DIGITAL MAPS: A TALE OF TWO PROJECTS

Petrology Research Project in the Andes (UW Milwaukee)

The Andes Mountains are a classic area to study an active continental arc, where subduction is occurring along the length of the western South America. At UW Milwaukee the students in the Igneous and Metamorphic Petrology course conducted petrology research in the Andes utilizing DDM's and associated databases (Figures 1 and 2). In the course one of the major goals was to create an authentic research experience for the students. The DDM's were an essential component of the research project, both in bringing in the field relations and as a way to organize and utilize the data in the context of the field relations. The Milwaukee area is geographically challenged with respect to access to field area with recently active volcanoes, yet through the use of DDM's the UW Milwaukee students are able to experience 'field work' on the Tatara San Pedro (TSP) volcanic complex in the Central Chilean Andes (36º S), the location and tectonic settings are show in Images 6-10 of the new DDM-TSP. The TSP DDM's enable students to visualize and interpret the field relations, for example the relationships between the subvolcanic intrusives and the major volcano building lavas, as in the case of Risco Bayo Pluton (unit Tgrb) in Figure 1, right side. Students used their own "field observations" in tandem with the other data available from the maps (for example, geochemical and paleomagnetic data, Figure 2) as part of an integrated research project. Field photographs of the samples localities provided context for the analytical data. We found that the multi-dimensional nature DDM's helped engage the students in the research.

The TSP Project is set-up in three parts. The first two parts provide the lead up to the group research project conducted in the third part. All the assignments are available at the following URL: http://www.uwm.edu/Course/422-302/TSPproject. The first part of the TSP Project is a lab on continental arc igneous activity where students are introduced to the TSP DDM map and work "hands-on" with samples from the volcanic complex. Students are asked to do relatively simple tasks that enable them to explore the DDM maps and retrieve the data. One goal is for the students to get familiar and conformable using the DDM's. Students learn how the field geology of the area and associated data are expressed in the DDM format. In the second component of the lab, students examine hand specimen and thin sections of samples from the TSP volcanic complex, from the underlying intrusives to the voluminous Quaternary basaltic andesites that built up the volcano. From their observations the students begin to make interpretations about aspects of the volcanoes evolution based on the mineralogy and textures.

The second part of the project is a homework assignment in which the students read an overview article on the TSP volcanic complex by Singer and others (1997). Using the background from the article and their "fieldwork" from the DDM, the students were then required to develop two research questions aimed at understanding some aspect of the evolution of the volcano that they would be interested to pursue for the project. For example, students could explore the evolution of the Holocene basalts and basaltic andesites in relationship to earlier flows by comparing trends in the Sr isotopic ratios. In class the groups met to discuss their ideas and then brainstorm to decide on which research questions they will pursue together for the research project (Part 3). Each group of three would have six research ideas (2 ideas x 3 students), which makes a productive starting point to begin the discussion. The groups sketch-out on action plan of what tasks need to be done, determine which individual is responsible for each aspect of the project and create a time-line for completing the project. At the end of the project each students self-evaluates and reports on their contributions to the finished project.

The third part of the TSP Project is the group research project where the students implement their research planned out in the second part of the project. In groups and then together as a class we discussed and sketched out a scheme of the important components to include in a poster. Based on the poster scheme, I created rubric on how the research projects would be assessed and then I distributed the rubric to the class as a guide. In conducting the research students used the geologic maps, field photographs, and analytical data, such as geochemical and paleomagnetic data, imbedded in the DDMs. Maps, images and data from the DDM's can be saved to a disk and exported into other programs, such as a graphics or spreadsheet program. Students had access to additional regional data sets and modeling programs such as "IgPet", which the students had utilized in earlier class assignments. One of the groups explored the genetic relationships between the Tertiary subvolcanic intrusives and the major Quaternary volcano building lavas based on the field relations and geochemistry (Figure 1). Each group's research culminated as a poster, such as would be presented at a Geological Society of America (GSA) or American Geophysical Union (AGU) meeting. Students used field photos of field relations and sample localities in the posters in addition to the analytical data and maps. Over the next two weeks students worked on their project, both during and outside of class time. The last class meeting before the posters were due was a "mock-up" day where I reviewed and commented on a rough-draft of the final poster. After completing the posters groups then presented their posters and discussed their research in the class. The students found that the DDMs helped engage them in the research. Ultimately, the research projects were high quality, comprehensive and creative. The research posters were placed on display outside the introductory geology lab for aspiring geology majors to peruse.

Modeling of Magma Evolution (UMass)

The Springerville is a classic example of a continental basaltic cinder-cone and flow dominated volcanic field, located in east-central Arizona (Condit and others, 1989, Condit and Connor, 1996), and was published as USGS Miscellaneous Investigation I-2431 (Condit and others, 1999). Use of this field in our Igneous and Metamorphic Petrology class at the University of Massachusetts-Amherst (UMass) provides students with insights and examples of the rocks and deposits found in this kind of volcanic field. In using the DDM.SVF, we typically team up students in pairs, with the most computer phobic student at the keyboard. Students are encouraged to work together, but are required to submit final answers in independent reports. Our ultimate goal is to get students to use the field relations and petrologic data of DDM.SVF as the basis for choosing a parent-daughter pair of flows on which to carry out a mass balance calculation of fractional crystallization. Along the way toward the final paper, written in a style for the journal Geology, two other assignments are completed. All of the assignments and data described here can be found on the web page ddm.geo.umass.edu/ddmsvfex and on the CD which is part of UMass-Amherst Geoscience Department's Contribution No. 72 (Condit, 2000).

The first of these two assignments is a short-answer exercise with the goal of getting the users familiar with the DDM.SVF program, and with the volcanic field. The hand-out coaches students through the exercise in 32 detailed steps that relate to them how to use the program, and in places along the way requires them to record comments about what the program does in response to their actions, and to make observations about the geology they are seeing displayed. The assignment begins with a click on a button that starts an automated six-minute "Tour" built into the DDM, that shows many of its capabilities. The tour ends in a part of the he program called the "DDM Overview" which is a series of pages that summarize how to use the program and its content. I usually give the students about an hour of in-lab time to start the assignment, and find that many students finish in that time, and take additional time to cruise through most of the 75 associated images. This assignment, by itself, may be useful to any geologist wishing to become more familiar with continental basaltic volcanism.

Reading the "Introductory" text, which is a summary of both the geology of the field (petrography, chemistry, volcanology) and how it is expressed in the DDM is a key part of this assignment. This text, found in a floating palette, is hyperlinked to many of the images and to additional supporting figures. In addition, it discusses among other things, how the units were classified in the four thematic maps, and what kind of information can be found in the Description of Map Units for each of the 409 units.

In the second assignment, I take a pair of lava flows and discuss why I choose to test them as possibly linked by the process of fractional crystallization. In this exercise, I have the students go through a itemized step-by-step process to evaluate this proposed link and examine what criteria I used, applying petrologic reasoning to the information one can obtain from careful examination of the DDM and the field relations and observations presented there. In addition to DDM.SVF, after I have picked two flows, I use two programs, "IgPet" and "Mixing" to assess this link quantitatively (these programs, written by Mike Carr at Rutgers University are available for Mac and Win32 platforms). Although this in-class assignment only requires short-answers, students are asked to include the example plots they produce with their answers (e.g. SiO_2 vs. MgO for minerals and whole-rock pairs), since similar ones for their own rocks will be needed for their third assignment, which is a final report on their own fractional crystallization model. To aid in this, at the outset, students are given a check sheet to help them follow through what products are needed from each step of the assignment, and to help them visualize the final report. We discuss one method of writing this report: how the checklist might form a basis for a report outline, and how, once that outline is composed, we can produce figures and tables as a result of following each step of this process, around which to then write the final report. We also discuss report formats, how they might vary from the one we will use, and how to aim the report at the correct audience.

An example of how we can use DDM.SVF to obtain the supporting field data is shown in the first step in this process. Here we use the DDM.SVF to find possible parent-daughter pairs, and to justify, as best we can from the map data, why we choose those pairs. Figure 3 is an example of this area, and summarizes some of the DDM's information supporting this choice. In the bottom center part of the Figure 3 we have a picritic (olivine-rich) flow (unit Qbb_2), which we hypothesize may represent the late erupted cumulate residuum (or bottom) of a magma chamber. The composition of the rest of that magma chamber we think might be represented by the earlier erupted flow (unit QTsfl), that lies beneath unit Qbb_2. As shown by the measurement (the white rectangle M#1, lower right), the vents for the two flows are within about two km of each other, and a visit to DDM.SVF's "Correlation of Map Units" for this area (not shown here, but available in the "Correlation-Charts" Menu) suggests an overlapping age for the flows. Examination of bulk chemistry (lower left, Figure 3) shows a decrease in MgO and an increase in SiO_2 from flow Qbb_2 as represented by sample 216L to flow QTsfl of sample 215L. A click on the photo icon (purple circle with 55) will show the user large olivine phenocrysts in the resulting photomicrograph. A look at the available mineral chemistry (Figure 3, bottom) shows that the olivine in flow Qbb_2 is MgO rich, suggesting it's removal from the bulk chemistry of Qbb_2 (sample 216L) might deplete the flow in MgO, as see in analyses 215L of unit QTsfl. DDM.SVF users can take a further look at the unit description of QTsfl and at the photo 15 of the vent for QTsfl, 9336A (not included here) which also shows a similar morphology supporting contemporaneous units, corroborated by an examination of the Correlation of Map Units found in the program. Another possible sample to test against 216L might be 260L, which represents an upper flow sheet of QTsf. This kind of reasoning can be carried out as a first step for choosing possible parent-daughter links for many of the units in the Springerville field. Additional constraints can be applied by looking at the extensive paleomagnetic data also show in the Correlation of Map units as well as in the Paleomagnetic thematic map. Because the map segments, images, and correlation charts can be saved to disk outside of the program, they can be used as supportive figures in the final write-up.

Although it does not directly involve using DDM.SVF, for the modeling work I include an extensive geochemical database (both whole-rock and mineral chemistry) that is formatted for the "IgPet" and "Mixing" programs. Additional isotopic data along with trace elements for many of the flows can also be found in the program, if more modeling is entertained in more advanced classes. All data can be saved out of the program to tab-delimited files if you want to model using programs other than "IgPet" and "Mixing"; the data I use for the modeling can be found on the web site: ddm.geo.umass.edu/svfex.

FUTURE WORK AND EXPANDED APPLICATIONS OF DDMs

In an ideal world we all would have access to key geologic field areas in geographically inaccessible parts of the world. DDMs provide a creative approach to circumventing limited access to ideal field areas because of geographical, financial and time limitations. Samples from key units in these field areas may be difficult to obtain, especially in the case of the TSP, where the samples used at UW Milwaukee were packed out by mule (and on grad student's backs!), and shipped back at some expense. Most of us who teach petrology can, however, find samples similar enough to many of these units to be able to offer a realistic simulation of what the rocks are like in thin section. For those wanting a more detailed description of TSP, see Dungan and others (2001). New versions of the DDM.SVF will include many more images, movies and two field trips. As noted above, the DDMs we used in this paper run only on the Macintosh computer. However newer cross-platform and web-enabled versions of them are being produced under a NSF-DUE-CCLI grant to Condit, funded for the period 2002-2005. This will enable instructors and students to create their own DDMs based on any field area of interest. One major advantage is that instructors could customize the DDMs projects to their course or research. Thus the web-enabled version expands the potential of the DDMs to much broader applications to fields such as geomorphology, historical geology and structural geology and beyond. In the future we envision that a broad spectrum of DDMs projects created could be created and available in a web-based format on an educational site such as DLESE (Digital Library for Earth System Education, www.dlese.org). For those wishing to produce their own DDM, please monitor the URL http://ddm.geo.umass.edu, where progress in producing the DDM-Template and Cookbook will be posted, and where announcements about short-courses on making DDMs will be posted. Associated with the NSF grant will be a more rigorous evaluation of the use of DDMs, which we anticipate publishing as they are completed.

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FIGURE CAPTIONS

Figure 1. The DDM.TSP's "Map" window's display of the geologic map of the NW quadrant of the Tatra-San Pedro volcanic complex. All sample and map symbols provide links to data; the camera provides a link to a photograph looking southwest. The ClickList of Images provides a "table of contents" of images, and is searchable and sortable via the buttons at the bottom, and provides access to the images by a click on the line describing each image in the list. A click on the symbol in the "Map Explanation" Palette will center the map on, and locate that map unit.

Figure 2. One of nine "Image" windows in the DDM.TSP, displaying one of 193 available images. A click on a sample site symbol on the image will display any data analyzed from that site. This image is the beta version of the cross-platform and web enabled DDM.TSP, which to date only includes the two data sets seen here. The Macintosh only version contains several additional data sets, which will be ported to the newer version in the future.

Figure 3. The DDM.SVF's "Map" window's display of the lithologic thematic map of the Blue Ridge Mountain Geographic Subdivision of the Springerville volcanic field. This map can be transformed to one of three additional thematic map types by a click on the buttons in the "Controls" palette, center, top. Other features are discussed in the text.

Figure1

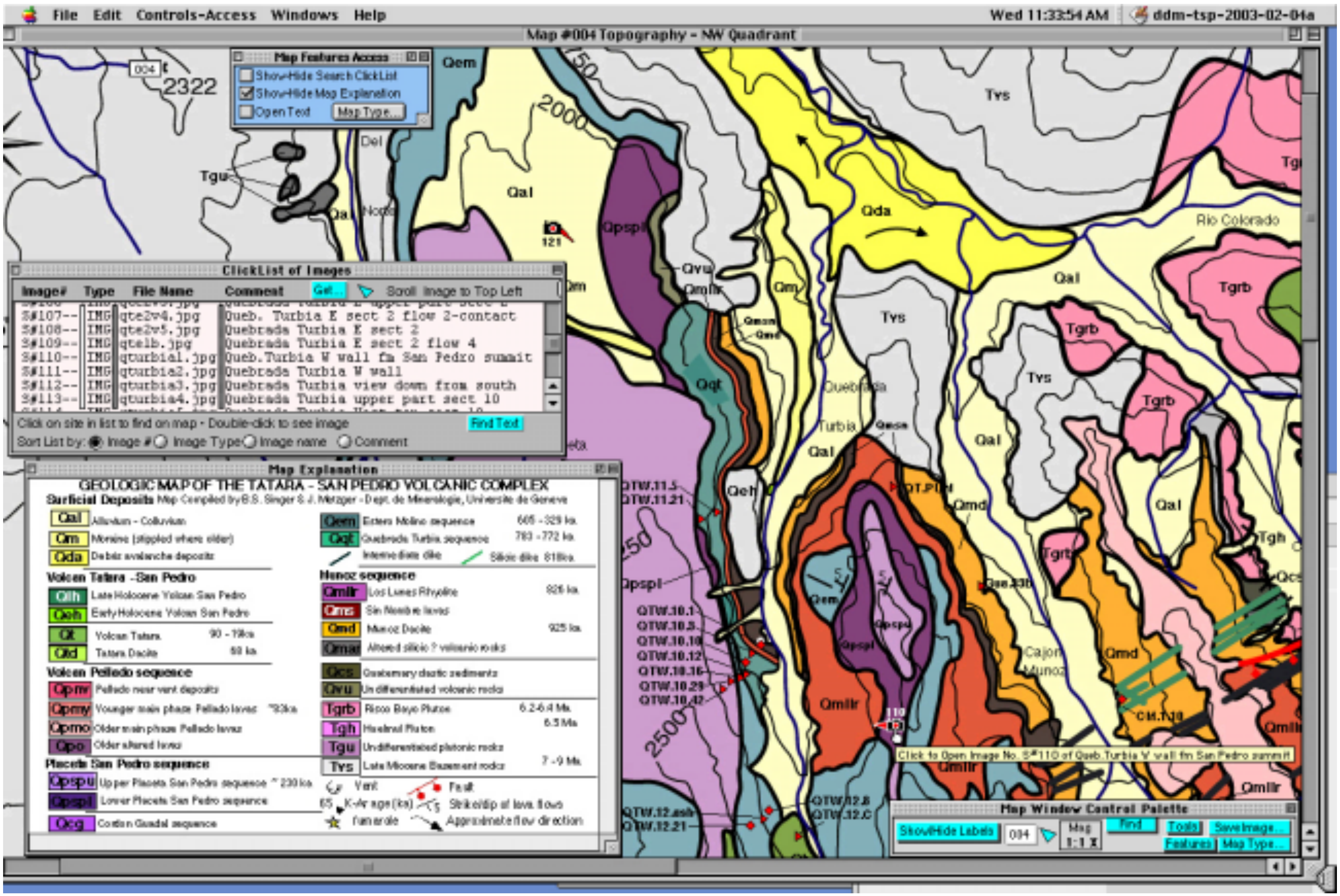
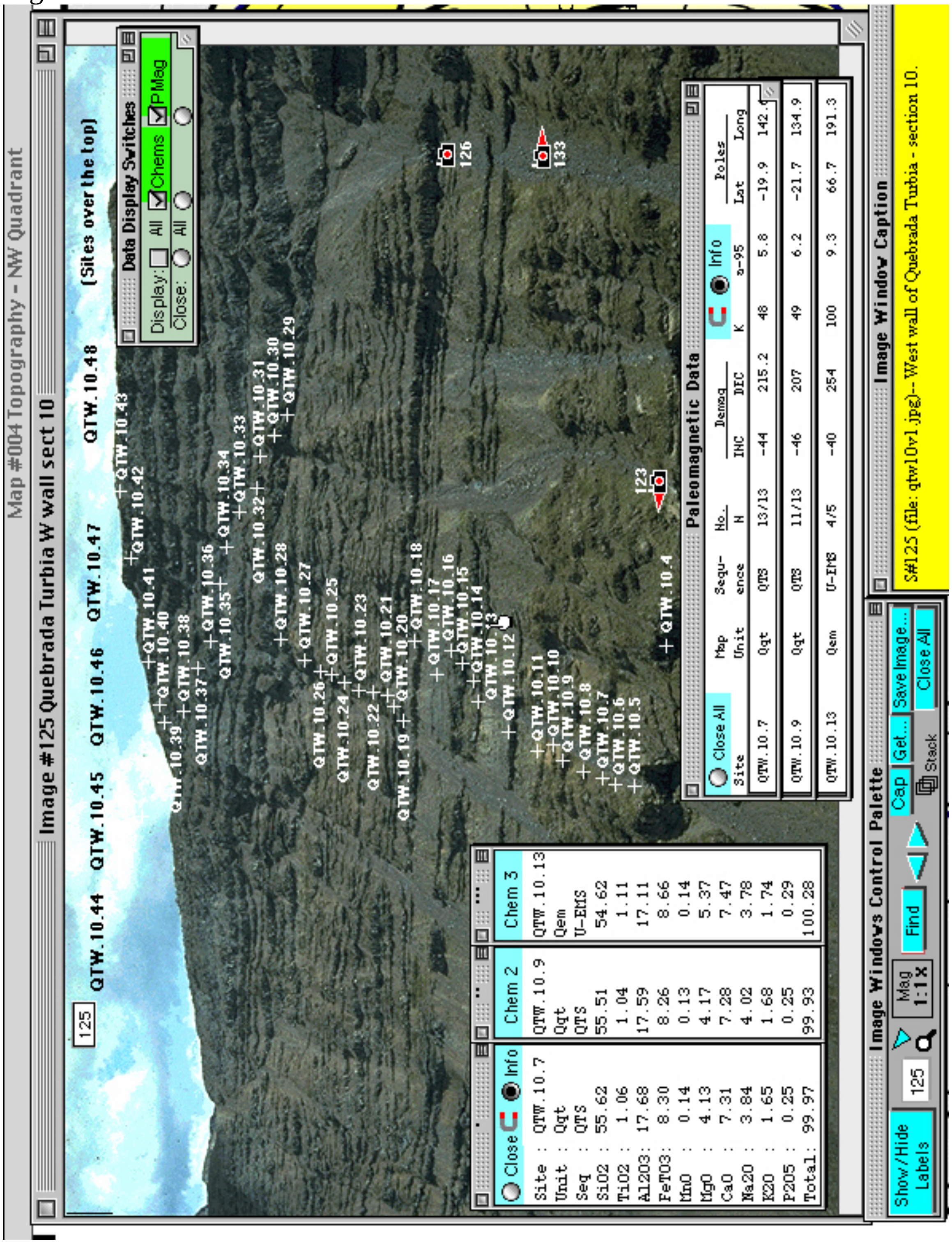

File Edit Controls-Access Windows Help
Wed 11:33:54 AM
ddm-tsp-2003-02-04a
Map #004 Topography - NW Quadrant
Map Features Access
Show-Hide Search ClickList
Show-Hide Map Explanation
Open Text
Map Type...
ClickList of Images
Image# Type File Name Comment
Scroll Image to Top Left
S#107-- IMG qte2v4.jpg Queb. Turbia E sect 2 flow 2-contact
S#108-- IMG qte2v5.jpg Quebrada Turbia E sect 2
S#109-- IMG qte1b.jpg Quebrada Turbia E sect 2 flow 4
S#110-- IMG qturbia1.jpg Queb.Turbia W wall fm San Pedro summit
S#111-- IMG qturbia2.jpg Quebrada Turbia W wall
S#112-- IMG qturbia3.jpg Quebrada Turbia view down from south
S#113-- IMG qturbia4.jpg Quebrada Turbia upper part sect 10
Click on site in list to find on map - Double-click to see image
Find Text
Sort List by: Image # Image Type Image name Comment
Map Explanation
GEOLOGIC MAP OF THE TATARA - SAN PEDRO VOLCANIC COMPLEX
Surficial Deposits Map Compiled by B.S. Singer & J. Metzger - Dept. de Mineralogie, Universite de Geneve
Qal Alluvium - Colluvium
Qm Moraine (stippled where older)
Qda Debris avalanche deposits
Volcan Tatara - San Pedro
Qlh Late Holocene Volcan San Pedro
Qeh Early Holocene Volcan San Pedro
Qt Volcan Tatara 90 - 19ka
Qtd Tatara Dacite 60 ka
Volcan Pellado sequence
Qpnv Pellado near vent deposits
Qpmy Younger main phase Pellado lavas ~83ka
Qpmo Older main phase Pellado lavas
Qpo Older altered lavas
Placeta San Pedro sequence
Qpspu Upper Placeta San Pedro sequence ~230 ka
Qpspl Lower Placeta San Pedro sequence
Qcg Cordon Guadal sequence
Qem Estero Molino sequence 605 - 329 ka
Qqt Quebrada Turbia sequence 783 - 772 ka
Intermediate dike
Silicic dike 818ka
Munoz sequence
Qmllr Los Lunes Rhyolite 826 ka
Qmsl Sin Nombre lavas
Qmd Munoz Dacite 925 ka
Qmar Altered silicic ? volcanic rocks
Qcs Quaternary clastic sediments
Qvu Undifferentiated volcanic rocks
Tgrb Risco Bayo Pluton 6.2-6.4 Ma
Tgh Huemul Pluton 6.5 Ma
Tgu Undifferentiated plutonic rocks
Tvs Late Miocene Basement rocks 7 - 9 Ma
Vent
Fault
K-Ar age (ka)
Strike/dip of lava flows
fumarole
Approximate flow direction
Rio Colorado
Quebrada
Turbia
Cajon
Munoz
2322
2000
2500
QTW.11.5
QTW.11.21
QTW.10.1
QTW.10.5
QTW.10.10
QTW.10.12
QTW.10.16
QTW.10.29
QTW.10.42
QTW.12.B
QTW.12.C
QTW.12.21
Click to Open Image No. S#110 of Queb.Turbia W wall fm San Pedro summit
Map Window Control Palette
Show/Hide Labels
Mag 1:1 X
Find
Tools
Save Image...
Features
Map Type...

Figure 2


Map #004 Topography - NW Quadrant
Image #125 Quebrada Turbia W wall sect 10
(Sites over the top)
Data Display Switches
Display: All Chems PMag
Close: All
Paleomagnetic Data
Image Windows Control Palette
Show/Hide Labels
Find
Cap
Get...
Save Image...
Close All
Stack
Image Window Caption
S#125 (file: qtw10v1.jpg)-- West wall of Quebrada Turbia - section 10.

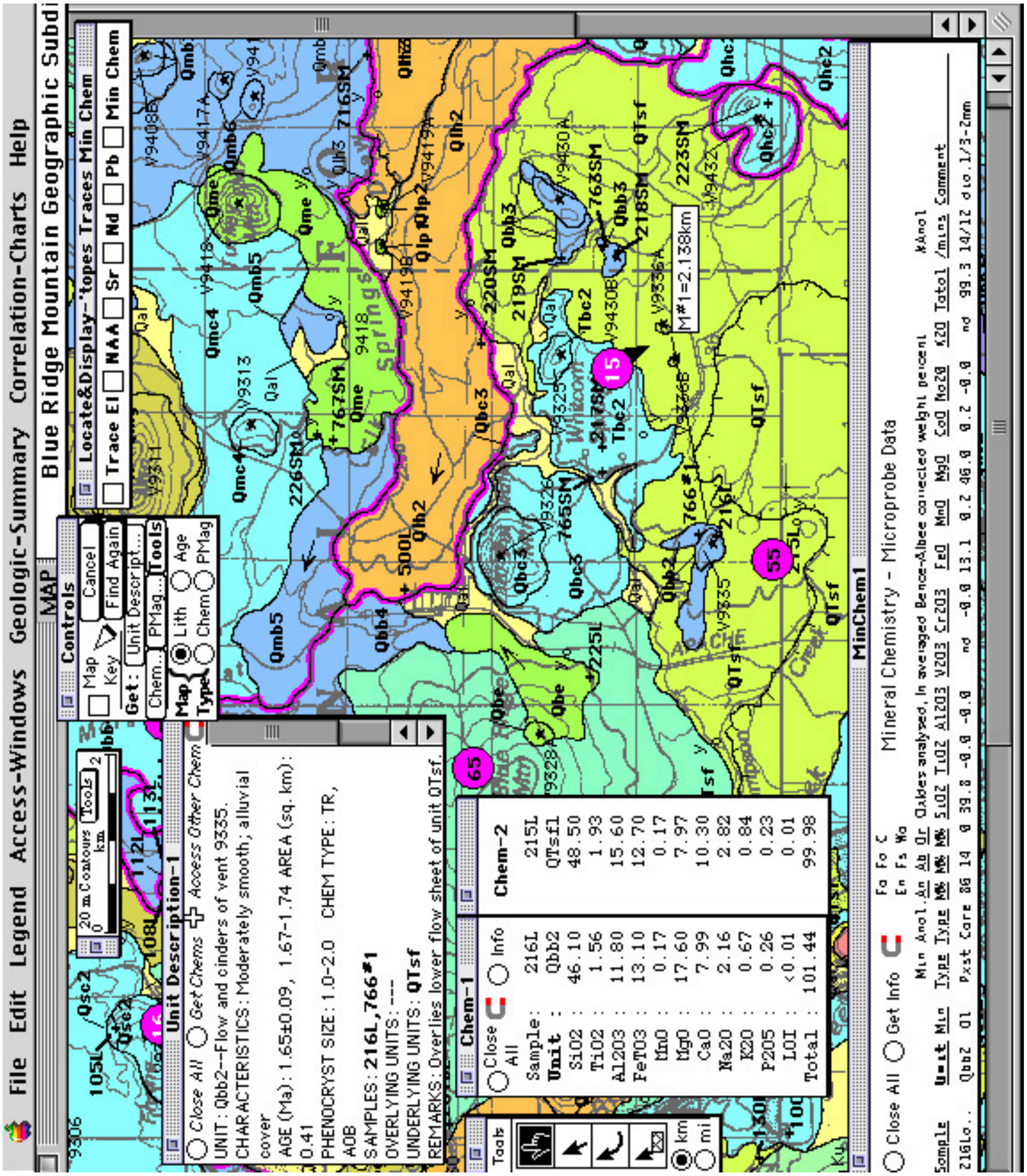

File Edit Legend Access-Windows Geologic-Summary Correlation-Charts Help
Blue Ridge Mountain Geographic Subdi
Locate&Display-'topes Traces Min Chem
Trace El NAA Sr Nd Pb Min Chem
Controls
Unit Description-1
UNIT: Qbb2--Flow and cinders of vent 9335.
CHARACTERISTICS: Moderately smooth; alluvial cover
AGE (Ma): 1.65±0.09, 1.67-1.74 AREA (sq. km): 0.41
PHENOCRYST SIZE: 1.0-2.0 CHEM TYPE: TR, AOB
SAMPLES: 216L,766#1
OVERLYING UNITS: ---
UNDERLYING UNITS: QTsf
REMARKS: Overlies lower flow sheet of unit QTsf
Chem-1
Chem-2
MinChem1
Mineral Chemistry - Microprobe Data
M#1=2.138km

Figure 3